3.0 THERMAL EVALUATION

This chapter of the SteriGenics Eagle Cask (SEC) presents the thermal evaluations which demonstrate that the SEC meets all applicable thermal criteria. The applicable thermal criteria used for these evaluations are defined in 10 CFR 71 [1]. Normal conditions of transport (NCT) and hypothetical accident condition (HAC) evaluations are performed to demonstrate that the SEC meets 10 CFR 71 requirements. The analytic demonstration techniques comply with the methodology presented in Regulatory Guide 7.6 [2] and Regulatory Guide 7.8 [3], as well as the IAEA Safety Series 6 [4].

See Section 1.2 for a detailed system description and Section 2.1 for the significant structural design criteria and features of the SEC.

3.1 Discussion

The SEC is designed to safely transport up to 330,000 curies of Cobalt-60 generating a maximum of 5,082 watts (17,344 Btu/hr) of heat. The Cobalt-60 will be encased with stainless steel tubes forming what is referred to as "source capsules" which are arranged around the periphery of the inner container of the cask as described in Section 1.2.

Thermal loads on the SEC arise from the Cobalt-60 source capsule decay heat and from the external environment, including insolation. The majority of the decay heat is deposited in the cask and in the source capsules themselves via gamma heating, while a smaller amount of heat is deposited in the source capsules due to beta decay. The SEC is designed to transfer the decay heat from the source capsules to the environment passively, while maintaining critical cask and payload temperatures within allowable values. Solar heating is considered as a normal part of component design, but is specifically addressed in terms of its effect on the cask under NCT as provided in Section 3.4. The effect of a HAC fire event on the cask is presented in Section 3.5. Cold temperature conditions are also considered as a normal part of cask design under both NCT and HAC.

The SEC can hold a maximum of 72 Cobalt-60 source capsules that qualify as special form under 10 CFR §71.75. Maximum decay heat loads and the source capsule configurations for these loads are summarized in Section 3.3. The heat loads are based on a 330,000 curie maximum payload. This heat load may be contained in as few as 18 source capsules. Since the heat distribution within the cask due to gamma heating varies according the cask and payload geometry and material composition, variable volumetric heat generation rates are used throughout the cask and payload. The computational method and heat distribution used to bound the thermal analyses are shown in Section 3.3. Zero decay heat is used for the purpose of demonstrating the compatibility of the SEC components with low temperature environments.

Specific ambient temperatures and solar heat loads are considered in the cask thermal evaluations. Ambient temperatures ranging from -40 °F to 100 °F are considered for NCT thermal-only loads, and -20 °F to 100 °F for NCT thermal-plus-structural loads with maximum heat and solar loading. The HAC fire event considers an ambient temperature range of -20 °F to 100 °F without solar heat loading before or during the fire event and maximum insolation after the fire event.

Details and assumptions used in the thermal models are described with the thermal evaluations. All evaluations are performed analytically and, when possible, assumptions are supported by test data. The significant conclusions derived from the thermal evaluation results include:

- All components of the SEC closure system (confinement seal, vent and drain port seals) remain within their allowable steady-state temperature ranges under NCT, and within their allowable transient temperature ranges under HAC.
- The maximum predicted volumetric average temperature of the SEC inner cavity atmosphere is 642 °F under NCT, leading to a maximum pressure of 23.9 psig. The maximum predicted volumetric average temperature of the inner cavity is 716 °F under HAC, leading to a maximum pressure of 26.5 psig. The maximum pressures are well within the design pressure of 50 psig.
- The maximum payload temperature during NCT of 786 °F does not exceed the long term limit of 800 °F for the source capsules.
- With a personnel barrier in place, the maximum temperature of any accessible surface of the cask does not exceed 185 °F in still 100 °F ambient air and no solar heating.

Together with its energy absorbing impact limiters, the SEC is evaluated and shown to provide thermal protection for the Cobalt-60 payload.

3.1.1 Design Criteria

The thermal design of the SEC is governed by a requirement to limit the temperatures and/or thermal gradient within the source capsules, shielding material, structural components, etc. during a combination of normal and off-normal events. The thermal acceptance criteria is selected to prevent thermally induced failures and the loss of structural properties within cask components due to elevated temperatures. A summary of component thermal acceptance criteria is provided in Table 3.1-1.

The SEC is evaluated for a series of normal thermal conditions of transport (NCT) and for the hypothetical accident conditions (HAC) thermal tests. Table 3.1-2 presents the design basis ambient conditions used in the evaluation of the SEC. These load combinations, that are in accordance with Regulatory Guide 7.8, are defined as follows:

1. ***NCT Warm:*** An ambient temperature of 100 °F with maximum decay heat and maximum insolation per 10 CFR §71.71(c)(1) averaged over 24 hours is used to evaluate the maximum temperatures within the SEC.
2. ***NCT Cold:*** A -40 °F steady state ambient temperature with no decay heat and zero insolation.
3. ***Shock and Vibration Conditions:*** Initial thermal conditions used for structural load combinations. Steady state ambient temperature conditions at -20 °F with no decay heat and zero insolation, and 100 °F with maximum decay heat and maximum insolation per 10 CFR §71.71(c)(1) averaged over 24 hours.
4. ***NCT Free Drop Conditions:*** Initial thermal conditions used for structural load combinations. Steady state ambient temperature conditions at -20 °F with no decay heat and

zero insolation, and 100 °F with maximum decay heat and maximum insolation per 10 CFR §71.71(c)(1) averaged over 24 hours.

5. ***HAC Free Drop Conditions:*** Initial thermal conditions used for structural load combinations. Steady state ambient temperature conditions at -20 °F with no decay heat and zero insolation, and 100 °F with maximum decay heat and maximum insolation per the 10 CFR §71.71(c)(1) averaged over 24 hours.

6. ***HAC Fire Event:*** A steady state ambient temperature of -20 °F or 100 °F with maximum decay heat and zero insolation prior to the event, followed by a thirty minute transient with an ambient temperature of 1,475 °F with maximum decay heat and zero insolation, and then back to a steady state ambient temperature of -20 °F or 100 °F with maximum decay heat and maximum insolation.

3.1.2 Overview of Thermal Design Features

3.1.2.1 Transportation Package

The SEC consists of three major components when assembled for transport: 1) the transportation cask, 2) the energy absorbing impact limiters that protect the cask from excessive impact loads for the NCT and HAC free drop events, and provide thermal protection for the HAC fire event, 3) the payload basket which contains up to 72 Cobalt-60 source capsules. See Sections 1.2.1 and 2.1.1, and the drawings in Section 1.3.1 for additional details on the SEC. The following components are used to enhance the thermal performance of the SEC:

- One 1/16 inch (0.0625 inch) and one 0.75 inch stainless steel fire shield are installed on the exterior surface of the cask between the two impact limiters. An air gap of 0.108 inches is present between the fire shields and the fire shield and the cask. This gap is maintained by wire spacers. These shields will protect the cask during a HAC fire event by providing insulating layers of air, additional thermal mass and a set of thermal radiation shields.
- The exterior surfaces of the cask and impact limiters are painted with a high emissivity, low solar absorptivity epoxy based paint. This paint will serve to maximize radiative heat transfer from the surface of the package while minimizing the contribution of insolation to the total package heat load. These coatings have been successfully used on spent fuel transportation casks to enhance heat transfer while maintaining an easily decontaminatable surface.
- Under NCT conditions, the air gaps at the interface between the impact limiter and cask tend to restrict heat flow from both the closure lid and cask bottom regions, as does the air space within the toroidal region of limiters. During a HAC fire, these gaps will provide an insulating boundary in a manner similar to the fire shield.
- For the purposes of the HAC evaluation , a projected worst case impact limiter damage scenario is examined. This scenario assumes a 30 foot center of gravity (c.g.) over corner drop, with subsequent side slapdown of the opposite end of the cask. In addition, worst case puncture bar damage is assumed wherein the bar crushes a portion of the fire shield, bringing it into contact with the cask outer shell. Further discussion of the damage scenario for HAC is presented in Section 3.5.

3.1.2.2 Personnel Barrier

A personnel barrier is used to provide a physical barrier between personnel and the SEC, which may have surface temperatures in excess of 250°F. The design of the personnel barrier provides a minimum 80% free opening and a nearly unobstructed flow of air around the SEC for convective cooling to the ambient environment.

The thermal interaction between the personnel barrier and the SEC is analyzed as part of the NCT analysis of the cask. The personnel barrier is assumed to be lost prior to the HAC fire event as the result of drop damage, etc. This assumption is conservative in that the absence of the personnel barrier will increase the total heat flow into the cask during the HAC fire event. This interaction for the NCT and HAC is explained in more detail in Sections 3.4 and 3.5, respectively.

Table 3.1-1 - Component Thermal Acceptance Criteria

Load Combinations		Cobalt-60 Source capsule	Cask Structural Steel (ASTM 304)①	Gamma Shielding Lead②	Impact Limiter (ASTM 304)①
		Max Limit	Max Limit	Max Limit	Max Limit
NCT	Warm Ambient 100°F	800	800	621	800
	Cold Ambient -40°F	800	800	621	800
	Shock and Vibration	800	800	621	800
	Free Drop (1 Foot)	800	800	621	800
HAC	Free Drop (30 Feet)	1475	NA	621	800
	Thermal (Fire)	1475	NA	621	NA

Notes:

① Target temperature to meet design material properties.

② Temperature represents the melting temperature of lead shielding material.

Table 3.1-2 - Transport Thermal Load Combinations

Load Combinations		Applicable Initial Conditions							
		Ambient Temperature		Solar Load		Decay Heat		Internal Pressure	
		100 °F	-20 °F	Max①	Zero	Max	Zero	Max	Min
Normal Conditions of Transport (NCT)	Cold Ambient -40 °F			×	×	×	×	×	×
	Shock and Vibration②	×	×	×	×	×	×	×	×
	Free Drop (1 Foot)	×	×	×	×	×	×	×	×
Hypothetical Accident Conditions (HAC)	Free Drop (30 Feet)	×	×	×	×	×	×	×	×
	Thermal③ (Fire)	×			×	×		×	

Notes:

① Insolation in accordance with 10 CFR §71.71(c)(1), averaged over 24 hours for cask interior temperatures and 12 hours for temperatures at cask exterior.

② Thermal conditions evaluated as an initial condition for structural load combinations.

③ Evaluations at end of HAC fire event and at post-fire steady-state conditions are required.

3.2 Summary of Thermal Properties of Materials

Analysis of the heat transfer within the SEC requires that thermal properties be defined for the materials used in their fabrication. Only properties for materials that constitute a significant heat transfer path are defined.

The SEC is constructed primarily of ASTM 304 stainless steel and lead. Miscellaneous components include ASTM [5] A320, Grade L43, alloy steel closure bolts and Viton O-ring seal.

The source capsules are constructed of a solid Cobalt 60 core in a ASTM 304 stainless steel tube with stainless steel end caps. The source capsule basket is constructed entirely of ASTM 304 stainless steel.

The void spaces within the SEC lead cavities caused by shrinkage and in the SEC interior cavity are filled with air. At the time of payload loading, the air pressure in the interior cavity is conservatively assumed to be at 14.7 psia, -40 °F to maximize predicted Maximum Normal Operating Pressure (MNOP).

The thermal properties of the principal materials used in the thermal evaluations are presented in Tables 3.2-1 through 3.2-3. Where necessary, the properties are presented as functions of temperature.

Table 3.2-1 - Material Properties, Homogenous Materials

Material	Temperature, °F	Thermal Conductivity, Btu/hr-in-°F	Specific Heat, Btu/lbm-°F	Density, lbm/in³	Notes
Type 304 Stainless Steel	-20.0	0.692	0.100	0.281	①
	70.0	0.717		---	
	100.0	0.725	0.111	---	
	200.0	0.775	0.124	---	
	400.0	0.867	0.130	---	
	600.0	0.942	0.134	---	
	800.0	1.020	0.140	---	
Lead	-148.0	1.775	0.031	0.411	②
	32.0	1.692		---	
	212.0	1.608		---	
	392.0	1.517		---	
	572.0	1.433		---	
	621.0	1.433			
Cobalt		3.320	0.099	0.320	③

Notes:

① ASME Code [6], Section II, Part D, Table TCD for Thermal Conductivity and Specific Heat. Density from Table NF-2.

② General Electric, *Properties of Solids, Thermal Conductivity, Metallic Materials*, Heat Transfer Division, July 1974.

③ Rohsenow, W. M. and J. P. Hartnett, *Handbook of Heat Transfer*, Table 27, McGraw Hill Publishing, New York, 1973.

Table 3.2-2 - Material Properties, Air

Temperature, °F	Thermal Conductivity, Btu/hr-in-°F	Specific Heat, Btu/lbm-°F	Density, g/cc	Viscosity, in²/sec	Prandtl Num.	Notes
-40	0.0011	0.242	Use idea gas law			①②③ ④
-20	0.0011					
70	0.0013			0.0261	0.708	
100	0.0013					
200	0.0015			0.0348	0.704	
300	0.0017			0.0446	0.700	
400	0.0018			0.0588	0.680	
500	0.0020					
600	0.0021			0.0796	0.680	
700	0.0023					
800	0.0024			0.1027	0.684	
900	0.0026					

Notes:

① Y.S. Touloukian, *Specific Heat – Nonmetallic Liquids and Gases*, Thermophysical Properties Research Center Data Series, Volume 6, Purdue University, 1970.

② Y.S. Touloukian, *Thermal Conductivity – Nonmetallic Liquids and Gases*, Thermophysical Properties Research Center Data Series, Volume 3, Purdue University, 1970.

③ E.R.G. Eckert, R. M. Drake, *Analysis of Heat Mass Transfer*, McGraw-Hill, New York, 1972.

④ Rohsenow, Hartnett, and Ganic, *Handbook of Heat Transfer Fundamentals*, 2nd Edition, McGraw-Hill Publishers, 1973.

Table 3.2-3 - Material Properties, Surface Emittance

Component	Material	Surface Emittance	Solar Absorptivity	Notes
Cask Exterior Surface	Paint	0.80	0.25	①
Cask Stainless Steel not in lead cavities	304SS	0.50	NA	③
Cask Stainless Steel in lead cavities	304SS	0.70	NA	②
Fire Shield Interior Surface	304SS	0.25	NA	③
Cask Lead	Lead	0.63	NA	④
Cobalt Source capsules	304SS/ Cobalt	0.80	NA	②

Notes:

① General Electric Heat Transfer Data Book, Section 515.5, *Properties of Solids: Emissivity*, 15 June 1961, p515.5-8; lists solar absorptivity values for white paint from 0.12 to 0.26; emissivity at 750 °F (399 °C) varies from 0.53 to 0.84; emissivity values at 125 °F (52 °C) varies from 0.90 to 0.95. Similar values are presented in Table 347 of F. F. Gubareff, J. Janssen, & R. Torborg, *Thermal Radiation Properties Survey*, Honeywell Research Center, Minneapolis., MN, 1960. For the HAC fire event, the paint (i.e., Tnemec Series 73 urethane top coat and Series 66 epoxy base coat) burn away and expose the underlying stainless steel surfaces. This surface is assumed to char to the minimum emissivity of 0.80 is required for the HAC fire in accordance with the requirement of 10 CFR §71.73(c)(3) [1]. Therefore, a value of 0.80 provides a conservative estimate for NCT conditions and meets the 10 CFR §71.73(c)(3) requirement for the HAC fire event.

② ORNL, *Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year Old Power Spent Fuel*, 1983, gives an emissivity value for Type 304 and similar stainless steels used in cask design, accounting for thermal cycling/long term oxidation.

③ Value taken from Gubareff, F. F., Janssen, J. E., and Torborg, R. H., *Thermal Radiation Properties Survey*, Honeywell Research Center, Minneapolis, Minnesota, 1960.

④ *Elements of Heat Transfer*, Bayazitoglu, Y and M. N. Ozisik, McGraw-Hill Book Company, New York, 1988. The value used is indicative of oxidized lead at 392°F.

3.3 Technical Specification of Components

3.3.1 Discussion of Temperature Sensitive Materials and Components

The materials used in the SteriGenics Eagle Cask (SEC) that are considered temperature sensitive are the Viton O-ring seal used for the closure lid/confinement boundary, the vent and drain ports, the lead shielding and the cobalt source capsules. The materials used to fabricate the other components of the system have working temperature ranges that extend well beyond the temperature levels seen for this application.

The Viton O-ring seals used in the lid and drain plugs have a working temperature range of -40 °F to 350 °F. Developmental testing demonstrates that this specific compound has a peak temperature rating of at least 380 °F for durations of 24 hours or less. Operation at temperatures between 350 °F and 380 °F is allowed for longer durations which decrease as a function of temperature.

The data collected in the O-ring testing covers NCT cold ambient and HAC fire temperatures, both extremes being applicable to the SEC. NCT warm conditions are expected for durations of as much as 60 days (i.e., a 60 day maximum shipping period). A 60 day seal allowable temperature value is derived from the development test data as follows. The high temperature capability of elastomeric materials is commonly plotted on semilog scales, with temperature plotted on the linear ordinate and time on the logarithmic abscissa [7]. Because of the direction of curvature of the elastomer time-temperature allowable value curves, the linear extrapolation from one time to a greater time is conservative because it would result in a lower temperature limit than the one actually indicated by the curve itself. Therefore, linear extrapolation of time-temperature data to longer times is conservative, using a logarithmic scale for time. Linearly extrapolating the segment between the 380 °F/24 hour point and the 350 °F/144 hour point leads to:

$$\frac{380\ {}^{\circ}\mathrm{F} - 350\ {}^{\circ}\mathrm{F}}{\ln(144\ \mathrm{hr}) - \ln(24\ \mathrm{hr})} = \frac{350\ {}^{\circ}\mathrm{F} - X\ {}^{\circ}\mathrm{F}}{\ln(1{,}440\ \mathrm{hr}) - \ln(144\ \mathrm{hr})}$$

where X is the allowable temperature value for 60 days (1,440 hours). Solving the equation yields a conservative temperature limit at 60 days of 311 °F. The full range of acceptable time-temperature results for the Viton material is presented in Table 3.3-1.

The lead shielding has a melting temperature of 621 °F. The structural analyses contained in Chapter 2.0 demonstrate that the SEC will retain its lead shielding under the proposed accident conditions. To preclude issues of stresses due to the expansion of lead upon melting and heat transfer through a molten metal medium, the design is such that no lead melt will occur during NCT or HAC conditions.

The remaining materials used in the SEC have significantly higher temperature capabilities. ASTM Type 304 stainless steel has a melting point above 2,550 °F and a maximum service temperature of 800 °F [6]. The maximum allowable long term temperature for the cobalt source capsules is 800°F to prevent creep [6] of the stainless steel cladding. During a fire event, the cobalt and its stainless steel casing must be kept below 2,550 °F, the melting temperature of stainless steel.

3.3.2 Thermal Loading from Cobalt-60 Source Capsules

The maximum payload for the SEC is 330,000 Ci of Cobalt-60. These loading may be contained in as few as 18 to as many as 72 pins. Cobalt-60 has a decay heat rate of 0.0154 W/Ci, for a thermal load of 5,082 watts (17,344 Btu/hr). The decay heat can be broken down into two components: heat due to beta decay and heat due to gamma decay. Beta decay, which is deposited entirely in the pins makes up 3.2% of the total decay, or 162 watts (555 Btu/hr) for the worst case payload. The remainder, 4,920 watts (16,789 Btu/hr), is due to gamma heating which is deposited in the cask walls, basket and pins according to their shielding capacity.

The MCNP shielding analysis described in Chapter 5.0 of this document also determined the decay heat distribution in the cask due to gamma heating. The worst case gamma heat distribution was determined to be the 72 pin configuration, due to the close spacing of the pin minimizing radiant heat transfer within the basket. It assumed that the pins were uniformly spaced within the basket. The gamma and total decay heat distributions for this case and the 18 pin case are presented in Section 3.4.1.1.3.

3.3.3 Maximum Allowable Pressure

Subsequent to the closure and sealing of the SEC, the air within the central cavity will increase in temperature and therefore increase the gas pressure in the internal cavity. As stated in Chapter 2.0, the maximum allowable internal pressure for the SEC is 64.7 psia or 50 psig.

Table 3.3-1 - Temperature Performance Capability Viton O-ring Material

Seal Temperature, °F	Steady State Time at Temperature	Leaktight	Related Regulatory Condition
-40	N/A	Yes	NCT cold
311	60 days	Yes	NCT warm
350	144 hours	Yes①	HAC post-fire
380	24 hours	Yes①	HAC peak fire

Notes:

① The O-ring seals were subjected to a hard vacuum of less than 0.0029 psia without any measured change in pressure; leaktightness is inferred.

3.4 Thermal Evaluation for Normal Conditions of Transport

This section presents the evaluation of the thermal performance of the SEC to demonstrate compliance with the 10 CFR §71.43(g) [1] and §71.71 conditions. The evaluation of the thermal performance of the SteriGenics Eagle Cask (SEC) for normal conditions of transport (NCT) is accomplished using analytical models.

3.4.1 Thermal Models

3.4.1.1 Analytical Thermal Models

The analytical thermal models for the SEC are developed using the ANSYS® Version 5.3 finite element analysis code [8]. This finite element code was originally developed by Swanson Engineering and has been used to provide thermal analyses for a number of package transportation license applications including the TN-32 Spent Fuel Cask developed by Transnuclear, Inc.[9].

The ANSYS® code provides the capability to simulate steady-state and transient temperatures using temperature dependent material properties and heat transfer via conduction, convection, and radiation. The code allows modeling various heat transfer coefficients as a function of geometry, fluid, and temperatures, for example, to estimate the effects of buoyancy driven heat transfer.

Since the cask design is largely axisymmetric, the thermal analysis of the SEC utilized a two-dimensional, axisymmetric geometry. Non-axisymmetric features, such as the fillets on the cask ends are modeled by using volume weighted average material properties. Solid entities are modeled by STIF55 two-dimensional thermal elements. Convection from the exterior surfaces of the cask is modeled by using a temperature difference dependent function. Radiation within the cask cavity, across air gaps in the cask and to the environment was accomplished using MATRIX50 radiation superelements developed using the ANSYS® AUX12 routine. Appendix 3.6.2 contains the input files for the ANSYS® model.

Figure 3.4-1 shows the cask thermal model used for 18 and 72 source capsule payloads. The 72 source capsule payload is arranged more densely than the 18 source capsule payload. This results in a greater amount of self shielding in the 72 source capsule payload, causing more of the decay heat to be deposited within the source capsules and basket. Nearly 70% of the total package heat is directly deposited in the cask walls, bottom and lid (See Section 3.4.1.1.3). The 18 source capsule configuration results in approximately 80% of the decay heat being deposited directly in the cask walls and lead shielding, which lowers the component temperatures. However, since the remaining 20% of the decay heat is distributed in significantly fewer capsules

For both configurations, heat deposited in the source capsules and basket is transferred to the inside surface of the cask via radiation and conduction through the air in the inner cavity. Since the source capsules and basket are not explicitly modeled in the cask model, this heat is represented by a uniform heat flux on the inside surface of the cask. The Cobalt-60 source capsule temperatures are predicted by a separate two-dimensional model of the source capsules and inner cavity air, Figure 3.4-2. The inner wall temperature of the cavity model is determined

by the cask thermal model, above, and heat is transferred from the source capsules to the basket and inner wall by radiation and conduction. Any convective effects are conservatively ignored in this cavity model. Additionally, heat transfer to the top and bottom of the cask cavity is also ignored.

For the NCT cases, it is assumed that the lead shielding shrinks causing 1/16" air gaps around the outer periphery of the lead cavity commensurate with the gaps found in previous lead filled cask designs [10]. Heat is transferred across these gaps by a combination of conduction and radiation.

3.4.1.1.2 Solar Loading

Under NCT, the package is mounted in an upright position upon its transport trailer. This establishes the orientation of the exterior surfaces of the package for determining the free convection heat transfer coefficients and insolation loading.

Table 3.4-1 presents the total daily insolation rate as a function of surface orientation from 10 CFR §71.71(c)(3). These values are divided by 24 for insolation on the cask surface and by 12 for the impact limiter surfaces to obtain average insolation rates for the steady-state NCT thermal analysis [11]. Accordingly, a 100 °F ambient temperature and the insolation values are used for heat input to the exterior package surfaces. Note that for the top and sides of the package, 20% of the incident solar radiation is intercepted by the personnel barrier.

Table 3.4-1 - SEC Package NCT Maximum Insolation Values

Form and Location of Surface	Total Insolation for a 12-Hour Period ($gcal/cm^2$)	(Btu/in^2)
Flat surfaces transported horizontally:		
• Base	none	none
• Other surfaces	800	20.49
Flat surfaces not transported horizontally	200	5.12
Curved surfaces	400	10.24

3.4.1.1.3 Decay Heat Loading

The maximum permissible payload for the SEC is 330,000 Curies of Cobalt-60 generating 5,082 watts (17,344 Btu/hr) of decay heat. As described in Section 3.3, over 90% of the decay heat from the cobalt source capsules is due to gamma heating. This heat is deposited in the cask, basket and source capsules. The remainder of the decay heat is due to beta decay, and is deposited directly in the source capsules. Figure 3.4-3 and accompanying Table 3.4-2 show the decay heat distribution for the two payload configurations as determined by the cask shielding model presented in Chapter 5.0. Regions of the cask that have gamma heating rates of less than 0.1 $Btu/hr\text{-}in^3$ are treated as zero with their heat being conservatively placed in the cobalt source capsules. The basket with 72 source capsules experiences much greater self shielding. However, the volumetric heat is more concentrated in the 18 source capsule

configuration. As a result, the 72 source capsule configuration yields higher cask temperatures while the 18 source capsule configuration yields the highest source capsule temperatures. Therefore, all cask temperatures are calculated using the 72 source capsule configuration, and only the source capsule temperatures are derived from the 18 source capsule configuration.

Table 3.4-2 - Decay Heat Distribution

	Volumetric Heat Generation ($Btu/hr\text{-}in^3$)	
	18 Capsule Configuration	72 Capsule Configuration
Lid Lead Zone A	0.1	0.1
Lid Lead Zone B	0.4	0.3
Lid Lead Zone C	2.6	2.2
Lid Side Wall Zone D_1/D_2	0.2/1.1	0.2/0.9
Lid Bottom Zone E	5.2	4.4
Inner Radial Wall Zone F	10.2	8.0
Inner Radial Wall Zone G	4.5	3.6
Radial Lead Shield Zone H	5.0	4.1
Inner Radial Wall Zone I	13.7	11.1
Inner Radial Wall Zone J	6.8	5.5
Radial Lead Shield Zone K	5.4	4.4
Radial Lead Shield Zone L	0.4	0.4
Inner Radial Wall Zone M	9.8	8.0
Inner Radial Wall Zone N	4.1	3.3
Radial Lead Shield Zone O	3.4	2.8
Cavity Bottom Zone P	5.1	4.3
Bottom Lead Shield Zone Q	2.5	2.2
Bottom Lead Shield Zone R	0.4	0.3
Source capsules (Includes β decay)	130.5	49.2

3.4.1.2 Test Thermal Model

No thermal test model is required. The design uses materials and features similar or identical to existing licensed packages. No unique features are included that would require a thermal test.

3.4.2 Maximum Temperatures

The maximum temperatures within SEC components for NCT with maximum decay heat are presented in Table 3.4-3. Figure 3.4-4 presents the temperature distribution within the cask for the 72 source capsule configuration, which represents controlling cask temperatures. Figure 3.4-5 presents the temperature distribution for the basket cross-section in the 72 source capsule configuration. The personnel barrier temperatures are based on a one-dimensional calculation where the entire cask that assumes the entire cask surface is at the maximum reported temperature.

3.4.3 Minimum Temperatures

The minimum temperatures within the SEC components for NCT for ambient temperatures of -20 °F and -40 °F, with maximum decay heat and without insolation, which represents the maximum thermal gradient cases are presented in Table 3.4-3.

The low temperature compatibility of the SEC components are evaluated for the case with an ambient temperature of -40 °F, zero decay heat load, and without insolation. The steady state temperatures of the cask and components for this analytically trivial case are -40 °F.

3.4.4 Maximum Internal Pressures

The determination of the maximum internal pressure within the SEC cavity is based on the ideal gas law. If a cask is filled at the minimum normal operating temperature, -40°F and is allowed to reach the NCT maximum bulk temperature for the cavity gas, 642 °F, the maximum pressure would be the product of the ratio of the absolute gas temperature to 420°F and atmospheric pressure, 14.7 psia. In the case of the SEC,

$$\frac{P_{max}}{P_{init}} = \frac{T_{air\,max}}{T_{init}}$$

$$\frac{P_{max}}{14.7\,psia} = \frac{1102°R}{420°R}$$

$$P_{max} = 38.6\,psia$$

The maximum pressure is less than the maximum design pressure of 50 psig.

3.4.5 Maximum Thermal Stresses

Figure 3.4-6 presents temperature distribution for the worst case gradients for the SEC. Structural analyses of the SEC are presented in Section 2.6, using the temperature distributions determined from the NCT analysis, and demonstrate the ability of the packaging components to maintain positive design margins for all combinations of NCT loads.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The results of the thermal evaluations presented in the previous sections, together with the structural analyses presented in Section 2.6, demonstrate that the SEC meets the NCT requirements of 10 CFR §71.71. The maximum and minimum cask component temperatures under the NCT conditions are within the allowable range for the respective material. While the surface temperature of the cask exceeds the 185 °F limitation imposed by 10 CFR §71.43(g) for exclusive use shipment in still air at 100 °F and in the shade, the presence of the personnel barrier limits the temperature of any accessible surface on the cask to 170 °F or less.

The Maximum Normal Operating Pressure (MNOP) within the SEC assembly is 38.6 psia, or 23.9 psig. The MNOP is well within design pressure for the SEC.

Table 3.4-3 - Maximum and Minimum NCT Temperatures for the SEC

Component	+100 °F, Max Insolation NCT Hot	-40 °F, No Insolation NCT Cold	-20 °F, No Insolation NCT Cold
Personnel Barrier	175/169①	144	148
Package Surface	353	263	275
Cask Outer Shell	384	296	308
Radial Lead Shield	487	398	410
Cask Inner Shell	500	412	423
Cask Lid	484	395	407
Cask Lid Lead	473	385	396
Cask Cavity Bottom	518	434	445
Cask Bottom Lead Shield	435	346	358
Impact Limiter	278	175	189
Cask Seal	369	279	291
Maximum Capsule Temperature	786/757②	NA	NA

Notes:

① With Solar Radiation/Without Solar Radiation

② 18 Capsule Configuration/72 Capsule Configuration

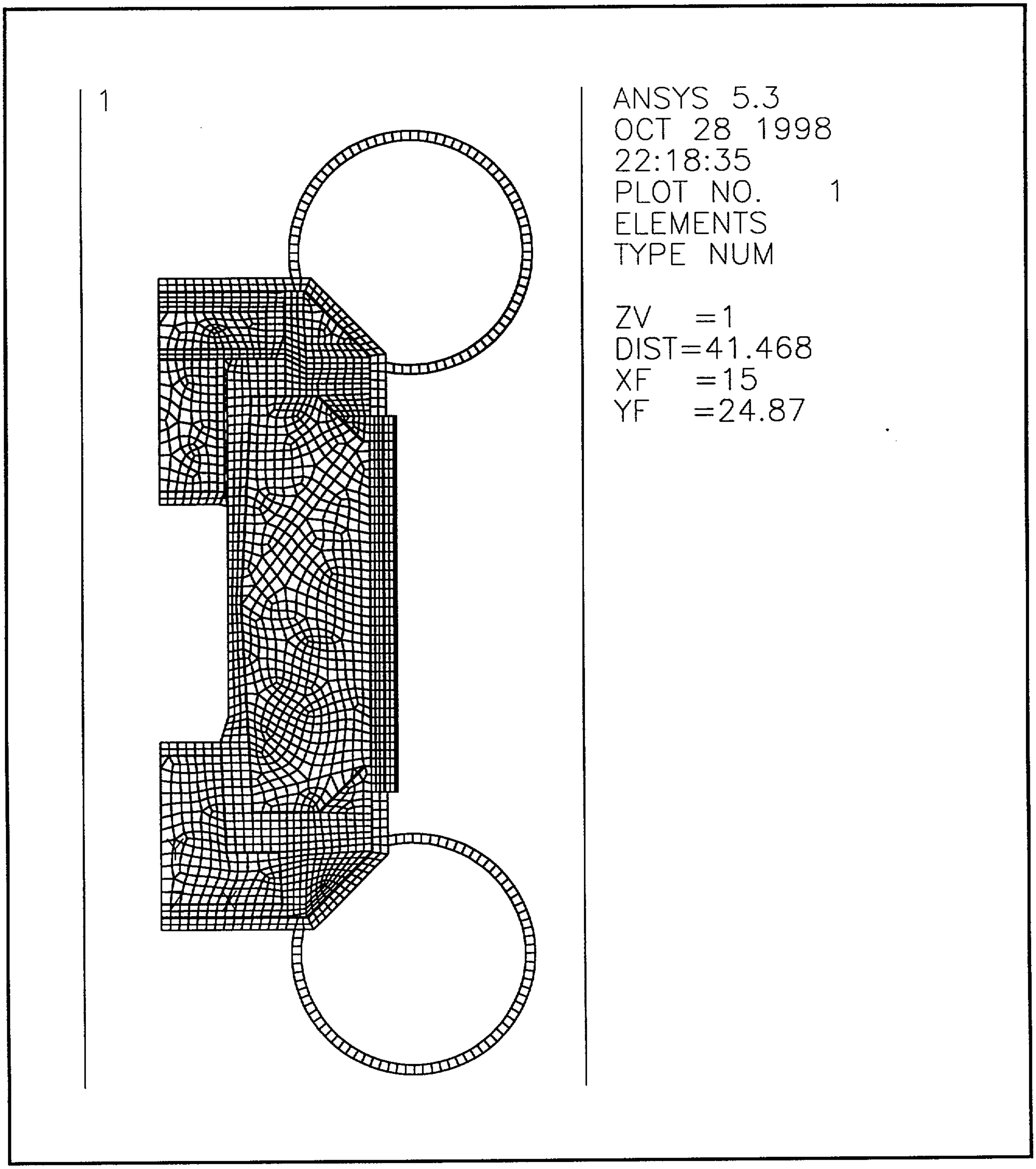

Figure 3.4-1 - Axisymmetrical SteriGenics Cobalt Cask ANSYS® Model

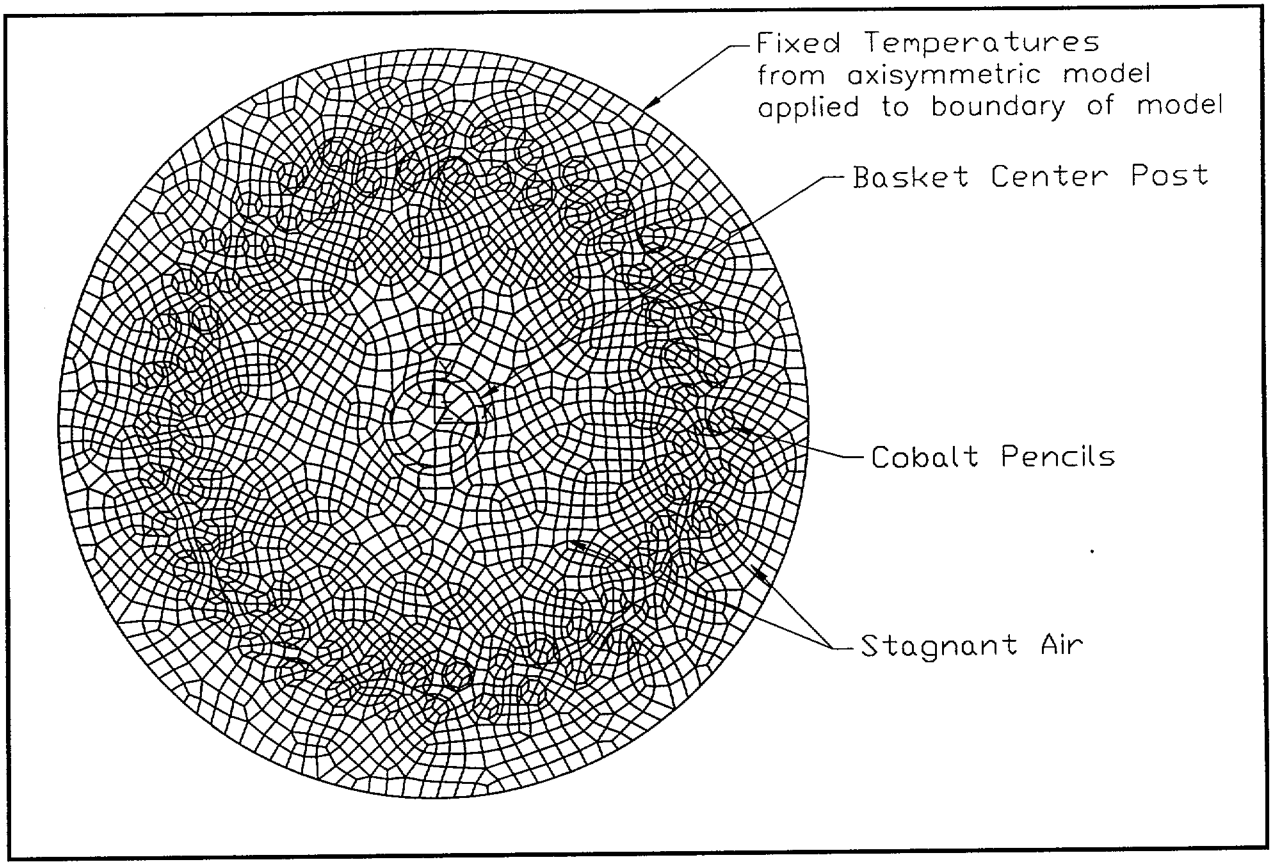

Figure 3.4-2 - Two-dimensional Model of SteriGenics Cobalt Cask Basket (shown in 72 source capsule configuration)

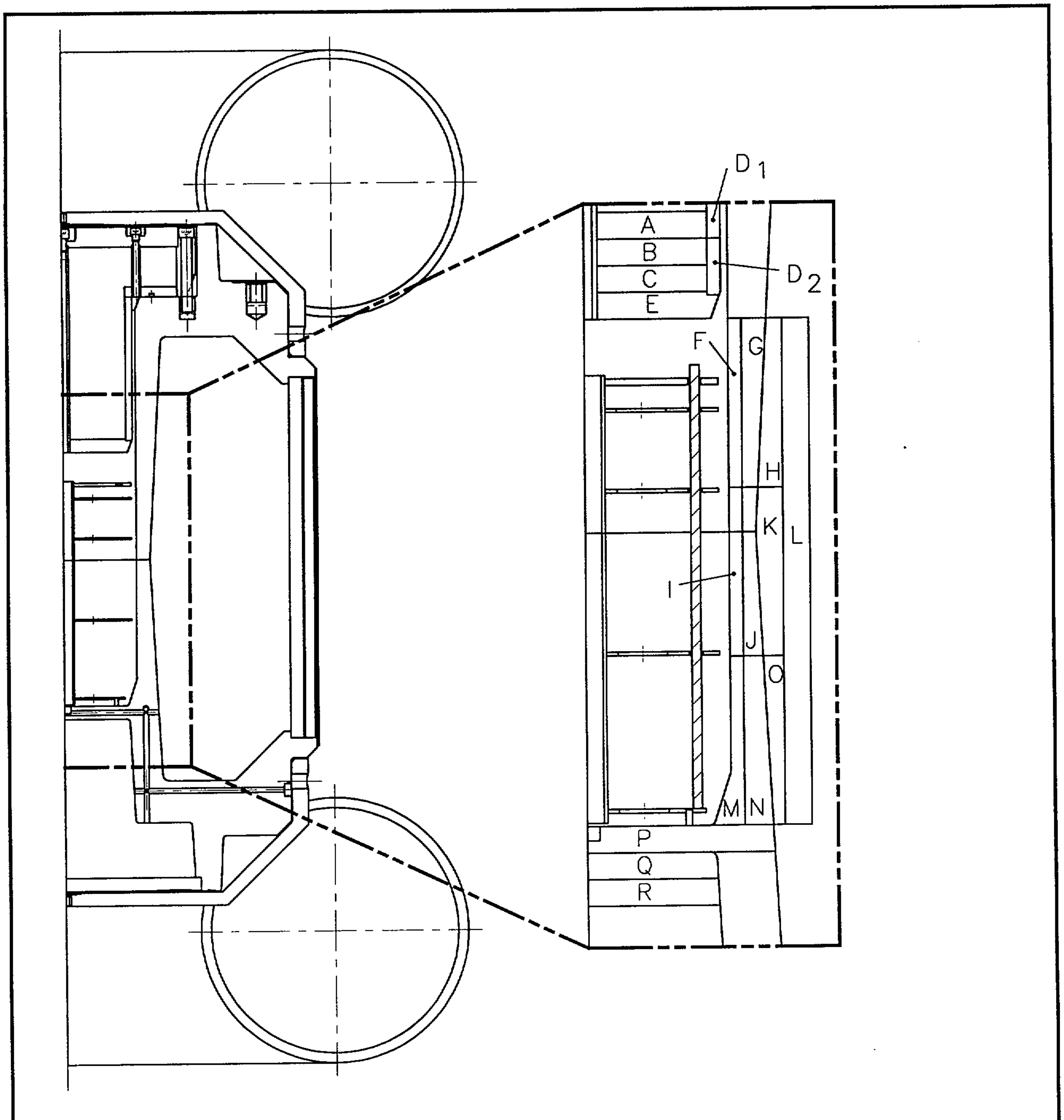

Figure 3.4-3 - Decay Heat Distribution (Refer to Table 3.4-2)

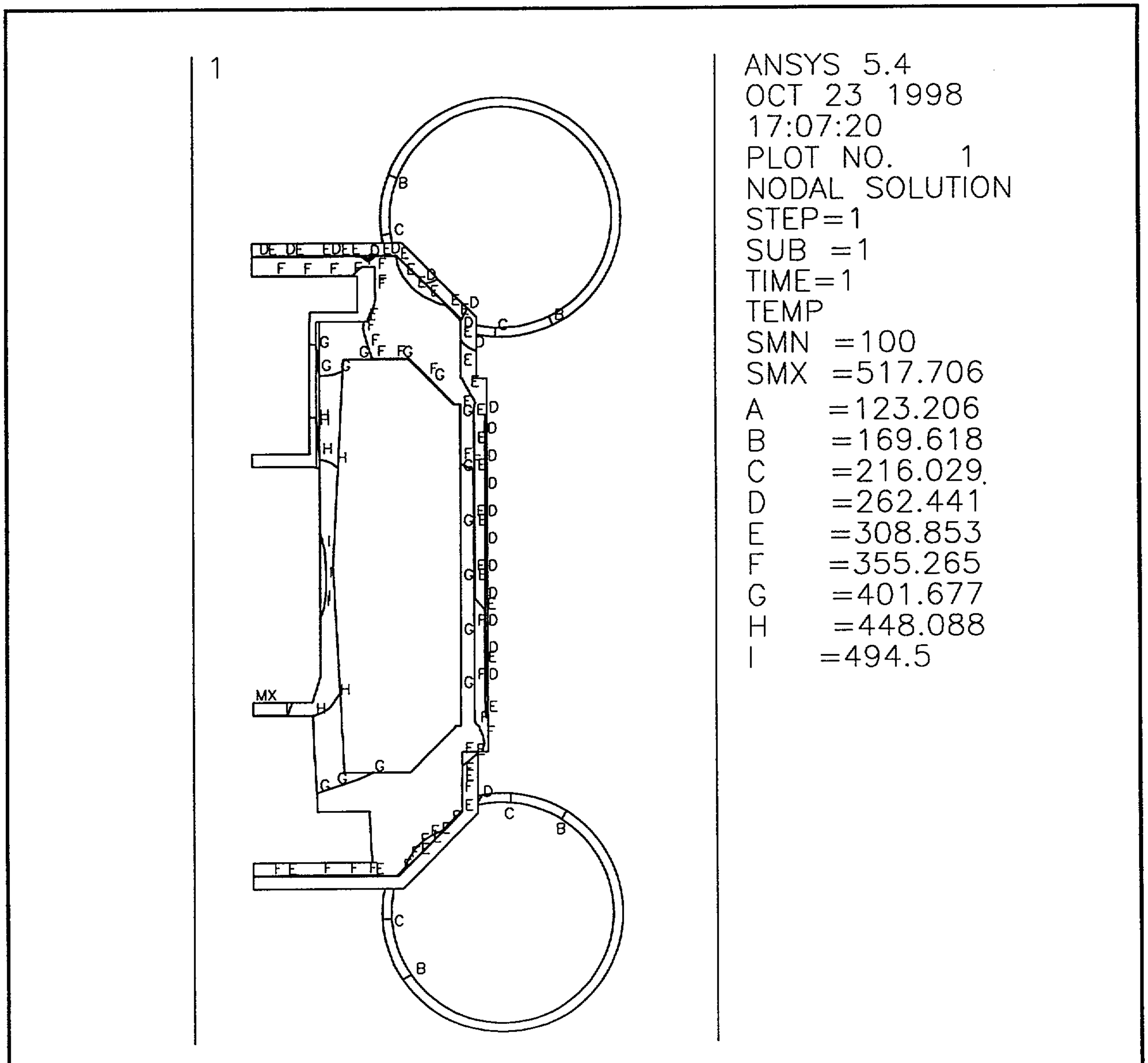

Figure 3.4-4 - Temperature Distribution within Cask for NCT (+100°F Ambient, Full Solar)

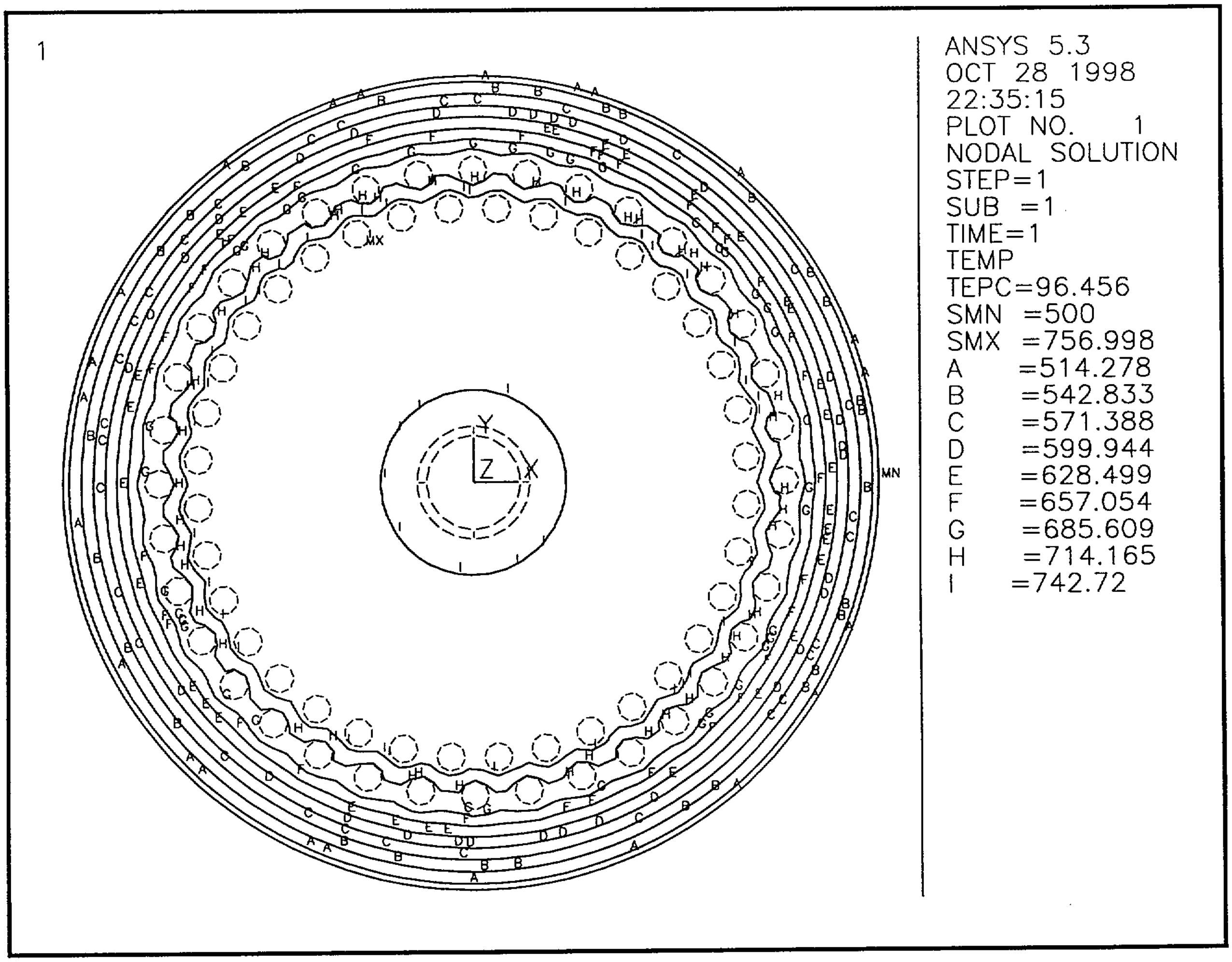

Figure 3.4-5 - Temperature Distribution within Basket for NCT (+100°F Ambient, Full Solar)

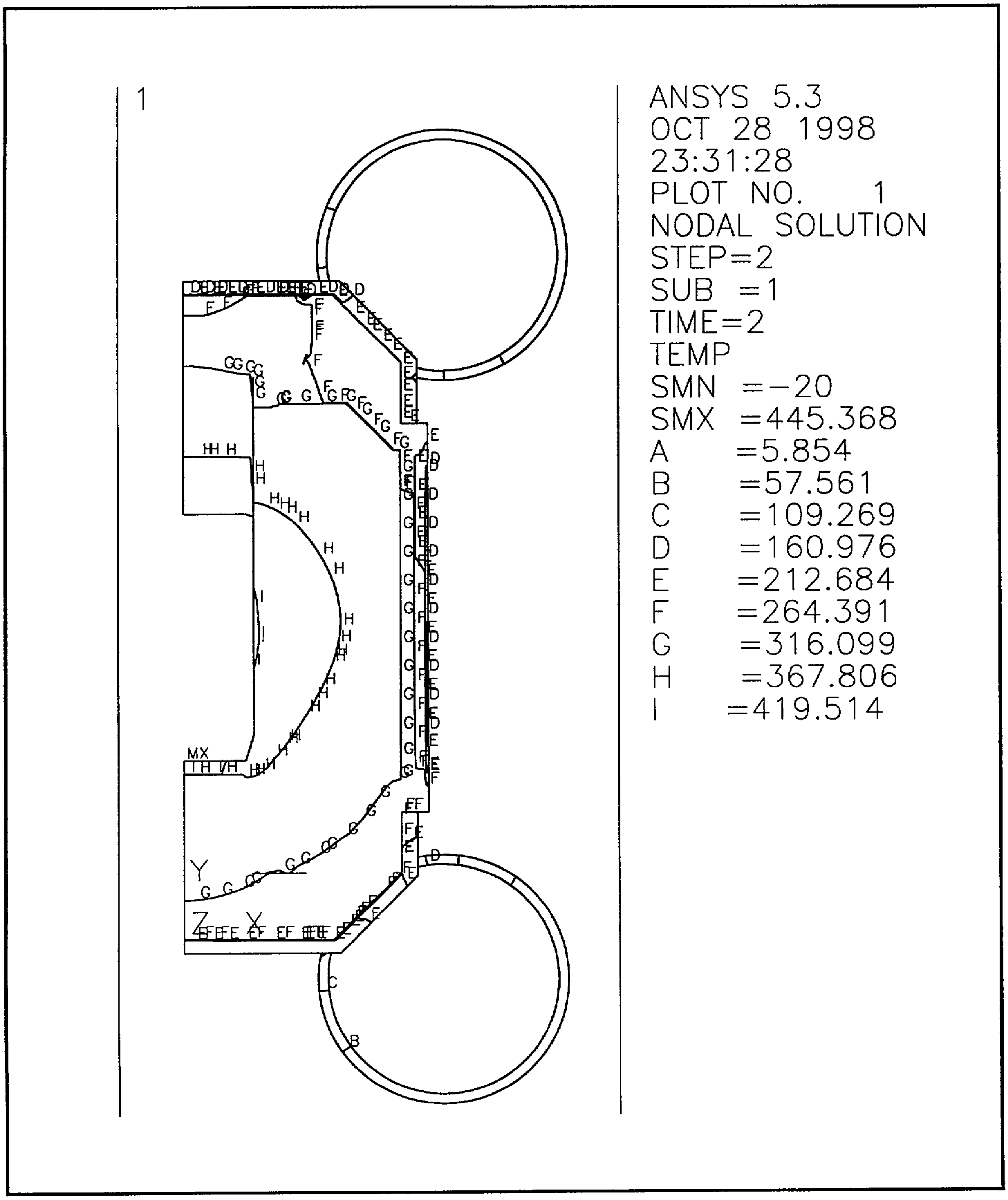

Figure 3.4-6 - Temperature Distribution within Cask for NCT (-20°F, No Solar)

3.5 Thermal Evaluation for Hypothetical Accident Conditions

3.5.1 Thermal Model

3.5.1.1 Analytical Thermal Model

This section presents the thermal analysis for the hypothetical accident condition (HAC) fire event specified in 10 CFR §71.73(c)(3) [1] for the SteriGenics Eagle Cask (SEC). Thermal performance of the package is evaluated analytically using the same axisymmetric two-dimensional thermal model used in the Normal Conditions of Transport (NCT) evaluation presented in Section 3.4.1, along with an additional three-dimensional submodel used to simulate the expected combined damage sustained from the HAC free drop and puncture event. The evaluation of the SEC is based on the 72 pin with maximum decay heat case since it represents the bounding case for all cask components. Discussions of the HAC thermal model as related to the damaged packaging are provided in Section 3.5.2.

3.5.1.2 Test Thermal Model

No hardware testing is performed in support of the analytical calculations

3.5.2 Package Conditions and Environment

The initial temperature distribution in the package prior to the HAC fire event is taken from the steady state conditions in the undamaged configuration, an ambient temperature of 100 °F maximum decay heat, and no insolation as allowed in 10 CFR §71.73(c)(3). An undamaged cask yields more conservative temperatures than a damaged cask, due to the anticipated lead slump and compression of the fire shield that would occur due to the drop and puncture tests.

Two models are used to evaluate the fire conditions. An axisymmetric model which represents the average cask temperature response during the HAC events which is identical to the NCT model described in Section 3.4 with the exception of the lack of solar radiation, and a three-dimensional cask midsection submodel (Figure 3.5-1) that models a section of the cask midsection, showing the effects of the pin puncture damage.

To determine the effect of a HAC fire event, the package models are exposed to a convective and radiative heat flux based on still, ambient air at 1,475 °F with an effective emissivity of 0.90. The duration of the HAC fire event is 30 minutes. Consistent with the requirements of 10 CFR §71.73(c)(3), during the fire, the surface absorptivity of all external surfaces is set to 0.8 and forced convection is assumed to be induced by the fire. After the 30 minute fire, the thermal boundary conditions are returned to the original ambient temperature of 100 °F, with maximum insolation, and natural convection. These conditions are maintained for five hours, which is sufficient determine the maximum temperatures for all components. The analyses are concluded with a post-fire, steady-state analysis. According to measurements of gas velocities during transportation package fire tests, an average convective heat transfer coefficient of 2.3 Btu/hr-ft^2-°F is conservatively used during fire conditions. Section 3.6.1.2 provides the details of these tests and the convection coefficient calculation. The personnel barrier is not

present during the HAC fire event, although its presence is assumed for determination of the initial cask temperatures.

Table 3.5-1 outlines the boundary conditions for the various phases of the HAC fire.

The worst case free drop and puncture bar damage to the transportation cask, per Section 2.10.1.2, is represented by a HAC side drop on the top impact limiter, slap down on the lower limiter, and a puncture bar impact at the mid point of the cask. These impacts result in significant deformations of the top and bottom limiters, however, the effective surface area remains the same, so their deformation has negligible effect on the cask. The puncture bar creates a 6 inch circular indentation in the fire shields and a lead slump that brings the lead shield into intimate contact with the outer cask shell. In accordance with the results of tests performed on lead shielded casks [12], the gaps between the fire shields and the cask are reduced to 1/20 of their precrush values. The crush of the fire shield is conservatively assumed to be applied to a 36 square inch segment of the cask midsection submodel (Figure 3.5-1), which is approximately 25% larger than anticipated. Figure 3.5-2 illustrates the damage assumptions used.

At the cessation of the HAC fire event, the environment is assumed to return to a 100°F ambient temperature with maximum insolation. To simulate the effects of charring, the solar absorptivity of the cask is increased to 0.8. The model is evaluated under transient conditions until all of the package components have reached their maximum temperatures. The model is finally evaluated for steady-state conditions for its post-fire, damaged state.

3.5.3 Package Temperatures

Table 3.5-2 details the peak temperatures for various SEC components during and after the HAC fire event for this case. The temperatures for features such as the impact limiter shell and fire shields reach their highest points at or shortly after the end of the 30 minute HAC fire. Temperatures within the SEC reach their maximum temperatures during the post-fire phase with the inner surface of the cask reaching its peak value 2 hours after the end of the HAC fire.

The large thermal mass of the outer cask shell and the insulating air gaps of the fire shield serve to lessen the effects of the fire for the lead shielding and cask payload. Similarly, the thermal mass of the inner radiation shield, lid and impact limiter as well as the air gaps between the limiter and cask protects the O-ring seal and cask shielding. The peak lead temperature of 602°F, which is nearly 20°F under the 621°F melting point of lead, occurs directly underneath the puncture pin impact point. The peak seal temperature is 513 °F. Figure 3.5-4 shows the temperatures of various components within the cask during the fire and post fire conditions based on the axisymmetric model. It shows that no lead melts and none of the cask or payload components exceed their maximum allowable temperatures.

Subsequent to the fire and post fire cooldown period, the surface and outer shell of the cask is slightly warmer than its pre-fire state. This is due to the application of maximum insolation on the outside surface of the cask, which, due to its charred state, has a higher solar absorptivity. However, due to lead slump, which causes contact between the outer shell of the cask the cask interior temperatures are somewhat lower.

3.5.4 Maximum Internal Pressures

The maximum internal pressure within the SEC is determined for the HAC fire event based on the absolute bulk temperature of the air within the payload cavity during the HAC event. The maximum HAC internal pressure for the SEC as calculated by ideal gas law indicate that at the maximum internal pressure during the HAC event occurs approximately 2 hours after the initiation of the fire and is 26.5 psig based on a 715.8 °F cavity air temperature. This does not exceed the 50 psig pressure design limit.

3.5.5 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

As can be seen in the previous sections and the structural analyses presented in Section 2.7.3, the SEC is shown to meet the HAC requirements of 10 CFR §71.73.

Table 3.5-1 - HAC Fire Event Boundary Conditions

Phase	Ambient Temperature	Insolation	Duration	Package Condition
1. Pre-Fire	100 °F	No	Steady State	Undamaged
2. Fire Transient	1,475 °F	No	30 Minutes	Impact Damaged, charred
3. Post-Fire Transient	100 °F	Yes	5 Hours	Impact Damaged, charred.
4. Post-Fire, Steady State	100 °F	Yes	Steady State	Impact Damaged, charred

Table 3.5-2 - Maximum HAC Temperatures for the SEC

Component	Maximum Temperatures, °F (°C)				
	Maximum Allowable Temperature	(1) Pre-Fire, Steady-State	(2) End of Fire	(3) Post Fire Steady-State	Maximum Transient Temperature
Package Surface/Impact Limiter	2,550 °F①	350 °F	1245 °F	342 °F	1245 °F
Cask Outer Shell	2,550 °F①	381 °F	828 °F	399 °F	828 °F
Radial Lead Shield	620 °F	484 °F	576 °F	456 °F	602 °F
Cask Inner Shell/Cavity Bottom	2,550 °F①	515 °F	515 °F	497 °F	615 °F
Cask Lid	2,550 °F①	480 °F	470 °F	466 °F	572 °F
Cask Lid Lead	620 °F	470 °F	470 °F	455 °F	562 °F
Cask Bottom Lead Shield	620 °F	432 °F	451 °F	426 °F	550 °F
Cask Lid Seal	NA	366 °F	369 °F	355 °F	475 °F

Notes:

① Melting Temperature per ASME B&PV Code, Section II, Part D

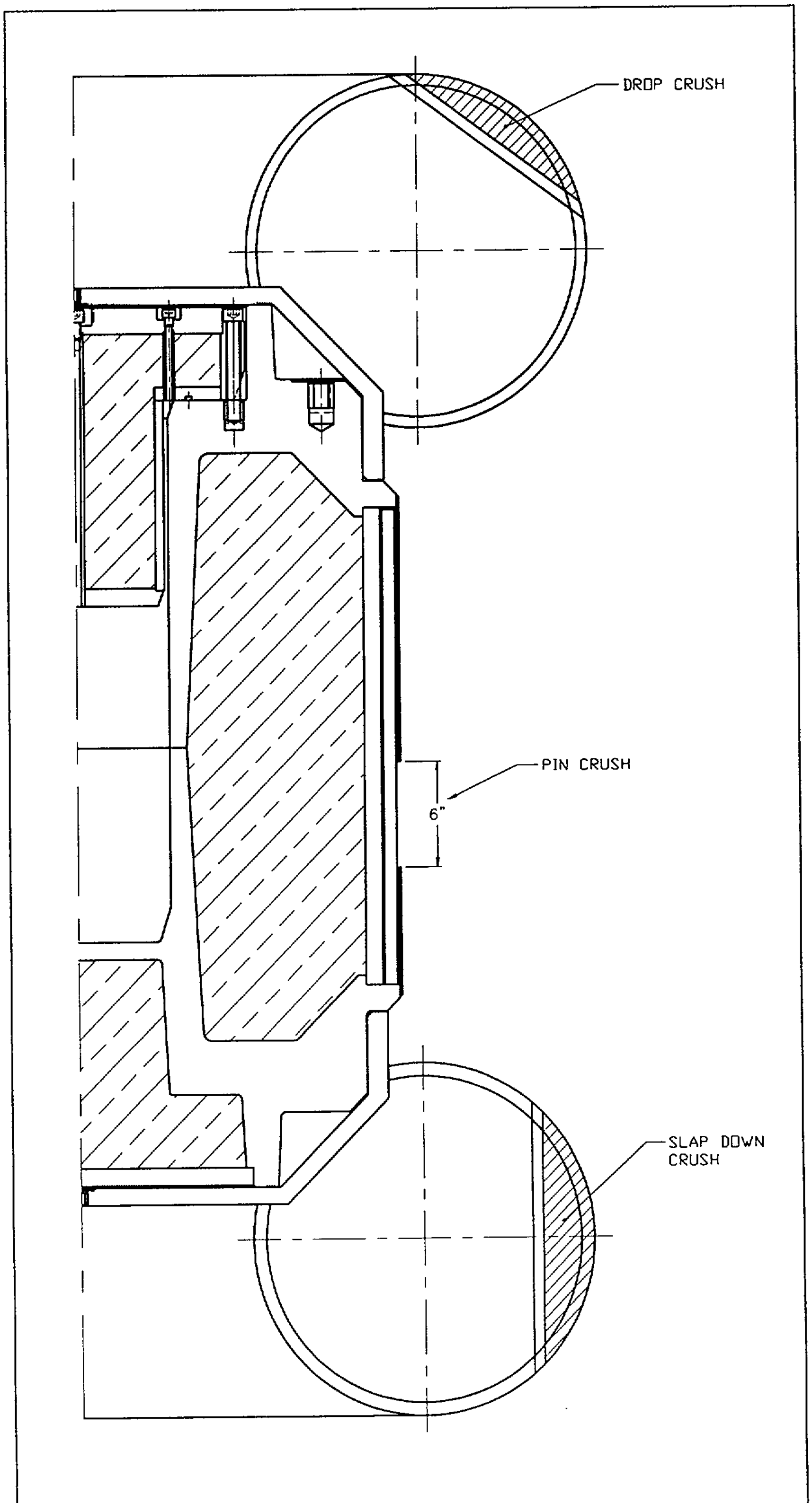

Figure 3.5-1 - Thermal Model HAC Damage

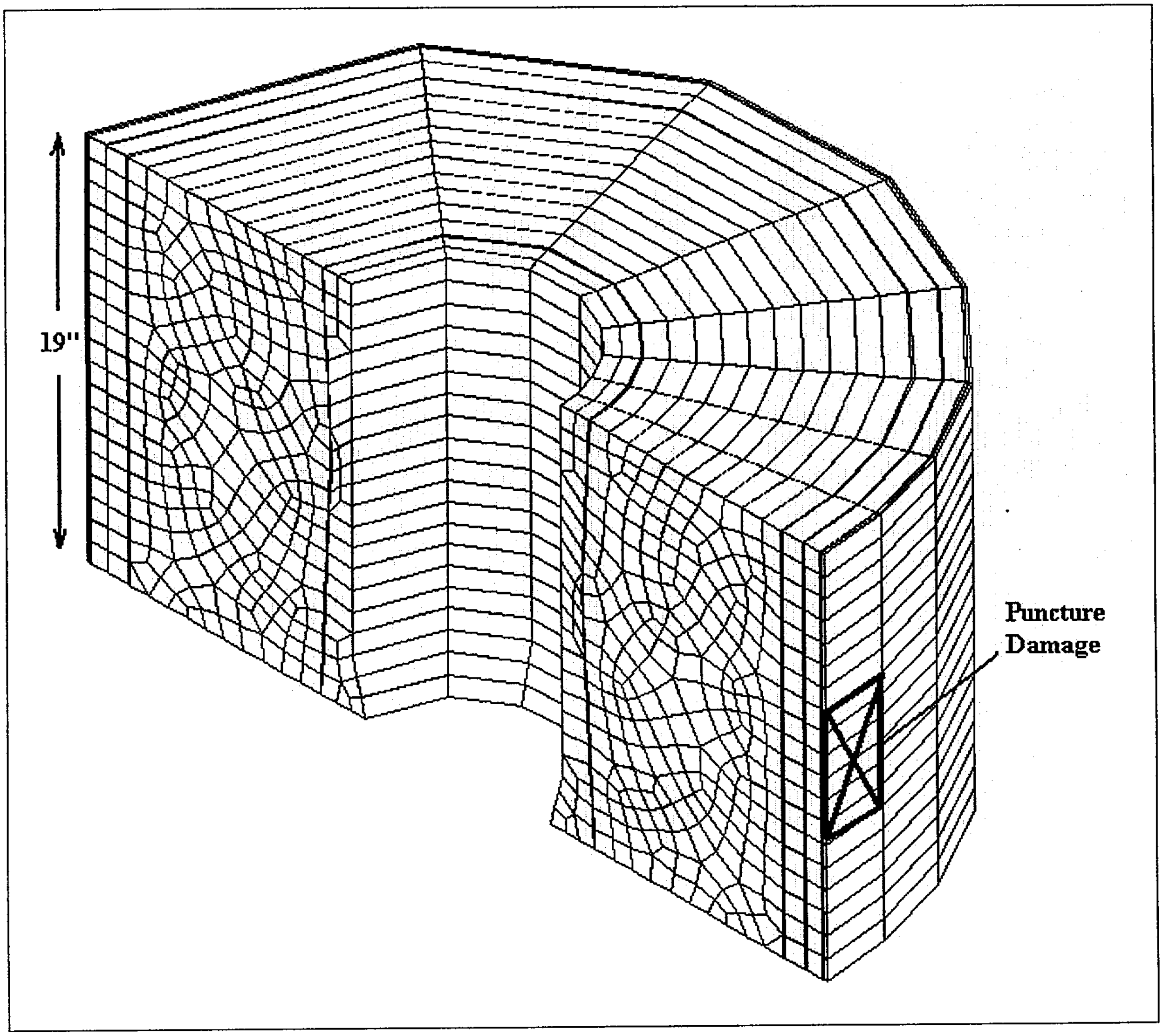

Figure 3.5-2 - Cask Three-Dimensional Midsection Thermal Model

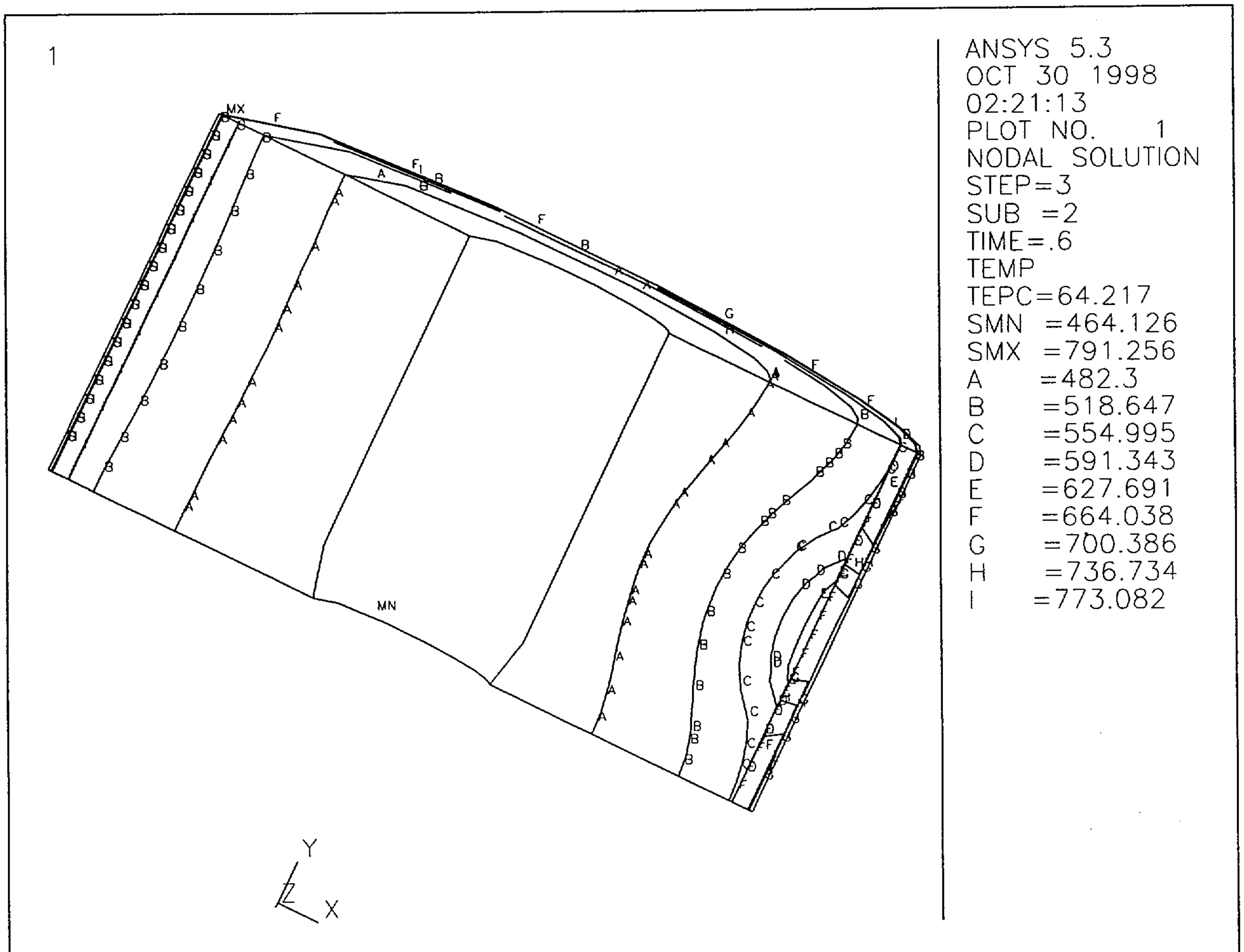

Figure 3.5-3 - Cask Three-Dimensional Midsection Thermal Model With Peak HAC Temperatures

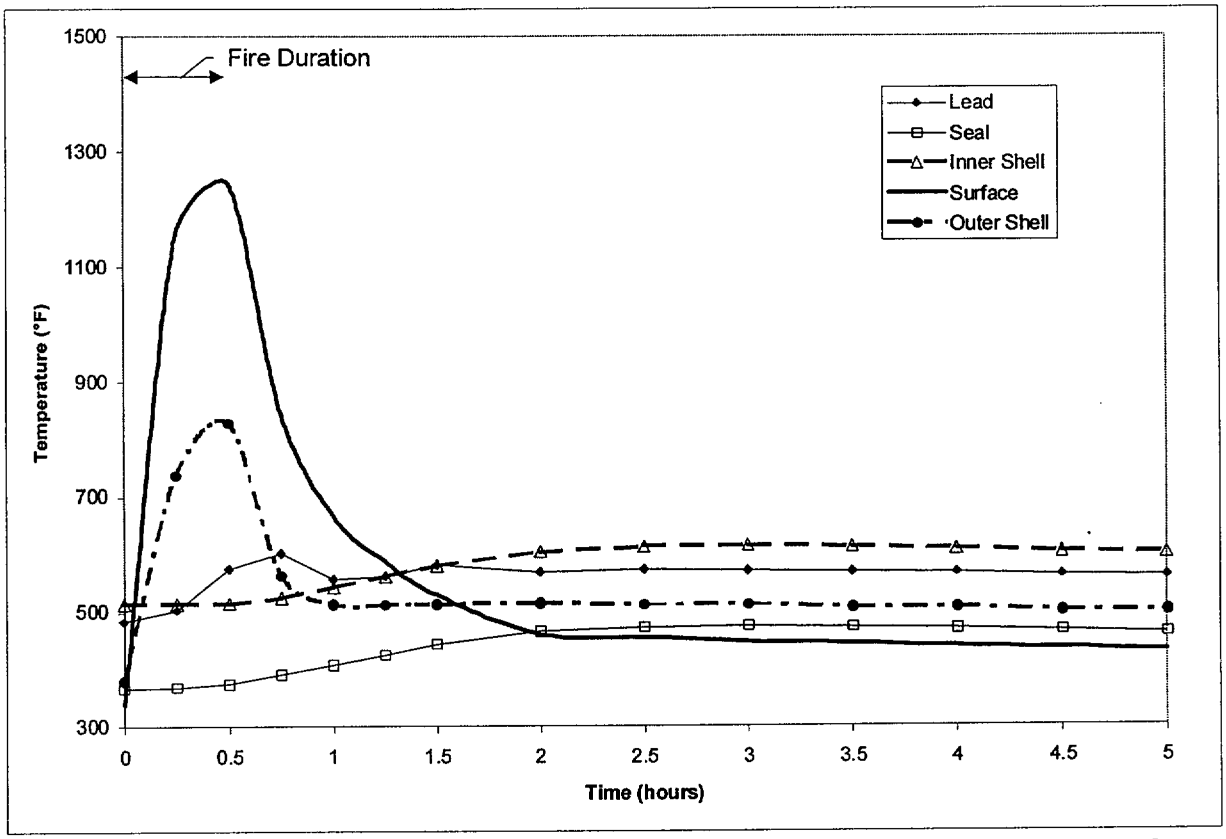

Figure 3.5-4 - Temperature Response of Selected Components During HAC Event

3.6 Appendices

3.6.1 References

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3. Regulatory Guide 7.8, *Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material*, Revision 1, United States Nuclear Regulatory Commission (USNRC) Office of Standards Development, March 1989.
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8. ANSYS® Version 5.3, ANSYS, Inc.
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11. N. N. Brown, S. E. Gianoulakis, *Comparison of 10 CFR 71 Normal Conditions with Bounding US "Hot Day" Extremes,* Packages for Transportation and Storage of Radioactive Materials, American Society of Mechanical Engineers, 1993.
12. Y. Bayazitoglu and M. Ozisik, *Elements of Heat Transfer*, McGraw-Hill Publishing, New York, 1988, pp180-181.
13. Burgess, M. H., *Heat Transfer Boundary Conditions in Pool Fires*, IAEA-SM-286/75P, Packaging and Transportation of Radioactive Materials, PATRAM '86 Symposium Proceedings, Volume 2, International Atomic Energy Agency, Vienna, Austria.
14. Gregory, J. J., N. R. Keltner, R. Mata, *Thermal Measurements in Large Pool Fires*, Heat and Mass Transfer in Fire, HTD-Volume 73.
15. Schneider, M. E., L. A. Kent, Measurements of Gas Velocities and Temperatures in a Large Open Pool Fire, Heat and Mass Transfer in Fire, HTD-Volume 73.

16. Y. Bayazitoglu and M. Ozisik, *Elements of Heat Transfer*, McGraw-Hill Publishing, New York, 1988, pp 211-212.

3.6.2 Convective Heat Transfer Coefficient Calculation

3.6.2.1 Natural Convection

During Normal Conditions of Transport (NCT) and the pre- and postfire HAC package conditions, it is conservatively assumed that there is negligible wind and that heat is transferred from the package to the environment via natural convection.

Natural heat transfer coefficients from the outer surface of the package are calculated as follows.

From *Elements of Heat Transfer* [13], the convective heat transfer coefficient, h, is:

$$h = Nu\frac{k}{L} \text{ Btu/hr-in}^2\text{-°F}$$

where k is the conductivity of gas at film temperature (Btu/hr-in-°F) and L is the effective length of the vertical surface or cylinder diameter (in).

The Nusselt number, Nu, for vertical heated surfaces is:

$$Nu = \left(0.825 + \frac{0.387(Gr\,Pr)^{1/6}}{\left[1+(0.492/Pr)^{9/16}\right]^{8/27}}\right)^2 \qquad \text{for } 10^{-1} < GrPr < 10^{12}$$

The Nusselt number, Nu, for horizontal heated surfaces facing upward is:

$$Nu = 0.54(Gr\,Pr)^{1/4} \qquad \text{for } 10^5 < GrPr < 2\times10^7$$

$$Nu = 0.14(Gr\,Pr)^{1/3} \qquad \text{for } 10^7 < GrPr < 10^{10}$$

and, for horizontal heated surfaces facing downward:

$$Nu = 0.27(Gr\,Pr)^{1/4} \qquad \text{for } 3\times10^5 < GrPr < 3\times10^{10}$$

For both horizontal and vertical heated surfaces, the Grashof number, Gr, is:

$$Gr = \frac{g\beta\Delta TL^3}{\nu^2}$$

gravitational acceleration constant (in/s^2), β is the gas coefficient of thermal expansion (°F^{-1}), where $\beta = (T_{abs})^{-1}$ for an ideal gas, ΔT is the differential temperature (°F), where $\Delta T = |T_{wall} - T_\infty|$, ν is the kinematic viscosity of gas at the film temperature (in^2/hr), and Pr is the Prandtl number.

Note that k, Gr, and Pr are each a function of air temperature, and are described in Section 3.2, Table 3.2-2.

For use in the ANSYS® computer code, these correlations are simplified into a relationship that is based on the temperature difference between the cask and ambient air. To insure conservatism, the air thermal properties are assumed to correspond to an ambient temperature of 100°F, which maximizes air viscosity, thereby underestimating the heat transfer coefficient for the –20°F and –40°F cases.

Table 3.6-1 shows the heat transfer coefficients for the various surface orientations for an ambient air temperature of 100°F.

Table 3.6-1 - Temperature Difference Based Heat Transfer Coefficients

Temperature Difference	Vertical Surface	Horizontal Heated Side Up	Horizontal Heated Side Down
50 °F	0.0063	0.0055	0.0032
100 °F	0.0073	0.0066	0.0037
150 °F	0.0078	0.0072	0.0039
200 °F	0.0086	0.0080	0.0043
250 °F	0.0087	0.0081	0.0044
300 °F	0.0094	0.0087	0.0047
500 °F	0.0105	0.0097	0.0053

Note: All coefficients are Btu/hr-in^2-°F

3.6.2.2 Forced Convection During Hydrocarbon Fire

During a Hypothetical Accident Condition (HAC) hydrocarbon fire, the heated gasses surrounding the package will achieve velocities sufficient to induce forced convection on the surface of the package. Measurements taken during actual hydrocarbon tests predict average induced gas velocities of between 6 m/s (19.7 ft/s) [15] and 9 m/s (29.5 ft/s) [14]. Peak measured velocities have been as high as 15 m/s (49.2 ft/s), although these occurred 6.1 meters (20 ft) from the fire surface. Peak velocities 2.2 meters from the fire surface (7.2 ft) peak measured velocities were under 10 m/s (32.8 ft/s) [16].

Assuming a gas velocity of 9 m/s (29.5 ft/s) and a horizontally oriented cask with an outer diameter of 3.14 feet, per Elements of Heat Transfer [17] the convection coefficient can be expressed as,

$$h = Nu\frac{k}{L} \text{ Btu/hr-in}^2\text{-°F}$$

Where k is the conductivity of gas at film temperature (Btu/hr-in-°F) and L is the effective length of the vertical surface or cylinder diameter (in). For a horizontal cylinder being subjected to turbulent flow (Re > 5,000), the Nusselt number can be expressed as

$$Nu = 0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1+(0.4/\mathrm{Pr})^{2/3}\right]^{1/4}}\left[1+\left(\frac{\mathrm{Re}}{282{,}000}\right)^{5/8}\right]^{4/5}$$

were the Reynolds Number is expressed as

$\mathrm{Re} = \dfrac{u_\infty D}{\nu}$, u_∞ is average air velocity, D is cask diameter, ν is dynamic viscosity

Initial calculations determined that the surface of the cask exceeds 1200°F in under 10 minutes, therefore, a film temperature of 1350°F is assumed for determining air material properties. Specifically, Pr = 0.702, k = 0.039 Btu/hr-ft-°F and ν = .00129 ft²/sec.

The resulting Reynolds number is 71,800, the Nusselt number is 172.4 and the heat transfer coefficient is 2.14 Btu/hr-ft²-°F. This coefficient is applied to the entire exposed surface of the cask for the duration of the half hour fire simulation.

3.6.3 ANSYS Input Files

3.6.3.1 GOEND.INP

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/com To execute, enter ANSYS 5.3, and type "/INP,GOEND,INP"
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/inp,sgsolid,inp
/inp,caskmesh,inp
/inp,lidmesh,inp
/inp,limmesh,inp
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alls
/grap,full
save
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3.6.3.2 SGSOLID.INP

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fini
/cle
/prep7

! set up toolbar abbreviations
/NOPR
*ABBR,ANSYSWEB          ! turn off ansys web button (another stupid ansys
default)
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et,5,32  !toroid shells



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K,144,8.5,44.51
K,145,6.999216,44.51
K,146,6.999216,45.25
K,147,29.68800,52.88000
K,148,20.00000,62.56800
K,149,20.0,52.88
K,150,10.31200,52.88000
K,151,20.00000,43.19200
K,152,18.0,43.4
K,153,10.521,50.88

C*** Define mesh arc segments for material 4
LARC,147,148,149,9.688
LARC,148,150,149,9.688
LARC,151,147,149,9.688
LARC,152,151,149,9.688
LARC,150,153,149,9.688
LATT,5,5,5
LSEL,U,LINE,,ALL
ALLS

A,25,26,27,28
A,26,29,30,27
A,29,31,32,30
A,33,34,35,36
A,33,36,37,38
A,38,37,39,40
A,41,42,43,44
A,44,43,45,46
A,44,46,47,48
A,31,49,50,32
A,50,49,51,52
```

```
A,53,54,55,56
A,54,57,58,55
A,56,55,58,59
A,59,58,60,61
A,58,57,62,60
A,61,60,63,64
A,63,60,62,65
A,64,63,66,67
A,68,66,69,70
A,70,69,71,72
A,73,74,75,76
A,77,78,79,80,81,82
A,74,83,84,75
A,75,84,85,86
A,81,80,87,88
A,88,87,89,90
A,91,90,89,92,93,94
A,86,85,95,96
A,96,95,97,98
A,99,96,98,100,101
A,93,92,102,103
A,103,102,104,105
A,105,104,106,107,108,109
A,110,111,101,100,112
A,107,110,113,114,115,116
A,113,110,112,117,118
A,115,114,119,120,121
A,113,118,119,114
A,122,116,115,121,123
A,65,71,69,66,63
A,70,72,74,73
A,78,124,125,79
A,124,126,64,67,127,128,125
A,67,66,68,127
A,106,111,110,107
A,129,130,131,132,133
!A,133,134,129
A,131,135,136,132
A,137,136,132,138
A,138,137,139,140
A,140,139,141,142
A,142,141,143,144
A,145,144,142,146
A,34,35,145,146
A,42,36,37,41
AATT,2,2,2
ASEL,U,AREA,,ALL
ALLS


FLST,5,15,5,ORDE,4
FITEM,5,4
FITEM,5,-9
FITEM,5,47
```

```
FITEM,5,-55
ASEL,S, , ,P51X
AATT,3,3,3


FLST,5,5,5,ORDE,4
FITEM,5,1
FITEM,5,-3
FITEM,5,10
FITEM,5,-11
ASEL,S, , ,P51X
AATT,4,4,4

save,sgsolid,db
```

3.6.3.3 CASKMESH.INP

```
alls
resu,sgsolid,db
!Mesh
lccat,79,80
lccat,76,77
lccat,146,147
lccat,149,150
lccat,91,93
lccat,95,96
lccat,112,114
lccat,116,117
lccat,106,120
lccat,129,130
lccat,124,125
lccat,127,126
lccat,134,135
lccat,127,137
lccat,104,107
lccat,103,105
lccat,73,74
lccat,65,68
lccat,43,48
lccat,125,132
lccat,63,148


lesize,127,,,1
lesize,134,,,1
lesize,104,,,1
lesize,73,,,1
lesize,65,,,2
lesize,120,,,2
lesize,132,,,3
lesize,135,,,2
lesize,78,,,3
lesize,83,,,3
```

```
esize,.75
mshkey,1

asel,s,type,,2
arus,,13,22,9
arus,,31,39,8
alls,below,area
amesh,all

arsel,,13,22,9
aras,,31,39,8
mshk,
ames,all
```

3.6.3.4 LIDMESH.INP

```
alls

!Mesh
lccat,154,155
lesize,154,,,2
lesize,159,,,2
lesize,170,,,2
lesize,171,,,2
lesize,30,,,2

asel,s,area,,6
aatt,5,,3
alls

esize,.75
mshkey,1

asel,s,type,,3
alls,below,area
amesh,all


lsel,s,line,,180,200
ldele,all
```

3.6.3.5 LIMMESH.INP

```
alls

!Mesh
!lesize,8,,,24,1.1
lesize,7,,,2
!lesize,15,,,11,1.5
lesize,12,,,2
!lesize,38,,,3
!lesize,41,,,10,1.8
```

```
esize,.75
eshape,2
!mshkey,1

asel,s,type,,4
alls,below,area
amesh,all


lsel,s,type,,5
lmesh,all

alls
*get,nmax,node,0,num,max
LOCAL,12,0,0,24.87,0, , , ,1,1,
esel,s,type,,4,5
nsle
nsym,y,nmax,all
ESYM, ,nmax,all
alls
eplo
```

3.6.3.6 LEADMES3.INP

```
alls
csys,0
dsys,0
!Add Lead Gap Keypoints
k,204,kx(104)+0.0625,ky(104)+0.0625
k,180,kx(80)+0.0625,ky(80)
k,187,kx(87)+0.0625,ky(87)
k,189,kx(89)+0.0625,ky(89)
k,192,kx(92)+0.0625,ky(92)
k,202,kx(102)+0.0625,ky(102)
k,179,kx(79)+0.0625,ky(79)-0.0625
k,168,kx(68),ky(68)-0.0625
k,225,kx(125),ky(125)-0.0625
k,227,kx(127),ky(127)-0.0625
k,170,kx(70)-0.0625,ky(70)-0.0625
k,173,kx(73)-0.0625,ky(73)-0.0625
k,175,kx(75)-0.0625,ky(75)-0.0625
k,176,kx(76)-0.0625,ky(76)-0.0625
k,186,kx(86)-0.0625,ky(86)
k,196,kx(96)-0.0625,ky(96)+0.0625
k,199,kx(99)-0.0625,ky(99)+0.0625
k,201,kx(101)-0.0625,ky(101)+0.0625
k,206,kx(106),ky(106)+0.0625
k,211,kx(111),ky(111)+0.0625

! set up air areas
AATT,6,6,2,
A,104,102,202,204
```

```
A,102,92,192,202
A,92,89,189,192
A,89,87,187,189
A,87,80,180,187
A,80,79,179,180
A,79,125,225,179
A,125,127,227,225
A,127,68,168,227
A,68,70,170,168
A,70,73,173,170
A,73,76,176,173
A,76,75,175,176
A,75,86,186,175
A,86,96,196,186
A,96,99,199,196
A,99,101,201,199
A,101,111,211,201
A,111,106,206,211
A,106,104,204,206
AATT,6,6,2,
asel,r,area,,56,61

AATT,9,9,2
ALLS
ASEL,U,AREA,,ALL

! set up middle lead volume
!FLST,2,20,3
!FITEM,2,204
!FITEM,2,202
!FITEM,2,192
!FITEM,2,189
!FITEM,2,187
!FITEM,2,180
!FITEM,2,179
!FITEM,2,225
!FITEM,2,227
!FITEM,2,168
!FITEM,2,170
!FITEM,2,173
!FITEM,2,176
!FITEM,2,175
!FITEM,2,186
!FITEM,2,196
!FITEM,2,199
!FITEM,2,101
!FITEM,2,211
!FITEM,2,206
!A,P51X
A,180,179,225,227,168,170,173,176
A,176,175,186,196,199,202,192,189,187,180
A,199,201,211,206,204,202
!asel,a,area,,6
AATT,5,5,2
```

```
ALLS
asel,s,area,,72,75
AATT,5,5,2
alls
asel,s,area,,71
AATT,9,9,2
alls
AMESH,56,75
!amesh,6

ESHAPE,3
ESIZE,1.0
AMESH,76,78,2
!ESHAPE,2
AMESH,77

!Bottom Lead Cavity
k,194,kx(94),ky(94)-0.0625
k,193,kx(93)-0.0625,ky(93)-0.0625
k,203,kx(103)-0.0625,ky(103)
k,205,kx(105)-0.0625,ky(105)
k,209,kx(109)-0.0625,ky(109)-0.0625
k,207,kx(107)-0.0625,ky(107)-0.0625
k,216,kx(116)-0.0625,ky(116)+0.0625
k,222,kx(122),ky(122)+0.0625

!set up air nodes
ASEL,U,AREA,,ALL
a,94,93,193,194
a,93,103,203,193
a,103,105,205,203
a,105,109,209,205
a,109,107,207,209
a,107,116,216,207
a,116,122,222,216

AATT,6,6,2

ASEL,U,AREA,,ALL

l,222,194

al,240,225,228,230,232,235,237,239

!a,194,193,209,207,216,222
AATT,5,5,2
alls
ESHAPE,3
asel,s,area,,83,85,2
aatt,5,5,2
alls
asel,s,area,,80,82
asel,a,area,,84
```

```
aatt,9,9,2
alls


AMESH,79,86

!Lower Lid Lead Air gaps
ASEL,U,AREA,,ALL
k,339,kx(39),ky(39)-0.0625
k,337,kx(37)-0.0625,ky(37)-0.0625
k,341,kx(41)-0.0625,ky(41)
k,344,kx(44)-0.0625,ky(44)+0.0625
k,348,kx(48),ky(48)+0.0625

a,39,37,337,339
a,37,41,341,337
a,41,44,344,341
a,44,48,348,344
AATT,6,6,2
ALLS
ASEL,U,AREA,,ALL
A,339,337,341,344,348
AATT,5,5,2

k,433,kx(133),ky(133)-0.0625
k,432,kx(132)-0.0625,ky(132)-0.0625
k,438,kx(138)-0.0625,ky(138)
k,440,kx(140)-0.0625,ky(140)
k,442,kx(142)-0.0625,ky(142)+0.0625
k,446,kx(146),ky(146)+0.0625
k,334,kx(34),ky(34)+0.0625
k,333,kx(33),ky(33)+0.0625
k,338,kx(38),ky(38)+0.0625
k,340,kx(40),ky(40)+0.0625

ASEL,U,AREA,,ALL
A,133,132,432,433
A,132,138,438,432
A,138,140,440,438
A,140,142,442,440
A,142,146,446,442
A,146,34,334,446
A,34,33,333,334
A,33,38,338,333
A,38,40,340,338

AATT,6,6,2
ALLS
ASEL,U,AREA,,ALL
A,433,432,438,440,442,446,334,333,338,340
AATT,5,5,2
ALLS
asel,s,area,,87,90,3
asel,a,area,,96,100,1
```

```
aatt,5,5,2
alls
asel,s,area,,88,89
asel,a,area,,93,95
aatt,9,9,2
alls
AMESH,87,101

!***LINES CROSS IN THIS BLOCK
!PUT IN AIR GAPS FOR LID, IL'S ET AL
ASEL,U,AREA,,ALL
K,400,kx(81),32.755
A,45,43,42,36,35,77,82,400
! old line A,129,28,53,56,59,61,64,67,126,141,139,137,136,135,131,130
!Add New Node to permit good Mesh of air gap

k,453,10.073,49.880

A,129,28,53,56,59,61,64,126,141,139,137,136,135,131,130

a,54,30,32,62,57
A,35,36,43,45,400,77
!***BLOCK END

k,500,kx(123),ky(123)-0.14
a,123,121,120,500
!k,501,kx(119)+0.13,ky(119)
k,501,11.625,-0.14
k,502,kx(117),ky(117)-0.13

k,520,10.073,-0.14000

a,119,118,117,502,501
AATT,6,6,2

ALLS
asel,s,area,,104,107,3
aatt,10,6,2
alls
AMESH,102,104
amesh,106,107

!Define proper 2-d limiters
k,553,kx(153)+0.75,ky(153)
k,550,kx(150)+0.75,ky(150)
k,548,kx(148),ky(148)-0.75
k,547,kx(147)-0.75,ky(147)
k,551,kx(151),ky(151)+0.75
k,552,kx(152),ky(152)+0.75
LARC,547,548,149,9.00
LARC,548,550,149,9.00
LARC,551,547,149,9.00
LARC,552,551,149,9.00
LARC,550,553,149,9.00
```

```
l,153,553
l,150,550
l,148,548
l,147,547
l,151,551
l,152,552

asel,u,area,,all
esel,u,elem,,all
nsel,u,node,,all

al,291,5,292,290
al,293,2,292,287
al,294,1,293,286
al,294,3,295,288
al,295,4,296,289
asel,a,area,,1,3
asel,a,area,,10,11
aatt,4,4,4
!alls
amesh,107,112
amesh,1,3
amesh,10,11
!****
LOCAL,12,0,0,24.87,0, , , ,1,1,
!esel,s,type,,4,5
!FLST,4,257,1,ORDE,2
!FITEM,4,1755
!FITEM,4,-2011
NSYM,Y,6000,all
ESYM, ,6000,all
alls
eplo
! Add radiation shield
lgen,2,82,84,2,0.105,0.0,0.0
lgen,2,82,84,2,0.855,0.0,0.0
lgen,2,82,84,2,0.970,0.0,0.0
lgen,2,82,84,2,1.105,0.0,0.0

lgen,2,98,101,3,0.105,0.0,0.0
lgen,2,98,101,3,0.855,0.0,0.0
lgen,2,98,101,3,0.960,0.0,0.0
lgen,2,98,101,3,1.095,0.0,0.0
asel,u,area,,all

a,83,1,2,84
a,4,7,8,5
a,84,2,3,85
a,5,8,9,6
a,85,3,14,95,
a,6,9,20,17
a,95,14,15,97
a,17,20,21,18
```

```
AATT,6,6,2
ASEL,U,AREA,,ALL

a,1,4,5,2
a,7,10,11,8
a,2,5,6,3
a,8,11,12,9
a,3,6,17,14
a,9,12,23,20
a,14,17,18,15
a,20,23,24,21
aatt,3,3,3
alls
!esel,s,mat,,6
!asle,u
!asel,r,mat,,6
!amesh,all
esize,0.7360
asel,s,area,,113,114
asel,a,area,,119,121
asel,a,area,,127,128
aatt,2,2,2
alls
amesh,112,128

!End volumetric heat

! Add in lid cask 0.01 inch gap

asel,u,area,,all
a,144,143,126,124
a,145,144,124,78
a,35,145,78,77
aatt,6,6,2
alls
!Define elements manually
type,2
mat,6
!e,759,106,108,895
!e,895,108,107,889
!e,889,107,647,890
!e,890,647,648,891
!e,891,648,646,886
!e,886,646,660,887
!e,887,660,884,884

!*amesh,128,130
/inp,fixes,inp
```

3.6.3.7 FIXES.INP

```
!This finishes the conversion from a structural analysis ready to a thermal
!  ready model
!START THE FIX NOW
```

```
! GET NEW TOP AIR GAP CONFIGURED CORRECTLY
CSYS,0
DSYS,0
ACLEAR,103
A,129,28,453,53,56,59,61,64,126,141,139,137,136,135,131,130
AATT,6,6,2
AMESH,132
!FIX NUMBER ONE DONE
!  ADD IN TOP ELEMENTS
TYPE,2
MAT,6
E,1141,1,3,1138
E,1138,3,4,1174
E,1174,4,2,1172

! END FIX 2
! REALLY BEGIN FIX 3 NOW
aclear,106
asel,u,area,,all
a,123,121,120,520,500
aatt,6,6,2
amesh,all
alls
!end fix 3

!fix 4 lower il cask air gap

type,2
mat,6
e,698,2443,2440,700
e,700,2440,2476,699
e,699,2476,2474,695

!end fix 4

!fix 5 lower ild radial air gaps
type,2
mat,6
e,499,2525,2527,869
e,869,2527,2528,870
e,870,2528,582,582
e,2528,582,589,2529
e,2529,589,590,2530
e,2530,590,591,591
e,2530,591,592,2516
e,2516,592,588,2518
e,2518,588,671,2490

!end fix 5

!fix 6 upper il radial gap
mat,6
type,2
e,1188,49,74,1216
```

```
e,1216,74,73,1214
e,1214,73,748,748
!e,121,748,749,1228
!e,1214,748,749,1228
e,1214,748,1228,1228
e,748,1228,749,749
e,749,1228,109,109
e,1228,109,116,1227
e,1227,116,115,1226
e,1226,115,764,764
e,1226,764,765,1225
e,1226,764,765,765
e,1226,765,1225,1225
e,1225,765,766,766
e,1225,766,243,1223


!end fix 6

!fix 7 adding elements to the upper il cask to fire shield area
type,2
mat,6
e,1223,243,245,245
e,1223,245,1224,1224
e,245,246,1224,1224
e,1224,246,244,244
e,1224,244,1218,1218

!to lower il
e,499,2525,501,501
e,501,2525,2526,2526
e,501,2526,500,500
e,500,2526,496,496
e,496,2526,2520,2520

!end fix 7

! fix 8 lid to cask body gap very small

type,2
mat,6
e,932,127,129,129
e,932,129,1105,1105
e,1105,129,130,130
e,1105,130,128,1096
e,1096,128,792,1097
e,1097,792,1098,1098
e,1098,792,791,1092
e,1092,791,1093,1093
e,1093,791,803,803
e,1093,803,1090,1090

! end fix 8
```

```
! couple degrees of freedom in lower lead - fix 9
nsel,s,node,,544,546
nsel,a,ndoe,,548,549
nsel,a,node,,548,549
nsel,a,node,,3297,3300
cpintf,temp,0.43
!end fix 9


! fix 10 couple degrees of freedom for lid to ID
alls

nsel,s,node,,174,187
nsel,a,node,,3660,3669

cpintf,temp,0.6

alls

!end fix 10

! really do fix 11 now

! break top of inner shield
esel,s,elem,,2687,2717,30
emod,all,mat,6
alls

! Another CP - this time lower IL to cask
FLST,5,20,1,ORDE,6
FITEM,5,2490
FITEM,5,2492
FITEM,5,-2502
FITEM,5,3718
FITEM,5,3720
FITEM,5,-3726
NSEL,S, , ,P51X
nplot
cpintf,temp,0.4
! cpintf,temp,0.4
/PREP7
FINISH
/PREP7
cpintf,temp,0.4
alls
! THE

!big fix - some nodes are mega slightly off
/prep7
FINISH
/prep7
cpintf,temp,0.0008
```

```
! SET UP RADIATION SUPER FILE
lclear,1,5
esel,s,type,,5
edel,all
alls

esel,s,mat,,6,10,4
nsle,r
mat,3
type,5
esurf
esel,s,elem,,2943,3049,2
esel,a,elem,,3053,3065,2
esel,a,elem,,3068,3069
esel,a,elem,,3071,3092,2
emod,all,mat,5
alls
esel,s,elem,,2944,3048,2
esel,a,elem,,3051,3052
esel,a,elem,,3054,3066,2
esel,a,elem,,3067,3070,3
esel,a,elem,,3072,3090,2
esel,a,elem,,3093
emod,all,mat,2
alls
esel,s,type,,5
nsle,r

! Get surfaces reoriented
*GET,EMIN,ELEM,0,NUM,MIN
*GET,EMAX,ELEM,0,NUM,MAX

*DO,CNT,EMIN,EMAX,1
  *GET,ELNn,ELEM,ELN,NXTH
   ELN=ELNn

  *GET,EI,ELEM,ELN,NODE,1
  *GET,EJ,ELEM,ELN,NODE,2
!   *GET,EK,ELEM,ELN,NODE,3
!   *GET,EL,ELEM,ELN,NODE,4
  EMODIF,ELN,1,EJ,EI
  *IF,ELNn,EQ,EMAX,EXIT
*enddo
!ENORM,EMIN

fini

/AUX12
geom,1,30
vtype,0,500
mprint,1
emis,2,0.7
emis,3,0.5
emis,5,0.63
```

```
!WRITE,super

FINI
/PREP7
EDEL,ALL
ALLS

! Set up interior of impact limiters
type,5
mat,3

E,1171,1170
E,1170,1177
E,1177,1178
E,1178,1179
E,1179,1180
E,1180,1181
E,1181,1182
E,1182,1183
E,1183,1184
E,1184,1185
E,1185,1186
E,1186,1187
E,1187,1176
E,1176,3796
E,3796,3797
E,3797,3798
E,3798,3775
E,3775,3776
E,3776,3777
E,3777,3778
E,3778,3779
E,3779,3780
E,3780,3781
E,3781,3782
E,3782,3783
E,3783,3784
E,3784,3785
E,3785,3786
E,3786,3787
E,3787,3788
E,3788,3789
E,3789,3790
E,3790,3791
E,3791,3792
E,3792,3793
E,3793,3794
E,3794,3795
E,3795,3754
E,3754,3755
E,3755,3756
E,3756,3757
```

```
E,3757,3758
E,3758,3759
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nsle,r

/AUX12
geom,1,30
vtype,0,500
mprint,1

emis,3,0.5



!WRITE,ild

FINI
/PREP7
EDEL,ALL
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```
esel,s,type,,5
nsle,r

/AUX12
geom,1,30
vtype,0,500
mprint,1

emis,3,0.64



!WRITE,exd64
emis,3,0.80
!WRITE,exd80

FINI
/PREP7
EDEL,ALL
ALLS
```

3.6.3.8 MAT2.INP

```
g=386.4
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                           !
!    Stainless Steel Material Properties    !
!                                           !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,2,0.289
mp,emis,2,0.5
mptemp,1,-20,70,100,200,400,600
!kxx=Tc (Btu/hr/ft/F
mpdata,kxx,2,1,.692,.717,.725,.775,.867,.942
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,2,1,.111,.124,.13,.134,.140,0.158

mp,dens,3,0.289
mp,emis,3,0.5
mptemp,1,-20,70,100,200,400,600
mpdata,kxx,3,1,.692,.717,.725,.775,.867,.942
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,3,1,.111,.124,.13,.134,.140,0.158

mp,dens,4,0.289
mp,emis,4,0.5
mptemp,1,-20,70,100,200,400,600
mpdata,kxx,4,1,.692,.717,.725,.775,.867,.942
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,4,1,.111,.124,.13,.134,.140,0.158

mp,dens,7,0.289
mp,emis,7,0.5
```

```
mptemp,1,-20,70,100,200,400,600
mpdata,kxx,7,1,.692,.717,.725,.775,.867,.942
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,7,1,.111,.124,.13,.134,.140,0.158


!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                     !
!       Lead Material Properties      !
!                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,5,0.411
mp,emis,6,0.9
mptemp
mptemp,1,-148,32,212,392,572,621
mpdata,kxx,5,1,1.775,1.692,1.608,1.517,1.433,1.433
mptemp
mptemp,1,32,615.5,616.5,625.5,626.5,1500
mpdata,c,5,1,.031,.031,0.031,0.039,.039,.039



!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                     !
!       Air Material Properties       !
!            (A.F. Mills)             !
!                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,6,0.01
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mpdata,kxx,6,1,0.0011,0.0011,0.0013,0.0013,0.0015,0.0017
mpdata,kxx,6,7,0.0018,0.0020,0.0021,0.0023,0.0024,0.0026
mptemp
mptemp,1,0,100,200,300,400,500
!Vertical Surface HTC
mpdata,hf,6,1,0.0000013,0.0066,0.0080,0.0094,0.0100,0.0105
mp,c,6,0.00013

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                     !
!       Air Material Properties       !
!        for fillet area (1/9 value)  !
!            (A.F. Mills)             !
!                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,7,0.0011
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
```

```
mpdata,kxx,7,1,0.0011/9,0.0011/9,0.0013/9,0.0013/9,0.0015/9,0.0017/9
mpdata,kxx,7,7,0.0018/9,0.0020/9,0.0021/9,0.0023/9,0.0024/9,0.0026/9
mptemp
mptemp,1,0,100,200,300,400,500
! Upwards CV
mpdata,hf,7,1,0.0000013,0.0066,0.0080,0.0087,0.0092,0.0097
mp,c,7,0.00013

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                     !
!      Air Material Properties        !
!       Contact Resistance   !
!           (A.F. Mills)              !
!                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,9,0.0011
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mp,kxx,9,350.0*0.0625
mptemp
mptemp,1,-148,32,212,392,572,621
mpdata,kyy,9,1,1.775,1.692,1.608,1.517,1.433,1.433
mptemp
mptemp,1,0,100,200,300,400,500
!downwards cv
mpdata,hf,9,1,0.0000013,0.0037,0.0043,0.0047,0.0050,0.0053
mp,c,7,0.00013

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                     !
!      Air Material Properties        !
!       for fillet area (2 value)   !
!           (A.F. Mills)              !
!                                     !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,10,0.0011
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mpdata,kxx,10,1,0.00118*2,0.0011*2,0.0013*2,0.0013*2,0.0015*2,0.0017*2
mpdata,kxx,10,7,0.0018*2,0.0020*2,0.0021*2,0.0023*2,0.0024*2,0.0026*2
mptemp
mptemp,1,0,100,200,300,400,500
mpdata,hf,10,1,0.0000013,0.0060,0.0076,0.0087,0.0096,0.0103
mp,c,10,0.00013
mp,dens,10,0.0011

mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mpdata,kxx,11,1,0.00118*2,0.0011*2,0.0013*2,0.0013*2,0.0015*2,0.0017*2
```

```
mpdata,kxx,11,7,0.0018*2,0.0020*2,0.0021*2,0.0023*2,0.0024*2,0.0026*2
mptemp
mptemp,1,0,100,200,300,400,500
mpdata,hf,11,1,0.0000013,0.0060,0.0076,0.0087,0.0096,0.0103
mp,c,11,0.00013

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                           !
!    Stainless Steel Material Properties    !
!      in fillet area                       !
!                                           !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
mptemp
mp,dens,12,0.289/9.
mp,emis,12,0.5
mptemp,1,-20,70,100,200,400,600
!kxx=Tc (Btu/hr/ft/F
mpdata,kxx,12,1,.692/9.,.717/9.,.725/9.,.775/9.,.867/9.,.942/9.
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,12,1,.111,.124,.13,.134,.140,0.158
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!                                                   !
!  Fire  impacted air gap - 1/20th air conductivity !
!                                                   !
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

mp,dens,13,0.01
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mpdata,kxx,13,1,0.022,0.022,0.026,0.026,0.030,0.034
mpdata,kxx,13,7,0.036,0.040,0.042,0.046,0.048,0.052
mp,c,13,0.00013

mp,dens,14,0.013
mp,emis,14,0.5
mptemp
mptemp,1,-40,-20,70,100,200,300
mptemp,7,400,500,600,700,800,900
mpdata,kxx,14,1,0.0014,0.0014,0.0017,0.0017,0.0020,0.0022
mpdata,kxx,14,7,0.0024,0.0026,0.0028,0.0030,0.0032,0.0034
mptemp,1,0.0,200.,400.,600.,800.,1500.
mpdata,c,14,1,.111,.124,.13,.134,.140,0.158
```

4.0 CONTAINMENT

The SteriGenics Eagle Cask (SEC) is designed as a means of confinement for special form cobalt-60 source capsules. Containment of radioactive materials is provided by the special form construction of the payload. The three types of source capsules and their special form certification are as follows:

Manufacturer	Model Number	Certification Number
Nordion International, Inc.	C-188 capsule, Types 1 through 12	CDN/0010/S-85
Puridec	X.2089	GB/343/S-85
Neutron Products, Inc.	NPRP 450-10-B	USA/0458/S

Since the SEC does not provide containment, subsequent sections of this chapter are not applicable.

5.0 SHIELDING EVALUATION

5.1 Discussion and Results

This shielding evaluation supports the transport of Cobalt-60 source capsules in the SteriGenics Eagle Cask (SEC). Two bounding source terms were used in the shielding evaluation, where each bounding source term consists of a total 330,000 curies of Cobalt-60 capsules. The first source term has a payload of 72 source capsules, while the other has 18 source capsules. Each payload contains the same total inventory of 330,000 curies. The computer code MCNP [1] was utilized to perform the dose rate calculations.

The dose limits for this package are based on 10 CFR §71.47, 10 CFR §71.51, and 49 CFR §173.441. These limits are 200 mrem/hr at any accessible point on the exterior surface of the package, 10 mrem/hr at a distance of 2 m from the package, and 2 mrem/hr in any normally occupied space in the transport vehicle. The normally occupied space is conservatively assumed to be 2 m from the side of the SEC for this evaluation. After the SEC is subjected to hypothetical accident conditions, the limit is 1,000 mrem/hr at 1 m from the exterior surface of the package.

Both normal conditions of transport (NCT) and hypothetical accident conditions (HAC) were analyzed. The only damage to the SEC in the event of the hypothetical accident would be deformation of the impact limiters due to the free drop event and a slight indentation of the outer shell/thermal shield due to the puncture bar drop event. Therefore, the dose rates calculated without the impact limiters represents the SEC under HAC. The NCT and HAC dose rates for the SEC for the two source configurations are summarized in Table 5.1-1. These dose rates are well below their respective limits, even though no shielding credit was assumed for the personnel barrier for NCT.

The shielding calculations demonstrate that the dose rates meet the acceptance criteria with ample margin for uncertainties for both NCT and HAC. A number of uncertainties have a small affect on the accuracy of the results presented, but do not impact the results of the conclusions. These include small uncertainties in material compositions and densities, dimensional uncertainties, and in the cross section data in the MCNP library.

Table 5.1-1 Summary of Maximum Dose Rates for the SEC (mrem/hr)

Normal Conditions of Transport						
	Package Surface①			2 m from Surface of Package		
Payload	Side	Top	Bottom	Side	Top	Bottom
18 Capsule Source	34.1 (0.4%)②	99.0 (8.7%)	15.8 (1.7%)	1.37 (0.4%)	2.60 (14%)	0.47 (2.1%)
72 Capsule Source	24.9 (0.5%)②	82.3 (13%)	9.5 (3.1%)	0.99 (0.6%)	2.25 (26%)	0.31 (3.4%)
Limit	200	200	200	10③	10	10
Hypothetical Accident Conditions						
	Package Surface			1 m from Surface of Package		
Payload	Side	Top	Bottom	Side	Top	Bottom
18 Capsule Source	----	----	----	3.92 (0.4%)②	18.48 (9.6%)	3.91 (1.8%)
72 Capsule Source	----	----	----	2.85 (0.5%)②	15.17 (16%)	2.55 (2.2%)
Limit	----	----	----	1000	1000	1000

Notes:

① Package surface dose rates are the dose rates 1 cm from the surface.

② The one standard deviation statistical uncertainty (relative) in the Monte Carlo calculation. Dose rates do not include uncertaninty.

③ The dose rate limit for the driver is 2 mrem/hr. The driver is assumed to be located 2 m from the side of the cask.

5.2 Source Specification

The source used for these evaluations represents a worst-case loading of 330,000 curies of Cobalt-60. This 330,000 Curie source will be contained in either 18 or 72 capsules. The 72 capsule payload are located in two concentric circles, each containing 36 capsules (see Figure 5.3-3). The 18 capsule source is obtained by removing the outer row of capsules in the 72 capsule source and removing every other capsule in the inner row, and increasing the source strength of each of these 18 remaining capsules by a factor of four so the total inventory is still 330,000 curies; i.e., a partial loading of capsules is to first fill up the inner row.

The source is assumed to be uniform both radially and axially within the cobalt region of each pin. Each capsule has the same total strength for a given source; i.e., each capsule for the 18 capsule source has 330,000 curies/18 = 18,333.33 curies and each capsule for the 72 capsule source has 330,000 curies/72 = 4583.33 curies.

All shipments are bounded by these two sources.

5.2.1 Gamma Source

The ORIGEN2 [2] computer code was used to calculate the total strength and energy dependence of the photon source. The total photon strength is $2.5354 \times (10)^{16}$ photons/s for a 330,000 Curie source. The energy dependence of this source is given in Table 5.2-1.

5.2.2 Neutron Source

The radioactive source material (i.e., Cobalt-60) does not contain neutron emitters.

Table 5.2-1 Photon Source Used in the Monte Carlo Calculations for One Curie of Cobalt-60

Photon Energy (MeV)	Strength (photons/s)①	Photon Energy (MeV)	Strength (photons/s)①
0.015	1.961 E+09	0.375	3.041 E+06
0.025	3.388 E+08	0.575	1.746 E+05
0.0375	1.935 E+08	0.85	2.763 E+06
0.0575	2.182 E+08	1.1732	3.700 E+10
0.085	8.582 E+07	1.3325	3.700 E+10
0.125	3.296 E+07	2.25	3.921 E+05
0.225	1.084 E+07	2.75	1.213 E+03
		Total	**7.683 E+10**

Notes:

① 2.5354 E+16 photons/sec from 330,000 curies

5.3 Model Specification

5.3.1 Description of Radial and Axial Shielding Configuration

The SEC and the closure lid are constructed of stainless steel with the radial and axial cavities filled with lead (either by pouring or cutting and stacking lead plates). The cask shielding consists of approximately the following: a) 2.0 inches of steel and 10.375 inches of lead in the radial direction; b) 2.0 inches of steel and 11.88 inches of lead axially at the bottom; and c) 3.5 inches (closure lid plus the impact limiter 1-inch steel plate) of steel and 14.38 inches of lead axially through the closure lid. The closure lid also includes a 0.25 inch radial gap between the outside of the closure lid and the inside of the radial steel of the cask body for the lower 11.625 axial inches.

The following information was used for the calculations:

- The photon source as defined previously in Table 5-2.
- The ANSI/ANS-6.1.1-1991 (ANSI/ANS 1991) flux-to-dose conversion factors given in Table 5.3-1 to convert fluxes to dose rates, where these conversion factors conservatively assume the radiation exposure is from an anterior-posterior exposure.
- The drawings provided in Appendix 1.3.2, *Package General Arrangement Drawings*, were used to construct the initial MCNP calculational model for the SEC and the payload. Also used was Nordion International drawing No. C-188 for the C-188 Cobalt-60 Sealed Source. This drawing defines the capsule as two 8-inch lengths of Cobalt-60 with an ID of 0.28 inch and OD of steel clad of 0.38 inch, i.e., clad radial thickness of 0.05 inch. The radial distance of the center of each inner pin from the payload center is 3.50 inch and radial distance of the center of each outer pin from the payload center is 4.125 inch. The thin 0.277 inch steel spacer between the two 8-inch lengths of cobalt was added to the ends; i.e., the two 8-inch lengths were added together as one 16-inch length, to simplify the already complex geometry. The models conservatively do not include the 10 gauge (0.135 inch) stainless steel outer thermal shield radially beyond the main body of the SEC.

All of the MCNP cells describing the SEC are axially symmetric except for the vent port cells and the lead cells around the vent port these lead cells are also axially symmetric except for the asymmetry introduced by the vent port. Two calculational models were created, with the SEC geometry and dimensions being the same in both models. The only difference between the two models involves the source payload within the SEC. The basket in the SEC contains an inner row of 36 source capsule locations and an outer row of 36 source capsule locations (see Figure 5-3). In the first calculational model, the SEC is loaded with 72 Cobalt-60 source capsules filling all of the inner and outer row locations of the basket. In the second calculational model, only 18 source capsules are loaded in the inner radial row of the basket. These 18 source capsules are loaded in alternate locations in the inner row of the basket. The remaining 54 basket locations were replaced with voids for this second calculational model.

Table 5.3-1 Photon Flux-to-Dose Rate Conversion Factors

Energy (MeV)	Fluence-to-Dose Rate ($Sv\text{-}cm^2/ph$ ×1 E-12)	Flux-to-Dose Rate (mrem/hr per $ph/cm^2/s$)	Energy (MeV)	Fluence-to-Dose Rate ($Sv\text{-}cm^2/ph$ ×1 E-12)	Flux-to-Dose Rate (mrem/hr per $ph/cm^2/s$)
1.00 E-02	0.0620	2.232 E-5	5.00 E-01	2.5400	9.144 E-4
1.50 E-02	0.1570	5.625 E-5	6.00 E-01	2.9900	1.076 E-3
2.00 E-02	0.2380	8.568 E-5	8.00 E-01	3.8300	1.379 E-3
3.00 E-02	0.3290	1.184 E-4	1.00 E+00	4.6000	1.656 E-3
4.00 E-02	0.3650	1.314 E-4	1.50 E+00	6.2400	2.246 E-3
5.00 E-02	0.3840	1.382 E-4	2.00 E+00	7.6600	2.758 E-3
6.00 E-02	0.4000	1.440 E-4	3.00 E+00	10.2000	3.672 E-3
8.00 E-02	0.4510	1.624 E-4	4.00 E+00	12.5000	4.500 E-3
1.00 E-01	0.5330	1.919 E-4	5.00 E+00	14.7000	5.292 E-3
1.50 E-01	0.7770	2.797 E-4	6.00 E+00	16.7000	6.012 E-3
2.00 E-01	1.0300	3.708 E-4	8.00 E+00	20.8000	7.488 E-3
3.00 E-01	1.5600	5.616 E-4	1.00 E+01	24.7000	8.892 E-3
4.00 E-01	2.0600	7.416 E-4	1.20 E+01	28.9000	1.040 E-2

The calculational model of the SEC is shown in Figure 5.3-1, where the lead zones and some of the steel zones have been divided into a number of MCNP cells for optimization of the Monte Carlo calculation. Figure 5.3-2 shows the materials in the various zones. Most of the cask shield thickness is lead material in the radial direction, and in the lower and upper axial directions. However, in the lower and upper corners of the SEC, there are pathways from the payload area to the corner that are mostly steel. Since photons are attenuated more readily by lead than by steel on a per unit thickness basis, contact dose rates along the bottom of the SEC are greater for radii out near the corner than at the center.

Contact dose rates on the top of the SEC are influenced by another factor - photons can stream up through the 0.25 inch radial gap between the outside surface of the lower portion of the plug and the surrounding radial steel of the SEC. These photons, after subsequent attenuation through the remaining lead and steel, result in a higher contact dose rate directly above this gap than at other locations on the top surface of the SEC.

Figures 5.3-1 and 5.3-2 only show the SEC with the closure lid installed, and do not show the source capsules and source support steel structure in the central payload portion of the cask. Figure 5.3-3 is a plan view of the 72 Cobalt-60 source capsules at an elevation between the support plates. Figure 5.3-4 is a plan view at an elevation within one of the support plates. Figure 5.3-5 is an elevation view of the source capsules and support plates. Finally, Figure 5.3-6 shows an expanded radial view of a source capsule. Dimensions and materials are shown in these figures.

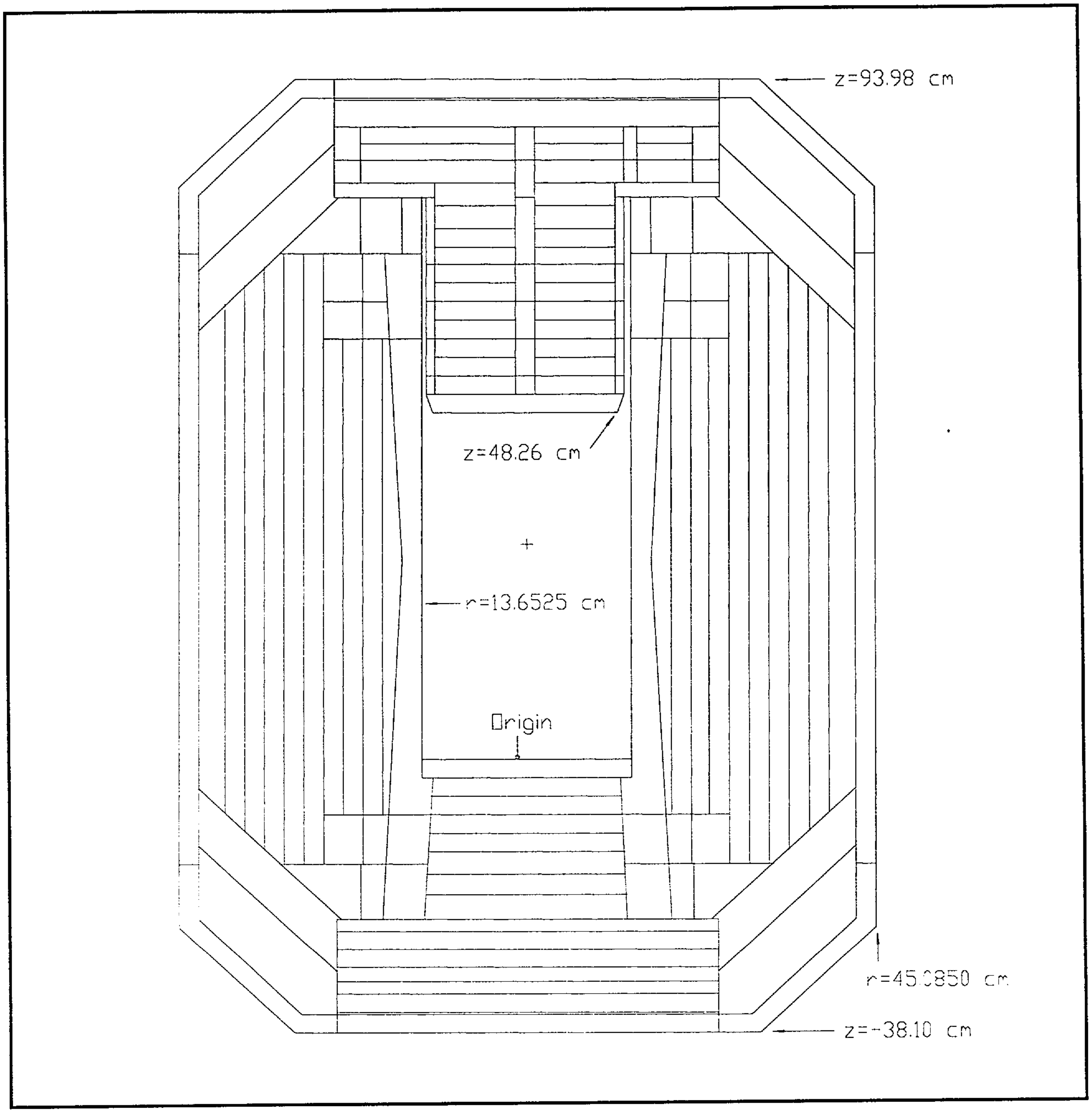

Figure 5.3-1 MCNP Elevation View of SEC Showing Major Dimensions

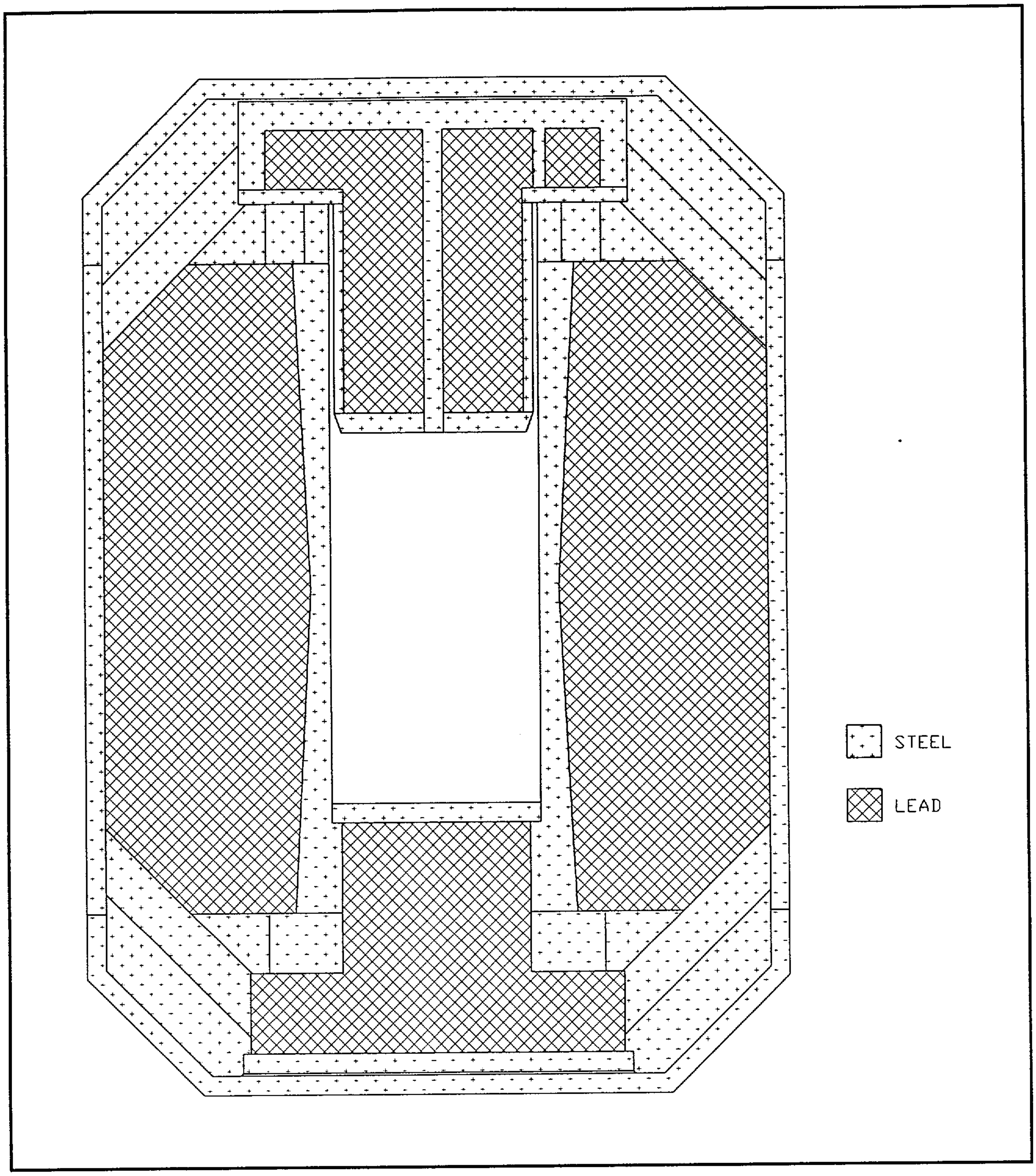

Figure 5.3-2 MCNP Elevation View of SEC Showing Materials

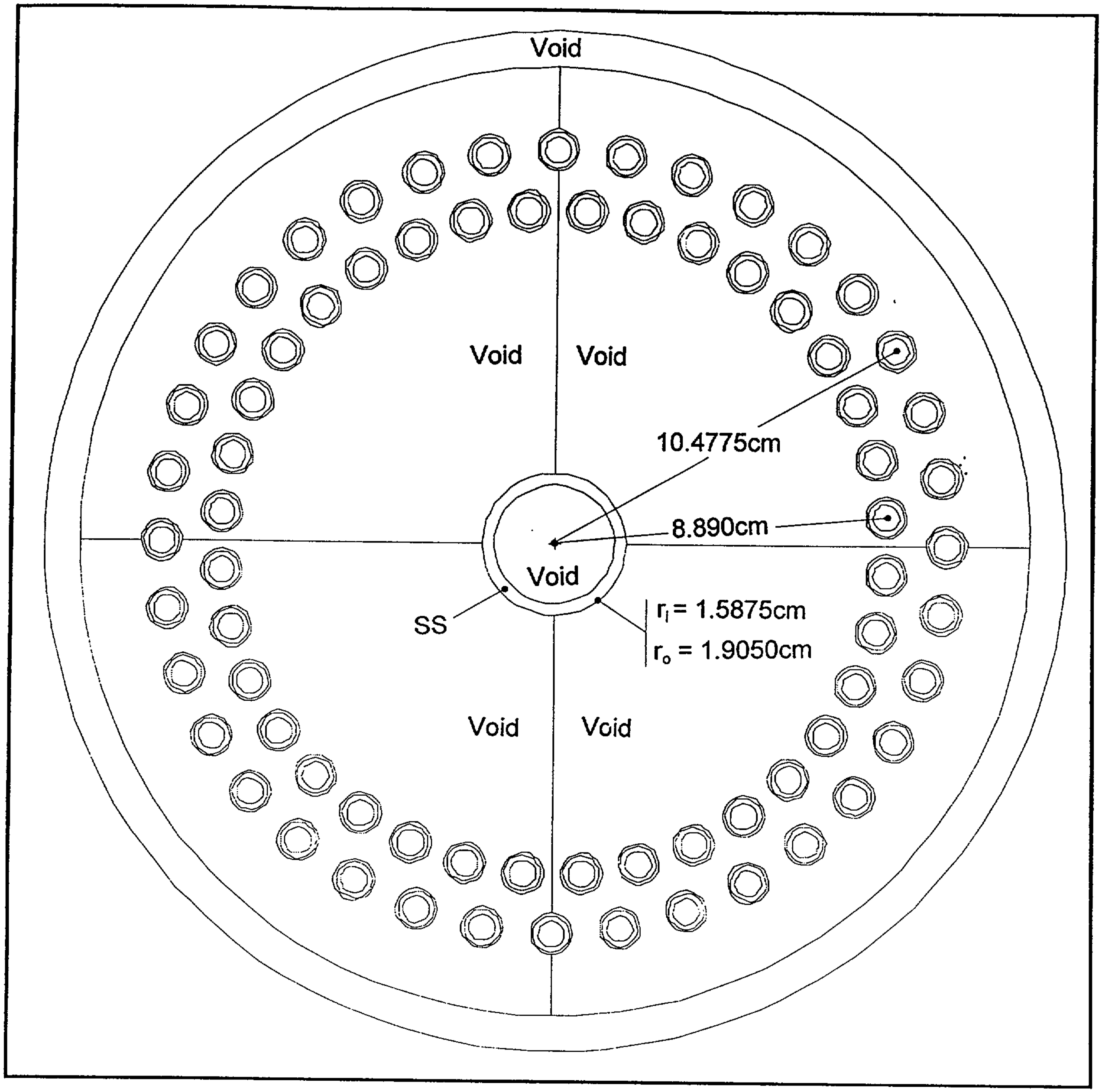

Figure 5.3-3 MCNP Plan View of Source at Elevation Between Plates

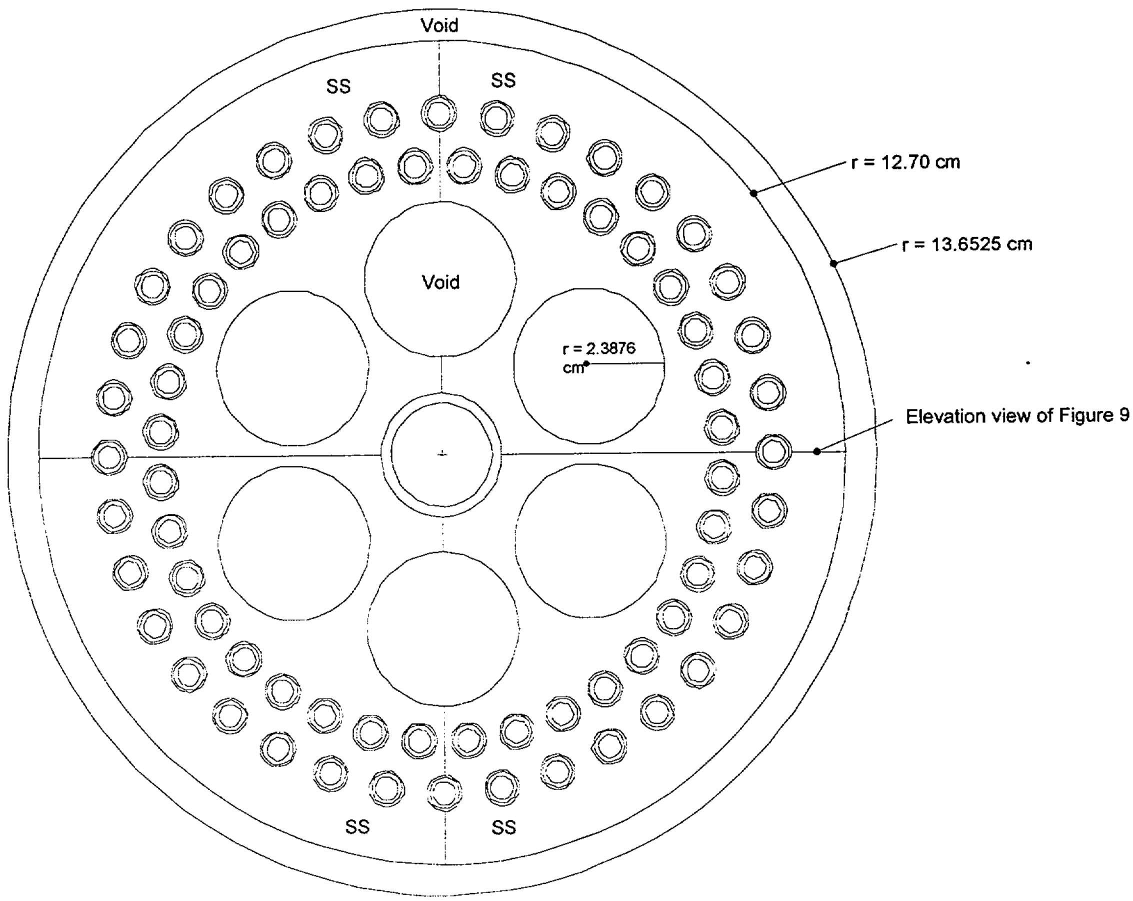

Figure 5.3-4 MCNP Plan View in Three Support Plates of Source

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure **5.3-5** **MCNP** Elevation View of Support Plates and Source Capsules (to scale)

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 5.3-6 **MCNP** Elevation View of a Source Capsule (not to scale, expanded radially)

5.3.2 Shield Regional Densities

Shielding consists of the SEC, including the upper plug, and the self-shielding within the source region itself. The SEC is made from Type 304 stainless steel and lead. Table 5.3-2 presents the material properties used in the calculations. The elemental attenuation properties are obtained from the data library for the MCNP computer code [1].

Table 5.3-2 Materials and Densities Used in the Calculations

Material	Density (g/cm^3)	Element	Weight Fraction (%)
Lead	11.34	Lead	100.00
Stainless Steel Type 304	8.02	Iron	68.72
		Chromium	19.00
		Nickel	9.25
		Manganese	2.00
		Phosphorus	1.00
		Carbon	0.03
Cobalt	8.90	Cobalt	100.00
Air	0.00123	Nitrogen	75.63
		Oxygen	24.37

5.4 Shielding Evaluation

The MCNP computer code [1] was used to perform the dose rate calculations. MCNP is a general-purpose Monte Carlo code with powerful geometry routines. It uses Evaluated Nuclear Data Files (ENDF/B) for cross sections [3]. The state-of-the-art ENDF/B system is maintained by the National Nuclear Data Center at Brookhaven National Laboratory under contract from DOE.

5.4.1 Dose Rates for Normal Transport Conditions

The normal transport condition is defined as fully loaded (18 or 72 capsules) 330,000 Curie Cobalt-60 source with the closure lid installed. Only the 1 inch thick steel at the top and bottom of the SEC is included for the impact limiters; i.e., the circular portion of the impact limiters is conservatively not included in the calculational model. For this analysis, the presence of the transport vehicle is ignored, and the exterior surface of the package is assumed to be the outside surface of the SEC.

Dose rates are calculated at contact (1 cm), at 1 m, and at 2 m (in air) from the radial side, top, and bottom of the SEC. The contact dose rates conservatively do not take credit for the personnel barrier. The 1-m dose rates are not needed for satisfying the limits, but are provided here for operational guidance.

There was considerable variation in the contact dose rate along the outer surfaces of the SEC because of the shield configuration -- particularly along the lower and upper surfaces. Shown in Table 5.4-1 is the contact dose rate as a function of location on the three outside surfaces for the 18 capsule source.

The maximum contact dose rate on the side occurs at the axial center of the source. The maximum contact dose rate along the top occurs above the 0.25 inch radial gap. The maximum contact dose rate along the bottom occurs at a large radius where the photon path from the source tends to be mostly through steel rather than lead. These locations for the maximum contact dose rates were the locations used for the contact dose rates given in the subsequent tables, and were also the locations of the maxima for the 72 capsule source.

Table 5.4-1 - Contact Dose Rates Along Outer Surfaces of SEC for 330 KCi 18 Capsule Source

Outer surface location	Distance along surface	Dose rates in mrem/hr (MCNP uncertainty①)
Side	z=-6.28 to 14.04 cm	22.1 (0.5%)
	z=14.04 to 34.36 cm②	34.1 (0.4%)
	z=34.36 to 54.68 cm	17.9 (0.5%)
Top	r=0.00 to 1.28 cm	3.0 (9.1%)
	r=1.28 to 11.65 cm	24.1 (8.2%)
	r=11.65 to 15.65 cm③	99.0 (8.7%)
	r=15.65 to 33.97 cm	8.8 (6.0%)
	r=33.97 to 45.09 cm	1.0 (2.2%)
Bottom	r=0.00 to 13.65 cm	2.0 (2.8%)
	r=13.65 to 21.27 cm	8.3 (3.0%)
	r=21.27 to 33.97 cm	11.5 (1.7%)
	r=33.97 to 45.09 cm	15.8 (1.7%)

Notes:

① The one standard deviation statistical uncertainty (relative) in Monte Carlo calculation. The dose rates do not include the uncertainty.

② Interval centered about axial center of source.

③ Above radial gap beyond plug.

The dose rates for NCT for the SEC and the corresponding allowable limits are summarized in Table 5.4-2. As shown, the dose rates are well under the regulatory NCT limits. In addition, the contact dose rates in Table 5.4-2 include no assumed shielding credit for the personnel barrier.

Table 5.4-1 - Dose Rates for the SEC for Normal Conditions of Transport

Location relative to cask	Cobalt-60 Source (330,000 Ci)	Dose rates in mrem/hr (MCNP uncertainty①)			
		Contact②	1 m	2 m	Driver
Side	18 Capsules	34.1 (0.4%)	3.92 (0.4%)	1.37 (0.4%)	1.37 (0.4%)
	72 Capsules	24.9 (0.5%)	2.85 (0.5%)	0.99 (0.6%)	0.99 (0.6%)
Top	18 Capsules	99.0 (8.7%)	5.91 (9.6%)	2.60 (14%)	----
	72 Capsules	82.3 (13%)	4.97 (16%)	2.25 (26%)	----
Bottom	18 Capsules	15.8 (1.7%)	1.24 (1.8%)	0.47 (2.1%)	----
	72 Capsules	9.5 (3.1%)	0.82 (2.2%)	0.31 (3.4%)	----
Limit		200	NA	10	2

Notes:

① The one standard deviation statistical uncertainty (relative) in Monte Carlo calculation. Dose rates do not include the uncertainty.

② Contact dose rates are the dose rates 1 cm from the surface.

5.4.2 Dose Rates for Hypothetical Accident Conditions

The only damage to the SEC in the event of an accident would be deformation of the impact limiters and a slight indentation of the outer shell/thermal shield due to the puncture bar drop event. The puncture bar damage on the SEC cask body may be estimated from the side puncture testing of a quarter scale, NuPac 125-B fuel cask [4]. During the testing of the quarter scale NuPac 125-B cask, the resultant indentation due to the puncture bar was 1.32 inches. For purposes of comparison, the NuPac 125-B cask has a gross weight-to-outer shell thickness ratio of 181,500/2.0 = 90,750 pounds per inch of shell thickness. Neglecting the outer and inner thermal shield shell thicknesses, the SEC has a gross weight-to-outer shell thickness ratio of 20,000/1.0 = 20,000 pounds per inch of shell thickness. Therefore, the SEC puncture bar side deformation is conservatively estimated to be (90,750/20,000) × 1.32 = 0.175 inches. Since there is greater steel thickness on the top (2½ inches) and bottom (2 inches) of the SEC to resist puncture bar damage, the side orientation bounds these two orientations. Assuming an equivalent amount of lead thickness reduction, this indentation will have minimal effect on the HAC dose rate at 1 m from the surface of the package.

Therefore, the surface dose rate without impact limiters represents the dose rate after HAC. This involves a calculation of the dose rate without the top inch of steel and the bottom inch of steel in the normal condition model; i.e., without the steel MCNP cell at the top of the plug in Figure 5.3-2 and without the bottom steel MCNP cell at the bottom of the SEC. As was assumed for the normal conditions analysis, the presence of the transport vehicle is ignored and the exterior surface of the package is assumed to be the outside surface of the SEC without the impact limiters.

The calculations to obtain the normal condition dose rates summarized in Table 5.4-2 are computationally expensive because of the streaming up the radial gap beyond the lower portion of the plug. Since the only change for accident conditions was the removal of the 1-inch of steel at the top and bottom of the SEC, dose rates were also tallied on the surfaces prior to entry of these two cells during the normal condition calculations. The ratio of the dose rate before the 1-inch of steel to the dose rate after the 1-inch of steel was applied to all the normal condition dose rate tallies (contact, 1 m, and 2 m) to obtain the accident condition dose rates above the top and below the bottom of the SEC -- these ratios are about a factor of three so the accident dose rates are about a factor of three higher than the corresponding normal condition dose rates in the upward and downward directions. The radial dose rates are unchanged since the impact limiters are not involved in the radial direction.

The HAC dose rates for the SEC containing either of the two sources are given in Table 5.4-3. These dose rates are well under the limit of 1,000 mrem/hr at 1 m. The contact and 2 m dose rates are not needed for satisfying the limit, but are provided here as additional information since they were available from the calculation.

Table 5.4-3 - Dose Rates for the SEC for Hypothetical Accident Conditions

Location relative to cask	Cobalt-60 Source (330,000 Ci)	Dose rates in mrem/hr (MCNP uncertainty①)		
		Contact②	1 m	2 m
Side	18 Capsules	34.1 (0.4%)	3.92 (0.4%)	1.37 (0.4%)
	72 Capsules	24.9 (0.5%)	2.85 (0.5%)	0.99 (0.6%)
Top③	18 Capsules	309.6 (8.7%)	18.48 (9.6%)	8.13 (14%)
	72 Capsules	251.4 (13%)	15.17 (16%)	6.87 (26%)
Bottom③	18 Capsules	49.9 (1.7%)	3.91 (1.8%)	1.48 (2.1%)
	72 Capsules	29.4 (3.1%)	2.55 (2.2%)	0.96 (3.4%)
Limit		NA	1,000	NA

Notes:

① The one standard deviation statistical uncertainty (relative) in Monte Carlo calculation. Dose rates do not include the uncertainty.

② Contact dose rates are the dose rates 1 cm from the surface.

③ These dose rates are obtained by multiplying the dose rate in the corresponding location in Table 5.4-2 by the ratio of the dose rate (top or bottom) inside the outer inch of steel to the corresponding dose rate (top or bottom) at the outer surface of the cask.

5.5 Appendices

5.5.1 References

1. Briesmeister, J. F., Editor, *MCNP - A General Monte Carlo N-Particle Transport Code, Version 4B*, LA-12625-M, Los Alamos National Laboratory, Los Alamos, New Mexico, 1997.

2. Schmittroth, F. A., 1994, *Conversion of ORIGEN2 to the Sun Workstations*, WHC-SD-SWD-006, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

3. BNL, 1991, *ENDF/B-VI Summary Documentation*, BNL-NCS-17541, 4th edition, Brookhaven National Laboratory, Upton, New York.

4. Nuclear Packaging, Inc., *"Safety Analysis Report for the NuPac 125-B Fuel Shipping Cask"*, NRC Docket No. 71-9200, Figure 2.10.6-30.

5.5.2 ORIGEN Input File

```
-1
-1
-1
TIT      1 Ci of Co-60
BAS      DECAY
LIP      0 0 0
LIB      0 1 2 3 381 382 383 9 0 0 1 1
PHO      101 102 103 10
RDA      SOURCE TERM
INP      -1 1 -1 -1 1 1
RDA      SHORT DECAY TO BUILD IN PROGENY FOR SHORT HALF LIFE PARENTS
MOV      -1 1 0 1.00
RDA
DEC      1.00      1   2   4   2     DECAY FOR 1 Day
RDA
CUT      5  1.E-10   7  1.E-10   9  1.E-10  -1
OPTL     4*8 8 8 7 8 16*8
OPTF     4*8 8 8 7 8 16*8
OPTA     4*8 8 8 7 8 16*8
OUT      2 1 -1 0
STP      4
1   270600 8.841E-04      0 0.000E+00      0 0.000E+00      0 0.000E+00
0
END
```

5.5.3 MCNP Input Files

MCNP INPUT FILE FOR 72 PENCIL SOURCE

```
 PacTec revised photon dose with 72 pin Co source, ir72d
c      i2 is input file inside cavity, i12 is cask outside cavity
c      radial cells beyond cavity -- ss, lead, ss
   1    3 -8.02 (-17:55) -34  14 (-157:-257) (17:155)  $ inner radial steel
   2    8 -11.34 -59      -34  14   157  257        $ 1st inch of radial lead
   3    8 -11.34 -60  59 -34  14              $ 2nd inch of radial lead
   4    8 -11.34 -61  60 -34  14              $ 3rd inch of radial lead
   5    8 -11.34 -62  61 -34  14              $ 4th inch of radial lead
   6    8 -11.34 -63  62 -38  11              $ 5th inch of radial lead
   7    8 -11.34 -64  63 -38  11              $ 6th inch of radial lead
   8    8 -11.34 -65  64 -38  11 -81 -82  $ 7th inch of radial lead
   9    8 -11.34 -66  65 -38     -81 -82  $ 8th inch of radial lead
  10    8 -11.34 -67  66         -81 -82  $ 9th inch of radial lead
  11    8 -11.34 -68  67         -81 -82  $ remainder radial lead
  12    3 -8.02   -69  68 -38  11              $ outer radial steel
c      remaining radial lead above and below
  13    8 -11.34 -60 257 -36  34              $ above small r, small z
  14    8 -11.34 -62  60 -36  34              $ above large r, small z
  15    8 -11.34 -60 257 -38  36              $ above small r, large z
  16    8 -11.34 -62  60 -38  36              $ above large r, large z
  17    8 -11.34 -60 157 -14  11              $ below small r
  18    8 -11.34 -62  60 -14  11              $ below large r
c      upper radial cells for corner -- ss
  21    3 -8.02 -257  55 -38  34              $ beyond lower plug
  22    3 -8.02   -57  55 -41  38              $ beyond top part of lower plug
  23    3 -8.02   -72  57 -41  38              $ further out radially
  24    3 -8.02   -81  72 -41  38              $ out to extended slant
  25    3 -8.02   -86  81 -68 (-41:73)      $ near upper corner
  26    3 -8.02   -84  86 -68  73 -49       $ within inch of upper corner
  27    3 -8.02   -69 -50 -85  38  73 (68:84:49)           $ upper corner
c      lower radial cells for corner -- ss
  28    3 -8.02 -157 155 -14  11              $ to bottom of radial lead
  29    3 -8.02 -157 155 -11   7              $ to top of lowest lead
  30    3 -8.02   -72 157 -11   7              $ further out radially
  31    3 -8.02   -82  72   7 -11              $ out to extended slant
  32    3 -8.02   -89  82 -68 (7:74)        $ near lower corner
  33    3 -8.02   -87  89 -68  74   1        $ within inch of upper corner
  34    3 -8.02   -69  90 -88 -11  74 (68:87:-1)           $ lower corner
c      lower cells below cavity -- ss, lead, ss
  41    3 -8.02   -55     -21  17             $ ss below cavity
  42    8 -11.34 -155      -17  15             $ 1st inch of axial lead
  43    8 -11.34 -155      -15  14             $ 2nd inch of axial lead
  44    8 -11.34 -155      -14  13             $ 3rd inch of axial lead
  45    8 -11.34 -155      -13  12             $ 4th inch of axial lead
  46    8 -11.34 -155      -12  10             $ 5th(+) inch of axial lead
  47    8 -11.34 -155      -10   8             $ remainder of axial lead (upper)
  48    8 -11.34 -155       -8   7             $ 1st inch of axial lead (lower)
  49    8 -11.34 -74        -7   6            $ 2nd inch of axial lead
  50    8 -11.34 -74        -6   5            $ 3rd inch of axial lead
```

```
   51   8 -11.34 -74        -5    4          $ 4th inch of axial lead
   52   8 -11.34 -74        -4    3          $ 5th(-) inch of axial lead
   53   8 -11.34 -74        -3    2          $ remainder of axial lead (lower)
   54   3 -8.02  -74        -2   94          $ lower lip of ss at bottom of cask
   55   3 -8.02  -74        -1   90          $ ss of bottom cap
   56   0        -74       -94    1          $ gap above top plug
c       lower plug above cavity  -- ss, lead
   61   3 -8.02  -54 -91 -30   28            $ lower steel in lower plug
   62   8 -11.34 -53  52 -32   30            $ 1st inch of axial lead
   63   8 -11.34 -53  52 -33   32            $ 2nd inch of axial lead
   64   8 -11.34 -53  52 -34   33            $ 3rd inch of axial lead
   65   8 -11.34 -53  52 -35   34            $ 4th inch of axial lead
   66   8 -11.34 -53  52 -36   35            $ 5th inch of axial lead
   67   8 -11.34 -53  52 -37   36            $ 6th inch of axial lead
   68   8 -11.34 -53  52 -39   37            $ 7th inch of axial lead
   69   8 -11.34 -53  52 -40   39            $ 8th(-) inch of axial lead
   70   8 -11.34 -53  52 -141  40            $ remainder of axial lead .
   71   3 -8.02  -54  53 -32   30            $ 1 to 2 inch ss on side
   72   3 -8.02  -52     -32   30            $ 1 to 2 inch ss in center
   73   3 -8.02  -54  53 -34   32            $ 2 to 4 inch ss on side
   74   3 -8.02  -52     -34   32            $ 2 to 4 inch ss in center
   75   3 -8.02  -54  53 -36   34            $ 4 to 6 inch ss on side
   76   3 -8.02  -52     -36   34            $ 4 to 6 inch ss in center
   77   3 -8.02  -54  53 -39   36            $ 6 to 8 inch ss on side
   78   3 -8.02  -52     -39   36            $ 6 to 8 inch ss in center
   79   3 -8.02  -54  53 -41   39            $ remainder ss on side
   80   3 -8.02  -52     -41   39            $ remainder ss in center
c       upper plug                  -- ss, lead, ss
   81   3 -8.02  -73  53 -42   41            $ lower steel in upper plug
c       lead cells 82 and 83 moved to lower portion
   82   8 -11.34 -53  52 -43 141             $ 1.2475 inch of axial lead
   83   8 -11.34 -53  52 -42  43             $ 1.2475 inch of axial lead
   84   8 -11.34 -72  52 -45  42   93        $ 3rd inch of axial lead
   85   8 -11.34 -72  52 -46  45   93        $ 4th(-) inch of axial lead
   86   8 -11.34 -72  52 -47  46   93        $ remainder of axial lead
   87   3 -8.02  -73  72 -45  42             $ 1 to 3 inch ss on side
   88   3 -8.02  -52     -45  41             $ 1 to 3 inch ss drain
   89   3 -8.02  -93     -45  42             $ 1 to 3 inch ss vent
   90   3 -8.02  -73  72 -47  45             $ remainder ss on side
   91   3 -8.02  -52     -47  45             $ remainder ss drain
   92   3 -8.02  -93     -47  45             $ remainder ss vent
   93   3 -8.02  -73     -48  47             $ steel at top
   94   0        -73     -49  48             $ gap above steel
c       top inch of steel
   95   3 -8.02  -73     -50  49
c       air cells around cask
  101   7 -0.00123  -111 -121  124  (69:50:-90:85:88)    $ 1 cm beyond cask
  102   7 -0.00123  -112 -122  125  (111:121:-124)       $ 1 m beyond cask
  103   7 -0.00123  -113 -123  126  (112:122:-125)       $ 2 m beyond cask
  104   7 -0.00123  -999            (113:123:-126)       $ sphere beyond
c       *******beginning payload geometry*******
c       short support leg
  398   3 -8.02  -405  404 -431   21
c       center support
```

```
 399   3 -8.02  -403  402 -441  430
c     lower pin support plate
 400   3 -8.02  -400  403 -432  431  421 422 423 424 425 426
c     lower perforated ss plate, four quadrants
 401   3 -8.02  -411  412 -401  403 -434  433  421 422    $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 402   3 -8.02   411  412 -401  403 -434  433  422 423    $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 403   3 -8.02   411 -412 -401  403 -434  433  424 425    $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 404   3 -8.02  -411 -412 -401  403 -434  433  425 426    $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     2nd  perforated ss plate, four quadrants
 405   3 -8.02  -411  412 -401  403 -436  435  421 422    $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 406   3 -8.02   411  412 -401  403 -436  435  422 423    $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 407   3 -8.02   411 -412 -401  403 -436  435  424 425    $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 408   3 -8.02  -411 -412 -401  403 -436  435  425 426    $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     3rd  perforated ss plate, four quadrants
 409   3 -8.02  -411  412 -401  403 -438  437  421 422    $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 410   3 -8.02   411  412 -401  403 -438  437  422 423    $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 411   3 -8.02   411 -412 -401  403 -438  437  424 425    $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 412   3 -8.02  -411 -412 -401  403 -438  437  425 426    $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     top  perforated ss plate, four quadrants
 413   3 -8.02  -411  412 -401  403 -440  439             $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 414   3 -8.02   411  412 -401  403 -440  439             $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 415   3 -8.02   411 -412 -401  403 -440  439             $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 416   3 -8.02  -411 -412 -401  403 -440  439             $ +x,-y
       728 729 730 731 732 733 734 735 736
```

```
          764 765 766 767 768 769 770 771 772 737
c       four quadrants of void around pins
  417     0           -411  412 -401 (403:441) -586  432         $ -x,+y
          701 702 703 704 705 706 707 708 709
          737 738 739 740 741 742 743 744 745 746
          (-433:434) (-435:436) (-437:438) (-439:440)
  418     0            411  412 -401 (403:441) -586  432         $ +x,+y
          710 711 712 713 714 715 716 717 718
          746 747 748 749 750 751 752 753 754 755
          (-433:434) (-435:436) (-437:438) (-439:440)
  419     0            411 -412 -401 (403:441) -586  432         $ +x,-y
          719 720 721 722 723 724 725 726 727
          755 756 757 758 759 760 761 762 763 764
          (-433:434) (-435:436) (-437:438) (-439:440)
  420     0           -411 -412 -401 (403:441) -586  432         $ +x,-y
          728 729 730 731 732 733 734 735 736
          764 765 766 767 768 769 770 771 772 737
          (-433:434) (-435:436) (-437:438) (-439:440)
c       void inside six large holes in 4 plates
  421     0            (-421:-422:-423:-424:-425:-426)
              ((431 -432):(433 -434):(435 -436):(437 -438))
c       remaining void inside cavity
  422     0            -55        21  ((-431 405):401:586)
                       (-28:(-41 30 54):(-30 28 91))
  423     0           -402 -441  430            $ inside steel post
  424     0           -404 -431   21 (-430:403) $ inside short support leg
  425     0           -401  400 -432  431       $ beyond bottom support plate
c       inner row of cobalt in 36 pins
  501   27 -8.90  -501    -584    583
  502   27 -8.90  -502    -584    583
  503   27 -8.90  -503    -584    583
  504   27 -8.90  -504    -584    583
  505   27 -8.90  -505    -584    583
  506   27 -8.90  -506    -584    583
  507   27 -8.90  -507    -584    583
  508   27 -8.90  -508    -584    583
  509   27 -8.90  -509    -584    583
  510   27 -8.90  -510    -584    583
  511   27 -8.90  -511    -584    583
  512   27 -8.90  -512    -584    583
  513   27 -8.90  -513    -584    583
  514   27 -8.90  -514    -584    583
  515   27 -8.90  -515    -584    583
  516   27 -8.90  -516    -584    583
  517   27 -8.90  -517    -584    583
  518   27 -8.90  -518    -584    583
  519   27 -8.90  -519    -584    583
  520   27 -8.90  -520    -584    583
  521   27 -8.90  -521    -584    583
  522   27 -8.90  -522    -584    583
  523   27 -8.90  -523    -584    583
  524   27 -8.90  -524    -584    583
  525   27 -8.90  -525    -584    583
  526   27 -8.90  -526    -584    583
```

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  527  27 -8.90  -527   -584   583
  528  27 -8.90  -528   -584   583
  529  27 -8.90  -529   -584   583
  530  27 -8.90  -530   -584   583
  531  27 -8.90  -531   -584   583
  532  27 -8.90  -532   -584   583
  533  27 -8.90  -533   -584   583
  534  27 -8.90  -534   -584   583
  535  27 -8.90  -535   -584   583
  536  27 -8.90  -536   -584   583
c      outer row of cobalt in 36 pins
  537  27 -8.90  -537   -584   583
  538  27 -8.90  -538   -584   583
  539  27 -8.90  -539   -584   583
  540  27 -8.90  -540   -584   583
  541  27 -8.90  -541   -584   583
  542  27 -8.90  -542   -584   583
  543  27 -8.90  -543   -584   583
  544  27 -8.90  -544   -584   583
  545  27 -8.90  -545   -584   583
  546  27 -8.90  -546   -584   583
  547  27 -8.90  -547   -584   583
  548  27 -8.90  -548   -584   583
  549  27 -8.90  -549   -584   583
  550  27 -8.90  -550   -584   583
  551  27 -8.90  -551   -584   583
  552  27 -8.90  -552   -584   583
  553  27 -8.90  -553   -584   583
  554  27 -8.90  -554   -584   583
  555  27 -8.90  -555   -584   583
  556  27 -8.90  -556   -584   583
  557  27 -8.90  -557   -584   583
  558  27 -8.90  -558   -584   583
  559  27 -8.90  -559   -584   583
  560  27 -8.90  -560   -584   583
  561  27 -8.90  -561   -584   583
  562  27 -8.90  -562   -584   583
  563  27 -8.90  -563   -584   583
  564  27 -8.90  -564   -584   583
  565  27 -8.90  -565   -584   583
  566  27 -8.90  -566   -584   583
  567  27 -8.90  -567   -584   583
  568  27 -8.90  -568   -584   583
  569  27 -8.90  -569   -584   583
  570  27 -8.90  -570   -584   583
  571  27 -8.90  -571   -584   583
  572  27 -8.90  -572   -584   583
c      inner row -- steel in 36 pins
  601   3 -8.02  -701 -586 432 (501:-583:584) (-601:-582:585)
  602   3 -8.02  -702 -586 432 (502:-583:584) (-602:-582:585)
  603   3 -8.02  -703 -586 432 (503:-583:584) (-603:-582:585)
  604   3 -8.02  -704 -586 432 (504:-583:584) (-604:-582:585)
  605   3 -8.02  -705 -586 432 (505:-583:584) (-605:-582:585)
  606   3 -8.02  -706 -586 432 (506:-583:584) (-606:-582:585)
```

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 607   3 -8.02  -707 -586 432 (507:-583:584) (-607:-582:585)
 608   3 -8.02  -708 -586 432 (508:-583:584) (-608:-582:585)
 609   3 -8.02  -709 -586 432 (509:-583:584) (-609:-582:585)
 610   3 -8.02  -710 -586 432 (510:-583:584) (-610:-582:585)
 611   3 -8.02  -711 -586 432 (511:-583:584) (-611:-582:585)
 612   3 -8.02  -712 -586 432 (512:-583:584) (-612:-582:585)
 613   3 -8.02  -713 -586 432 (513:-583:584) (-613:-582:585)
 614   3 -8.02  -714 -586 432 (514:-583:584) (-614:-582:585)
 615   3 -8.02  -715 -586 432 (515:-583:584) (-615:-582:585)
 616   3 -8.02  -716 -586 432 (516:-583:584) (-616:-582:585)
 617   3 -8.02  -717 -586 432 (517:-583:584) (-617:-582:585)
 618   3 -8.02  -718 -586 432 (518:-583:584) (-618:-582:585)
 619   3 -8.02  -719 -586 432 (519:-583:584) (-619:-582:585)
 620   3 -8.02  -720 -586 432 (520:-583:584) (-620:-582:585)
 621   3 -8.02  -721 -586 432 (521:-583:584) (-621:-582:585)
 622   3 -8.02  -722 -586 432 (522:-583:584) (-622:-582:585)
 623   3 -8.02  -723 -586 432 (523:-583:584) (-623:-582:585)
 624   3 -8.02  -724 -586 432 (524:-583:584) (-624:-582:585)
 625   3 -8.02  -725 -586 432 (525:-583:584) (-625:-582:585)
 626   3 -8.02  -726 -586 432 (526:-583:584) (-626:-582:585)
 627   3 -8.02  -727 -586 432 (527:-583:584) (-627:-582:585)
 628   3 -8.02  -728 -586 432 (528:-583:584) (-628:-582:585)
 629   3 -8.02  -729 -586 432 (529:-583:584) (-629:-582:585)
 630   3 -8.02  -730 -586 432 (530:-583:584) (-630:-582:585)
 631   3 -8.02  -731 -586 432 (531:-583:584) (-631:-582:585)
 632   3 -8.02  -732 -586 432 (532:-583:584) (-632:-582:585)
 633   3 -8.02  -733 -586 432 (533:-583:584) (-633:-582:585)
 634   3 -8.02  -734 -586 432 (534:-583:584) (-634:-582:585)
 635   3 -8.02  -735 -586 432 (535:-583:584) (-635:-582:585)
 636   3 -8.02  -736 -586 432 (536:-583:584) (-636:-582:585)
c     outer row of cobalt in 36 pins
 637   3 -8.02  -737 -586 432 (537:-583:584) (-637:-582:585)
 638   3 -8.02  -738 -586 432 (538:-583:584) (-638:-582:585)
 639   3 -8.02  -739 -586 432 (539:-583:584) (-639:-582:585)
 640   3 -8.02  -740 -586 432 (540:-583:584) (-640:-582:585)
 641   3 -8.02  -741 -586 432 (541:-583:584) (-641:-582:585)
 642   3 -8.02  -742 -586 432 (542:-583:584) (-642:-582:585)
 643   3 -8.02  -743 -586 432 (543:-583:584) (-643:-582:585)
 644   3 -8.02  -744 -586 432 (544:-583:584) (-644:-582:585)
 645   3 -8.02  -745 -586 432 (545:-583:584) (-645:-582:585)
 646   3 -8.02  -746 -586 432 (546:-583:584) (-646:-582:585)
 647   3 -8.02  -747 -586 432 (547:-583:584) (-647:-582:585)
 648   3 -8.02  -748 -586 432 (548:-583:584) (-648:-582:585)
 649   3 -8.02  -749 -586 432 (549:-583:584) (-649:-582:585)
 650   3 -8.02  -750 -586 432 (550:-583:584) (-650:-582:585)
 651   3 -8.02  -751 -586 432 (551:-583:584) (-651:-582:585)
 652   3 -8.02  -752 -586 432 (552:-583:584) (-652:-582:585)
 653   3 -8.02  -753 -586 432 (553:-583:584) (-653:-582:585)
 654   3 -8.02  -754 -586 432 (554:-583:584) (-654:-582:585)
 655   3 -8.02  -755 -586 432 (555:-583:584) (-655:-582:585)
 656   3 -8.02  -756 -586 432 (556:-583:584) (-656:-582:585)
 657   3 -8.02  -757 -586 432 (557:-583:584) (-657:-582:585)
 658   3 -8.02  -758 -586 432 (558:-583:584) (-658:-582:585)
 659   3 -8.02  -759 -586 432 (559:-583:584) (-659:-582:585)
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 660   3 -8.02  -760 -586 432 (560:-583:584) (-660:-582:585)
 661   3 -8.02  -761 -586 432 (561:-583:584) (-661:-582:585)
 662   3 -8.02  -762 -586 432 (562:-583:584) (-662:-582:585)
 663   3 -8.02  -763 -586 432 (563:-583:584) (-663:-582:585)
 664   3 -8.02  -764 -586 432 (564:-583:584) (-664:-582:585)
 665   3 -8.02  -765 -586 432 (565:-583:584) (-665:-582:585)
 666   3 -8.02  -766 -586 432 (566:-583:584) (-666:-582:585)
 667   3 -8.02  -767 -586 432 (567:-583:584) (-667:-582:585)
 668   3 -8.02  -768 -586 432 (568:-583:584) (-668:-582:585)
 669   3 -8.02  -769 -586 432 (569:-583:584) (-669:-582:585)
 670   3 -8.02  -770 -586 432 (570:-583:584) (-670:-582:585)
 671   3 -8.02  -771 -586 432 (571:-583:584) (-671:-582:585)
 672   3 -8.02  -772 -586 432 (572:-583:584) (-672:-582:585)
c     inner row -- void beyond steel
 701   0            -701 601 -585  582
 702   0            -702 602 -585  582
 703   0            -703 603 -585  582
 704   0            -704 604 -585  582
 705   0            -705 605 -585  582
 706   0            -706 606 -585  582
 707   0            -707 607 -585  582
 708   0            -708 608 -585  582
 709   0            -709 609 -585  582
 710   0            -710 610 -585  582
 711   0            -711 611 -585  582
 712   0            -712 612 -585  582
 713   0            -713 613 -585  582
 714   0            -714 614 -585  582
 715   0            -715 615 -585  582
 716   0            -716 616 -585  582
 717   0            -717 617 -585  582
 718   0            -718 618 -585  582
 719   0            -719 619 -585  582
 720   0            -720 620 -585  582
 721   0            -721 621 -585  582
 722   0            -722 622 -585  582
 723   0            -723 623 -585  582
 724   0            -724 624 -585  582
 725   0            -725 625 -585  582
 726   0            -726 626 -585  582
 727   0            -727 627 -585  582
 728   0            -728 628 -585  582
 729   0            -729 629 -585  582
 730   0            -730 630 -585  582
 731   0            -731 631 -585  582
 732   0            -732 632 -585  582
 733   0            -733 633 -585  582
 734   0            -734 634 -585  582
 735   0            -735 635 -585  582
 736   0            -736 636 -585  582
c     outer row -- void beyond steel
 737   0            -737 637 -585  582
 738   0            -738 638 -585  582
 739   0            -739 639 -585  582
```

```
 740   0           -740 640 -585  582
 741   0           -741 641 -585  582
 742   0           -742 642 -585  582
 743   0           -743 643 -585  582
 744   0           -744 644 -585  582
 745   0           -745 645 -585  582
 746   0           -746 646 -585  582
 747   0           -747 647 -585  582
 748   0           -748 648 -585  582
 749   0           -749 649 -585  582
 750   0           -750 650 -585  582
 751   0           -751 651 -585  582
 752   0           -752 652 -585  582
 753   0           -753 653 -585  582
 754   0           -754 654 -585  582
 755   0           -755 655 -585  582
 756   0           -756 656 -585  582
 757   0           -757 657 -585  582
 758   0           -758 658 -585  582
 759   0           -759 659 -585  582
 760   0           -760 660 -585  582
 761   0           -761 661 -585  582
 762   0           -762 662 -585  582
 763   0           -763 663 -585  582
 764   0           -764 664 -585  582
 765   0           -765 665 -585  582
 766   0           -766 666 -585  582
 767   0           -767 667 -585  582
 768   0           -768 668 -585  582
 769   0           -769 669 -585  582
 770   0           -770 670 -585  582
 771   0           -771 671 -585  582
 772   0           -772 672 -585  582
 999   0            999                  $ outside world

c      cask elevation boundaries
   1   pz  -35.56          $ bottom of lower -- 1" above bottom of cask
   2   pz  -32.6898        $ bottom of lower lead
   3   pz  -30.9500
   4   pz  -28.8798
   5   pz  -26.3398
   6   pz  -23.7998
   7   pz  -22.2250
   8   pz  -18.7198        $ top of lowest lead, bottom of next lowest
   9   pz  -17.78
  10   pz  -15.71          $ half way between 12 and 8
  11   pz  -14.2875        $ bottom of lead on radial side
  12   pz  -12.70
  13   pz  -10.16          $ bottom of outer radial steel lip
  14   pz   -7.62
  15   pz   -5.08
  16   pz   -3.81
  17   pz   -2.54          $ top of 2nd lead layer, bottom of ss under
cavity
```

```
     18    pz    -1.27
     21    pz     0.0           $ bottom of cavity
     22    pz     7.62
     23    pz    15.24
     24    pz    22.86
     25    pz    30.48
     26    pz    38.10
     27    pz    45.72
     28    pz    48.26          $ bottom of lid at top of cavity
     29    pz    49.53
     30    pz    50.80          $ bottom of lower lead in top plug
     31    pz    52.07
     32    pz    53.34
     33    pz    55.88
     34    pz    58.42
     35    pz    60.96
     36    pz    63.50
     37    pz    66.04
     38    pz    70.1675        $ top of radial lead
     39    pz    68.58
     40    pz    70.97          $ midway since not exact inch
     41    pz    77.7875        $ top of lower portion of plug
     42    pz    79.6925        $ top of steel in upper portion of plug
     43    pz    76.52385
     44    pz    80.3402
     45    pz    82.8802
     46    pz    85.1027        $ midway
     47    pz    87.3252        $ top of top lead in plug
     48    pz    91.1352        $ top of steel in top plug
     49    pz    91.4400        $ top of steel just beyond top plug
     50    pz    93.980         $ top of cask
c          cask radial boundaries
     51    cz    0.8001         $ inside tube for top drain port
     52    cz    1.2827         $ ouside of tube for top drain port
     53    cz   11.7475         $ inside lead in lower lead of top plug
     54    cz   13.0175         $ outside steel in lower of top plug
     55    cz   13.6525         $ radial wall of cavity (inner steel)
     56    cz   15.5575
     57    cz   16.1925         $ outside inner radial steel, inside lead
     58    cz   17.4625
     59    cz   18.7325         $ 1 inch into lead
     60    cz   21.2725         $ 2 inches into lead
     61    cz   23.8125         $ 3 inches into lead
     62    cz   26.3525         $ 4 inches into lead
     63    cz   28.8925         $ 5 inches into lead
     64    cz   31.4325         $ 6 inches into lead
     65    cz   33.9725         $ 7 inches into lead
     66    cz   36.5125         $ 8 inches into lead
     67    cz   39.0525         $ 9 inches into lead
     68    cz   42.5450         $ outer edge of lead, inside far steel
     69    cz   45.0850         $ outside radial edge of cask, without 10 ga
     72    cz   21.5900         $ outside edge of lead in top lead of top plug
     73    cz   25.0825         $ outside edge of steel in top of top plug
     74    cz   24.7650         $ outside edge of lead in bottom lead of cask
```

```
  81    z  68.2498 33.9725   59.6773 42.5450  $ slant at outer top of r lead
  82    z -13.6398 32.7025   -3.7973 42.5450  $ slant at outer bot of r lead
  83    z  68.2498 17.8431   63.1698 16.1925  $ slant at inner top of r lead
  84    z  91.44   29.1084   78.0034 42.545   $ slant, outer top (inside)
cask
  85    z  95.0321 29.1084   81.5955 42.545   $ slant, outer top cask - ss
  86    z  76.2498 33.9725   67.6773 42.545   $ slant half way for imp
  87    z -22.1234 42.5450  -35.5600 29.1084  $ slant outer b (inside) cask
  88    z -25.7155 42.5450  -39.1521 29.1084  $ slant outer b cask - ss
  89    z -11.7155 42.5450  -25.1521 29.1084  $ slant half way for imp
  90   pz -38.1             $ bottom of cask
  91    z  50.80   13.0175   48.26   12.0930  $ slant at bottom of plug
  92  c/z  13.8175  0.0       0.47625         $ inside vent port
  93  c/z  13.8175  0.0       0.79375         $ outside vent port
  94   pz -35.2298          $ bottom of lower plug, top of gap
  95   pz 14.04239          $ lower dose tally (-4" from source center)
  96   pz 34.36239          $ upper dose tally (+4" from source center)
  97   pz -6.27761          $ dose tally (-12" from source center)
  98   pz 54.68239          $ dose tally (+12" from source center)
  99   cz   11.6525         $ dose tally (-2 cm from radial outside cavity)
 100   cz   15.6525         $ dose tally (+2 cm from radial outside cavity)
 111   cz   46.0850         $ one cm beyond
 112   cz  145.0850         $ one m beyond
 113   cz  245.0850         $ two m beyond
 121   pz   94.98           $ one cm above
 122   pz  193.98           $ one m above
 123   pz  293.98           $ two m above
 124   pz  -39.1            $ one cm below
 125   pz -138.1            $ one m below
 126   pz -238.1            $ two m below
 999   so  5000.0           $ outer air
 141   pz   73.3552
 155    z   27.6 10.67816 -2.54   12.26566
 157    z   27.6 16.1925  -2.54   17.7800
 257    z   27.6 16.1925  70.1675 18.415
c      *******beginning of payload surfaces*****
 400   cz   11.2776           $ radius of lower steel plate to rest pins
 401   cz   12.70             $ radius of steel plates to support pins
 402   cz    1.5875           $ inner radius of center support
 403   cz    1.9050           $ outer radius of center support
 404   cz    9.3726           $ inner radius of short legs
 405   cz   10.0076           $ outer radius of short legs
 411   px    0.0
 412   py    0.0
c      six large cylindrical penetrations in support plates
 421   c/z  -4.674372  2.698750  2.3876
 422   c/z   0.0       5.39750   2.3876
 423   c/z   4.674372  2.698750  2.3876
 424   c/z   4.674372 -2.698750  2.3876
 425   c/z   0.0      -5.39750   2.3876
 426   c/z  -4.674372 -2.698750  2.3875
 430   pz    0.3302                     $ bottom of support cylinder
c      planes for support plates
 431   pz    1.2827
```

```
  432    pz     1.6256
  433    pz    16.2179
  434    pz    16.5608
  435    pz    31.7627
  436    pz    32.1056
  437    pz    39.3827
  438    pz    39.7256
  439    pz    41.9354
  440    pz    42.5704
  441    pz    42.8752
c      cobalt radii of 72 pins
  501    1   cz    0.3556
  502    2   cz    0.3556
  503    3   cz    0.3556
  504    4   cz    0.3556
  505    5   cz    0.3556
  506    6   cz    0.3556
  507    7   cz    0.3556
  508    8   cz    0.3556
  509    9   cz    0.3556
  510   10   cz    0.3556
  511   11   cz    0.3556
  512   12   cz    0.3556
  513   13   cz    0.3556
  514   14   cz    0.3556
  515   15   cz    0.3556
  516   16   cz    0.3556
  517   17   cz    0.3556
  518   18   cz    0.3556
  519   19   cz    0.3556
  520   20   cz    0.3556
  521   21   cz    0.3556
  522   22   cz    0.3556
  523   23   cz    0.3556
  524   24   cz    0.3556
  525   25   cz    0.3556
  526   26   cz    0.3556
  527   27   cz    0.3556
  528   28   cz    0.3556
  529   29   cz    0.3556
  530   30   cz    0.3556
  531   31   cz    0.3556
  532   32   cz    0.3556
  533   33   cz    0.3556
  534   34   cz    0.3556
  535   35   cz    0.3556
  536   36   cz    0.3556
  537   37   cz    0.3556
  538   38   cz    0.3556
  539   39   cz    0.3556
  540   40   cz    0.3556
  541   41   cz    0.3556
  542   42   cz    0.3556
  543   43   cz    0.3556
```

```
  544   44   cz    0.3556
  545   45   cz    0.3556
  546   46   cz    0.3556
  547   47   cz    0.3556
  548   48   cz    0.3556
  549   49   cz    0.3556
  550   50   cz    0.3556
  551   51   cz    0.3556
  552   52   cz    0.3556
  553   53   cz    0.3556
  554   54   cz    0.3556
  555   55   cz    0.3556
  556   56   cz    0.3556
  557   57   cz    0.3556
  558   58   cz    0.3556
  559   59   cz    0.3556
  560   60   cz    0.3556
  561   61   cz    0.3556
  562   62   cz    0.3556
  563   63   cz    0.3556
  564   64   cz    0.3556
  565   65   cz    0.3556
  566   66   cz    0.3556
  567   67   cz    0.3556
  568   68   cz    0.3556
  569   69   cz    0.3556
  570   70   cz    0.3556
  571   71   cz    0.3556
  572   72   cz    0.3556
c      elevations of cobalt pin
c      use surface 432    581      pz   1.6256
  582       pz    2.3876     $ top of lower cap
  583       pz    3.88239    $ bottom of cobalt
  584       pz   44.52239    $ top of cobalt
  585       pz   46.01718    $ bottom of upper cap
  586       pz   46.77918    $ top of pin
c      steel beyond cobalt radii of 72 pins
  601    1   cz    0.4826
  602    2   cz    0.4826
  603    3   cz    0.4826
  604    4   cz    0.4826
  605    5   cz    0.4826
  606    6   cz    0.4826
  607    7   cz    0.4826
  608    8   cz    0.4826
  609    9   cz    0.4826
  610   10   cz    0.4826
  611   11   cz    0.4826
  612   12   cz    0.4826
  613   13   cz    0.4826
  614   14   cz    0.4826
  615   15   cz    0.4826
  616   16   cz    0.4826
  617   17   cz    0.4826
```

```
618  18  cz  0.4826
619  19  cz  0.4826
620  20  cz  0.4826
621  21  cz  0.4826
622  22  cz  0.4826
623  23  cz  0.4826
624  24  cz  0.4826
625  25  cz  0.4826
626  26  cz  0.4826
627  27  cz  0.4826
628  28  cz  0.4826
629  29  cz  0.4826
630  30  cz  0.4826
631  31  cz  0.4826
632  32  cz  0.4826
633  33  cz  0.4826
634  34  cz  0.4826
635  35  cz  0.4826
636  36  cz  0.4826
637  37  cz  0.4826
638  38  cz  0.4826
639  39  cz  0.4826
640  40  cz  0.4826
641  41  cz  0.4826
642  42  cz  0.4826
643  43  cz  0.4826
644  44  cz  0.4826
645  45  cz  0.4826
646  46  cz  0.4826
647  47  cz  0.4826
648  48  cz  0.4826
649  49  cz  0.4826
650  50  cz  0.4826
651  51  cz  0.4826
652  52  cz  0.4826
653  53  cz  0.4826
654  54  cz  0.4826
655  55  cz  0.4826
656  56  cz  0.4826
657  57  cz  0.4826
658  58  cz  0.4826
659  59  cz  0.4826
660  60  cz  0.4826
661  61  cz  0.4826
662  62  cz  0.4826
663  63  cz  0.4826
664  64  cz  0.4826
665  65  cz  0.4826
666  66  cz  0.4826
667  67  cz  0.4826
668  68  cz  0.4826
669  69  cz  0.4826
670  70  cz  0.4826
671  71  cz  0.4826
```

```
  672  72  cz   0.4826
c      cap radii of 72 pins
  701   1  cz   0.5550
  702   2  cz   0.5550
  703   3  cz   0.5550
  704   4  cz   0.5550
  705   5  cz   0.5550
  706   6  cz   0.5550
  707   7  cz   0.5550
  708   8  cz   0.5550
  709   9  cz   0.5550
  710  10  cz   0.5550
  711  11  cz   0.5550
  712  12  cz   0.5550
  713  13  cz   0.5550
  714  14  cz   0.5550
  715  15  cz   0.5550
  716  16  cz   0.5550
  717  17  cz   0.5550
  718  18  cz   0.5550
  719  19  cz   0.5550
  720  20  cz   0.5550
  721  21  cz   0.5550
  722  22  cz   0.5550
  723  23  cz   0.5550
  724  24  cz   0.5550
  725  25  cz   0.5550
  726  26  cz   0.5550
  727  27  cz   0.5550
  728  28  cz   0.5550
  729  29  cz   0.5550
  730  30  cz   0.5550
  731  31  cz   0.5550
  732  32  cz   0.5550
  733  33  cz   0.5550
  734  34  cz   0.5550
  735  35  cz   0.5550
  736  36  cz   0.5550
  737  37  cz   0.5550
  738  38  cz   0.5550
  739  39  cz   0.5550
  740  40  cz   0.5550
  741  41  cz   0.5550
  742  42  cz   0.5550
  743  43  cz   0.5550
  744  44  cz   0.5550
  745  45  cz   0.5550
  746  46  cz   0.5550
  747  47  cz   0.5550
  748  48  cz   0.5550
  749  49  cz   0.5550
  750  50  cz   0.5550
  751  51  cz   0.5550
  752  52  cz   0.5550
```

```
 753  53  cz   0.5550
 754  54  cz   0.5550
 755  55  cz   0.5550
 756  56  cz   0.5550
 757  57  cz   0.5550
 758  58  cz   0.5550
 759  59  cz   0.5550
 760  60  cz   0.5550
 761  61  cz   0.5550
 762  62  cz   0.5550
 763  63  cz   0.5550
 764  64  cz   0.5550
 765  65  cz   0.5550
 766  66  cz   0.5550
 767  67  cz   0.5550
 768  68  cz   0.5550
 769  69  cz   0.5550
 770  70  cz   0.5550
 771  71  cz   0.5550
 772  72  cz   0.5550

c      transformations for 72 pins
 tr1       -8.856171610   0.774813652  0.0
 tr2       -8.587080960   2.300900220  0.0
 tr3       -8.057077410   3.757075070  0.0
 tr4       -7.282262800   5.099092960  0.0
 tr5       -6.286180970   6.286178110  0.0
 tr6       -5.099096780   7.282260420  0.0
 tr7       -3.757079120   8.057075500  0.0
 tr8       -2.300904510   8.587080000  0.0
 tr9       -0.774818003   8.856170650  0.0
 tr10       0.774810851   8.856171610  0.0
 tr11       2.300897600   8.587081910  0.0
 tr12       3.757072450   8.057078360  0.0
 tr13       5.099091530   7.282264230  0.0
 tr14       6.286176680   6.286182400  0.0
 tr15       7.282259940   5.099097730  0.0
 tr16       8.057075500   3.757079600  0.0
 tr17       8.587080000   2.300904510  0.0
 tr18       8.856170650   0.774817705  0.0
 tr19       8.856171610  -0.774811506  0.0
 tr20       8.587081910  -2.300898310  0.0
 tr21       8.057077410  -3.757073880  0.0
 tr22       7.282263280  -5.099092480  0.0
 tr23       6.286181450  -6.286177640  0.0
 tr24       5.099096780  -7.282260890  0.0
 tr25       3.757078410  -8.057075500  0.0
 tr26       2.300903560  -8.587080000  0.0
 tr27       0.774817228  -8.856170650  0.0
 tr28      -0.774811625  -8.856171610  0.0
 tr29      -2.300898310  -8.587081910  0.0
 tr30      -3.757073160  -8.057078360  0.0
 tr31      -5.099091530  -7.282264230  0.0
 tr32      -6.286176680  -6.286182400  0.0
```

```
 tr33     -7.282259460  -5.099098210  0.0
 tr34     -8.057074550  -3.757080790  0.0
 tr35     -8.587080000  -2.300906420  0.0
 tr36     -8.856170650  -0.774819970  0.0
 tr37    -10.477500000  -0.000000916  0.0
 tr38    -10.318323100   1.819397570  0.0
 tr39     -9.845629690   3.583514450  0.0
 tr40     -9.073781970   5.238748070  0.0
 tr41     -8.026231770   6.734805110  0.0
 tr42     -6.734809400   8.026228900  0.0
 tr43     -5.238752840   9.073779110  0.0
 tr44     -3.583519220   9.845627780  0.0
 tr45     -1.819402580  10.318322200  0.0
 tr46     -0.000004205  10.477500000  0.0
 tr47      1.819394230  10.318324100  0.0
 tr48      3.583511350   9.845630650  0.0
 tr49      5.238745210   9.073783870  0.0
 tr50      6.734803200   8.026233670  0.0
 tr51      8.026227950   6.734810830  0.0
 tr52      9.073779110   5.238753800  0.0
 tr53      9.845627780   3.583519940  0.0
 tr54     10.318322200   1.819402930  0.0
 tr55     10.477500000   0.000004059  0.0
 tr56     10.318324100  -1.819394830  0.0
 tr57      9.845630650  -3.583512310  0.0
 tr58      9.073782920  -5.238746640  0.0
 tr59      8.026232720  -6.734804630  0.0
 tr60      6.734809400  -8.026228900  0.0
 tr61      5.238752840  -9.073779110  0.0
 tr62      3.583519700  -9.845627780  0.0
 tr63      1.819402930 -10.318322200  0.0
 tr64      0.000004538 -10.477500000  0.0
 tr65     -1.819393990 -10.318324100  0.0
 tr66     -3.583511110  -9.845631600  0.0
 tr67     -5.238746170  -9.073782920  0.0
 tr68     -6.734803680  -8.026233670  0.0
 tr69     -8.026227000  -6.734811310  0.0
 tr70     -9.073778150  -5.238754750  0.0
 tr71     -9.845627780  -3.583521600  0.0
 tr72    -10.318322200  -1.819404840  0.0
mode     p
phys:p    j 1
imp:p    1  4  16  64 256 1024 4096 16384 49152 294912 1769472 10616832 $ 12
        16 512 512 16384 16 256                                           $ 18
        32 2048 8192 32768 262144 2097152 16777216                        $ 27
        16 128 1024 8192 65536 524288 4194304                             $ 34
         1  4  16  64  256 1024 8192 16384 98304 294912 1769472 10616832 $ 52
        42467328 84934656 169869312       1                               $ 56
         1  4  16  64  256 1024 4096 32768 98304 196608                   $ 70
         4  4  16  16  256  256 4096  4096 49152  49152                   $ 80
         196608 393216 393216   393216   3145728  12582912                $ 86
         786432  2r   6291456  2r    50331648   1    100663296            $ 95
         169869312 1r 339738624 1r                                  $ air    104
          1. 243r 0.0            $ payload plus outside world
```

```
c       wgt=7.683e10 x 330000 = 2.5354e16
sdef    erg=d7  cel=d1  pos fcel d2  axs=0 0 1  ext=d3
        rad d4  wgt=2.5354e16
sc7        ORIGEN2 FROM TONY SAVINO FOR 1 CURIE OF CO-60
c          MEV         phot/s     Mev/s
#          si7          sp7
            l            d
          0.015      1.961E+09 $ 2.942E+07
          0.025      3.388E+08 $ 8.470E+06
          0.0375     1.935E+08 $ 7.256E+06
          0.0575     2.182E+08 $ 1.255E+07
          0.085      8.582E+07 $ 7.295E+06
          0.125      3.296E+07 $ 4.120E+06
          0.225      1.084E+07 $ 2.439E+06
          0.375      3.041E+06 $ 1.140E+06
          0.575      1.746E+05 $ 1.004E+05
          0.85       2.763E+06 $ 2.349E+06
          1.1732     3.700E+10 $ 4.341E+10
          1.3325     3.700E+10 $ 4.930E+10
          2.25       3.921E+05 $ 8.822E+05
          2.75       1.213E+03 $ 3.336E+03
c          Total     7.683E+10 $ 9.279E+10
c
c         9.279e10 (MeV/s) x 1.6022e-13 (watts/MeV/s) = 0.014867 Watts/Curie
c         Total except neutrino = 4.162e-13 x 3.7e10  = 0.015399 Watts/Curie
c         Photon Energy for 330,000 Curies            = 4,906.1 Watts
c         Total Energy ex neutrino for 330,000 Curies = 5,081.7 Watts
sc1     72 pin cell numbers with equal probability
si1     l  501 70i 572
sp1     1. 71r
sc3     axial extent
si3     3.88239 44.52239
sp3     -21 0
sc4     radial uniform in pin
si4     0.3356
sp4     -21 1
ds2   l  -8.856171610   0.774813652 0.0     -8.587080960   2.300900220 0.0
         -8.057077410   3.757075070 0.0     -7.282262800   5.099092960 0.0
         -6.286180970   6.286178110 0.0     -5.099096300   7.282260420 0.0
         -3.757079120   8.057075500 0.0     -2.300904040   8.587080000 0.0
         -0.774818003   8.856170650 0.0      0.774811268   8.856171610 0.0
          2.300897600   8.587081910 0.0      3.757072930   8.057078360 0.0
          5.099091530   7.282264230 0.0      6.286176680   6.286182400 0.0
          7.282259940   5.099097730 0.0      8.057074550   3.757079600 0.0
          8.587080000   2.300904510 0.0      8.856170650   0.774817705 0.0
          8.856171610  -0.774811506 0.0      8.587081910  -2.300898310 0.0
          8.057077410  -3.757073880 0.0      7.282263760  -5.099092480 0.0
          6.286181450  -6.286177640 0.0      5.099096780  -7.282260890 0.0
          3.757078410  -8.057075500 0.0      2.300903320  -8.587080000 0.0
          0.774817228  -8.856170650 0.0     -0.774812043  -8.856171610 0.0
         -2.300898310  -8.587081910 0.0     -3.757073640  -8.057078360 0.0
         -5.099091530  -7.282264230 0.0     -6.286176680  -6.286182400 0.0
         -7.282259460  -5.099098210 0.0     -8.057074550  -3.757080790 0.0
         -8.587080000  -2.300906420 0.0     -8.856170650  -0.774819970 0.0
```

```
         -10.477500000   -0.000000916 0.0    -10.318323100    1.819397570 0.0
          -9.845629690    3.583514450 0.0     -9.073781970    5.238748070 0.0
          -8.026231770    6.734805110 0.0     -6.734808920    8.026228900 0.0
          -5.238752840    9.073779110 0.0     -3.583518980    9.845627780 0.0
          -1.819402580   10.318322200 0.0     -0.000003737   10.477500000 0.0
           1.819394230   10.318324100 0.0      3.583511830    9.845630650 0.0
           5.238745210    9.073783870 0.0      6.734803200    8.026233670 0.0
           8.026227950    6.734810830 0.0      9.073779110    5.238753800 0.0
           9.845627780    3.583519940 0.0     10.318322200    1.819402930 0.0
          10.477500000    0.000004059 0.0     10.318324100   -1.819394830 0.0
           9.845630650   -3.583512310 0.0      9.073782920   -5.238746640 0.0
           8.026232720   -6.734804630 0.0      6.734809400   -8.026228900 0.0
           5.238752840   -9.073779110 0.0      3.583519220   -9.845627780 0.0
           1.819402930  -10.318322200 0.0      0.000004070  -10.477500000 0.0
          -1.819393990  -10.318324100 0.0     -3.583511590   -9.845631600 0.0
          -5.238746170   -9.073782920 0.0     -6.734803680   -8.026233670 0.0
          -8.026227000   -6.734811310 0.0     -9.073778150   -5.238754750 0.0
          -9.845627780   -3.583521600 0.0    -10.318322200   -1.819404840 0.0
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
c     (cask is fabricated w/ SS-304, insignificant difference for shielding)
m3      6000.50c -0.0003   25055.50c -0.02   15031.50c -0.01
       28000.50c -0.0925   24000.50c -0.19   26000.55c -0.6872
m7      8016.50c 0.22       7014.50c 0.78                      $ air
m8     82000.50c  1.0                                          $ lead
m27    27000.50c  1.0                                          $ Cobalt
c       ansi/ans-6.1.1-1991 AP fluence-to-dose,photons(mrem/hrr/(p/cm**2/s)
de0     log  .01 .015 .02 .03 .04 .05
             .06 .08 .10 .15 .20 .30
             .40 .50 .60 .80 1.0 1.5
             2.0 3.0 4.0 5.0 6.0 8.0
             10. 12.
df0     log  2.232e-5 5.652e-5 8.568e-5 1.184e-4 1.314e-4 1.382e-4
             1.440e-4 1.624e-4 1.919e-4 2.797e-4 3.708e-4 5.616e-4
             7.416e-4 9.144e-4 1.076e-3 1.379e-3 1.656e-3 2.246e-3
             2.758e-3 3.672e-3 4.500e-3 5.292e-3 6.012e-3 7.488e-3
             8.892e-3 1.040e-2
fc812   surface radial dose rate (mrem/hr), 3rd entry
f812:p  69
fs812   -97  -95 -96  -98
fc822   surface l axial dose rate (mrem/hr), 1st entry,  1 is no impact lim.
f822:p  90   1
fs822  -55   -60
fc832   surface u axial dose rate (mrem/hr), 3rd entry, 49 is no impact lim.
f832:p  50  49
fs832  -52 -99 -100
fc842   1 cm  radial dose rate (mrem/hr), 3rd entry
f842:p  111
fs842   -97  -95 -96  -98
fc852   1 cm  l axial dose rate (mrem/hr), 1st entry
f852:p  124
fs852   -55   -60  -65
fc862   1 cm  u axial dose rate (mrem/hr), 3rd entry
f862:p  121
fs862  -52 -99 -100   -65
```

```
fc872   1 m  radial dose rate (mrem/hr), 3rd entry
f872:p  112
fs872   -97   -95 -96  -98
fc882   1 m  l axial dose rate (mrem/hr), 1st entry
f882:p  125
fs882    -60
fc892   1 m  u axial dose rate (mrem/hr), 1st entry
f892:p  122
fs892   -100
fc902   2 m  radial dose rate (mrem/hr), 3rd entry
f902:p  113
fs902    -97  -95 -96  -98
fc912   2 m  l axial dose rate (mrem/hr), 1st entry
f912:p  126
fs912    -60
fc922   2 m  u axial dose rate (mrem/hr), 1st entry
f922:p  123
fs922   -100
print   10 50  110
prdmp   j -240  1
nps     50000000
ctme    2880
```

MCNP INPUT FILE FOR 18 PENCIL SOURCE

```
 PacTec revised photon dose with 18 pin inner Co source, ir18di
c       radial cells beyond cavity -- ss, lead, ss
    1   3 -8.02 (-17:55) -34  14 (-157:-257) (17:155)  $ inner radial steel
    2   8 -11.34 -59      -34  14   157  257        $ 1st inch of radial lead
    3   8 -11.34 -60   59 -34  14            $ 2nd inch of radial lead
    4   8 -11.34 -61   60 -34  14            $ 3rd inch of radial lead
    5   8 -11.34 -62   61 -34  14            $ 4th inch of radial lead
    6   8 -11.34 -63   62 -38  11            $ 5th inch of radial lead
    7   8 -11.34 -64   63 -38  11            $ 6th inch of radial lead
    8   8 -11.34 -65   64 -38  11 -81 -82    $ 7th inch of radial lead
    9   8 -11.34 -66   65 -38     -81 -82    $ 8th inch of radial lead
   10   8 -11.34 -67   66         -81 -82    $ 9th inch of radial lead
   11   8 -11.34 -68   67         -81 -82    $ remainder radial lead
   12   3 -8.02  -69   68 -38  11            $ outer radial steel
c       remaining radial lead above and below
   13   8 -11.34 -60 257 -36   34            $ above small r, small z
   14   8 -11.34 -62   60 -36  34            $ above large r, small z
   15   8 -11.34 -60 257 -38   36            $ above small r, large z
   16   8 -11.34 -62   60 -38  36            $ above large r, large z
   17   8 -11.34 -60 157 -14   11            $ below small r
   18   8 -11.34 -62   60 -14  11            $ below large r
c       upper radial cells for corner -- ss
   21   3 -8.02 -257   55 -38  34            $ beyond lower plug
   22   3 -8.02   -57  55 -41  38            $ beyond top part of lower plug
   23   3 -8.02   -72  57 -41  38            $ further out radially
   24   3 -8.02   -81  72 -41  38            $ out to extended slant
   25   3 -8.02   -86  81 -68 (-41:73)       $ near upper corner
```

```
   26   3 -8.02  -84  86 -68  73 -49      $ within inch of upper corner
   27   3 -8.02  -69 -50 -85  38  73 (68:84:49)      $ upper corner
c       lower radial cells for corner -- ss
   28   3 -8.02 -157 155 -14  11          $ to bottom of radial lead
   29   3 -8.02 -157 155 -11   7          $ to top of lowest lead
   30   3 -8.02  -72 157 -11   7          $ further out radially
   31   3 -8.02  -82  72   7 -11          $ out to extended slant
   32   3 -8.02  -89  82 -68 (7:74)       $ near lower corner
   33   3 -8.02  -87  89 -68  74   1      $ within inch of upper corner
   34   3 -8.02  -69  90 -88 -11  74 (68:87:-1)      $ lower corner
c       lower cells below cavity -- ss, lead, ss
   41   3 -8.02  -55      -21  17          $ ss below cavity
   42   8 -11.34 -155     -17  15          $ 1st inch of axial lead
   43   8 -11.34 -155     -15  14          $ 2nd inch of axial lead
   44   8 -11.34 -155     -14  13          $ 3rd inch of axial lead
   45   8 -11.34 -155     -13  12          $ 4th inch of axial lead
   46   8 -11.34 -155     -12  10          $ 5th(+) inch of axial lead
   47   8 -11.34 -155     -10   8          $ remainder of axial lead (upper)
   48   8 -11.34 -155      -8   7          $ 1st inch of axial lead (lower)
   49   8 -11.34 -74      -7   6          $ 2nd inch of axial lead
   50   8 -11.34 -74      -6   5          $ 3rd inch of axial lead
   51   8 -11.34 -74      -5   4          $ 4th inch of axial lead
   52   8 -11.34 -74      -4   3          $ 5th(-) inch of axial lead
   53   8 -11.34 -74      -3   2          $ remainder of axial lead (lower)
   54   3 -8.02  -74      -2  94          $ lower lip of ss at bottom of cask
   55   3 -8.02  -74      -1  90          $ ss of bottom cap
   56   0        -74     -94   1          $ gap above top plug
c       lower plug above cavity  -- ss, lead
   61   3 -8.02  -54 -91 -30  28          $ lower steel in lower plug
   62   8 -11.34 -53  52 -32  30          $ 1st inch of axial lead
   63   8 -11.34 -53  52 -33  32          $ 2nd inch of axial lead
   64   8 -11.34 -53  52 -34  33          $ 3rd inch of axial lead
   65   8 -11.34 -53  52 -35  34          $ 4th inch of axial lead
   66   8 -11.34 -53  52 -36  35          $ 5th inch of axial lead
   67   8 -11.34 -53  52 -37  36          $ 6th inch of axial lead
   68   8 -11.34 -53  52 -39  37          $ 7th inch of axial lead
   69   8 -11.34 -53  52 -40  39          $ 8th(-) inch of axial lead
   70   8 -11.34 -53  52 -141 40          $ remainder of axial lead
   71   3 -8.02  -54  53 -32  30          $ 1 to 2 inch ss on side
   72   3 -8.02  -52     -32  30          $ 1 to 2 inch ss in center
   73   3 -8.02  -54  53 -34  32          $ 2 to 4 inch ss on side
   74   3 -8.02  -52     -34  32          $ 2 to 4 inch ss in center
   75   3 -8.02  -54  53 -36  34          $ 4 to 6 inch ss on side
   76   3 -8.02  -52     -36  34          $ 4 to 6 inch ss in center
   77   3 -8.02  -54  53 -39  36          $ 6 to 8 inch ss on side
   78   3 -8.02  -52     -39  36          $ 6 to 8 inch ss in center
   79   3 -8.02  -54  53 -41  39          $ remainder ss on side
   80   3 -8.02  -52     -41  39          $ remainder ss in center
c       upper plug                -- ss, lead, ss
   81   3 -8.02  -73  53 -42  41          $ lower steel in upper plug
c       lead cells 82 and 83 moved to lower portion
   82   8 -11.34 -53  52 -43 141          $ 1.2475 inch of axial lead
   83   8 -11.34 -53  52 -42  43          $ 1.2475 inch of axial lead
   84   8 -11.34 -72  52 -45  42  93      $ 3rd inch of axial lead
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  85   8 -11.34 -72  52 -46  45  93       $ 4th(-) inch of axial lead
  86   8 -11.34 -72  52 -47  46  93       $ remainder of axial lead
  87   3 -8.02  -73  72 -45  42           $ 1 to 3 inch ss on side
  88   3 -8.02  -52     -45  41           $ 1 to 3 inch ss drain
  89   3 -8.02  -93     -45  42           $ 1 to 3 inch ss vent
  90   3 -8.02  -73  72 -47  45           $ remainder ss on side
  91   3 -8.02  -52     -47  45           $ remainder ss drain
  92   3 -8.02  -93     -47  45           $ remainder ss vent
  93   3 -8.02  -73     -48  47           $ steel at top
  94   0        -73     -49  48           $ gap above steel
c      top inch of steel
  95   3 -8.02  -73     -50  49
c      air cells around cask
 101   7 -0.00123  -111 -121  124  (69:50:-90:85:88)     $ 1 cm beyond cask
 102   7 -0.00123  -112 -122  125  (111:121:-124)        $ 1 m beyond cask
 103   7 -0.00123  -113 -123  126  (112:122:-125)        $ 2 m beyond cask
 104   7 -0.00123  -999            (113:123:-126)        $ sphere beyond
c      *******beginning payload geometry*******
c      short support leg
 398   3 -8.02  -405  404 -431   21
c      center support
 399   3 -8.02  -403  402 -441  430
c     lower pin support plate
 400   3 -8.02  -400  403 -432  431  421 422 423 424 425 426
c     lower perforated ss plate, four quadrants
 401   3 -8.02  -411  412 -401  403 -434  433  421 422     $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 402   3 -8.02   411  412 -401  403 -434  433  422 423     $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 403   3 -8.02   411 -412 -401  403 -434  433  424 425     $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 404   3 -8.02  -411 -412 -401  403 -434  433  425 426     $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     2nd  perforated ss plate, four quadrants
 405   3 -8.02  -411  412 -401  403 -436  435  421 422     $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 406   3 -8.02   411  412 -401  403 -436  435  422 423     $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 407   3 -8.02   411 -412 -401  403 -436  435  424 425     $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 408   3 -8.02  -411 -412 -401  403 -436  435  425 426     $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     3rd  perforated ss plate, four quadrants
 409   3 -8.02  -411  412 -401  403 -438  437  421 422     $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
```

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 410   3 -8.02    411  412 -401  403 -438  437  422 423    $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 411   3 -8.02    411 -412 -401  403 -438  437  424 425    $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 412   3 -8.02   -411 -412 -401  403 -438  437  425 426    $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     top   perforated ss plate, four quadrants
 413   3 -8.02   -411  412 -401  403 -440  439             $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
 414   3 -8.02    411  412 -401  403 -440  439             $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
 415   3 -8.02    411 -412 -401  403 -440  439             $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
 416   3 -8.02   -411 -412 -401  403 -440  439             $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
c     four quadrants of void around pins
 417   0           -411  412 -401 (403:441) -586  432      $ -x,+y
       701 702 703 704 705 706 707 708 709
       737 738 739 740 741 742 743 744 745 746
       (-433:434) (-435:436) (-437:438) (-439:440)
 418   0            411  412 -401 (403:441) -586  432      $ +x,+y
       710 711 712 713 714 715 716 717 718
       746 747 748 749 750 751 752 753 754 755
       (-433:434) (-435:436) (-437:438) (-439:440)
 419   0            411 -412 -401 (403:441) -586  432      $ +x,-y
       719 720 721 722 723 724 725 726 727
       755 756 757 758 759 760 761 762 763 764
       (-433:434) (-435:436) (-437:438) (-439:440)
 420   0           -411 -412 -401 (403:441) -586  432      $ +x,-y
       728 729 730 731 732 733 734 735 736
       764 765 766 767 768 769 770 771 772 737
       (-433:434) (-435:436) (-437:438) (-439:440)
c     void inside six large holes in 4 plates
 421   0            (-421:-422:-423:-424:-425:-426)
          ((431 -432):(433 -434):(435 -436):(437 -438))
c     remaining void inside cavity
 422   0            -55        21   ((-431 405):401:586)
                    (-28:(-41 30 54):(-30 28 91))
 423   0           -402 -441  430             $ inside steel post
 424   0           -404 -431   21 (-430:403) $ inside short support leg
 425   0           -401  400 -432  431        $ beyond bottom support plate
c     inner row of "void" in 36 pins for case with only 18 cobalt pins
 501  27 -8.90  -501    -584    583
 502   0        -502    -584    583
 503  27 -8.90  -503    -584    583
 504   0        -504    -584    583
 505  27 -8.90  -505    -584    583
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  506   0         -506   -584   583
  507   27 -8.90  -507   -584   583
  508   0         -508   -584   583
  509   27 -8.90  -509   -584   583
  510   0         -510   -584   583
  511   27 -8.90  -511   -584   583
  512   0         -512   -584   583
  513   27 -8.90  -513   -584   583
  514   0         -514   -584   583
  515   27 -8.90  -515   -584   583
  516   0         -516   -584   583
  517   27 -8.90  -517   -584   583
  518   0         -518   -584   583
  519   27 -8.90  -519   -584   583
  520   0         -520   -584   583
  521   27 -8.90  -521   -584   583
  522   0         -522   -584   583
  523   27 -8.90  -523   -584   583
  524   0         -524   -584   583
  525   27 -8.90  -525   -584   583
  526   0         -526   -584   583
  527   27 -8.90  -527   -584   583
  528   0         -528   -584   583
  529   27 -8.90  -529   -584   583
  530   0         -530   -584   583
  531   27 -8.90  -531   -584   583
  532   0         -532   -584   583
  533   27 -8.90  -533   -584   583
  534   0         -534   -584   583
  535   27 -8.90  -535   -584   583
  536   0         -536   -584   583
c      outer row of cobalt in 18 pins
  537   0         -537   -584   583
  538   0         -538   -584   583
  539   0         -539   -584   583
  540   0         -540   -584   583
  541   0         -541   -584   583
  542   0         -542   -584   583
  543   0         -543   -584   583
  544   0         -544   -584   583
  545   0         -545   -584   583
  546   0         -546   -584   583
  547   0         -547   -584   583
  548   0         -548   -584   583
  549   0         -549   -584   583
  550   0         -550   -584   583
  551   0         -551   -584   583
  552   0         -552   -584   583
  553   0         -553   -584   583
  554   0         -554   -584   583
  555   0         -555   -584   583
  556   0         -556   -584   583
  557   0         -557   -584   583
  558   0         -558   -584   583
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 559   0        -559   -584   583
 560   0        -560   -584   583
 561   0        -561   -584   583
 562   0        -562   -584   583
 563   0        -563   -584   583
 564   0        -564   -584   583
 565   0        -565   -584   583
 566   0        -566   -584   583
 567   0        -567   -584   583
 568   0        -568   -584   583
 569   0        -569   -584   583
 570   0        -570   -584   583
 571   0        -571   -584   583
 572   0        -572   -584   583
c     inner row -- steel in 36 pins
 601   3 -8.02  -701 -586 432 (501:-583:584)  (-601:-582:585)
 602   0        -702 -586 432 (502:-583:584)  (-602:-582:585)
 603   3 -8.02  -703 -586 432 (503:-583:584)  (-603:-582:585)
 604   0        -704 -586 432 (504:-583:584)  (-604:-582:585)
 605   3 -8.02  -705 -586 432 (505:-583:584)  (-605:-582:585)
 606   0        -706 -586 432 (506:-583:584)  (-606:-582:585)
 607   3 -8.02  -707 -586 432 (507:-583:584)  (-607:-582:585)
 608   0        -708 -586 432 (508:-583:584)  (-608:-582:585)
 609   3 -8.02  -709 -586 432 (509:-583:584)  (-609:-582:585)
 610   0        -710 -586 432 (510:-583:584)  (-610:-582:585)
 611   3 -8.02  -711 -586 432 (511:-583:584)  (-611:-582:585)
 612   0        -712 -586 432 (512:-583:584)  (-612:-582:585)
 613   3 -8.02  -713 -586 432 (513:-583:584)  (-613:-582:585)
 614   0        -714 -586 432 (514:-583:584)  (-614:-582:585)
 615   3 -8.02  -715 -586 432 (515:-583:584)  (-615:-582:585)
 616   0        -716 -586 432 (516:-583:584)  (-616:-582:585)
 617   3 -8.02  -717 -586 432 (517:-583:584)  (-617:-582:585)
 618   0        -718 -586 432 (518:-583:584)  (-618:-582:585)
 619   3 -8.02  -719 -586 432 (519:-583:584)  (-619:-582:585)
 620   0        -720 -586 432 (520:-583:584)  (-620:-582:585)
 621   3 -8.02  -721 -586 432 (521:-583:584)  (-621:-582:585)
 622   0        -722 -586 432 (522:-583:584)  (-622:-582:585)
 623   3 -8.02  -723 -586 432 (523:-583:584)  (-623:-582:585)
 624   0        -724 -586 432 (524:-583:584)  (-624:-582:585)
 625   3 -8.02  -725 -586 432 (525:-583:584)  (-625:-582:585)
 626   0        -726 -586 432 (526:-583:584)  (-626:-582:585)
 627   3 -8.02  -727 -586 432 (527:-583:584)  (-627:-582:585)
 628   0        -728 -586 432 (528:-583:584)  (-628:-582:585)
 629   3 -8.02  -729 -586 432 (529:-583:584)  (-629:-582:585)
 630   0        -730 -586 432 (530:-583:584)  (-630:-582:585)
 631   3 -8.02  -731 -586 432 (531:-583:584)  (-631:-582:585)
 632   0        -732 -586 432 (532:-583:584)  (-632:-582:585)
 633   3 -8.02  -733 -586 432 (533:-583:584)  (-633:-582:585)
 634   0        -734 -586 432 (534:-583:584)  (-634:-582:585)
 635   3 -8.02  -735 -586 432 (535:-583:584)  (-635:-582:585)
 636   0        -736 -586 432 (536:-583:584)  (-636:-582:585)
c     outer row of steel in 36 pins
 637   0        -737 -586 432 (537:-583:584)  (-637:-582:585)
 638   0        -738 -586 432 (538:-583:584)  (-638:-582:585)
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 639    0          -739 -586 432 (539:-583:584)  (-639:-582:585)
 640    0          -740 -586 432 (540:-583:584)  (-640:-582:585)
 641    0          -741 -586 432 (541:-583:584)  (-641:-582:585)
 642    0          -742 -586 432 (542:-583:584)  (-642:-582:585)
 643    0          -743 -586 432 (543:-583:584)  (-643:-582:585)
 644    0          -744 -586 432 (544:-583:584)  (-644:-582:585)
 645    0          -745 -586 432 (545:-583:584)  (-645:-582:585)
 646    0          -746 -586 432 (546:-583:584)  (-646:-582:585)
 647    0          -747 -586 432 (547:-583:584)  (-647:-582:585)
 648    0          -748 -586 432 (548:-583:584)  (-648:-582:585)
 649    0          -749 -586 432 (549:-583:584)  (-649:-582:585)
 650    0          -750 -586 432 (550:-583:584)  (-650:-582:585)
 651    0          -751 -586 432 (551:-583:584)  (-651:-582:585)
 652    0          -752 -586 432 (552:-583:584)  (-652:-582:585)
 653    0          -753 -586 432 (553:-583:584)  (-653:-582:585)
 654    0          -754 -586 432 (554:-583:584)  (-654:-582:585)
 655    0          -755 -586 432 (555:-583:584)  (-655:-582:585)
 656    0          -756 -586 432 (556:-583:584)  (-656:-582:585)
 657    0          -757 -586 432 (557:-583:584)  (-657:-582:585)
 658    0          -758 -586 432 (558:-583:584)  (-658:-582:585)
 659    0          -759 -586 432 (559:-583:584)  (-659:-582:585)
 660    0          -760 -586 432 (560:-583:584)  (-660:-582:585)
 661    0          -761 -586 432 (561:-583:584)  (-661:-582:585)
 662    0          -762 -586 432 (562:-583:584)  (-662:-582:585)
 663    0          -763 -586 432 (563:-583:584)  (-663:-582:585)
 664    0          -764 -586 432 (564:-583:584)  (-664:-582:585)
 665    0          -765 -586 432 (565:-583:584)  (-665:-582:585)
 666    0          -766 -586 432 (566:-583:584)  (-666:-582:585)
 667    0          -767 -586 432 (567:-583:584)  (-667:-582:585)
 668    0          -768 -586 432 (568:-583:584)  (-668:-582:585)
 669    0          -769 -586 432 (569:-583:584)  (-669:-582:585)
 670    0          -770 -586 432 (570:-583:584)  (-670:-582:585)
 671    0          -771 -586 432 (571:-583:584)  (-671:-582:585)
 672    0          -772 -586 432 (572:-583:584)  (-672:-582:585)
c     inner row -- void beyond steel
 701    0                -701 601 -585  582
 702    0                -702 602 -585  582
 703    0                -703 603 -585  582
 704    0                -704 604 -585  582
 705    0                -705 605 -585  582
 706    0                -706 606 -585  582
 707    0                -707 607 -585  582
 708    0                -708 608 -585  582
 709    0                -709 609 -585  582
 710    0                -710 610 -585  582
 711    0                -711 611 -585  582
 712    0                -712 612 -585  582
 713    0                -713 613 -585  582
 714    0                -714 614 -585  582
 715    0                -715 615 -585  582
 716    0                -716 616 -585  582
 717    0                -717 617 -585  582
 718    0                -718 618 -585  582
 719    0                -719 619 -585  582
```

```
 720    0          -720 620 -585   582
 721    0          -721 621 -585   582
 722    0          -722 622 -585   582
 723    0          -723 623 -585   582
 724    0          -724 624 -585   582
 725    0          -725 625 -585   582
 726    0          -726 626 -585   582
 727    0          -727 627 -585   582
 728    0          -728 628 -585   582
 729    0          -729 629 -585   582
 730    0          -730 630 -585   582
 731    0          -731 631 -585   582
 732    0          -732 632 -585   582
 733    0          -733 633 -585   582
 734    0          -734 634 -585   582
 735    0          -735 635 -585   582
 736    0          -736 636 -585   582
c      outer row -- void beyond steel
 737    0          -737 637 -585   582
 738    0          -738 638 -585   582
 739    0          -739 639 -585   582
 740    0          -740 640 -585   582
 741    0          -741 641 -585   582
 742    0          -742 642 -585   582
 743    0          -743 643 -585   582
 744    0          -744 644 -585   582
 745    0          -745 645 -585   582
 746    0          -746 646 -585   582
 747    0          -747 647 -585   582
 748    0          -748 648 -585   582
 749    0          -749 649 -585   582
 750    0          -750 650 -585   582
 751    0          -751 651 -585   582
 752    0          -752 652 -585   582
 753    0          -753 653 -585   582
 754    0          -754 654 -585   582
 755    0          -755 655 -585   582
 756    0          -756 656 -585   582
 757    0          -757 657 -585   582
 758    0          -758 658 -585   582
 759    0          -759 659 -585   582
 760    0          -760 660 -585   582
 761    0          -761 661 -585   582
 762    0          -762 662 -585   582
 763    0          -763 663 -585   582
 764    0          -764 664 -585   582
 765    0          -765 665 -585   582
 766    0          -766 666 -585   582
 767    0          -767 667 -585   582
 768    0          -768 668 -585   582
 769    0          -769 669 -585   582
 770    0          -770 670 -585   582
 771    0          -771 671 -585   582
 772    0          -772 672 -585   582
```

```
  999   0              999                 $ outside world

c       cask elevation boundaries
     1   pz  -35.56           $ bottom of lower -- 1" above bottom of cask
     2   pz  -32.6898         $ bottom of lower lead
     3   pz  -30.9500
     4   pz  -28.8798
     5   pz  -26.3398
     6   pz  -23.7998
     7   pz  -22.2250
     8   pz  -18.7198         $ top of lowest lead, bottom of next lowest
     9   pz  -17.78
    10   pz  -15.71           $ half way between 12 and 8
    11   pz  -14.2875         $ bottom of lead on radial side
    12   pz  -12.70
    13   pz  -10.16           $ bottom of outer radial steel lip
    14   pz   -7.62
    15   pz   -5.08
    16   pz   -3.81
    17   pz   -2.54           $ top of 2nd lead layer, bottom of ss under
cavity
    18   pz   -1.27
    21   pz    0.0            $ bottom of cavity
    22   pz    7.62
    23   pz   15.24
    24   pz   22.86
    25   pz   30.48
    26   pz   38.10
    27   pz   45.72
    28   pz   48.26           $ bottom of lid at top of cavity
    29   pz   49.53
    30   pz   50.80           $ bottom of lower lead in top plug
    31   pz   52.07
    32   pz   53.34
    33   pz   55.88
    34   pz   58.42
    35   pz   60.96
    36   pz   63.50
    37   pz   66.04
    38   pz   70.1675         $ top of radial lead
    39   pz   68.58
    40   pz   70.97           $ midway since not exact inch
    41   pz   77.7875         $ top of lower portion of plug
    42   pz   79.6925         $ top of steel in upper portion of plug
    43   pz   76.52385
    44   pz   80.3402
    45   pz   82.8802
    46   pz   85.1027         $ midway
    47   pz   87.3252         $ top of top lead in plug
    48   pz   91.1352         $ top of steel in top plug
    49   pz   91.4400         $ top of steel just beyond top plug
    50   pz   93.980          $ top of cask
c        cask radial boundaries
    51   cz   0.8001          $ inside tube for top drain port
```

```
  52   cz    1.2827           $ ouside of tube for top drain port
  53   cz   11.7475           $ inside lead in lower lead of top plug
  54   cz   13.0175           $ outside steel in lower of top plug
  55   cz   13.6525           $ radial wall of cavity (inner steel)
  56   cz   15.5575
  57   cz   16.1925           $ outside inner radial steel, inside lead
  58   cz   17.4625
  59   cz   18.7325           $ 1 inch into lead
  60   cz   21.2725           $ 2 inches into lead
  61   cz   23.8125           $ 3 inches into lead
  62   cz   26.3525           $ 4 inches into lead
  63   cz   28.8925           $ 5 inches into lead
  64   cz   31.4325           $ 6 inches into lead
  65   cz   33.9725           $ 7 inches into lead
  66   cz   36.5125           $ 8 inches into lead
  67   cz   39.0525           $ 9 inches into lead
  68   cz   42.5450           $ outer edge of lead, inside far steel .
  69   cz   45.0850           $ outside radial edge of cask, without 10 ga
  72   cz   21.5900           $ outside edge of lead in top lead of top plug
  73   cz   25.0825           $ outside edge of steel in top of top plug
  74   cz   24.7650           $ outside edge of lead in bottom lead of cask
  81    z   68.2498 33.9725    59.6773 42.5450   $ slant at outer top of r lead
  82    z  -13.6398 32.7025    -3.7973 42.5450   $ slant at outer bot of r lead
  83    z   68.2498 17.8431    63.1698 16.1925   $ slant at inner top of r lead
  84    z   91.44   29.1084    78.0034 42.545    $ slant, outer top (inside)
cask
  85    z   95.0321 29.1084    81.5955 42.545    $ slant, outer top cask - ss
  86    z   76.2498 33.9725    67.6773 42.545    $ slant half way for imp
  87    z  -22.1234 42.5450   -35.5600 29.1084   $ slant outer b (inside) cask
  88    z  -25.7155 42.5450   -39.1521 29.1084   $ slant outer b cask - ss
  89    z  -11.7155 42.5450   -25.1521 29.1084   $ slant half way for imp
  90   pz  -38.1               $ bottom of cask
  91    z   50.80   13.0175    48.26   12.0930   $ slant at bottom of plug
  92  c/z   13.8175  0.0        0.47625          $ inside vent port
  93  c/z   13.8175  0.0        0.79375          $ outside vent port
  94   pz  -35.2298            $ bottom of lower plug, top of gap
  95   pz  14.04239            $ lower dose tally (-4" from source center)
  96   pz  34.36239            $ upper dose tally (+4" from source center)
  97   pz  -6.27761            $ dose tally (-12" from source center)
  98   pz  54.68239            $ dose tally (+12" from source center)
  99   cz    11.6525           $ dose tally (-2 cm from radial outside cavity)
 100   cz    15.6525           $ dose tally (+2 cm from radial outside cavity)
 111   cz    46.0850           $ one cm beyond
 112   cz   145.0850           $ one m beyond
 113   cz   245.0850           $ two m beyond
 121   pz    94.98             $ one cm above
 122   pz   193.98             $ one m above
 123   pz   293.98             $ two m above
 124   pz   -39.1              $ one cm below
 125   pz  -138.1              $ one m below
 126   pz  -238.1              $ two m below
 999   so   5000.0             $ outer air
 141   pz    73.3552
 155    z    27.6 10.67816 -2.54   12.26566
```

```
  157     z    27.6 16.1925  -2.54    17.7800
  257     z    27.6 16.1925  70.1675 18.415
c       *******beginning of payload surfaces*****
  400    cz    11.2776           $ radius of lower steel plate to rest pins
  401    cz    12.70             $ radius of steel plates to support pins
  402    cz     1.5875           $ inner radius of center support
  403    cz     1.9050           $ outer radius of center support
  404    cz     9.3726           $ inner radius of short legs
  405    cz    10.0076           $ outer radius of short legs
  411    px     0.0
  412    py     0.0
c       six large cylindrical penetrations in support plates
  421    c/z   -4.674372  2.698750   2.3876
  422    c/z    0.0       5.39750    2.3876
  423    c/z    4.674372  2.698750   2.3876
  424    c/z    4.674372 -2.698750   2.3876
  425    c/z    0.0      -5.39750    2.3876
  426    c/z   -4.674372 -2.698750   2.3875
  430    pz     0.3302                         $ bottom of support cylinder
c       planes for support plates
  431    pz     1.2827
  432    pz     1.6256
  433    pz    16.2179
  434    pz    16.5608
  435    pz    31.7627
  436    pz    32.1056
  437    pz    39.3827
  438    pz    39.7256
  439    pz    41.9354
  440    pz    42.5704
  441    pz    42.8752
c       cobalt radii of 72 pins
  501    1   cz    0.3556
  502    2   cz    0.3556
  503    3   cz    0.3556
  504    4   cz    0.3556
  505    5   cz    0.3556
  506    6   cz    0.3556
  507    7   cz    0.3556
  508    8   cz    0.3556
  509    9   cz    0.3556
  510   10   cz    0.3556
  511   11   cz    0.3556
  512   12   cz    0.3556
  513   13   cz    0.3556
  514   14   cz    0.3556
  515   15   cz    0.3556
  516   16   cz    0.3556
  517   17   cz    0.3556
  518   18   cz    0.3556
  519   19   cz    0.3556
  520   20   cz    0.3556
  521   21   cz    0.3556
  522   22   cz    0.3556
```

```
523  23  cz   0.3556
524  24  cz   0.3556
525  25  cz   0.3556
526  26  cz   0.3556
527  27  cz   0.3556
528  28  cz   0.3556
529  29  cz   0.3556
530  30  cz   0.3556
531  31  cz   0.3556
532  32  cz   0.3556
533  33  cz   0.3556
534  34  cz   0.3556
535  35  cz   0.3556
536  36  cz   0.3556
537  37  cz   0.3556
538  38  cz   0.3556
539  39  cz   0.3556
540  40  cz   0.3556
541  41  cz   0.3556
542  42  cz   0.3556
543  43  cz   0.3556
544  44  cz   0.3556
545  45  cz   0.3556
546  46  cz   0.3556
547  47  cz   0.3556
548  48  cz   0.3556
549  49  cz   0.3556
550  50  cz   0.3556
551  51  cz   0.3556
552  52  cz   0.3556
553  53  cz   0.3556
554  54  cz   0.3556
555  55  cz   0.3556
556  56  cz   0.3556
557  57  cz   0.3556
558  58  cz   0.3556
559  59  cz   0.3556
560  60  cz   0.3556
561  61  cz   0.3556
562  62  cz   0.3556
563  63  cz   0.3556
564  64  cz   0.3556
565  65  cz   0.3556
566  66  cz   0.3556
567  67  cz   0.3556
568  68  cz   0.3556
569  69  cz   0.3556
570  70  cz   0.3556
571  71  cz   0.3556
572  72  cz   0.3556
c     elevations of cobalt pin
c     use surface 432    581      pz    1.6256
 582       pz   2.3876     $ top of lower cap
 583       pz   3.88239    $ bottom of cobalt
```

```
  584       pz  44.52239    $ top of cobalt
  585       pz  46.01718    $ bottom of upper cap
  586       pz  46.77918    $ top of pin
c     steel beyond cobalt radii of 72 pins
  601    1  cz    0.4826
  602    2  cz    0.4826
  603    3  cz    0.4826
  604    4  cz    0.4826
  605    5  cz    0.4826
  606    6  cz    0.4826
  607    7  cz    0.4826
  608    8  cz    0.4826
  609    9  cz    0.4826
  610   10  cz    0.4826
  611   11  cz    0.4826
  612   12  cz    0.4826
  613   13  cz    0.4826
  614   14  cz    0.4826
  615   15  cz    0.4826
  616   16  cz    0.4826
  617   17  cz    0.4826
  618   18  cz    0.4826
  619   19  cz    0.4826
  620   20  cz    0.4826
  621   21  cz    0.4826
  622   22  cz    0.4826
  623   23  cz    0.4826
  624   24  cz    0.4826
  625   25  cz    0.4826
  626   26  cz    0.4826
  627   27  cz    0.4826
  628   28  cz    0.4826
  629   29  cz    0.4826
  630   30  cz    0.4826
  631   31  cz    0.4826
  632   32  cz    0.4826
  633   33  cz    0.4826
  634   34  cz    0.4826
  635   35  cz    0.4826
  636   36  cz    0.4826
  637   37  cz    0.4826
  638   38  cz    0.4826
  639   39  cz    0.4826
  640   40  cz    0.4826
  641   41  cz    0.4826
  642   42  cz    0.4826
  643   43  cz    0.4826
  644   44  cz    0.4826
  645   45  cz    0.4826
  646   46  cz    0.4826
  647   47  cz    0.4826
  648   48  cz    0.4826
  649   49  cz    0.4826
  650   50  cz    0.4826
```

```
   651   51   cz    0.4826
   652   52   cz    0.4826
   653   53   cz    0.4826
   654   54   cz    0.4826
   655   55   cz    0.4826
   656   56   cz    0.4826
   657   57   cz    0.4826
   658   58   cz    0.4826
   659   59   cz    0.4826
   660   60   cz    0.4826
   661   61   cz    0.4826
   662   62   cz    0.4826
   663   63   cz    0.4826
   664   64   cz    0.4826
   665   65   cz    0.4826
   666   66   cz    0.4826
   667   67   cz    0.4826
   668   68   cz    0.4826
   669   69   cz    0.4826
   670   70   cz    0.4826
   671   71   cz    0.4826
   672   72   cz    0.4826
c       cap radii of 72 pins
   701    1   cz    0.5550
   702    2   cz    0.5550
   703    3   cz    0.5550
   704    4   cz    0.5550
   705    5   cz    0.5550
   706    6   cz    0.5550
   707    7   cz    0.5550
   708    8   cz    0.5550
   709    9   cz    0.5550
   710   10   cz    0.5550
   711   11   cz    0.5550
   712   12   cz    0.5550
   713   13   cz    0.5550
   714   14   cz    0.5550
   715   15   cz    0.5550
   716   16   cz    0.5550
   717   17   cz    0.5550
   718   18   cz    0.5550
   719   19   cz    0.5550
   720   20   cz    0.5550
   721   21   cz    0.5550
   722   22   cz    0.5550
   723   23   cz    0.5550
   724   24   cz    0.5550
   725   25   cz    0.5550
   726   26   cz    0.5550
   727   27   cz    0.5550
   728   28   cz    0.5550
   729   29   cz    0.5550
   730   30   cz    0.5550
   731   31   cz    0.5550
```

```
 732  32  cz   0.5550
 733  33  cz   0.5550
 734  34  cz   0.5550
 735  35  cz   0.5550
 736  36  cz   0.5550
 737  37  cz   0.5550
 738  38  cz   0.5550
 739  39  cz   0.5550
 740  40  cz   0.5550
 741  41  cz   0.5550
 742  42  cz   0.5550
 743  43  cz   0.5550
 744  44  cz   0.5550
 745  45  cz   0.5550
 746  46  cz   0.5550
 747  47  cz   0.5550
 748  48  cz   0.5550
 749  49  cz   0.5550
 750  50  cz   0.5550
 751  51  cz   0.5550
 752  52  cz   0.5550
 753  53  cz   0.5550
 754  54  cz   0.5550
 755  55  cz   0.5550
 756  56  cz   0.5550
 757  57  cz   0.5550
 758  58  cz   0.5550
 759  59  cz   0.5550
 760  60  cz   0.5550
 761  61  cz   0.5550
 762  62  cz   0.5550
 763  63  cz   0.5550
 764  64  cz   0.5550
 765  65  cz   0.5550
 766  66  cz   0.5550
 767  67  cz   0.5550
 768  68  cz   0.5550
 769  69  cz   0.5550
 770  70  cz   0.5550
 771  71  cz   0.5550
 772  72  cz   0.5550

c       transformations for 72 pins
 tr1      -8.856171610   0.774813652  0.0
 tr2      -8.587080960   2.300900220  0.0
 tr3      -8.057077410   3.757075070  0.0
 tr4      -7.282262800   5.099092960  0.0
 tr5      -6.286180970   6.286178110  0.0
 tr6      -5.099096780   7.282260420  0.0
 tr7      -3.757079120   8.057075500  0.0
 tr8      -2.300904510   8.587080000  0.0
 tr9      -0.774818003   8.856170650  0.0
 tr10      0.774810851   8.856171610  0.0
 tr11      2.300897600   8.587081910  0.0
```

tr12	3.757072450	8.057078360	0.0
tr13	5.099091530	7.282264230	0.0
tr14	6.286176680	6.286182400	0.0
tr15	7.282259940	5.099097730	0.0
tr16	8.057075500	3.757079600	0.0
tr17	8.587080000	2.300904510	0.0
tr18	8.856170650	0.774817705	0.0
tr19	8.856171610	-0.774811506	0.0
tr20	8.587081910	-2.300898310	0.0
tr21	8.057077410	-3.757073880	0.0
tr22	7.282263280	-5.099092480	0.0
tr23	6.286181450	-6.286177640	0.0
tr24	5.099096780	-7.282260890	0.0
tr25	3.757078410	-8.057075500	0.0
tr26	2.300903560	-8.587080000	0.0
tr27	0.774817228	-8.856170650	0.0
tr28	-0.774811625	-8.856171610	0.0
tr29	-2.300898310	-8.587081910	0.0
tr30	-3.757073160	-8.057078360	0.0
tr31	-5.099091530	-7.282264230	0.0
tr32	-6.286176680	-6.286182400	0.0
tr33	-7.282259460	-5.099098210	0.0
tr34	-8.057074550	-3.757080790	0.0
tr35	-8.587080000	-2.300906420	0.0
tr36	-8.856170650	-0.774819970	0.0
tr37	-10.477500000	-0.000000916	0.0
tr38	-10.318323100	1.819397570	0.0
tr39	-9.845629690	3.583514450	0.0
tr40	-9.073781970	5.238748070	0.0
tr41	-8.026231770	6.734805110	0.0
tr42	-6.734809400	8.026228900	0.0
tr43	-5.238752840	9.073779110	0.0
tr44	-3.583519220	9.845627780	0.0
tr45	-1.819402580	10.318322200	0.0
tr46	-0.000004205	10.477500000	0.0
tr47	1.819394230	10.318324100	0.0
tr48	3.583511350	9.845630650	0.0
tr49	5.238745210	9.073783870	0.0
tr50	6.734803200	8.026233670	0.0
tr51	8.026227950	6.734810830	0.0
tr52	9.073779110	5.238753800	0.0
tr53	9.845627780	3.583519940	0.0
tr54	10.318322200	1.819402930	0.0
tr55	10.477500000	0.000004059	0.0
tr56	10.318324100	-1.819394830	0.0
tr57	9.845630650	-3.583512310	0.0
tr58	9.073782920	-5.238746640	0.0
tr59	8.026232720	-6.734804630	0.0
tr60	6.734809400	-8.026228900	0.0
tr61	5.238752840	-9.073779110	0.0
tr62	3.583519700	-9.845627780	0.0
tr63	1.819402930	-10.318322200	0.0
tr64	0.000004538	-10.477500000	0.0
tr65	-1.819393990	-10.318324100	0.0

```
 tr66     -3.583511110  -9.845631600  0.0
 tr67     -5.238746170  -9.073782920  0.0
 tr68     -6.734803680  -8.026233670  0.0
 tr69     -8.026227000  -6.734811310  0.0
 tr70     -9.073778150  -5.238754750  0.0
 tr71     -9.845627780  -3.583521600  0.0
 tr72    -10.318322200  -1.819404840  0.0
mode    p
phys:p    j 1
imp:p   1  4   16   64 256 1024 4096 16384 49152 294912 1769472 10616832 $ 12
       16 512 512 16384 16 256                                           $ 18
       32 2048 8192 32768 262144 2097152 16777216                        $ 27
       16 128 1024 8192 65536 524288 4194304                             $ 34
        1  4   16   64   256 1024 8192 16384 98304 294912 1769472 10616832 $ 52
       42467328 84934656 169869312       1                               $ 56
        1  4   16   64   256 1024 4096 32768 98304 196608                $ 70
        4  4   16   16   256   256 4096   4096 49152  49152            . $ 80
        196608 393216 393216   393216   3145728  12582912                $ 86
        786432  2r    6291456  2r    50331648   1    100663296           $ 95
        169869312 1r 339738624 1r                               $ air    104
         1. 243r 0.0           $ payload plus outside world
c      wgt=7.683e10 x 330000 = 2.5354e16
sdef   erg=d7  cel=d1  pos fcel d2  axs=0 0 1  ext=d3
       rad d4  wgt=2.5354e16
sc7       ORIGEN2 FROM TONY SAVINO FOR 1 CURIE OF CO-60
c         MEV        phot/s    Mev/s
#         si7          sp7
           l           d
        0.015     1.961E+09 $ 2.942E+07
        0.025     3.388E+08 $ 8.470E+06
        0.0375    1.935E+08 $ 7.256E+06
        0.0575    2.182E+08 $ 1.255E+07
        0.085     8.582E+07 $ 7.295E+06
        0.125     3.296E+07 $ 4.120E+06
        0.225     1.084E+07 $ 2.439E+06
        0.375     3.041E+06 $ 1.140E+06
        0.575     1.746E+05 $ 1.004E+05
        0.85      2.763E+06 $ 2.349E+06
        1.1732    3.700E+10 $ 4.341E+10
        1.3325    3.700E+10 $ 4.930E+10
        2.25      3.921E+05 $ 8.822E+05
        2.75      1.213E+03 $ 3.336E+03
c        Total    7.683E+10 $ 9.279E+10
c
c       9.279e10 (MeV/s) x 1.6022e-13 (watts/MeV/s) = 0.014867 Watts/Curie
c       Total except neutrino = 4.162e-13 x 3.7e10  = 0.015399 Watts/Curie
c       Photon Energy for 330,000 Curies            = 4,906.1 Watts
c       Total Energy ex neutrino for 330,000 Curies = 5,081.7 Watts
sc1    72 pin cell numbers with equal probability
si1    1 501 503 505 507 509 511 513 515 517 519 521 523 525 527 529
         531 533 535
sp1    1. 17r
sc3    axial extent
si3    3.88239 44.52239
```

```
sp3     -21 0
sc4     radial uniform in pin
si4     0.3556
sp4     -21 1
ds2   l  -8.856171610   0.774813652 0.0  $  -8.587080960   2.300900220 0.0
         -8.057077410   3.757075070 0.0  $  -7.282262800   5.099092960 0.0
         -6.286180970   6.286178110 0.0  $  -5.099096300   7.282260420 0.0
         -3.757079120   8.057075500 0.0  $  -2.300904040   8.587080000 0.0
         -0.774818003   8.856170650 0.0  $   0.774811268   8.856171610 0.0
          2.300897600   8.587081910 0.0  $   3.757072930   8.057078360 0.0
          5.099091530   7.282264230 0.0  $   6.286176680   6.286182400 0.0
          7.282259940   5.099097730 0.0  $   8.057074550   3.757079600 0.0
          8.587080000   2.300904510 0.0  $   8.856170650   0.774817705 0.0
          8.856171610  -0.774811506 0.0  $   8.587081910  -2.300898310 0.0
          8.057077410  -3.757073880 0.0  $   7.282263760  -5.099092480 0.0
          6.286181450  -6.286177640 0.0  $   5.099096780  -7.282260890 0.0
          3.757078410  -8.057075500 0.0  $   2.300903320  -8.587080000 0.0
          0.774817228  -8.856170650 0.0  $  -0.774812043  -8.856171610 0.0
         -2.300898310  -8.587081910 0.0  $  -3.757073640  -8.057078360 0.0
         -5.099091530  -7.282264230 0.0  $  -6.286176680  -6.286182400 0.0
         -7.282259460  -5.099098210 0.0  $  -8.057074550  -3.757080790 0.0
         -8.587080000  -2.300906420 0.0  $  -8.856170650  -0.774819970 0.0
c     SS-304L from Nuclear Systems Materials Handbook Rev. 36
c     (cask is fabricated w/ SS-304, insignificant difference for shielding)
m3      6000.50c -0.0003  25055.50c -0.02  15031.50c -0.01
       28000.50c -0.0925  24000.50c -0.19  26000.55c -0.6872
m7      8016.50c 0.22     7014.50c 0.78                     $ air
m8     82000.50c  1.0                                       $ lead
m27    27000.50c  1.0                                       $ Cobalt
c       ansi/ans-6.1.1-1991 AP fluence-to-dose,photons(mrem/hr/(p/cm**2/s)
de0     log  .01 .015 .02 .03 .04 .05
             .06 .08 .10 .15 .20 .30
             .40 .50 .60 .80 1.0 1.5
             2.0 3.0 4.0 5.0 6.0 8.0
             10. 12.
df0     log  2.232e-5 5.652e-5 8.568e-5 1.184e-4 1.314e-4 1.382e-4
             1.440e-4 1.624e-4 1.919e-4 2.797e-4 3.708e-4 5.616e-4
             7.416e-4 9.144e-4 1.076e-3 1.379e-3 1.656e-3 2.246e-3
             2.758e-3 3.672e-3 4.500e-3 5.292e-3 6.012e-3 7.488e-3
             8.892e-3 1.040e-2
fc812   surface radial dose rate (mrem/hr), 3rd entry
f812:p  69
fs812   -97  -95 -96  -98
fc822   surface l axial dose rate (mrem/hr), 1st entry,  1 is no impact lim.
f822:p  90   1
fs822  -55   -60
fc832   surface u axial dose rate (mrem/hr), 3rd entry, 49 is no impact lim.
f832:p  50  49
fs832  -52 -99 -100
fc842   1 cm  radial dose rate (mrem/hr), 3rd entry
f842:p  111
fs842   -97  -95 -96  -98
fc852   1 cm  l axial dose rate (mrem/hr), 1st entry
f852:p  124
```

```
fs852    -55    -60   -65
fc862    1 cm  u axial dose rate (mrem/hr), 3rd entry
f862:p   121
fs862   -52 -99 -100   -65
fc872    1 m  radial dose rate (mrem/hr), 3rd entry
f872:p   112
fs872    -97   -95 -96  -98
fc882    1 m  l axial dose rate (mrem/hr), 1st entry
f882:p   125
fs882     -60
fc892    1 m  u axial dose rate (mrem/hr), 1st entry
f892:p   122
fs892    -100
fc902    2 m  radial dose rate (mrem/hr), 3rd entry
f902:p   113
fs902     -97  -95 -96  -98
fc912    2 m  l axial dose rate (mrem/hr), 1st entry
f912:p   126
fs912     -60
fc922    2 m  u axial dose rate (mrem/hr), 1st entry
f922:p   123
fs922    -100
print    10 50 110
prdmp    j -240  1
nps      50000000
ctme     2880
```

MCNP CONTINUE RUN INPUT FILE FOR 18 PENCIL SOURCE

```
continue
ctme   3000
nps   42000000
```

6.0 CRITICALITY

This section does not apply, since the SteriGenics Eagle Cask does not carry any fissile material.

7.0 OPERATING PROCEDURES

The SteriGenics Eagle Cask (SEC) packaging is designed to transport up to 330,000 curies of Cobalt-60 in the form of up to 72 special form radioactive source capsules.

7.1 Loading Procedures

This section delineates the procedures for loading a payload into the SEC. Hereafter, reference to specific SEC packaging components may be found in Appendix 1.3.2, *Packaging General Arrangement Drawings*.

7.1.1 Loading the SEC in a Shielding Pool

The following procedures are required to load the SEC in a water-filled shielding pool:

1. **Remove the SEC from the Exclusive Use Transport Vehicle.**
2. **Remove the Personnel Barrier.** Remove the fasteners which attach the personnel barrier to the shipping skid. Remove the personnel barrier.
3. **Release and Remove Upper Impact Limiter.** The upper impact limiter is attached to the cask body with twelve ball-lock pins. Remove each ball-lock pin. Remove the fastener in the recessed center plate of the impact limiter and attach a lift eye. Attach a lift sling to the lift eye and lift off the top impact limiter. Free the lower impact limiter by releasing the twelve ball-lock pins.
4. **Visually Inspect the Package.** Visually inspect the package for defects or damage. Any significant defects or damage shall be fully documented. Defects or damage shall be repaired or resolved per Section 8.2 prior to loading the SEC with a payload.
5. **Install Lifting Attachments into Cask Body.** Install two lifting attachments into the threaded 1-8 UNC lifting holes in the cask body. Attach a lid lifting fixture to the four threaded lifting holes in the cask closure lid.
6. **Remove the Cask Closure Lid Vent Port Plug.** Loosen and remove the cask closure lid vent port plug. Visually inspect the vent port plug for defects or damage.
7. **Lift the Cask from the Lower Impact Limiter.** Position a lifting device above the SEC. Attach two lifting devices to the lifting attachments. Lift the cask body from lower impact limiter.
8. **Remove the Cask Body Drain Port Plug.** Remove the cask body drain plug. Visually inspect the cask body drain plug for defects or damage.
9. **Remove the Closure Lid Drain Port Plug.** Loosen and remove the closure lid drain port plug. Visually inspect the closure lid drain plug for defects or damage.
10. **Remove the Cask Closure Lid Bolts.** Loosen and remove the twelve cask closure lid bolts.
11. **Lower the Cask Into the Shielding Pool.** Position the cask over the shielding pool and slowly lower until the top of the cask body is just covered by water. Allow the water to fill

the cask cavity. Lower the cask into position in the shielding pool and remove the lifting hooks.

12. **Remove the Cask Closure Lid.** Attach a lifting device to the cask closure lid lifting fixture and raise the cask closure lid, taking care to avoid binding. Set the cask closure lid aside.
13. **Load the Payload Basket.** Attach a lifting device to the payload basket lifting hoop. Raise the payload basket over the cask body and lower into the cask cavity. Detach the lifting device from the payload basket. Note that the payload basket may either be preloaded with Cobalt-60 source capsules or may be loaded subsequent to placing the payload basket inside the cask cavity.
14. **Load the Payload Basket with Special Form Source Capsules.** Commence loading the Cobalt-60 source capsules into the payload basket. Source capsules shall be loaded starting with the inner row, utilizing every other hole. The maximum authorized source capsule activity is 18,333 curies, with a total package limit of 330,000 curies.
15. **Replace the Cask Closure Lid.** Attach lifting device to cask closure lid lifting attachment. Raise the cask closure lid and position over the cask body. Lower the cask closure lid onto the cask body, aligning the cask closure lid bolt holes on the lid and cask body using the alignment strip.
16. **Lift the Cask from the Shielding Pool.** Attach a lifting device to cask lifting attachments. Raise the cask out of pool, allowing water to drain from the cask cavity.
17. **Replace the Closure Lid Bolts.** Install the closure lid bolts, tightening to a snug tight condition.
18. **Drying the Cask Cavity.** Subsequent to draining the cask, wait one-half hour minimum to permit the cask to self-dry. To facilitate the drying process, air or inert gas may be blown through the cask cavity. However, if inert gas is utilized, air must be introduced into the cask cavity to displace the inert gas.
19. **Tighten the Closure Lid Bolts.** Tighten the closure lid bolts to 80 ±10 lb-ft.
20. **Replace the Closure Lid Drain Plug.** Replace and tighten the closure lid drain plug. Tighten to 40 ±5 lb-ft.
21. **Replace the Cask Body Drain Plug.** Replace and tighten the cask body drain plug. Tighten to 110 ±10 lb-in.
22. **Replace the Cask Closure Lid Vent Port Plug.** Install the closure lid vent port plug, tightening to 110 ±10 lb-in.
23. **Replace the Cask on the Lower Impact Limiter.** Install the cask into the lower impact limiter, aligning the impact limiter ball-lock pins with their mounting holes.
24. **Remove the Lifting Attachments**. Remove the cask closure lid lifting attachment and the cask body lifting attachments.
25. **Replace the Upper Impact Limiter**. Using a lifting device, install the upper impact limiter onto the cask body, aligning the ball-lock pins with their mounting holes. Decouple crane hooks from impact limiter.

26. **Install the Tamper Indicator Seals.** Install tamper indicating seals on both the upper and lower impact limiters.

27. **Replace the Personnel Barrier.** Install the personnel barrier over the cask assembly. Secure the personnel barrier to the transportation skid with the required fasteners.

28. **Load the SEC Onto Exclusive Use Transport Vehicle.** Secure transportation skid to transport vehicle.

29. **Monitor External Radiation.** Monitor external radiation per the guidelines of 49 CFR §173.427 [1], Subpart I.

30. **Determine the Surface Contamination.** Determine the surface contamination levels for the SEC per the guidelines of 49 CFR §173.403.

31. **Determine the Shielding Transport Index.** Determine the shielding transport index of the SEC transportation package per the guidelines of 49 CFR §173.403.

32. **Complete All Shipping Papers.** Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172 [2].

33. **Verify Package Marking.** SEC package marking shall be in accordance with 10 CFR §71.85(c) [3] and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Package placarding shall be in accordance with Subpart F of 49 CFR 172.

7.1.2 Loading the SEC in a Dry Environment

The following procedures are required to load the SEC in a hot cell or other dry loading station:

1. **Remove the SEC from the Exclusive Use Transport Vehicle.**

2. **Remove the Personnel Barrier.** Remove the fasteners which attach the personnel barrier to the shipping skid Remove the personnel barrier.

3. **Release and Remove Upper Impact Limiter**. The upper impact limiter is attached to the cask body with twelve ball-lock pins. Remove each ball-lock pin. Remove the fastener in the recessed center plate of the impact limiter and attach a lift eye. Attach a lift sling to the lift eye and lift off the top impact limiter. Free the lower impact limiter by releasing the (12) ball-lock pins.

4. **Visually Inspect the Package.** Visually inspect the package for defects or damage. Any significant defects or damage shall be fully documented. Defects or damage shall be repaired or resolved per Section 8.2 prior to loading the SEC with a payload.

5. **Install Lifting Attachments into Cask Body**. Install two lifting attachments into the threaded 1-8 UNC lifting holes in the cask body. Attach a lid lifting fixture to the four threaded lifting holes in the cask closure lid.

6. **Remove the Cask Closure Lid Vent Port Plug.** Loosen and remove the cask closure lid vent port plug. Visually inspect the vent port plug seal for defects or damage.

7. **Lift the Cask from the Lower Impact Limiter.** Position a lifting device above the SEC. Attach two lifting devices to the lifting attachments. Lift the cask body from lower impact limiter.
8. **Remove the Cask Closure Lid Bolts.** Loosen and remove the twelve cask closure lid bolts.
9. **Place the Cask into the Hot Cell.** Position the cask into the hot cell or other dry loading station.
10. **Remove the Cask Closure Lid.** Attach a lifting device to the cask closure lid lifting fixture and raise the cask closure lid, taking care to avoid binding. Set the cask closure lid aside.
11. **Load the Payload Basket**. Attach a lifting device to the payload basket lifting hoop. Raise the payload basket over the cask body and lower into the cask cavity. Detach the lifting device from the payload basket. Note that the payload basket may either be preloaded with Cobalt-60 source capsules or may be loaded subsequent to placing the payload basket inside the cask cavity.
12. **Load the Payload Basket with Special Form Source Capsules.** Commence loading the Cobalt-60 source capsules into the payload basket. Source capsules shall be loaded starting with the inner row, utilizing every other hole. The maximum authorized source capsule activity is 18,333 curies with a total package limit of 330,000 curies.
13. **Replace the Cask Closure Lid.** Attach lifting device to cask closure lid lifting attachment. Raise the cask closure lid and position over the cask body. Lower the cask closure lid onto the cask body, aligning the cask closure lid bolt holes on the lid and cask body using the alignment strip.
14. **Remove the Cask from the Hot Cell.**
15. **Replace the Closure Lid Bolts.** Install the closure lid bolts, tightening the bolts to 80 ±10 lb-ft.
16. **Replace the Cask Closure Lid Vent Port Plug.** Install the closure lid vent port plug, tightening to 110 ±10 lb-in.
17. **Replace the Cask on the Lower Impact Limiter.** Install the cask into the lower impact limiter, aligning the impact limiter ball-lock pins with their mounting holes.
18. **Remove the Lifting Attachments**. Remove the cask closure lid lifting attachment and the cask body lifting attachments.
19. **Replace the Upper Impact Limiter**. Using a lifting device, install the upper impact limiter onto the cask body, aligning the ball-lock pins with their mounting holes. Decouple crane hooks from impact limiter.
20. **Install the Tamper Indicator Seals.** Install tamper indicating seals on both the upper and lower impact limiters.
21. **Replace the Personnel Barrier.** Install the personnel barrier over the cask assembly. Secure the personnel barrier to the transportation skid with the required fasteners.

22. **Load the SEC Onto Exclusive Use Transport Vehicle.** Secure transportation skid to transport vehicle.

23. **Monitor External Radiation.** Monitor external radiation per the guidelines of 49 CFR §173.427, Subpart I.

24. **Determine the Surface Contamination.** Determine the surface contamination levels for the SEC per the guidelines of 49 CFR §173.403.

25. **Determine the Shielding Transport Index.** Determine the shielding transport index of the SEC transportation package per the guidelines of 49 CFR §173.403.

26. **Complete All Shipping Papers.** Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172.

27. **Verify Package Marking.** SEC package marking shall be in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Package placarding shall be in accordance with Subpárt F of 49 CFR 172.

7.2 Procedures for Unloading the Package

This section delineates the procedures for unloading a payload from the SEC. Hereafter, reference to specific SEC packaging components may be found in Appendix 1.3.2, *Packaging General Arrangement Drawings.*

7.2.1 Unloading the SEC in a Shielding Pool

The following procedures are required to unload the SEC cask in a water-filled pool:

1. **Remove the SEC from the Exclusive Use Transport Vehicle.**
2. **Remove the Personnel Barrier.** Remove the fasteners which attach the personnel barrier to the shipping skid Remove the personnel barrier.
3. **Release and Remove Upper Impact Limiter.** The upper impact limiter is attached to the cask body with twelve ball-lock pins. Remove each ball-lock pin. Remove the fastener in the recessed center plate of the impact limiter and attach a lift eye. Attach a lift sling to the lift eye and lift off the top impact limiter. Free the lower impact limiter by releasing the (12) ball-lock pins.
4. **Visually Inspect the Package.** Visually inspect the package for defects or damage. Any significant defects or damage shall be fully documented. Defects or damage shall be repaired or resolved per Section 8.2 prior to loading the SEC with a payload.
5. **Install Lifting Attachments into Cask Body.** Install two lifting attachments into the threaded 1-8 UNC lifting holes in the cask body. Attach a lid lifting fixture to the four threaded lifting holes in the cask closure lid.
6. **Lift the Cask from the Lower Impact Limiter.** Position a lifting device above the SEC. Attach two lifting devices to the lifting attachments. Lift the cask body from lower impact limiter.
7. **Remove the Cask Body Drain Port Plug.** Remove the cask body drain plug. Visually inspect the cask body drain plug for defects or damage.
8. **Remove the Closure Lid Drain Port Plug.** Loosen and remove the closure lid drain port plug. Visually inspect the closure lid drain plug for defects or damage.
9. **Remove the Cask Closure Lid Bolts.** Loosen and remove the twelve cask closure lid bolts.
10. **Lower the Cask Into the Shielding Pool.** Position the cask over the shielding pool and slowly lower until the top of the cask body is just covered by water. Allow the water to fill the cask cavity. Lower the cask into position in the shielding pool and remove the lifting hooks.
11. **Remove the Cask Closure Lid.** Attach a lifting device to the cask closure lid lifting fixture and raise the cask closure lid, taking care to avoid binding. Set the cask closure lid aside.
12. **Unload the Payload Basket.** Attach a lifting device to the payload basket lifting hoop. Raise the payload basket from the cask cavity and lower into the receiving station. Detach

the lifting device from the payload basket. If the payload basket is to be unloaded while in the cask cavity, remove the Cobalt-60 source capsules from the payload basket.

7.2.2 Unloading the SEC in a Dry Environment

The following procedures are required to unload the SEC in a hot cell or other dry unloading station:

1. **Remove the SEC from the Exclusive Use Transport Vehicle.**
2. **Remove the Personnel Barrier.** Remove the fasteners which attach the personnel barrier to the shipping skid Remove the personnel barrier.
3. **Release and Remove Upper Impact Limiter.** The upper impact limiter is attached to the cask body with twelve ball-lock pins. Remove each ball-lock pin. Remove the fastener in the recessed center plate of the impact limiter and attach a lift eye. Attach a lift sling to the lift eye and lift off the top impact limiter. Free the lower impact limiter by releasing the (12) ball-lock pins.
4. **Visually Inspect the Package.** Visually inspect the package for defects or damage. Any significant defects or damage shall be fully documented. Defects or damage shall be repaired or resolved per Section 8.2 prior to loading the SEC with a payload.
5. **Install Lifting Attachments into Cask Body.** Install two lifting attachments into the threaded 1-8 UNC lifting holes in the cask body. Attach a lid lifting fixture to the four threaded lifting holes in the cask closure lid.
6. **Loosen the Cask Closure Lid Vent Port Plug.** Loosen and remove the cask closure lid vent port plug. Visually inspect the vent port plug seal for defects or damage.
7. **Lift the Cask from the Lower Impact Limiter.** Position a lifting device above the SEC. Attach two lifting devices to the lifting attachments. Lift the cask body from lower impact limiter.
8. **Remove the Cask Closure Lid Bolts.** Loosen and remove the twelve cask closure lid bolts.
9. **Place the Cask into the Hot Cell.** Position the cask into the hot cell or other dry loading station.
10. **Remove the Cask Closure Lid.** Attach a lifting device to the cask closure lid lifting fixture and raise the cask closure lid, taking care to avoid binding. Set the cask closure lid aside.
11. **Unload the Payload Basket.** Attach a lifting device to the payload basket lifting hoop. Raise the payload basket out of the cask cavity and lower into the receiving station. Detach the lifting device from the payload basket. If the payload basket is to be unloaded while in the cask cavity, remove the Cobalt-60 source capsules from the payload basket.

7.3 Preparing an Empty Package for Transport

Previously used and empty SEC transportation packages shall be prepared and transported per the requirements of 49 CFR §173.427 [1], Subpart I.

7.4 Appendix

7.4.1 References

1. Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers - General Requirements for Shipments and Packaging*, 1-1-97 Edition.
2. Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 1-1-97 Edition.
3. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

8.0 ACCEPTANCE TESTS AND MAINTENANCE

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85(c) [1], this section discusses the inspections and tests to be performed prior to first use of a SteriGenics Eagle Cask (SEC).

8.1.1 Visual Inspection

All SEC materials of construction and welds shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.2, *Packaging General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

8.1.2 Structural and Pressure Tests

8.1.2.1 Lifting Device Load Testing

The SEC does not contain any lifting devices requiring load testing.

8.1.2.2 Pressure Tests

Per the requirements of 10 CFR §71.85(b), the SEC confinement system boundary shall be pressure tested to 150% of the maximum normal operating pressure (MNOP) to verify structural integrity. The MNOP of the SEC is equal to 23.9 psig. However, the SEC pressure test will utilize the design pressure of 50 psig as the MNOP. Thus, the SEC confinement system shall be pressure tested to $50 \times 1.5 = 75$ psig.

Following confinement system boundary pressure testing, the accessible base material and welds related to the pressure testing of the confinement system shall be visually inspected for plastic deformation or cracking, and liquid penetrant inspected per ASME Boiler and Pressure Vessel Code, Section V [2], Section 6, and ASME Boiler and Pressure Vessel Code, Section III [3], Division 1, Subsection NB, Article NB-5000, as delineated on the drawings in Appendix 1.3.2, *Packaging General Arrangement Drawings*. Indications of cracking or distortion shall be recorded on a nonconformance report and dispositioned prior to final acceptance in accordance with the cognizant quality assurance program.

8.1.3 Leak Tests

The SEC provides only a confinement system for the special form Cobalt-60 source capsules. Therefore, leak tests of the confinement system boundary are not required for acceptance of the SEC.

8.1.4 Component Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

The SEC does not contain any valves, rupture discs, or fluid transport devices. However, the SEC does contain two drain ports and a vent port to facilitate cask cavity drying during wet loading.

8.1.4.2 Gaskets

The SEC provides only a confinement system for the special form Cobalt-60 source capsules. The Viton O-ring seal only provides a weather seal for the SEC cavity.

8.1.5 Tests for Shielding Integrity

Poured lead shielding integrity shall be confirmed via gamma scanning. Two gamma scan techniques are utilized. The primary difference is in the method used to determine acceptance criteria. Both gamma scan techniques are exactly the same in all other respects and are conducted as discussed below.

A gamma probe is used to scan the outer cask surface while an Iridium-192, Cobalt-60, or similar source of sufficient strength is positioned within a collimator along the centerline of the cask cavity. The cask outer surface is marked with a grid and a chart is made to reflect the gridded surface. The source is first placed on the bottom of the cask cavity while the surface is scanned around its circumference. The source is then moved up the predetermined distance to the next gridline and the circumference scanned again. This sequence is repeated until the entire cask outer surface is scanned. Dose rates are recorded from each grid square by scanning every point in the grid and recording the maximum dose rates in the corresponding grid on the chart. This data then serves as the raw gamma scan results. All dose rates are in milliroentgens per hour (mR/hr).

The dose rates are evaluated by comparing them to predetermined dose rate values for nominal (as designed) lead thickness and nominal-less-10% lead thickness. The two different methods utilized to determine acceptance criteria for this data are as follows:

The first method, the Laboratory Calibration Method, utilizes test blocks of the cask wall made up of lead and steel plates. The test blocks simulate nominal (as designed) and nominal-less-10% lead thicknesses. The source is placed behind the nominal test block assembly at a distance equal to the inside radius of the cask. The probe is then placed on the outside of the test block assembly and the dose rate recorded. This test sequence is repeated on the nominal-less-10% test block assembly. The resultant dose rate values are then utilized as acceptance criteria for the actual cask gamma scan. Additionally, the expected dose rate values for nominal and reduced (nominal-less-10%) thickness shielding are calculated utilizing attenuation values for steel and lead as correlation verification.

The second, the Field Calibration Method, utilizes a specially fabricated test lid that incorporates a holder for various lead and steel plate thicknesses. The fixture is installed onto the cask with the test lid set up to simulate the nominal lead thickness. The source is placed below the test lid, inside the cask, at a distance equal to the inside radius of the cask. The dose rate is then

measured and recorded. The test lid is adjusted to establish the nominal-less-10% lead thickness configuration. The source is again placed below the test lid at a distance equal to the inside radius of the cask, and the dose rate is again measured and recorded. The value for nominal-less-10% lead thickness is utilized as the maximum acceptable dose rate value for the SEC.

Plate or sheet lead may be also be utilized in the lower cask body cavities and in the closure lid. For plate or sheet lead integrity, ultrasonic examination of each plate or sheet is performed with prior to installation to ensure that no voids exist within the plate or sheet. Voids in excess of 10% of the lead plate or sheet thickness are not acceptable for installation into the SEC.

8.1.6 Thermal Acceptance Tests

Material properties established in Chapter 3.0 are conservative for the analyses performed. As such, acceptance tests for material thermal properties are not performed.

Prior to its first use, a completed production SEC shall be subjected to a thermal acceptance test to ensure that the cask will meet the thermal design criteria. This test shall be performed only once on a single SEC to demonstrate that the cask design passively rejects decay heat from the special form Cobalt-60 source capsule payload in accordance with the analytical predictions provided in Chapter 3.0.

8.1.6.1 Discussion of Test Setup

To validate the cask's thermal heat transfer design, a heat source will be installed into the SEC cavity. The SEC will then be closed in accordance with Section 7.1, *Loading Procedures*. Temperature measurements will then be recorded for the inner and outer surfaces of the SEC and then compared to the analytical predictions of the same thermal configuration.

8.1.6.2 Test Procedure

An internal heat source capable of generating 4.7 kW minimum will be installed into the SEC cavity. Thermocouple or temperature indicating strips will be installed on the inner and outer surface of the cask, in the cavity bore, in the vicinity of the sealing surface, on the closure lid, and on the outer thermal shield surface. A minimum of three positions around the circumference and three axial positions as well as the cask bottom will be used to record the temperatures.

8.1.6.3 Acceptance Criteria

The acceptance criteria shall be calculated for the change in temperature across the cask wall based on the internal heat and exterior ambient conditions using the same analytical methods used to predict the cask performance for NCT in Section 3.4.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the SEC to the requirements of 10 CFR §71.87.

8.2.1 Structural and Pressure Tests

Other than the acceptance tests required for first use, no structural or pressure tests are necessary to ensure continued performance of the packaging.

8.2.2 Leak Tests

The SEC provides only a confinement system for the special form Cobalt-60 source capsules. Therefore, leak tests of the confinement system boundary are not required for maintenance of the SEC.

8.2.3 Subsystem Maintenance

The following sections describe subsystems maintenance.

8.2.3.1 Fasteners

All threaded fasteners shall be visually inspected before each use for deformed or stripped threads. Any damaged fasteners shall be repaired or replaced prior to further use. At a minimum, the closure lid bolts shall be replaced after 150 uses.

The drain and vent port plugs shall be visually inspected before each use for deformed or stripped threads. Any damaged seal plugs or test port plugs and covers shall be repaired or replaced prior to further use.

All other fasteners need not be replaced except when damaged beyond repairable use.

8.2.3.2 Seal Areas and Grooves

At the time of seal replacement and before each use, visually inspect the O-ring seal groove and mating sealing surface for damage. Using emery cloth, smooth and polish any damaged areas to a surface finish as specified in Appendix 1.3.2, *Packaging General Arrangement Drawings*.

8.2.3.3 Impact Limiters

The ball-lock pins that attach the impact limiters shall be visually inspected before each use for any damage that could reduce their effectiveness. Damaged pins shall be repaired or replaced prior to future use.

Painted surfaces shall be repaired if the accumulative damage exceeds 1,000 in^2, which is approximately 5% of the painted surface area. Damaged surfaces shall be prepared per the paint manufacturer's specifications and painted as specified in Appendix 1.3.2, *Packaging General Arrangement Drawings*.

8.2.4 Valves, Rupture Discs, and Gaskets on the Containment Vessel

This section describes the inspection and replacement schedule for these components.

8.2.4.1 Valves

The SEC does not contain any valves requiring periodic testing.

8.2.4.2 Rupture Discs

The SEC does not contain any rupture discs requiring periodic testing.

8.2.4.3 Gaskets

All packaging O-ring seals and gaskets shall be replaced annually or when damaged, per the size and material specifications provided in Appendix 1.3.2, *Packaging General Arrangement Drawings*.

8.2.5 Shielding

Other than the acceptance tests required for first use, no shielding tests are necessary to ensure continued performance of the packaging.

8.2.6 Thermal

Other than the acceptance tests required for first use, no thermal tests are necessary to ensure continued performance of the packaging.

8.3 APPENDIX

8.3.1 References

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.
2. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V, *Nondestructive Examination*, 1995 Edition, 1997 Addenda.
3. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Power Plant Components*, 1995 Edition, 1997 Addenda.