3.0 THERMAL EVALUATION

This Section identifies, describes, discusses, and analyzes the principal thermal engineering design of the 8-120B package. Compliance with the performance requirements of 10 CFR 71 (Reference 3-1) is demonstrated.

3.1 DESCRIPTION OF THERMAL DESIGN

Two components contribute to the thermal protection of the cask body. These components are the impact limiters which provide thermal protection to the ends of the cask and the fire shield which protects the side walls between the impact limiters.

3.1.1 DESIGN FEATURES

Figure 3-1 shows the design features of the components contributing to the thermal protection of the cask. These components are identified in the figure with solid red color.

The fire shield is made of 3/16" steel sheet metal. In order to provide an air gap between the cask outer shell and the fire shield, 5/32" diameter wires are helically wrapped around the cask outer shell. The fire shield is welded to the cask body at the two ends. Cut-outs are provided in the fire shield in order to wrap around the tie down lugs and lifting ear pads.

The impact limiters are sheet metal enclosures filled with polyurethane foam which acts as insulation barrier to heat flow. The impact limiters are attached together with the help of turnbuckles on the ends of the cask as shown in Figure 3-1. The impact limiters remain attached to the cask body during the HAC drop tests (See Section 2.7). Therefore they provide thermal insulation to the cask during the NCT events and the fire test. The central portion of both, the top and the bottom, impact limiters contain a hollow region that is covered by sheet-metal (upper) or steel plate (lower). In the puncture drop test, which precedes the fire test, these covers may rupture and provide a direct path to the secondary lid and the baseplate. In order to protect the seals a thermal-shield is externally attached to the secondary lid.

3.1.2 CONTENT'S DECAY HEAT

The maximum decay heat of the waste component is 200 watt. The minimum decay heat of zero Watt is used in the evaluation of other limiting case.

3.1.3 SUMMARY TABLES OF TEMPERATURES

The maximum temperatures in various important components of the cask during the NCT events are summarized in Table 3-1. Table 3-2 summarizes the maximum temperature in these components during the HAC fire test. The time at which these components achieve the maximum temperature is also identified in Table 3-2. The results summarized in Table 3-1 and 3-2 are discussed in detail in Sections 3.3 and 3.4.

3.1.4 SUMMARY TABLE OF MAXIMUM PRESSURES

The summary of maximum pressures during the NCT and HAC fire test are provided in Table 3-3. The details of these pressure calculations are provided in Sections 3.3.2 and 3.4.3 for NCT and HAC fire test, respectively.

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

3.2.1 MATERIAL PROPERTIES

The material properties of the cask components used in the analysis of the 8-120B package are provided in Tables 3-4 through 3-6. Table 3-4 provides the temperature independent properties of the steel and lead components. Table 3-5 provides the temperature dependent specific heat and thermal conductivity of stainless steel, carbon steel and lead. Table 3-6 provides the temperature dependent density, specific heat and conductivity of air. Material properties have been obtained from standard references (References 3-2 through 3-6) and are identified in Tables 3-4 through 3-6.

3.2.2 COMPONENT SPECIFICATIONS

The metallic components that are important for the thermal performance of the package are made of steel. The non-metallic components are specified as follows:

- The seals used in the package are specified to be elastomer, 50-70 Shore A Durometer, usable temperature range that meets or exceeds the range required to meet the Normal Conditions of Transport (minimum= -40°F, maximum= +180°F) and meets or exceeds the temperature required to meet the Hypothetical Accident Conditions (+340°F) as specified by ES-C-038 (Reference 8.4.2).
- Lead is specified to be ASTM B-29 commercial grade. The melting temperature is 622°F.
- Polyurethane foam used in the impact limiters are specified by ES-M-175 (Reference 8.4.1). All the pertinent thermal properties are included in this specification.

3.3 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

The thermal analyses of the 8-120B package under various loading conditions have been performed using finite element modeling techniques. ANSYS finite element analysis code (Reference 3-7) has been employed to perform the analyses. Two finite element models have been employed in performing the NCT thermal analyses. A three-dimensional solid model and a 2-dimensional axisymmetric model were used in the analyses. For the load cases in which the mechanical loading on the cask are non-uniform, a three dimensional finite element model was used. To obtain the temperature distribution in the cask where the bolt loadings have no effect on the results, a two-dimensional axisymmetric finite element model has been used.

The cask geometry is symmetrical about a vertical plane, so a one-half model of the cask is represented in the 3-dimensional model. The impact limiters are not explicitly included in the finite element model. For NCT the impact limiters are conservatively represented by fully-isolated boundary conditions, and only the exposed portions of the fire shield and cask body are used for the heat rejection to the ambient.

Figure 3-2 shows the three-dimensional finite element model used in various thermal load analyses. Figure 3-3 shows the material property modeling of various components of the cask.

The internal heat load has been modeled in the FEM in two different ways - implicitly (in 3-d model) and explicitly (in 2-d model). In the implicit model the heat load is applied as a uniform flux over the cavity of the cask. This results in a conservative cask body temperature. However, the cavity temperature predicted is not conservative. To get a conservative prediction of the cask cavity temperature, the internal contents of the cask is explicitly represented in the 2-d model. The cask body structural evaluation has been performed with the implicit model results and the cask cavity temperature needed for the calculation of internal pressure has been obtained from the explicit model.

The cask body structural evaluation has been performed in Section 2 with the temperature results obtained in this section.

The details of the analyses, including the assumptions, modeling details, boundary conditions, and input and output data are included in Energy*Solutions* document TH-027 (Reference 3-8).

3.3.1 HEAT AND COLD

The finite element model described in Section 3.3 is analyzed for the following loading conditions:

- Hot Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (1). The loading includes a 100° F ambient temperature, solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation. The temperature distribution in the cask body under this loading condition is shown in Figure 3-4.
- Cold Environment – This load case is based on the requirements of 10 CFR 71.71 (c) (2). The loading includes a -40° F ambient temperature, no solar insolation, and maximum internal heat load. This loading is used as one of the extreme initial conditions for the normal conditions of transport (NCT) and hypothetical accident condition (HAC) test evaluation. The temperature distribution in the cask body under this loading condition is shown in Figure 3-5.
- Normal Hot - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a 100° F ambient temperature, no solar insolation, and maximum internal heat load. The temperature distribution in the cask body under this loading condition is shown in Figure 3-6.
- Normal Cold - This load case is based on the requirements of 10 CFR 71.71 (b). The loading includes a -20° F ambient temperature, no solar insolation, and maximum internal heat load. The temperature distribution in the cask body under this loading condition is shown in Figure 3-7.

The 2-d axisymmetric model, with the explicit heat loading, has been analyzed for the hot environment conditions. The temperatures results from this model have been used to report the waste and cavity temperatures. Figure 3-8 shows the temperature distribution in the cask and its internal contents.

The temperature distributions in the 8-120B cask under various conditions analyzed in this section are used in the structural analyses presented in Section 2. Under the cold conditions with minimum (zero) heat loading the body temperature of the cask reaches the ambient temperature in steady state. Therefore, no thermal analyses for this case are needed. On the other hand, with any amount of heat load, there exist temperature gradients in various parts of the cask. To capture these two effects, the evaluation of the cask in Section 2 has been performed for the two cold conditions one with the maximum internal heat load and another with minimum (zero) heat load. These two load cases envelope the conditions of maximum and minimum temperature gradient through the cask body.

The thermal analysis shows that under the normal conditions of transport there is no reduction in packaging effectiveness. The heat transfer capability of the components is not reduced under NCT, nor are there changes in material properties that affect structural performance, containment, or shielding. It has also been demonstrated that the maximum temperature of the accessible portion of the package is 160.6°F which is less than 185°F, required by 10 CFR 71.43(g), for an exclusive use shipment.

3.3.2 MAXIMUM NORMAL OPERATING PRESSURE

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air, water vapor, oxygen, and hydrogen, behaves as an ideal gas. To determine the maximum internal pressure under normal conditions in the cask (MNOP) the temperature of the gas mixture within the cask was evaluated. The maximum temperature of the cask cavity under normal conditions is 197.87°F, (see Table 3-1). The gas mixture in the cavity is conservatively assumed to be 200°F.

The maximum pressure is the sum of three components:

1. The pressure due to the increased temperature of the gas in the cavity;
2. The pressure due to water in the cask (vapor pressure of water); and
3. The pressure due to generation of gas (hydrogen and oxygen) by radiolysis.

1. The cask on loading has an internal pressure equal to ambient, assumed to be 1 atm absolute (14.7 psia) at 70 °F (21.1 °C, 294.3 K) and defined as P_1 in the equation below. Per the ideal gas law, the increased partial pressure of the air initially sealed in the fixed volume of the cask at the ambient temperature as it is heated to 200 °F (93.3 °C, 366.5°K) is:

$$P_2 = P_1 \times \frac{T_2}{T_1} = (14.7\, psia) \times \frac{366.5\, K}{294.3\, K} = 18.31\, psia$$

2. Since the cask cavity is assumed to also contain water, the vapor pressure of water must be added to the pressure in the cavity. The vapor pressure contributed by water (P_{H2O}) in the cavity at 200°F (93.3 °C) is 11.52 psia (interpolated from the table Vapor Pressure of Water from 0 °C to 370 °C, page 6-15, from Reference 3-4, a copy of the table is attached as Attachment 3A). Adding the water vapor pressure at 200 °F to the partial pressure of the initially-sealed air at this temperature gives:

$$P_3 = P_2 + P_{H2O} = 18.31\,psia + 11.52\,psia = 29.83\,psia$$

3. Further, the cask atmosphere is assumed to contain five volume percent (5 vol%) hydrogen (H_2) gas due to radiolysis of the water. By stoichiometry of the water molecule (H_2O), the cask atmosphere will also contain 2.5 vol% oxygen (O_2) gas generated by radiolysis. Noting that partial pressures in an ideal gas mixture are additive and behave the same as ideal gas volume fractions or mole fractions, the partial pressure of hydrogen is described by the following equation:

$$P_{H2} = 0.05 \times (P_{air} + P_{H2O} + P_{H2} + P_{O2})$$

Combining P_{air} and P_{H2O} into P_3 per item 2 above, and noting that $P_{O2} = 0.5 \times P_{H2}$, gives:

$$P_{H2} = 0.05 \times (P_3 + 1.5P_{H2})$$

Solving this equation explicitly for P_{H2} gives:

$$P_{H2} = \frac{(0.05)P_3}{1-(0.05)(1.5)} = \frac{(0.05)(29.83\,psia)}{1-(0.05)(1.5)} = 1.61\,psia$$

Recalling the stoichiometric relationship between hydrogen and oxygen liberated by radiolysis of water, and again combining the pressures of the initially sealed air and water vapor as P_3, the total pressure in the cask at 200 °F is:

$$P_{Total} = P_3 + 1.5P_{H2} = 32.25\,psia$$

Therefore, the MNOP in gage pressure is calculated as:

$$\text{MNOP} = P_{Total} - P_1 = 32.25\text{ psia} - 14.7\text{ psia} = 17.6\text{ psig}$$

The MNOP value is conservatively set at 35.0 psig for use in the cask structural analysis under normal conditions of transport (NCT).

3.3.3 THERMAL STRESSES

The structural evaluation of the package under the normal conditions of transport loading is performed in Reference (2-13). All the stresses are within the design allowable values established for 8-120B package.

3.4 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

The thermal analyses of the 8-120B package under HAC fire conditions have been performed using finite element model, described in Section 3.3. A nonlinear thermal transient analysis is performed to obtain the time-history of the temperature in package.

The temperature results from the thermal analyses have been used for performing the structural evaluation of the 8-120B Cask under HAC fire. The maximum temperature of the cavity during the entire transient has been used for calculating the cask pressure during the HAC fire.

The impact limiters of the 8-120B package have been shown to remain attached to the cask body during the free drop tests. The effect of these drop tests is a local crushing of the foam, and possible rupture of the impact limiter skin. The puncture drop on the impact limiters will crush the foam and may also rupture the skin in the vicinity of the impact location. The rupture of the impact limiter skin after the drop and puncture tests may expose the polyurethane foam material to the fire. However, the polyurethane fire retardant characteristics will mitigate the effect of the direct exposure to fire due to formation of intumescent char. The intumescent char has the ability to seal large voids which could be caused by the impact damage. The char also provides a secondary thermal barrier which breaks down very slowly at 2000 to 2200°F.

The 5-gallon bucket tests performed by General Plastics where the open face of the bucket is exposed to direct fire show the formation of the char that prevents the fire from extending into the underlying foam. These tests also indicate that for the 11¾" foam thickness in the test, the effect of 30-minute fire has a minimal effect on the end opposite the exposed end. These tests were performed for various density foams and it was shown that the effectiveness of the foam is enhanced with the increasing foam density. With 25 lb/ft^3 foam density and a minimum foam thickness of 11" in the 8-120B cask package, the effect of exposure of a small portion of foam due to rupture during the drop and puncture test will not have a significant effect on the impact limiter performance during the fire. Therefore, the same boundary conditions at the interface between the cask and the impact limiter as those under the NCT (total thermal insulation) have been used for the HAC fire test analyses. However, the puncture drop test may result in failure of the steel covers on the central hollow region of the upper and lower impact limiters, which could result in the regions of the cask located underneath these covers being exposed directly to the fire. Therefore, the central hollow regions of the upper and lower impact limiters are conservatively modeled fully exposed for the HAC fire test.

The direct impact of the puncture bar on the sidewall of the cask will remove the air gap provided between the fire-shield and the cask body. The fire shield may come in contact with the cask body near the impact location. During the HAC fire test extra amount of heat will be input to the cask body locally near the impact point. Analyses have also been performed to evaluate the conditions in which the fire-shield is damaged during the puncture drop test. The fire is assumed to hit the area directly where the puncture bar damages the fire shield. It has been shown that under these conditions the cask experiences locally high temperatures but they are within the acceptable limit for the materials. See Reference 3-10 for the details of this analysis.

The details of the analyses, including the assumptions, modeling details, boundary conditions, and input and output data are included in EnergySolutions document TH-028 (Reference 3-10).

3.4.1 INITIAL CONDITIONS

The initial temperature condition, used for the HAC fire test analysis is obtained by running the finite element model with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - yes
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

3.4.2 FIRE TEST CONDITIONS

The fire transient is run with the body temperature resulting from the above initial conditions. The fire transient is run for 30 minutes (1,800 sec) with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - no
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by forced convection – yes
- Ambient air temperature - 1475°F

The end of fire analysis of the model is performed with the body temperature resulting from the above fire transient to 1801 sec with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - no
- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

The cool-down analysis of the model is performed with the body temperature resulting from the above fire transient to 22,500 sec with the following boundary conditions:

- Internal heat load – 200 W
- Solar insolation - yes

- Heat Transfer to the ambient by radiation – yes
- Heat transfer to the ambient by natural convection – yes
- Ambient air temperature - 100°F

Figure 3-9 shows the boundary conditions used during the fire transient analysis.

3.4.3 MAXIMUM TEMPERATURES AND PRESSURE

From the analyses of the finite element model, a time-history data of the temperature in various components of the cask is obtained. The fire shield, outer shell, inner shell, lead, and seal were considered as the critical components of the cask. The temperatures at representative locations in these components are monitored during the entire fire and cool down transient analysis. The nodes that are monitored at these critical components are shown in Figure 3-10.

Figure 3-11 gives the plot of the time-history data at the representative nodes of the cask components. Figure 3-12 gives the same data in cask components that are not directly exposed to the fire. The maximum temperature of various components of the cask during the entire transient analysis is presented in Table 3-2. The temperature profile in the cask during the cool-down period is shown in Figure 3-13. The temperature profile of the cask cavity at the time when its internal contents attain the maximum temperature is shown in Figure 3-14. Figure 3-15 shows the temperature profile in the cask body with the damage to the fire shield caused during the puncture drop.

The scenario in which the hollow central portion of the impact limiters is breached during the puncture drop test that precedes the fire test has been analyzed in Energy*Solutions* document TH-0002 (Reference 3-11). In Reference 3-11 a finite element model of the secondary lid with the thermal shield is analyzed for the HAC fire test. The finite element model is reproduced in Figure 3-13. The temperature time-history plot of the representative seal locations is shown in Figure 3-14. Figure 3-15 shows the temperature contour plot of the secondary lid with the thermal-shield at the time when the seal temperature attains the maximum value.

The scenario in which the thermal-shield is also damaged during the puncture drop test is also addressed in Reference 3-11. An axisymmetric finite element model has been used to evaluate the maximum seal temperatures in the damaged condition. The finite element model is reproduced in Figure 3-16. The temperature time-history plot of the representative seal locations is shown in Figure 3-17. Figure 3-18 shows the temperature contour plot of the secondary lid with the damaged thermal-shield at 5,400 seconds after the fire initiation of the fire.

The maximum internal pressure of the cask is calculated assuming that the gas within the cask, a mixture of air, water vapor, oxygen, and hydrogen, behaves as an ideal gas. The average temperature of the air inside the cask is obtained from Energy*Solutions* document TH-0001 (Reference 3-12). In this document the HAC fire analysis of the 8-120B Cask is performed with the assumption that the lower hollow portion of the impact limiter has been breached during the puncture drop test that precedes the HAC fire test. Consequently, a portion of the baseplate is directly exposed to the fire, which results in the highest temperature of the cask cavity. The average cask air temperature calculated in Reference 3-11 is 266°F.

The gas mixture temperature in the cavity is conservatively assumed to be 275°F. Assuming 32.3 psia (see Section 3.3.2) exists inside the cask at 200°F, the pressure in the cask at 275°F, P_2, may be calculated by the ideal gas relationship:

$$P_2 = \frac{T_2}{T_1} \cdot P_1 \text{, where T is in degrees absolute}$$

$$P_2 = 35.9 \text{ psia}$$

The vapor pressure contributed by water in the cavity at 275°F is 45.4 psia (interpolated from the table Vapor Pressure of Water from 0 to 370 °C , page 6-15, from Reference 3-4, a copy of the table is attached as Attachment 3A).

Therefore, the maximum pressure during the HAC fire,

$$P_{max} = 35.9 + 45.4 - 14.7 = 66.62 \text{ psig}$$

The value used for P_{max} is conservatively set at 155 psig.

3.4.4 MAXIMUM THERMAL STRESSES

The structural evaluation of the package under the HAC fire test conditions is performed in Section 2.7.4 of this SAR. The maximum thermal stresses in the package with the corresponding allowable stresses are compared in Table 2-23. All the stresses are within the design limits established for the 8-120B package.

3.4.5 ACCIDENT CONDITIONS FOR FISSILE PACKAGES FOR AIR TRANSPORT

Not applicable.

3.5 APPENDIX

3.5.1 LIST OF REFERENCES

(3-1) Code of Federal Regulations, Title 10, Part 71, Packaging and Transportation of Radioactive Material.

(3-2) Heat Transfer, J.P. Holman, McGraw Hill Book Company, New York, Fifth Edition, 1981.

(3-3) Cask Designers Guide, L.B. Shappert, et. al, Oak Ridge National Laboratory, February 1970, ORNL-NSIC-68.

(3-4) CRC Handbook of Chemistry and Physics, Robert C. Weast and Melvin J. Astel, eds., CRC Press, Inc., Boca Raton, Florida, 62nd ed., 1981.

(3-5) ASME Boiler & Pressure Vessel Code, 2001, Section II, Part D, Materials, The American Society of Mechanical Engineers, New York, NY, 2001.

(3-6) Rohsenow and Hartnett, Handbook of Heat Transfer, McGraw Hill Publication, 1973.

(3-7) ANSYS, Release 12.1, ANSYS Inc., Canonsburg, PA, 2009

(3-8) Energy*Solutions* Document No. TH-027, Rev.0, Steady State Thermal Analyses of the 8-120B Cask Using a 3-D Finite Element Model.

(3-9) RH TRU Payload Appendices Rev. 0, June 2006 U.S. Department of Energy.

(3-10) Energy*Solutions* Document No. TH-028, Rev.0, Hypothetical Fire Accident Thermal Analyses of the 8-120B Cask.

(3-11) Energy*Solutions* Document No. TH-0002, Rev.2, Evaluation of Effectiveness of the Secondary Lid Thermal-Shields for the 8-120B and 10-160B Casks.

(3-12) Energy*Solutions* Document No. TH-0001, Rev.1, HAC Fire Analyses of the 8-120B and 10-160B casks with Ruptured Impact Limiter Ends.

3.5.2 ATTACHMENT

This table gives the vapor pressure of water at intervals of 1° C from the melting point to the critical point.

T/°C	*P*/kPa	*T*/°C	*P*/kPa	*T*/°C	*P*/kPa	*T*/°C	*P*/kPa
0	0.61129	55	15.752	110	143.24	165	700.29
1	0.65716	56	16.522	111	148.12	166	717.83
2	0.70605	57	17.324	112	153.13	167	735.70
3	0.75813	58	18.159	113	158.29	168	753.94
4	0.81359	59	19.028	114	163.58	169	772.52
5	0.87260	60	19.932	115	169.02	170	791.47
6	0.93537	61	20.873	116	174.61	171	810.78
7	1.0021	62	21.851	117	180.34	172	830.47
8	1.0730	63	22.868	118	186.23	173	850.53
9	1.1482	64	23.925	119	192.28	174	870.98
10	1.2281	65	25.022	120	198.48	175	891.80
11	1.3129	66	26.163	121	204.85	176	913.03
12	1.4027	67	27.347	122	211.38	177	934.64
13	1.4979	68	28.576	123	218.09	178	956.66
14	1.5988	69	29.852	124	224.96	179	979.09
15	1.7056	70	31.176	125	232.01	180	1001.9
16	1.8185	71	32.549	126	239.24	181	1025.2
17	1.9380	72	33.972	127	246.66	182	1048.9
18	2.0644	73	35.448	128	254.25	183	1073.0
19	2.1978	74	36.978	129	262.04	184	1097.5
20	2.3388	75	38.563	130	270.02	185	1122.5
21	2.4877	76	40.205	131	278.20	186	1147.9
22	2.6447	77	41.905	132	286.57	187	1173.8
23	2.8104	78	43.665	133	295.15	188	1200.1
24	2.9850	79	45.487	134	303.93	189	1226.9
25	3.1690	80	47.373	135	312.93	190	1254.2
26	3.3629	81	49.324	136	322.14	191	1281.9
27	3.5670	82	51.342	137	331.57	192	1310.1
28	3.7818	83	53.428	138	341.22	193	1338.8
29	4.0078	84	55.585	139	351.09	194	1368.0
30	4.2455	85	57.815	140	361.19	195	1397.6
31	4.4953	86	60.119	141	371.53	196	1427.8
32	4.7578	87	62.499	142	382.11	197	1458.5
33	5.0335	88	64.958	143	392.92	198	1489.7
34	5.3229	89	67.496	144	403.98	199	1521.4
35	5.6267	90	70.117	145	415.29	200	1553.6
36	5.9453	91	72.823	146	426.85	201	1586.4
37	6.2795	92	75.614	147	438.67	202	1619.7
38	6.6298	93	78.494	148	450.75	203	1653.6
39	6.9969	94	81.465	149	463.10	204	1688.0
40	7.3814	95	84.529	150	475.72	205	1722.9
41	7.7840	96	87.688	151	488.61	206	1758.4
42	8.2054	97	90.945	152	501.78	207	1794.5
43	8.6463	98	94.301	153	515.23	208	1831.1
44	9.1075	99	97.759	154	528.96	209	1868.4
45	9.5898	100	101.32	155	542.99	210	1906.2
46	10.094	101	104.99	156	557.32	211	1944.6
47	10.620	102	108.77	157	571.94	212	1983.6
48	11.171	103	112.66	158	586.87	213	2023.2
49	11.745	104	116.67	159	602.11	214	2063.4
50	12.344	105	120.79	160	617.66	215	2104.2
51	12.970	106	125.03	161	633.53	216	
52	13.623	107	129.39	162	649.73	217	
53	14.303	108	133.88	163	666.25	218	
54	15.012	109	138.50	164	683.10	219	

Attachment 3A
Vapor Pressure of Water from 0° to 370° C

Table 3-1 - Summary of Maximum NCT Temperatures

Component	**Maximum Calculated Temp.**		**Maximum Allowable Temperature (°F)**
	Location (Node Nos.)	**Value (°F)**	
Fire Shield	40,028	160.6	185(1)
Outer Shell	1,376	161.3	(2)
Inner Shell	10,521	161.5	(2)
Lead	14,411	161.4	622(3)
Baseplate	2,430	162.3	(2)
Primary Lid	37,675	162.2	(2)
Secondary Lid	27,023	162.6	(2)
Primary Seal	25,430	161.6	180(5)
Secondary Seal	37,678	162.2	180(5)
Vent Seal	34,802	161.8	180(5)
Impact Limiter	27,594	161.9	(2)
Cask Cavity	2,029	197.87	(4)
Waste Container	2,041	197.92	(2)

NOTES:

(1) Based on the requirements of 10CFR71.43(g)

(2) Set by stress conditions.

(3) Melting point of lead.

(4) Used for establishing the cask maximum normal operating pressure (MNOP).

(5) Established based on the maximum calculated temperature.

Table 3-2 - Summary of Maximum Hypothetical Fire Temperatures

Component	Maximum Calculated Temp.			Maximum Allowable Temperature (°F)
	Location (Node Nos.)	Time (Sec.)	Value (°F)	
Fire Shield	42,910	1,800	1,392	N.A
Outer Shell	12,531	1,800.3	464.4	800
Inner Shell	8,015	4,461.7	295.5	800
Lead	14,338	4,461.7	295.8	622(1)
Baseplate	2,430	936.48	206.3	800
Primary Lid	37,675	612.66	202.9	800
Secondary Lid	27,023	1,566.13	192.6	800
Primary Lid Seals	25,430	18,225	212.4	235(2)
Secondary Lid Seals	-	-	338(7)	340(2)
Vent Seal	34,802	24,000	206.9	235(2)
Impact Limiter	27,594	24,000	205.1	500(4)
Cask Cavity	(3)	1,800	320.5	(5)
Waste Contents	2,013	40,289	239.7	(6)

NOTES:

(1) Lead melting point temperature.
(2) Established from the maximum calculated temperature.
(3) Obtained from the temperature contour plot. See Figure 19.
(4) Temperature at which the foam material shows 0% thermal decomposition. Obtained from the General Plastics' sales brochure.
(5) Temperature used for calculating the cavity pressure.
(6) Waste contents temperature is obtained for reference purpose.
(7) Obtained from Reference 3-11.

Table 3-3 - Summary of Maximum Pressures during NCT and HAC Fire Test

Condition	Maximum Pressure (psig)	Reference
NCT	35.0	Section 3.3.2
HAC Fire Test	155	Section 3.4.3

Table 3-4 - Temperature-Independent Metal Thermal Properties

Material	**Property**	**Reference: Page**	**Value**
Steel	Density	4: 536	0.2824 lb/in^3
	ε (Outside)	2: 648	0.8
	ε (Inside)	5:133	0.15
Lead	Density	4: 535	0.4109 lb/in^3
	Spec. Heat	4: 535	0.0311 Btu/lb-°F
	Melting Point	6: B-29	621.5 °F

Table 3-5 - Temperature-Dependent Metal Thermal Properties

Temp. (°F)	**Stainless Steel** (Ref. 7)		**Carbon Steel** (Ref.7)		**Lead** (Ref.8)
	Sp. Heat Btu/lb-°F	**Conductivity** ×10^{-3} Btu/sec-in-°F	**Sp. Heat** Btu/lb-°F	**Conductivity** ×10^{-3} Btu/sec-in-°F	**Conductivity** ×10^{-3} Btu/sec-in-°F
70	0.117	0.199	0.104	0.813	0.465
100	0.117	0.201	0.106	0.803	0.461
150	0.120	0.208	0.109	0.789	0.455
200	0.122	0.215	0.113	0.778	0.448
250	0.125	0.222	0.115	0.762	0.441
300	0.126	0.227	0.118	0.748	0.435
350	0.128	0.234	0.122	0.731	0.428
400	0.129	0.241	0.124	0.715	0.422
450	0.130	0.245	0.126	0.701	0.415
500	0.131	0.252	0.128	0.683	0.409
550	0.132	0.257	0.131	0.667	0.402
600	0.133	0.262	0.133	0.648	0.395
650	0.134	0.269	0.135	0.632	0.389
700	0.135	0.273	0.139	0.616	0.389
750	0.136	0.278	0.142	0.600	0.389
800	0.136	0.282	0.146	0.583	0.389
900	0.138	0.294	0.154	0.551	0.389
1,000	0.139	0.306	0.163	0.519	0.389
1,100	0.141	0.315	0.172	0.484	0.389
1,200	0.141	0.324	0.184	0.451	0.389
1,300	0.143	0.336	0.205	0.417	0.389
1,400	0.144	0.345	0.411	0.380	0.389
1,500	0.145	0.354	0.199	0.363	0.389

Table 3-6 - Temperature-Dependent Air Thermal Properties

Temp. (°F)	**Air** (Ref.4)		
	Density $\times 10^{-5}$ lb/in^3	**Sp. Heat** Btu/lb-°F	**Conductivity** $\times 10^{-7}$ Btu/sec-in-°F
70	4.3507	0.2402	3.4491
100	4.1117	0.2404	3.5787
150	3.7517	0.2408	3.9028
200	3.4676	0.2414	4.1759
250	3.2361	0.2421	4.4468
300	3.0307	0.2429	4.7037
350	2.8310	0.2438	4.9560
400	2.6730	0.2450	5.2037
450	2.5220	0.2461	5.4491
500	2.3964	0.2474	5.6875
550	2.2778	0.2490	5.9213
600	2.1684	0.2511	6.1435
650	2.0706	0.2527	6.3634
700	1.9803	0.2538	6.5810
750	1.8981	0.2552	6.7894
800	1.8177	0.2568	6.9954
900	1.6898	0.2596	7.4097
1,000	1.5712	0.2628	7.8032
1,100	1.4722	0.2659	8.1759
1,200	1.3848	0.2689	8.5440
1,300	1.3044	0.2717	8.8981
1,400	1.2350	0.2742	9.2847
1,500	1.1707	0.2766	9.7060

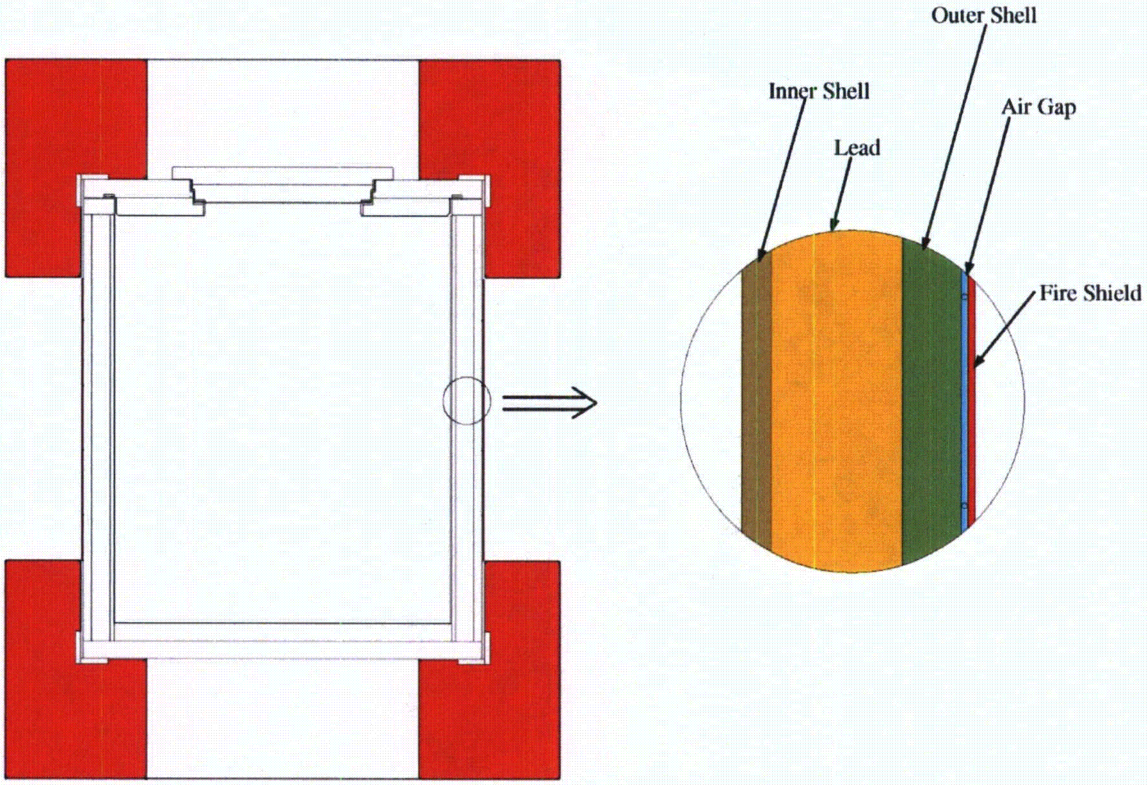

Figure 3-1 - 8-120B Cask Design Features Important to Thermal Performance

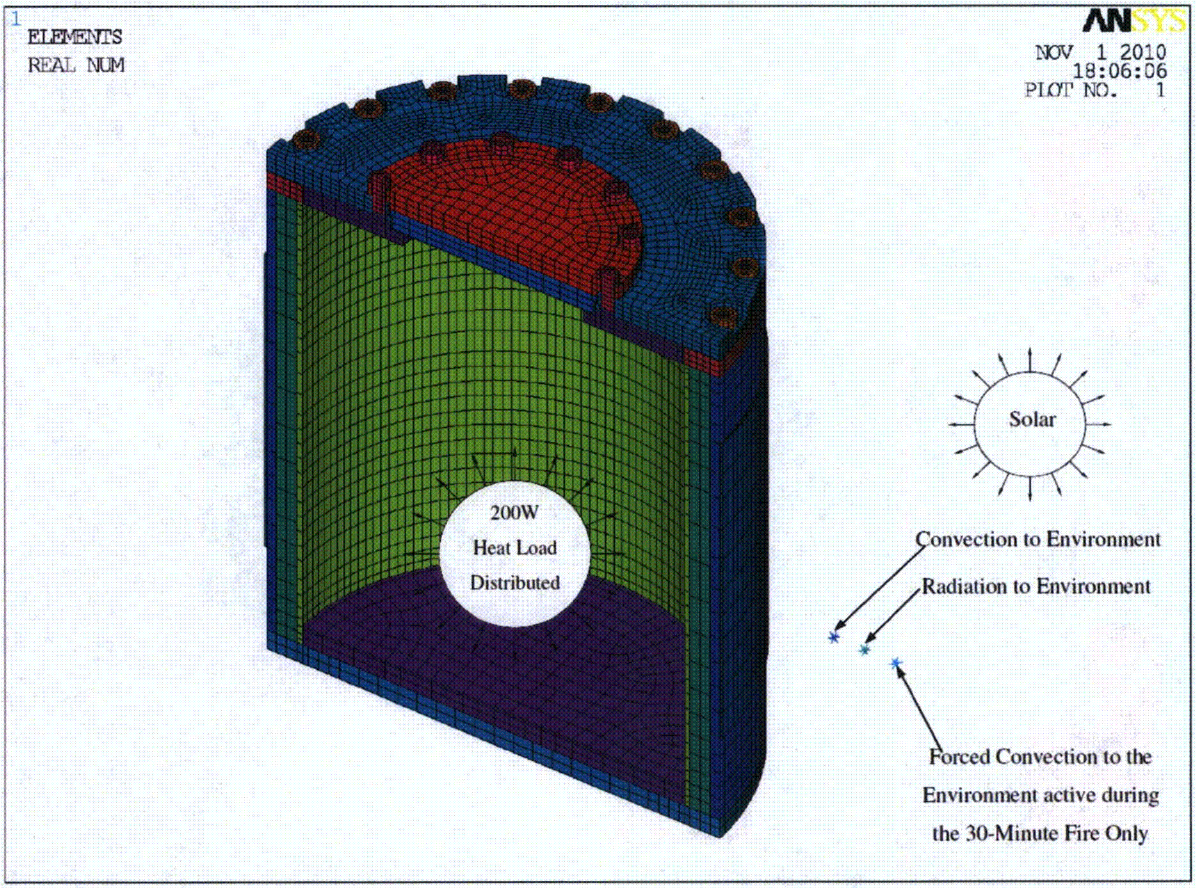

Figure 3-2 - Finite Element Model of the 8-120B Cask Used for the Thermal Analyses

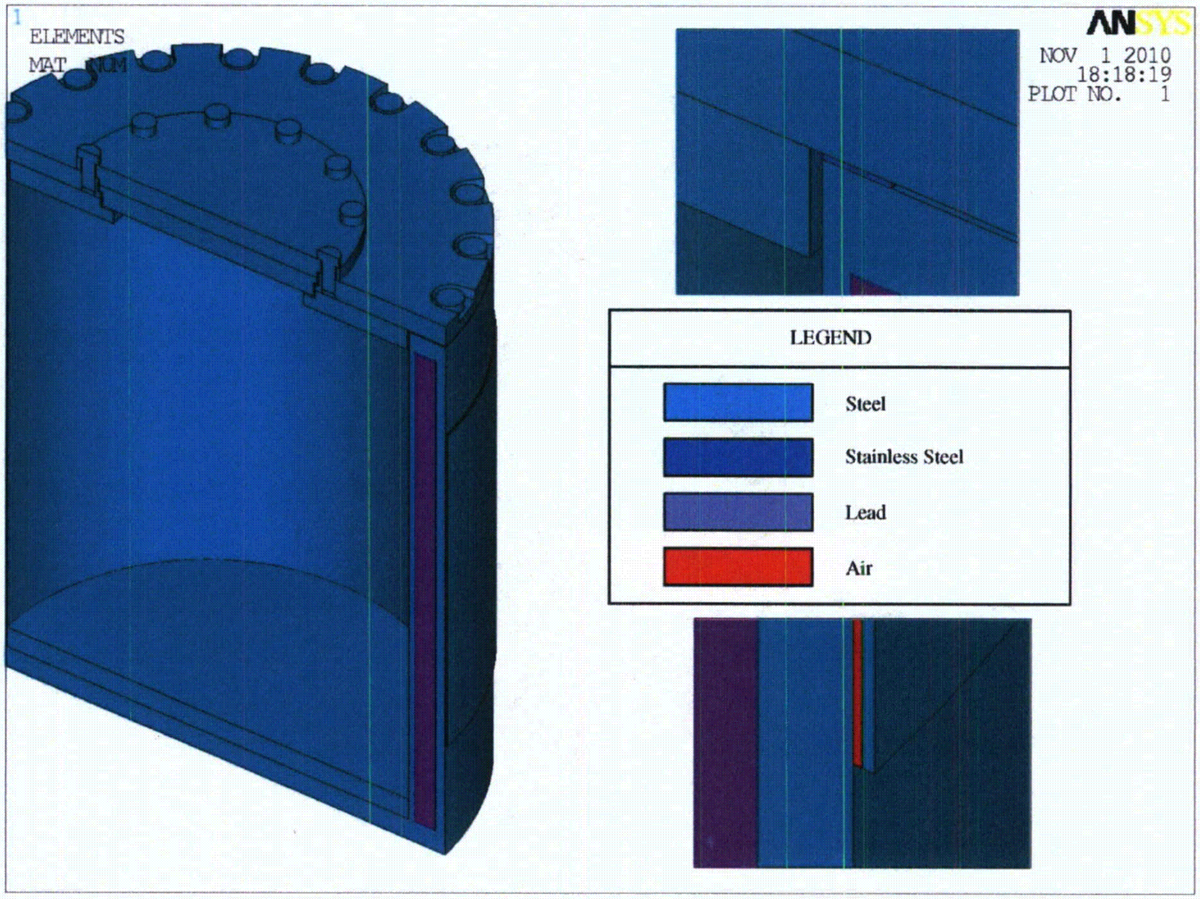

Figure 3-3 - Materials Used in the Finite Element Model

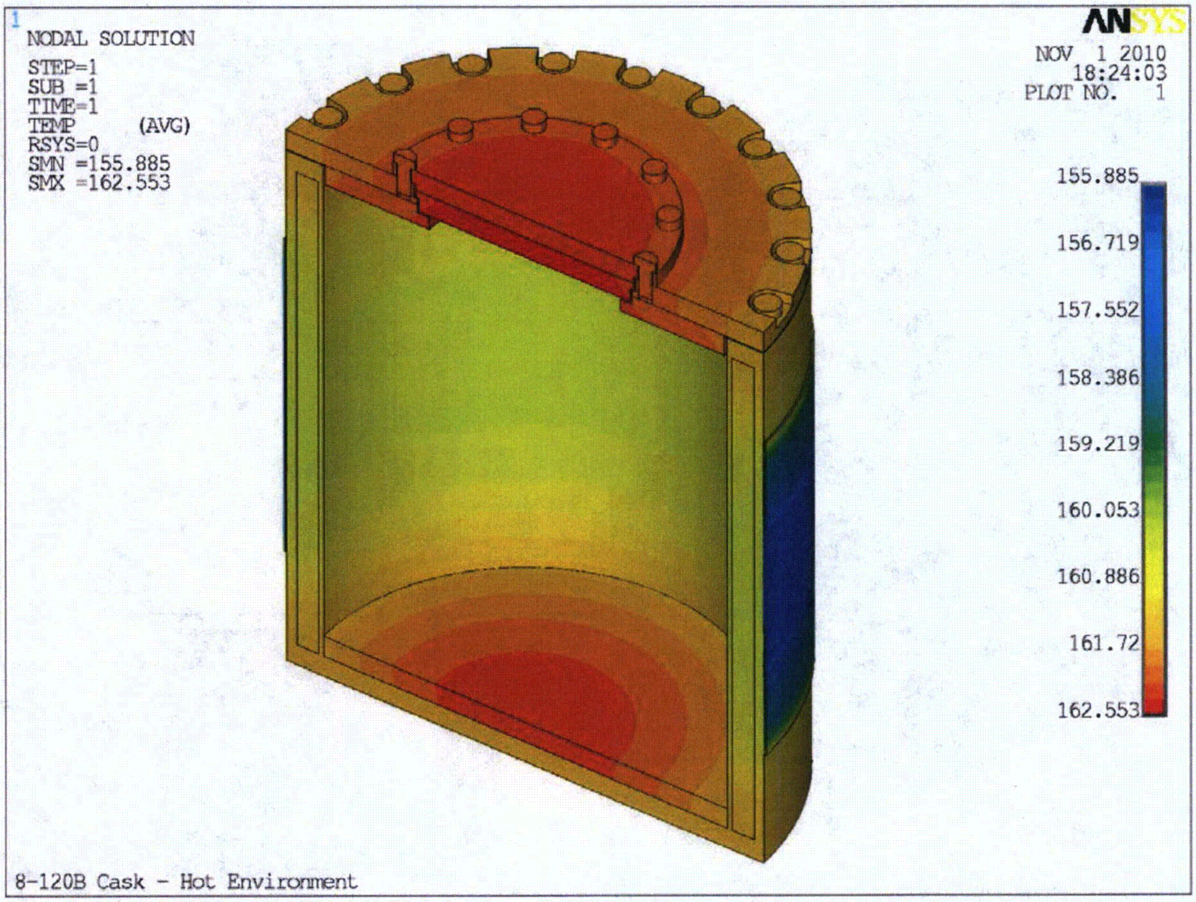

Figure 3-4 - Temperature Distribution – Hot Environment

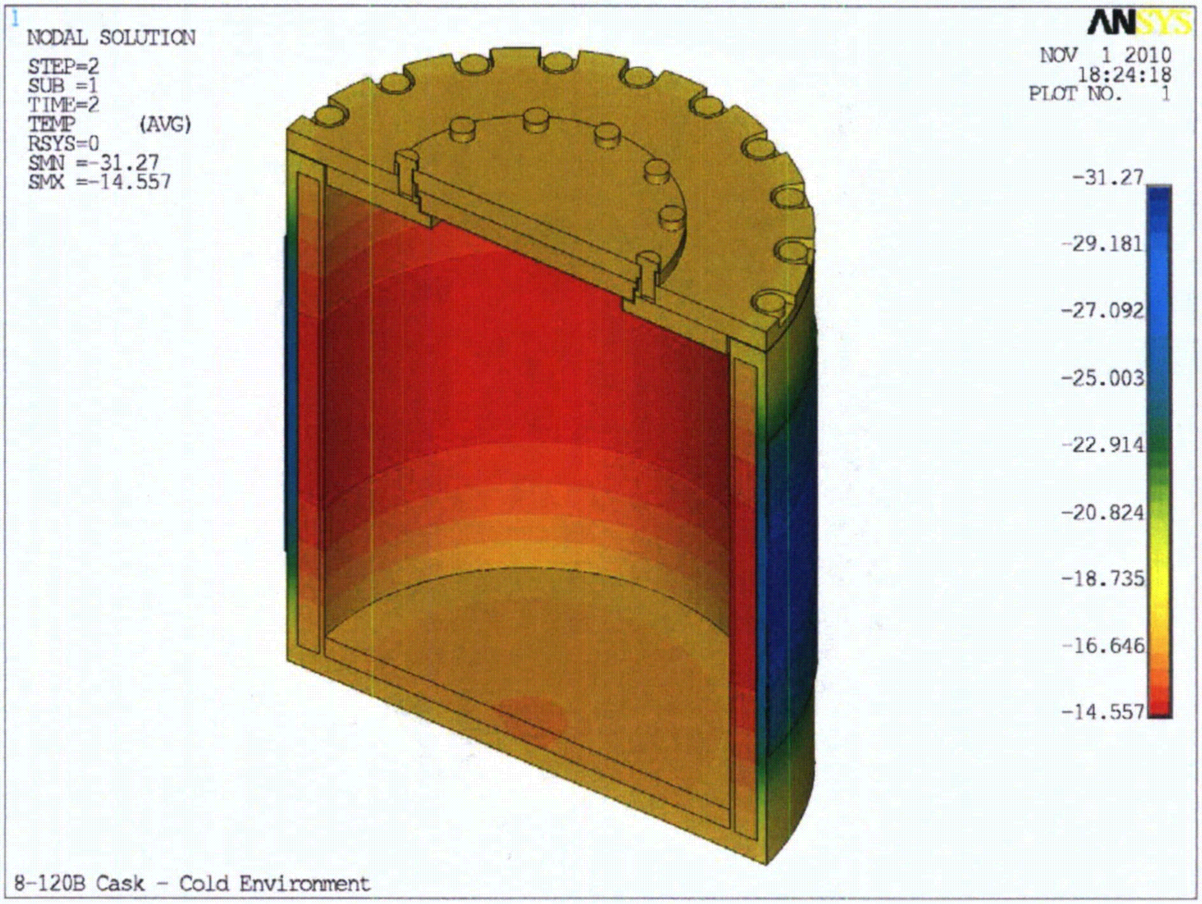

Figure 3-5 - Temperature Distribution – Cold Environment

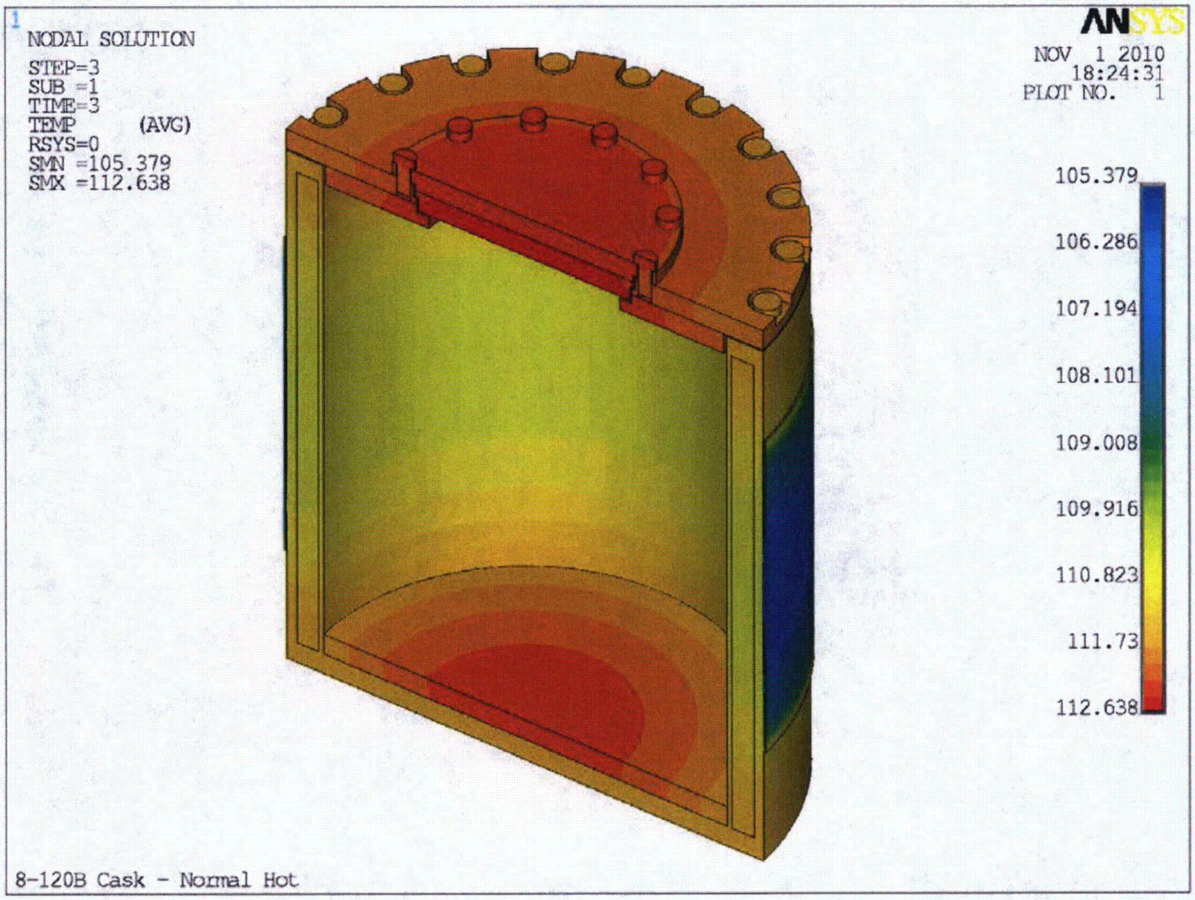

Figure 3-6 - Temperature Distribution – Normal Hot

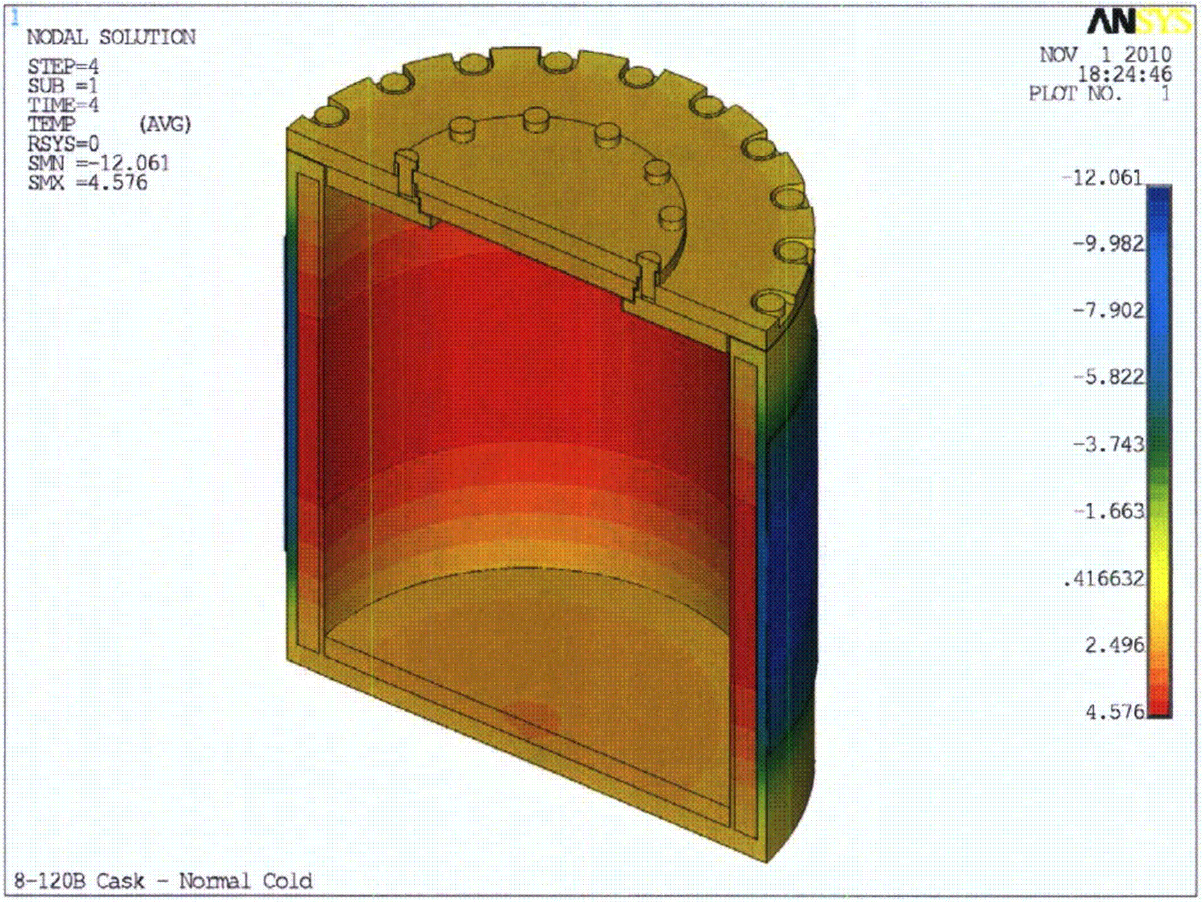

Figure 3-7 - Temperature Distribution – Normal Cold

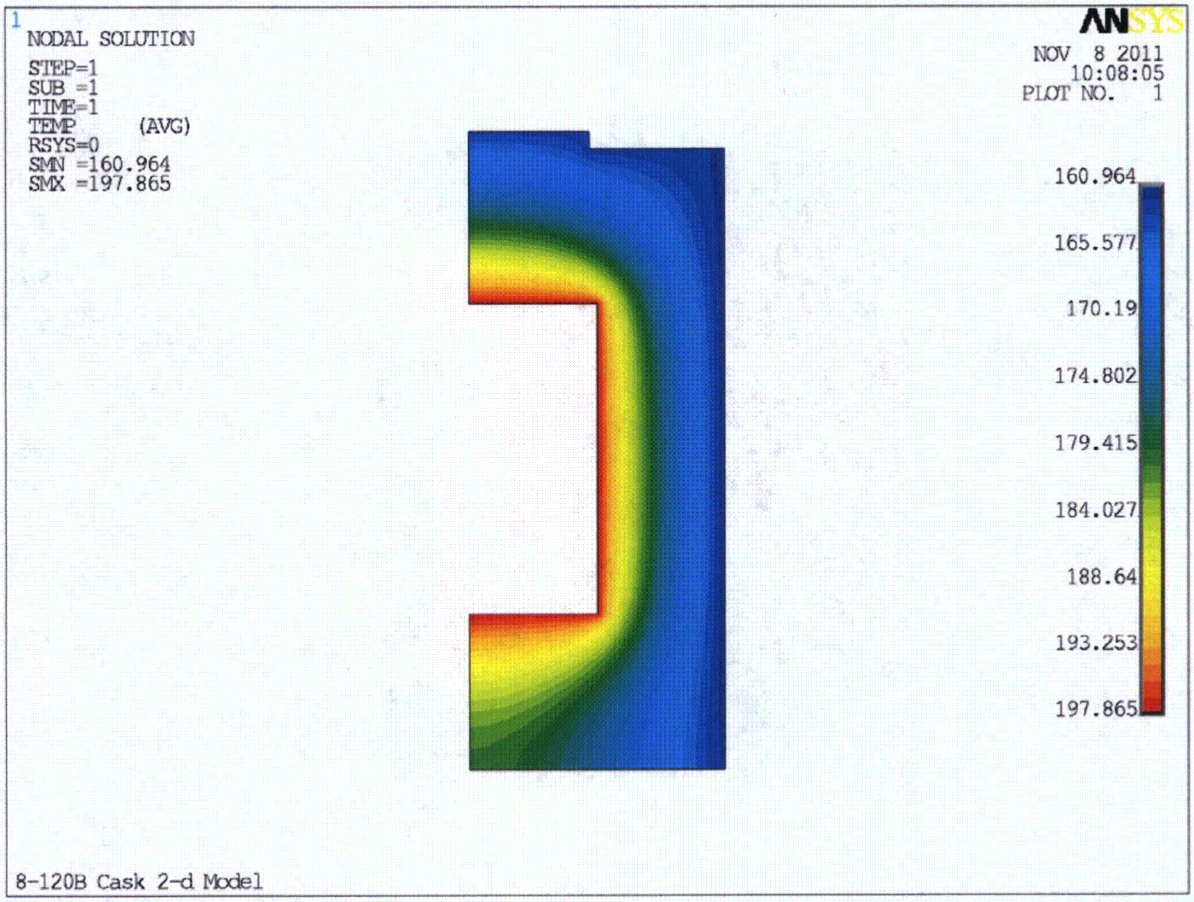

Figure 3-8 - Temperature Distribution in the Cask Cavity– Hot Environment

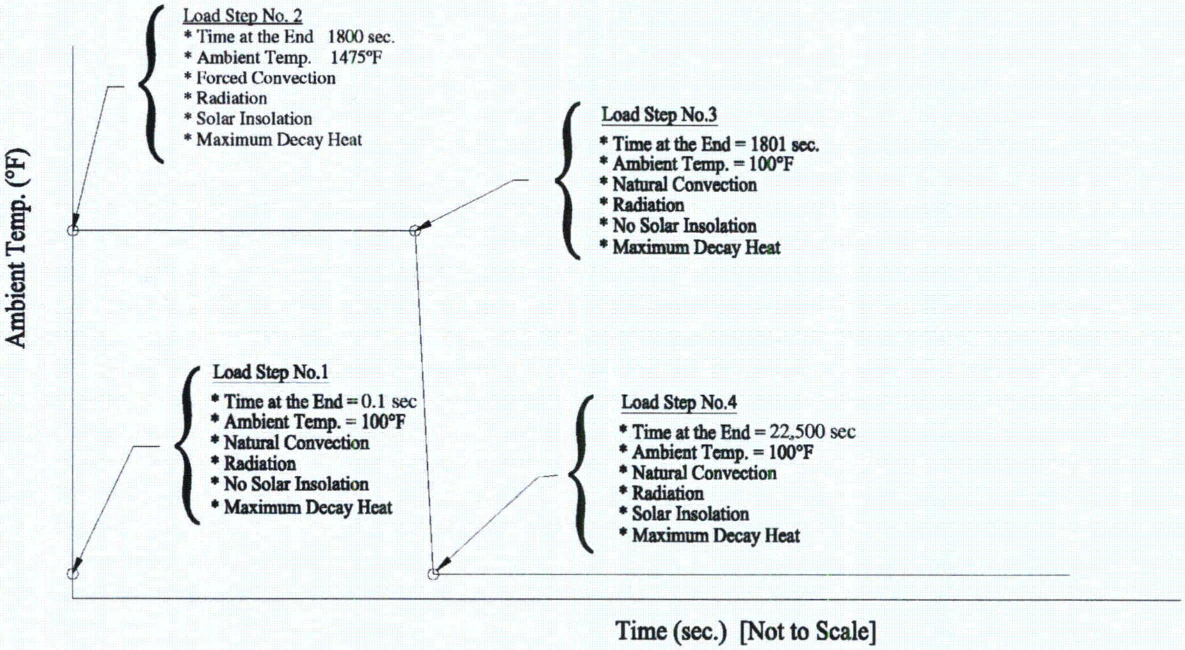

Figure 3-9 - HAC Fire Analysis Load Steps and Boundary Conditions

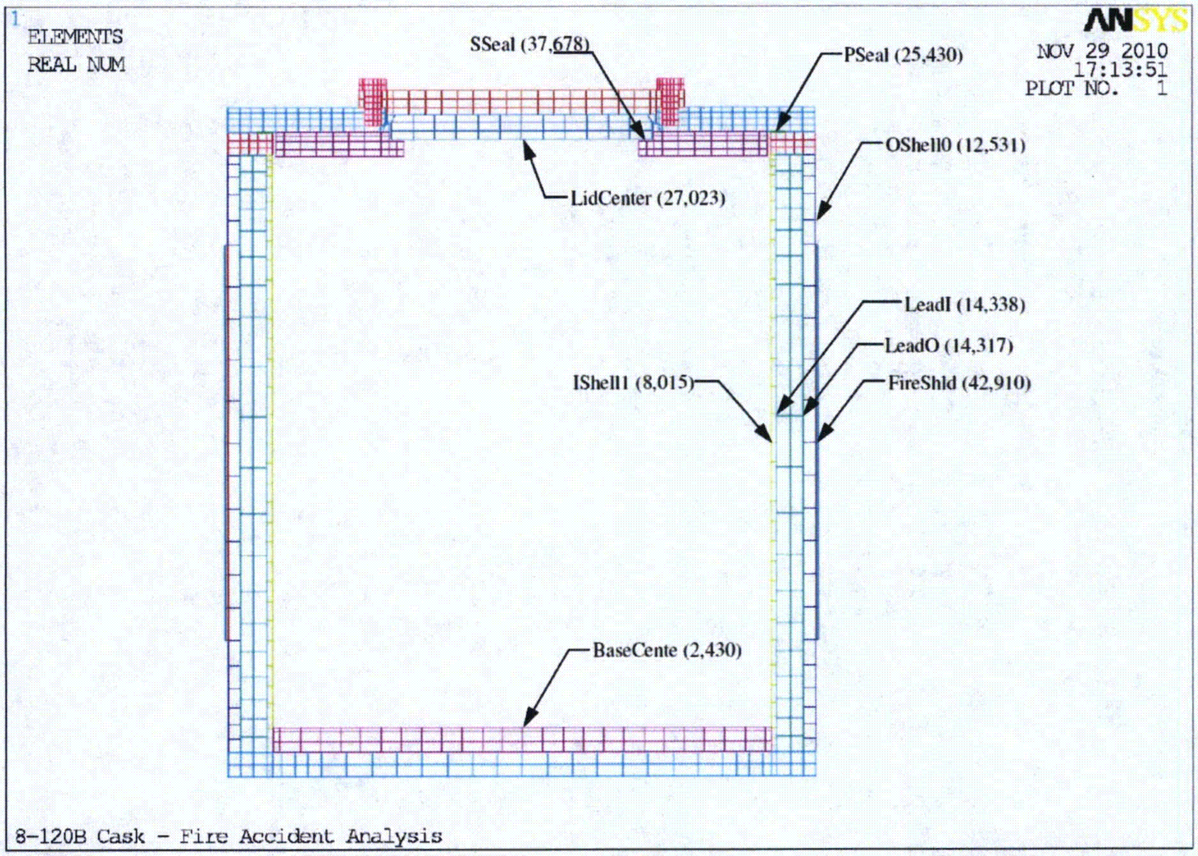

Figure 3-10 - Identification of the Nodes where Time-History is Monitored

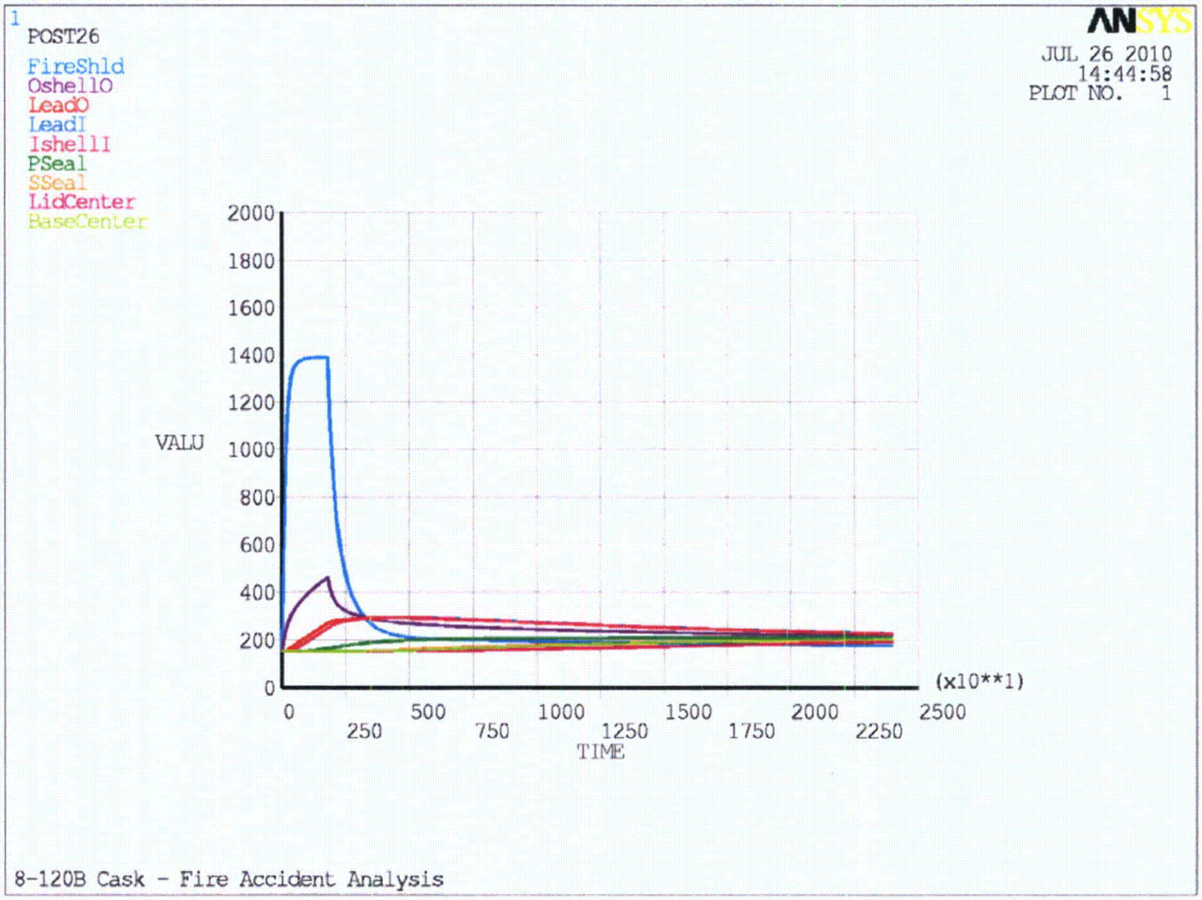

Figure 3-11 - Temperature Time-History Plot in Various Components of the Cask

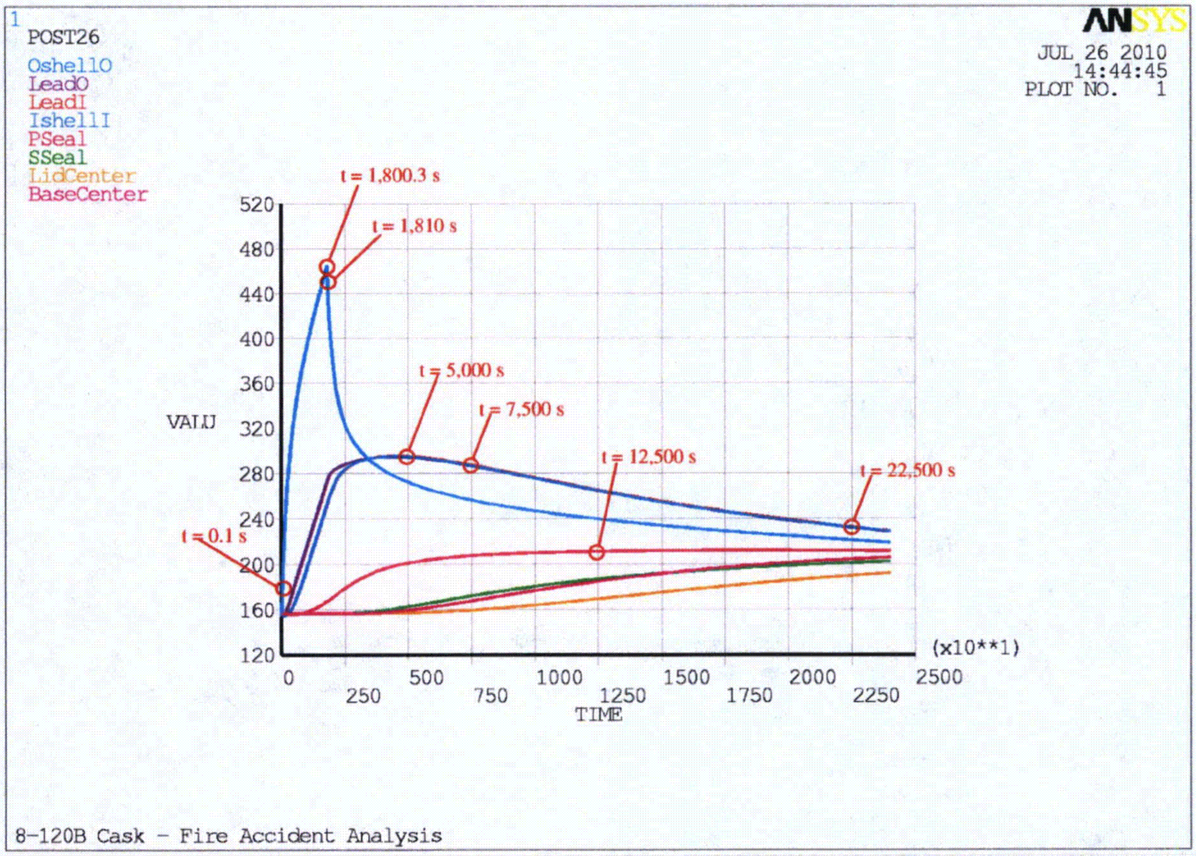

Figure 3-12 - Temperature Time-History Plot in Various Components of the Cask

(Not Under Direct Contact with the Fire)

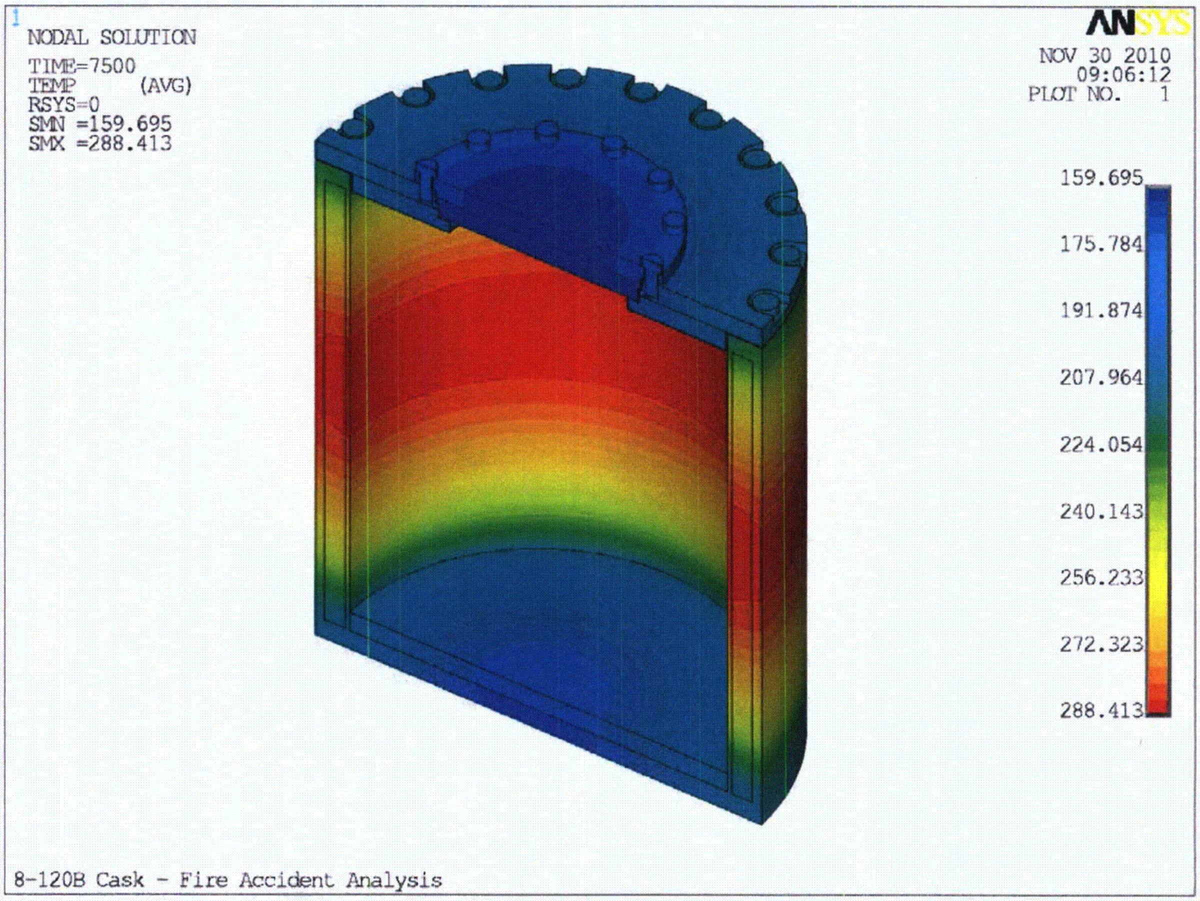

Figure 3-13 - Temperature Distribution – 7,500 Sec. After the Start of the Fire

(Please refer to Reference 3-10 for temperature contour plots at various other times)

(From 2-d Model)

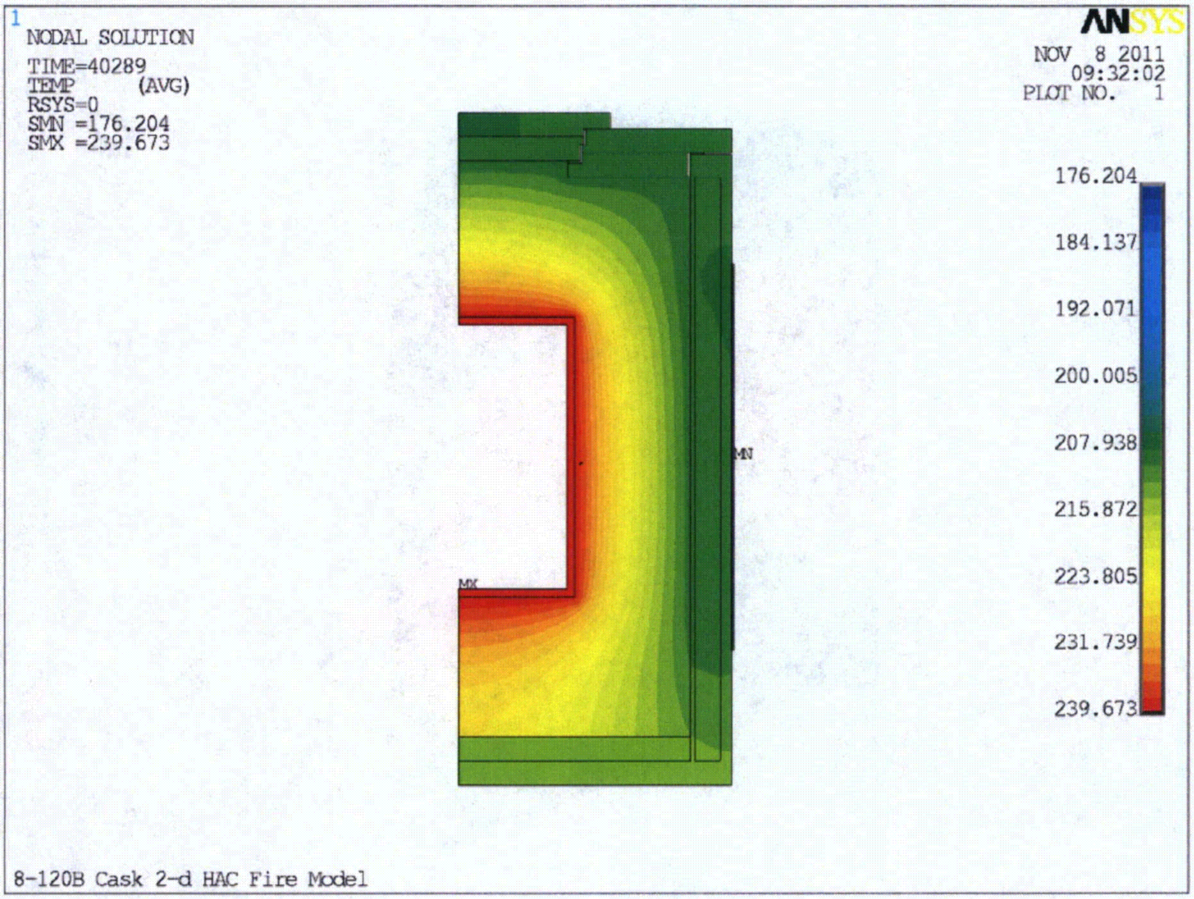

Figure 3-14 - Temperature Distribution in the Cask Cavity – 40,289 Sec. After the Start of the Fire

(From 2-d Model)

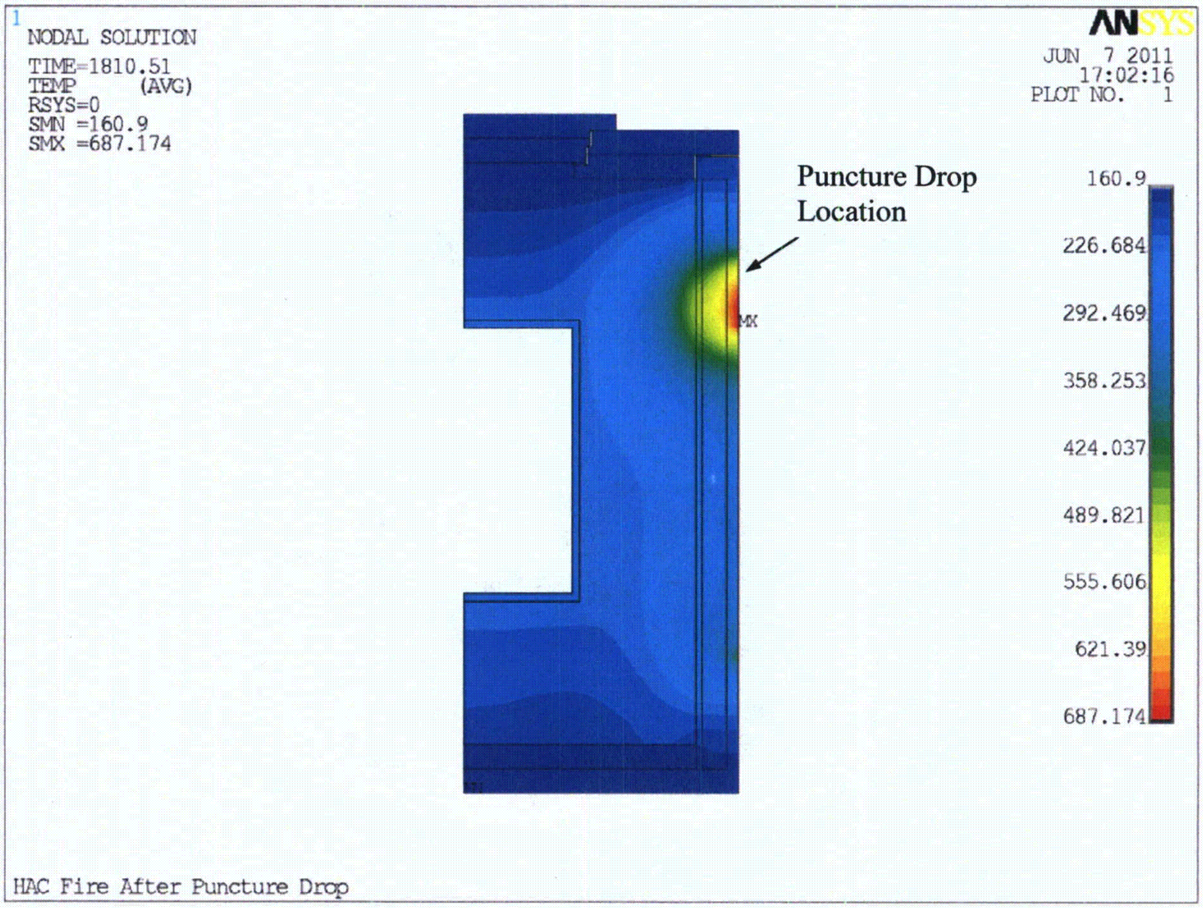

Figure 3-15 - Temperature Distribution in the Cask with Puncture Drop Damage – 7,500 Sec. After the Start of the Fire

(From 2-d Model)

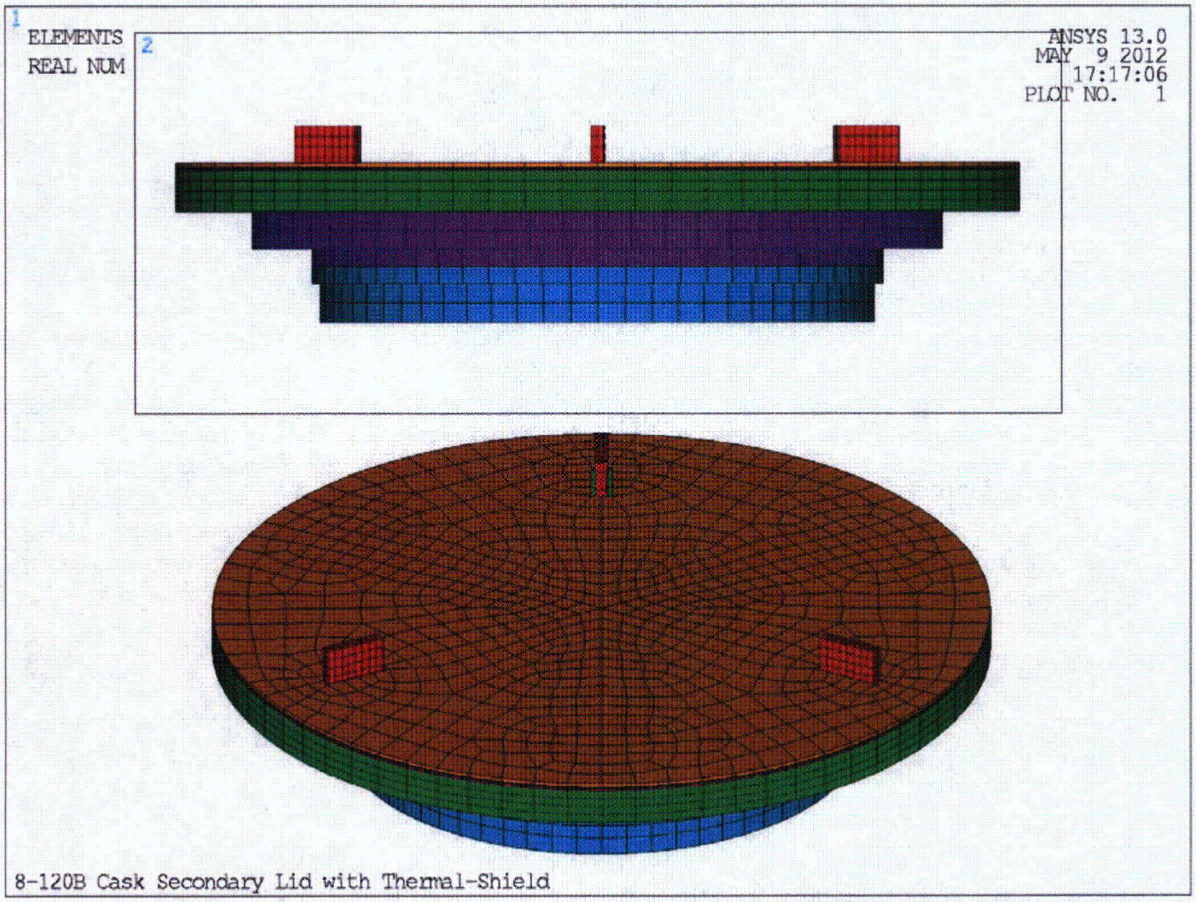

Figure 3-16 - 8-120B Cask Secondary Lid with Thermal-Shield - Complete FEM

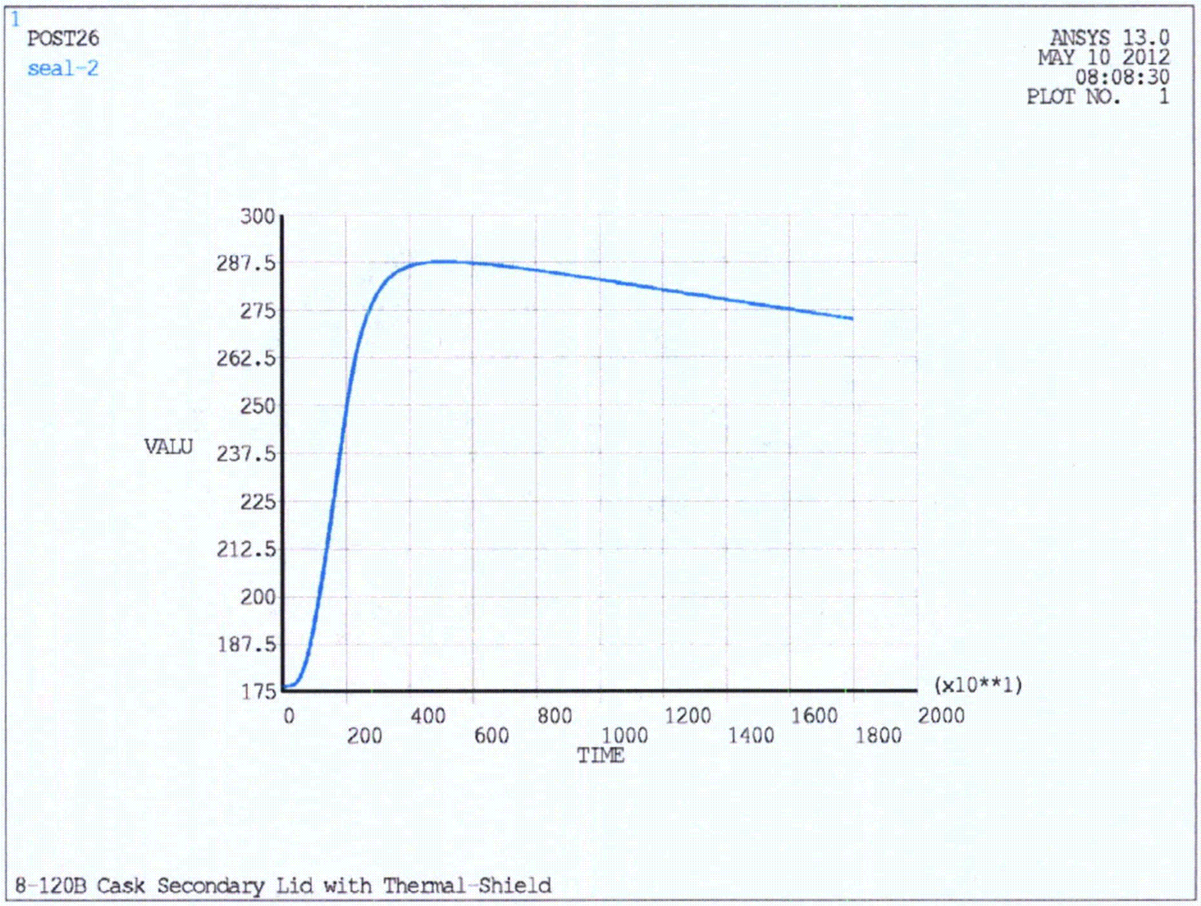

Figure 3-17 - 8-120B Cask Secondary Lid Seal Temperature Time-History Plot – With Thermal-Shield

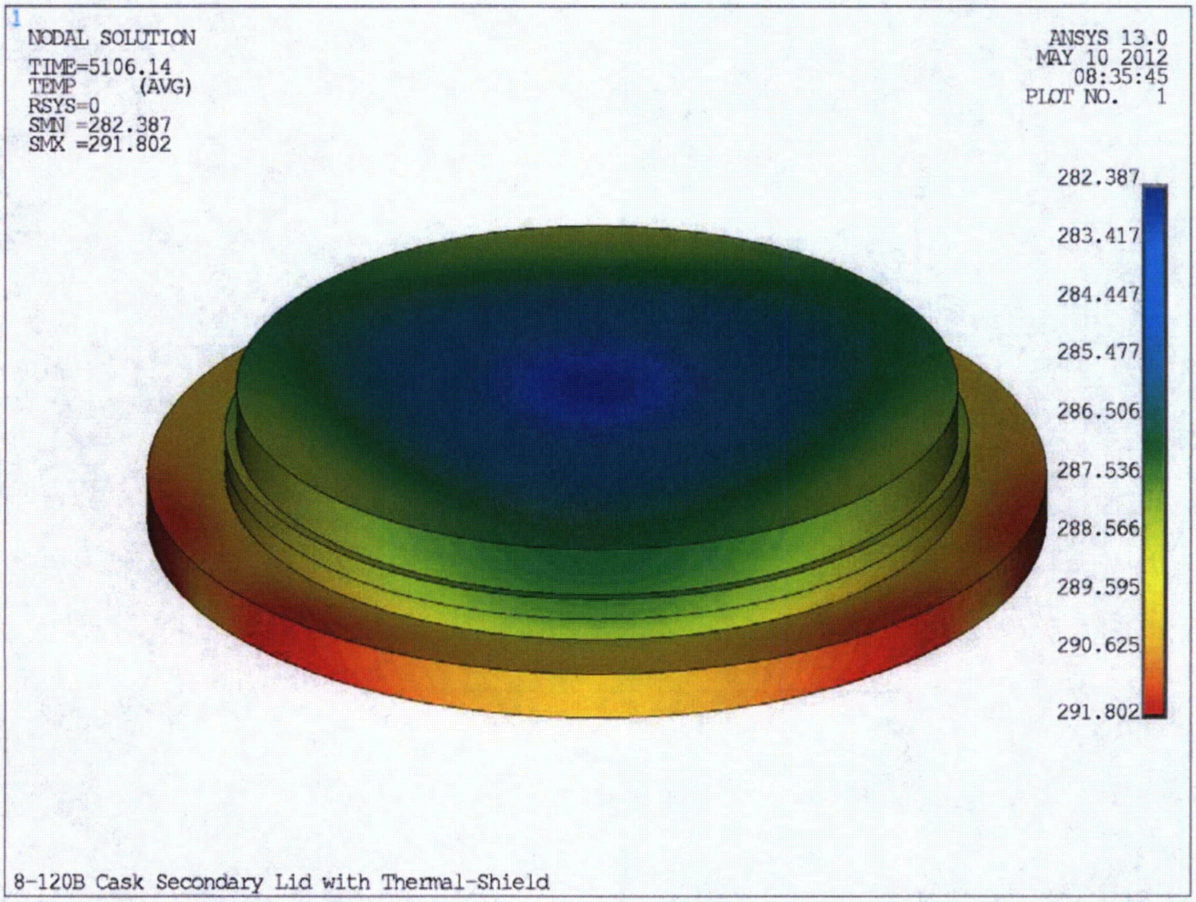

Figure 3-18 - 8-120B Cask Secondary Temperature Contour Plot at the Time When the Secondary Lid Seal Reaches the Peak Value - With Thermal-Shield

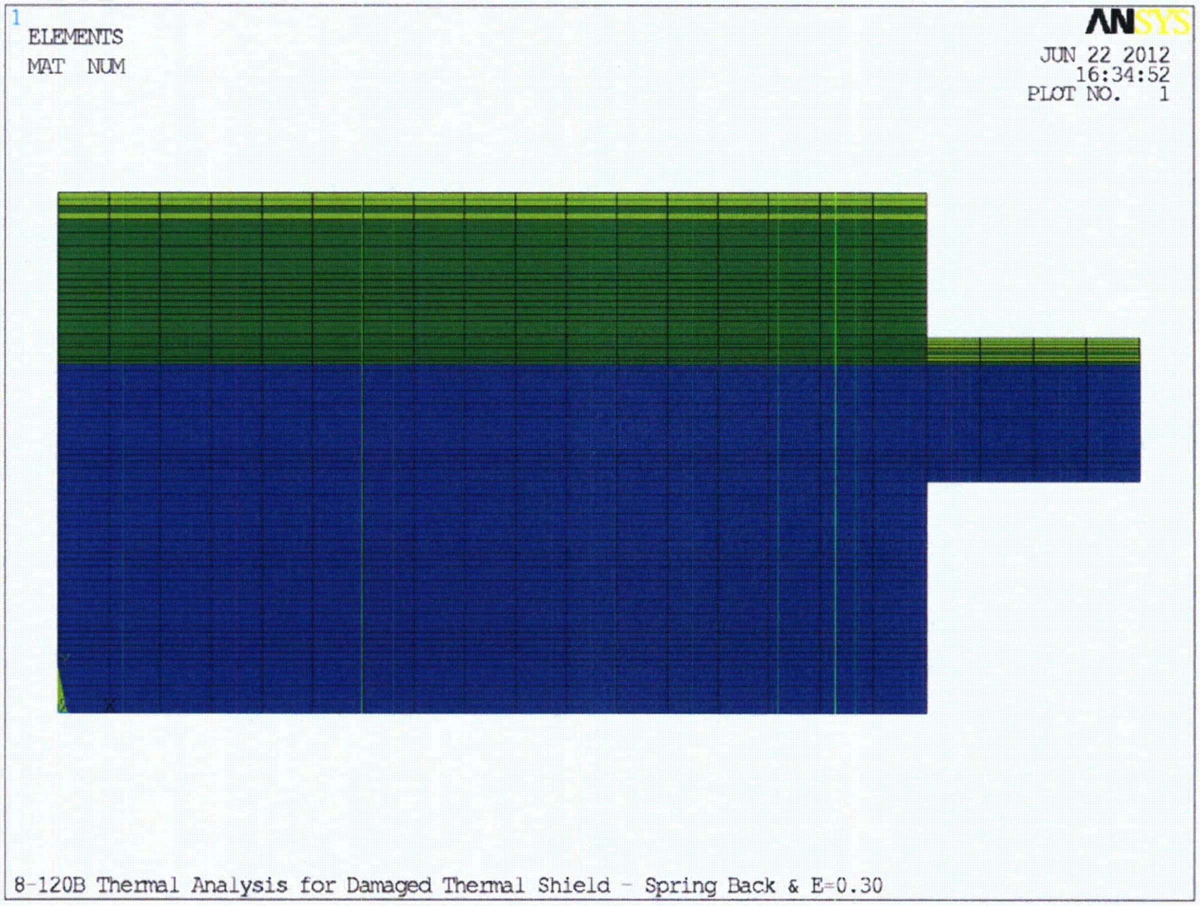

Figure 3-19 - 8-120B Cask Secondary Lid with Thermal-Shield (Damaged) – FEM

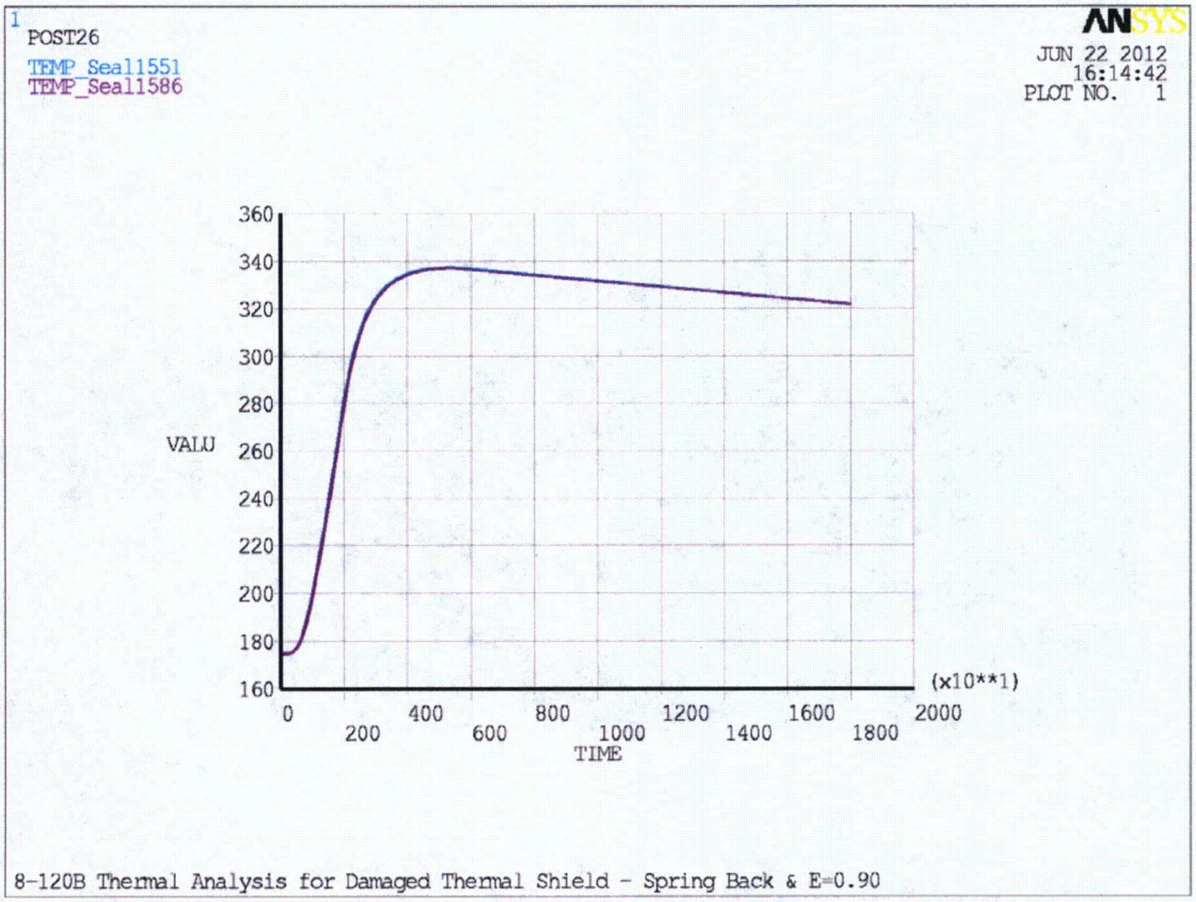

Figure 3-20 - 8-120B Cask Secondary Lid Seal Temperature Time-History Plot – With Thermal-Shield (Damaged)

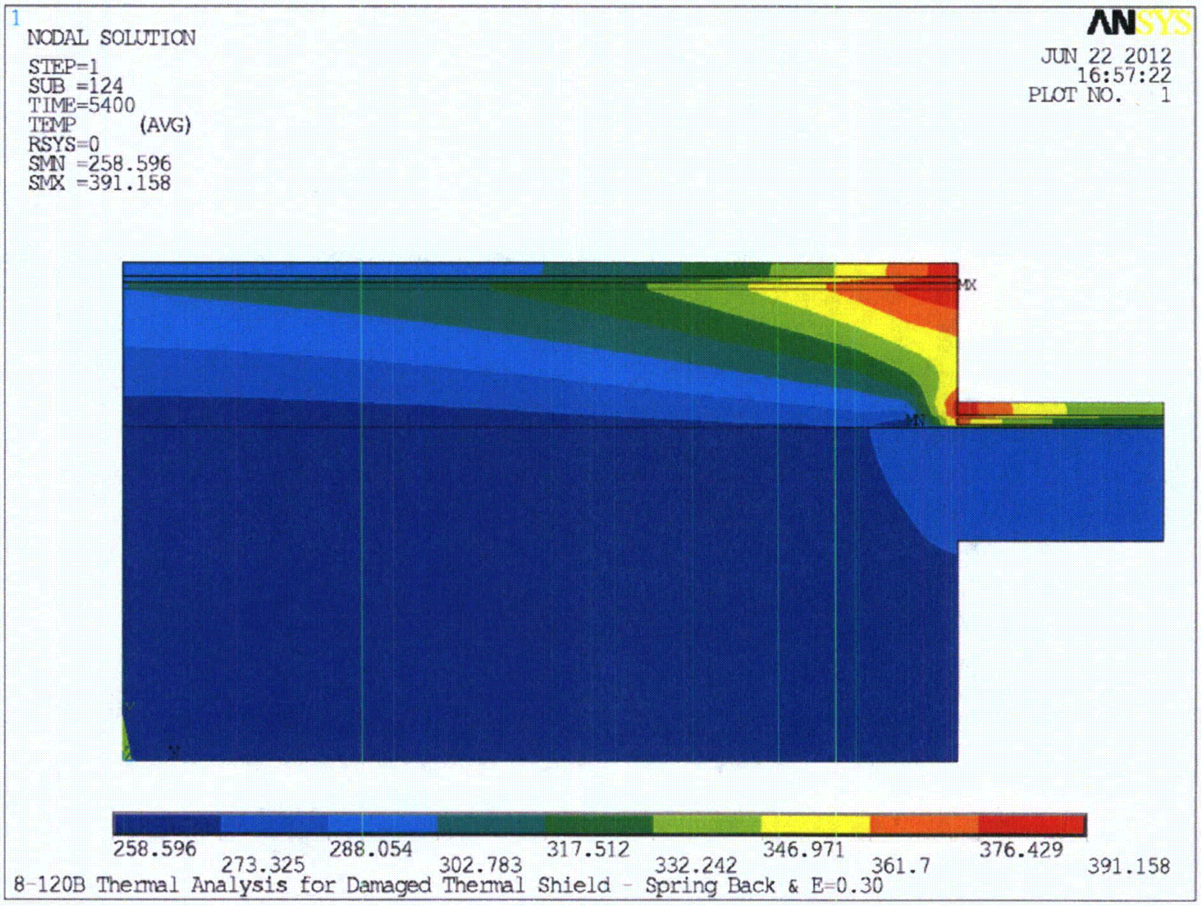

Figure 3-21 - 8-120B Cask Secondary Temperature Contour Plot at 5,400 Seconds after the Initiation of Fire

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4.0 CONTAINMENT

This chapter describes the containment configuration of the Model 8-120B Package for Normal Transport and Hypothetical Accident Conditions.

4.1 DESCRIPTION OF CONTAINMENT SYSTEM

4.1.1 CONTAINMENT VESSEL

The package containment vessel is defined as the inner shell of the shielded transport cask, together with the associated lid, o-ring seals and lid closure bolts. The inner shell of the cask or containment vessel consists of a right circular cylinder of 62 inches inner diameter and 75 inches inside height. The shell is fabricated of ¾" thick carbon steel plate, ASTM A516-70. At the base, the cylindrical shell is attached to a circular end plate with full penetration welds. The primary lid is attached to the cask body with twenty (20) equally spaced 2-8 UN bolts. A secondary lid covers an opening in the primary lid and is attached to the primary lid using twelve (12) equally spaced 2-8 UN bolts. See Section 4.1.4 for closure details.

4.1.2 CONTAINMENT PENETRATION

There are three penetrations of the containment vessel. These are: (1) the primary lid with the containment boundary of the primary lid's inner o-ring, (2) the secondary lid with the containment boundary of the secondary lid's inner o-ring, and (3) the cask vent port located in the primary lid. A vent port penetrates the primary lid into the main cask cavity. The vent penetration is sealed with a Parker Stat-O-Seal. The primary and secondary lids are sealed with elastomeric o-rings.

4.1.3 WELDS AND SEALS

The containment vessel is fabricated using full penetration groove welds. Seals (vent seal and o-rings) meet the requirements of ES Specification, ES-C-038 [Ref. 4.4].

4.1.4 CLOSURE

The primary lid closure consists of two 3-1/4" thick laminated plates, stepped to fit over and within the top edge of the cylindrical body. The lid is supported at the perimeter of the cylindrical body by a thick plate (bolt ring) welded to the top of the inner and outer cylindrical body walls. This plate contains a 14-gauge stainless steel ring at a location, which corresponds to the sealing surface for the o-rings mounted in the lid. The lid is attached to the cask body by twenty (20) equally spaced 2-8 UN bolts. These bolts are torqued to 500 ft-lbs ± 10 % (lubricated). Two (2) solid elastomeric o-rings are retained in machined grooves at the lid perimeter. Groove dimensions prevent over-compression of the o-rings by the closure bolt pre-load forces and hypothetical accident impact forces. The cask is fitted with a secondary lid of similar construction attached to the primary lid with twelve (12) equally spaced identical bolts. The secondary lid is also sealed with two (2) solid, elastomeric o-rings in machined grooves.

The vent penetration is sealed with a Parker Stat-O-Seal, which is used beneath the heads of the hex head cap screws. Table 4-1 gives the torque values for the cap screws.

Table 4-1 - Bolt and Cap Screw Torque Requirements

Location	Size (in.)	Torque Values (ft-lbs, ± 10% lubricated)
Vent Seal Bolt	1/2	20
Primary Lid	2-8UN	500
Secondary Lid	2-8UN	500

4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

The 8-120B package is designed, fabricated, and leak tested to preclude release of radioactive materials in excess of the limits prescribed in 10CFR71.51(a)(1).

Of the permitted contents discussed in Section 1, two are considered in the following calculations as representative of the various types and forms permitted in the 8-120B; powdered solids and irradiated hardware. In this section and Section 4.2.1 below, the maximum permitted reference leakage rates (as defined in ANSI N14.5 – 1997 [Ref. 4.1]) for normal and hypothetical accident conditions are calculated for powdered solids and irradiated hardware waste forms, and the most restrictive of these (i.e., the smallest leakage rate permitted) is taken as the reference leakage rate for the 8-120B cask and the basis for the acceptance criteria for leak testing. It is shown that the reference leakage rate (L_R) for the 8-120B cask is 1.54×10^{-6} ref-cm^3/sec, and that the release limits specified in 10CFR 71.51(a)(1) are met by limiting the release rate of the 8-120B to less than this value.

As discussed above, the most limiting type of radioactive waste contents permitted in the 8-120B is either powdered solids or irradiated hardware. The maximum permitted volumetric and reference leakage rates for Normal Conditions of Transport (NCT) are calculated for powdered solids and irradiated hardware ($L_{R\_N\_PS}$ and $L_{R\_N\_IH}$, respectively). Similar calculations are performed in Section 4.3 for Hypothetical Accident Conditions (HAC) ($L_{R\_A\_PS}$ and $L_{R\_A\_IH}$, respectively). The most restrictive of these four values is taken to be the maximum permitted reference leakage rate, L_R.

4.2.1 MAXIMUM PERMITTED LEAK RATE

In this section the maximum permitted leakage rate under Normal Conditions of Transport is calculated for the 8-120B package. 10CFR71.51(a)(1) states that the containment requirements for normal conditions of transport are:

> *...no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of* $10^{-6}A_2$ *per hour, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.*

ANSI N14.5-1997 (Ref 4.1) states that the permissible leak rate shall be determined by Equation 4-1 below:

$$\mathrm{L} = \frac{\mathrm{R}}{\mathrm{C}}\ (cm^3/s) \quad (\mathrm{Eqn.}\,4-1)$$

Where:

L = permissible volumetric leak rate ($\mathrm{cm^3/sec}$)

R = package containment requirements (Ci/sec)

C = activity per unit volume of the medium that could escape from the containment system ($\mathrm{Ci/cm^3}$)

For normal conditions of transport:

$$\mathrm{R_N} = \mathrm{A_2} \times 10^{-6}\,\frac{1}{\mathrm{hr}} \quad \Rightarrow \quad \mathrm{R_N} = 2.78 \times 10^{-10}\,\frac{\mathrm{A_2}}{\mathrm{sec}} \qquad \text{10CFR71}$$

Determine the volume of the 8-120B cavity using dimensions from SAR drawing (Ref. 4.2):

$$\mathrm{L_{cavity}} = 75\ \mathrm{in} \qquad \mathrm{L_{cavity}} = 190.5\ \mathrm{cm}$$

$$\mathrm{D_{cavity}} = 61.8\ \mathrm{in} \qquad \mathrm{D_{cavity}} = 156.972\ \mathrm{cm}$$

The void volume of a typical hardware shipment and a powdered solids shipment are, respectively, 68% and 37% of the cask cavity volume. For leak rate calculations, the void volume ($\mathrm{V_{cavity}}$) is conservatively assumed to be 25% of the cavity volume. Therefore,

$$\mathrm{V_{cavity}} = \frac{(.25)\pi \cdot \mathrm{D_{cavity}}^2 \cdot \mathrm{L_{cavity}}}{4} \quad \Rightarrow \quad \mathrm{V_{cavity}} = 9.217 \times 10^5\ \mathrm{cm^3}$$

In Sections 4.2.2 and 4.2.3 below, the maximum permitted volumetric leak rates under normal conditions of transport ($\mathrm{L_N}$) are calculated for powdered solids and irradiated hardware respectively, and each is then converted into a reference leak rates ($\mathrm{L_{R\_N}}$).

4.2.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT (POWDERED SOLIDS)

Note: The following calculation for $\mathrm{L_{N\_PS}}$ follows the methodology in NUREG/CR-6487 (Ref. 4.3)

$\mathrm{C_{NPS}}$ = concentration of releasable material during normal conditions of transport, $\mathrm{C_i/cm^3}$

ρ = density of powder aerosol, g/cm^3

ρ = 1 x 10^{-6} g/cm^3 from NUREG/CR-6487 (Ref. 4.3)

Assume the mass (M) of the powdered solid is 60 grams and the activity (A) is 3000 A_2.

S_A = specific activity of the releasable material, A_2/g; = A/M = 50 A_2/g
C_{NPS} = $S_AH\rho$

Using Eqn. 4-1:

$$L_{N\_PS} = \frac{R_N}{C_{NPS}}$$

Then,

L_{N_PS} = 5.556 x 10^{-6} cm^3/sec **Maximum permitted volumetric leakage rate, normal conditions, powdered solids under the condition that the mass exceeds 60 grams or SA is less than 50.**

Next, determine the Reference Leakage Rate, $L_{R\_N\_PS}$, normal conditions, powdered solids, for a volumetric leak rate L_{N_PS}:

μ_{air} = 0.0214 cP (Ref. 4.1)

M_{air} = 29.0 gm/mole (Ref. 4.1)

a = 0.6 cm, assumed length for hole leaking air (equals o-ring diameter)

For normal conditions of transport:

T_N = 180°F (from Chapter 3)

MNOP = P_{u_N} = 3.38 atm (from Chapter 3)

P_{u_N} = 3.38 atm

P_{d_N} = 1.0 atm

$$P_{a\_N} = \frac{P_{u\_N} + P_{d\_N}}{2} \quad \Rightarrow \quad P_{a\_N} = 2.19\ atm$$

Use Eqn. B.3, B.4, and B.5 in ANSI N14.5 - 1997. Determine the diameter of a hole, D_{max1} that would leak L_{N_PS}.

L_{N_PS} = 5.56 x 10^{-6} cm/sec (from above)

$$F_{mn}(D_{max}) = \frac{\left[3.8 \times 10^3 \cdot D_{max}{}^3 \cdot \sqrt{\frac{T_N}{M_{air}}}\right]}{a \cdot P_{a\_N}} \; (cm^3/atm \cdot sec) \;\; (\text{Eqn. B.4 of ANSI N14.5} - 1997)$$

Also,

$$F_{cn}(D_{max}) = \frac{2.49 \times 10^6 \cdot D_{max}{}^4}{a \cdot \mu_{air}} \; (cm^3/atm \cdot sec) \;\; (\text{Eqn. B.3 of ANSI N14.5} - 1997)$$

Use Eqn. B.5 from ANSI N14.5 - 1997. Let D_{max1} represent the diameter of the hole that will leak L_{N_PS}:

Solve for D_{max1}:

$$L(D_{max1}) = \left[(F_{cn}(D_{max1}) + F_{mn}(D_{max1})) \cdot (P_{u\_N} - P_{d\_N}) \cdot \frac{P_{a\_N}}{P_{u\_N}}\right] - L_{N\_PS}$$

$D_{max1} = 3.57 \times 10^{-4}$ cm

Now calculate $L_{R\_N\_PS}$ based on D_{max1}. At standard conditions:

$P_{u\_S} = 1.0$ atm

$P_{d\_S} = 0.1$ atm

$P_{a\_S} = 0.55$ atm

$T_S = 298$ K

Eqns. B.3, B.4, and B.5 at standard conditions become:

$$F_{mstd}(D_{max}) = \frac{3.81 \times 10^3 \cdot (D_{max})^3 \cdot \sqrt{\frac{T_S}{M_{air}}}}{a \cdot P_{a\_S}}$$

Simplify this equation:

$$F_{mstd}(D_{max}) \rightarrow 3.70 \times 10^4 \cdot D_{max}{}^3$$

$$F_{cstd}(D_{max}) = \frac{2.49 \times 10^6 \cdot (D_{max})^4}{a \cdot \mu_{air}}$$

Simplify this equation:

$$F_{cstd}(D_{max}) \rightarrow 2.24 \times 10^8 \cdot D_{max}{}^4$$

Therefore, Eqn. B.5 at standard conditions and a hole diameter D_{max1} is:

$$L_{R\_N\_PS}(D_{max1}) = \left(F_{cstd}(D_{max1}) + F_{mstd}(D_{max1})\right) \cdot \left(P_{u\_S} - P_{d\_S}\right) \cdot \frac{P_{a\_S}}{P_{u\_S}}$$

Thus,

$L_{R\_N\_PS}(D_{max1}) = 2.64 \times 10^{-6}$ cm^3/sec **Standard leak rate, normal conditions, powdered solids.**

4.2.3 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT (IRRADIATED HARDWARE)

Assume that the worst case source term for irradiated hardware is control rod blades having the same type and level of surface contamination as spent fuel, and that the potentially releasable contents from the control rod blades is entirely from this surface contamination. The surface contamination on the control rod blades that is equivalent to spent fuel is characterized in NUREG/CR-6487 (Ref. 4.3).

The following information was derived from Ref. 4.3, except as noted:

- bounding value for surface activity; worst case is for BWR fuel, $S_B = 1254 \times 10^{-6}$ Ci/cm^2
- surface area of control rod blade, $SA_B = 44{,}500$ cm^2 , cruciform shape has 4 blade surfaces, blade width = 9.8", length conservatively assumed to be 175", A = 4 x 9.8" x 175", see Ref. 4.3
- A_2 for BWR fuel crud, normal transport conditions = 11.0 Ci
- fraction of surface activity that can spall off the surface of a blade and therefore is potentially releasable, normal transport conditions, $f_N = .15$

In addition, conservatively set the weight of control rod blade at 200 lbs, Ref. 4.3.

Given:

- assumed upper bound payload weight capacity of 8-120B cask = 14,680 lbs.
- number of control rod blades that can be transported in the 8-120B; assume 100% packing efficiency; N
- C_{NIH} = activity concentration in the cavity that could potentially escape during normal conditions of transport, irradiated hardware, Ci/cm^3
- total surface activity available for release on the surface of the control rod blades, normal transport conditions, RL_N:
- number of control rod blades in the cavity = N

N= 14680/200 N = 73 blades

f_N = .15

S_B = 1254×10^{-6} C_i/cm^2

SA_B = 44500 cm^2

RL_N = $N \cdot S_B \cdot SA_B \cdot f_N \rightarrow RL_N = 6.11 \times 10^2$ C_i

$$C_{NIH} = \frac{RL_N}{V_{cavity} \cdot (11.0)} \quad \Rightarrow \quad C_{NIH} = 6.027 \times 10^{-5} \cdot cm^{-3}$$

From Eqn. 1-1 above:

$L_{N\_IH} = R_N/C_{NIH} = 4.609 \times 10^{-6}$ cm^3/sec **Maximum permitted volumetric leakage rate, normal conditions of transport, for irradiated hardware.**

Next, determine the Reference Leakage Rate, $L_{R\_N\_IH}$, normal conditions, irradiated hardware, for a volumetric leak rate L_{N_IH}:

Follow the same steps used above. First, determine a D_{max2} that would leak L_{N_IH}:

Use Eqn. 4-2:

$$L(D_{max2}) = \left[(F_{cn}(D_{max2}) + F_{mn}(D_{max2})) \cdot (P_{u\_N} - P_{d\_N}) \cdot \frac{P_{a\_N}}{P_{u\_N}}\right] - L_{N\_IH}$$

Solve this equation for D_{max2}:

$$D_{max2} = 3.4 \times 10^{-4} \text{ cm}$$

Now substitute D_{max2} into Eqn. B.5 and determine $L_{R\_N\_IH}$ at standard conditions:

$$L_{R\_N\_IH}(D_{max2}) = (F_{cstd}(D_{max2}) + F_{mstd}(D_{max2})) \cdot (P_{u\_S} - P_{d\_S}) \cdot \frac{P_{a\_S}}{P_{u\_S}}$$

$L_{R\_N\_IH}(D_{max2}) = 2.20 \times 10^{-6}$ cm^3/sec **Standard leak rate, normal conditions, irradiated hardware.**

4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS (TYPE B PACKAGES)

In this section the maximum permitted leakage rates under Hypothetical Accident Conditions are calculated for the 8-120B package. 10CFR71.51(a)(2) states that the containment requirements for Hypothetical Accident Conditions are:

> *...no escape of krypton-85 exceeding 10A_2 in 1 week, no escape of other radioactive material exceeding a total amount A_2 in 1 week, and no external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package.*

Following the methodology from Section 4.2 in Sections 4.3.1 and 4.3.2 below, the maximum permitted volumetric leakage rates under Hypothetical Accident Conditions are calculated for powdered solids and irradiated hardware, L_{A_PS} and L_{A_IH} respectively. In Section 4.3.1 the reference leakage rate corresponding to L_{A_PS}, $L_{R\_A\_PS}$, is calculated, and in Section 4.3.2 the reference leakage rate corresponding L_{A_IH}, $L_{R\_A\_IH}$, is calculated.

In Section 4.4, $L_{R\_A\_PS}$ and $L_{R\_A\_IH}$ are compared to the reference leakage rates for Normal Conditions of Transport calculated in Section 4.2.1 to determine the most restrictive, and thus the reference air leakage rate for the 8-120.

$R_A = 1 \cdot \frac{A_2}{\text{week}}$ $R_A = 1.65 \times 10^{-6} \frac{A_2}{\text{sec}}$ 10CFR71

4.3.1 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS (POWDERED SOLIDS)

Use the same parameters as Section 4.2.2:

C_{APS} = concentration of releasable materials during hypothetical accident conditions, C_i/cm^3

C_{APS} = C_{NPS}

Using Eqn. 1-1:

L_{A_PS} = R_A/C_{APS} = 0.033 cm^3/sec Volumetric leakage rate, hypothetical accident conditions, powdered solids.

Next, determine the reference leakage rate, $L_{R\_A\_PS}$, accident conditions, powdered solids, for a volumetric leak rate L_{A_PS}:

P_{d_A} = 1 atm (Ref. 4.1)

μ_{air} = 0.0185 cP (Ref. 4.1)

M_{air} = 29.0 gm/mol (Ref. 4.1)

A = 0.6 cm assumed length of hole leaking air (equals o-ring diameter)

For hypothetical accident conditions:

T_A = 325°F

HACP = P_{u_A} = 155 psig

P_{u_A} = 155 psig (from Section 3)

$P_{u\_A}(x) = (x + 14.7)\text{ psi}$

$P_{u\_A} = 11.6\text{ atm}$

$P_{d\_A} = 1\text{ atm}$

$$P_{a\_A} = \frac{P_{u\_A} + P_{d\_A}}{2} = 6.28\text{ atm}$$

Equations B.3 and B.4 at accident conditions are as follows:

$$F_{mA}(D_{max}) = \frac{3.8 \times 10^3 \cdot D_{max}{}^3 \cdot \sqrt{\frac{T_A}{M_{air}}}}{a \cdot P_{a\_A}} \text{ (Eqn. B. 3, ANSI N14.5 – 1997)}$$

$F_{mA}(D_{max}) = 3.91 \times 10^3 \cdot D_{max3}\ \text{cm}^3/\text{atm}\cdot\text{sec}$

$$F_{cA}(D_{max}) = \frac{2.49 \times 10^6 \cdot D_{max}{}^4}{a \cdot \mu_{air}} \text{ (Eqn. B. 4, ANSI N14.5 – 1997)}$$

$F_{cA}(D_{max}) = 1.85 \times 10^8 \cdot D_{max4}\ \text{cm}^3/\text{atm}\cdot\text{sec}$

Let D_{max3} represent the diameter of the hole that will leak L_{A_PS}:

$L_{A\_PS} = 0.033\text{ cm}^3/\text{sec}$

$$L(D_{max3}) = \left[\left(F_{cA}(D_{max3}) + F_{mA}(D_{max3})\right) \cdot (P_{u\_A} - P_{d\_A}) \cdot \frac{P_{a\_A}}{P_{u\_A}}\right] - L_{A\_PS}$$

Solve this equation for D_{max3}:

$D_{max3} = 2.4 \times 10^{-3}\text{ cm}$

Substitute this value of D_{max3} into Eqn B.3 at standard conditions:

$$L_{R\_A\_PS}(D_{max3}) = \left(F_{cstd}(D_{max3}) + F_{mstd}(D_{max3})\right) \cdot (P_{u\_S} - P_{d\_S}) \cdot \frac{P_{a\_S}}{P_{u\_S}}$$

$L_{R\_A\_PS}(D_{max3}) = 0.004\text{ cm}^3/\text{sec}$ Standard leak rate, accident conditions, powdered solids.

4.3.2 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS (IRRADIATED HARDWARE)

(See Section 4.4 for the basic assumptions regarding control rod blades and irradiated hardware.)

For accident conditions:

- A_2 for BWR fuel, accident conditions = 11.0 Ci (Ref. 4.3)
- fA = 1.0 (Ref. 4.3) fraction of surface activity potentially that can spall off surface of a blade and therefore is potentially releasable under accident conditions,

C_{AIH} = activity concentration in the cavity that could potentially escape during accident conditions, irradiated hardware, C_i/cm^3

RL_A = $N \cdot S_B \cdot SA_B \cdot f_A \Rightarrow RL_A = 4.07 \times 10^3\ C_i$

$$C_{AIH} = \frac{RL_A}{V_{cavity} \cdot (11.0)} \quad \Rightarrow \quad C_{AIH} = 4.02 \times 10^{-4} \cdot A_2 \cdot C_i/cm^3$$

$L_{A\_IH} = R_A/C_{AIH} = 4.12 \times 10^{-3}\ cm^3/sec$ Volumetric leak rate, Hypothetical Accident Conditions, Irradiated hardware

Next, determine the reference leakage rate, $L_{R\_A\_IH}$, accident conditions, irradiated hardware, for a volumetric leak rate L_{A_IH}:

Follow the same steps used in Section 4.3.1 above. First, determine a D_{max4} that would leak L_{A_IH}:

$L_{A\_IH} = 4.12 \times 10^{-3}\ cm^3/sec$ (from above)

$$L(D_{max4}) = \left[\left(F_{cA}(D_{max4}) + F_{mA}(D_{max4}) \right) \cdot (P_{u\_A} - P_{d\_A}) \cdot \frac{P_{a\_A}}{P_{u\_A}} \right] - L_{A\_IH}$$

Solve this equation for D_{max4}

$D_{max4} = 1.40 \times 10^{-3}\ cm$

Now substitute D_{max4} into Eqn B.5 and determine $L_{R\_A\_IH}$ at standard conditions:

$$L_{R\_A\_IH}(D_{max4}) = \left(F_{cstd}(D_{max4}) + F_{mstd}(D_{max4}) \right) \cdot (P_{u\_S} - P_{d\_S}) \cdot \frac{P_{a\_S}}{P_{u\_S}}$$

$L_{R\_A\_IH}(D_{max4}) = 4.77 \times 10^{-4}\ cm^3/sec$ Standard leak rate, accident conditions, irradiated hardware.

4.4 REFERENCE AIR LEAKAGE RATE

The following table summarizes results in Sections 4.2 and 4.3 above:

	Max. Volumetric Leak Rate (cm^3/sec)	Max. Hole Diameter (cm)	Reference Leak Rate (cm^3/sec)
Normal Conditions of Transport, Powdered Solids	$L_{N\_PS} = 5.56 \times 10^{-6}$	$D_{max1} = 3.57 \times 10^{-4}$	$L_{R\_N\_PS} = 2.64 \times 10^{-6}$
Normal Conditions of Transport, Irradiated Hardware	$L_{N\_IH} = 4.61 \times 10^{-6}$	$D_{max2} = 3.4 \times 10^{-4}$	$L_{R\_N\_IH} = 2.20 \times 10^{-6}$
Hypothetical Accident Conditions, Powdered Solids	$L_{A\_PS} = 0.033$	$D_{max3} = 2.4 \times 10^{-3}$	$L_{R\_A\_PS} = 0.004$
Hypothetical Accident Conditions, Irradiated Hardware	$L_{A\_IH} = 4.12 \times 10^{-3}$	$D_{max4} = 1.40 \times 10^{-3}$	$L_{R\_A\_IH} = 4.77 \times 10^{-4}$

The reference leak rate for powdered solids was determined based on the assumption that the powdered solid source has a mass of at least 60 grams or the SA is less than 50. With these constraints, $L_{R\_N\_PS}$ is not the most restrictive leak rate. The most restrictive reference leak rate is $L_{R\_N\_IH}$, for normal conditions of transport, irradiated hardware, and will be the reference leak rate for the cask. Therefore, for the 8-120B cask:

$L_R = 2.20 \times 10^{-6}$ ref·cm^3/sec 8-120B cask reference air leakage rate

4.5 DETERMINATION OF EQUIVALENT REFERENCE LEAKAGE RATE FOR R-134A GAS

The purpose of this calculation is to determine the allowable leak rate using the R-134a halogen gas that may be used to perform the annual verification leak tests on the 8-120B cask. This halogen gas is now in widespread use as a replacement gas for R-12 in many industrial applications.

This calculation uses formulas presented in ANSI N14.5 - 1997.

$L_R = 2.2 \times 10^{-6}$ cm^3/sec

As calculated above, maximum diameter hole through the O-ring corresponding to this leakage rate is:

$D_{MAX} = D_{max2}$ cm $\Rightarrow D_{MAX} = 3.4 \times 10^{-4}$ cm

Determine the equivalent air/R134a mixture (L_{mix}) that would leak from D_{MAX} during a leak test. Assume the cask void is first evacuated to 20" Hg vacuum (9.92" Hg abs) and then pressurized to 25 psig (2.7 atm) with an air/R134a mixture.

$$P_{mix} = 2.701 \text{ atm}$$

$$P_{air} = 9.92 \text{ in. Hg} = 0.332 \text{ atm}$$

$$P_{R134a} = P_{mix} - P_{air} \Rightarrow P_{R134a} = 2.37 \text{ atm}$$

$$P_d = 1.0 \text{ atm}$$

$$P_a = \frac{P_{mix} + P_d}{2} \Rightarrow P_a = 1.85 \text{ atm}$$

The properties of R134a are:

$$M_{R134a} = 102 \text{ gm/mole}$$

$$\mu_{R134a} = 0.012 \text{ cP}$$

$$M_{mix} = \frac{M_{R134a} \cdot P_{R134a} + M_{air} \cdot P_{air}}{P_{mix}} = 93.04 \frac{gm}{mole} \quad \text{(Eqn. B7 of ANSI N14.5 – 1997)}$$

$$\mu_{mix} = \frac{\mu_{air} \cdot P_{air} + \mu_{R134a} \cdot P_{R134a}}{P_{mix}} = 0.0128 \text{ cP} \quad \text{(Eqn. B. 8 of ANSI N14.5 – 1997)}$$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and R134a do not change significantly over the range of temperatures evaluated:

$T = 273, 278, \ldots, 328 \text{ K}$ Temperature range for test: 32°F to 130°F

$$F_c = \frac{2.49 \times 10^6 \cdot D_{MAX}{}^4}{a \cdot \mu_{mix}} = 4.541 \times 10^{-6} \frac{cm^3}{atm \cdot sec}$$

$$F_m(T) = \frac{3.81 \times 10^6 \cdot D_{MAX}{}^3 \cdot \sqrt{\frac{T}{M_{mix}}}}{a \cdot P_a}$$

$$L_{mix}(T) = \left(F_c + F_M(T)\right) \cdot (P_{mix} - P_d) \cdot \frac{P_a}{P_{mix}}$$

$$T_F(T) = \left[(T - 273) \cdot \frac{9}{5} + 32\right] {}^\circ F$$

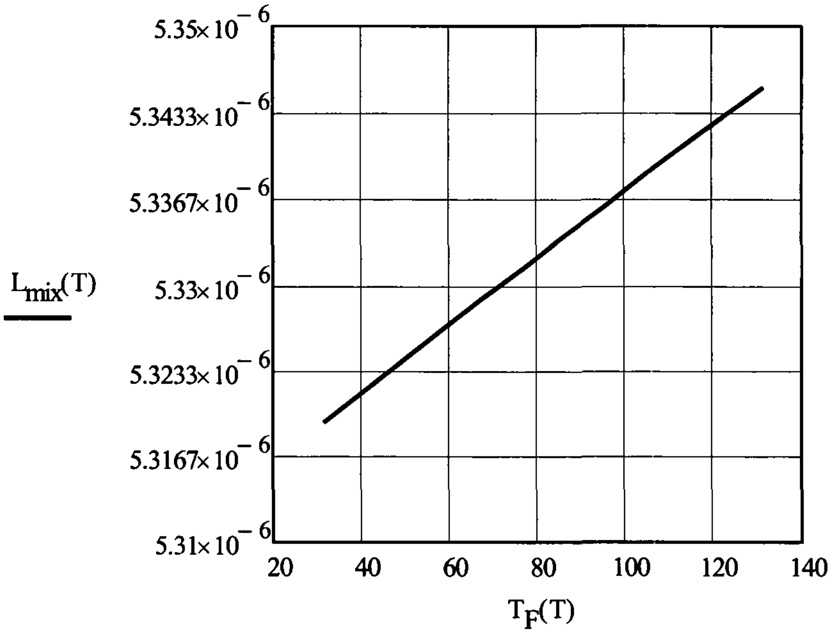


Figure 4-1 - Allowable He/Air Mixture Test Leakage, cm^3/sec, versus test temperature, °F

The R-134a component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the R-134a partial pressure to the total pressure of the mix, as follows.

$$L_{R134a}(T) = L_{mix}(T) \cdot \frac{P_{R134a}}{P_{mix}}$$

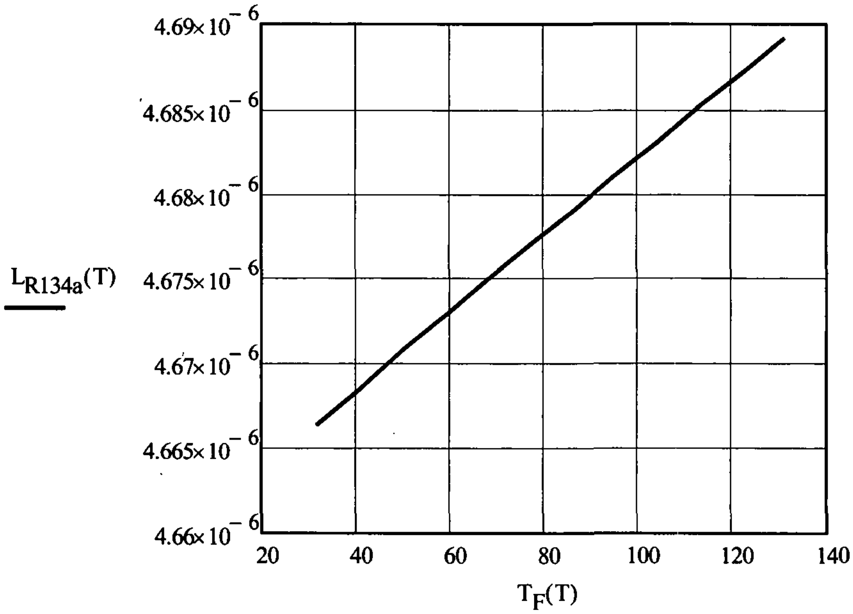


Figure 4-2 - Allowable R-134a Test Leakage, cm^3/sec, versus Test Temperature, °F

Determine the equivalent mass flow rate for L_{R134a} in oz/yr:

$$N(T) = \frac{P_{R134a} \cdot V}{R_o \cdot T} \qquad \text{(Ideal Gas Law)}$$

Where,

$$R_o = 82.05 \frac{cm^3 \cdot atm}{mol}$$

$$V = 1\ cm^3$$

This data can then be used to convert the volumetric leak rate for R-134a calculated above to a mass leak rate. By dividing N by V, the number of moles per unit volume can be multiplied by the molecular weight of the gas and the maximum allowable volumetric leak rate to determine the maximum allowable mass leak rate, as a function of test temperature as shown in the graph below. The conversion from grams per second to ounces per year is also shown below.

$$1.0 \frac{gm}{sec} = 1.11 \times 10^6 \frac{oz}{yr} \qquad \text{(Conversion of gm/ sec to oz/year)}$$

$$L(T) = L_{R134a}(T) \cdot \frac{N(T)}{V} \cdot M_{R134a}$$

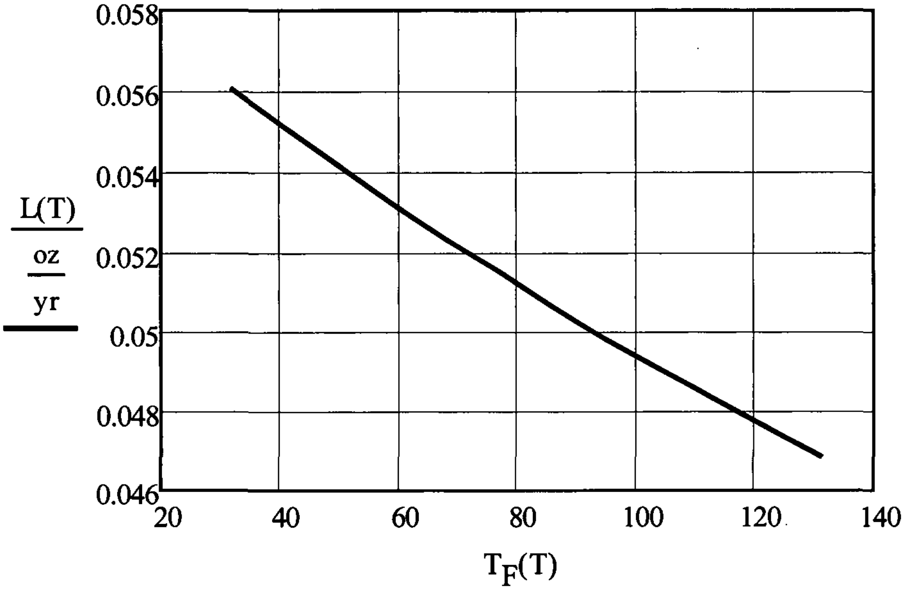


Figure 4-3 - Allowable R-134a Test Leakage, oz/yr, versus Test Temperature, °F

Figure 4-4 can be used to determine the allowable leak rate based on the temperature at the time of the test. A simplified version of the equation can be used to validate the curve:

$$L(T_F) = 4.872 \times 10^{-2} \cdot \left(\frac{5}{9} \cdot T_F \cdot 255.2\right)^{-0.5} + 15.28 \cdot \left(\frac{5}{9} \cdot T_F + 255.2\right)^{-1}$$

According to ANSI N14.5 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity in oz/yr is presented below:

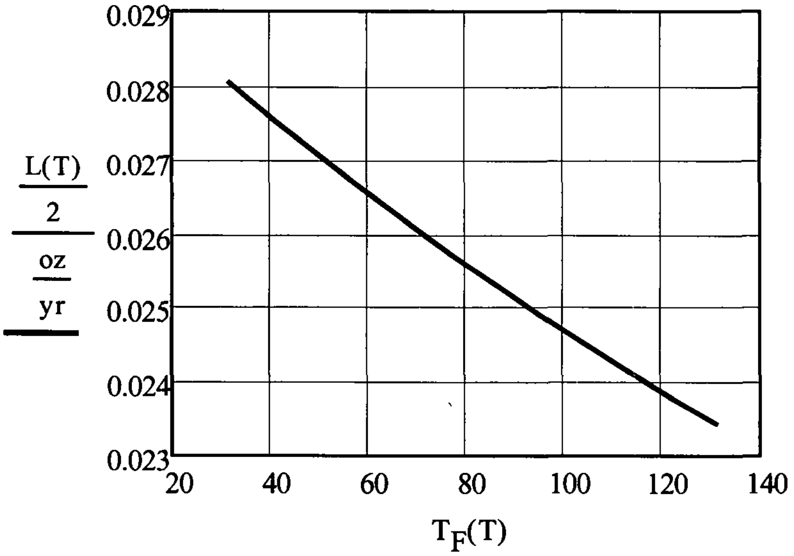


Figure 4-4 - Allowable R-134a test leakage sensitivity, oz/yr, versus test temperature, °F

A simplified version of the equation can be used to validate the sensitivity curve:

$$\frac{L(T_F)}{2} = 2.436 \times 10^{-2} \cdot \left(\frac{5}{9} \cdot T_F \cdot 255.2\right)^{-0.5} + 7.64 \cdot \left(\frac{5}{9} \cdot T_F + 255.2\right)^{-1}$$

4.6 DETERMINATION OF EQUIVALENT REFERENCE LEAKAGE RATE FOR HELIUM GAS

The purpose of this calculation is to determine the allowable leak rate using the Helium gas that may be used to perform the annual verification leak tests on the 8-120B cask.

This calculation uses formulas presented in ANSI N14.5 - 1997.

$$L_R = 2.2 \times 10^{-6} \frac{cm^3}{sec}$$

As calculated above, maximum diameter hole through the O-ring corresponding to this leakage rate is:

$$D_{MAX} = D_{max2}\ \text{cm} \quad \Rightarrow \quad D_{MAX} = 3.4 \times 10^{-4}\ \text{cm}$$

Determine the equivalent air/helium mixture (L_{mix}) that would leak from D_{MAX} during a leak test. Assume the cask void is first evacuated to 20" Hg vacuum (9.92" Hg abs) and then pressurized to 1 psig (1.07 atm) with an air/helium mixture.

$$P_{air} = 0.33\ \text{atm} \qquad P_d = 0.01\ \text{atm} \qquad P_{mix} = 1.07\ \text{atm}$$

$$P_{He} = P_{mix} - P_{air}$$

$$P_a = \frac{P_{mix} + P_{air}}{2} = 0.54\ \text{atm}$$

$$M_{He} = 4.0 \cdot \frac{g}{mol} \quad \text{(ANSI N14.5 – 1997)}$$

$$\mu_{He} = 0.0198\ \text{cP} \quad \text{(ANSI N14.5 – 1997)}$$

$$M_{mix} = \frac{M_{He} \cdot P_{He} + M_{air} \cdot P_{air}}{P_{mi}} = 11.75\ \frac{g}{mol} \quad \text{(Eqn. B. 7 of ANSI N14.5 – 1997)}$$

$$\mu_{mix} = \frac{\mu_{air} \cdot P_{air} + \mu_{He} \cdot P_{He}}{P_{mi}} = 0.019\ \text{cP} \quad \text{(Eqn. B. 8 of ANSI N14.5 – 1997)}$$

Determine L_{mix} as a function of temperature. Assume the viscosities of air and Helium do not change significantly over the range of temperatures evaluated:

$T = 273, 278, \ldots, 328\ \text{K}$ Temperature range for test: 32°F to 130°F

$$F_c = \frac{2.49 \times 10^6 \cdot D_{MAX}{}^4}{a \cdot \mu_{mix}} \quad \text{(Eqn. B. 3 of ANSI N14.5 – 1997)}$$

$$F_m(T) = \frac{3.81 \times 10^6 \cdot D_{MAX}{}^3 \cdot \sqrt{\frac{T}{M_{mix}}}}{a \cdot P_a} \quad \text{(Eqn. B. 4 of ANSI N14.5 – 1997)}$$

$$L_{mix}(T) = \left(F_c + F_M(T)\right) \cdot (P_{mix} - P_d) \cdot \frac{P_a}{P_{mix}} \quad \text{(Eqn. B. 5 of ANSI N14.5 – 1997)}$$

$$T_F(T) = \left[(T - 273) \cdot \frac{9}{5} + 32\right] °F$$

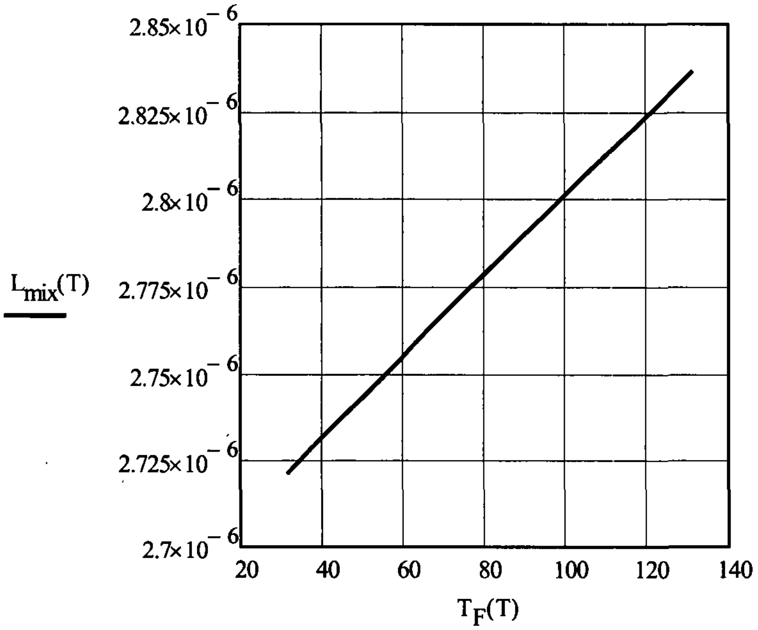


Figure 4-5 - Allowable R-134a/Air Mixture Test Leakage, cm^3/sec, versus test temperature, °F

The Helium component of this leak rate can be determined by multiplying the leak rate of the mixture by the ratio of the Helium partial pressure to the total pressure of the mix, as follows.

$$L_{He}(T) = L_{mix}(T) \cdot \frac{P_{He}}{P_{mix}}$$

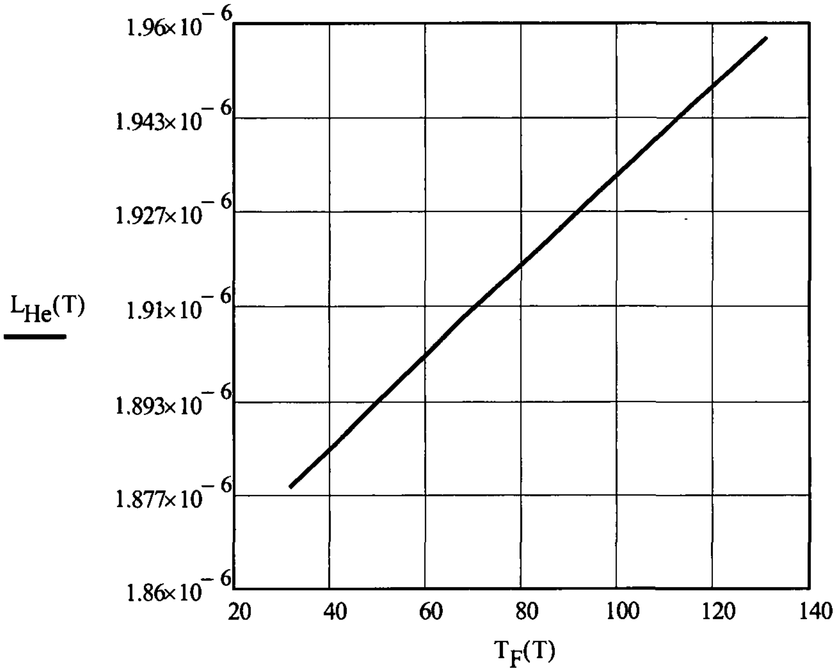


Figure 4-6 - Allowable He Test Leakage, cm^3/sec, versus test temperature, °F

Figure 4-6 can be used to determine the allowable leak rate based on the temperature at the time of the test. A simplified version of the equation can be used to validate the curve:

$$L_{He}(T_F) = 2.114 \times 10^{-6} + 5.193 \times 10^{-8} \cdot \left(\frac{5}{9} \cdot T_F + 255.2\right)^{0.5}$$

According to ANSI N14.1 methodology, the maximum allowable leak rate must be divided by 2 to determine the minimum sensitivity for the test. A graph of the required sensitivity is presented below.

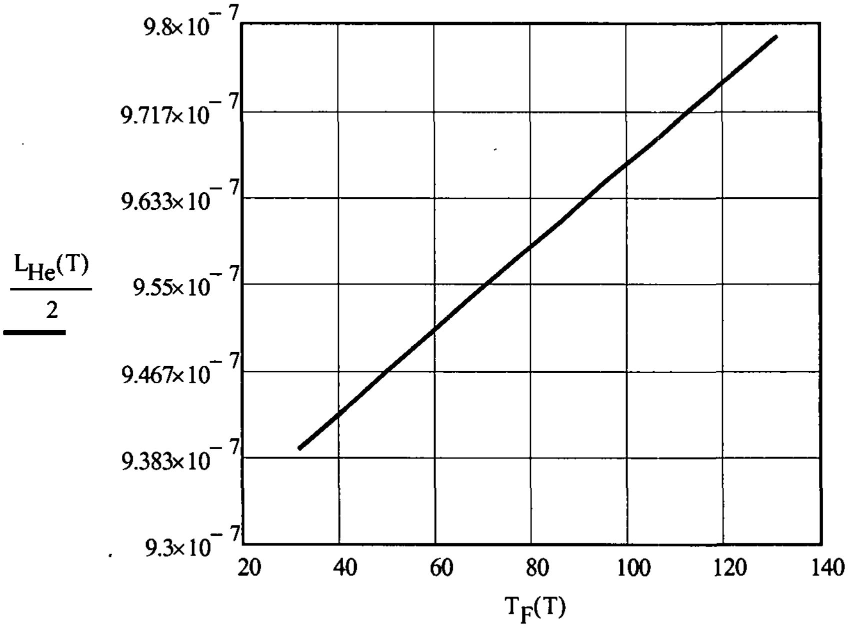


Figure 4-7 - Allowable helium test leakage sensitivity, cm^3/sec, versus test temperature, °F

A simplified version of the equation can be used to validate the sensitivity curve:

$$\frac{L_{He}(T_F)}{2} = \frac{2.114\times10^{-6}+5.193\times10^{-8}\cdot\left(\frac{5}{9}\cdot T_F+255.2\right)^{0.5}}{2}$$

4.7 DETERMINING TIME FOR PRE-SHIPMENT LEAK TEST USING AIR OR NITROGEN

The pre-shipment leak test is to be performed by the pressure drop test method using air or nitrogen. The test will be performed on the closure lid and vent port. In this section the minimum hold time for each of the tests is determined.

4.7.1 MINIMUM HOLD TIME FOR CLOSURE LID

The pre-shipment leak test is performed by charging the annulus between the O-rings of the closure lid with air at 18 psig and holding the pressure for the prescribed time. The maximum volume of the test manifold is 10 cm^3, which is added to the annulus volume.

The annulus between the O-rings is 1/8" deep and 1/8" wide with a center-line diameter (primary lid) of 63 7/8". The volume of the annulus is:

$$ID_{ann} = \left[(63.875)-\frac{1}{8}\right]\text{in} \quad \Rightarrow \qquad ID_{ann} = 63.75\text{ in}$$

$$\mathrm{OD_{ann}} = \left(63.875 + \frac{1}{8}\right)\mathrm{in} \quad \Rightarrow \quad \mathrm{OD_{ann}} = 64.00\ \mathrm{in}$$

$$\mathrm{V_{ann}} = \frac{\pi}{4}\cdot(.125\ \mathrm{in})\left(\mathrm{OD_{ann}}^2 - \mathrm{ID_{ann}}^2\right)$$

$$\mathrm{V_{ann}} = 3.14\ \mathrm{in}^3 \quad \Rightarrow \quad \mathrm{V_{ann}} = 51.38\ \mathrm{cm}^3$$

$$\mathrm{V_T} = \mathrm{V_{ann}} + 10\ \mathrm{cm}^3 \quad \Rightarrow \quad \mathrm{V_T} = 61.4\ \mathrm{cm}^3$$

Use Equation B.14 from ANSI N14.5 to determine the required hold time given the maximum permitted leak rate, where:

L = atm-cm^3/sec of air at standard conditions

V_{ann} = gas volume in the test annulus

T_s = reference absolute temperature, 298 K

H = test duration, hrs

P_s = standard pressure, 1 atm

P_1 = gas pressure in annulus at start of test, 1.232 atm (18.1 psig)

P_2 = gas pressure in annulus at end of test, 1.225 atm (18.0 psig)

T_1 = gas temperature in annulus at start of test, K

T_2 = gas temperature in annulus at end of test, K

$\mathrm{T_s} = 298\ \mathrm{K} \qquad \mathrm{T_1} = \mathrm{T_s} \qquad \mathrm{T_2} = \mathrm{T_s}$

$\mathrm{P_s} = 1\ \mathrm{atm}$

$\mathrm{P_1} - \mathrm{P_2} = \mathrm{P_{delta}}$ Maximum permitted P_d = sensitivity of pressure gage:

$\mathrm{P_{delta}} = .1\ \mathrm{psi} \qquad \mathrm{P_{delta}} = 0.007\ \mathrm{atm}$

$$\mathrm{L} = \frac{\mathrm{V_T}\cdot\mathrm{T_s}}{3600\ \mathrm{H}\cdot\mathrm{P_s}}\cdot\left(\frac{\mathrm{P_1}}{\mathrm{T_1}} - \frac{\mathrm{P_2}}{\mathrm{T_2}}\right)\frac{\mathrm{cm}^3}{\mathrm{sec}}$$

The maximum permitted sensitivity for the pre-shipment leak test as prescribed in ANSI N14.5 - 1997 is 10^{-3} ref-cm^3/sec. From Equation B.17 in ANSI N14.5, the maximum permitted leak rate when the sensitivity is prescribed is:

$$\mathrm{L} < \frac{\mathrm{S}}{2}$$

therefore,

$$L = \frac{10^{-3}}{2}\frac{\mathrm{cm}^3}{\mathrm{sec}}$$

Rearranging Eqn. 4.7-1 to solve H:

$$H = \frac{V_T \cdot T_s \cdot P_{delta}}{3600\frac{\mathrm{sec}}{\mathrm{hr}} \cdot L \cdot P_s \cdot T_s} \qquad \text{Eqn. 4.7} - 2$$

$H = 13.92$ min **For conservatism, the test will be conducted for 15 minutes.**

The smaller diameter secondary lid will be conservatively tested for the same time as the primary.

4.7.2 MINIMUM HOLD TIME FOR VENT PORT

Volume of vent port cavity:

$$V_{vent} = \frac{\pi}{4}(1.875\ \mathrm{in})^2 \cdot 1.125\ \mathrm{in}$$

Volume of seal plug head inside vent port cavity:

$$V_{seal} = \frac{\pi}{4}(1.5\ \mathrm{in})^2 \cdot (1\ \mathrm{in})$$

$$V_{test} = V_{vent} - V_{seal} \qquad V_{test} = 21.945\ \mathrm{cm}^3$$

$$V_T = V_{test} + 31.6\ \mathrm{cm}^3$$

$$H = \frac{V_T \cdot T_s \cdot P_{delta}}{3600\frac{\mathrm{sec}}{\mathrm{hr}} \cdot L \cdot P_s \cdot T_s} = 0.202\ \mathrm{hr} = 12.145\ \mathrm{min}$$

For conservatism, the test will be conducted for 15 minutes.

4.8 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

The following leakage tests are conducted on the 8-120B package as required by ANSI N14.5:

Table 4-2 - Leakage Tests of the 8-120B Package

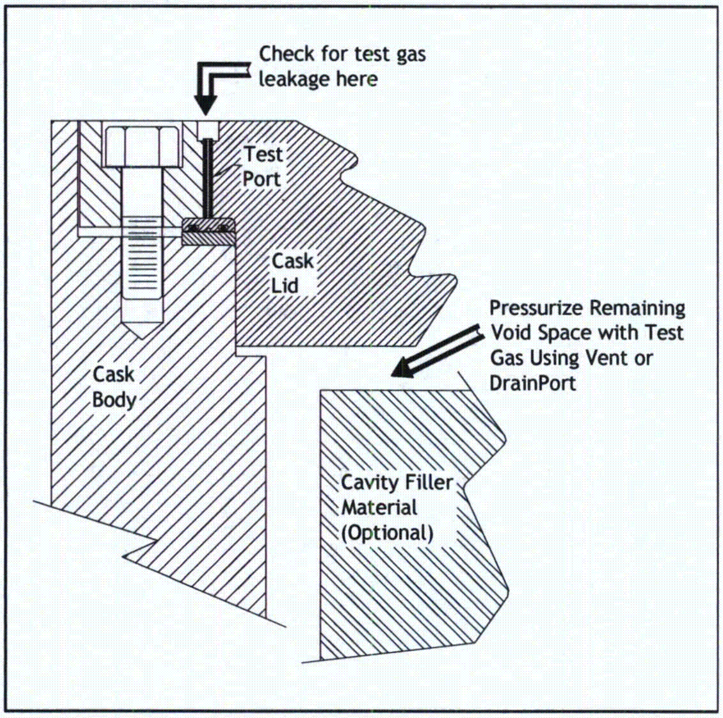
Test	Frequency	Test Gas	Acceptance Criteria	Procedure
Maintenance	After maintenance, repair (such as weld repair), or replacement of components of the containment system.	R-134a, or helium (optional)	$< L_R$*	8.2.2.1
Fabrication	Prior to first use of the 8-120B.			8.1.4
Periodic	Within 12 months prior to each shipment.			8.2.2.1
Pre-Shipment	Before each shipment, after the contents are loaded and the package is closed.	nitrogen or air (optional)	sensitivity $< 10^{-3}$ ref-cm^3/sec	8.2.2.2

* Adjusted for the individual properties of the test gas; sensitivity is $< L_R/2$.

As shown in Table 4-2, the Maintenance, Fabrication, and Periodic leakage tests may be performed using R-134a, or helium as the tracer gas. The acceptance criterion for these tests is the reference air leakage rate, L_R, which is calculated in Section 4.4. An equivalent maximum permissible leakage rate to L_R has been calculated in Sections 4.5 and 4.6 for R-134a and He, respectively, adjusting for individual properties for the gas plus the test pressure and temperature. The equivalent leakage becomes the acceptance criteria for the particular gas being used to perform the test.

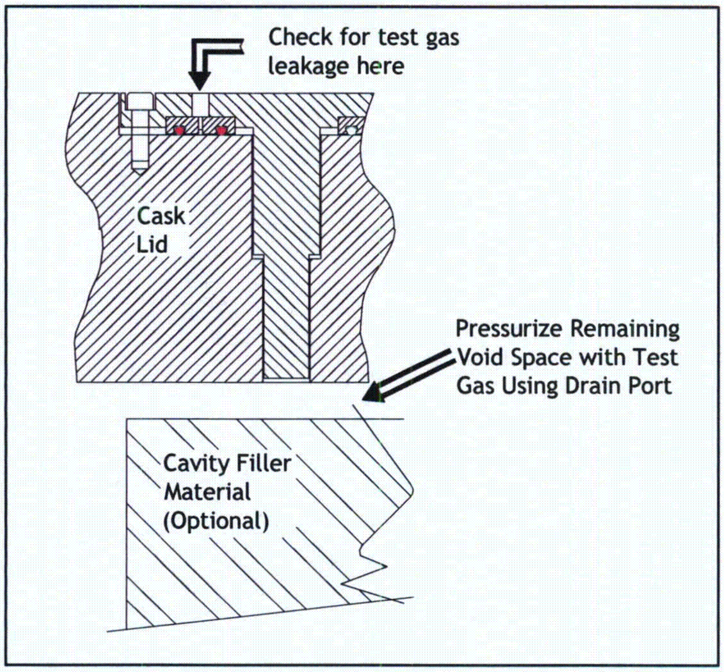
The Fabrication leakage tests are performed on the entire containment boundary including the closure lid, the vent port, the cask inner shell and base plate, and associated weldings. The procedure for performing the leakage tests is described in Section 8.1.4.

The Maintenance and Periodic leakage tests are performed on the closure lid and the vent port. The detailed procedure for performing these tests is given in 8.2.2.1, but generally they will be conducted as follows:



- Pressurize the void space in the cavity with a test gas using the vent port in the lid. Some of the volume of the cavity may be temporarily filled to reduce the volume of test gas required to conduct the test.
- Check for leaks of the inner (containment boundary) O-ring using the test port in the lid.

Figure 4-8 - Periodic Leak Test of Closure Lid



- Pressurize the void space in the cavity with a test gas using the drain port. Some of the volume of the cavity may be temporarily filled to reduce the volume of test gas required to conduct the test.
- Check for leaks of the inner (containment boundary) vent port cover plate O-ring.

Figure 4-9 - Periodic Leak Test of Vent Port

4.9 PERIODIC VERIFICATION LEAK RATE DETERMINATION FOR LEAKTIGHT STATUS

4.9.1 INTRODUCTION

The purpose of this section is to describe the method for performing a periodic leak test to demonstrate meeting the leaktight criterion per ANSI N14.5-1997. This test method is only applicable to a 8-120B cask with o-rings and seals that meet the helium permeability requirement of Seal Specification ES-C-038 [Ref. 4.4].

4.9.2 TEST CONDITIONS

The test is performed with a mass spectrometer leak detector. The test is conducted on the 8-120B by evacuating the cask cavity to at least 90% vacuum then pressurizing the cask cavity with helium (+1 psig, -0 psig). The annulus between the o-rings is evacuated until the vacuum is sufficient to operate the helium mass spectrometer leak detector and the helium concentration in the annulus is monitored. The acceptance criterion is 1.0×10^{-7} atm-cm^3/sec of air (leaktight). The detector sensitivity must be less than or equal to 5.0×10^{-8} atm-cm^3/sec. Similar tests are performed on the vent port.

4.10 REFERENCES

4.1 American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials, American National Standards Institute, Inc., New York, ANSI N14.5-1997, 1997.

4.2 8-120B Drawing, C-110-E-0007, Energy*Solutions*

4.3 Containment Analysis for Type B Packages Used to Transport Various Contents, LLNL, NUREG/CR-6487, 1996

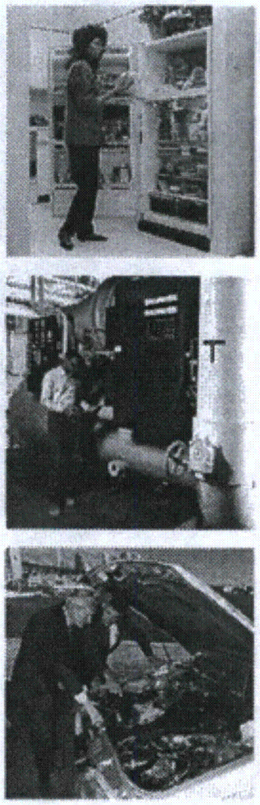
4.4 ES Specification, ES-C-038, Seal Specification for the 8-120B Cask

Appendix 4.1 - Properties of R-134a (4 pages)

Technical Information

P134a

DuPont™ Suva®
refrigerants

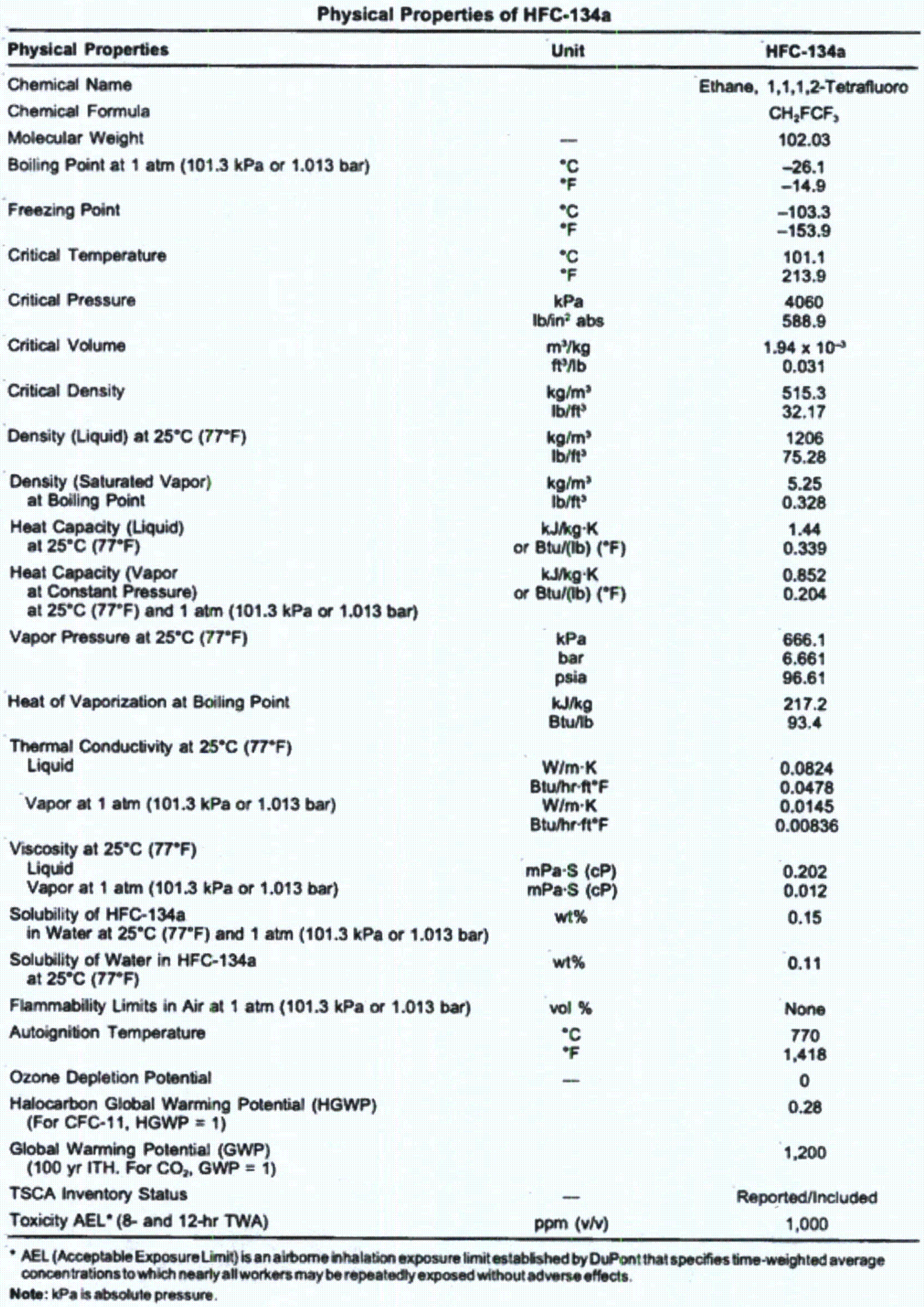


DuPont HFC-134a

Properties, Uses, Storage, and Handling

DuPont™ Suva® 134a refrigerant
DuPont™ Suva® 134a (Auto) refrigerant
DuPont™ Formacel® Z-4 foam expansion agent
DuPont™ Dymel® 134a aerosol propellant

The miracles of science™

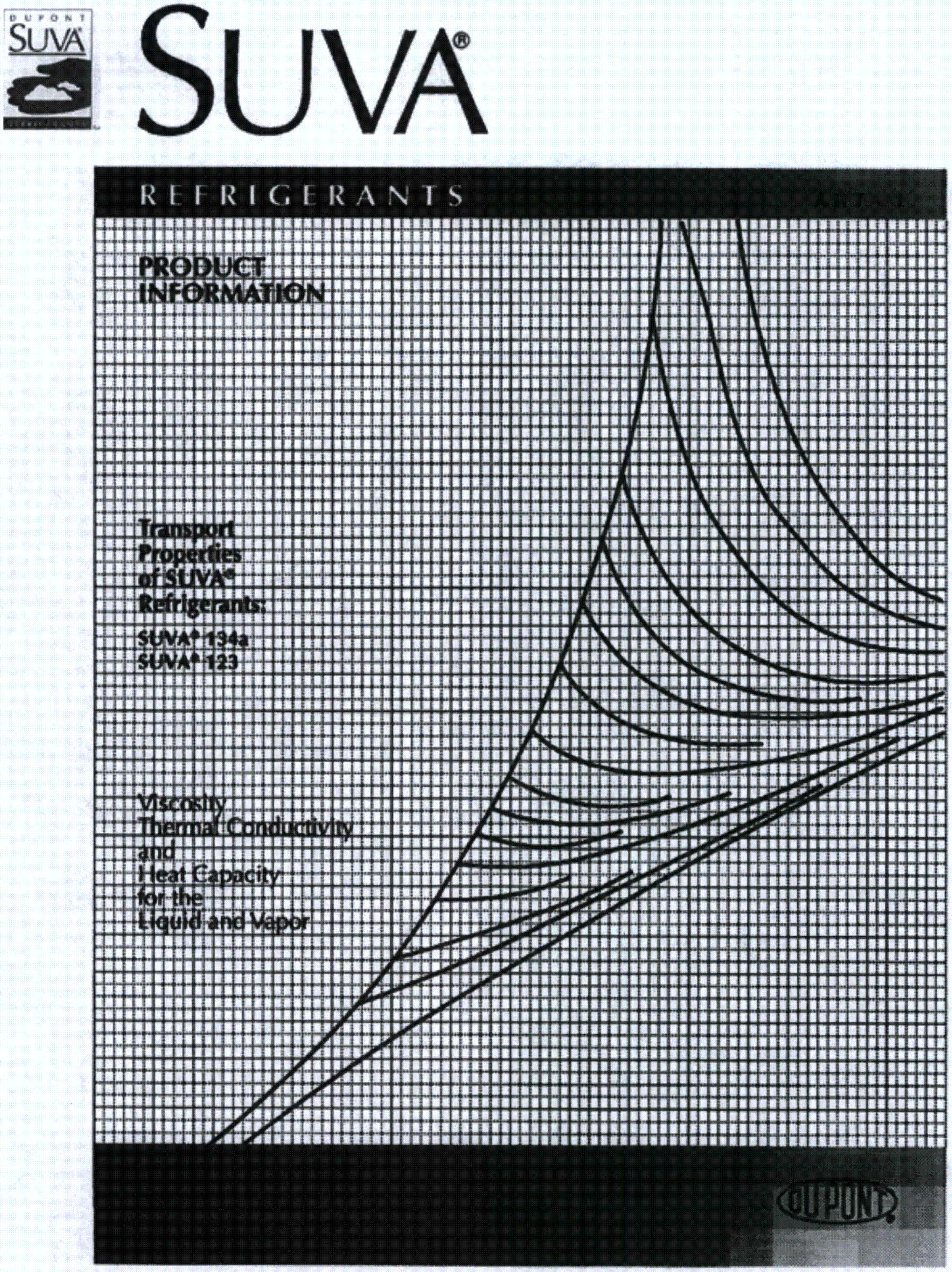


Physical Properties of HFC-134a

Physical Properties	Unit	HFC-134a
Chemical Name		Ethane, 1,1,1,2-Tetrafluoro
Chemical Formula		CH_2FCF_3
Molecular Weight	—	102.03
Boiling Point at 1 atm (101.3 kPa or 1.013 bar)	°C	−26.1
	°F	−14.9
Freezing Point	°C	−103.3
	°F	−153.9
Critical Temperature	°C	101.1
	°F	213.9
Critical Pressure	kPa	4060
	lb/in^2 abs	588.9
Critical Volume	m^3/kg	1.94×10^{-3}
	ft^3/lb	0.031
Critical Density	kg/m^3	515.3
	lb/ft^3	32.17
Density (Liquid) at 25°C (77°F)	kg/m^3	1206
	lb/ft^3	75.28
Density (Saturated Vapor) at Boiling Point	kg/m^3	5.25
	lb/ft^3	0.328
Heat Capacity (Liquid) at 25°C (77°F)	kJ/kg·K	1.44
	or Btu/(lb) (°F)	0.339
Heat Capacity (Vapor at Constant Pressure) at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	kJ/kg·K	0.852
	or Btu/(lb) (°F)	0.204
Vapor Pressure at 25°C (77°F)	kPa	666.1
	bar	6.661
	psia	96.61
Heat of Vaporization at Boiling Point	kJ/kg	217.2
	Btu/lb	93.4
Thermal Conductivity at 25°C (77°F)		
Liquid	W/m·K	0.0824
	Btu/hr·ft°F	0.0478
Vapor at 1 atm (101.3 kPa or 1.013 bar)	W/m·K	0.0145
	Btu/hr·ft°F	0.00836
Viscosity at 25°C (77°F)		
Liquid	mPa·S (cP)	0.202
Vapor at 1 atm (101.3 kPa or 1.013 bar)	mPa·S (cP)	0.012
Solubility of HFC-134a in Water at 25°C (77°F) and 1 atm (101.3 kPa or 1.013 bar)	wt%	0.15
Solubility of Water in HFC-134a at 25°C (77°F)	wt%	0.11
Flammability Limits in Air at 1 atm (101.3 kPa or 1.013 bar)	vol %	None
Autoignition Temperature	°C	770
	°F	1,418
Ozone Depletion Potential	—	0
Halocarbon Global Warming Potential (HGWP) (For CFC-11, HGWP = 1)		0.28
Global Warming Potential (GWP) (100 yr ITH. For CO_2, GWP = 1)		1,200
TSCA Inventory Status	—	Reported/Included
Toxicity AEL* (8- and 12-hr TWA)	ppm (v/v)	1,000

* AEL (Acceptable Exposure Limit) is an airborne inhalation exposure limit established by DuPont that specifies time-weighted average concentrations to which nearly all workers may be repeatedly exposed without adverse effects.

Note: kPa is absolute pressure.



DUPONT SUVA

SUVA®

REFRIGERANTS

ART-1

PRODUCT INFORMATION

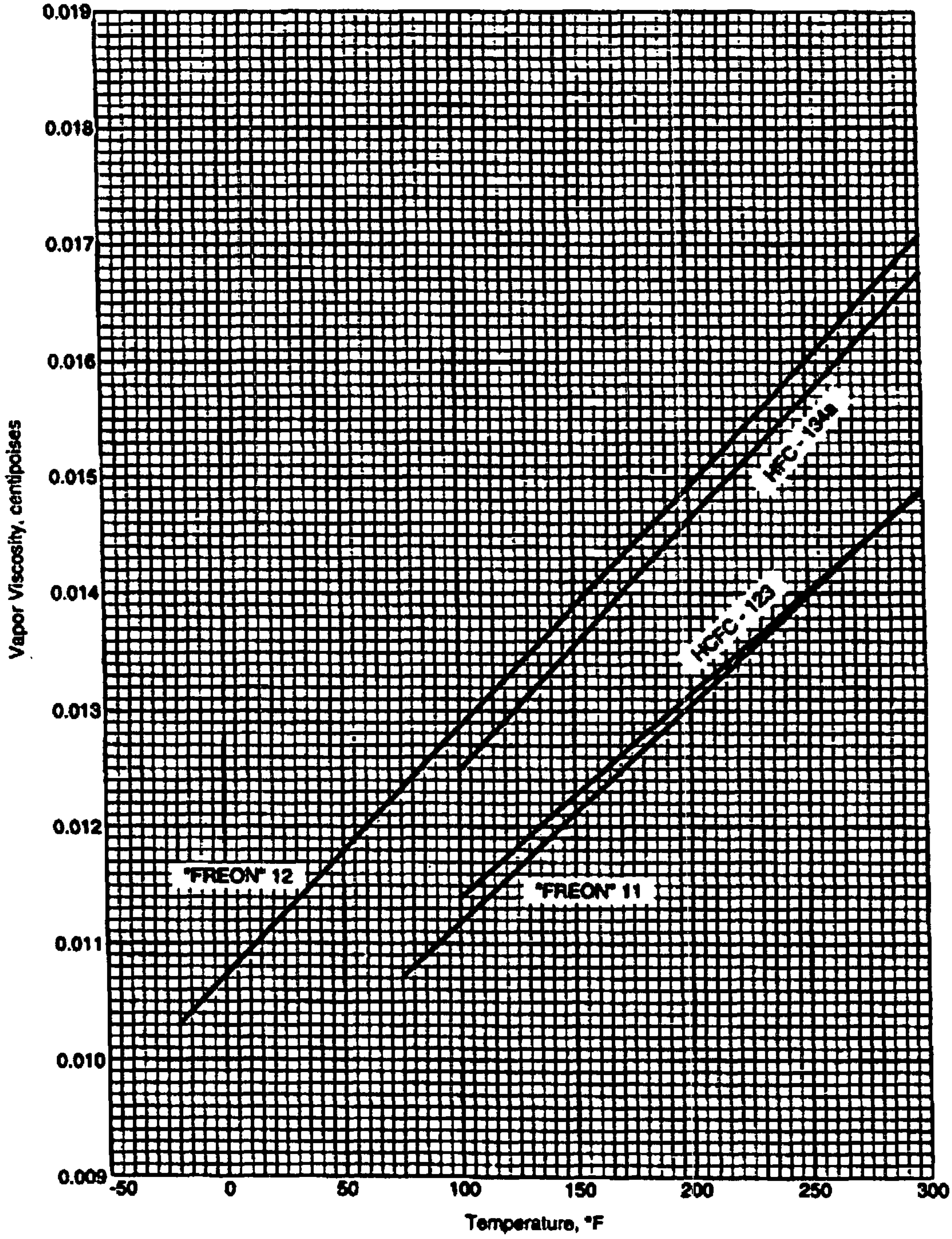
Transport Properties of SUVA® Refrigerants:

SUVA® 134a
SUVA® 123

Viscosity
Thermal Conductivity
and
Heat Capacity
for the
Liquid and Vapor

DUPONT

Vapor Viscosity at Atmospheric Pressure



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5.0 SHIELDING EVALUATION

5.1 DESCRIPTION OF SHIELDING DESIGN

The Model 8-120B packaging consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents.) Tests and analysis performed under chapters 2.0 and 3.0 have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport. Prior to each shipment, radiation readings will be taken based on individual loadings to assure compliance with applicable regulations as determined in 10CFR71.47 (see Section 7.1, step 7.1.21.3).

The 8-120B will be operated under "exclusive use" such that the contents in the cask will not create a dose rate exceeding 200 mrem/hr on the cask surface, or 10 mrem/hr at two meters from the outer lateral surfaces of the vehicle. The package shielding must be sufficient to satisfy the dose rate limit of 10CFR71.51(a)(2) which states that any shielding loss resulting from the hypothetical accident will not increase the external dose rate to more than 1000 mrem/hr at one meter from the external surface of the cask.

5.1.1 SHIELDING DESIGN FEATURES

The cask side wall consists of an outer 1.5 inch thick steel shell surrounding 3.35 inches of lead and an inner containment shell wall of 0.75 inch thick steel and steel 12-guage thick cladding.

The primary cask lid consists of two layers of 3.25 inch thick steel, giving a total material shield thickness of 6.5 inches of steel. This lid closure is made in a stepped configuration to eliminate radiation streaming at the lid/cask body interface.

A secondary lid is located at the center of the main lid, covering a 29.0 inch opening. The secondary lid is constructed of two 3.25 inch steel plates with multiple steps machined in the secondary lid. These match steps in the primary lid, eliminating radiation streaming pathways. A stainless steel thermal shield covers the secondary lid and is attached to the secondary lid lifting lugs. This axial thermal shield is conservatively ignored in the shielding evaluation.

The impact limiters and radial thermal barrier provide a small amount of additional shielding. The impact limiters have 12 gage steel skin; and the lower impact limiter has a ½" thick steel cover plate in the "hole." The radial thermal barrier is 3/16" steel.

5.1.2 MAXIMUM RADIATION LEVELS

The 8-120B package carries a range of contents, from small concentrated sources to large volume homogeneous materials and combinations of these, and may include nearly every radionuclide. In order to determine the maximum activity of any particular radionuclide or mixture of radionuclides, a series of evaluations of bounding source configurations over a range of gamma energies are performed. The resulting set of source limits ensure that any content meeting the source limit for the appropriate configuration and gamma energy will comply with the the most restrictive of the dose rate limits from 10 CFR 71.47 and §71.51. These evaluations are presented in Section 5.4.

In order to provide a concise summary of the results, the point source results for only Co-60 and Cs-137 are provided in Table 5-1. This table gives both normal and accident condition dose rates for the maximum Co-60 and Cs-137 point source in the cask.

Table 5-1 - Summary of Maximum Dose Rates (mrem/hr)

	Package Surface		**1 m from Surface**		**2m from 8' trailer**
Condition	**Side**	**Top/Bottom**	**Side**	**Top/Bottom**	**Side**
NCT					
Co-60 Source	190.0	75.1	NA	NA	3.1
Cs-137 Source	182.6	190.0	NA	NA	5.3
Allowable	200	200	NA	NA	10.0
HAC					
Co-60 Source	NA	NA	102.2	34.9	NA
Cs-137 Source	NA	NA	424.9	93.4	NA
Allowable	NA	NA	1000.0	1000.0	NA

The following assumptions were used to develop the values given in the table.

5.1.2.1 Normal Conditions

The source is modeled as a point source (1 cm dia x 1 cm high) at the location within the cask cavity that yields maximum peak cask exterior dose rates (i.e., at the top corner of the cavity, or on the side of the cask cavity at an elevation between the top and bottom impact limiters). Reference 5.7.2 includes a complete summary of the package response functions for all source configurations of interest.

5.1.2.2 Accident Conditions

1. Lead slump of 0.15" resulting from the accident drop analysis is incorporated in the model
2. Thinning of the lead shield layer due to the puncture drop is incorporated by reducing the lead thickness by 0.5"
3. The source is modeled as a point source (1 cm dia x 1 cm high) in the top corner of the cavity (partially up into the chamfer region at the bottom corner of the primary cask lid so that the bottom of the source is flush with the top of the lead). Reference 5.7.2 includes a complete summary of the package response functions for all source configurations of interest.

5.1.2.3 Conclusion

For the Co-60 point source case, the maximum allowable payload gamma source is governed by the 200 mrem/hr dose rate limit that applies on the cask body side, under NCT. The results determine a maximum allowable source strength of 1.277 x 10^{11} γ/sec (1.73 Ci) for that isotope. At this source strength, the results show a dose rate of close to 200 mrem/hr on the package side surface, and dose rates that are well under their regulatory limits at all other locations. An administrative margin of 5% is then applied (to account for any uncertainties), which reduces the allowable Co-60 gamma source strength to 1.213 x 10^{11} γ/sec (1.64 Ci). Because of the 5% administrative margin, the actual peak dose rate is 190.0 mrem/hr, as shown in Table 5-1.

For the Cs-137 point source case, the maximum allowable payload gamma source strength is governed by the 200 mrem/hr dose rate limit that applies on the package top surface, under NCT. The results determine a maximum allowable source strength of 5.719 x 10^{12} γ/sec (77.3 Ci) for that isotope. At this source strength, the results show a dose rate of close to 200 mrem/hr on the package surface, and dose rates that are well under their regulatory limits at all other locations. An administrative margin of 5% is then applied (to account for any uncertainties), which reduces the allowable Cs-137 gamma source strength to 5.433 x 10^{12} γ/sec (73.4 Ci). Because of the 5% administrative margin, the actual peak dose rate is 190.0 mrem/hr, as shown in Table 5-1.

As the results do not exceed the allowable dose rates, the 8-120B cask meets the shielding requirements of 10 CFR Part 71.

5.2 SOURCE SPECIFICATION

5.2.1 GAMMA SOURCE

Analyses are performed for idealized source configurations that bound any actual source configuration that may occur. These bounding configurations are: a point source at the center of the cask cavity in the NCT configuration, a point source at the side of the cask cavity in the NCT configuration, a point source at the top corner of the cask cavity in the NCT configuration, a point source in the top corner of the cask cavity in the HAC configuration, and a uniform mass of material within a defined source region, as described in Section 5.4, for both NCT and HAC configurations. Further details of the analyses are found in Ref. 5.7.2.

All of the analyses described above are performed for several gamma energy levels, ranging from 0.5 MeV to 3.5 MeV. Two specific isotope cases, Co-60 and Cs-137 (and the corresponding specific gamma energies) are also analyzed. The Cs-137 source includes an equilibrium amount of Ba-137m. The gamma energy and abundance of Co-60 and Cs-137 are shown in Table 5-2.

Table 5-2 - Gamma Energy and Abundance

Radionuclide	Gamma Energy MeV	Abundance # of Gamma/decay
^{60}Co	1.176	1
	1.333	1
^{137}Cs	0.662	0.85

5.2.2 NEUTRON SOURCE

There are no significant sources of neutron radiation in the radioactive materials carried in the 8-120B cask that result in measureable neutron doses outside the cask. A shielding analysis (SAR Chapter 5) for a cask with a similar geometry and shield materials (Ref. 5.7.4) shows that a 1.1 E+08 n/s neutron source produces a dose rate of 9.4 mrem/hr at 2m from the side of the trailer. Limiting the neutron emission rate from the 8-120B contents to less than 1 E+05 n/s will result in a dose rate less than 0.1 mrem/hr. Thus, setting the total neutron emission to less than 1 E+05 n/s will result in a neutron dose rate that is a small fraction of the transport limit.

5.2.3 BETA SOURCE

Significant beta emitters may be qualified as equivalent gammas as described in Section 5.4.4.

5.3 MODEL SPECIFICATION

5.3.1 DESCRIPTION OF RADIAL AND AXIAL SHIELDING CONFIGURATION

5.3.1.1 Normal Conditions of Transport (NCT)

The walls of the 8-120B cask, 0.75" inner wall, a 12-guage inner steel cladding, and a 1.5" outer steel wall, with a 3.35" lead layer between, are modeled as cylindrical shells around the cavity cylinder. The base and lid of the cask are two 3.25" steel plates, for a total thickness of 6.5". Standard minimum sheet and plate tolerances are modeled, except for drawing items 4 and 9 which were modeled at maximum tolerance thickness as this positions the lid and point-source as high as possible with respect to the top of the lead. This geometry is shown in Figure 5-1; the impact limiters are not shown. The cask is transported upright, i.e., with the axis of the cylinder vertical. Doses are evaluated at contact with the cask sidewall, the impact limiter surface, and at 2m from the 8' wide trailer. The impact limiter ends and side surfaces are modeled at reduced dimensions consistent with the maximum NCT impact limiter deformations in Table 2-10. Corner crush was not modeled because the peak dose rates do not occur at the corners.

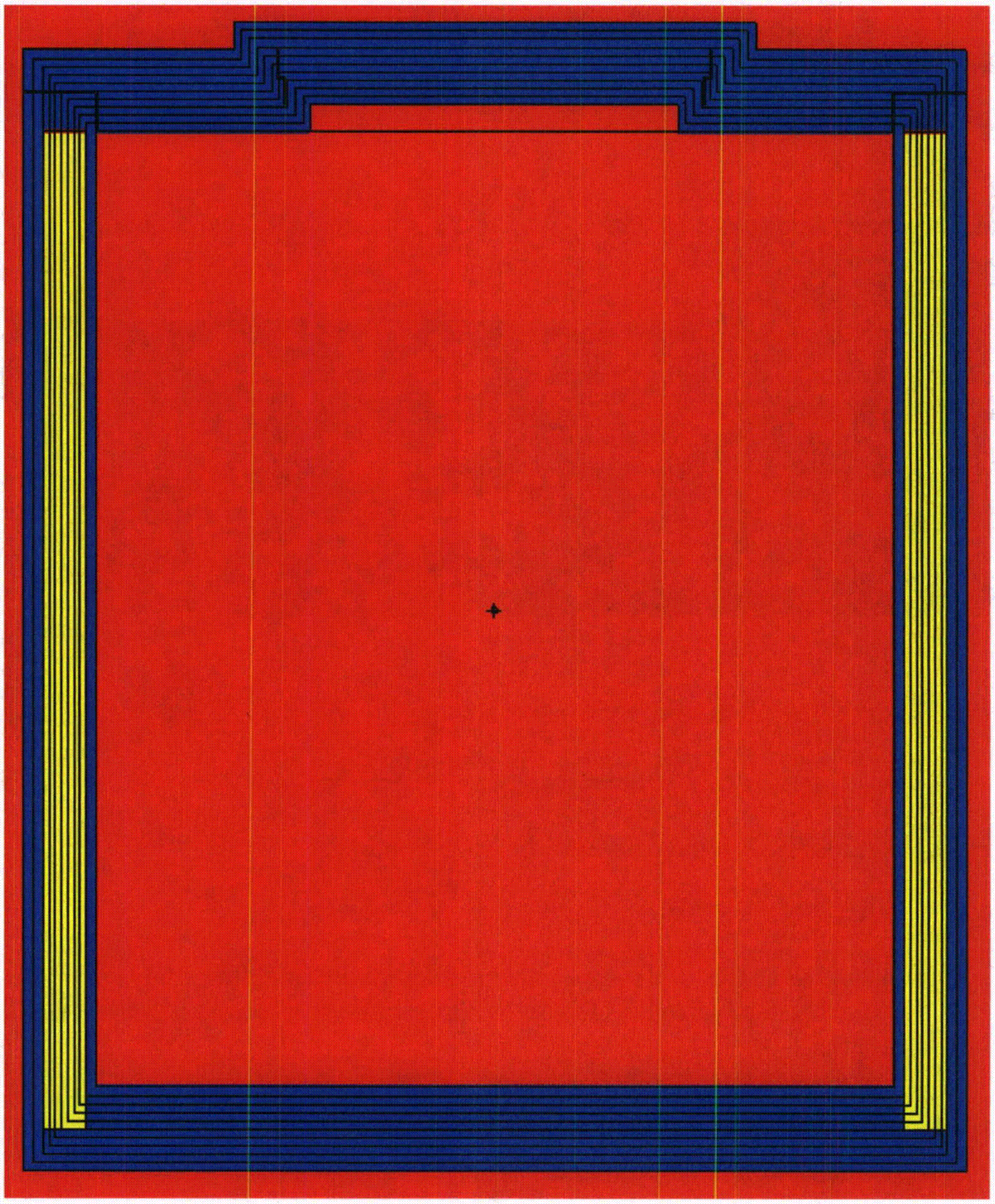


Figure 5-1 - Cask Model

5.3.1.2 Hypothetical Accident Conditions (HAC)

As discussed in Chapter 2, the hypothetical accident 30' drop results in a 0.15" lead slump and the puncture drop causes a local ½" thinning of the lead layer. The HAC model has a 0.15" air-filled void at the top of the lead shield layer. Also, to conservatively reflect the puncture drop thinning, the thickness of the radial lead shield is reduced by ½" in the HAC model. The impact limiters are conservatively ignored. The HAC model is shown in Figure 5-2. Doses are determined at 1 m from the sidewall and the lid.

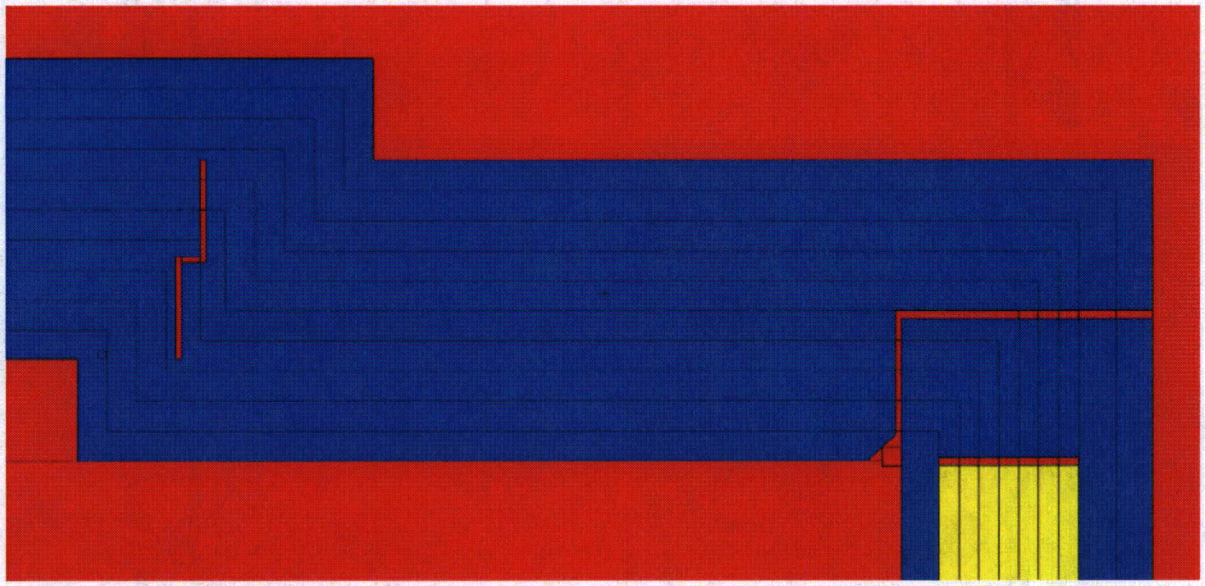


Figure 5-2 - HAC Cask Model

See Reference 5.7.2 for additional details of the MCNP models.

5.3.2 MATERIAL PROPERTIES

The compositions and densities of the materials modeled in the shielding analyses are described in Table 5-3 below. The table also lists the MCNP material/cross-section identifier (ZAID) for each modeled material.

Table 5-3 - Material Composition and Density

Material	Total Density (g/cc)	Composition	MCNP ZAID
Carbon Steel	7.82	99% Fe 1% C	26000.84p 8000.84p
Lead	11.34	100% Pb	82000.84p
Air	0.001205	76.508% N 23.479% O 0.013% C	7000.84p 8000.84p 6000.84p

5.4 SHIELDING EVALUATION

The 8-120B package carries a range of contents, from small concentrated sources to large volume homogeneous materials and combinations of these, and may include nearly every radionuclide. In order to determine the maximum source strength of any particular radionuclide or mixture of radionuclides, a series of evaluations of bounding source configurations over a range of gamma energies are performed to determine the maximum source strength (γ/sec) or maximum source strength density (γ/sec·g) for each combination of configuration and energy that results in the meeting the most restrictive of the dose rate limits from 10 CFR 71.47 and §71.51. The resulting set of source strength limits ensure that any content meeting the source strength limit for the appropriate configuration and gamma energy will comply with the §71.47 and §71.51 limits.

5.4.1 METHODS

The gamma dose rates were calculated using MCNP Version 5, rev. 1.51.

In addition to the point source locations noted in Section 5.2, a uniformly-distributed gamma source is modeled within the source region. The uniform mass that fills the defined source region is zirconium, iron, or aluminum, whichever has the more conservative (smaller) attenuation coefficient at the gamma energy thus bounding other contents materials. The uniform mass is set at a density of 9.0 g/cc, which exceeds the density of nearly all expected payloads. Since the distributed source analyses determine limits in source strength density (γ/sec·g), this density bounds all other lower density contents. Defined source regions include the entire cask interior cavity, a "55 gallon" source zone centered within the cavity and a 2.5 ft^3 source zone centered within the cavity. All the above source zones are modeled for the NCT cask configuration. For the HAC cask configuration, only the full-cask-cavity source zone is modeled.

For the normal condition of transport (NCT) cases, dose rates are tallied on the vertical surface two meters from the package/transporter side (i.e., 322 cm from the cask centerline), and on the package surface which includes the impact limiter side and end surfaces as well as the cask body side cylindrical surface that lies between the impact limiters.

For the HAC point source cases, the dose rates are tallied at two locations on the surface one meter from the cask body. One location lies on the radial one meter surface, directly across from the source point (viewing the source point through the lead slump gap). The second location lies on the top one meter surface, directly above the source point, viewing the source point through the gap between the radial cask body and the lower part of the primary cask lid.

For the HAC distributed source cases, the dose rates are tallied over the entire spans of the surfaces that lie one meter from the side, top and bottom of the cask body.

For each of the analyses, the peak dose rates (per source gamma) that occur on each of the (NCT or HAC) regulatory surfaces described above are determined.

From these peak dose rates, limits are calculated over the range of gamma energies 0.5-3.5 MeV and for the radionuclides Co-60 and Cs-137. The limits are determined, in source strength (γ/sec) for the point source configurations and in source strength density (γ/sec·g) for the distributed source cases. The regulatory dose rate limit for each surface is divided by the highest per-source-gamma dose rate for that surface, to yield a maximum source strength, in γ/sec. The lowest of the allowable source strengths is then selected as the limiting gamma source strength for that case. Then, for the distributed source cases (only), the allowable source strength is divided by the modeled source region mass to yield the allowable source strength density in γ/sec·g.

Analysis Method Uncertainties and Conservatisms

The MCNP-calculated dose rates are adjusted upwards to account for statistical uncertainty in the MCNP results before they are used to determine source limits. These statistical uncertainties (which are conservatively accounted for in the source limit calculations) are less than 5% for all MCNP results that govern payload source limits. Tallies with statistical uncertainties between 5% and 10 %, and those tallies that did not pass all 10 MCNP statistical checks, are evaluated to determine the suitability of the tally and rerun as necessary.

Uncertainties in the analyses performed to demonstrate that an upper-bound payload material density (of 9.0 g/cc) yields maximum cask exterior dose rates may result in an uncertainty of less than 1% in the final dose rate results. Uncertainties in evaluations performed to determine the most conservative payload material (element) to be modeled in the 0.5 MeV and 3.5 MeV gamma analyses may also result in an uncertainty of ~1% in the final dose rate results. Finally, cask exterior dose rate contributions from neglected beta sources (discussed below in Section 5.4.4) could increase the final dose rate results by as much as ~1%.

The above analytical uncertainties, which could yield as much as a 3% increase in cask exterior dose rates, will be more than offset by conservatisms in the analysis method, for virtually all actual payloads. Conservatisms include modeling minimum steel plate thicknesses, neglecting all payload self shielding and concentrating the source into a point, in the worst possible cavity location, in the γ/sec limit calculations, modeling the entire cask cavity as being filled with the highest source strength density material (that occurs anywhere within the payload) in the γ/sec·g limit calculations, rounding gamma energies up (to the nearest evaluated value) when determining source strength limits, and modeling the lowest attenuation material within the payload to determine the γ/sec·g limit. Also, as discussed below in Section 5.4.4, the method used to treat beta sources is conservative by more than a factor of 100.

The sources of uncertainty and conservatism in the analyses are discussed in more detail in Reference 5.7.2.

Although the conservatisms in the analysis would more than offset any uncertainties, for virtually all actual payloads, all final payload source limits are reduced by an administrative margin of 5%, to account for uncertainties in the analysis.

5.4.2 INPUT AND OUTPUT DATA

The MCNP input and output files are found in Reference 5.7.3. The input file lists the inputs that define the source dimensions, shield dimensions, materials and density, and source spectrum.

5.4.3 FLUX-TO-DOSE-RATE CONVERSION

The flux to exposure rate conversion factors are listed in Table 5-4 (Ref. 5.7.1).

Table 5-4 - Gamma-Ray-Flux-To-Dose-Rate Conversion Factors (ANSI/ANS-6.1.1 1977)

GammaEnergy (MeV)	DCV (rem/hr) per (γ/cm^2-sec)
0.015	1.95E-06
0.025	8.01E-07
0.045	3.17E-07
0.08	2.61E-07
0.15	3.79E-07
0.30	7.59E-07
0.50	1.15E-06
0.65	1.44E-06
0.75	1.60E-06
0.90	1.83E-06
1.25	2.32E-06
1.75	2.93E-06
2.5	3.72E-06
3.5	4.63E-06
4.5	5.42E-06
5.5	6.19E-06
6.5	6.93E-06
7.5	7.66E-06
9.0	8.77E-06
12.0	1.10E-05

5.4.4 EXTERNAL RADIATION LEVELS AND SOURCE STRENGTH LIMITS

5.4.4.1 Gamma Source Strength Limits

The results of the analyses of the bounding configurations are compared to the external radiation limits allowed for the various compliance locations identified in §71.47 and §71.51. The configuration, at each energy, that has the largest ratio of result to limit is set as the governing configuration from which the limits are established.

The final results of the shielding evaluation are the limits on payload gamma source strength (γ/sec) and payload gamma source strength density (γ/sec·g), which vary as a function of gamma energy and payload configuration. These limits are presented, for all gamma energies and all analyzed source configurations, in Table 5-5 below. The limits are presented graphically in Figure 5-3 and Figure 5-4.

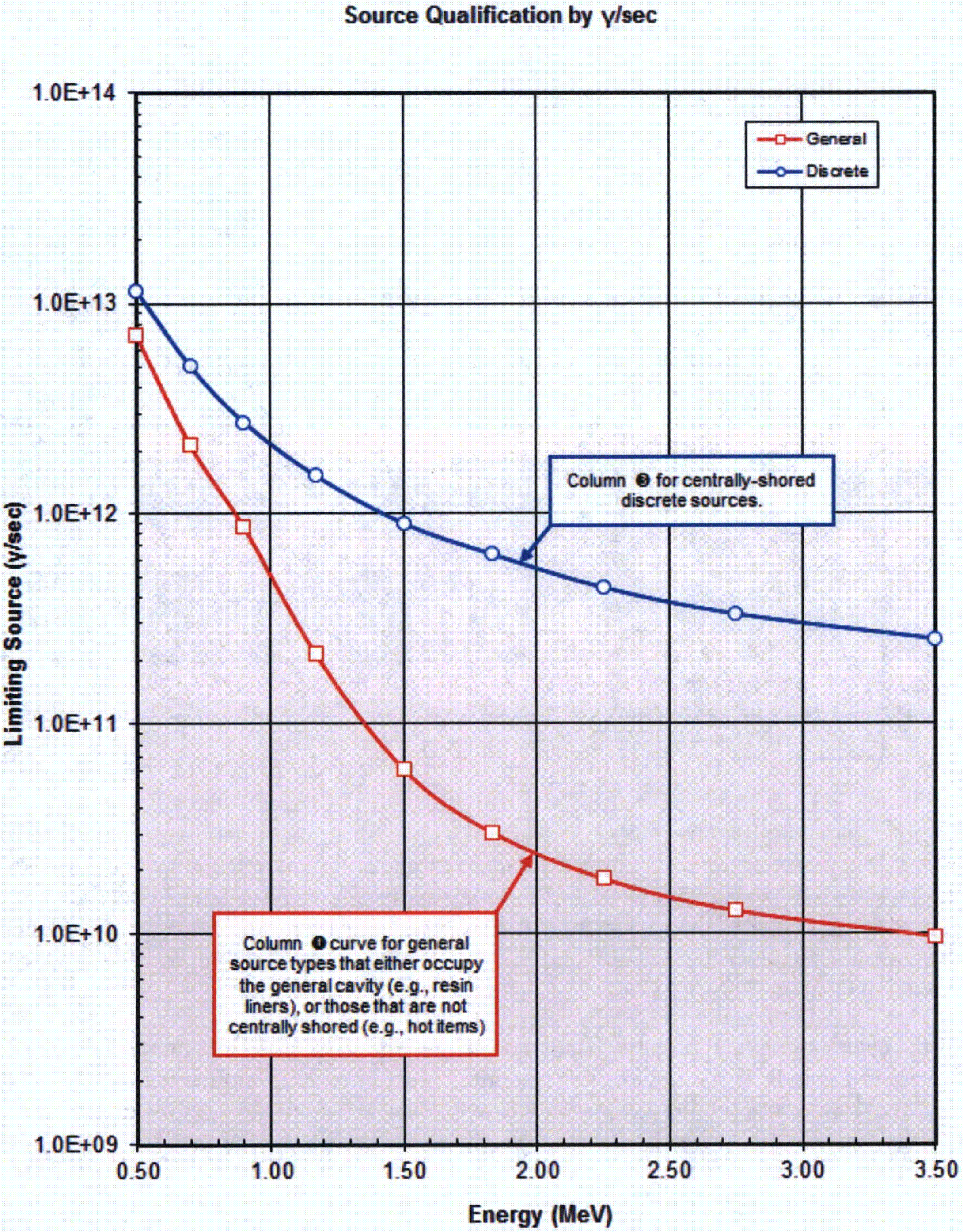
Table 5-5 - Final Payload Source Strength and Source Strength Density Limits

Energy (MeV)	General Sources		Discrete Sources (shored at centroid)*		
	Source γ/sec	Source Density γ/sec·g	Source γ/sec	Source Density γ/sec·g	
				2.5 ft^3	55 gal
	❶	❷	❸	❹	❺
3.50	9.611E+09	4.434E+05	2.504E+11	2.957E+06	1.563E+06
2.75	1.285E+10	6.515E+05	3.293E+11	4.301E+06	2.281E+06
2.25	1.823E+10	1.065E+06	4.432E+11	6.800E+06	3.634E+06
1.83	3.040E+10	2.061E+06	6.404E+11	1.279E+07	6.869E+06
1.50	6.111E+10	4.938E+06	8.971E+11	2.920E+07	1.592E+07
1.17	2.142E+11	1.640E+07	1.528E+12	8.418E+07	6.173E+07
0.90	8.635E+11	5.539E+07	2.747E+12	2.796E+08	1.919E+08
0.70	2.131E+12	1.887E+08	5.088E+12	9.566E+08	6.366E+08
0.50	7.075E+12	1.298E+09	1.151E+13	6.529E+09	4.185E+09
Co-60	1.393E+11	1.182E+07	1.294E+12	6.169E+07	4.074E+07
Cs-137	2.580E+12	2.556E+08	5.768E+12	1.281E+09	8.536E+08

**For discrete source limits, use columns ❸and ❹ when the payload object meets the 2.5 ft^3 size criteria, or columns ❸and ❺ when it meets the 55 gallon size criteria. When the size meets neither criteria use columns ❶and ❷.*

The "general" source limits shown in the left side of Table 5-5 apply for payloads that fill most of the cask cavity or are not shored within a smaller volume at the cavity center. The discrete source limits shown in the right part of Table 5-5 may apply if the payload meets the size criteria and is shored to the center of the cask cavity. (There are also restrictions on height and diameter, for payloads qualified under the "2.5 ft^3" and "55 gal" limits shown above in Table 5-5, which are discussed in Chapter 7 of this SAR.)

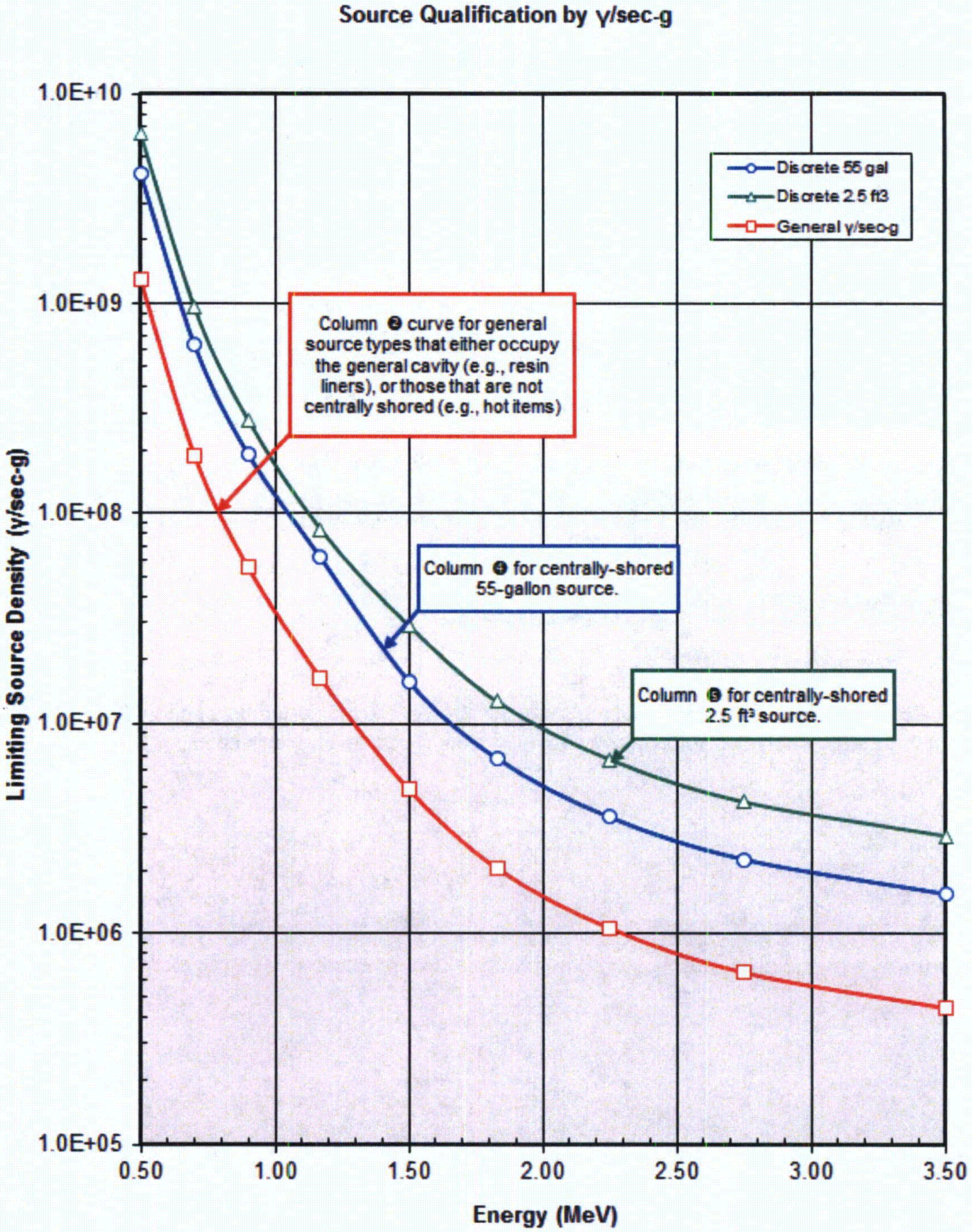
Detail of the calculations (and process) used to determine the payload source limits shown in Table 5-5 are found in Ref. 5.7.2. Note a 5% administrative margin is applied which effectively reduces all the source strength limits presented above in Table 5-5 by 5%. Application of the margin (as part of the sum of fractions method) is discussed below in Section 5.5.



Column ❸ for centrally-shored discrete sources.

Column ❶ curve for general source types that either occupy the general cavity (e.g., resin liners), or those that are not centrally shored (e.g., hot items)

Figure 5-3 - Payload Gamma Source Strength Limit vs. Gamma Energy



Column ❷ curve for general source types that either occupy the general cavity (e.g., resin liners), or those that are not centrally shored (e.g., hot items)

Column ❹ for centrally-shored 55-gallon source.

Column ❺ for centrally-shored 2.5 ft³ source.

Figure 5-4 - Payload Gamma Source Strength Density Limit vs. Gamma Energy

5.4.4.2 Beta Source Strength Limits

Beta particles lose their energy continuously as they pass through matter, emitting Bremsstrahlung gammas over their range. These Bremsstrahlung gammas, however, have the potential to be significant contributors to package dose rates because the allowable (3000 A_2) source activity for betas can be much higher than for gamma emitters (e.g., as much as 42,000 Ci of ^{32}P vs. 4144 Ci of ^{137}Cs). The method for qualifying significant 8-120B beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in Section 5.5.

This method is only applied to beta sources (pure beta emitters) with activities greater than 2E+12 betas per second, and peak beta energy levels between 0.3 MeV and 3.5 MeV. Isotopes with peak beta energies less than 0.3 MeV can be neglected. Isotopes with peak beta energies over 3.5 MeV may not be shipped in the cask. Beta source strengths less than 2E+12 betas per second do not contribute significantly to cask exterior dose rates and are, thus, not significant. See Ref. 5.7.2 for additional details and validating calculations.

The beta source can be converted to an equivalent gamma source by:

$$S_\gamma = S_\beta \cdot \frac{S_\gamma}{S_\beta}$$

where

S_γ = equivalent monoenergetic gamma source strength, γ/sec, at the maximum beta energy E_{max}.
S_β = beta source strength, β/sec, at the beta energy spectrum for the nuclide of interest

and

$$\frac{S_\gamma}{S_\beta} = (\mathit{fraction\,of\,energy\,converted\,from\,betas\,to\,photons})\left(\frac{\mathit{beta}\,E_{avg}}{\mathit{photon\,energy}}\right)$$

Conservatively assume all gammas are at the beta maximum energy E_{max}, the energy ratio becomes:

$$\frac{S_\gamma}{S_\beta} = f\left(\frac{E_{avg}}{E_{\max}}\right)$$

where

E_{avg} = average energy of the beta source distribution, MeV
E_{max} = maximum energy of the source distribution, MeV.

The fraction of the incident beta energy that is converted to gamma energy, f, is given by (Ref. 5.7.3).

$$f \cong 3.5 \times 10^{-4} Z E_{\max}$$

where

f = the fraction of the incident beta energy that is converted to gamma energy,
Z = atomic number of the absorber

So

$$\frac{S_\gamma}{S_\beta} = 3.5 \times 10^{-4} Z E_{\max} \left(\frac{E_{avg}}{E_{\max}} \right)$$

The resulting equation to convert a beta source to an equivalent gamma source at the beta's maximum energy is therefore:

$$S_\gamma = S_\beta \left(3.5 \times 10^{-4} Z E_{avg} \right)$$

For a single material absorber, use the Z of the material. For compounds or mixtures, use a weighted average Z_w:

$$Z_W = \sum_{i=1}^{n} \left(\frac{m_i}{m_{total}} \cdot Z_i \right)$$

Z_w should be determined, as described above, for both the waste payload and the wall of the secondary container (liner) that the waste resides in. Then, the higher of the two Z_w values should be conservatively used as the basis of the equivalent gamma source calculation. This conservatism is necessary since it is not known what fraction of the beta-to-gamma conversion occurs within the waste material and within the secondary container wall material.

The proposed method for qualifying significant 8-120B beta emitters is to represent the beta emitter as an equivalent gamma emitter and treat it like any other gamma energy line per the methods described in the remainder of this calculation. In this way, significant beta emitters can be accounted for along with other gamma emitters. The entire (equivalent) gamma source (S_γ) is modeled at the same energy as the peak beta energy for the beta-emitting isotope. This gamma energy level is rounded up to the nearest (higher) gamma energy level for which source limits are presented in Table 5-5.

For common container and waste materials (for which Z is 26 or less), the formula above yields an equivalent gamma source that is less than 1% of the isotope's beta source. Furthermore, comparisons to rigorous MCNP beta shielding analyses show that the method (and formula) described above yields cask exterior gamma dose rates (due to payload beta emissions) that are conservative (high) by more than a factor of 100. Thus, a beta source will yield cask exterior dose rates that are only ~0.01% as high as the cask exterior dose rates produced by a gamma source of the same strength and energy level.

For the above reasons, the beta source for isotopes that emit both betas and gammas can be neglected, since any cask exterior dose rate contributions from the beta source will be negligible compared to those produced by the isotope's gamma source. Thus, the procedure described above is only to be used for pure beta-emitting isotopes with a significant beta source.

A procedure for evaluating beta emitters is included in Chapter 7 Attachment 1 which establishes limits for large activity beta sources.

5.5 PAYLOAD QUALIFICATION

Radioactive 8-120B contents must be qualified to ensure the shipment will meet the regulatory dose limits from §71.47 and §71.51

To qualify a payload, the cask user determines 1) a gamma source strength (γ/sec) and 2) a gamma source strength density (γ/sec·g) for their payload, based on the gamma energy that applies for the payload, whether the payload is shored at the cavity centroid, and the size and volume of the payload. The payload qualifies for shipment in the 8-120B cask if it meets either one of the source strength or source strength density limits in Table 5-5. Note that when determining compliance with the source strength density limit, the highest source strength density (or "hottest") section of the waste must be used (i.e., the "hottest" material that occurs anywhere within the waste or within any waste/payload item). Averaging of the source strength density, between payload items or within any payload item, is not allowed.

To qualify payloads that emit gammas at multiple energies or when portions of the payloads are radiologically different, a sum of fractions approach is used. For multiple payload items, the user performs a separate qualification evaluation for each payload item/energy, and then use a sum of fractions approach to qualify the overall cask payload. For each gamma energy or payload item, two fractions are determined, one based on the ratio of the payload source strength (γ/sec) over the allowable source strength, and one based on the ratio of the source strength density (γ/sec·g) over the allowable source strength density. The lower of the two fractions is then selected, for each gamma energy or payload item. The resulting fractions are then summed. The total (sum of fractions) may not exceed 0.95.

Note that the qualification procedure is performed for each gamma energy emitted by the waste, and that the procedures performed for each gamma energy are completely independent. Thus, a payload item may qualify under the γ/sec limit for one gamma energy, and qualify under the γ/sec·g limit for a different gamma energy (although this is unlikely). Each gamma energy is evaluated separately because a separate, independent shielding analysis is performed for each gamma energy. For each gamma energy, the γ/sec and γ/sec·g limits are determined using shielding models that are bounding for any payload configuration. Thus, for each gamma energy, any payload that meets either the γ/sec limit or the γ/sec·g limit (established for that gamma energy) will not yield cask exterior dose rates over regulatory limits. Cask exterior dose rate contributions from multiple gamma energies are effectively summed through the use of the sum of fractions approach described above.

When determining the γ/sec and γ/sec·g limits, payload gamma energy levels are conservatively rounded up to the nearest (higher) gamma energy level for which source limits are presented in Table 5-5. Given this rounding, multiple payload gamma energies can be combined into a single, overall source, which is then compared to the source strength limits (shown in Table 5-5) which correspond to a gamma energy that is equal to or higher than that of all the gamma energies within the combined group.

This qualification process is shown in the flowchart below (Figure 5-5)

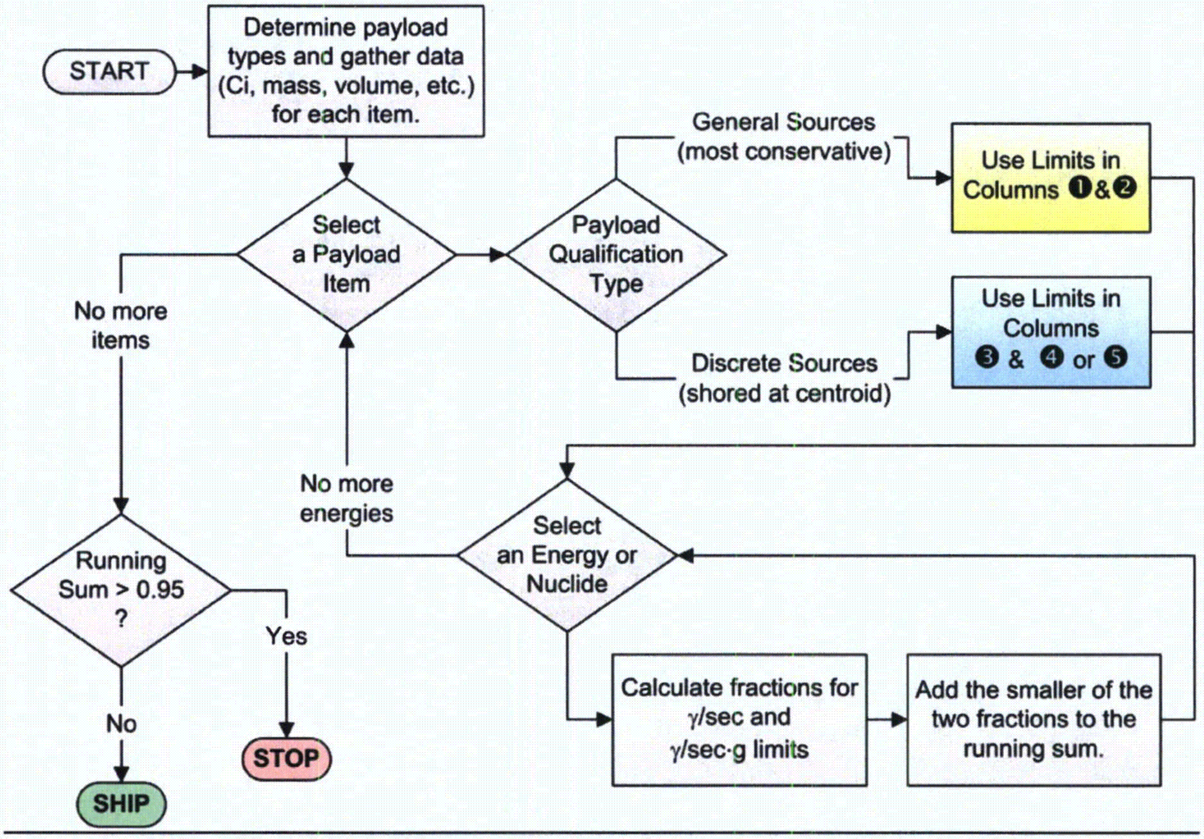


Figure 5-5 - Payload Qualification Flow Chart

5.6 CONCLUSION

The cask shielding must be able to limit the dose rate to the limits of §71.47 and §71.51. This section demonstrates compliance with this requirement. Structural analysis (Section 2.0) demonstrates that the cask wall will not fail during the hypothetical accident. However, lead slump may occur during a drop giving an isolated region in the sidewall without lead. Lead slump cannot occur in the lid or bottom of the cask since lead is not present in these parts of the cask. With application of the source qualification process from Section 5.5, the contents will meet the dose rate limits.

5.7 REFERENCES

5.7.1 ANSI/ANS 6.1.1-1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."
5.7.2 ES Calculation, NU-391 Rev. 7, "8-120B Shielding Response"
5.7.3 Cember, H., "Introduction to Health Physics," Pergamon Press, 2nd Ed.
5.7.4 ES Document, 10-160B SAR, Consolidated Revision. 5, 2012

6.0 CRITICALITY EVALUATION

Not applicable to the 8-120B package.

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7.0 OPERATING PROCEDURE

This chapter describes the general procedure for loading and unloading of the 8-120B Cask.

The maximum permissible activity is the lesser of the activity determined by: 1) Attachment 1 for beta and gamma emitters, 2) 3000 A_2, or 3) having a decay heat of 200 watts. Radioactive contents are to be transported as exclusive use, per 10 CFR 71.4.

For contents that could radiolytically generate combustible hydrogen, see Attachment 2 for instructions on determination of hydrogen concentration.

Powdered solids shipments require that the most recent periodic leak test meets the requirements of Section 8.3.2.1 for leaktight status.

7.1 LOADING THE PACKAGING

NOTE: Prior to loosening the impact limiter ratchet binders, inspect the exterior of the package for damage, e.g., large dents, gouges, tears to the impact limiter skin and thermal shield. Contact EnergySolutions if damage is present. The cask may not be used as a Type B package until the damage is assessed by Energy*Solutions* and repairs, if required, are made to achieve conformance with the drawings listed in the CoC.

7.1.1 Impact Limiter Removal

7.1.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.1.1.2 Using suitable lifting equipment, remove upper impact limiter assembly. Care should be exercised to prevent damage to impact limiter during handling and storage.

7.1.2 Secondary Lid Thermal Shield Removal

7.1.2.1 Remove the ball lock pins from each of the three retaining pins and remove the retaining pins from secondary lid lift lugs.

7.1.2.2 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.

7.1.3 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.1.3.1 Disconnect cask to trailer tie-down equipment.

7.1.3.1.1 Inspect cask lifting ear bolts for defects. Obtain replacement bolts as specified on the drawing listed in 5(a)(3) of the CoC for any bolts that show cracking or other visual signs of distress.

7.1.3.1.2 Inspect cask lifting ear threaded holes for defects. Contact Energy*Solutions* if any bolt holes show signs of cracking or visual signs of distress.

7.1.3.2 Attach cask lifting ears and torque bolts to 200 ft-lbs. ± 20 ft-lbs. lubricated.

NOTE: The cables used for lifting the cask must have a true angle, with respect to the horizontal of not less than 60°.

7.1.3.3 Using suitable lifting equipment, remove cask from trailer and the lower impact limiter and place cask in level loading position.

NOTE: In certain circumstances, loading may be accomplished through the secondary lid, into a pre-positioned waste liner that has been properly shored or into pre-positioned shoring, while the primary lid remains on the cask. Alternate "(A)" steps have been included to accommodate this situation.

7.1.4 Loosen and remove the twenty (20) bolts, which secure the primary lid to cask body.

7.1.4A Loosen and remove the twelve (12) bolts, which secure the secondary lid to the primary lid.

7.1.5 Inspect the bolts for defects. Obtain replacement bolts as specified on the drawing listed in 5(a)(3) of the CoC for any bolts that show cracking or other visual signs of distress.

NOTE: The cables used for lifting either lid must have a true angle, with respect to the horizontal, of not less than 45°.

7.1.6 Remove primary lid from cask body using suitable lifting equipment. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

7.1.6A Remove secondary lid from cask body using suitable lifting equipment. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

7.1.7 Inspect the bolts holes for defects. Contact Energy*Solutions* for any bolt holes that show signs of cracking or visual signs of distress.

7.1.8 Inspect cask interior for damage, loose materials or moisture. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing. Contact EnergySolutions if damage is present.

NOTE: **Radioactively contaminated liquids may be pumped out or removed by use of an absorbent material. Removal of any material from inside the cask shall be performed under the supervision of qualified health physics personnel with the necessary H.P. monitoring and radiological health safety precautions and safeguards.**

NOTE: **When seals are replaced, leak testing is required as specified in Section 8.3.2.1.**

NOTE: **Verify intended contents meet the requirements of the Certificate of Compliance.**

NOTE: **Ensure the contents, secondary container, and packaging are chemically compatible, i.e., will not react to produce flammable gases.**

7.1.9 Place disposable liner, drums or other containers into the pre-positioned shoring and install additional shoring or bracing, if necessary, to restrict movement of contents during normal transport.

7.1.9A Process liner as necessary, and cap using standard capping devices. Provide shoring if necessary to limit movement during transport, or if required by the radiological qualification procedure of Attachment 1.

7.1.10 Perform two independent physical verifications of the secondary container's closure system to ensure that it is properly closed and secured. This requirement is waived[1] for uniformly distributed resins, filters, and for solidified wastes with no dimension less than 1 cm.

7.1.11 Clean and inspect lid seal surfaces.

7.1.12 Replace the primary lid on the cask body. Secure the lid by hand tightening the twenty (20) primary lid bolts.

7.1.12.1 Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 250 ft-lbs. ± 25 ft-lbs.

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[1] The basis for double verification is to assure that small, high-specific activity particles do not have the potential to migrate up into the annular gap between the primary lid and the cask bolting flange. Payloads containing any form of isotope sources, or containing highly activated fines, swarf, crud, or other hot particles less than 1 cm in size are therefore not exempt.

7.1.12.2 Re-Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 500 ft-lbs. ± 50 ft-lbs.

7.1.12A Replace the secondary lid on the primary lid. Secure the lid by hand tightening the twelve (12) secondary lid bolts.

7.1.12.1A Torque, using a star pattern, the twelve (12) secondary lid bolts (lubricated) to 250 ft-lbs. ± 25 ft-lbs.

7.1.12.2A Re-torque, using a star pattern, the twelve (12) secondary lid bolts (lubricated) to 500 ft-lbs. ± 5 0 ft-lbs.

7.1.13 Replace the vent port cap screw and seal (if removed) and torque to 20 ft-lbs. ± 2 ft-lbs.

7.1.14 Leak test the primary lid and secondary lid O-rings and the vent port, in accordance with Section 8.3.2.2, prior to every shipment.[2]

7.1.15 If cask has been removed from trailer, proceed as follows to return cask to trailer:

7.1.15.1 Using suitable lifting equipment, lift and position, cask into lower impact limiter on trailer in the same orientation as removed.

7.1.15.2 Unbolt and remove cask lifting ears.

7.1.15.3 Reconnect cask to trailer using tie-down equipment.

7.1.16 Installation of Upper Impact Limiter and Secondary Lid Thermal Shield

7.1.16.1 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.

7.1.16.2 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs and insert the ball lock pins into the retaining pins.

7.1.16.3 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.

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[2] The pre-shipment leak test of the primary lid, secondary lid, and vent port seals is required before every 8-120B cask shipment, even if the lid bolts or vent port socket head cap screw have not been loosened during loading operations. This requirement is necessary to assure that the 8-120B cask containment system is properly assembled prior to every shipment since it should not be assumed that the containment system is properly assembled prior to loading operations.

7.1.17 Attach and hand tighten ratchet binders between upper and lower impact limiter assemblies.

7.1.18 Cover lift lugs as required.

7.1.19 Inspect package for proper placards and labeling.

7.1.20 Complete required shipping documentation.

7.1.21 Prior to shipment of a loaded package, the following shall be confirmed:

7.1.21.1 That the licensee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 20.1906(a) meets and follows the requirements of 10 CFR 20.1906, as applicable.

7.1.21.2 That trailer placarding and package labeling meet DOT specifications (49 CFR 172).

7.1.21.3 That the provisions of 10 CFR 71.87 are met including that the external radiation dose rates are less than or equal to 200 millirem per hour (mrem/hr) at the surface and less than or equal to 10 mrem/hr at 2 meters in accordance with 10 CFR 71.47 by performing radiation surveys. These surveys should be sufficient to ensure that a non-uniform distribution of radioactivity does not cause the surface or 2m limit to be exceeded.

The SAR thermal analysis demonstrates that by meeting the 200w decay heat limit, the temperature requirement of 10 CFR 71.43(g) is met. No temperature survey is required.

7.1.21.4 That all security seals are properly installed.

7.1.21.5 Prior to shipping a loaded package, inspect the exterior of the cask for damage, e.g., large dents, gouges, tears to the impact limiter skin and thermal shield. Contact Energy*Solutions* if damage is present.

7.1.21.6 Prior to shipping a loaded package, confirm that the periodic leak test described in Section 8.3.2.1 has been performed. For shipments of powdered radioactive materials, confirm that most recent periodic leak test of the 8-120B demonstrated leaktight status.

7.2 UNLOADING THE PACKAGE

In addition to the following sequence of events for unloading a package, packages containing quantities of radioactive material in excess of Type A quantities specified in 10 CFR 20.1906(a) shall be received, monitored, and handled by the licensee receiving the package in accordance with the requirements of 10 CFR 20.1906, as applicable. Identification of packages containing greater than Type A quantities can be made by review of the shipping papers accompanying the shipment.

7.2.1 Move the unopened package to an appropriate level unloading area.

7.2.2 Perform an external examination of the unopened package. Record any significant observations.

7.2.3 Remove security seal(s), as required.

7.2.4 Impact Limiter Removal

7.2.4.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.2.4.2 Using suitable lifting equipment, remove upper impact limiter assembly. Care should be exercised to prevent damage to impact limiter during handling and storage.

7.2.5 Secondary Lid Thermal Shield Removal

7.2.5.1 Remove the ball lock pins from each of the three retaining pins and remove the retaining pins from secondary lid lift lugs.

7.2.5.2 Using suitable lifting equipment, remove the secondary lid thermal shield. Care should be taken to prevent damage to thermal shield during handling and storage.

7.2.6 If cask must be removed from trailer, refer to Step 7.1.3.

7.2.7 Loosen and remove the twenty (20) primary lid bolts.

NOTE: The cables used for lifting the lid must have a true angle with respect to the horizontal of not less than 45 degrees.

7.2.8 Using suitable lifting equipment, lift lid from cask using care during handling operations to prevent damage to cask and lid seal surfaces.

7.2.9 Remove contents.

NOTE: Radioactively contaminated liquids may be pumped out or removed by use of an absorbent material. Removal of any material from inside the cask shall be performed under the supervision of qualified health physics personnel with the necessary H.P. monitoring and radiological health safety precautions and safeguards.

7.2.10 Assemble packaging in accordance with loading procedure (7.1.10 through 7.1.19).

7.3 PREPARATION OF EMPTY PACKAGING FOR TRANSPORT

7.3.1 Confirm the cavity is empty of contents are far as practicable

7.3.2 Survey the interior; decontaminate the interior if the limits of 49 CFR 173.428(d) are exceeded

7.3.3 Install the lid.

7.3.4 Install the lid closure bolts.

7.3.5 Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 250 ft-lbs. ± 25 ft-lbs.

7.3.6 Re-Torque, using a star pattern, the twenty (20) primary lid bolts (lubricated) to 500 ft-lbs. ± 50 ft-lbs.

7.3.7 Re-install the vent port cap screw with the seal. Torque the vent port cap screw to 20±2 ft-lbs.

7.3.8 Decontaminate the exterior surfaces of the package as necessary.

7.3.9 Inspect the exterior and confirm it is unimpaired.

7.3.10 Using suitable lifting equipment, lift, inspect for damage and install the secondary lid thermal shield.

7.3.11 Install the three secondary lid thermal shield retaining pins into the secondary lid lift lugs and insert the ball lock pins into the retaining pins.

7.3.12 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed

7.3.13 Attach the tamper-indicating seals.

7.3.14 Confirm the requirements of 49 CFR 173.428 are met.

Attachment 1
Determination of Acceptable Beta and Gamma Source Strength

(see Chapter 5 for the derivation of the beta and gamma source strength limits)

Background and Definitions

8-120B contents (payloads) have acceptable beta and gamma sources when they can be shown to meet the requirements in Table 7-1 using the procedure described in this Attachment. Source qualification is based on a sum-of-fractions method, where sources are broken down into separate gamma energy lines and compared to the corresponding limit for that group. For some payloads, it may be necessary to subdivide the payload into separate items, determining fractions for each item by energy group then summing the fractions to determine acceptability.

Table 7-1 categorizes the limits into source strength (γ/sec) and source strength density (γ/sec·g). For each energy, the fraction to be summed is the lowest of the γ/sec and γ/sec·g fractions. Table 7-1 has five columns of limits, denoted ❶ through ❺. Depending on the nature of the payload, the user must select a pair of columns to use for each payload item, one γ/sec column and one γ/sec·g column. The "general" payload columns (❶,❷) are the most conservative and are suitable for any payload item. Higher limits are acceptable for special cases where a reduced volume item is shored about the centroid of the package cavity (e.g., an isotope source). These are termed "discrete" payload items, and are distinguished as follows:

- Use the 2.5 ft^3 limits (❸,❹) when the payload item has a volume of 2.5 ft^3 (70,792 cm) or less, a height of 28 inches (71.16 cm) or less, and a diameter of 17.65 inches (44.84 cm) or less, and is shored at the centroid of the cavity.
- Use the 55-gallon limits (❸,❺) when the payload item has a volume of 7.7 ft^3 (218,868 cm^3) or less, a height of 33.5 inches (85.1 cm) or less, and a diameter of 25.7 inches (65.3 cm) or less, and is shored at the centroid of the cavity.
- If the payload item does not meet the requirements of either the 2.5 ft^3 or 55-gallon definitions, regardless of shoring, then use the γ/sec limit for general sources ❶, and the general γ/sec·g limit ❷.

Source limits from Table 7-1 may not be interpolated in energy. The proper procedure for gammas (and for equivalent bremsstrahlung gammas) is to round source energies up to the next higher energy level in Table 7-1.

For the purpose of qualification, the total γ/sec source strength for the entire payload is determined for each gamma energy group. Then, for each gamma energy group, the γ/sec·g source strength density is conservatively determined based on the highest source strength ("hottest") portion of the payload. Averaging of the source strength density is not allowed, either between payload items or within payload items. This conservative approach ensures that package dose rate limits will be met, even for payloads for which the source strength density is not uniform within its volume/mass, since the analysis and qualification is based on the highest source strength density material that occurs anywhere within the payload. Once the applicable γ/sec source strength and γ/sec·g source strength density are determined for the payload, they are compared to the corresponding limits that are determined as discussed above.

For some payloads, use of the highest source strength density may be inappropriately conservative (e.g., payloads with a small mass of high source strength density material within a large mass of much lower source strength density material). The qualification methodology takes these payloads into consideration, and allows the payload to be separated into distinct components (or "payload items"), for which the qualification process is performed separately (e.g., one qualification for the high source strength density components/materials and another qualification for the low source strength density materials). As an example, for radiologically non-homogenous materials such as contaminated soil with hot "chunks", the components would be the soil and the hotter particles.

Crud/contamination (or any similar finely distributed powder or granular) sources must be treated separately if there is a potential for redistribution (i.e., if the source is not chemically or physically bound to its substrate or bulk material). In such cases, the crud (or powder) source component must be qualified using only the γ/sec limits.

Gamma sources below 0.3 MeV may be neglected. Any sources with gamma energies above 3.5 MeV are not qualified at this time. Table 7-1 has two special rows for the common radioactive nuclides, ^{60}Co and ^{137}Cs; and so their fractions may be calculated directly without breaking them down into their separate energy lines.

Pure beta emitters (e.g., ^{3}H, ^{32}P, ^{35}S, ^{90}Sr, ^{90}Y) can affect package exterior gamma dose rates due to bremsstrahlung radiation. These emitters must therefore be qualified by converting the beta source strength into an equivalent bremsstrahlung (gamma) source and entering the equivalent gammas like any other gamma source line in the sum-of-fractions. Beta sources with maximum beta energies below 0.3 MeV or payload source strengths less than 2E+12 β/sec may be neglected. Beta sources with peak beta energies over 3.5 MeV are not qualified at this time. Beta source strength from isotopes with significant gamma source strength may also be neglected. The method for converting betas is presented in the procedure below and the methodology is discussed in Chapter 5 of the SAR.

Payload items with densities between 0.0 and 9.0 g/cc are within the range of validity for Table 7-1 γ/sec·g limits. Most materials fall within this range, with the exception of lead and some exotic metals. Do not consider liner, or other secondary container, materials when calculating density. Densities are for the basic material, and should not include voids. Radioactive payload items with densities above 9.0 g/cc must be qualified using the γ/sec limits alone.

In summary, all sources must be accounted for using the sum-of-fractions method described in the following procedure. The only sources which may be considered insignificant (and not included in the sum-of-fractions) are:

- Gammas with energies below 0.3 MeV,
- All pure beta emitters with peak energies below 0.3 MeV,
- Pure beta emitters with peak energies above 0.3 MeV when the combined source of all such betas is under 2×10^{12} β/sec.
- Beta emissions from gamma-emitting isotopes.

Table 7-1 - Payload Source Strength and Source Strength Density Limits

Energy (MeV)	**General Sources**		**Discrete Sources (shored at centroid)***		
	Source γ/sec	Source Density γ/sec·g	Source γ/sec	Source Density γ/sec·g	
				2.5 ft^3	55 gal
	❶	❷	❸	❹	❺
3.50	9.611E+09	4.434E+05	2.504E+11	2.957E+06	1.563E+06
2.75	1.285E+10	6.515E+05	3.293E+11	4.301E+06	2.281E+06
2.25	1.823E+10	1.065E+06	4.432E+11	6.800E+06	3.634E+06
1.83	3.040E+10	2.061E+06	6.404E+11	1.279E+07	6.869E+06
1.50	6.111E+10	4.938E+06	8.971E+11	2.920E+07	1.592E+07
1.17	2.142E+11	1.640E+07	1.528E+12	8.418E+07	6.173E+07
0.90	8.635E+11	5.539E+07	2.747E+12	2.796E+08	1.919E+08
0.70	2.131E+12	1.887E+08	5.088E+12	9.566E+08	6.366E+08
0.50	7.075E+12	1.298E+09	1.151E+13	6.529E+09	4.185E+09
Co-60	1.393E+11	1.182E+07	1.294E+12	6.169E+07	4.074E+07
Cs-137	2.580E+12	2.556E+08	5.768E+12	1.281E+09	8.536E+08

**For discrete source limits, use columns ❸ and ❹ when the payload object meets the 2.5 ft^3 size criteria, or columns ❸ and ❺ when it meets the 55 gallon size criteria. When the size meets neither criteria use columns ❶ and ❷.*

Qualification Procedure

The Payload Qualification Flowchart (Figure 7-1) provides a graphical overview of the qualification process. The procedure below provides more detailed step-wise instructions.

1. Determine the number of types of material (payload items) in the payload. For each item, determine the configuration (i.e., general or discrete), isotopic source strength (in γ/sec), isotopic source strength density (in γ/sec·g for the hottest portion of the payload item), dimensions, volume, mass, and maximum mass density. Determine the payload totals for each parameter.

2. For payloads that include pure beta emitters with maximum beta energies > 0.3 MeV and $\sum S_\beta \geq$ 2E+12 β/sec, convert each beta source to an equivalent gamma source for each payload item.

   - Confirm that no isotope peak beta energies are > 3.5 MeV; materials with beta energies > 3.5 MeV are unacceptable.
   - The equivalent gamma source for each payload item, S_γ, equals 3.5E-04 S_β Z_w $E_{\beta avg}$ in gammas per sec; where:

     S_β is the beta source strength in β/sec ,
     Z_w is the weighted average Z of the beta-absorbing material; for a single material absorber, use the Z of the material, for compounds or mixtures, use a weighted average Z_w:

     $$Z_W = \sum_{i=1}^{n}\left(\frac{m_i}{m_{total}} \cdot Z_i\right)$$

     Z_w is determined, as described above, for both the waste payload and the wall of the secondary container (liner) that the waste resides in, the higher of the two Z_w values is used, and
     $E_{\beta avg}$ is the <u>average</u> energy of the beta in MeV.

   - The resulting equivalent gamma source has strength S_γ at an energy of $E_{\beta max}$, the <u>maximum</u> beta energy.
   - Include the equivalent gamma source along with the other gamma source(s) determined in Step 3.
   - Equivalent gamma energies must be rounded up to the next higher energy level listed in Table 7-1.

3. For each gamma energy of each payload item (ignoring gamma energies below 0.3 MeV), calculate the total γ/sec for the payload item <u>and</u> the γ/sec·g for the hottest (highest source strength density) portion of the item.

   - ^{60}Co and ^{137}Cs may be treated like single "energies" since they have their own limits in Table 7-1.
   - Gamma energies must be rounded up to the next higher energy level listed in Table 7-1.

   - If any gammas have energies above 3.5 MeV, the material is unacceptable for transport in the package.
   - For payloads with a large number of gammas, the gammas may be grouped into the energy groups in Table 7-1and the total gamma sources can be determined for each group. The energies listed in Table 7-1are the maximum energies for the groups.
   - Calculations of γ/sec·g should not include the mass of liners or other secondary containers.

4. For each payload item, select the two appropriate limit columns (❶ through ❺) in Table 7-1: one each for γ/sec and γ/sec·g. Base the γ/sec on the total γ/sec for the item, and the γ/sec·g on the highest source strength density ("hottest") portions of the item.

   - Confirm that the density of each payload item is less than 9.0 g/cm$^{3.}$ Items with higher densities can only be qualified using the γ/sec limits because the γ/sec·g limits are not valid for $\rho \geq 9.0$ g/cm^3.
   - For "discrete" sources, confirm that the sources meet the shoring requirement and the volume and the physical dimension specifications listed in the beginning of this Attachment.
   - Crud/contamination (or powder) payload items can only be qualified using the γ/sec limits (Table 7-1, column ❶ or ❸).

5. For each energy, calculate the γ/sec and γ/sec·g fractions (i.e., payload item source/limit fraction). Select the <u>smallest</u> of each pair of fractions at each energy and add the resulting fraction to the running sum of fractions.

6. Repeat Steps 4-5 for each payload item, adding the fractions to the running sum.

7. If the sum-of-fractions is less than 0.95, the payload's radiological source is acceptable.

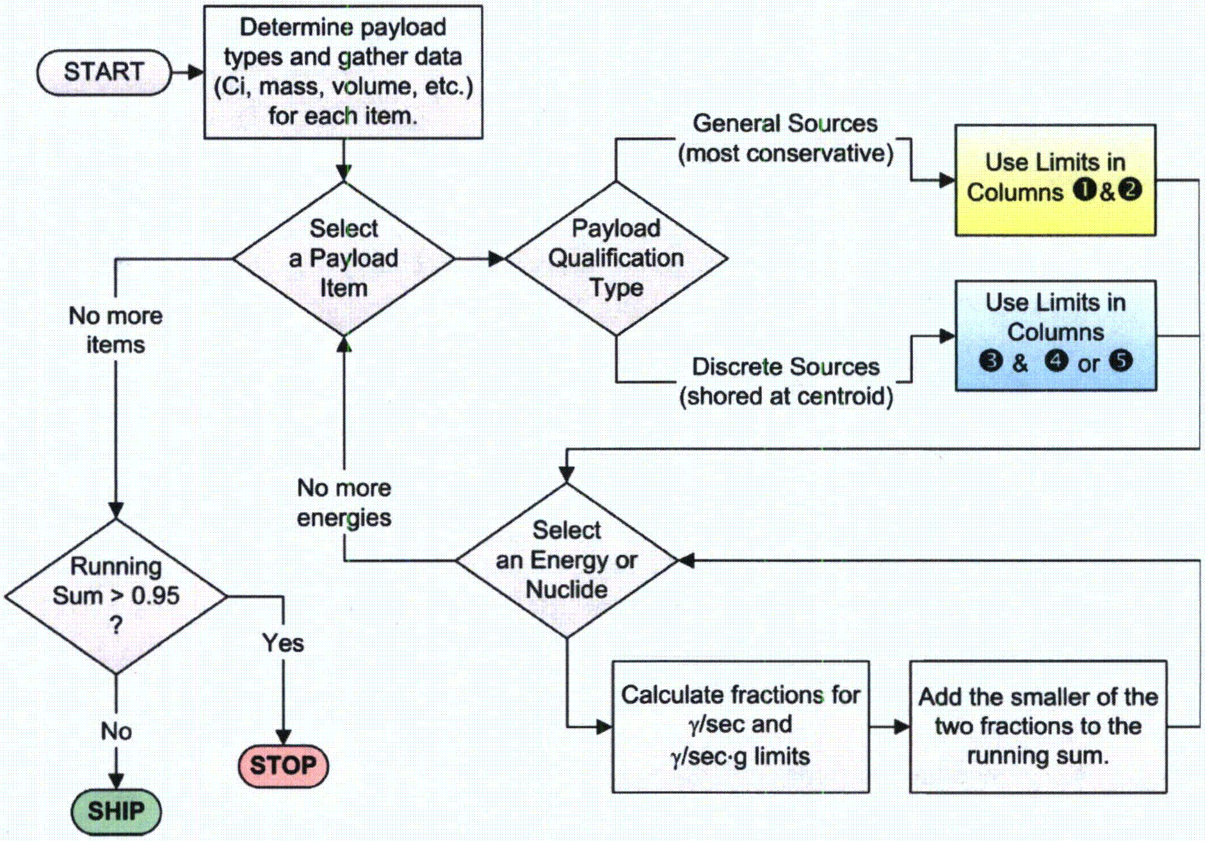

Figure 7-1 – Payload Qualification Flow Chart

Example 1 - Cs-137 Source Capsule

Problem: Determine the acceptability of a 50 Ci ^{137}Cs source to be centrally shored. The source is a metal capsule 2 cm in diameter by 10 cm long, and the Cs source pellet weighs 50 g.

Step 1: Characterize Source

Given in the problem statement.

Step 2: Convert Beta Source to Equivalent Gamma Source

Not applicable (Cs-137 is not a pure beta emitter).

Step 3: Calculate Gamma Source Strengths and Source Strength Densities

The qualification Table has specific limits for ^{137}Cs, so it is not necessary to do the qualification by energy line. The source's Ci source strength must be converted to γ/sec and γ/sec·g in order to calculate the source/limit fractions. ^{137}Cs produces 0.85 gammas per decay with an energy of 0.66 MeV. The total source strength is

$$3.7\times10^{10}\,\frac{d}{Ci}\times\frac{0.85\gamma}{d}\times 50Ci = 1.57\times10^{12}\,\frac{\gamma}{\sec},$$

and, dividing by 50 g, the total source strength density is 3.14E10 γ/sec·g.

Step 4: Select the Limits

Since this payload is to be shipped in a shored configuration, the payload is a "discrete" type payload. The size fits within the defined envelope for the 2.5 ft^3 payload, therefore the column ❸ and ❹ limits apply for γ/sec and γ/sec·g, respectively.

Steps 5-7 Sum the Fractions

For this example, there is only one fraction to calculate[3].

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits			Fractions, F		F_{min}
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	Source	Discrete	2.5 ft3	Cs-137	1.57E+12	3.15E+10	Cs-137	❸ 5.77E+12	❹ 1.28E+09	2.73E-01	2.46E+01	2.73E-01
											Sum:	2.73E-01

Since the sum is less than 0.95, the source is an acceptable payload.

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[3] Always perform calculations with the full precision for the limits shown in Table . In these examples, full precision data was used, but the number of digits is reduced for presentation purposes.

Example 2 – Solidified Process Waste

Problem: Determine the acceptability of a 100 ft^3 secondary container containing solidified process waste. The activity is uniformly distributed. The measured weight of the filled container is 13,100 lbs, and the weight of the empty container is 1,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is:

5 Ci of ^{60}Co, 10 Ci of ^{137}Cs, 50 Ci of ^{55}Fe, 4 Ci of ^{54}Mn, and 20 Ci of ^{90}Sr

Step 1: Characterize Source

Given in the problem statement.

Step 2: Convert Beta Source to Equivalent Gamma Source

^{90}Sr emits beta radiation through its own decay, plus the decay of its short-lived daughter product, ^{90}Y. So the beta production rate is 20 Ci * 3.7E+10 d/Ci *2 = 1.5E+12 β/sec. Since this is below the threshold of 2E+12 β/sec, the beta production is not significant and can be disregarded.

Step 3: Calculate Gamma Source Strengths and Source Strength Densities

The qualification Table has specific limits for ^{60}Co and ^{137}Cs, but it will be necessary to do the qualification by energy line for the remaining nuclides. After converting the Ci data to gamma energy lines for the remaining nuclides (neglecting any gamma energy lines < 0.3 MeV), the following source data are to be used for qualification. The γ/sec·g source strength densities are based on 12,000 lbs, the actual weight of the radioactive material. The mass density is assumed to be uniform for the payload.

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec□	γ/sec□g
Co-60	3.70E+11	6.80E+04
Cs-137	3.15E+11	5.78E+04
0.8348	1.48E+11	2.72E+04

Step 4: Select the Limits

Since this payload does not meet the definition of either of the two discrete shored configurations (2.5 ft^3 or 55 gal), it is a "general" type payload. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

Steps 5-7 Sum the Fractions

For this example, there are three lines: a ^{60}Co line, ^{137}Cs line, and one energy line representing ^{54}Mn (^{55}Fe and ^{90}Sr are disregarded because ^{55}Fe gammas are below 0.3 MeV, and the ^{90}Sr betas are below 2E+12 β/sec).

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits					Fractions, F		F_{min}
					γ/sec	γ/sec·g	Energy	γ/sec		γ/sec·g		γ/sec	γ/sec·g	
1	Solidified Waste Cont.	General		Co-60	3.70E+11	6.80E+04	Co-60	❶	1.39E+11	❸	1.18E+07	2.66E+00	5.75E-03	5.75E-03
2	Solidified Waste Cont.	General		Cs-137	3.15E+11	5.78E+04	Cs-137	❶	2.58E+12	❸	2.56E+08	1.22E-01	2.26E-04	2.26E-04
3	Solidified Waste Cont.	General		0.8348	1.48E+11	2.72E+04	0.9	❶	8.63E+11	❷	5.54E+07	1.71E-01	4.91E-04	4.91E-04
													Sum:	6.47E-03

Since the sum is less than 0.95, the container is an acceptable payload.

Example 3 – Dewatered Resin Liner

Problem: Determine the acceptability of a 100 ft^3 steel secondary container containing dewatered resin. The activity is uniformly distributed. The measured weight of the filled container is 13,100 lbs; the weight of the empty container is 1,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is: 5 Ci of ^{60}Co, 10 Ci of ^{137}Cs, 50 Ci of ^{55}Fe, 4 Ci of ^{54}Mn, and 30 Ci of ^{90}Sr. Also included is a 100 gram piece of activated metal, not shored, with an activity of 0.5 Ci of ^{60}Co. The activated metal is steel with a density of 8 g/cm^3.

This differs from Example 2 in that there is more ^{90}Sr, and there is the additional piece of activated metal.

Step 1: Characterize Source

Given in the problem statement.

Step 2: Convert Beta Source to Equivalent Gamma Source

^{90}Sr emits beta radiation through its own decay, plus the decay of its short-lived daughter product, ^{90}Y. So the total beta production rate is 30 Ci * 3.7E+10 d/Ci * 2 = 2.22E+12 betas/sec. Since this is above the threshold of 2E+12 betas/sec, the beta production must be considered. Using the procedure to convert beta into equivalent gamma radiation described in Attachment 1, the ^{90}Sr/^{90}Y betas[4] will be treated as follows:

E_{maxSr} = 0.54 MeV, E_{avgSr} = 0.19 MeV

E_{maxY} = 2.27 MeV, E_{avgY} = 0.93 MeV

Z_{Resin} = 5.6, Z_{Steel} = 26

Z_w= 26 (the higher of the resin Z and the liner wall Z)

$S_{\gamma Sr}$ =(1.11E+12)(3.5E-04)(26)(0.19)= <u>1.92E+08 γ/s @ 0.54 MeV</u>

$S_{\gamma Y}$ =(1.11E+12)(3.5E-04)(26)(0.93)= <u>9.39E+09 γ/s @ 2.27 MeV</u>

Step 3: Calculate Gamma Source Strengths and Source Strength Densities

This payload must be broken into two payload items, due to the physical and radiological differences between the resins and the activated metal.

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[4] Cember, H., "Introduction to Health Physics," Pergamon Press, 2nd Ed.

Resin Payload Item

Like Example 2, the following source data are to be used for qualification of the gamma emitters. The mass density is assumed to be uniform for the resin portion of the payload.

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec·g	γ/sec·g
Co-60	3.70E+11	6.80E+04
Cs-137	3.15E+11	5.78E+04
0.8348	1.48E+11	2.72E+04

Activated Metal Payload Item

^{60}Co emits two gammas per disintegration, therefore the total source strength for the activated metal is (0.5 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 3.7E+10 γ/sec. Dividing by the mass of 100 g, the source strength density is 3.7E+08 γ/sec. The mass density is assumed to be uniform for the 100 gram piece of metal.

Step 4: Select the Limits

Resin Payload Item - Since this payload item does not meet the definitions of either of the two discrete shored configurations (2.5 ft^3 or 55 gal), it is a "general" type payload. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

Activated Metal Payload Item – This payload item is small and fits within the defined envelope for the 2.5 ft^3 payload, however it is not shored, and so the activated metal is also a "general" type payload item. Columns ❶ and ❷ apply for the γ/sec and γ/sec·g limits, respectively.

Steps 5-7 Sum the Fractions

For this example, there are six lines: 1-3 are for the resin gamma emitters, 4-5 are for the bremsstrahlung gammas produced by ^{90}Sr and ^{90}Y, and one line for the activated metal ^{60}Co.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits					Fractions, F		F$_{min}$
					γ/sec	γ/sec·g	Energy		γ/sec		γ/sec·g	γ/sec	γ/sec·g	
1	Resin	General		Co-60	3.70E+11	6.80E+04	Co-60	❶	1.39E+11	❷	1.18E+07	2.66E+00	5.75E-03	5.75E-03
2	Resin	General		Cs-137	3.15E+11	5.78E+04	Cs-137	❶	2.58E+12	❷	2.56E+08	1.22E-01	2.26E-04	2.26E-04
3	Resin	General		0.8348	1.48E+11	2.72E+04	0.9	❶	8.63E+11	❷	5.54E+07	1.71E-01	4.91E-04	4.91E-04
4	Resin (betas)	General		0.54	1.92E+08	3.53E+01	0.7	❶	2.13E+12	❷	1.89E+08	9.01E-05	1.87E-07	1.87E-07
5	Resin (betas)	General		2.27	9.39E+09	1.73E+03	2.75	❶	1.29E+10	❷	6.51E+05	7.30E-01	2.65E-03	2.65E-03
6	Metal	General		Co-60	3.70E+10	3.70E+08	Co-60	❶	1.39E+11	❷	1.18E+07	2.66E-01	3.13E+01	2.66E-01
													Sum:	2.75E-01

Since the sum is less than 0.95, the container is an acceptable payload.

Example 4 – Activated Waste with Non-Fixed Contamination

Problem: Determine the acceptability of a 100 ft^3 steel secondary container containing activated metal. The measured weight of the filled container is 7,100 lbs; the weight of the empty container is 1,100 lbs. The metal is composed of mildly activated steel, with non-fixed surface contamination. The contaminated surface area is estimated to be 500 ft^2. There is one small piece of activated steel with a significantly higher activity. Determine whether this smaller item can be included in the shipment, and whether it needs to be shored. The isotopic activities, determined by analysis of samples of the waste, are as follows:

- Most of the steel has similar radiological properties. Based on an analysis of the highest-activity sample, the constituents are: 20 Ci of ^{58}Co, 30 Ci of ^{60}Co, and 20 Ci of ^{54}Mn.
- The small activated metal item has a mass of 100 g, dimensions of 1" x 1" x 24", with an activity of 6 Ci of ^{60}Co.
- The non-fixed crud contamination level, based on the highest-activity sample, is 50,000 dpm, which has been determined to be 50% ^{55}Fe, 30% ^{137}Cs, and 20% ^{60}Co. The contaminated surface area is 500 ft^2.

Step 1: Characterize Source

Given in the problem statement.

Step 2: Convert Beta Source to Equivalent Gamma Source

Not applicable since the beta source is less than 2E+12 β/sec.

Step 3: Calculate Gamma Source Strengths and Source Strength Densities

100g Activated Metal Payload Item

^{60}Co emits two gammas per disintegration, therefore the total source strength for the small activated metal item is (6 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 4.44E+11 γ/sec. Dividing by the mass of 100 g, the source strength density is 4.44E+09 γ/sec. The mass density is assumed to be uniform for the small activated metal item.

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec□	γ/sec□g
Co-60	4.44E+11	4.44E+09

Remaining Activated Metal Payload Item

^{60}Co emits two gammas per disintegration, therefore the total ^{60}Co source strength for the activated metal is (30 Ci)(2 γ/d)(3.7E+10 d/sec-Ci) = 2.22E+12 γ/sec. The remaining nuclides, ^{58}Co and ^{54}Mn, were converted to individual energy lines[5] (E<0.3 MeV were neglected). Sources were divided by 2.72E+06 g (i.e., 6,000 lb) to obtain the γ/sec·g. The mass density of the metal is assumed to be uniform. The resulting sources are:

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec□	γ/sec□g
Co-60	2.22E+12	8.16E+05
0.511	2.21E+11	8.12E+04
0.8108	7.36E+11	2.70E+05
0.8348	7.40E+11	2.72E+05
0.8639	5.45E+09	2.00E+03
1.6747	3.97E+09	1.46E+03

Crud Payload Item

50,000 dpm is equivalent to 2.25E-08 Ci per 100 cm^2. The total source strength is therefore (2.25E-08 Ci/100cm^2) (500 ft^2)(929 cm^2/ft^2) = 1.05E-04 Ci. The nuclide breakdown is therefore: 5.23E-05 Ci of ^{55}Fe, 3.14E-05 Ci of ^{137}Cs, and 2.09E-05 Ci of ^{60}Co. ^{55}Fe can be neglected since it does not emit any gammas > 0.3 MeV. We can only use the γ/sec limit for qualification. The source inputs are therefore:

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec□	γ/sec□g
Co-60	1.55E+06	
Cs-137	9.88E+05	

Step 4: Select the Limits

The 100g activated item would meet the size criteria for the 55-gallon discrete shored configuration if both the container were shored and the item was shored within the container, in which case its limits would be columns ❸ and ❺ for γ/sec and γ/sec·g, respectively. Otherwise, since it would be unshored, the limits in columns ❶ and ❷ would apply for γ/sec and γ/sec·g, respectively.

The remaining activated metal does not meet the definitions of either of the two discrete shored configurations (2.5 ft^3 or 55 gal), so it is a "general" type payload item. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

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[5] MicroShield, Version 8.01, Grove Engineering.

The crud is free to move within the cavity and is therefore a "general" type payload item. Also, as discussed in the first section of this Attachment, crud must be qualified using the γ/sec limit. Thus, the limit in column ❶,in γ/sec, applies for the crud.

Steps 5-7 Sum the Fractions

First we will try qualifying the payload without shoring the small activated item. Note that it is not acceptable to average the activated metal together with the small 100 g item.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits					Fractions, F		F_{min}
					γ/sec□	γ/sec□g	Energy	γ/sec		γ/sec□g		γ/sec	γ/sec□g	
1	100g activated item	General	55 gal	Co-60	4.44E+11	4.44E+09	Co-60	❶	1.39E+11	❷	1.18E+07	3.19E+00	3.76E+02	3.19E+00
2	Remaining metal	General		Co-60	2.22E+12	8.16E+05	Co-60	❶	1.39E+11	❷	1.18E+07	1.59E+01	6.90E-02	6.90E-02
3	Remaining metal	General		0.511	2.21E+11	8.12E+04	0.7	❶	2.13E+12	❷	1.89E+08	1.04E-01	4.30E-04	4.30E-04
4	Remaining metal	General		0.8108	7.36E+11	2.70E+05	0.9	❶	8.63E+11	❷	5.54E+07	8.52E-01	4.88E-03	4.88E-03
5	Remaining metal	General		0.8348	7.40E+11	2.72E+05	0.9	❶	8.63E+11	❷	5.54E+07	8.57E-01	4.91E-03	4.91E-03
6	Remaining metal	General		0.8639	5.45E+09	2.00E+03	0.9	❶	8.63E+11	❷	5.54E+07	6.31E-03	3.61E-05	3.61E-05
7	Remaining metal	General		1.6747	3.97E+09	1.46E+03	1.83	❶	3.04E+10	❷	2.06E+06	1.31E-01	7.08E-04	7.08E-04
8	Crud	General		Co-60	1.55E+06		Co-60	❶	1.39E+11	❷	1.18E+07	1.11E-05		1.11E-05
9	Crud	General		Cs-137	9.88E+05		Cs-137	❶	2.58E+12	❷	2.56E+08	3.83E-07		3.83E-07
													Sum:	3.27E+00

This approach does not pass. Since the discrete shored payload items have higher limits, we can try to see if shoring the 100g item will pass.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits					Fractions, F		F_{min}
					γ/sec□	γ/sec□g	Energy	γ/sec		γ/sec□g		γ/sec	γ/sec□g	
1	100g activated item	Discrete	55 gal	Co-60	4.44E+11	4.44E+09	Co-60	❸	1.29E+12	❺	4.07E+07	3.43E-01	1.09E+02	3.43E-01
2	Remaining metal	General		Co-60	2.22E+12	8.16E+05	Co-60	❶	1.39E+11	❷	1.18E+07	1.59E+01	6.90E-02	6.90E-02
3	Remaining metal	General		0.511	2.21E+11	8.12E+04	0.7	❶	2.13E+12	❷	1.89E+08	1.04E-01	4.30E-04	4.30E-04
4	Remaining metal	General		0.8108	7.36E+11	2.70E+05	0.9	❶	8.63E+11	❷	5.54E+07	8.52E-01	4.88E-03	4.88E-03
5	Remaining metal	General		0.8348	7.40E+11	2.72E+05	0.9	❶	8.63E+11	❷	5.54E+07	8.57E-01	4.91E-03	4.91E-03
6	Remaining metal	General		0.8639	5.45E+09	2.00E+03	0.9	❶	8.63E+11	❷	5.54E+07	6.31E-03	3.61E-05	3.61E-05
7	Remaining metal	General		1.6747	3.97E+09	1.46E+03	1.83	❶	3.04E+10	❷	2.06E+06	1.31E-01	7.08E-04	7.08E-04
8	Crud	General		Co-60	1.55E+06		Co-60	❶	1.39E+11	❷	1.18E+07	1.11E-05		1.11E-05
9	Crud	General		Cs-137	9.88E+05		Cs-137	❶	2.58E+12	❷	2.56E+08	3.83E-07		3.83E-07
													Sum:	4.23E-01

Since the sum is less than 0.95, the container is an acceptable payload if the container and 100 g item are shored such that the 100g item is located at the centroid of the cask cavity.

Example 5 – Contaminated Soil

Problem: Determine the acceptability of a 100 ft^3 steel secondary container containing a contaminated soil mixture. The activity is not uniformly distributed. The measured weight of the filled container is 10,100 lbs; the weight of the empty container is 1,100 lbs. 5% of the payload mass is made up of small bits of grout used to immobilize contamination. The size of the grout chunks ranges from 0.1 cm to 10 cm. The grout contains ^{137}Cs at a maximum concentration of 350 Ci/ft^3. The remaining 95% of the material is soil with a activity of 10 Ci/ft^3 of ^{137}Cs. The density of the soil and grout are both 100 lb/ft^3. Activities were determined by analysis of samples of the most active representative waste.

Step 1: Characterize Source

Given in the problem statement.

Step 2: Convert Beta Source to Equivalent Gamma Source

Not applicable (Cs-137 is not a pure beta emitter).

Step 3: Calculate Gamma Source Strengths and Source Strength Densities

We will evaluate the payload two ways: one treating the entire payload as a single item with a bounding source strength (γ/sec) and source strength density (γ/sec·g), and the second assuming we will treat the payload as two separate items: grout and soil.

If there is a potential for the contamination to redistribute, then it would be appropriate to qualify the source using only the γ/sec limits. For this example, the grout physically prevents its contamination from redistribution, and for simplicity we assume that the soil, which has a much lower source strength density, also physically binds its contaminants. For both payload items, we will therefore perform the qualification using both source strength (γ/sec) and source strength density (γ/sec·g). Note that this example does account for the possibility that the grout will redistribute (or concentrate) itself within the soil, since the single payload approach will use the higher source strength density (γ/sec·g) of the grout in the qualification.

Grout Payload Item

The grout gamma source strength is (350 Ci/ft^3)(1 ft^3/100 lb)(9,000 lb*0.05) (3.7E+10 d/sec-Ci)(0.85 γ/d) = 4.95E+13 γ/sec. Dividing by the mass (450 lb, or 2.04E+05 g), the source strength density would be 2.43E+08 γ/sec·g.

Payload Source Term	
γ/sec	γ/sec·g
4.95E+13	2.43E+08

Soil Payload Item

The soil gamma source strength is (10 i/ft^3)(1 ft^3/100 lb)(9,000 lb*0.95)(3.7E+10 d/sec-Ci)(0.85 γ/d) = 2.69E+13 γ/sec. Dividing by the mass (8550 lb, or 3.88E+06 g), the source strength density would be 6.93E+06 γ/sec·g.

Energy (MeV),or Nuclide	Payload Source Term	
	γ/sec	γ/sec·g
Cs-137	2.69E+13	6.93E+06

Combined Grout/Soil Payload Item

If the payload is treated as a single item, the γ/sec is set equal to the sum of the γ/sec for both the grout and soil components. The γ/sec·g is set equal to that of the "hottest" component (i.e., the grout). Thus, the gamma source strength would be 5.66E+13 γ/sec (4.95E+13 + 2.69E+13). The γ/sec·g equals the 2.43E+08 value that applies for the grout.

Payload Source Term	
γ/sec	γ/sec·g
7.64E+13	2.43E+08

Step 4: Select the Limits

Since none of these payload items meets the definition of either of the two discrete shored configurations (2.5 ft^3 or 55 gal), they are "general" type payload items. The limits in columns ❶ and ❷ apply for γ/sec and γ/sec·g, respectively.

Steps 5-7 Sum the Fractions

As a first try, we attempt to qualify the payload as being two components: the grout and soil.

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits					Fractions, F		F_{min}
					γ/sec	γ/sec·g	Energy		γ/sec		γ/sec·g	γ/sec	γ/sec·g	
1	Grout	General		Cs-137	4.95E+13	2.43E+08	Cs-137	❶	2.58E+12	❷	2.56E+08	1.92E+01	9.50E-01	9.50E-01
2	Soil	General		Cs-137	2.69E+13	6.93E+06	Cs-137	❶	2.58E+12	❷	2.56E+08	1.04E+01	2.71E-02	2.71E-02
													Sum:	9.77E-01

Since the sum is greater than 0.95, the container is not an acceptable payload.

It is acceptable, however, to treat the payload as a single (combined) item, with a γ/sec equal to the sum of the component (grout and soil) γ/sec values, and a γ/sec·g equal to that of the "hottest" component (i.e., the grout).

Line	Payload Item	Type	Shape (Discrete Only)	Energy (MeV),or Nuclide	Payload Source Term		Limits			Fractions, F		F_{min}
					γ/sec	γ/sec·g	Energy	γ/sec	γ/sec·g	γ/sec	γ/sec·g	
1	All-grout	General		Cs-137	7.64E+13	2.43E+08	Cs-137	❶ 2.58E+12	❷ 2.56E+08	2.96E+01	9.50E-01	9.50E-01
											Sum:	9.50E-01

Since the sum is less than 0.95, the container is an acceptable payload.

This example illustrates that there is no benefit from dividing a payload into multiple payload items if all of the items qualify under the γ/sec·g limit. If the payload is divided, one of the (γ/sec·g) fractions will be that which applies for the grout (i.e., 0.950). If the single payload approach is used, the γ/sec·g value is set to that which applies for the "hottest" item (the grout), so the total fraction for the entire payload would be 0.950. Separating small, high source strength density items from the overall payload only helps if those small (low mass) items are qualified under the γ/sec limit, and not the γ/sec·g limit.

Attachment 2
Determination of Hydrogen Concentration

1. Determine the radionuclide concentration in the contents.

   For any package containing materials with radioactivity concentration not exceeding that for LSA, ensure the shipment occurs within 10 days of preparation, or within 10 days of venting the secondary container.

   For packages which satisfy the previous conditions, go to step 11, otherwise continue with step 2.

2. Determine the secondary package(s) void volume and the cask cavity void volume.
3. Identify the secondary container(s) vent path, if applicable
4. Determine the quantity of hydrogenous contents
5. Determine the G value of the hydrogenous contents per NUREG/CR-6673[6], Section 3.
6. Determine the energy deposition rate in the hydrogenous contents
7. Determine the hydrogen generation rate per NUREG/CR-6673, Section 4.2
8. Determine the effective hydrogen transport rate due to diffusion for the vent path; see NUREG/CR-6673, Section 4.1
9. Determine the shipping time to reach a hydrogen concentration of 5% in the package; see NUREG/CR-6673, Section 4.2.2.1 and Appendix F, Example #4.
10. If the time to reach 5% concentration is more than double the expected shipping time, the shipment meets the hydrogen concentration requirement.
11. Authorize the shipment

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[6] B. L. Anderson et al. *Hydrogen Generation in TRU Waste Transportation Packages* , NUREG/CR-6673, Lawrence Livermore National Laboratory, Livermore, CA, February 2000

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8.0 Acceptance Tests and Maintenance Program

Acceptance tests for Configurations 1 and 2 have different weld examination and leak tests than Configuration 3. Maintenance is the same for all configurations. Any reference to drawings, either in general or by specific number, means the drawings listed in the CoC.

8.1 ACCEPTANCE TESTS – CONFIGURATIONS 1 AND 2 (CASKS FABRICATED BEFORE APRIL 1, 1999)

Prior to the first use of the 8-120B package fabricated to Configuration 1 or 2, the following tests and evaluations will be performed.

8.1.1 VISUAL EXAMINATION

The package will be examined visually for any adverse conditions in materials or fabrication. Welds shall be examined for compliance to the drawings. Weld integrity shall be verified by visual examination and magnetic particle or dye penetrant. NDE examinations shall be performed by an ASME Certified inspector. Acceptance criteria for NDE shall be according to ASME Code Section III, Div. 1-Section NB5342 or NB5352 as applicable.

8.1.2 STRUCTURAL TESTS

No structural testing is required.

8.1.3 LEAK TESTS

This test shall be performed prior to acceptance and operation of a newly fabricated package in accordance with ASTM E-427 using a leak detector capable of detecting the applicable leak rates specified in Figures 4-4 and 4-7 in Chapter 4. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST. The standard's setting shall correspond to the approved leak rates specified in Figures 4-4 and 4-7 in Chapter 4.

All four containment boundary penetrations must be tested.

- The volume above the vent port Stat-O-Seal
- The volume between the drain line plug and interior of the cask
- The annulus between the o-ring seals of the primary lid
- The annulus between the o-ring seals of the secondary lid

All four of these volumes must be evacuated to a minimum vacuum of 20" Hg, and then be pressurized to a minimum pressure of 25 psig with pure dichlorodifluoromethane (R-12) or 1,1,1,2 – tetrafluoroethane (R-134a). Use the detector probe to "sniff" the following areas:

- The vent port penetration on the underside of the primary lid
- Around the outer plug of the drain line
- Interior side of the inner o-ring for the primary lid

- Interior side of the inner o-ring for the secondary lid

Leak detection shall be in accordance with the specifications of ASTM E-427.

Any condition, which results in leakage in excess of the applicable values specified in Figures 4-3 and 4-6 in Chapter 4 shall be corrected.

8.1.4 COMPONENT TESTS

Gaskets and seals will be procured and examined in accordance with the Energy*Solutions* Quality Assurance Program.

8.1.5 TEST FOR SHIELDING INTEGRITY

Shielding integrity of the package will be verified by gamma scan or gamma probe methods to assure the package is free of significant voids in the poured lead shield annulus. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria will be that voids resulting in shield loss in excess of 10 % of the normal lead thickness in the direction measured shall not be acceptable. Remedy for an unacceptable gamma scan include actions such as controlled re-heating of the cask body to melt the lead to remove any voids or streaming paths. This process may be used as long as average metal temperatures are kept below ~800°F. If the remedy could affect more than just the unacceptable area, e.g., re-heating of the cask body, all affected portions will be re-scanned.

8.1.6 THERMAL ACCEPTANCE TESTS

No thermal acceptance testing will be performed on the 8-120B package. Refer to the Thermal Evaluation, Chapter 3.0 of the report.

8.2 ACCEPTANCE TESTS – CONFIGURATION 3 (CASKS FABRICATED AFTER APRIL 1, 1999)

Prior to the first use of an 8-120B package fabricated to Configuration 3, the following tests and evaluations will be performed:

8.2.1 VISUAL INSPECTIONS AND MEASUREMENTS

Throughout the fabrication process, confirmation by visual examination and measurement are required to be performed to verify that the 8-120B packaging dimensionally conforms to the drawing referenced in the current Certificate of Compliance for the 8-120B.

The packaging is also required to be visually examined for any adverse conditions in materials or fabrication that would not allow the packaging to be assembled and operated per Section 7.0 or tested in accordance with the requirements of Section 8.0.

Throughout the fabrication process, the fabricator shall request approval from Energy*Solutions* prior to implementation of any options allowed in the drawing.

8.2.2 WELD EXAMINATIONS

8.2.2.1 All welding of the Containment Boundary identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection ND, except as follows:

a. Due to the geometry of the joint configuration, between Item 17 and 18, NDE of the ¾" bevel groove weld and the 1" bevel groove weld may be done by progressive surface examination utilizing the MT method in lieu of RT or UT.

b. Due to the geometry of the joint configuration, between Item 3 and 5A, NDE of the ¾" v groove weld may be done by progressive surface examination utilizing the MT method in lieu of RT or UT.

c. Due to the geometry of the joint configuration, between Item 3 and 4, NDE of the ¾" v groove weld may be done by utilizing the UT + MT methods in lieu of RT.

8.2.2.2 All welding of Non-Containment Boundary items identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection NF (Class 3), except as follows:

a. The Root Pass and the Final Pass of the v groove weld between Item 5A, Cask Bottom Plate and Item 5B, Cask Bottom Plate Outer Ring, shall be done in accordance with ASME Code, Section III, Division I, Subsection NF-5230 by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection NF, Article NF-5340.

b. The Root Pass and the Final Pass of the bevel groove weld between Item 5B, Cask Bottom Plate and Item 1, Outer Cask Shell, shall be done in accordance with ASME Code, Section III, Division I, Subsection NF-5230 by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection NF, Article NF-5340.

8.2.2.3 Welding on lifting and tiedown lugs identified on drawing C-110-E-0007 will be done in accordance with ASME Code, Section III, Division I, Subsection NF (Class 3) and shall be inspected by magnetic particle examination (MT) with acceptance requirements of ASME Code, Section III, Division I, Subsection ND, Article ND-5340 or NF, Article NF-5340. Inspection shall be before and after 150% load test.

8.2.3 STRUCTURAL AND PRESSURE TESTS

A pressure test of the containment system will be performed as required by 10CFR71.85. As determined in Section 3.4.4, the maximum normal operating pressure for the cask cavity is 35 psig; therefore the minimum test pressure will be 1.5 x 35 = 52.5 psig. The hydrostatic test pressure will be held for a minimum of 10 minutes prior to initiation of any examinations. Following the 10 minute hold time, the cask body, lid and lid/body closure shall be examined for leakage. Any leaks, except from temporary connections, will be remedied and the test and inspection will be repeated. After depressurization and draining, the cask cavity and seal areas will be visually inspected for cracks and deformation. Any cracks or deformation will be remedied and the test and inspection will be repeated.

8.2.4 LEAKAGE TESTS

8.2.4.1 General requirements

- Testing method – Per ANSI N-14.5 in accordance with ASTM E-427 if using a halogen leak detector or ASTM E-499 if using a helium leak detector.
- Test Sensitivity – the test method must be capable of meeting the appropriate sensitivity requirements specified in Figures 4-4 or 4-7 in Section 4.0. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST.
- The leak standard's setting shall correspond to the approved leak test rate (see Section 4.0).
- Any condition, which results in leakage in excess of the maximum allowable leak rate specified in Figures 4-3 or 4-6 (depending on the test gas used), shall be corrected and re-tested.

8.2.4.2 Testing of the entire containment boundary will be performed prior to lead pour to allow access to all containment welds. The containment boundary includes: the inner shell, the cask bottom base plate (BOM 5A), the bolting ring, the lids, the O-ring seal plates of both lids, the inner O-ring of both lids, and the vent port cap screw and its seal.

- (Optional) Insert the sealed metal cavity filler canister into the cask cavity. Verify the canister does not obstruct the vent penetration. The metal must be chemically compatible with the cask liner and the test gas.
- Assemble the cask lids per Section 7.1.
- Evacuate the cask cavity to 20" Hg vacuum, minimum (sealed metal cavity filler canister may be used within the cask cavity)
- Pressurize the cask cavity to a minimum pressure of:

1) 25 psig with pure 1,1,1,2 – tetrafluoroethane (R-134a),
   or
2) 1 psig with pure helium.

- Check for leakage of the inner shell and base plate components
- Measure the leakage of the inner (containment) O-ring via the test port in each lid.
- Check for leakage at the vent port.

8.2.5 COMPONENT AND MATERIAL TESTS

Energy*Solutions* will apply its USNRC approved 10CFR71 Appendix B Quality Assurance Program, which implements a graded approach to quality based on a component's or material's importance to safety to assure all materials used to fabricate and maintain the 8-120B are procured with appropriate documentation which meet the appropriate tests and acceptance criteria for packaging materials.

This includes as example:

- ASTM steel material used for shells, lids, bolts, etc. will comply with and meet ASTM manufacturing requirements.
- Containment seals will be made from elastomeric compounds that have been qualified using ES-C-038 (Reference 8.4.2), which includes requirements for hardness, low temperature compatibility, permeability, and temperature-pressure testing. Fabricated seals are suitable for use if the delivered seals are traceable to a batch of material manufactured under the same process as, and having the same chemical composition as, a qualified compound. Acceptance testing for containment seals will include hardness and low temperature compatibility testing on each batch of elastomer, plus dimensional inspections on each seal, all per the acceptance criteria in ES-C-038.
- The impact limiter foam will meet the requirements of ES-M-175 (Reference 8.4.1).

8.2.6 SHIELDING TESTS

Shielding integrity of the package will be verified by gamma scan to assure the package lead layer meets or exceeds the minimum thickness specified on the cask drawing. All gamma scanning will be performed on a 4-inch square or less grid system. The acceptance criteria (maximum dose rate value) will be determined by: Option 1) measurement of the maximum dose rate value using a test block, which has shield layers that replicate the cask geometry per the drawing, using the gamma scan source and reproducing the source/shield/detector geometry that will be used during the scan of the cask, or Option 2) calculation of the maximum dose rate value using detailed modeling software (MCNP or equivalent) incorporating the specific cask dimensions from the drawing and the source/shield/detector geometry applicable to the gamma scan. Any location on the cask which shows a gamma scan dose rate value greater than the maximum dose rate value will be identified as unacceptable. All unacceptable areas will be remedied and re-scanned. Remedy for an unacceptable gamma scan include actions such as controlled re-heating of the cask body to melt the lead to remove any voids or streaming paths. This process may be used as long as average metal temperatures are kept below ~800°F. If the remedy could affect more than just the unacceptable area, e.g., re-heating of the cask body, all affected portions will be re-scanned.

8.2.7 THERMAL TESTS

No thermal acceptance testing will be performed on the 8-120B packaging. Refer to the Thermal Evaluation, Section 3.0 of this report.

8.2.8 MISCELLANEOUS TESTS

No miscellaneous testing will be performed on the 8-120B packaging.

8.3 MAINTENANCE PROGRAM

Energy*Solutions* operates an ongoing preventative maintenance program for all shipping packages. The 8-120B package will be subjected to routine and periodic inspection and tests as outlined in this section and the approved procedure based on these requirements. Defective items are replaced or remedied, including testing, as appropriate.

Examples of inspections performed prior to each use of the cask include:

- Cask Seal Areas: O-rings are inspected for any cracks, tears, cuts, or discontinuities that may prevent the O-ring from sealing properly. O-ring seal seating surfaces are inspected to ensure they are free of scratches, gouges, nicks, cracks, etc. that may prevent the O-ring from sealing properly. Defective items are replaced or remedied, as appropriate and tested in accordance with Section 8.3.2.
- Cask bolts, bolt holes, and washers are inspected for damaged threads, severe rusting or corrosion pitting. Defective items are replaced or remedied, as appropriate.
- Lift Lugs and visible lift lug welds are inspected to verify that no deformation of the lift lug is evident and that no obvious defects are visible. Defective items are replaced or remedied, as appropriate and tested in accordance with Section 8.2.2.5.

8.3.1 STRUCTURAL AND PRESSURE TESTS

No routine or periodic structural or pressure testing will be performed on the 8-120B packaging.

8.3.2 LEAKAGE TESTS

8.3.2.1 Periodic and Maintenance Leak Test.

The 8-120B packaging shall have been leak tested as described below within the preceding 12-month period before actual use for shipment and after maintenance, repair (such as weld repair), or replacement of components of the containment system. Shipments of powdered radioactive materials shall be performed only when the most recent periodic leak test meets the requirements for leaktight status.

The 8-120B packaging seals shall have been replaced within the 12-month period before actual use for shipment.

General requirements

- Testing method – Per ANSI N-14.5 in accordance with ASTM E-427 if using a halogen leak detector or ASTM E-499 if using a helium leak detector.
- Test Sensitivity – the test method must be capable of meeting the appropriate sensitivity requirements specified in Figures 4-4 or 4-7 or 5.0×10^{-8} atm-cm^3/sec for leaktight status. Calibration of the leak detector shall be performed using a leak rate standard traceable to NIST.
- The leak standard's setting shall correspond to the approved leak test rate (see Section 4.0). A maximum leak rate of 1.0×10^{-7} atm-cm^3/sec of air is required leaktight status.

- Any condition, which results in leakage in excess of the appropriate maximum allowable leak rate specified in Figures 4-3, 4-6 or 1.0 x 10^{-7} atm-cm^3/sec for leaktight status, shall be corrected and re-tested.

Testing of the Lids and Vent

- (Optional) Insert the sealed metal cavity filler canister into the cask cavity. Verify the canister does not obstruct the vent penetration. The metal must be chemically compatible with the cask liner and the test gas.
- Assemble the cask lids per Section 7.1.
- Evacuate the cask cavity to 20" Hg vacuum (minimum) or 90% vacuum for the leak tight test.
- Pressurize the cask cavity to the following pressure:
  1) 25 psig (minimum) with pure 1,1,1,2 – tetrafluoroethane (R-134a),
     or
  2) 1 psig (minimum) with pure helium (or 0 to 1 psig with pure helium for leaktight status).
- Measure the leakage of the inner (containment) O-ring via the test port in each lid.
- Measure the leakage of the vent port.

Testing of the Lids – Optional Method

- Assemble the cask lids per Section 7.1.
- Connect to the O-ring test port on the lid and evacuate the annulus between the cask lid O-rings to 20" Hg vacuum (minimum)
- Pressurize the O-ring annulus to a minimum pressure of 25 psig with pure 1,1,1,2 – tetrafluoroethane (R-134a),
- Check for leakage of the inner (containment) O-ring by moving a detector probe along the interior surface of the inner seal according to the specifications of ASTM E-427.

Testing of the Vent – Optional Method

- Assemble the cask Vent Port Cap Screw and Seal per Section 7.1.
- With the vent port cover (Item 30) removed, connect to and evacuate the volume above (lid exterior) the Vent Port Cap Screw and Seal (Items 26 and 27) to 20" Hg vacuum (minimum)
- Pressurize the volume to a minimum pressure of 25 psig with pure 1,1,1,2 – tetrafluoroethane (R-134a),
- Check for leakage of the Vent Port Cap Screw and Seal by moving a detector probe along the interior surface of the Primary Lid in the area of the vent port according to the specifications of ASTM E-427.

The requirements for Periodic and Maintenance Leak Testing of the 8-120B are summarized in Table 8-1.

Table 8-1 - Periodic and Maintenance Leak Test of 8-120B

Component	Test Gas	Max. Leak Rate[1]	Minimum Sensitivity[1]	Test Pressure	Procedure	Alternate Procedure
Lid	R-134a	Fig. 4.3	Fig. 4.4	Evacuate cask cavity to 20" Hg then pressurize to 25 psig.	After pressurizing the cask cavity with the test gas, check for gas leakage from the cask Lid inner O-ring using the cask Lid test port.	After pressurizing between the lid O-ring annulus with the test gas, check for gas leakage from the cask Lid inner O-ring using a detector probe.
	Helium	Fig. 4.6	Fig. 4.7	Evacuate cask cavity to 20" Hg, or 90% vacuum for the leak tight test, then pressurize to 1 psig.	After pressurizing the cask cavity with the test gas, check for gas leakage from the cask Lid inner O-ring using the cask Lid test port.	N/A
Vent Port	R-134a	Fig. 4.3	Fig. 4.4	Evacuate cask cavity to 20" Hg then pressurize to 25 psig.	After pressurizing the cask cavity with the test gas, check for gas leakage from the Vent Port and Seal.	After pressurizing the volume above the Vent Port Cap Screw and Seal with the test gas, check for gas leakage from the vent penetration on the inner side of the lid using a detector probe.
	Helium	Fig. 4.6	Fig. 4.7	Evacuate cask cavity to 20" Hg, or 90% vacuum for the leak tight test, then pressurize to 1 psig.	After pressurizing the cask cavity with the test gas, check for gas leakage from the Vent Port Cap Screw and Seal.	N/A

Notes:

(1) Shipments of powdered radioactive materials shall be performed only when the most recent periodic leak test meets the requirements of Section 8.3.2.1 for leaktight status.

8.3.2.2 Pre-Shipment Leak Test

a. This test is required before every 8-120B cask shipment to verify that the containment system has been assembled properly.

b. The test will be performed by pressurizing the annulus between the O-ring seals of each lid, or inlet to the vent port with dry air or nitrogen to 18 psig.

Note: The pre-shipment leak test is typically performed using a test manifold that may be constructed from tubing, fittings, isolation valves and a pressure gauge. Any test apparatus used for this test must have an internal volume, with isolation valves closed and the apparatus connected to the test port location, of less than or equal to 10 cm^3 to achieve the required test sensitivity for the hold time specified in Section 8.3.2.2.d.

Note: If air is used for the test, the air supply should be clean and dry. If it is not, or if the quality of the air supply is uncertain, the test should be performed with nitrogen to ensure reliable results.

c. The test shall be performed using a pressure gauge, accurate within 1%, or less, of full scale.

d. The test pressure shall be applied for at least 15 minutes for the lid or vent port. A drop in pressure of greater than 0.1 psig shall be cause for test failure.

e. Sensitivity at the test conditions is equivalent to the prescribed procedure sensitivity of 10^{-3} ref-cm^3/sec based on dry air at standard conditions as defined in ANSI N14.5-1997.

Table 8-2 summarizes pre-shipment leak test requirements for the 8-120B:

Table 8-2 - Pre-Shipment Leak Test of 8-120B Components

Component	Hold Time	Procedure
Lid	15 min.	Connect test manifold to the test port. Pressurize void between O-rings with the test gas, close the isolation valves and hold for the minimum hold time. A drop in pressure of greater than the minimum detectable amount shall be cause for test failure.
Vent Port	15 min.	Remove the threaded cap covering the vent port. Connect test manifold to the vent port. Pressurize the seal and head of the vent port cap screw for the minimum hold time. A drop in pressure of greater than the minimum detectable amount shall be cause for test failure.

8.3.3 COMPONENT AND MATERIAL TESTS

Cask seals (O-rings) are inspected each time the cask lids or vent port cap screw are removed. Inspection and replacement of the seal is discussed in Section 8.3.

New seals are lightly coated with a lightweight lubricant such as Parker Super O-Lube or equivalent prior to installation. The lubricant will minimize deterioration or cracking of the elastomer during usage and tearing if removal from the dovetail groove is necessary for inspection. Coating the exposed surfaces of installed lid seals with the lightweight lubricant immediately prior to closing the lid can help to minimize deterioration or cracking of the seal during use. Excess lubricant should be wiped off before closing the lid.

Painted surfaces, identification markings, and match marks used for closure orientation shall be visually inspected to ensure that painted surfaces are in good condition, identification markings are legible, and that match marks used for closure orientation remain legible and are easy to identify.

Visible cask external and cavity welds shall be inspected within twelve months prior to use to verify that the welds specified by the applicable cask drawing are present and that no obvious weld defects are visible. If paint is covering these welds, the inspection may be completed without removing the paint.

8.3.4 THERMAL TESTS

No periodic or routine thermal testing will be performed on the 8-120B packaging.

8.3.5 MISCELLANEOUS TESTS

8.3.5.1 Repair of Bolt Holes

Threaded inserts may be used for repair of bolt holes. The following steps shall be performed for each repair using a threaded insert.

a. Install threaded insert(s), sized per manufacturer's recommendation, per the manufacturer's instructions.

b. At a minimum, each repaired bolt hole(s) will be tested for proper installation by assembling the joint components where the insert is used and tightening the bolts to their required torque value.

   Note: If the repair is to bolt holes for lifting components, then a load test will also be performed to the affected components equal to 150% of maximum service load.

c. Each threaded insert shall be visually inspected after testing to insure that there is no visible damage or deformation to the insert.

8.4 REFERENCES

8.4.1 Energy*Solutions* Specification ES-M-175, “Polyurethane Foam Specification.”
8.4.2 EnergySolutions Specification ES-C-038, “8-120B Seal Specification.”

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