3.0 THERMAL EVALUATION

This chapter identifies and describes the principal thermal design aspects of the 435-B package. The 435-B package is used to transport radioactive sources in the Long Term Storage Shield (LTSS) or shielded devices containing their sources. The evaluations presented in this chapter demonstrate the compliance of the 435-B package[1] as a Type B(U)-96 shipping container with the thermal requirements of Title 10, Part 71 of the Code of Federal Regulations [1]. Further guidance for the evaluation is taken from NUREG-1609 [2] and Regulatory Guide 7.8 [4].

Specifically, all package components are shown to remain within their respective temperature limits under the normal conditions of transport (NCT). Further, per 10 CFR §71.43(g), the maximum temperature of the accessible package surfaces is demonstrated to be less than 122 °F for the maximum decay heat loading, an ambient temperature of 100 °F, and no insolation. Finally, the 435-B package is shown to retain sufficient thermal protection following the HAC free and puncture drop scenarios to maintain all package component temperatures within their respective short term limits during the regulatory fire event and subsequent package cool-down.

3.1 Description of Thermal Design

The principal components of the 435-B package are illustrated in Figure 1.2-1 through Figure 1.2-5 of Section 1.0, *General Information.* The principal components are: 1) a lower body assembly (or base), which includes a polyurethane foam filled impact limiter, 2) an upper body assembly (or bell) that bolts to the base, 3) and two internal impact limiter assemblies. The packaging is fabricated primarily of Type 304 austenitic stainless steel, polyurethane foam, and a small amount of 6061 aluminum. See Section 1.0, *General Information*, for more detail.

3.1.1 Design Features

The primary heat transfer mechanisms within the 435-B packaging are conduction, convection, and radiation. The principal heat transfer from the exterior of the packaging is via convection and radiation to the ambient environment. The 435-B transport packaging incorporates several thermal protection features intended to limit the peak package temperatures during the HAC fire event. These thermal protection features include the following:

1) dual thermal shields over the cylindrical body shell,
2) a single thermal shield over the upper torispherical head,
3) the inclusion of a closure bolt enclosure structure (see Figure 1.2-4) that provides distance separation and thermal protection for the closure bolt heads and upper surface of the upper body flange from the ambient conditions,
4) an impact limiter that surrounds and encompasses the lower portion of the upper body assembly as well as the package base, and
5) internal impact limiters that are configured to restrict heat flow between the payload and the torispherical heads.

[1] The term 'packaging' refers to the assembly of components necessary to ensure compliance with the regulatory requirements, but does not include the payload. The term 'package' includes both the packaging components and the payload.

The side of the package is thermally protected from the high heat fluxes generated during the HAC fire event via the use of dual thermal shields. The shields are located between the tube sheet and approximately the location of the weld between the torispherical head and cylindrical body shell. The dual thermal shield creates two thin, air-filled gaps between the cylindrical shell of the package and the ambient using and two relatively thin stainless steel sheets. Figure 3.1-1 illustrates the layout of the dual shield arrangement. The inner sheet of the dual thermal shield is 0.060 inches thick and the outer sheet is 0.105 inches thick. The gaps are formed by a spiral wrap of stainless steel wire, 0.105 inches in nominal diameter, wrapped on a 3-inch pitch and tack welded in place. Small spacer strips at each end of the shield are welded in place to fully seal the gaps. To further thermally isolate the package side from the hot ambient conditions, the outer face of the cylindrical shell, both faces of the inner shield sheet, and the inside face of the outer shield sheet are brightened to an ASTM A480 type 3 or 4 finish to lower the emissivity and reduce heat transfer via radiation.

The upper torispherical head is covered by a similarly configured thermal shield, except that a single 0.105 inches thick stainless steel sheet is used. Again, spiral wrapped 0.105 inches diameter stainless steel wire on a 3-inch pitch is used to form the gap and the outer surface of the ½-inch torispherical head and the inner face of the head thermal shield are brightened to lower emissivity and reduce heat transfer via radiation.

Additional thermal protection is provided by the closure bolt enclosure structure depicted in Figure 1.2-4 of Section 1.0, *General Information.* The enclosure provides approximately 11 inches of spatial separation between the closure bolt heads and upper surface of the upper body flange from the ambient conditions. A rain shield prevents moisture from entering the individual bolt access tubes, but also serves as a radiation and convection shield during the HAC fire event. The integrity of the rain shield attachment was demonstrated from physical drop testing on the certification test units (CTUs) of the 435-B package (see Appendix 2.12.3, *Certification Test Results*) where, despite intentional attempts to dislodge it, the rain shield remained attached and functioning throughout the entire test program. The inclusion of blocks of 30 lb/ft^3 polyurethane foam between the individual bolt access tubes and 0.5 inches of refractory insulation paper against the lower 8 inches of the cylindrical body shell provides further thermal protection.

Thermal and impact protection for the bottom and lower sides of the package is provided by the external impact limiter which is integral with and permanently connected to the lower body assembly. The 0.12 inches thick inner cylindrical shell of the impact limiter is welded to the outer edge of the lower flange. The outer shell (tapered top, outer cylinder, and flat bottom) is ¼ inches thick. The tapered top includes a short lead-in chamfer to guide the upper body assembly into place. The outer cylindrical shell is 70 inches in diameter and approximately 21 inches tall and features plastic melt–out plugs designed to relieve pressure generated by the thermal decomposition of the polyurethane foam during the HAC fire event. The inside surface of the bottom shell is covered with a ¼-inch thick layer of refractory insulation paper to reduce the thermal decomposition of the underlying polyurethane foam during the HAC fire event. The cavity of the limiter is filled with rigid, closed–cell polyurethane foam at a nominal density of 15 lb/ft^3. The foam is poured in place.

Except for an approximately 0.30 inch gap between the head and the side thermal shields and a 3.5 inch diameter segment at the center of the upper torispherical head, the entire exterior surface of the containment boundary is shielded from direct exposure to the HAC generated temperature environment by the various thermal features described above. The lack of a thermal shield at the center of the upper torispherical head is partially offset by the presence of the upper body assembly lifting boss which effectively increases the local thickness of the head to 2 inches with an accompanying increase in the local thermal mass.

Heat transfer between the payload and the ends of the 435-B packaging is restricted by the presence of the internal impact limiters located at each end of the payload cavity (see Figures 1.2-2 and 1.2-5 in Section 1.0, *General Information*). The array of 130, 2-inch diameter × 0.035-inch wall thickness, ASTM A249 or A269, Type TP304 stainless steel tubes greatly restricts the axial heat conduction between the payload and the torispherical heads via conduction. Likewise, the presence of the spherically curved stabilizer sheet and the low view factor down the length of the tubes effectively limits direct thermal radiation exchange between the torispherical heads and the aluminum base sheet of the internal impact limiters. The flat side of the impact limiters is made from a ½-inch thick, ASTM B209, 6061-T651 aluminum plate. The base of the tubes are anchored in shallow grooves machined into one side of the aluminum plate, while the other end is stabilized by passing through a 0.105-inch thick stainless steel tube stabilizer sheet which is spherically curved to match shape of the torispherical heads.

The void spaces within the packaging are filled with air nominally at 0 psig.

3.1.1.1 Design Features of LTSS Payload

The LTSS (Long Term Storage Shield) is one of the authorized payloads to be transported in the 435-B packaging. Figures 1.2-8 and 1.2-9, Section 1.0, *General Information*, provide an overview and a cross-section view of the LTSS. The LTSS consists of a central steel magazine, or barrel, surrounded by thick lead encased in a steel shell. All steel used in the LTSS is ASTM type 304 stainless steel. The barrel contains four longitudinal holes, each of which can accommodate one drawer assembly. Each end of the LTSS is closed using a lead-filled, hinged door. Except for minor exterior features, the LTSS exhibits quarter symmetry in the circumferential direction and half symmetry in the axial direction.

The LTSS can contain two types of drawer assemblies, each approximately 21.5 inches long and 2.5 inches in diameter. The Large Source Drawer (see Figure 1.2-10, Section 1.0, *General Information*) contains two end shields made of tungsten and a NLM-52 special form capsule made of stainless steel. The NLM-52 special form capsule is available in five different lengths, ranging from 74 mm to 325 mm. Each NLM-52 special form capsule may contain one or more sealed sources taken from shielded devices such as industrial irradiators, medical equipment, or research facilities. Other special form or non-special form capsules may be used that have the same length, diameter, and at least as much radiation attenuation as the NLM-52 capsule series, although the NLM 52 nomenclature is used elsewhere in this chapter for convenience. Typically the sealed source capsules are loaded and welded in an argon gas environment. Air is assumed to fill all other void volumes within the LTSS.

The other drawer type transported in the LTSS is the T80/T780. Like the Large Source Drawer, the T80 and T780 drawers are approximately 21.5 inches long and 2.5 inches in diameter. Instead of a special foam capsule, the T80/T780 drawers have a 1.1-inch diameter cross-drilled hole at the center which accepts a sealed source capsule. The T80/T780 drawers are made of brass with a wall thickness of 0.2 inches and an end thickness of 0.8 inches. For the T80 drawer, the shielding on each side of the source is 9.2 inches of poured lead. For the T780 drawer, the shielding may be lead, tungsten, or depleted uranium. If tungsten or depleted uranium is used, the shielding would be in the form of machined bars. The lead filled T80/780 drawers are depicted in Figure 1.2-11, Section 1.0, *General Information.*

The position of the LTSS within the package payload cavity is maintained by the LTSS lodgment. The LTSS lodgment, depicted in Figure 1.2-6, Section 1.0, *General Information,* is a weldment made from ASTM B209, 6061 T651 aluminum alloy and is designed to support the LTSS with its axis vertical and its lower end approximately 8 inches above the bottom surface of the lodgment. The main structural components of the lodgment are 8 equally spaced 0.5-inch thick ribs running longitudinally and two 0.5-inch thick circumferential ribs going around the body of the LTSS. A "hub" made from 6061-T6, 4-inch, schedule 40 pipe is used to anchor the longitudinal ribs. Additional stiffening is provided by a number of 2 × 2 × ¼ angles. The lodgment is constructed with an upper and lower half that are connected via 8 clevises and bolts in double shear. The base of the LTSS rests on a ½-inch thick plate covered with a ½-inch thick layer of neoprene rubber. Neoprene rubber is also used on the tapered edges of the lower ribs, but there is nominally no contact between lodgment ribs and the LTSS.

3.1.1.2 Design Features of Shielded Device Payload

The second type of authorized payload to be transported in the 435-B packaging are the Group 1 and 3 shielded devices. Shielded devices are units designed and manufactured to provide a safe radiation source for industrial, medical, or research purposes. Each such device includes a sealed source (or a group of sources), shielding lead, and a steel shell to surround the shielding material and provide structure. Figures 1.2-12 to 1.2-16, Section 1.0, *General Information,* illustrate a sampling of Group 1 and 3 shielded devices. Cabinets, stands, or unnecessary appurtenances attached to the devices are not transported. Prior to loading, movable sources are placed in the safe shipping position and the structural integrity is evaluated.

All Group 1 devices use Cs-137 as the radiation source and have a weight of approximately 3,300 lb. All of the devices are shielded with lead, which is contained within a thick steel shell weldment. Group 3 devices are similar and have a maximum weight is approximately 2,650 lb. While the general shape and size of devices in Group 1 and 3 are similar, the exact dimensions and shapes are varied. For that reason, dunnage will be used to block and brace the device into position within the inner container (IC). Acceptable blocking/dunnage materials are metallic structures or polymeric foam.

The IC is designed to hold and provide support for the shielded device and the blocking materials during transport. It is depicted in Figure 1.2-7, Section 1.0, *General Information.* The IC is 59.5 inches tall and 42.75 inches in outer diameter, with an interior cavity of 36.0 inches in diameter and 53.0 inches long. The IC is a weldment made from ASTM A240, Type 304 stainless steel. The shell, the base, and the inner sheet of the lid are made from 1/4-inch thick material; the bolting flanges, of 1/2-inch thick material; and the grid pattern of stiffening and energy absorbing ribs on the outside are made from 3/16-inch thick material. The base structure is 4.0 inches thick and is stiffened by 8 ribs made from 1/4-inch thick material. The lid, attached using bolts and nuts, is 2.5 inches deep, with three, 1/4-inch thick ribs and three threaded blocks near the outer diameter for lifting the entire IC. The open space in the lid is filled with eight layers of 1/4-inch thick refractory insulation paper. The top of the lid is sealed with 16 GA (0.06-inch thick) sheet metal.

3.1.2 Content's Decay Heat

As discussed in Section 1.2.2, *Contents*, the contents within the LTSS and shielded device payloads is limited by the isotope involved. The maximum decay heat loading in the LTSS is limited to 200W, which is conservatively assumed to occur within one, minimum-size sealed source located in one drawer (Large Source Drawer or T80/780 drawer) of the LTSS. This maximum heat dissipation is associated with Co-60 source material, which deposits a significant portion of its heat directly into the surrounding shielding material via gamma rays. A discussion of the modeling of the gamma heating is provided in Section 3.5.3.2, *LTSS and LTSS Lodgment Thermal Model*. The decay heat loading in the shielded devices is conservatively set at 30W, which is approximately 150% of the heat generated by the maximum device activity stated in Table 1.2-2. All of the heat dissipation for the shielded devices is conservatively assumed to originate within the sealed source.

3.1.3 Summary Tables of Temperatures

Table 3.1-1 and Table 3.1-2 provide summaries of the package component temperatures with the LTSS and shielded device payloads, respectively, under normal and accident conditions. The temperatures for normal conditions are based on an analytical model of the 435-B package with an ambient temperature of 100 °F and the 10 CFR §71.71(c)(1) prescribed insolation applied as a diurnal loading (i.e., *NCT Hot* condition). The temperatures for accident conditions are based on a transient simulation using an analytical model of a damaged 435-B package. The damage conditions represent the worst-case hypothetical pre-fire damage predicted from a combination of physical drop testing using full-scale CTUs and analytical structural evaluations.

The results for NCT conditions demonstrate that significant thermal margins exist for all package components. Further, the NCT evaluations demonstrate that the accessible surface temperatures will be below the maximum 122 °F permitted by 10 CFR §71.43(g) for non-exclusive use shipment when transported in a 100 °F environment with no insolation (i.e., *NCT Hot (no solar)* condition). The results for HAC conditions also demonstrate that the design of the 435-B package provides sufficient thermal protection to yield component temperatures that are significantly below the acceptable limits defined for each component. See Sections 3.2.2, *Component Specifications*, Section 3.3, *Thermal Evaluation for Normal Conditions of Transport*, and Section 3.4, *Thermal Evaluation for Hypothetical Accident Conditions*, for more discussion.

3.1.4 Summary Tables of Maximum Pressures

Table 3.1-3 presents a summary of the maximum pressures predicted under NCT and HAC conditions. The 435-B package has a design maximum pressure of 25 psig (39.7 psia). Based on an assumed fill gas temperature of 70 °F and one atmosphere, the maximum pressure rise under NCT will be 2.3 psig, while the maximum pressure rise under HAC conditions will be 8.2 psig. Based on the NCT pressure, the maximum normal operating pressure (MNOP) is set at a bounding level of 5 psig. The maximum HAC pressure is conservatively assumed to be 10 psig.

Table 3.1-1 – Maximum NCT and HAC Temperatures with LTSS Payload

Location / Component	NCT, °F	HAC, °F ④	Allowable Temperature, °F ③	
			Normal	Accident
Sealed Source Capsule ①	882	905	1,100	1,100
NLM-52 Special Form Capsule	263	338	800	800
Large Source Drawer	218	295	800	800
LTSS Liner	190	270	800	800
LTSS Lead	185	265	620	620
LTSS Shell	176	257	800	800
Lodgment, Lower Half	157	449	400	1,100
Lodgment, Upper Half	152	396	400	1,100
Shell	152	1,156	800	1,300
Inner Thermal Shield	148	1,335	2,500	2,500
Outer Thermal Shield	148	1,421	2,500	2,500
Top Thermal Shield	192	1,437	2,500	2,500
Lower Internal Impact Limiter	155	250	400	1,100
Upper Internal Impact Limiter	164	1,050	400	1,100
Lower Torispherical Head	147	258	800	1,300
Upper Torispherical Head	183	1,269	800	1,300
Closure Seals	144	253	250	400
Vent Port Sealing Washer	144	256	250	400
Impact Limiter - Max. Foam - Avg. Foam - Shell	 151 132 151	 N/A N/A 1,474	 300 300 800	 N/A N/A 2,500
Max. Accessible Surface without Insolation	117 ②	-	122	N/A
Cask Cavity Bulk Gas	152	348	N/A	N/A

Notes: ① Results assume smallest source capsule (i.e., assumed 1.45" length x 0.72" diameter) dissipating 200 W in shortest NLM-52 special form capsule filled with argon gas.

② Maximum temperature occurs for the narrow band at base of the side thermal shield. Bulk of accessible surfaces are at a lower temperature.

③ See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

④ Listed peak HAC temperatures represent the maximum from two separate damage scenarios, see Section 3.4.3, *Maximum Temperatures and Pressure*.

Table 3.1-2 – Maximum NCT and HAC Temperatures with Shielded Device Payload

Location / Component	NCT, °F	HAC, °F	Allowable Temperature, °F③	
			Normal	Accident
Sealed Source Capsule ①	471	499	1,100	1,100
SD Drawer	192	236	800	800
SD Liner	153	200	800	800
SD Lead	152	200	620	620
SD Shell	152	199	800	800
Foam Dunnage	152	392	300	400
IC	134	972	800	2,500
Shell	146	1,147	800	1,300
Inner Thermal Shield	142	1,309	2,500	2,500
Outer Thermal Shield	142	1,419	2,500	2,500
Top Thermal Shield	191	1,436	2,500	2,500
Lower Internal Impact Limiter	127	210	400	1,100
Upper Internal Impact Limiter	156	837	400	1,100
Lower Torispherical Head	129	242	800	1,300
Upper Torispherical Head	180	1,082	800	1,300
Closure Seals	129	234	250	400
Vent Port Sealing Washer	129	236	250	400
Impact Limiter				
- Max. Foam	148	N/A	300	N/A
- Avg. Foam	124	N/A	300	N/A
- Shell	148	1,473	800	2,500
Max. Accessible Surface without Insolation	103②	-	122	N/A
Cask Cavity Bulk Gas	134	338	N/A	N/A

Notes: ① Results assume smallest source capsule (i.e., assumed 1.7" length x 1.57" diameter) dissipating 30 W.
② Maximum temperature occurs for the narrow band at base of the side thermal shield. Bulk of accessible surfaces are at a lower temperature.
③ See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

Table 3.1-3 – Summary of Maximum Pressures

Condition	Cask Cavity Pressure
NCT	2.3 psi gauge
HAC	8.2 psi gauge

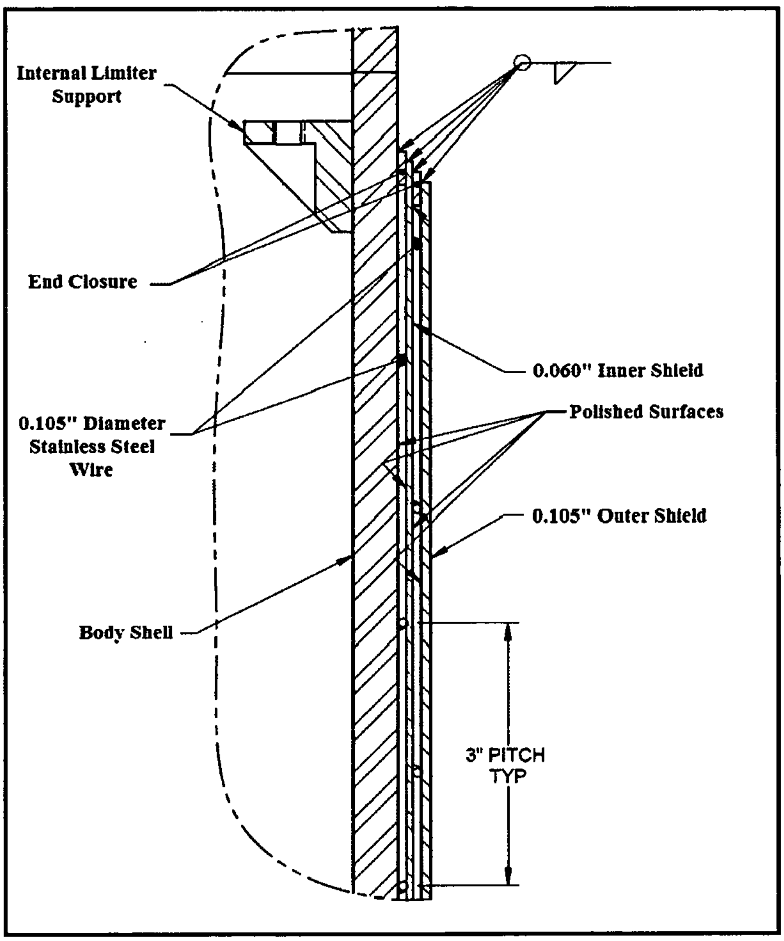


Figure 3.1-1: Dual Thermal Shield Layout

3.2 Material Properties and Component Specifications

This section presents the thermal properties and specifications of the materials that affect heat transfer within the 435-B packaging and the LTSS, the shielded devices, and their support structures. Included are the gases (i.e., argon, and air) that may be present within the package and the gas (air) external to the package. The thermal absorptivities and emissivities appropriate for the package surface conditions for each thermal condition are identified.

3.2.1 Material Properties

The 435-B packaging is fabricated primarily of Type 304 austenitic stainless steel, polyurethane foam, and a small amount of 6061 aluminum. The closure bolts are fabricated from ASTM 320, Grade L43 alloy steel. ASTM 320, Grade L43 steel has approximately twice the thermal conductivity of Type 304 stainless steel at temperatures up to 800°F, while the specific heats of the two materials are similar at all temperature levels. The thermal model does not specifically model either the bolt's material or the bolt geometry. Justification for this modeling approach is provided in Appendix 3.5.3, *Analytical Thermal Model.*

The LTSS and shielded device payloads are fabricated primarily of Type 304 stainless steel and lead with minor amounts of tungsten and brass. The LTSS lodgment is fabricated of 6061-T6 aluminum, while the IC is fabricated of Type 304 stainless steel and refractory paper insulation. The shielded devices dunnage/blocking is assumed to be fabricated of polyurethane foam.

Table 3.2-1 presents the thermal properties of Type 304 stainless steel, 6061 aluminum, QQ-L-171E Grade A or C lead, tungsten, and brass. Properties for temperatures between the tabulated values are calculated via linear interpolation within the heat transfer code. The thermal properties for Type 304 stainless steel and 6061 aluminum are taken from the ASME material properties database [9] and the density is taken from an on-line materials database [8]. QQ-L-171E Grade A or C lead is 99.9% lead plus a small amount of copper (i.e., 0.04% to 0.08%) and other elements that are added for improved structural properties. The values listed in Table 3.2-1 are for ASTM B29 copperized lead [15] which has the same chemical makeup as QQ-L-171E Grade C lead. The nominal density for lead is 708 lbm/ft^3 [8].

The emissivity of 'as-received' Type 304 stainless steel has been measured as 0.25 to 0.28 [18], while the emissivity of weathered Type 304 stainless steel has been measured as being between 0.36 to 0.44 [20]. An emissivity of 0.30 is assumed for the emittance from all non-brightened interior stainless steel surfaces based on a slightly weathered surface condition. A slightly lower emissivity of 0.25 is assumed for the mating surfaces at the closure seal due to the finer surface finish applied and maintained in that region. The outer face of the upper torispherical head and the cylindrical shell will receive a number 4 finish per ASTM A480, while both faces of the inner shield sheet, and the inside face of the outer shield sheet will receive a number 3 finish. The emissivity of a number 4 finish is 0.15, while the emissivity for a number 3 finish is 0.175 [21]. The emissivity of the outer faces of the package exposed to the ambient is 0.40 based on a weathered surface [20]. The solar absorptivity of Type 304/304L stainless steel for temperatures below 200°F is approximately 0.44 for the 'as-received' condition and 0.52 for the 'clean and smooth' condition [19]. A conservative value of 0.52 is used for normal conditions of transport.

The aluminum surfaces of the LTSS lodgment are assumed to have an emissivity of 0.20 based on an 'as-received' rough finish that has oxidized [19]. The emissivity for lead is not needed since the lead is assumed to be intimate contact with its surrounding surfaces and any radiative heat transfer is captured by the value assumed for the surface-to-surface contact. The intimate contact assumption reflects design experience that long term lead slump will yield an insignificant gap at the lead interface even if an initial gap is created following the lead pour process due to differential expansion.

Tungsten is used for shielding in the Large Source Drawers of the LTSS, while brass is used for the sleeves of the T80/780 source drawer for the LTSS and the source drawer for the Gammacell-40 shielded device. Thermal properties for tungsten are taken from [16] and for UNS C36000 brass from [8]. A temperature independent value for the thermal properties of brass is appropriate due to the limited extent of the material and the fact that temperature dependant properties for the material are not significant to the thermal results. Tungsten and brass are assumed to have emissivity values of 0.11 and 0.30, respectively, based on oxidized surfaces [19].

The polyurethane foam used in the impact limiter, the closure bolt enclosure structure, and dunnage/blocking for the shielded devices is based on a proprietary formulation that provides predictable impact-absorption performance under dynamic loading, while also providing an intumescent char layer that insulates and protects the underlying materials when exposed to HAC fire conditions. The thermal properties under NCT conditions are obtained from the manufacturer's website [5]. Because the website provides data at only a few specific densities and since the thermal conductivity of the material is tied to its density, interpolation is used to arrive at the listed material properties. Further, the manufacturing process for the poured in place foam can yield densities that are $\pm$15% of the targeted value. As such, the calculation for 15 lb_m/ft^3 (pcf) foam used in the impact limiter addresses the properties associated with both the low and high tolerance density foam (i.e., 12.75 and 17.25 pcf foam, see Table 3.2-2). Since the low tolerance foam yields a lower thermal conductivity, it is assumed for NCT operations, while the higher thermal conductivity of the high tolerance density foam is used for HAC evaluation to conservatively bound the heat flow into the package. The same process is not required for the 30 pcf foam used in closure bolt enclosure structure since it is formed from blocks with essentially zero deviation from the target density. The density of the dunnage/blocking foam used for the shielded devices is not important to safety since the level of heat transfer through the material is insignificant regardless of its density. The modeling assumes the properties of 15 pcf foam. The performance of polyurethane foam under HAC conditions is addressed in Appendix 3.5.4, *'Last-A-Foam' Response under HAC Conditions*. The potential for increased cavity pressure due to foam off-gassing addressed in Section 3.4.3.2, *Maximum HAC Pressures*, is conservatively based on the maximum foam dunnage weight permitted.

The refractory paper insulation used at the base of the impact limiter, the closure bolt enclosure structure, and the IC lid is a lightweight material processed from highly washed, spun, high purity alumina silica fibers that are formed into a highly flexible sheet. The material is easy to cut, wrap, or form, and it offers low thermal conductivity, low heat storage, and high heat reflectance. The material is resilient with excellent compression recovery. The thermal properties presented in Table 3.2-2 are based on the manufacturer's product brochure for LyTherm® 1530-L [17].

The thermal properties for neoprene synthetic rubber are also presented in Table 3.2-2. The properties, based on the *Polymer Data Handbook* [11], are assumed to be constant with temperature. The density value assumed in the modeling is conservatively low for neoprene with a 85 Duro hardness.

The polyurethane foam and the LyTherm® refractory paper material have an assumed emissivity of approximately 0.90 [19] based on a combination of the material type and surface roughness. The same emissivity is assumed for the neoprene rubber.

The thermal properties for air, as derived from curve fits provided in [23], are presented in Table 3.2-3. Because the gas thermal conductivity varies significantly with temperature, the computer model calculates the thermal conductivity between the package and the ambient as a function of the mean film temperature. The calculation conservatively assumes argon as the backfill gas in the NLM-52 special form capsule used in the Large Source Drawers of the LTSS. Those properties, presented in Table 3.2-4, were also derived from curve fits provided in [23].

3.2.2 Component Specifications

The acceptance criteria for normal conditions is that the package components remain within their respective thermal limits and that the 435-B packaging maintains containment for the payload. Only a few materials used in the 435-B packaging are considered temperature sensitive. These are the butyl rubber compound used for the containment boundary and vent/test port seals, the polyurethane foam used in the impact limiters, and the 6061-T6 aluminum used in the internal impact limiters. The materials considered temperature sensitive for the payloads are the 6061-T6 aluminum used for the LTSS lodgment, the lead used for the radiological shielding of the sealed sources, the outer shell of the sealed sources, and the polyurethane foam used for dunnage/blocking of the shielded devices. The other materials either have temperature limits above the maximum expected temperatures or are not considered essential to the function of the package.

The butyl rubber compound used for the containment and vent/test port seals is fabricated from Rainier Rubber compound R0405-70. Butyl rubber has a long term temperature range of at least -40 °F to 250 °F and a short-term limit of 400 °F for 8 hours. See Section 2.12.5, *Seal Performance Tests*, for the basis of these temperature limits.

Below 250 °F the variation in the thermal properties with temperature for the proprietary polyurethane foam are slight and reversible. While small variations in the foam properties will occur between 250 and 500 °F as water vapor and non-condensable gases are driven out of the foam, the observed changes in foam thermal conductivity, specific heat, and density are slight and begin for temperatures above 325 °F. For conservatism, a long-term limit of 300 °F is assumed for the foam. There is no short term temperature limit for the foam used in the impact limiter as its decomposition under exposure to high temperatures is part of its mechanism for providing thermal protection during the HAC fire event. A short term temperature limit of 400 °F is assumed for foam used as dunnage/blocking for the shielded devices within the IC. This temperature limit is conservatively below 500 °F where significant weight loss due to thermal decomposition begins to occur for the material. A detailed description of the foam's behavior under elevated temperatures is presented in Appendix 3.5.4, *'Last-A-Foam' Response Under HAC Conditions*.

Aluminum has a melting point of approximately 1,100°F [8]; however for strength purposes the normal operational temperature is limited to 400 °F based on structural strength considerations for aluminum [9]. The limit under HAC conditions is 1,100 °F. Since the internal impact limiters are fabricated from a combination of stainless steel and aluminum, the lower temperature limits for aluminum are conservatively assumed as the allowable temperature for the internal impact limiters.

Type 304 stainless steel has a melting point above 2,500 °F [8], but in compliance with ASME B&PV Code [10], its allowable temperature is limited to 800°F for structural components (e.g., the material's structural properties are relied on for loads postulated to occur in the respective operating mode or accidental free drop condition). As such, the appropriate upper temperature limit under normal conditions is 800 °F for stainless steel components that form the containment boundary or are used in the payload support. An allowable short term temperature limit of 1,300 °F is used for the torispherical heads of the package's containment boundary based on evaluations presented in Section 2.7.4.3, *Stress Calculations*. The same temperature limit will conservatively bound the short term limit for the cylindrical shell of the package's containment boundary. The IC does not have a structural role after the free drop. As such, the appropriate short-term temperature limit is the melting point for stainless steel (2,500 °F). The upper limit for all other stainless steel components is assumed to be 2,500 °F for both normal and accident conditions.

Neoprene (polychloroprene) rub strips are attached to the LTSS lodgment via adhesive to provide protection against fretting on the LTSS. Properties of neoprene related to its potential thermal decomposition/combustion under elevated temperatures are as follows:

a) chemical formulation [11]: $-[CH_2\text{-}Cl\text{-}C{=}CH\text{-}CH_2]_n-$,
b) working temperature range [8]: -40 °F to 200 °F
c) oxygen index [12]: 32-35% at atmospheric pressure,
d) melting temperature: N/A - thermoset material
e) temperature for initial decomposition [14]: 500 °F
f) auto ignition temperature [12]: >700 °F in a 21% oxygen concentration environment

As a thermoset plastic, uncontrolled heating of neoprene will result in thermal decomposition and not melting. The high oxygen index demonstrates why neoprene can't support combustion without an external ignition source under normal atmospheric conditions. The typical adhesives [13] used to bond the neoprene rub strips to consist of principally of solvents that outgas during the curing process, while the non-volatile components consist of polymers, including polychloroprene, and cure and vulcanization agents. As a result, the cured adhesive layer exhibits properties similar to neoprene. Based on the above information, the appropriate temperature range under normal conditions is -40 °F to 200 °F and 500 °F for accident conditions. Maintaining the neoprene below 500 °F will prevent significant off-gassing and eliminate any possibility for auto ignition of the material.

The temperature sensitive material for the payloads include the 6061-T6 aluminum used for the LTSS lodgment, the lead used for the radiological shielding of the sealed sources, the outer shell of the sealed sources and the polyurethane foam used for dunnage/blocking of the shielded devices. The allowable temperature limits for the LTSS lodgment are the same as discussed for aluminum. The QQ-L-171E lead used for payload shielding serves no structural purpose but avoidance of lead melting is desirable because of possible shielding loss associated with the movement of the lead within the cavity. As such, the temperature limitation for either normal or accident conditions is the melting point for lead of approximately 620 °F [8].

The maximum allowable shell temperature for the source capsule is 1,100 °F (600 °C) [22]. The maximum accessible outside surface temperature of the package shall be less than 122 °F in 100 °F air temperature and in the shade [1]. The minimum allowable service temperature for all package components is below -40 °F.

Table 3.2-1 – Thermal Properties of Metallic Materials (2 pages)

Material	Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lb_m-°F)	Density (lb_m/in^3)
Stainless Steel Type 304	-40①	8.2	0.112	0.289
	70	8.6	0.114	
	100	8.7	0.115	
	200	9.3	0.119	
	300	9.8	0.123	
	400	10.4	0.126	
	500	10.9	0.129	
	600	11.3	0.130	
	700	11.8	0.132	
	800	12.3	0.134	
	1000	13.1	0.135	
	1200	14.0	0.138	
	1400	14.9	0.141	
	1500	15.3	0.142	
Aluminum Type 6061-T6	-40①	93.2	0.208	0.0975
	70	96.1	0.214	
	100	96.9	0.216	
	150	98.0	0.220	
	200	99.0	0.222	
	250	99.8	0.224	
	300	100.6	0.227	
	350	101.3	0.230	
	400	101.9	0.231	
	600①	104.3	0.236	
Copperized Lead (QQ-L-171E Grade A or C)	-58	21.7	0.030	0.410
	32	20.4	0.030	
	80.6	30.0	0.030	
	158	19.9	0.031	
	260.6	19.4	0.032	
	428	18.4	0.033	
	608	16.5	0.033	
	620.6	16.4	0.036	

Table 3.2-1 – Thermal Properties of Metallic Materials (2 pages)

Material	Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/in³)
Tungsten	80	100.5	0.032	0.697
	260	91.9	0.033	
	620	79.2	0.034	
	980	72.2	0.035	
Brass	-	66.5	0.091	0.307

Note: ① Properties values at indicated temperature based on linear extrapolation of other values

Table 3.2-2 – Thermal Properties of Non-Metallic Materials

Material	Temperature (°F)	Thermal Conductivity (Btu/hr-ft-°F)	Specific Heat (Btu/lbm-°F)	Density (lbm/ft³)
Polyurethane Foam	-	0.0262	0.353	17.25
	-	0.0213		12.75
	-	0.0398		30
LyTherm® Paper Insulation	100	0.020	0.136	7.5
	500	0.036	0.209	
	800	0.047	0.227	
	1300	0.069	0.245	
	1600	0.082	0.254	
Neoprene	-	0.110	0.522	76.8

Table 3.2-3 – Thermal Properties of Air

Temperature (°F)	Density (lb_m/in^3)①	Specific Heat (Btu/lb_m-°F)	Dynamic Viscosity (lb_m/ft-hr)	Thermal Conductivity (Btu/hr-ft-°F)	Prandtl Number②	Coef. Of Thermal Exp. ($°R^{-1}$)③
-40	Use Ideal Gas Law w/ Molecular wt = 28.966	0.240	0.03673	0.0121	Compute as $Pr = c_p\mu / k$	Compute as $\beta = 1/(°F+459.67)$
0		0.240	0.03953	0.0131		
50		0.240	0.04288	0.0143		
100		0.241	0.04607	0.0155		
200		0.242	0.05207	0.0178		
300		0.243	0.05764	0.0199		
400		0.245	0.06286	0.0220		
500		0.248	0.06778	0.0240		
600		0.251	0.07242	0.0259		
700		0.253	0.07680	0.0278		
800		0.256	0.08098	0.0297		
900		0.259	0.08500	0.0315		
1000		0.262	0.08887	0.0333		
1200		0.269	0.09620	0.0366		
1400		0.274	0.10306	0.0398		
1500		0.277	0.10633	0.0412		

Table Notes:

① Density computed from ideal gas law as $\rho = PM/RT$, where R= 1545.35 ft-lbf/lb-mole-R, T= temperature in °R, P= pressure in lbf/ft^2, and M= molecular weight of air. For example, at 100 °F and atmospheric pressure of $14.69 lbf/in^2$, $\rho = (14.69*144\ in^2/ft^2*28.966\ lbm/lb\text{-}mole)/(1545.35*(100+459.67)) = 0.071$ lbm/ft^3.

② Prandtl number computed as $Pr = c_p\mu / k$, where c_p = specific heat, μ = dynamic viscosity, and k = thermal conductivity. For example, at 100 °F, Pr = 0.241*0.04607/0.0155 = 0.72.

③ Coefficient of thermal expansion is computed as the inverse of the absolute temperature. For example, at 100 °F, $\beta = 1/(100+459.67) = 0.00179$.

Table 3.2-4 – Thermal Properties of Argon

Temperature (°F)	Density (lb_m/in^3)①	Specific Heat (Btu/lb_m-°F)	Dynamic Viscosity (lb_m /ft-hr)	Thermal Conductivity (Btu/hr-ft-°F)	Prandtl Number②	Coef. Of Thermal Exp. ($°R^{-1}$)③
-40	Use Ideal Gas Law w/ Molecular wt = 39.948 g/mole	0.124	0.0444	0.0083	Compute as $Pr = c_p\mu / k$	Compute as $\beta = 1/(°F+459.67)$
0			0.0480	0.0089		
50			0.0524	0.0097		
100			0.0566	0.0105		
200			0.0645	0.0120		
300			0.0718	0.0134		
400			0.0788	0.0148		
500			0.0853	0.0160		
600			0.0914	0.0172		
700			0.0972	0.0183		
800			0.1028	0.0194		
900			0.1081	0.0205		
1000			0.1133	0.0215		
1200			0.1230	0.0234		

Table Notes:

① Density computed from ideal gas law as $\rho = PM/RT$, where R= 1545.35 ft-lbf/lb-mole-R, T= temperature in °R, P= pressure in lbf/ft^2, and M= molecular weight of argon. For example, at 100 °F and atmospheric pressure of $14.69 lbf/in^2$, $\rho = (14.69*144\ in^2/ft^2*39.948\ lbm/lb\text{-}mole)/(1545.35*(100+459.67)) = 0.098\ lbm/ft^3$.

② Prandtl number computed as $Pr = c_p\mu / k$, where c_p = specific heat, μ = dynamic viscosity, and k = thermal conductivity. For example, at 100 °F, Pr = 0.124*0.0566/0.0105 = 0.67.

③ Coefficient of thermal expansion is computed as the inverse of the absolute temperature. For example, at 100 °F, $\beta = 1/(100+459.67) = 0.00179$.

3.3 Thermal Evaluation for Normal Conditions of Transport

This section presents the thermal and gas generation evaluation of the 435-B package under normal conditions of transport (NCT). The package and payload configurations are assumed to be as described in Section 3.1, *Description of Thermal Design*. The thermal model used in the evaluation is described in Appendix 3.5.3, *Analytical Thermal Model*, while the thermal properties assumed for the various components are presented in Section 3.2.1, *Material Properties*. These evaluations establish the thermal and gas safety basis required to assess compliance with the 10CFR71 safety criteria [1] for the *NCT Hot*, *NCT Hot (no solar)*, and *NCT Cold* conditions. The safety basis for the *NCT Hot* ambient condition is evaluated using a diurnal cycle for insolation.

3.3.1 Heat and Cold

The NCT thermal performance is determined using a 3-D thermal model of the 435-B package and its enclosed LTSS and shielded device payloads. For the bounding LTSS payload, the model provides a full height, 180° representation of the system using approximately 32,600 thermal nodes, 11,000 solids, and 12,000 planar elements. The LTSS modeling conservatively assumes that only one Large Source Drawer in the LTSS is loaded with isotope material dissipating a maximum 200 W of decay heat. The temperatures and thermal gradients arising from this loading condition will bound those associated with the other loading scenarios.

The NCT model for the shielded devices uses a quarter symmetry with approximately 20,000 thermal nodes, 5,300 solids, and 5,250 planar elements. A quarter symmetry model is used for the evaluation of the shielded device since asymmetric heat loading is not a factor as it is for the LTSS payload. The modeling for both payloads is developed for use with the Thermal Desktop® [25] and SINDA/FLUINT [26] computer programs. Details of the thermal models and the analysis methodology are provided in Appendix 3.5.3, *Analytical Thermal Model.*

3.3.1.1 Maximum Temperatures

<u>LTSS Payload</u>

Table 3.3-1 presents the predicted 435-B package temperatures under NCT conditions for the transportation of the LTSS payload dissipating 200 W of decay heat. The analysis assumes the package is backfilled with air at atmospheric pressure at the time of loading. The results demonstrate that large thermal margins exist for all packaging and payload components. The minimum thermal margin of 106°F (i.e., 250 - 144°F), occurs for the cask closure seals. The large temperature rise between the special form capsule and the sealed source capsule in the Large Source Drawer is due to the conservative assumption of the 200 W loading occurring within a single, minimum size source capsule and no credit for direct contact between the source capsule and special form capsule sides. The relatively low temperatures seen for the other LTSS components reflects the effectiveness of the lead shielding to disperse the heat flux over the entire volume of the LTSS. The relatively large ratio of surface area of the 435-B package to the 200 W heat loading allows the package to dissipate the heat loading to the ambient conditions with only a small ΔT.

Figure 3.3-1 presents the predicted temperature distribution within the 435-B package for the NCT Hot condition and at the point in the diurnal insolation cycle where the solar heating on the package reaches its maximum. It is clearly evident from the temperature distribution that the majority of the temperature rise between the ambient and the source capsule occurs within the Large Source Drawer of the LTSS (note, for purposes of enhancing the clarity of the displayed temperature contours, the source capsule is not shown).

Since the use of the T80/780 drawer to house the sealed source capsule will result in a much smaller gap between the source capsule and the drawer and eliminate the added resistance posed by the presence of the NLM-52 special form capsule and the Large Source Drawer between the ends of the source capsule and the LTSS liner, the results for the Large Source Drawer above will bound those achieved with the T80/780 drawers regardless of whether lead, tungsten, or depleted uranium is used for shielding.

Evaluation of the package for an ambient air temperature of 100 °F without insolation loads demonstrates that the peak temperature for the accessible exterior surfaces of the packaging is below the maximum 122°F permitted by 10 CFR §71.43(g) for non-exclusive use shipments. As seen in Figure 3.3-2, the peak accessible surface temperature of 117°F occurs in a narrow band at the base of the side thermal shields where the closeout welds provide a direct thermal path to the package shell. Beyond this narrow region the accessible surface temperatures are significantly lower.

<u>Shielded Device Payload</u>

Table 3.3-2 presents the predicted 435-B package temperatures under NCT conditions for the transportation of a generic shielded device payload dissipating 30 W of decay heat. The analysis assumes the package is backfilled with air at atmospheric pressure at the time of loading.

Figure 3.3-3 presents the predicted temperature distribution within the 435-B package for the NCT Hot condition and at the point in the diurnal insolation cycle where the solar heating on the package reaches its maximum. It is clearly evident from the temperature distribution that the majority of the temperature rise between the ambient and the source capsule occurs very near the source.

3.3.1.2 Minimum Temperatures

Table 3.3-1 presents the predicted package temperatures for the cold condition of transport (i.e., -20 °F, no solar, consistent with Regulatory Guide 7.8 [4]) with the LTSS payload. Since a portion of the heat transfer between the LTSS and the package shell is via radiation, the change in the temperature gradient between adjacent components of the packaging is larger for the cold ambient temperature versus the hot conditions. However, due to the relatively low decay heat loading, the differences are relatively small and not thermally significant. Table 3.3-2 presents the cold condition results for the generic shielded device.

The minimum package temperature achieved for either payload will occur with a zero decay heat load and an ambient air temperature of -40 °F per 10 CFR §71.71(c)(2). The evaluation of this steady-state thermal condition requires no formal thermal calculation since all package components will eventually achieve the -40 °F temperature. As discussed in Section 3.2.2, *Component Specifications*, -40 °F is within the allowable operating temperature range for all package components.

3.3.2 Maximum Normal Operating Pressure

The package cavity is assumed to be filled with air at atmospheric pressure following loading procedure. None of the packaging components nor the LTSS or shielded devices contain material that is expected to decompose or outgas under the predicted NCT thermal conditions. As such, the pressurization of the package cavity will arise solely from ideal gas expansion.

The peak pressure developed within the package cavity under NCT conditions is estimated by assuming that the bulk average gas temperature at the time of loading is 70 °F. Combining this temperature with the predicted bulk gas temperature under the NCT Hot conditions and the ideal gas law yields:

$$\text{Cavity Pressure} = 14.7\text{psia}\frac{(152^\circ\text{F} + 460^\circ\text{F})}{(70^\circ\text{F} + 460^\circ\text{F})} - 14.7\text{ psia}$$

$$\text{Cavity Pressure} = 2.3\text{ psig}$$

Based on this same approach, the NCT pressures for the other transport conditions and for the shielded device payload are presented in Table 3.3-3. For conservatism, the maximum normal operating pressure (MNOP) within the package cavity is set at a bounding level of 5 psig.

Table 3.3-1 – NCT Temperatures for 435-B Packaging with LTSS Payload

Component	Temperature (°F)			
	NCT Hot (No Solar)	NCT Hot	NCT Cold	Allowable Temperature③
Sealed Source Capsule ①	877	882	852	1,100
Special Form Capsule	246	263	143	800
Large Source Drawer	201	218	95	800
LTSS Liner	172	190	61	800
LTSS Lead	167	185	56	620
LTSS Shell	159	176	48	800
Lodgment, Lower Half	137	157	24	400
Lodgment, Upper Half	128	152	13	400
Shell	121	152	5	800
Inner Thermal Shield	117	148	0	2,500
Outer Thermal Shield	117	148	-1	2,500
Top Thermal Shield	112	192	-5	2,500
Lower Internal Impact Limiter	135	155	21	400
Upper Internal Impact Limiter	118	164	3	400
Lower Torispherical Head	126	147	8	800
Upper Torispherical Head	110	183	-7	800
Closure Seals	121	144	4	250
Vent Port Sealing Washer	120	144	3	250
Impact Limiter				
- Max. Foam	126	151	8	300
- Avg. Foam	110	132	-9	300
- Shell	118	151	0	800
Max. Accessible Surface	117②	-	-	122
Cask Cavity Bulk Gas	128	152	13	N/A

Notes: ① Results assume smallest source capsule (i.e., assumed 1.45" length x 0.72" diameter) dissipating 200 W in shortest special form capsule filled with argon gas.

② Maximum temperature occurs for the narrow band at the base of the side thermal shield. Bulk of accessible surfaces are at a lower temperature.

③ See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

Table 3.3-2 – NCT Temperatures for 435-B Packaging with SD Payload

Component	Temperature (°F)			
	NCT Hot (No Solar)	NCT Hot	NCT Cold	Allowable Temperature③
Sealed Source Capsule ①	461	471	399	1,100
SD Drawer	176	192	71	800
SD Liner	136	153	24	800
SD Lead	136	152	24	620
SD Shell	135	152	23	800
Foam Dunnage	135	152	23	300
IC	111	134	-7	800
Shell	105	146	-14	800
Inner Thermal Shield	104	142	-16	2,500
Outer Thermal Shield	103	142	-16	2,500
Top Thermal Shield	101	191	-19	2,500
Lower Internal Impact Limiter	104	127	-15	400
Upper Internal Impact Limiter	101	156	-18	400
Lower Torispherical Head	103	129	-16	800
Upper Torispherical Head	101	180	-19	800
Closure Seals	103	129	-17	250
Vent Port Sealing Washer	103	129	-17	250
Impact Limiter				
- Max. Foam	103	148	-16	300
- Avg. Foam	101	124	-18	300
- Shell	102	148	-17	800
Max. Accessible Surface	103②	-	-	122
Cask Cavity Bulk Gas	108	134	-10	N/A

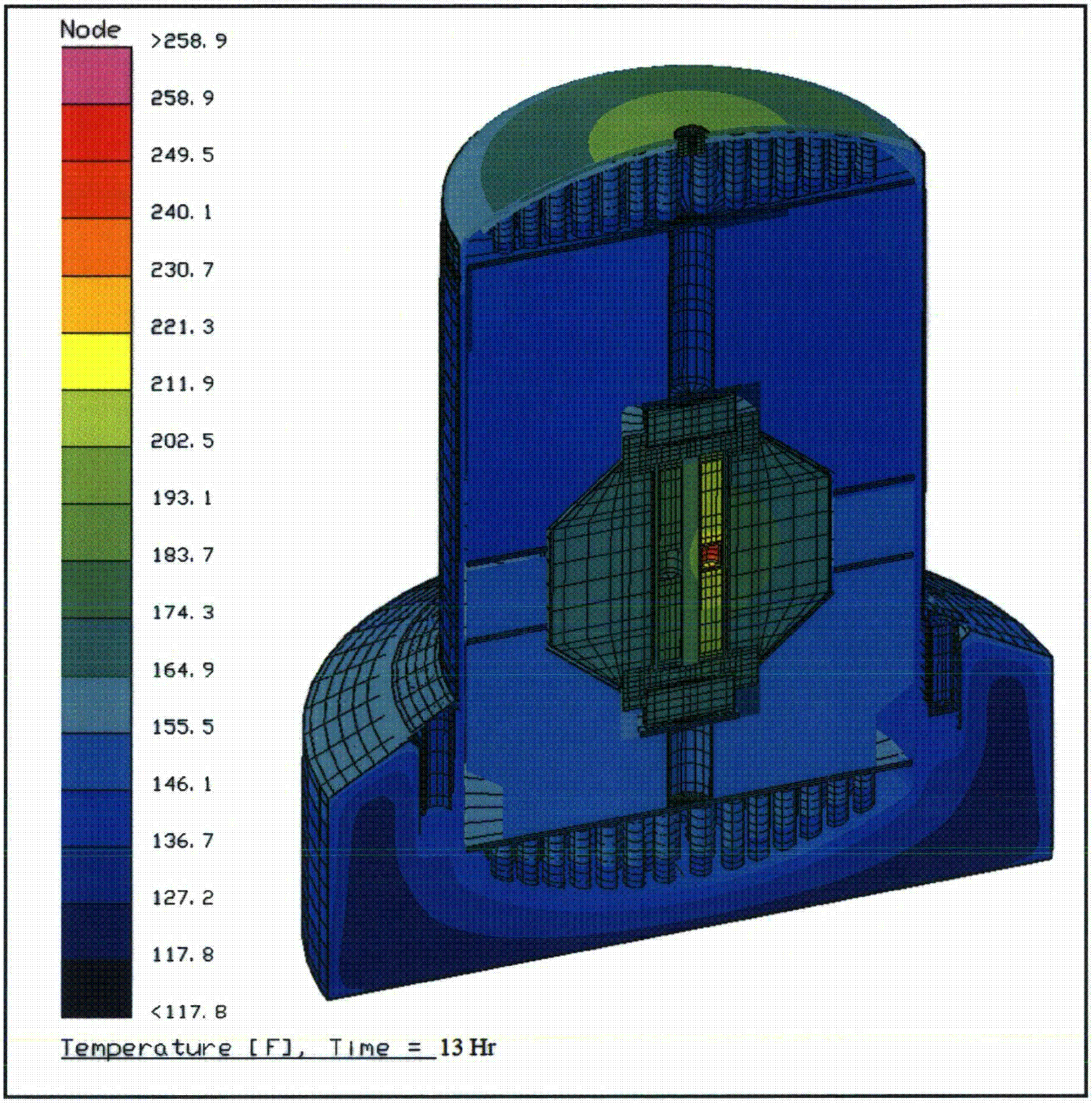
Note: ① Results assume smallest source capsule (i.e., assumed 1.7" length x 1.57" diameter) dissipating 30 W.

② Maximum temperature occurs for the narrow band at the base of the side thermal shield. Bulk of accessible surfaces are at a lower temperature.

③ See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

Table 3.3-3 – NCT Pressures for 435-B Packaging

Condition	Package Cavity Pressure	
	LTSS Payload	Shielded Device Payload
NCT Hot (No Solar)	1.6 psi gauge	1.1 psi gauge
NCT Hot	2.3 psi gauge	1.8 psi gauge
NCT Cold	-1.6 psi gauge	-2.2 psi gauge



Note: For display clarity, the source capsule temperatures are not shown in the figure

Figure 3.3-1 – NCT Temperature Distribution for LTSS Payload[1]

[1] Temperature distribution shown at point of peak solar heating during 24 hour diurnal cycle on insolation

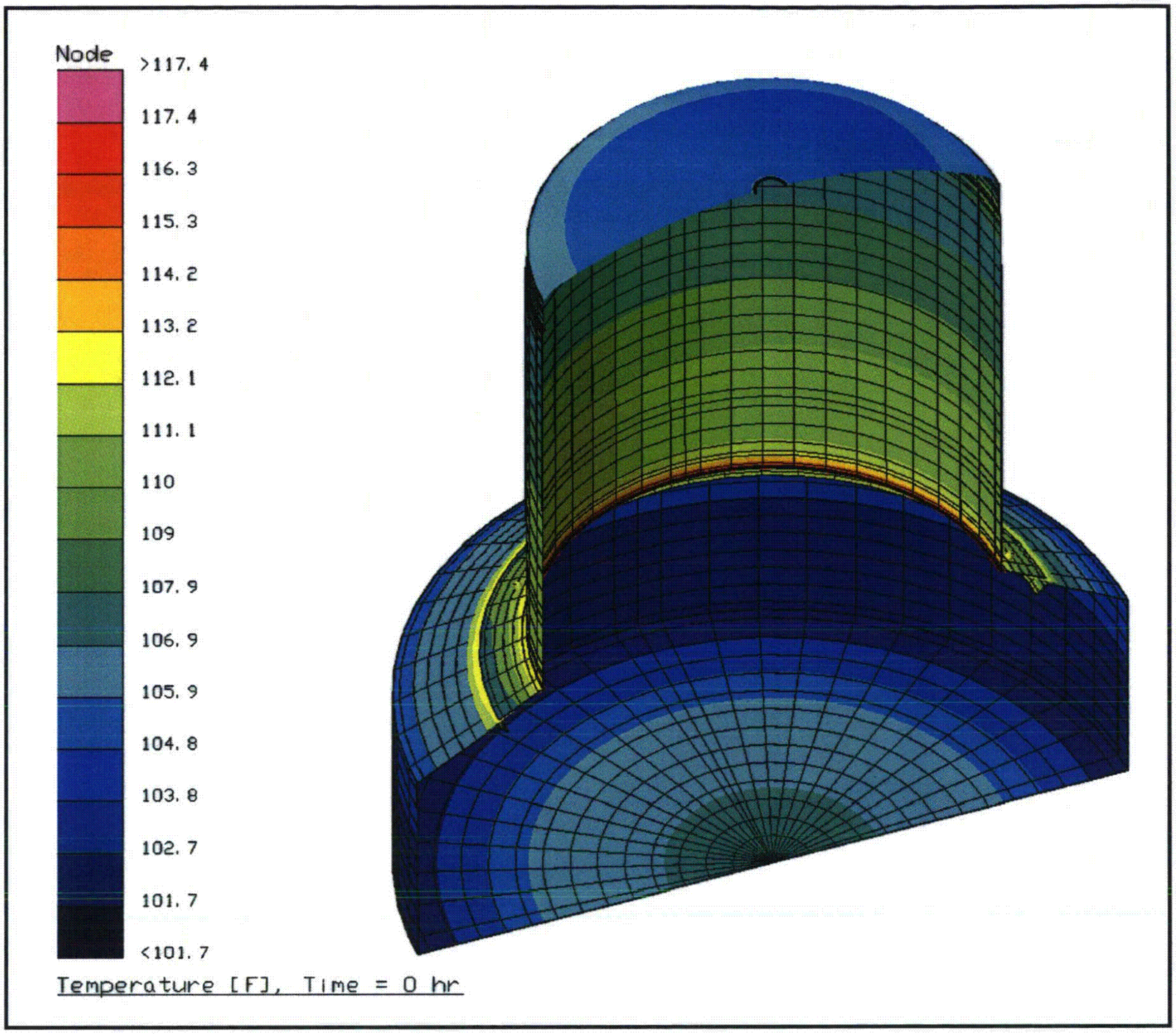
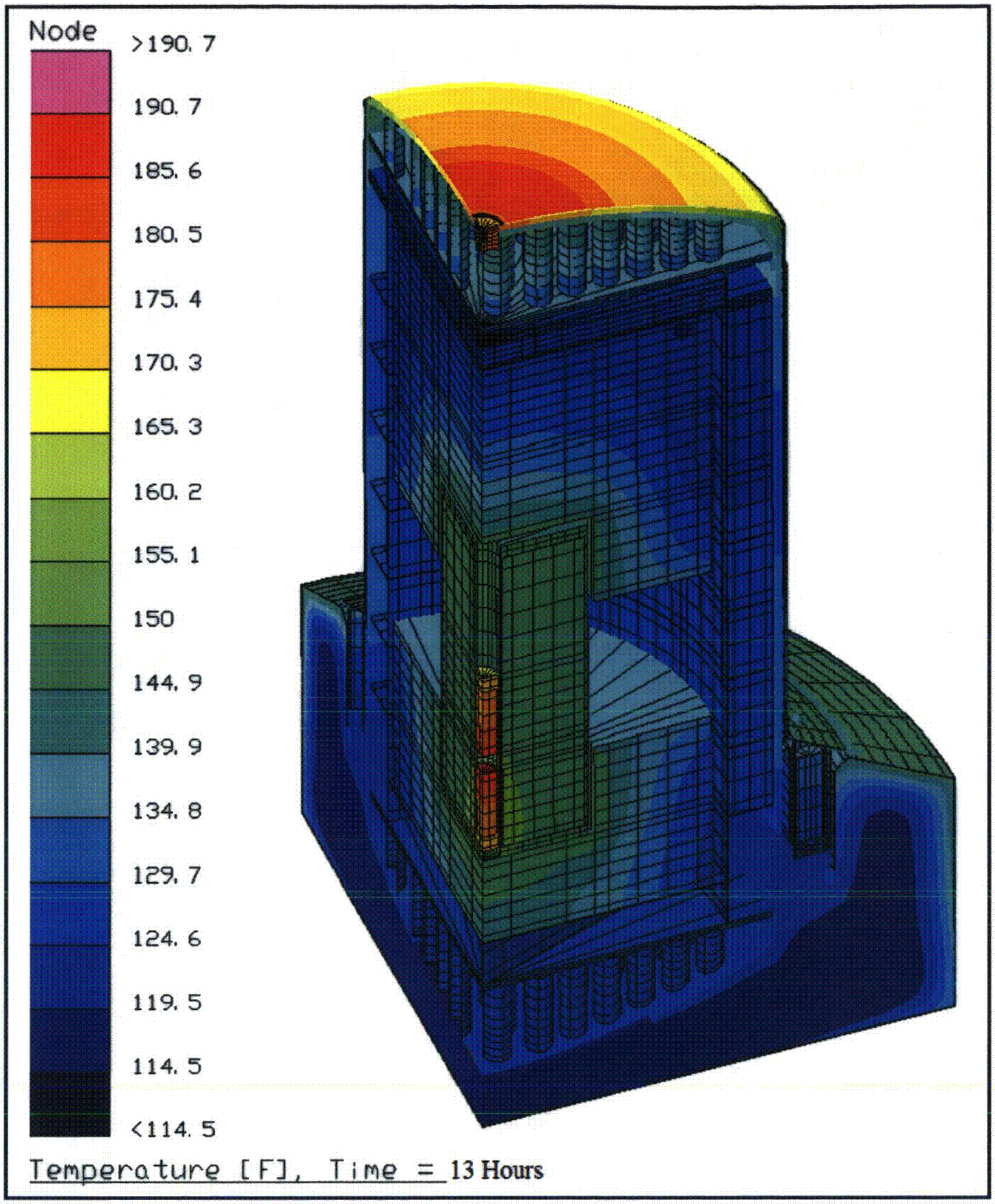


Figure 3.3-2 – Accessible Surface Temperature Distribution



Note: For display clarity, the source capsule temperatures are not shown in the figure

Figure 3.3-3 – NCT Temperature Distribution for Generic Shielded Device[2]

[2] Temperature distribution shown at point of peak solar heating during 24 hour diurnal cycle on insolation

3.4 Thermal Evaluation for Hypothetical Accident Conditions

This section presents the thermal evaluation of the 435-B package under the hypothetical accident condition (HAC) specified in 10 CFR §71.73(c)(4). The evaluation is based on modified versions of the analytical NCT thermal models for the 435-B package with the LTSS and shielded device payloads. Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, presents a description of the modifications made to the NCT model to reflect the HAC conditions.

Physical testing using prototypic full-scale certification test units (CTUs) is used to establish the expected level of damage sustained by the 435-B package from the 10 CFR 71.73 prescribed free and puncture drops preceding the HAC fire event. The configuration and initial conditions of the test article, the test facilities and instrumentation used, and the test results are documented in Section 2.12.3, *Certification Test Results*. An overview of the test results, the rationale for selecting the worst-case damage scenario, and the details of the thermal modeling used to simulate the package conditions during the HAC fire event are provided in Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*.

3.4.1 Initial Conditions

The initial conditions assumed for the package prior to the HAC event are described below in terms of the modifications made to the NCT thermal model to simulate the assumed package conditions prior to and during the HAC event. These thermal model modifications are:

- simulated the expected damage arising from side or head down HAC free drops, determined in Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, to represent the worst case damage, and added the associated puncture drop damage,
- changed the package orientation from upright to horizontal to reflect the assumed position of the package following an HAC accident event and since this orientation maximizes the heat transfer between the shell of the package and the payloads,
- added heat transfer to and from the base of the package to simulate a fully engulfing fire event,
- increased the emissivity of all external surfaces to 0.8 and the solar absorptivity to 0.9 to account for possible oxidation and/or soot accumulation on the surfaces,
- increased the emissivity of the interior surface of the outer thermal shield from 0.175 to 0.225 to account for potential oxidization during the course of the HAC event,
- removed 1.8 to 2.8 inches of foam from the exterior portions of the impact limiter foam block and added heat transfer via radiation within the impact limiter enclosures with an emissivity of 0.95 to account for the loss of polyurethane foam from thermal decomposition. While this foam volume would be gradually lost over the course of the 30-minute fire event, the modeling conservatively assumes this foam volume is lost instantaneously at the start of the fire event.

- assumed an initial temperature distribution equivalent to the package at steady-state conditions with a 100 °F ambient and no insolation. This assumption complies with the requirement of 10 CFR §71.73(b).

Based on the CTU drop test results discussed in Section 2.12.3, *Certification Test Results*, the LTSS and shielded device payloads are predicted to remain intact and experience no significant damage or re-positioning as a result of the drop events. Since the package geometry is essentially axi-symmetrical, the thermal performance under HAC conditions is independent of the rotational orientation of the package.

3.4.2 Fire Test Conditions

The fire test conditions analyzed to address the 10 CFR §71.73(c) requirements are as follows:

- The initial pre-fire ambient conditions are assumed to be 100°F ambient with no insolation,
- At time = 0, a fully engulfing fire environment consisting of a 1,475°F ambient with an effective emissivity of 1.0 is used to simulate the average flame temperature of the hydrocarbon fuel/air fire event. The assumption of an average flame emissivity coefficient of 1.0 conservatively bounds the minimum 0.9 flame emissivity specified by 10 CFR Part 71.73(c)(4).
- The convection heat transfer coefficients between the package and the ambient during the 30-minute fire event are based on an average gas velocity of 10 m/sec [28]. Following the 30-minute fire event the convection coefficients are based on still air.
- The ambient condition of 100 °F with insolation is assumed following the 30-minute fire event. A solar absorptivity of 0.9 is assumed for the exterior surfaces to account for potential soot accumulation on the package surfaces.

The transient analysis is continued for 8 hours after the end of the 30-minute fire to capture the peak package temperatures.

3.4.3 Maximum Temperatures and Pressure

3.4.3.1 Side Drop Damage with LTSS Payload

Table 3.4-1 presents the predicted peak temperature seen for the 435-B package with the LTSS payload under the side drop damage HAC conditions. The side drop damage scenario is predicted in Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, to yield the worst case damage to the package components that thermally protects the closure seals and the bottom portion of the package. As seen from the table, despite the damage sustained by the package under this drop scenario the thermal protection features incorporated into the package design limits the heat flux into the package resulting in significant thermal margins for all package components.

The closure and vent/test port seals remain approximately 150°F below their maximum allowable short-term temperature limit due to a combination of the thermal shielding provided by the closure bolt enclosure structure and the amount of foam remaining. This temperature margin is significant, especially given the conservative assumptions used to model the loss of the protective polyurethane foam. In addition, the peak temperature predicted for the vent/test port seal assumes the worst case side drop impact limiter damage is assumed to align directly opposite the port location.

The large thermal mass of the LTSS payload effectively limits the temperature rise of the LTSS components during the fire event to approximately 100°F or less. The relatively cool mass of the LTSS payload also limits the rise of the bulk average package cavity gas temperature (and, thus the cavity pressure) to approximately 200 °F (i.e., a peak temperature of 345 °F). The lead used for shielding in the LTSS remains well below its melting point.

Figure 3.4-1 and Figure 3.4-2 illustrate the temperature response profiles for selected package components for the side drop damage scenario with the LTSS payload. Again, the low temperature rise seen for the LTSS payload and closure seals over the HAC event demonstrates the thermal protection afforded by the 435-B package design.

Figure 3.4-3 illustrates the temperature distribution within the 435-B package at the end of the 30-minute hypothetical fire. The fact that the high temperatures are limited to narrow regions on the exterior of the packaging temperature distribution demonstrates the thermal protection afforded to the package by the dual side thermal shields, the closure bolt enclosure structure, and the polyurethane filled impact limiter. The location of the damaged segments of the packaging is indicated by annotations in the figure. Although the modeling doesn't physically reflect the geometry realignment to the package exterior caused by the side drop damage, the thermal conductors used in the modeling have been modified to reflect the geometry realignment and associated effects of the damage. These modeling changes include higher conductance between the thermal shields to reflect potential contact from puncture bar damage, a narrowing of the air gap between the thermal shields and the package shell at the damaged area, and the crush of the polyurethane foam filled impact limiter and subsequent thermal decomposition under the HAC generated temperatures. See Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, for details of the HAC thermal modeling. The effect of the side crush on the loss of foam depth in the impact limiter can be seen by comparing the depiction of the foam boundary on the right and left sides of the figure.

Figure 3.4-4 depicts the package temperature distribution at 60 minutes (i.e., 30 minutes after the end of the fire event) when the bulk average gas temperature in the package cavity is predicted to reach its maximum. The exterior of the package has cooled dramatically by this point. The moderating effect of the LTSS thermal mass on the bulk average gas temperature can be clearly seen in the figure by its significantly lower temperature than its surrounding packaging components.

The temperature distribution within the LTSS lodgment at the point where it reaches its peak temperature is shown in Figure 3.4-5. The asymmetry of the temperature distribution is due to the assumption that the package is on its side following the HAC drop events and there is direct contact between the vertical ribs on one side of the lodgment and the package shell. The localized effect of the postulated puncture bar damage to the package side thermal shield and shell is clearly seen in the figure. See Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, for details of the puncture bar damage modeling.

3.4.3.2 Head Down Drop Damage with LTSS Payload

Table 3.4-2 presents the predicted peak temperature for the 435-B package with a LTSS payload under the head down drop HAC conditions. The head down damage scenario was selected for analysis (see Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*) because of the resulting damage to the torispherical head and its protective top shield. As seen, except for the higher temperatures seen for the top torispherical head, the remaining peak package temperatures are similar to those seen for the side drop damage scenario. This is partially due to the fact that both damage scenarios assume that the package ends up on its side, but mostly reflects the thermal protection afforded by the package design despite the damage scenario.

Figure 3.4-6 and Figure 3.4-7 illustrate the temperature response profiles for selected package components for the head down drop damage scenario with the LTSS payload. The temperature trends are similar to those seen for the side drop damage scenario. Figure 3.4-8 illustrates the temperature distribution within the 435-B package at the end of the 30-minute hypothetical fire. Figure 3.4-9 illustrates the temperature distribution across the torispherical head at the end of the 30-minute hypothetical fire. The localized effect of the simulated puncture bar impact to the head is clearly seen in the figure. See Appendix 3.5.3.5, *Description of Thermal Model for HAC Conditions*, for details of the puncture bar damage modeling.

3.4.3.1 Side Drop Damage with Shielded Device Payload

The thermal performance of the 435-B packaging with the shielded device payload under HAC conditions is bounded by those for the LTSS payload due to the higher decay loading of the LTSS payload. However, a separate HAC evaluation is conducted for the shielded device payload configuration to ensure that the foam dunnage temperatures will remain below its thermal decomposition point during the fire event. The modeling is conducted using the same packaging model as used for the LTSS HAC side drop damage evaluation, except that a quarter symmetry representation of the package is used. This level of modeling will produce conservative results since it effectively over-predicts the impact of the concentrated drop damage.

Table 3.4-3 presents the predicted peak temperature seen for the 435-B package with the shielded device payload under the side drop damage HAC conditions. As expected, the results for the 435-B packaging components are essentially the same as seen for the LTSS payload. The results for the shielded device components show that all remain within their associated temperature limits. In particular, the foam dunnage temperature remains below 400 °F, which is well below the 500 °F point where thermal decomposition just begins (see Appendix 3.5.4, *'Last-A-Foam' Response under HAC Conditions*) and well below the 570 to 670 °F level where the bulk of the thermal decomposition occurs. As such, thermal decomposition of the foam will not contribute to any significant package pressurization.

Figure 3.4-10 illustrates the temperature response profiles for selected payload components for the side drop damage scenario with the shielded device payload. The thermal response for the 435-B packaging components are similar to those depicted in Figure 3.4-1. Figure 3.4-11 illustrates the temperature distribution within the 435-B package at the 46-minute point in the fire event (i.e., when the foam dunnage is predicted to reach its maximum temperature point). As seen from the figure, the combination of the IC and the foam dunnage effectively thermally isolates the shielded device from the HAC heat flux.

The temperature distribution within the IC at the end of the 30-minute fire and at the point where the cylindrical shell of the IC reaches its peak temperature is shown in Figure 3.4-12. The asymmetry of the temperature distribution is due to the assumption that the package is on its side following the HAC drop events and there is direct contact between the vertical ribs on one side of the IC and the package shell. The localized effect of the postulated puncture bar damage to the package side thermal shield and shell is clearly seen in the figure wherein a short-term peak temperature of 972 °F is achieved for a short section of a the IC's rib. The majority of the IC remains well below its long-term temperature limit of 800 °F. The peak and average temperature of the IC's cylindrical shell at the end of the 30-minute fire is 374 °F and 177 °F, respectively. The IC's cylindrical shell peak temperature of 432 °F is achieved after 43 minutes when the associated average of the cylindrical shell is 239 °F.

3.4.3.2 Maximum HAC Pressures

Under the HAC condition, the maximum peak bulk average gas temperature achieved during the HAC transient (for the LTSS payload case) is 348 °F. Based on an assumed backfill gas temperature of 70 °F, the predicted maximum pressure within the cask cavity in the LTSS case is computed to be:

$$\text{Cavity Pressure} = 14.7\text{psia}\,\frac{(348^{o}\text{F} + 460^{o}\text{F})}{(70^{o}\text{F} + 460^{o}\text{F})} - 14.7\text{ psia}$$

$$\text{Cavity Pressure} = 7.7\text{ psig}$$

Considering both the LTSS and shielded device payloads, the only content material with any potential for off-gassing at the temperatures reached under HAC is the polyurethane foam dunnage that may be used with the shielded device payload. Foam decomposition evaluations using TGA (Thermogravimetric Analysis) indicate a slight off-gassing will begin at foam temperatures above 325 °F. Based on the TGA curves [6], this initial off-gassing is limited to approximately a 2% weight loss for a temperature rise from 325 to 435 °F. Interpolating this curve yields a 0.45% weight loss for foam between 325 and 350 °F and 1.4% weight loss for foam between 325 and 400 °F.

A mass weighted averaging of the foam dunnage model used for the shielded device payload demonstrates that 3% of the total foam mass reached a temperature range of 325 to 350 °F during the HAC transient and 0.52% of the total foam mass reached a temperature range of 350 to 400 °F. The bulk average temperature of the foam dunnage remained below 180 °F throughout the HAC transient. Given a maximum foam dunnage weight of 500 lb (Section 7.1.2.2, *Loading the Inner Container (IC) into the 435-B*) and the interpolated weight loss factors above, the maximum gas generation will be 500 lb × (0.03 × 0.0045 + 0.0052 × 0.014) = 0.104 lb. This weight loss occurs in the form of water vapor and/or the gas used for the foam blowing agent. As such, the 0.104 lb of gas is equivalent to a maximum of 2.6 g-moles of gas generation, based on a molecular weight for water vapor of 18 g/g-mole.

The interior volume of the containment is 106,232 in^3 [29]. The displacement volume of both internal impact limiters is 1,973 in^3 (assuming 72 lb of aluminum and 73 lb of Type 304 stainless steel for each limiter and densities from Section 2.2.1, *Material Properties and Specifications*). The displacement volume of the IC is 4,000 in^3 (assuming 1,160 lb of Type 304 stainless steel), and the volume within the IC, which has an inner diameter of 36 inches and is 53 inches long, is

53,947 in^3. For conservatism, the entire internal volume of the IC is assumed to be filled by either foam or the payload for the purposes of the pressure calculation.

The minimum net void volume within the package is therefore:

106,232 in^3 – 1,973 in^3 – 4,000 in^3 –53,947 in^3 = 46,312 in^3 (758.9 liters).

The minimum quantity of air required to fill the package's payload cavity to a pressure of 1 atmosphere at 70 °F (294 K) is determined via:

g-moles fill gas = Press * Volume / [0.08206 L-atm/(g-mole-K) * T(K) * 14.7 psia/L-atm]
= 14.7 * 758.9 /[0.08206 * 294 K * 14.7]
= 31.5 g-moles

Since the rise in the dunnage foam temperatures lag the peak bulk average cavity gas temperature, the actual peak foam off-gassing will not occur until over 90 minutes after the cavity gas temperature peaks. This fact, illustrated in Figure 3.4-13, results in a lower ideal gas expansion effect and a lower associated cavity pressure. The peak cavity pressure achieved under the HAC transient for the shielded device payload is predicted to be 8.2 psig. This estimated pressure rise is conservative since it ignores the potential for any generated water vapor to quickly re-condense on the surfaces of the IC and internal impact limiters remaining below 212 °F and not contribute to an added pressure rise in the package cavity. For information, the "stairstep" changes in the curve for the foam off-gassing quantity and, to a lesser degree, the curve for cavity pressure are due to the conservative analysis logic which assigns the entire gas generation quantity for each temperature range as soon as the minimum temperature level is exceeded and then assumes no further gas generation until the minimum temperature value of the next temperature range is exceeded.

For conservatism, a peak HAC pressure of 10 psig is used for either payload configuration.

3.4.4 Maximum Thermal Stresses

The maximum thermal stresses under the HAC condition are addressed in Section 2.7.4, *Thermal*.

Table 3.4-1 – HAC Temperatures for Side Drop Damage with LTSS

Component	Temperature (°F)			
	End of Fire	Peak	Post-fire Steady State	Allowable②
Sealed Source Capsule①	877	905	887	1,100
Special Form Capsule	246	338	282	800
Large Source Drawer	201	295	238	800
LTSS Liner	176	270	210	800
LTSS Lead	176	265	205	620
LTSS Shell	180	257	197	800
Lodgment, Lower Half	445	449	177	1,100
Lodgment, Upper Half	306	396	167	1,100
Shell	1,127	1,127	170	1,300
Inner Thermal Shield	1,323	1,323	167	2,500
Outer Thermal Shield	1,420	1,420	166	2,500
Top Thermal Shield	1,437	1,437	152	2,500
Lower Internal Impact Limiter	167	250	175	1,100
Upper Internal Impact Limiter	891	891	154	1,100
Lower Torispherical Head	240	258	168	1,300
Upper Torispherical Head	1,083	1,083	149	1,300
Closure Seals	148	253	166	400
Vent Port Sealing Washer	163	256	166	400
Impact Limiter - Max. Foam - Avg. Foam - Shell	 N/A N/A 1,474	 N/A N/A 1,474	 N/A N/A 164	 N/A N/A 2,500
Cask Cavity Bulk Gas	298	345	167	N/A

Notes: ① Results assume smallest source capsule dissipating 200 W in shortest special form capsule filled with argon gas.

② See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

Table 3.4-2 – HAC Temperatures for Head Down Drop Damage with LTSS

Component	Temperature (°F)			
	End of Fire	Peak	Post-fire Steady State	Allowable②
Sealed Source Capsule①	877	903	887	1,100
Special Form Capsule	246	336	283	800
Large Source Drawer	201	294	239	800
LTSS Liner	176	268	211	800
LTSS Lead	174	264	206	620
LTSS Shell	177	255	198	800
Lodgment, Lower Half	319	370	179	1,100
Lodgment, Upper Half	304	395	168	1,100
Shell	1,156	1,156	172	1,300
Inner Thermal Shield	1,335	1,335	168	2,500
Outer Thermal Shield	1,421	1,421	167	2,500
Top Thermal Shield	1,430	1,430	149	2,500
Lower Internal Impact Limiter	157	244	177	1,100
Upper Internal Impact Limiter	1040	1,050	153	1,100
Lower Torispherical Head	236	254	174	1,300
Upper Torispherical Head	1,268	1,269	145	1,300
Closure Seals	148	251	168	400
Vent Port Sealing Washer	161	250	168	400
Impact Limiter - Max. Foam - Avg. Foam - Shell	 N/A N/A 1,474	 N/A N/A 1,474	 N/A N/A 166	 N/A N/A 2,500
Cask Cavity Bulk Gas	308	348	168	N/A

Notes: ① Results assume smallest source capsule dissipating 200 W in shortest special form capsule filled with argon gas.

② See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.

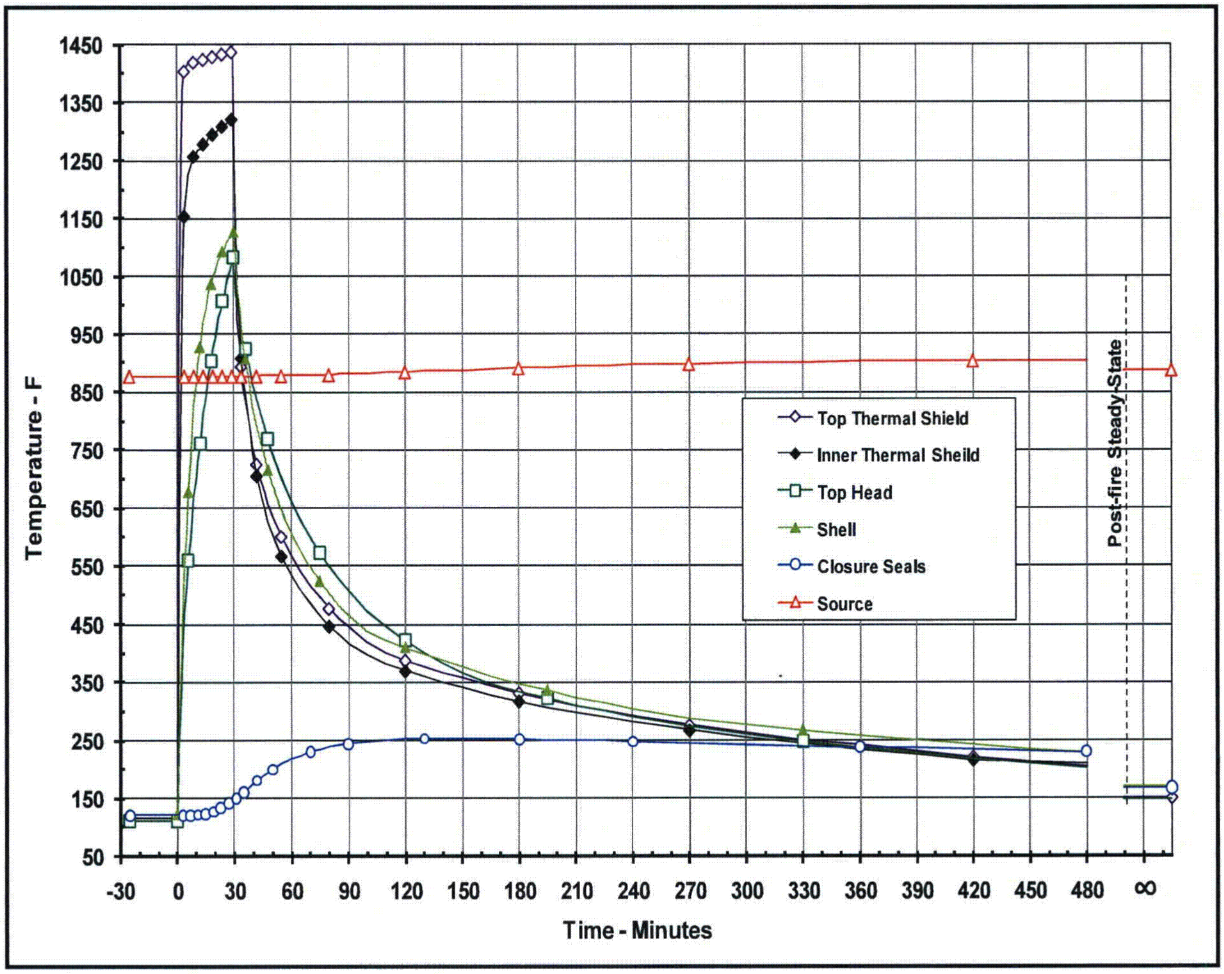
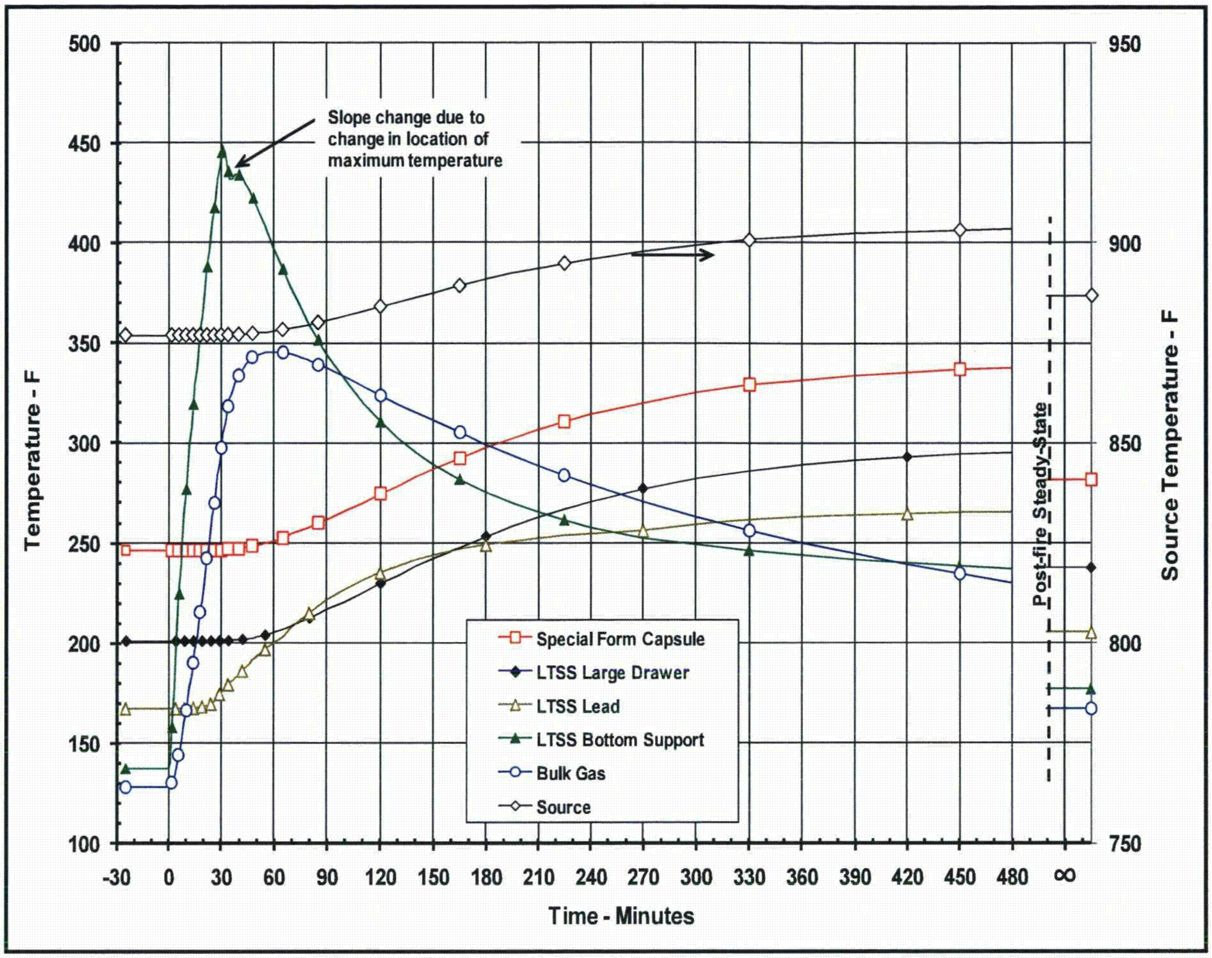


Figure 3.4-1 – Package HAC Temperature Response – Side Drop Damage with LTSS



Note: Scale for source temperature shown on right hand side

Figure 3.4-2 – LTSS HAC Temperature Response – Side Drop Damage

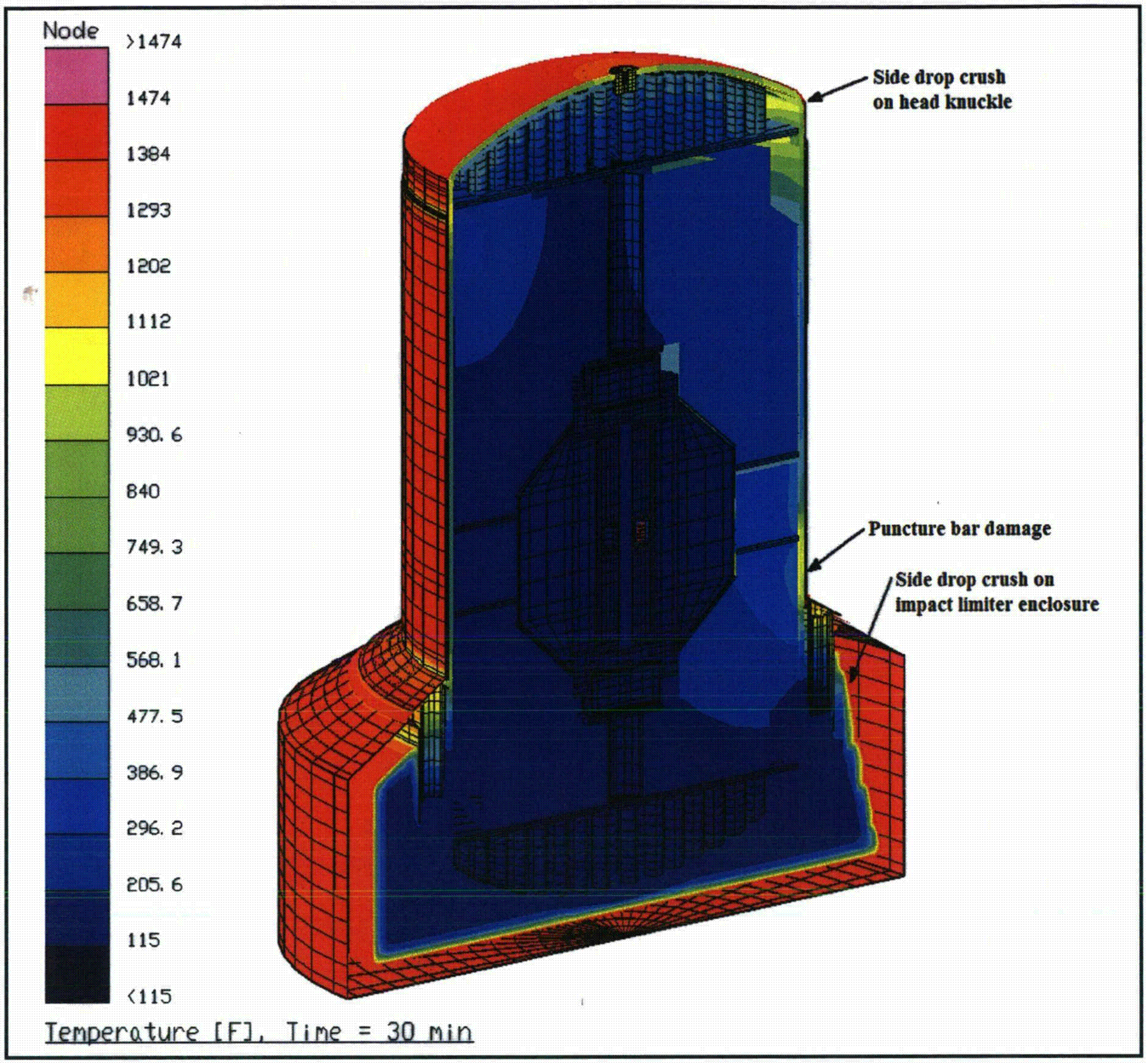


Figure 3.4-3 – Side Drop HAC Temperature Distribution with LTSS at End of 30 Minute Fire

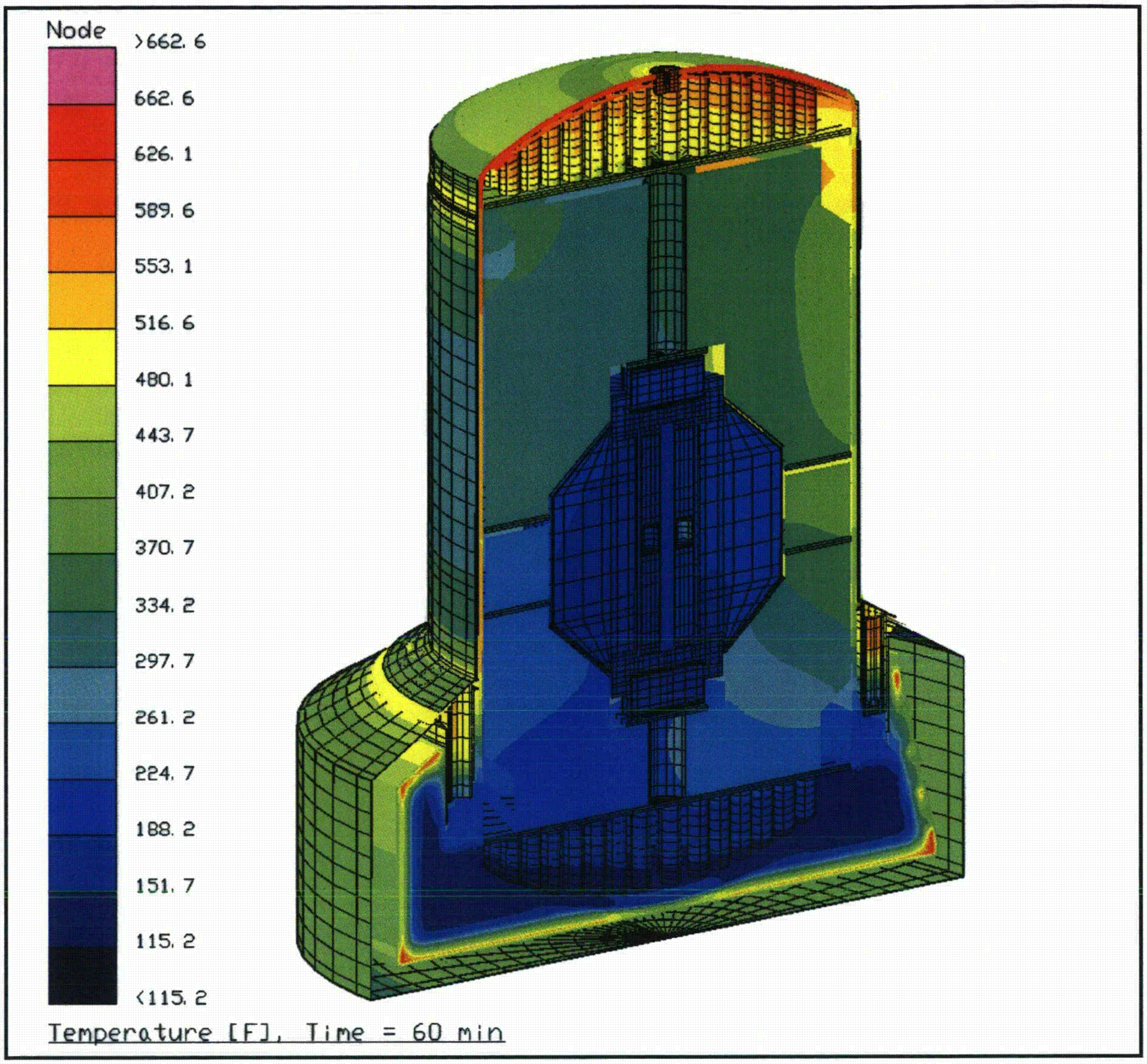


Figure 3.4-4 – Side Drop HAC Temperature Distribution with LTSS at 60 Minutes

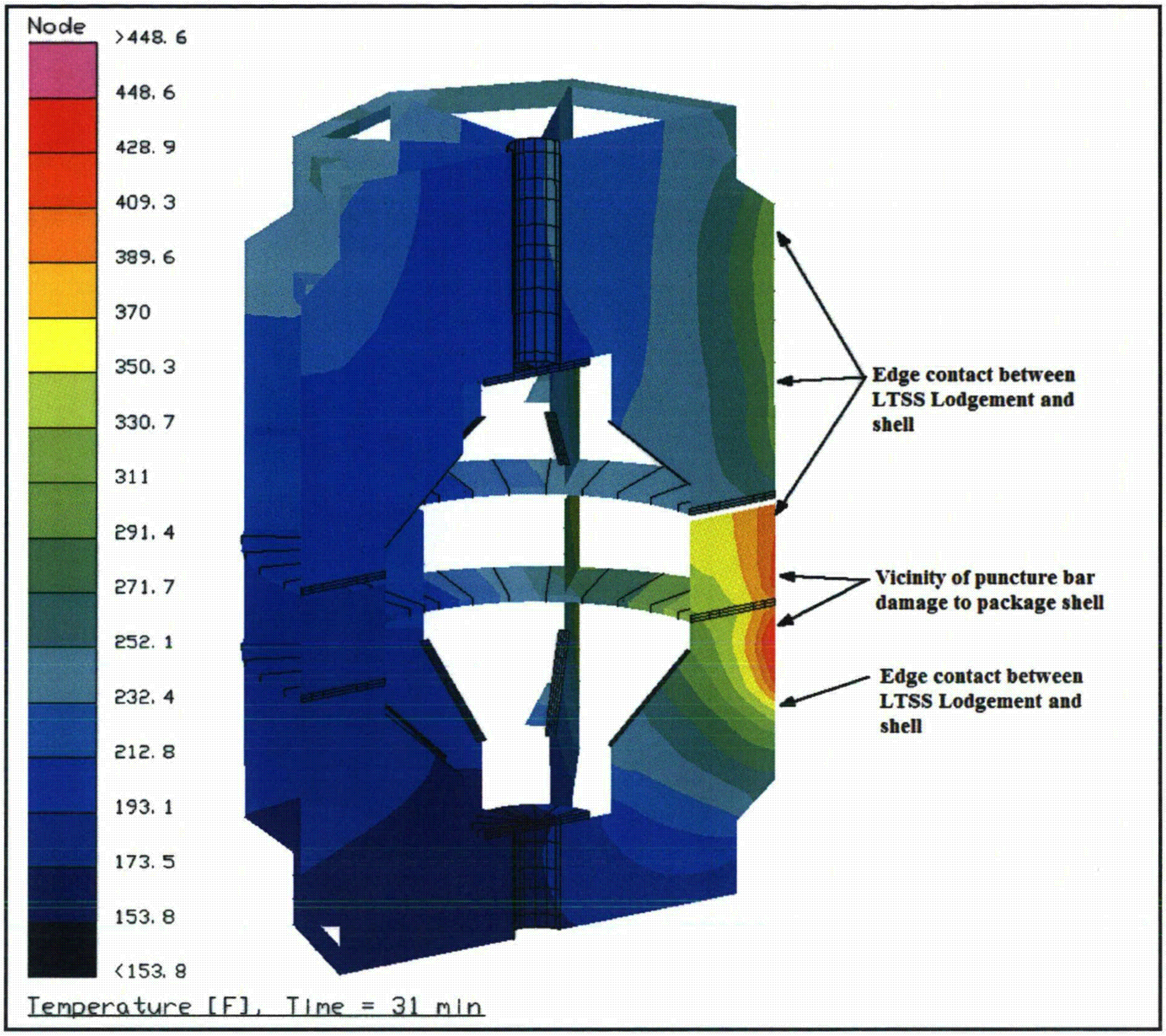


Figure 3.4-5 – Side Drop HAC Temperature Distribution for LTSS Lodgment at 31 Minutes

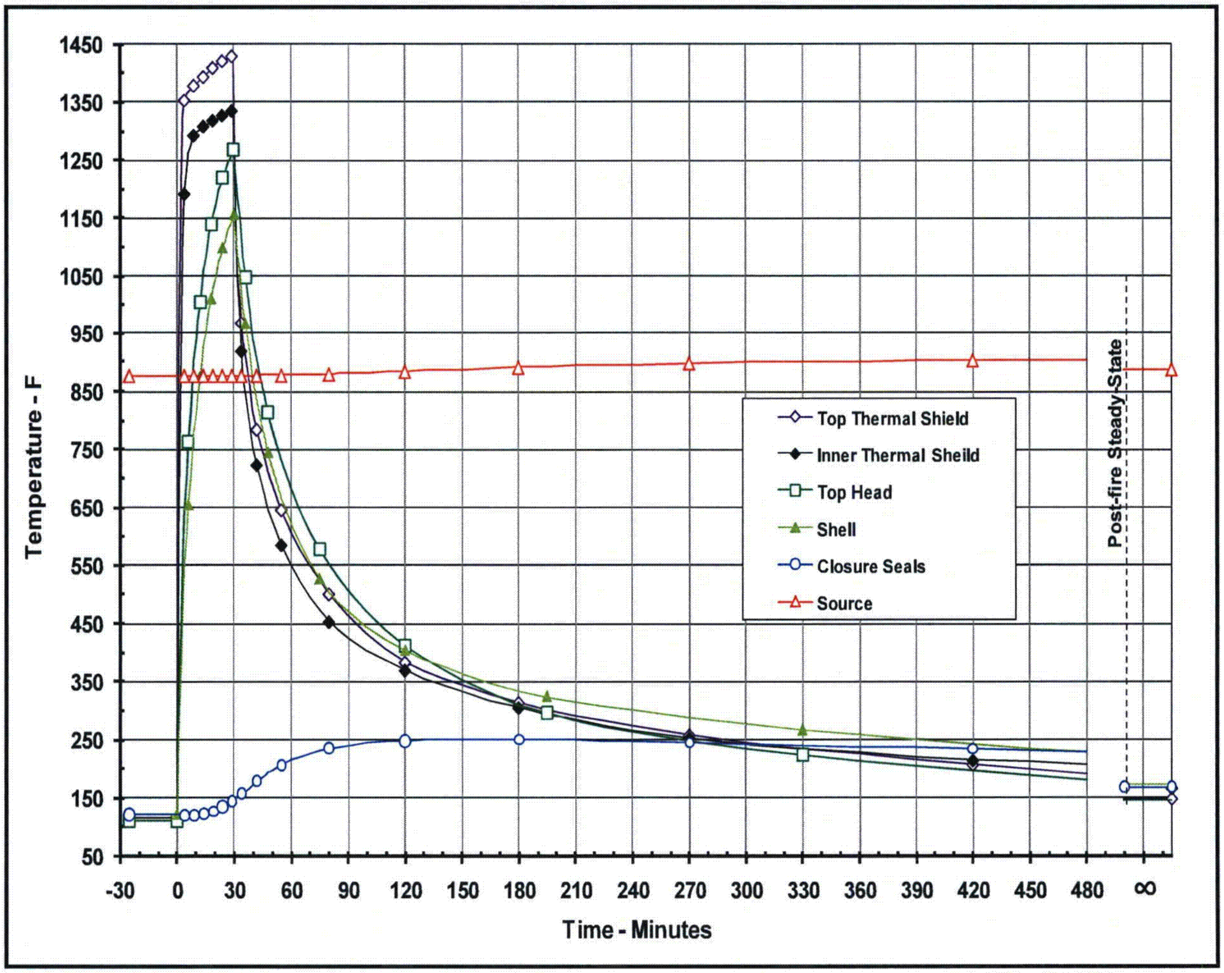
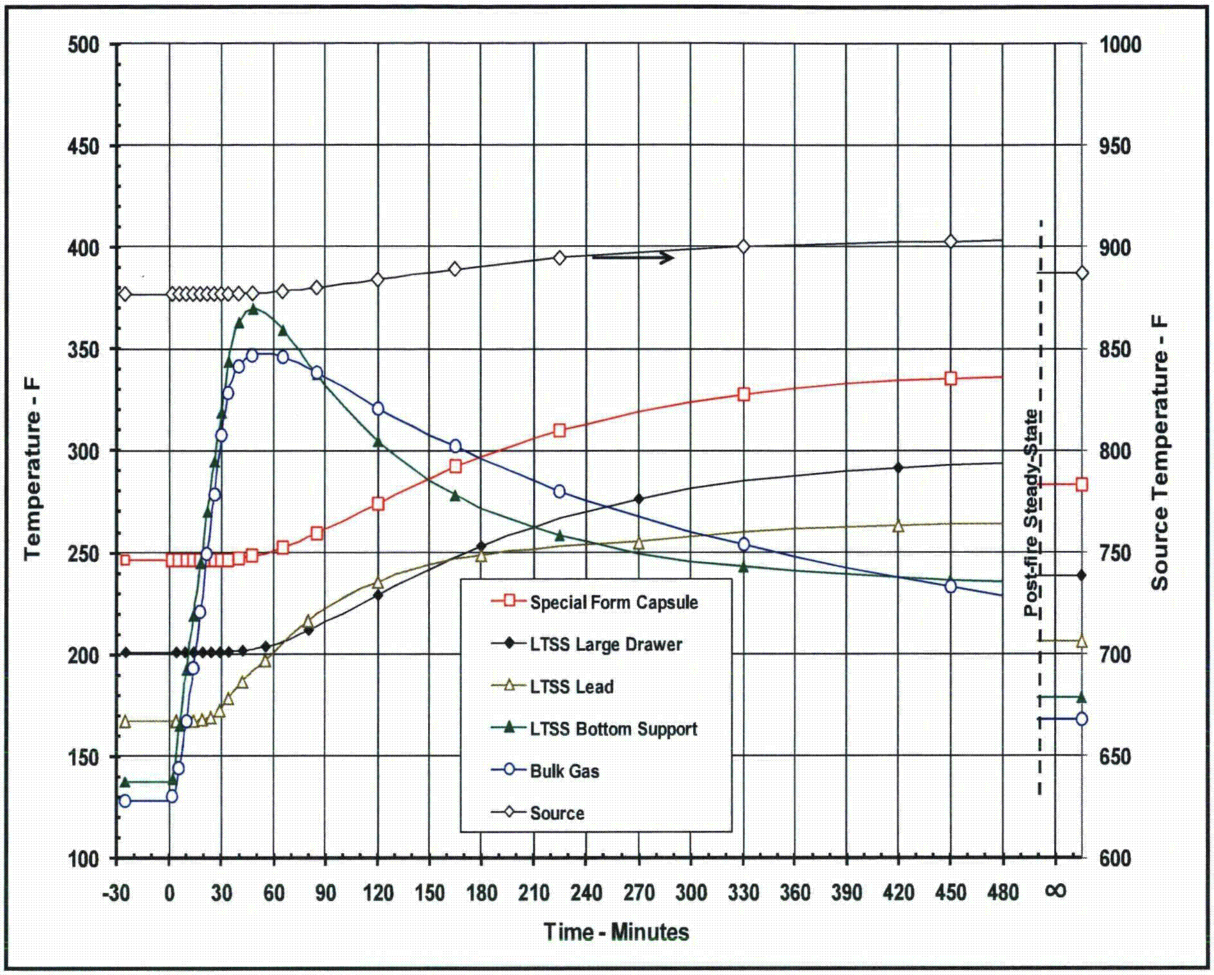


Figure 3.4-6 – Package HAC Temperature Response – Head Down Drop Damage with LTSS



Note: Scale for source temperature shown on right hand side

Figure 3.4-7 – LTSS HAC Temperature Response – Head Down Drop Damage

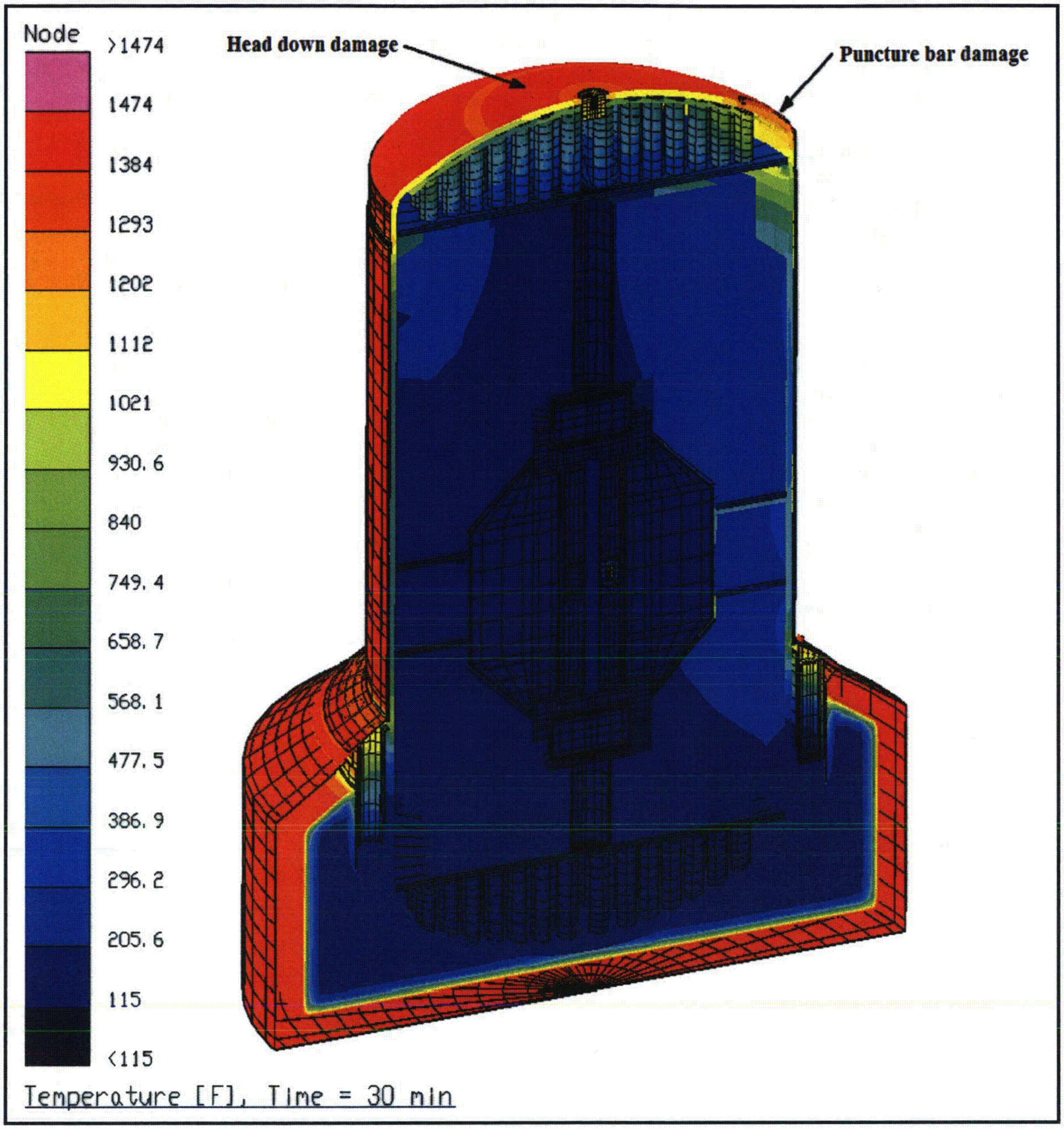


Figure 3.4-8 – Head Down Drop HAC Temperature Distribution with LTSS at End of 30 Minute Fire

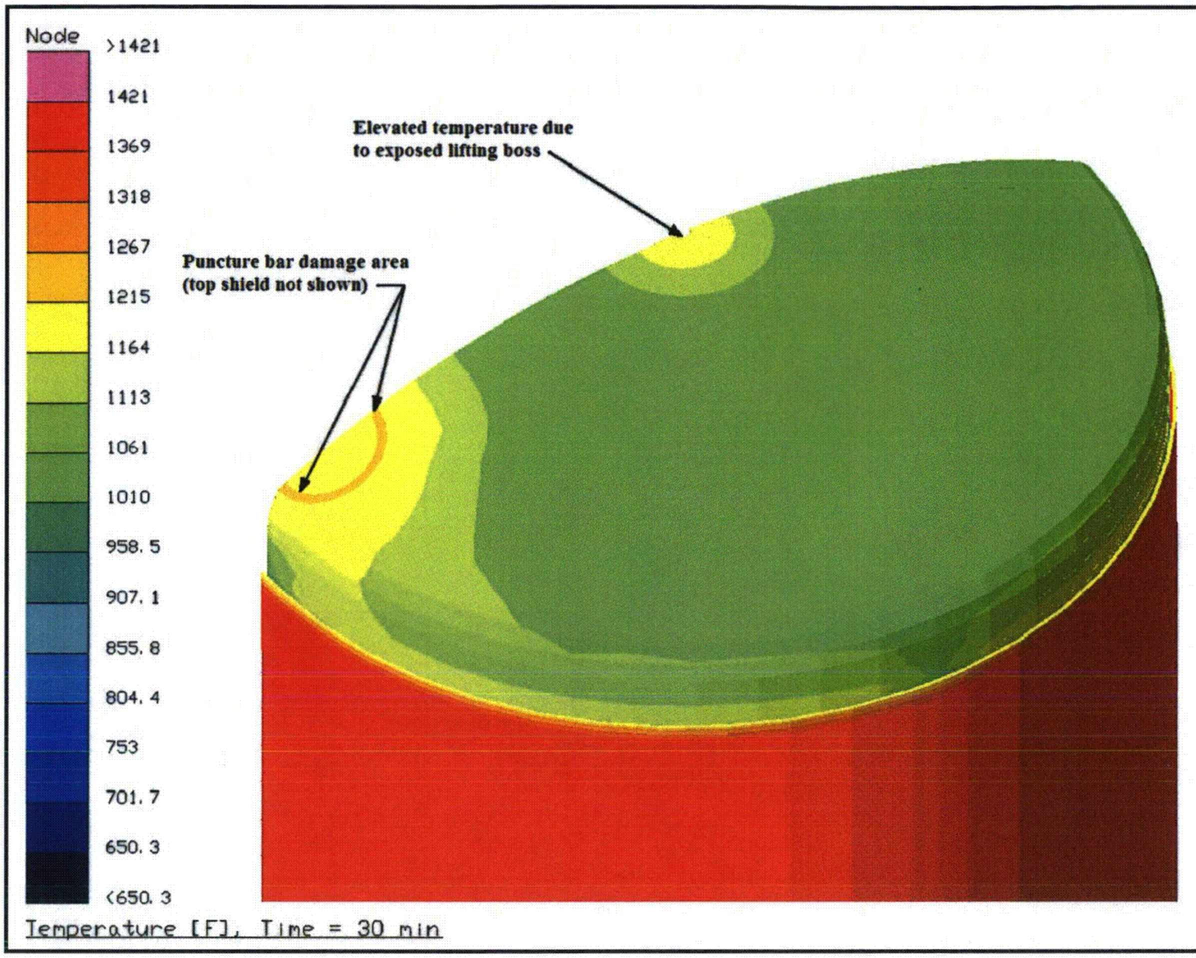


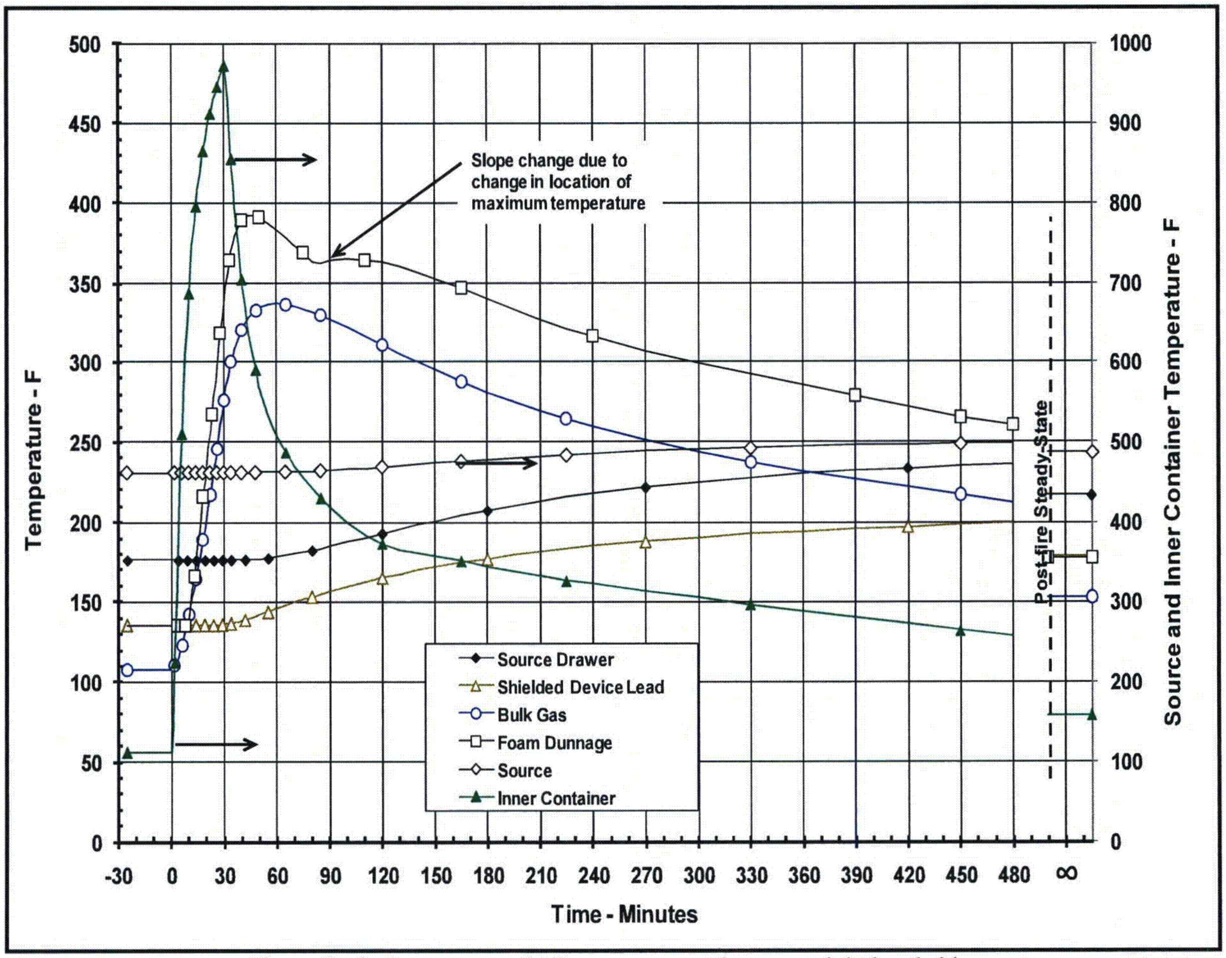
Figure 3.4-9 – Temperature Effect of Puncture Bar Damage for Head Down Drop

Table 3.4-3 – HAC Temperatures for Side Drop Damage with Shielded Device

Component	Temperature (°F)			
	End of Fire	Peak	Post-fire Steady State	Allowable②
Sealed Source Capsule①	461	499	487	1,100
SD Drawer	176	236	217	800
SD Liner	137	200	179	800
SD Lead	136	200	178	620
SD Shell	136	199	178	800
Foam Dunnage	339	392	178	400
IC	972	972	158	2,500
Shell	1,147	1,147	154	1,300
Inner Thermal Shield	1,309	1,309	153	2,500
Outer Thermal Shield	1,419	1,419	153	2,500
Top Thermal Shield	1,436	1,436	144	2,500
Lower Internal Impact Limiter	115	210	149	1,100
Upper Internal Impact Limiter	837	837	142	1,100
Lower Torispherical Head	225	242	149	1,300
Upper Torispherical Head	1,081	1,082	141	1,300
Closure Seals	130	234	150	400
Vent Port Sealing Washer	145	236	149	400
Impact Limiter				
- Max. Foam	N/A	N/A	N/A	N/A
- Avg. Foam	N/A	N/A	N/A	N/A
- Shell	1,473	1,473	151	2,500
Cask Cavity Bulk Gas	276	338	152	N/A

Notes: ① Results assume smallest source capsule (i.e., assumed 1.7" length x 1.57" diameter) dissipating 30 W.

② See Section 3.2.2, *Component Specifications*, for basis of listed temperature criterion.



Note: Scale for source and IC temperatures shown on right hand side

Figure 3.4-10 – Shielded Device HAC Temperature Response – Side Drop Damage

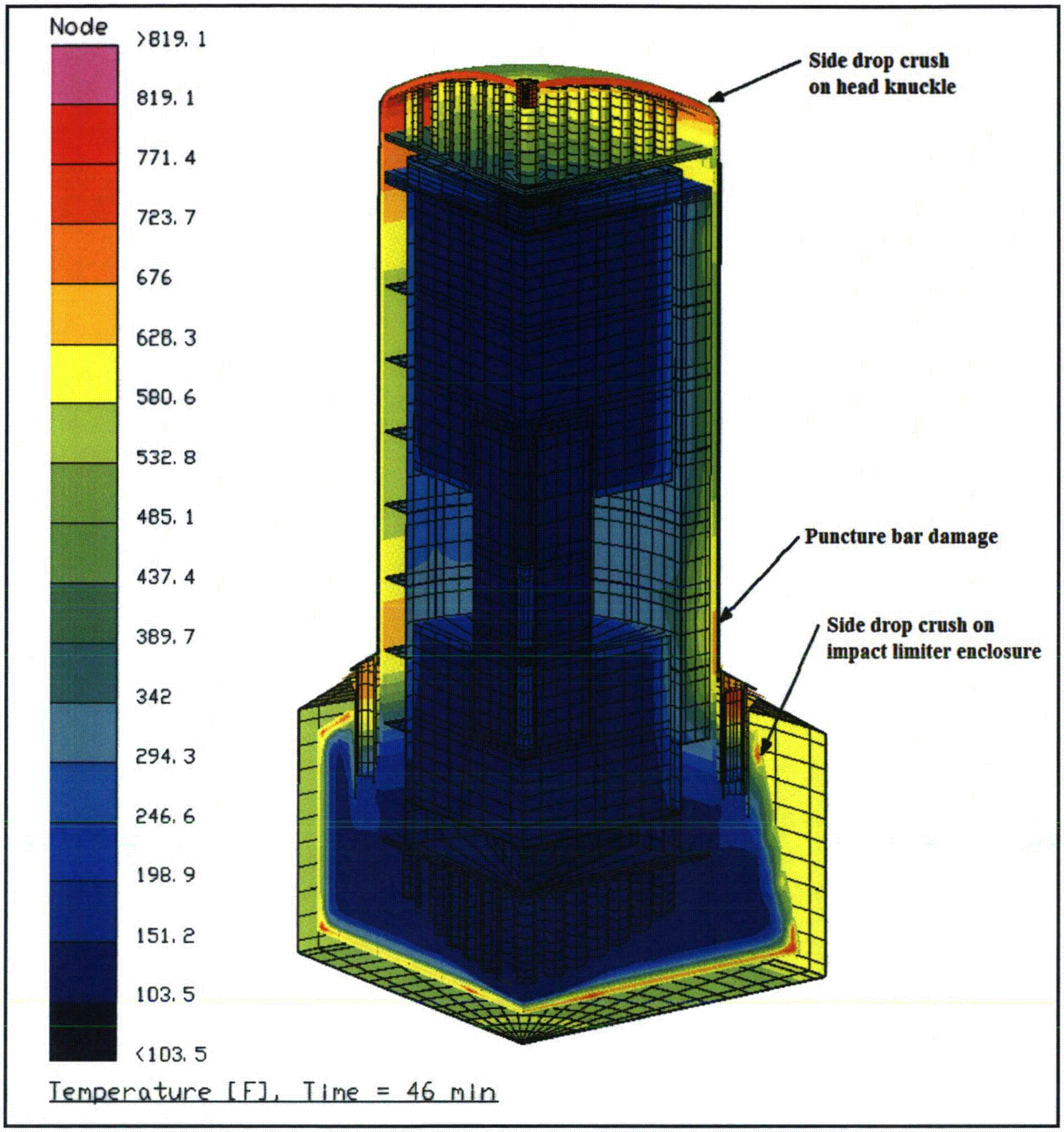


Figure 3.4-11 – Side Drop HAC Temperature Distribution with Shielded Device

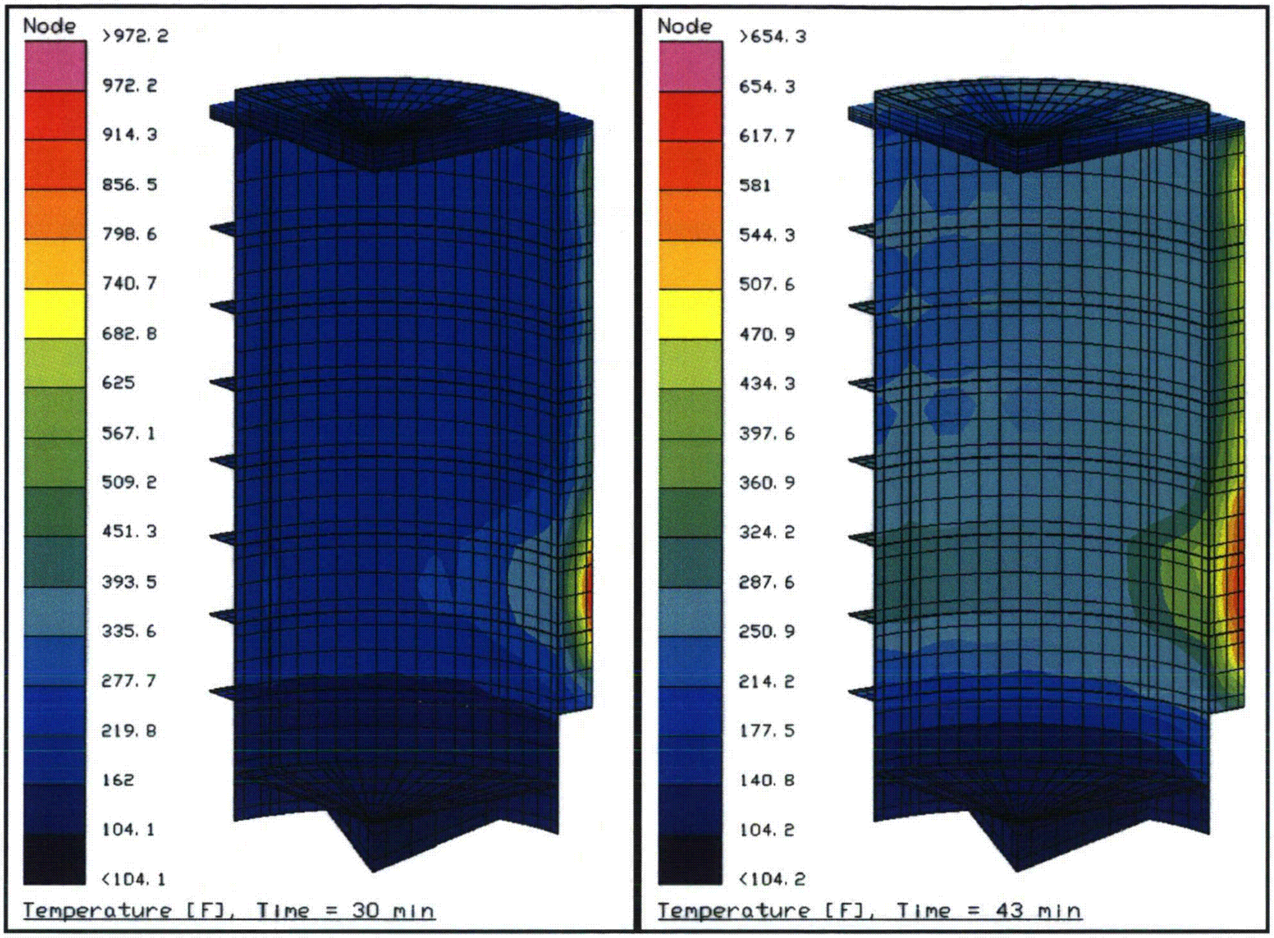
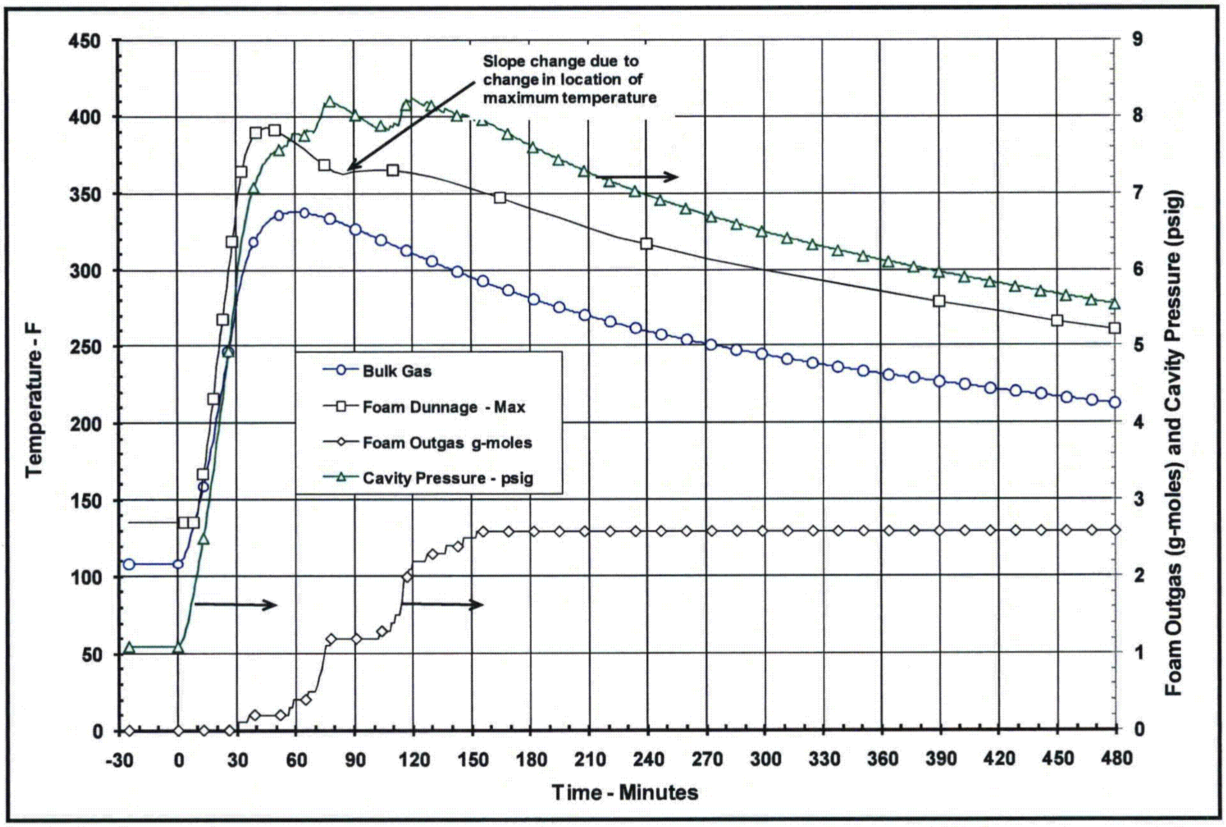


Figure 3.4-12 – Side Drop HAC Temperature Distribution in IC



Note: Scale for cavity pressure and foam outgas quantity shown on right hand side

Figure 3.4-13 – Shielded Device HAC Cavity Pressure Response – Side Drop Damage

3.5 Appendices

3.5.1 References

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3.5.2 Computer Analysis Results

Due to the size and number of the output files associated with each analyzed condition, results from the computer analysis are provided on a CD-ROM.

3.5.3 Analytical Thermal Model

This section presents details of the thermal modeling used to simulate the 435-B packaging and its authorized payloads. The analytical model is developed for use with the Thermal Desktop® [25] and SINDA/FLUINT [26] computer programs. These programs work together to provide the functions needed to build, exercise, and post-process a thermal model. The codes are validated for generating safety basis calculations for nuclear related projects [27] and have been used for numerous other safety evaluations.

The Thermal Desktop® computer program provides graphical input and output display functions, as well as computing the thermal mass, conduction, and radiation exchange conductors for the defined geometry and thermal/optical properties. Thermal Desktop® is designed to run as an application module within the AutoCAD™ design software. As such, all of the CAD tools available for generating geometry within AutoCAD™ can be used for generating a thermal model. In addition, the use of the AutoCAD™ layers tool presents a convenient means of segregating the thermal model into its various elements.

The SINDA/FLUINT computer program is a general purpose code that handles problems defined in finite difference (i.e., lumped parameter) and/or finite element terms and can be used to compute the steady-state and transient behavior of the modeled system. Although the code can be used to solve any physical problem governed by diffusion-type equations, specialized functions used to address the physics of heat transfer and fluid flow make the code primarily a thermal code.

Together, the Thermal Desktop® and SINDA/FLUINT codes provide the capability to simulate steady-state and transient temperatures using temperature dependent material properties and heat transfer via conduction, convection, and radiation. Complex algorithms may be programmed into the solution process for the purposes of computing heat transfer coefficients as a function of the local geometry, gas thermal properties as a function of species content, temperature, and pressure.

3.5.3.1 Description of 435-B Packaging Thermal Model for NCT Conditions

The 435-B packaging is represented by a 3-dimensional, half symmetry thermal model for the NCT evaluations. This modeling choice captures the full height of the packaging components and allows the incorporation of the varying insolation loads that will occur along the length of the package, the various degrees of symmetry within the payload, and the non-symmetry of the HAC free drop damage. The various packaging components are defined using a combination of planar and solid elements. Program features within the Thermal Desktop® computer program automatically compute the various areas, lengths, thermal conductors, and view factors involved in determining the individual elements that make up the thermal model of the complete assembly.

Figure 3.5-1 to Figure 3.5-5 illustrate various views of the 435-B packaging thermal model used for the NCT evaluations. The model is composed of solid and plate type elements representing the various packaging components. Thermal communication between the various components is via conduction, radiation, and surface-to-surface contact. A total of approximately 26,400 nodes, 10,300 planar elements and surfaces, and 10,500 solid elements are used to simulate the modeled components. Twenty two of the solid elements are finite difference solids (i.e., FD solids), a Thermal Desktop® computer program feature that permits a group of solid elements to be represented by a single entity. As such, the number of individual solid 'bricks' utilized in the modeling is actually significantly larger than the 10,500 value indicated above. In addition, one boundary node is used to represent the ambient environment for convection and radiation purposes.

As seen from a comparison of Figure 3.5-1 with Figure 1.2-2, Section 1.0, *General Information*, the modeling accurately captures the geometry of the various components of the 435-B packaging, including the lower body assembly and its polyurethane foam filled impact limiter, the upper body assembly (or bell), and the two internal impact limiter assemblies. Also captured, but not easily seen due to the scale of the figure, are the side and top thermal shields. The maximum spatial resolution provided by the thermal modeling for the metallic package body components is approximately 1 inch in the radial direction, 2.25 inches in the axial direction, and every 7.5° in the circumferential direction. Greater spatial resolution (i.e., smaller radial and axial distances) is provided near the cask ends where larger thermal gradients are expected.

A lower radial resolution is provided for the polyurethane foam in the impact limiter since the low thermal conductivity of the foam will yield correspondingly low heat flows. Since the fabrication tolerance of the polyurethane foam used to fill the impact limiter can yield foam densities that are $\pm$15% of the targeted 15 lb_m/ft^3 (pcf) foam density and since the foam's conductivity is a function of its density, the thermal modeling conservatively assumes a low tolerance foam density (i.e., 15 pcf less 15% ≈ 12.75 pcf) for NCT evaluations and a high tolerance foam density (i.e., 15 pcf plus 15% ≈ 17.25 pcf) for HAC evaluations.

Figure 3.5-2 illustrates the thermal modeling used for the containment boundary of the 435-B packaging. As seen from the figure, the modeling captures much of the geometry detail in the upper and lower flanges, as well as the welded joint between the ½-inch thick plate of the lower torispherical head and the cylindrical shell and the thicker ends of the flange sections. The 24 closure bolts are not specifically modeled. Instead, the flange and bolt material are modeled as a homogenized region of Type 304 stainless steel. As pointed out in Section 3.2.1, *Material Properties*, the thermal conductivity of the ASTM 320, Grade L43 bolts is approximately twice that of the Type 304 stainless steel used for the flange, while the specific heat values are similar between the two materials. However, since the cross-section area of 1-1/4-7 UNC bolts represents only 62% of the flange area that is lost due to the presence of the 1.38 inch bolt holes, the net effect of ignoring the material property differences and treating the flange as a homogenous solid for conduction purposes drops from a factor of 2 to 1.25. This net effect drops to only about 1.02 when the localized enhanced conductivity represented by the closure bolts is smeared across the entire bolt flange area. The added surface area of the bolt heads doesn't have any significant effect since the bolts are enclosed by the tubes and shells which provide protection from HAC puncture bar impact or heat input from the HAC fire event. As such, the specific modeling of the closure bolts can be neglected without significantly impacting the accuracy of the predicted temperatures. The thermal model does include an enhanced conductivity between the upper and lower flanges to mimic the thermal conductance provided by the bolt shanks.

Figure 3.5-3 illustrates the thermal representation of the top and side thermal shields used in the modeling. The shields are modeled as surface elements since their relative thinness will yield essentially zero ΔT across their thickness. Heat transfer between each shield and its underlying surface is modeled as a combination of radiation and conduction across a 0.105-inch thick air gap and conduction through a 0.105-inch diameter stainless steel wire wrap on 3-inch centers. For conservatism under NCT condition, the conduction through the wire wrap is ignored for NCT.

A significant level of thermal protection to the thermally sensitive closure seals is provided by the closure bolt enclosure structure at the lower end of the upper body assembly. The closure bolt enclosure structure consists of tubes and shells which provides access to the closure bolts and the vent port and seal test port while also protecting these components from HAC puncture bar impact or excessive heat input from the HAC fire event. Figure 1.2-4, Section 1.0, *General Information*, illustrates the detail in this area, while Figure 3.5-4 illustrates the thermal representation used for the same region. As seen from a comparison of the two figures, the thermal modeling accurately captures the individual components and the complex geometry in this area. Included, but not seen in the figure, are the blocks of 30 pcf foam used between the individual bolt access tubes to thermally isolate the cylindrical shell from potentially high temperatures that may occur near the exterior of the enclosure structure during the HAC fire.

The thermal modeling of the internal impact limiters is illustrated in Figure 3.5-5. As seen, the modeling captures the individual stainless steel tubes and the 0.105-inch thick stainless steel tube stabilizer sheet which is spherically curved to match the shape of the torispherical heads. The Thermal Desktop® program automatically calculates the conduction and radiation between the various components of the internal impact limiters.

3.5.3.2 LTSS and LTSS Lodgment Thermal Model

Figure 3.5-6 illustrates the thermal modeling of the LTSS used for this evaluation. As with the 435-B packaging, the modeling represents a 3-dimensional, half symmetry thermal model. Approximately 4,200 nodes, 620 planar elements, and 600 solid elements are used to simulate the modeled components of the LTSS, the Large Source Drawer, and the source capsule. The modeling captures the individual components of the LTSS in a manner that the thermal properties of each significant component depicted in Figure 1.2-9, Section 1.0, *General Information*, and the gaps between the individual components are captured. Although the LTSS can accommodate 4 Large Source Drawers, the thermal modeling assumes that only one of the drawers is loaded with a source capsule dissipating the maximum 200 watts allowed for the entire LTSS. This assumption yields the worst case concentration of decay heat loading possible for the LTSS. The bounding 200 W heat load requires a Co-60 source which dissipates a significant amount of its energy in the form of gamma rays. Based on Monte Carlo N-Particle (MCNP) calculations using a source height of 1.45-in and diameter of 0.72-in, a Co-60 source will deposit approximately 20% of the decay heat within the source volume and the remaining 80% outside the source where the gamma rays emitted by the source are absorbed. While the gamma ray absorption will be distributed throughout the lead volume, the modeling conservatively assumes the entire absorption of this 80% portion occurs at the ends of the tungsten shielding in the Large Source Drawer and within a 6.75 inch high segment of the LTSS liner adjacent to the special form capsule. In reality, the heat deposition would occur over a much greater volume of the LTSS, thus lowering the effective heat flux at any point in the LTSS.

The LTSS is supported within the 435-B packaging by the LTSS lodgment. Thermal modeling of the lodgment (see Figure 3.5-7) is accomplished using approximately 2,000 nodes, 1,225 planar elements, and 12 finite-difference solids. Heat transfer between the LTSS and the lodgment is via radiation, convection, and conduction across the neoprene rubber covered ½-inch thick plate at the base of the lodgment and via the neoprene rubber covered pads on the tapered edges of the lower ribs.

Although convection heat transfer between the LTSS, the LTSS lodgment, and the interior of the 435-B packaging is assumed for NCT, the effect on the NCT temperatures is modest. A sensitivity analysis showed that completely ignoring convection or conduction through the airspace around the LTSS and LTSS lodgment raises the source capsule temperature by less than 10 °F and the LTSS lead shielding temperature by only 30 °F from the values presented in Section 3.3, *Thermal Evaluation for Normal Conditions of Transport*. These temperature increases are insignificant in comparison to the available margins for both components. Alternatively, ignoring convection will reduce the bulk gas temperature and payload temperatures under HAC conditions. As such, credit for convection heat transfer within the modeling is appropriate.

Figure 3.5-8 illustrates the combined modeling of 435-B packaging with the LTSS payload.

3.5.3.3 Shielded Device and Inner Containment Thermal Model

As described in Section 1.0, *General Information*, the size and geometry of the Group 1 and 3 shielded devices vary. However, while the exact dimensions and shapes are varied, the general shape and size of devices in Group 1 and 3 are similar, especially after the cabinets, stands, or unnecessary appurtenances attached to the devices are removed prior to transportation. Given the variance in geometry, the modeling approach for the shielded devices was to develop a generic representation of a device that would thermally bound the Group 1 and 3 shielded devices. After considering the thermal features of the various Group 1 and 3 devices, the Gammacell-40 device was selected as the appropriate basis for developing a generic device whose thermal performance would bound the other devices. The 15.9 inch diameter and 28.7 inch length of the cylindrical body of the Gammacell-40 yields a surface area that is slightly less than that for the Gammator M38, and Gammacell 1000 and 3000 devices, while its weight is less than the Gammacell 1000 and 3000 devices and 18% higher than the Gammator M38. The smaller Group 1 devices, such as the Gammator 50B and B34 devices also have a significantly lower decay heat loading than the 30 W design basis used for the generic device. Further, the Gammacell-40 device uses a source capsule that is relatively compact, whereas the source for many of the other Group 1 and 3 devices uses elongated, pencil shaped sources. As such, a concentrated heat source based on the Gammacell-40 design will yield conservative source capsule temperatures.

The Group 1 and 3 generic device assumes 6 inches of lead shielding in a right cylinder geometry with a 15.9 inch diameter and 28.7 inch height. The source is assumed to be contained within a drawer assembly like that used for the Gammacell-40 device. Figure 3.5-9 illustrates the thermal model of the generic shielded device used for NCT evaluations. As seen, the modeling represents a 90° segment versus the 180° segment used for the LTSS modeling. A quarter symmetry model is appropriate for the shielded devices since a single source location within the device exists, thus asymmetric heat loading is not a factor as it was for the LTSS payload. Approximately 1,350 nodes, 11 planar elements, and 11 finite-difference solid elements are used to simulate the modeled components of the device. As previously explained, a finite-difference solid is a Thermal Desktop® computer program feature that permits a group of solid elements to be represented by a single entity. As such, the number of individual solid 'bricks' utilized in the modeling of the shielded device is actually significantly larger.

The modeling captures the off-center location of the source drawer (like that of the Gammacell-40 device) when it is in its storage location. This off-center location is significant when considering that the packaging dunnage is assumed to surround the ends of the device, thus restricting the heat transfer from the ends. The modeling also reflects the transport of a small source capsule (i.e., 1.7 inch long by 1.57 inch in diameter) versus the pencil shaped capsules used for many Group 1 and 3 devices. The smaller capsule yields a worst case heat concentration for the evaluation. The entire 30 W decay heat assumed for the shielded devices is conservatively assumed to be deposited within the source capsule.

Figure 3.5-10 illustrates alternate views of the Inner Container (IC) and the assumed blocking/dunnage used to support the shielded device in the IC. The IC is modeled using approximately 2,500 nodes, 80 planar elements, and 8 finite-difference solid elements. The blocking/dunnage may consist of either a metallic framework or use a rigid polyurethane foam. Since solid blocking like rigid polyurethane foam would restrict the heat transfer between the shielded device and the IC much more than would an open, metallic framework, the thermal modeling conservatively assumes the use of polyurethane foam. An additional 2,500 nodes and 16 finite-difference solid elements are used to model the foam dunnage. The foam dunnage is conservatively assumed to cover the ends and extend over the sides of the shielded device leaving only 50% or more of the side surface exposed to the IC interior.

As with the LTSS payload, convection heat transfer between the IC and the interior surfaces of the 435-B packaging and between the shielded device and the IC are assumed. Again, a sensitivity analysis showed that completely ignoring convection or conduction through the airspace raises the source capsule temperature by less than 10 °F. Since this temperature increase is insignificant in comparison to the available margins and since ignoring convection will reduce the bulk gas temperature and payload temperatures under HAC conditions, including credit for convection heat transfer within the modeling is appropriate.

Figure 3.5-11 illustrates the combined modeling of 435-B packaging with the generic shielded device payload.

3.5.3.4 Insolation Loads

The insolation loading on the 435-B package is based on the total 10CFR71.71(c)(1) specified insolation values over a 12-hour period [1]. Since the 435-B packaging is characterized by a thermally light upper body assembly, a lower body assembly encased by a foam filled impact limiter, and thermally massive interior payloads, the temperature response to diurnal changes in the insolation loading will vary significantly between the various packaging components and the payloads.

As such, the use of a time-averaged insolation loading based on the 10CFR71.71(c)(1) specified insolation over 12 hours will not accurately capture the peak component temperatures near the package's exterior under NCT conditions. Instead, the 10CFR71.71(c)(1) specified insolation values over a 12-hour period are converted to an equivalent diurnal insolation loading cycle. This analysis methodology follows the recommendations of IAEA Safety Guide TS-G-1.1

¶654.4 [3] which states that "the more precise way to model insolation is to use a time dependent sinusoidal heat flux".

A sine wave model is used to simulate the variation in the applied insolation on the surfaces of the package over a 24-hour period, except that when the sine function is negative, the insolation level is set to zero. The timing of the sine wave is set to achieve its peak at 12 pm and the peak value of the curve is adjusted to ensure that the total energy delivered matched the 10CFR71.71(c)(1) specified values. As such, the total energy delivered in one day by the sine wave solar model is given by:

$$\int_{6 \cdot hr}^{18 \cdot hr} Q_{peak} \cdot \sin\left(\frac{\pi \cdot t}{12 \cdot hr} - \frac{\pi}{2}\right) dt = \left(\frac{24 \cdot hr}{\pi}\right) \cdot Q_{peak}$$

Using the expression above for the peak rate of insolation, the peak rates for insolation on horizontal flat and the vertical curved surfaces is calculated as follows:

$$Q_{top} = \left(800 \frac{cal}{cm^2}\right) \cdot \left(\frac{\pi}{24\,hr}\right) \qquad Q_{top} = 2.68 \frac{Btu}{hr - in^2}$$

$$Q_{side} = \left(200 \frac{cal}{cm^2}\right) \cdot \left(\frac{\pi}{24\,hr}\right) \qquad Q_{top} = 0.67 \frac{Btu}{hr - in^2}$$

Conversion factors of 1 cal/cm^2-hr = 0.0256 Btu/hr-in^2 are used in the above calculations. These peak rates are multiplied by the sine function and the surface solar absorptivity to create the insolation values as a function of time of day. Figure 3.5-12 illustrates the level of insolation on flat horizontal, horizontal curved, and vertical surfaces versus time of day assumed for the evaluation of package performance under *NCT Hot* conditions. The diurnal cycle modeling approach results in a peak hourly insolation loading that is approximately 57% higher than the specified 10CFR71.71(c)(1) value averaged over 12 hours. However, the total insolation load applied to each surface of the package is the same as that specified by 10CFR71.71(c)(1).

3.5.3.5 Description of Thermal Model for HAC Conditions

The thermal evaluations for the hypothetical accident condition (HAC) are conducted using an analytical thermal model of the 435-B packaging loaded with the LTSS and shielded device payloads. The HAC thermal models are modified versions of the NCT models described above. The principal model modifications consist of simulating the expected package damage resulting from the drop events that precede the HAC fire, changing the package surface emissivities to reflect the assumed presence of soot and/or surface oxidization, and simulating the thermal performance of the polyurethane foam used in the impact limiter.

Physical testing using a series of prototypic full scale certification test units (CTUs) is used to establish the expected level of damage sustained by the 435-B packaging as a result of the 10 CFR 71.73 prescribed free and puncture drops that precede the HAC fire event. Documentation of the configuration and initial conditions of the CTUs, a description of the test facility, CTU instrumentation, and the test results is presented in Appendix 2.12.3, *Certification Test Results*. The drop tests covered a range of hypothetical free drop orientations and puncture bar drops. An overview of the results of the drop tests is provided below.

1) Three free drop orientations were tested: a bottom end drop, a simultaneous side drop on the limiter and knuckle, and a C.G.-over-knuckle drop. Of these orientations, the worst case physical damage to the package occurs from the simultaneous side drop with elevated foam temperatures (i.e., test event D4). Overall, the resulting damage is thermally insignificant. The combined damage from both the NCT and HAC drops in this orientation resulted in flat regions on both the impact limiter and the knuckle of the package head. The impact limiter flat measured 25-1/2 inches long (along cask axis) and 33 inches wide (orthogonal). The knuckle flat was 11-1/2 inches long and 18-1/2 inches wide. The worst case radial crush distance of the polyurethane foam in the impact limiter was 4-13/16 inches, as measured from the cask body O.D. Since the impact occurred with the cask axis at an angle of approximately 13° to the ground, the crush in the direction of impact was 4-13/16 × cos(13) = 4.68 inches. The depth of foam remaining, as measured perpendicular from the outer surface of the foam to the flange upper corner, was 5-1/8 inches. The crush at the knuckle was significantly less.
2) Two separate free drops in the bottom-down orientation (i.e., D1 and D5) resulted in a crush distance of only 5/16 inches or less. This level of damage is seen as negligible and no visible damage to the CTUs was seen.
3) The NCT and HAC C.G.-over-knuckle drops (i.e., test event D3) resulted in creation of a flat spot on the torispherical head, offset towards one side. The combined damage created a flat spot 21 inches long in the radial direction and 33-1/2 inches long in the circumferential direction. The internal impact limiter tubes located below the test D3 impact were crushed, and the plate of the upper internal limiter was buckled from both the D3 and D4 impacts. The deformation of the package head due to test event D3 is shown in Figure 2.12.3-45 and Figure 2.12.3-46 in Appendix 2.12.3, *Certification Test Results*, where the head thermal shield has been locally cut away to expose the containment boundary. The lower limiter had little damage. The lodgment showed some buckling of the radial plate adjacent to the impact of the D3 test, but little other damage (see Figure 2.12.3-47). The LTSS was supported in essentially its original position. Note that the LTSS was thoroughly tested in Test Series D1 and D2. The only additional damage to the LTSS from Test Series D3 and D4 was some shallow deformations (approximately 1/8 inches or less) due to support from the lodgment's circular plates in the side (D4) free drops.
4) With the exception of test event D3, no significant deformation of the LTSS lodgment or the IC was noted as a result of the other drop orientations.

No scaling of the noted crush dimensions are required since the CTUs are full scale representations of the 435-B package. However, the projected damage did need to be scaled to reflect the full effect of temperature on the polyurethane foam's structural properties since the warm drop test event D4 did not fully capture the peak foam NCT foam temperature and, thus, the worst case crush. This warm foam scaling added an estimated 0.5 inches to the expected crush depth, reducing the foam depth, as measured perpendicular from the outer surface of the foam to the flange upper corner, from 5-1/8 inches to 4.63 inches, as discussed in Section 2.7.1.5.2, *Maximum Impact Limiter Crush Deformation.*

Based on a review of the above damage results, two damage events were selected to bound the worst-case scenarios for the 435-B package: 1) a simultaneous side drop on the limiter and knuckle and 2) a head down drop. The head down drop is used instead of the tested C.G.-over-knuckle drop since the head down drop damage affects the entire head versus the localized damage at the knuckle and because the simultaneous side drop on the limiter and knuckle already captured some of the effect of damage to the knuckle region of the package.

Figure 3.5-13 illustrates the assumed crush lines at the center of the impact zone for the side drop damage scenario. The modeled depth of the crush at the knuckle is approximately 2 inches. This crush depth yields a impact zone on the model that measures approximately 18.5 inches wide by 11.5 inches high, matching the measured knuckle flat observed from the CTU testing. Guidance for modeling the effect of the knuckle damage is taken from Figures 2.12.3-45 and 2.12.3-46 in Appendix 2.12.3, *Certification Test Results*. These figures illustrate a cutaway at the torispherical head following the C.G.-over-knuckle drop and demonstrate that the wire standoffs between the head and the top shield were left intact and, as evidenced by the lack of scuff marks on the head, that a direct contact between the top shield and the head did not occur. Based on this observation, the knuckle damage is simulated by conservatively assuming that the air gap separating the thermal shields is reduced by half and that direct contact between the shell and the aluminum plate of the upper internal impact limiter occurs over a 30 degree angle. Heat transfer via the wire wrap is also conservatively assumed everywhere.

Per Appendix 3.5.4, *'Last-A-Foam' Response under HAC Conditions*, approximately 2.5 inches of the nominal 15 pcf polyurethane foam will thermally decompose during a 30 minute HAC fire event. Since the HAC modeling assumes a conservatively low foam density of 12.75 pcf, the foam loss (or recession depth) is increased to 2.8 inches for this low end density. In the vicinity of crush damage the effective foam density will increase as a result of the crush, thus decreasing the local foam recession depth accordingly. Per the warm foam scaling discussed above, the foam depth at the package flange is reduced from approximately 8.75 inches to 4.63 inches, yielding an increase in the effective density of approximately 88% at the centerline of the damage. Based on an initial foam density of 12.75 pcf, an effective foam density of approximately 24 pcf will occur at the centerline of the damage, yielding an associated foam recession depth of approximately 1.5 inches. For conservatism, the modeling assumes a recession depth of 1.8 inches at the centerline of the impact limiter damage, increasing to 2.8 inches at the circumferential edges of the side drop damage.

Given a maximum foam recession depth of 2.8 inches, any foam depth remaining after the HAC drop events greater than approximately 3.25 inches will result in the underlying temperatures rising only marginally during the HAC fire event. Examination of Figure 3.5-13 demonstrates that, with the exception of the upper portion of the impact limiter, the side drop will leave sufficient foam everywhere to prevent any significant temperature rise on the backside of the remaining foam.

For modeling expediency, the physical geometry changes resulting from the drop event are not captured by the HAC modeling. Instead, the effect of the geometry realignment is captured by adjusting the conductors within the HAC model from the associated surface and any underlying component. For example, in the vicinity of the side crush, the gap between the outer edges of the foam and the impact limiter shell at the end of the 30-minute fire is modeled as 1.8 inches (i.e., the foam recession depth) versus the variable distance indicated by the undamaged impact limiter shell geometry.

The controlling puncture bar damage for the side drop event is one that will enhance damage to the impact limiter and the underlying closure seals. Of the various CTU tested puncture bar scenarios to the lower end of the package, only the P7 orientation resulted in a thermally significant damage. The P1, P4, P5, and P6 scenarios did not result in damage that would significantly degrade the thermal resistance offered by the undamaged package geometry. While the P7 scenario is an oblique strike on side thermal shield through the C.G., the modeled damage location was shifted downward on the package to a point just above the rain shield in order to maximize the potential impact on the closure seals. In reality, since this location is not at the package C.G., the damage would be expected to be less severe than that noted from the P7 test.

Figures 2.12.3-30 and 2.12.3-36 in Appendix 2.12.3, *Certification Test Results*, illustrates the level of damage resulting from the P7 puncture bar attack. The modeling conservatively captures the observed damage by assuming direct contact over approximately a 6-inch diameter area between all layers of the dual thermal shield and the shell.

The head down drop damage scenario is depicted in Figure 3.5-14. The head crush line is assumed to be approximately 4 inches down from the top. Again, for modeling expediency, the physical geometry realignment resulting from the drop event is not captured by the HAC model, but is reflected in the adjusted conductors between the top shield and the underlying components. In this case, the thickness of the wire wrap and the associated air gap is reduced by 1/3 and the heat transfer via the wire wrap increased by a factor of approximately 2 to account for the assumed enhanced contact between the assumed flattened surfaces of the wire wrap and the adjacent thermal shield and torispherical head surfaces.

While the tubes of the upper internal impact limiter will be crushed as a result of the head down drop scenario, the effect on the radiation and conduction along the length of the tubes is limited since the expected folding in the tube walls will maintain the same total heat transfer length for conduction and increase the effective blockage of heat transfer via radiation. Although heat transfer via conduction through the fill gas along the length of the internal impact limiter will increase, this heat transfer mode represents an insignificant fraction of the total heat transfer. The nominal 0.6 inch gap between the tube stabilizer sheet of the internal impact limiter and the torispherical head is reduced to 0.1 inch to reflect the tube crushing and assumed shifting of the package internal components for the post-drop horizontal package orientation.

The associated puncture bar damage is taken to be the P3 orientation (i.e., C.G.-over-knuckle) from the CTU testing. Guidance for modeling the effect of a puncture bar attack in the knuckle region is taken from Figures 2.12.3-45 and 2.12.3-46 in Appendix 2.12.3, *Certification Test Results*. As previously explained, these figures illustrate a cutaway at the torispherical head following the C.G.-over-knuckle drop. A close examination of the figures demonstrate that puncture bar impact left an imprint around a portion of the bar's circumference, but the lack of a scuff mark would indicate that full area contact is not made. Based on this observation, the knuckle damage is simulated by conservatively assuming direct contact between the top thermal shield and the torispherical head in an 0.5-inch wide annular region around the circumference of the puncture bar. Heat transfer via the wire wrap is also conservatively assumed everywhere.

Beyond the specific modifications to simulate the HAC damage scenarios, the NCT thermal model for the package was modified for the HAC evaluations via the following steps:

1) Assume the package has been ejected from its transport support and is lying on its side for all damage scenarios. As such, the convective heat transfer from the package's exterior surfaces is based on a horizontal orientation. In addition, the adiabatic boundary condition assumed for selected surfaces of the lower impact limiter under NCT conditions are switched to active heat transfer surfaces.
2) The surface emissivity for all exterior surfaces is assumed to be 0.8 to account for potential oxidation and/or soot accumulation. The emissivity of all inside surfaces of the impact limiter exposed as the result of foam decomposition is assumed to be 0.95 to account for adherence of foam char.
3) Thermal conductance via the stand-off wire wrap under the thermal shields is assumed for the HAC condition. Thermal credit for the wire wrap was conservatively ignored for the NCT evaluations.
4) 1.8 to 2.8 inches of foam (see above) is removed from around the perimeter of the impact limiter at the start of the HAC evaluation. This change conservatively bounds the impact of the gradual decomposition of the foam over the 30 minute fire event.
5) Assume no significant damage to the LTSS and shielded device payloads but that the payloads have shifted to create edge contact between the LTSS lodgment and IC and the package bell. The orientation of the contacting surfaces is conservatively assumed to align with the location of the drop damage.

3.5.3.6 Convection Coefficient Calculation

The 435-B package thermal model uses semi-empirical relationships to determine the level of convection heat transfer from the exterior package surfaces under both the regulatory NCT and HAC conditions. The convective heat transfer coefficient, h_c, has a form of:

$$h_c = Nu \frac{k}{L}$$

where k is the thermal conductivity of the gas at the mean film temperature and L is the characteristic length of the vertical or horizontal surface. The convection coefficient is correlated via semi-empirical relationships against the local Rayleigh number and the characteristic length. The Rayleigh number is defined as:

where $$Ra_L = \frac{\rho^2 g_c \beta L^3 \Delta T}{\mu^2} \times Pr$$

g_c = gravitational acceleration, 32.174 ft/s^2 β= coefficient of thermal expansion, °R^{-1}
ΔT = temperature difference, °F ρ = density of air at the film temperature, lb_m/ft^3
μ= dynamic viscosity, lb_m/ft-s Pr = Prandtl number = (c_p μ) / k
L = characteristic length , ft k = thermal conductivity at film temp., Btu/ft-hr-°F
c_p = specific heat, Btu/ lb_m -°F Ra_L = Rayleigh #, based on length 'L'

Note that k, c_p, and μ are each a function of air temperature as taken from Table 3.2-3. Values for ρ are computed using the ideal gas law, β for an ideal gas is simply the inverse of the absolute temperature of the gas, and Pr is computed using the values for k, c_p, and μ from Table

3.2-3. Unit conversion factors are used as required to reconcile the units for the various properties used.

The natural convection from a discrete vertical surface is computed using Equations 3-19, 3-21 to 3-25 of reference [24], which is applicable over the range $1 <$ Rayleigh number (Ra) $< 10^{12}$:

$$Nu^T = \overline{C}_L Ra^{1/4}$$

$$\overline{C}_L = \frac{0.671}{\left(1 + (0.492/Pr)^{9/16}\right)^{4/9}}$$

$$Nu_L = \frac{2.8}{\ln(1 + 2.8/Nu^T)}$$

$$Nu_t = C_t^V Ra^{1/3}$$

$$C_t^V = \frac{0.13\,Pr^{0.22}}{\left(1 + 0.61\,Pr^{0.81}\right)^{0.42}}$$

$$Nu = \frac{h_c L}{k} = \left[(Nu_L)^6 + (Nu_t)^6\right]^{1/6}$$

The natural convection from a vertical cylindrical surface is computed by applying a correction factor to the laminar Nusselt number (Nu_L) determined using the same methodology and Nu_t for a vertical plate (see above). The characteristic dimension, L, is the height of the vertical cylinder and D is the cylinder's diameter. The correction factor as defined by Equations 3-39 to 3-41 of reference [24] is:

$$Nu_{L\text{-Cylinder}} = \frac{\delta}{\ln(1+\delta)} Nu_{L\text{-Plate}}$$

$$\delta = \frac{1.8 \times L/D}{Nu^T_{Plate}}$$

$$Nu_{Vert.\,Cylinder} = \frac{h_c L}{k} = \left[(Nu_{L\text{-Cylinder}})^6 + (Nu_{t\text{-Plate}})^6\right]^{1/6}$$

Natural convection from horizontal surfaces is computed from Equations 3-34 to 3-38 of reference [24], where the characteristic dimension (L) is equal to the plate surface area divided by the plate perimeter. For a heated surface facing upwards or a cooled surface facing downwards and $Ra > 1$:

$$Nu = \frac{h_c L}{k} = \left[(Nu_L)^{10} + (Nu_t)^{10}\right]^{1/10}$$

$$Nu_L = \frac{1.4}{\ln\left(1 + 1.4/\left(0.835 \times \overline{C}_L Ra^{1/4}\right)\right)}$$

$$\overline{C}_L = \frac{0.671}{\left(1 + (0.492/Pr)^{9/16}\right)^{4/9}}$$

$$\mathrm{Nu_t} = 0.14 \times \mathrm{Ra}^{1/3}$$

For a heated surface facing downwards or a cooled surface facing upwards and $10^5 < \mathrm{Ra} < 10^{10}$, the correlation is as follows:

$$\mathrm{Nu} = \mathrm{Nu_L} = \frac{0.527}{\left(1+(1.9/\mathrm{Pr})^{9/10}\right)^{2/9}}\mathrm{Ra}^{1/5}$$

Calculation of the convection coefficient from a horizontal cylindrical surface is computed using Equation 3-43, reference [24], where the characteristic length, D, is the outer diameter of the cylinder. This equation, applicable for $10^{-5} < \mathrm{Ra} < 10^{12}$, is as follows:

$$\mathrm{Nu} = \frac{h_c D}{k} = \left\{0.60 + \frac{0.387\mathrm{Ra_D}^{1/6}}{\left[1+(0.559/\mathrm{Pr})^{9/16}\right]^{8/27}}\right\}^2$$

The convection heat transfer coefficients between the package and the ambient during the 30-minute fire event are based on an average gas velocity of 10 m/sec [28] and the Colburn relation for forced convection of:

$$\mathrm{Nu} = 0.036 \times \mathrm{Pr}^{1/3} \times \mathrm{Re}^{0.8}$$

Given the turbulent nature of the 30-minute fire event, a characteristic length of 0.25 feet is conservatively used for all surfaces to define the probable limited distance for boundary growth. The resulting convection coefficient values exceed the 10 $\mathrm{W/m^2}$-°C suggested for large packages by IAEA advisory material [3].

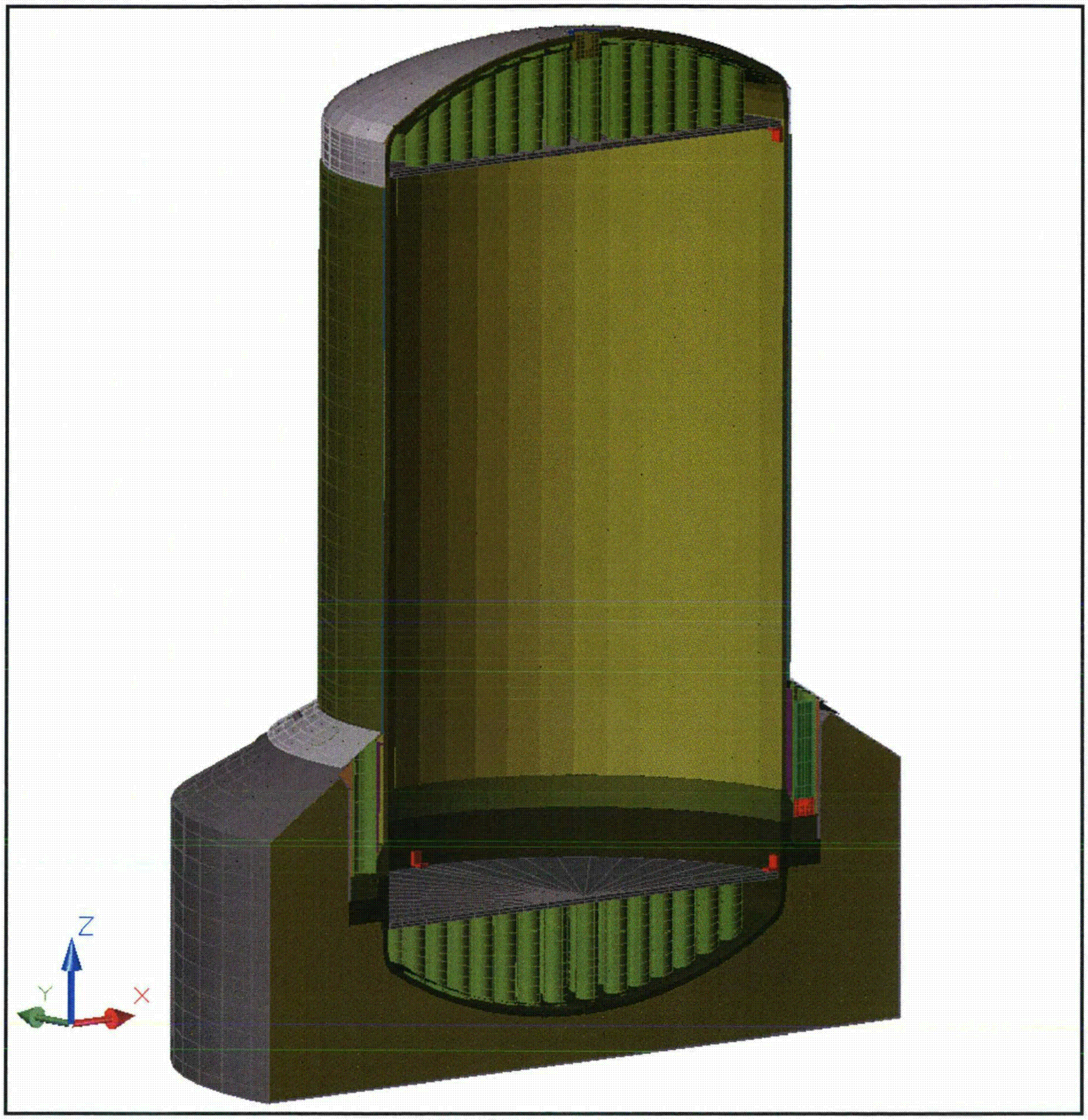


Figure 3.5-1 – Isometric View of 'Solids' Thermal Model for 435-B Packaging

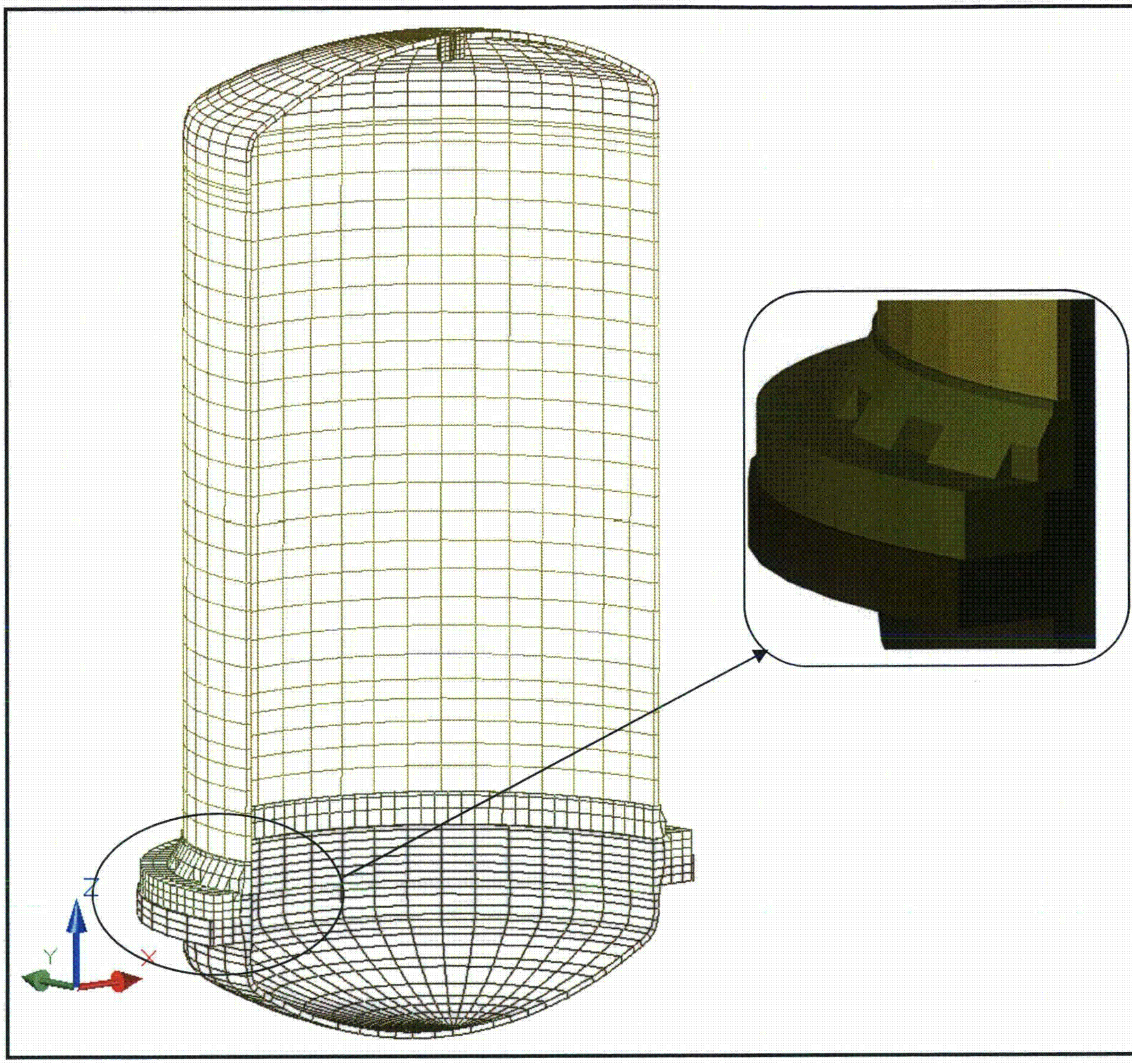


Figure 3.5-2 – Isometric View of 'Solids' Thermal Model for Containment Boundary

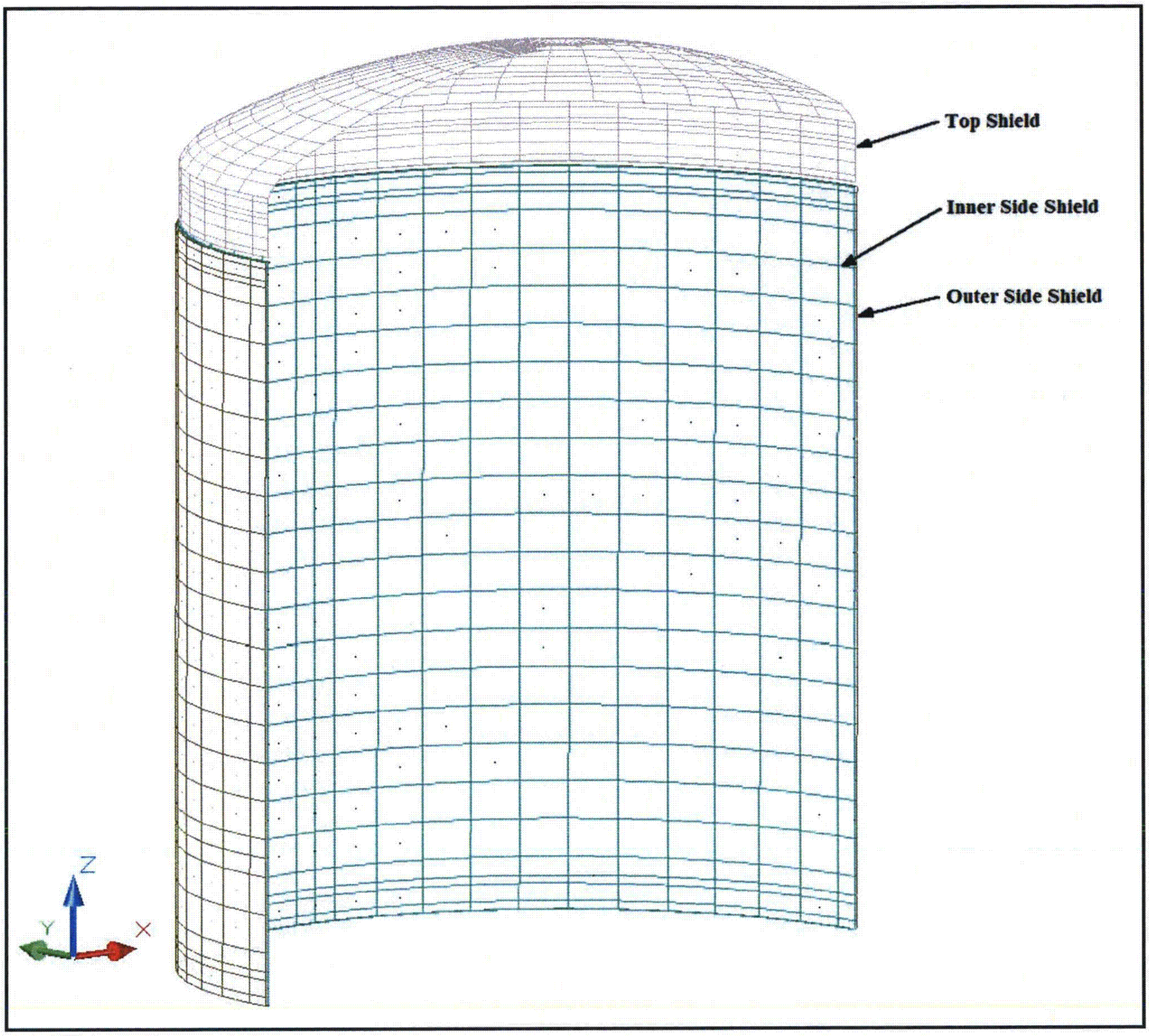


Figure 3.5-3 – Thermal Model for Top and Side Thermal Shields

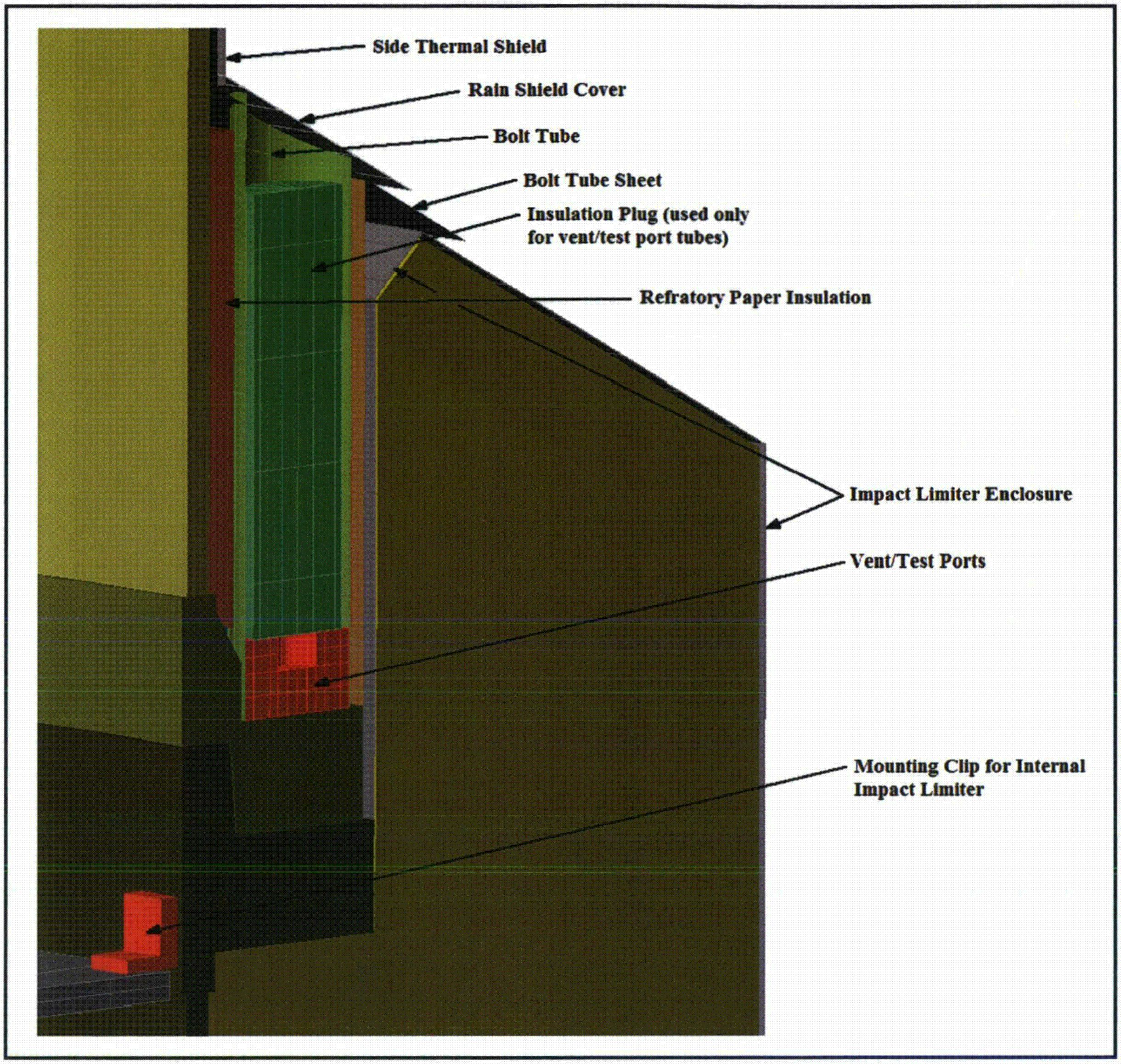


Figure 3.5-4 – Thermal Modeling at Closure Bolt Enclosure Structure

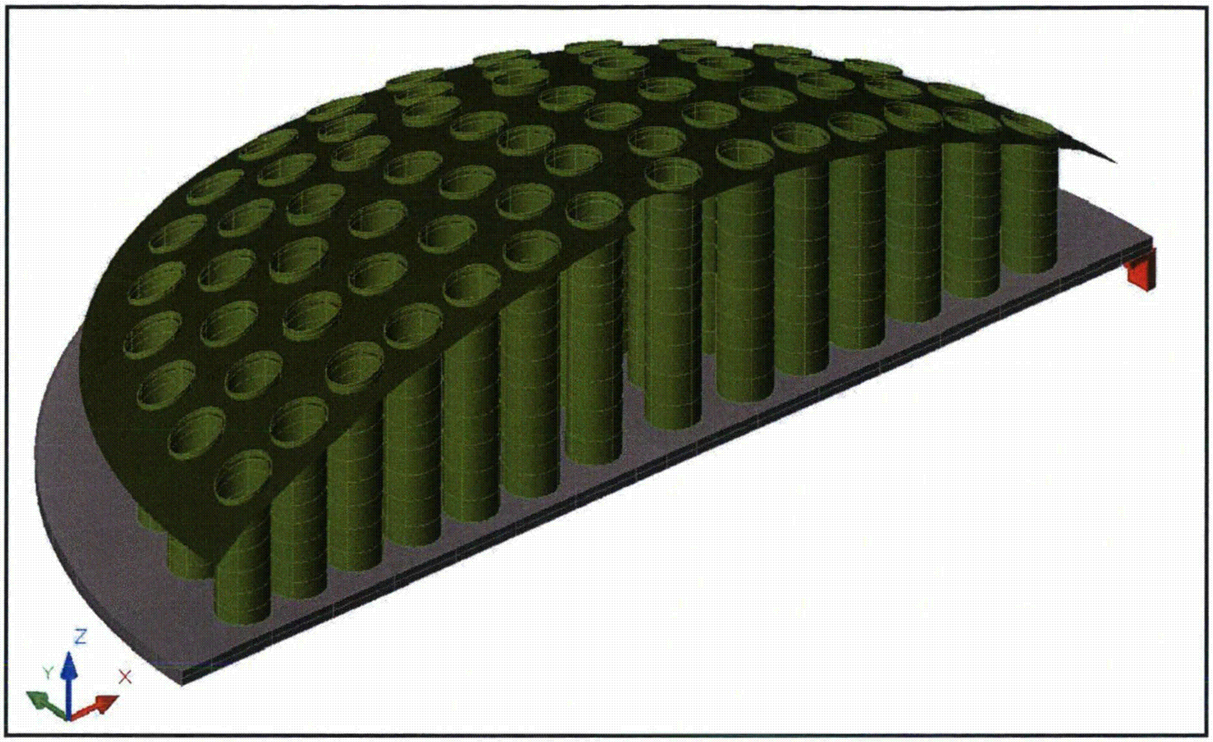


Figure 3.5-5 – Isometric View of Thermal Model for Internal Impact Limiters

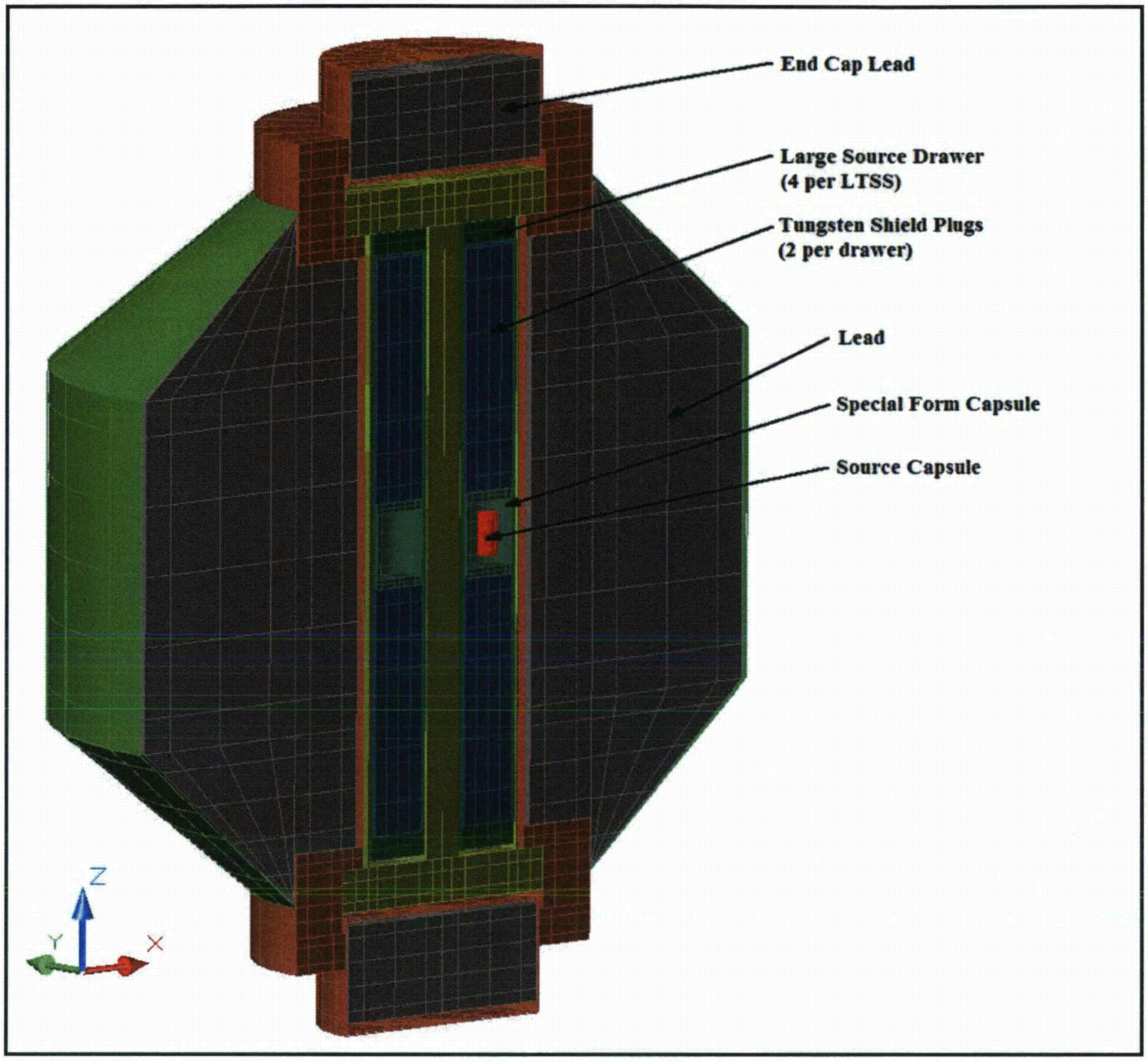


Figure 3.5-6 – Isometric View of Thermal Model for LTSS

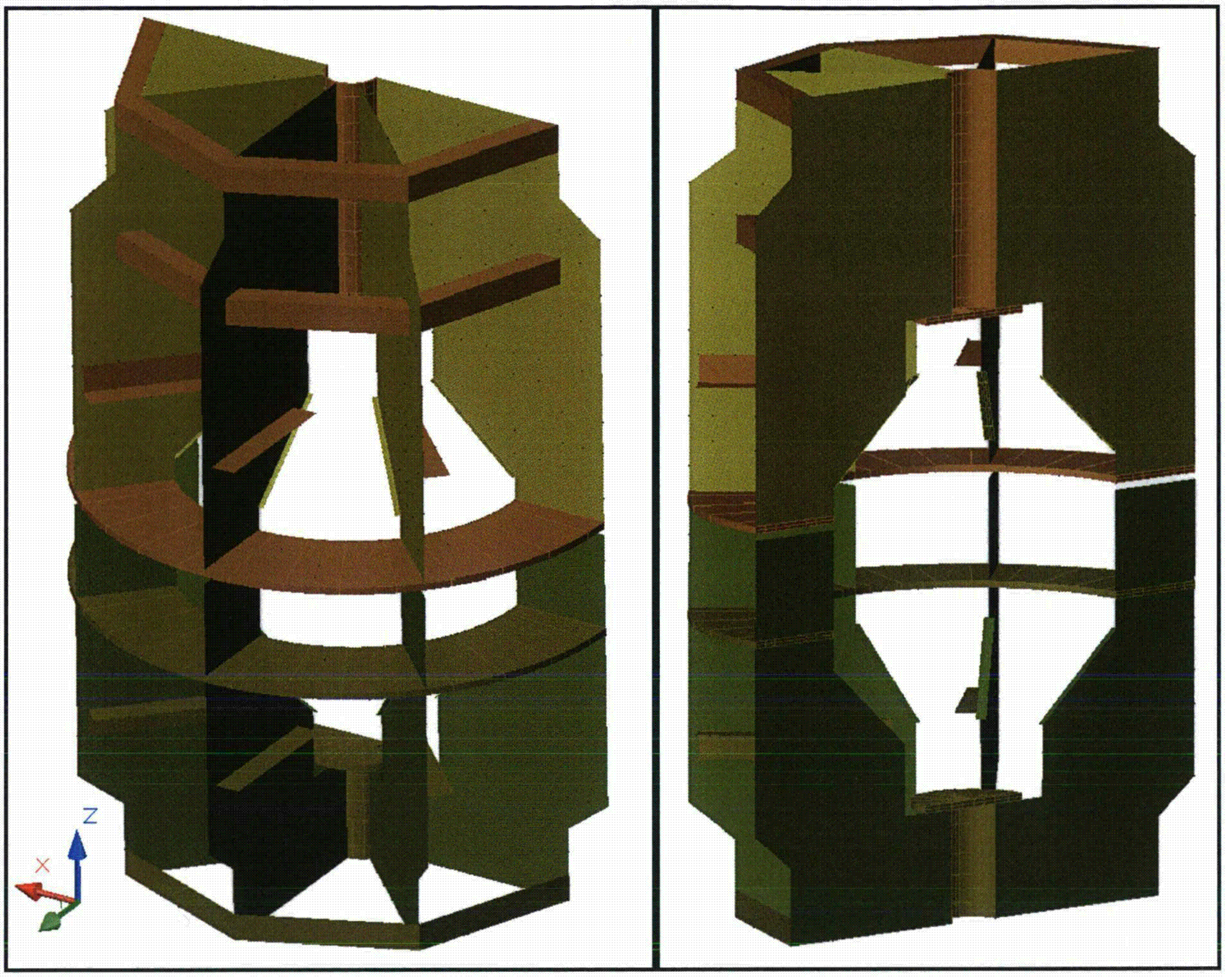


Figure 3.5-7 – Alternate Views of Thermal Model for LTSS Lodgment

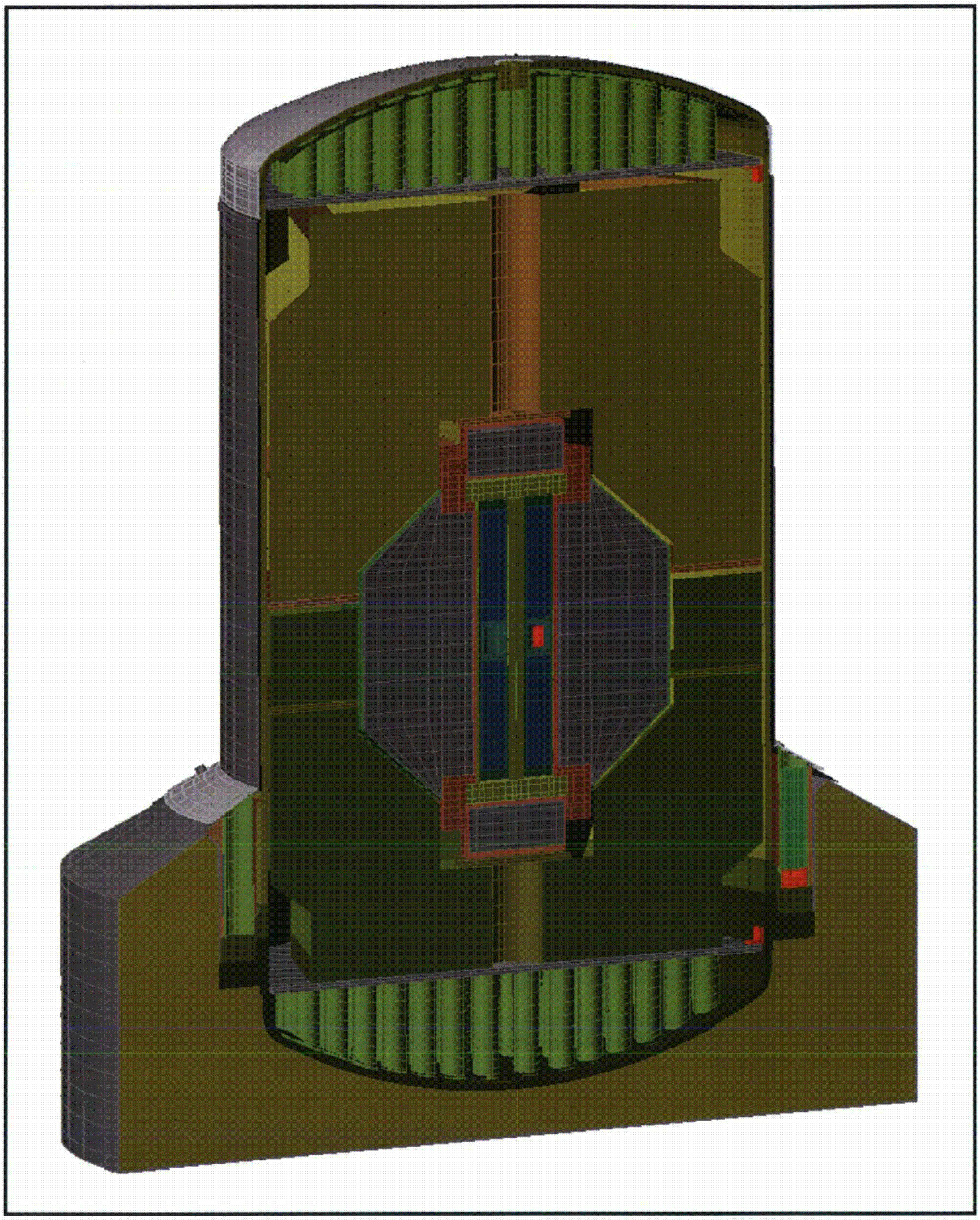


Figure 3.5-8 – Combined Modeling of 435-B Packaging with LTSS Payload

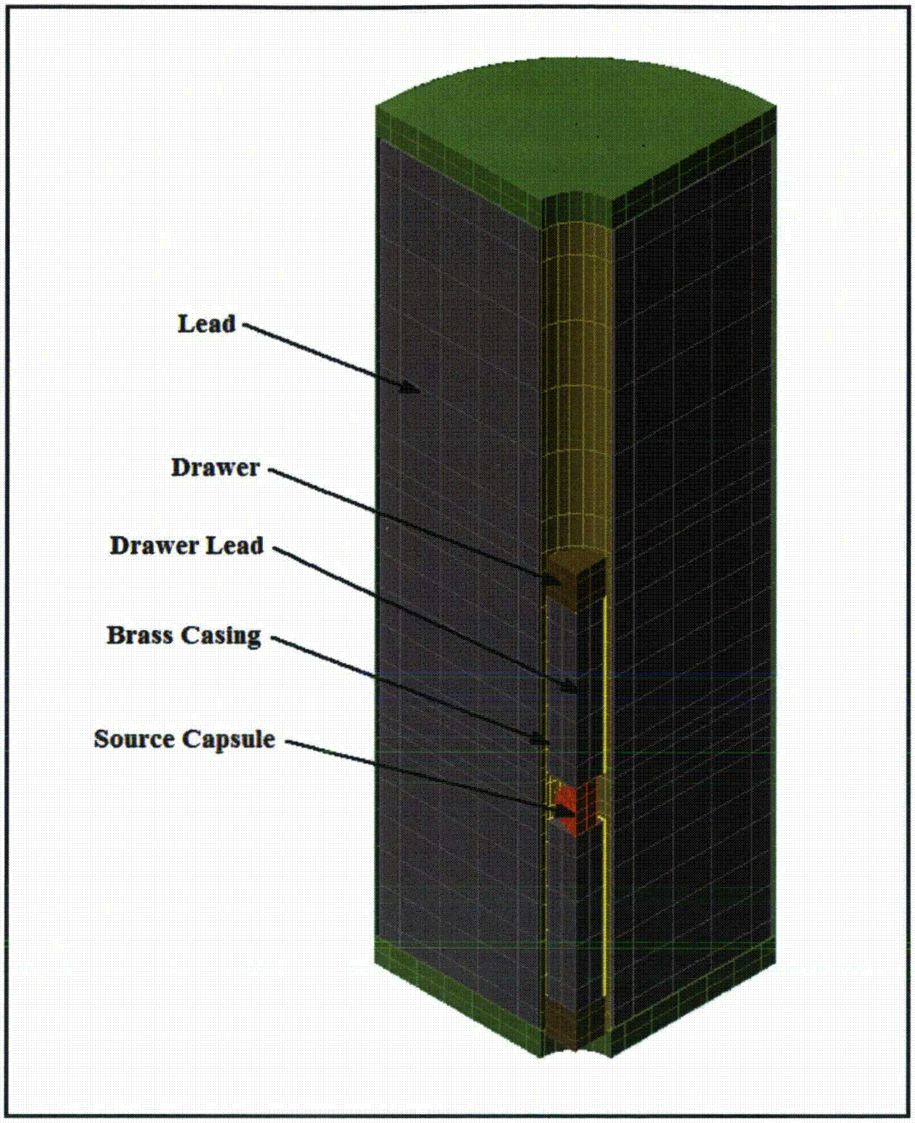


Figure 3.5-9 – Thermal Model for Generic Shielded Device

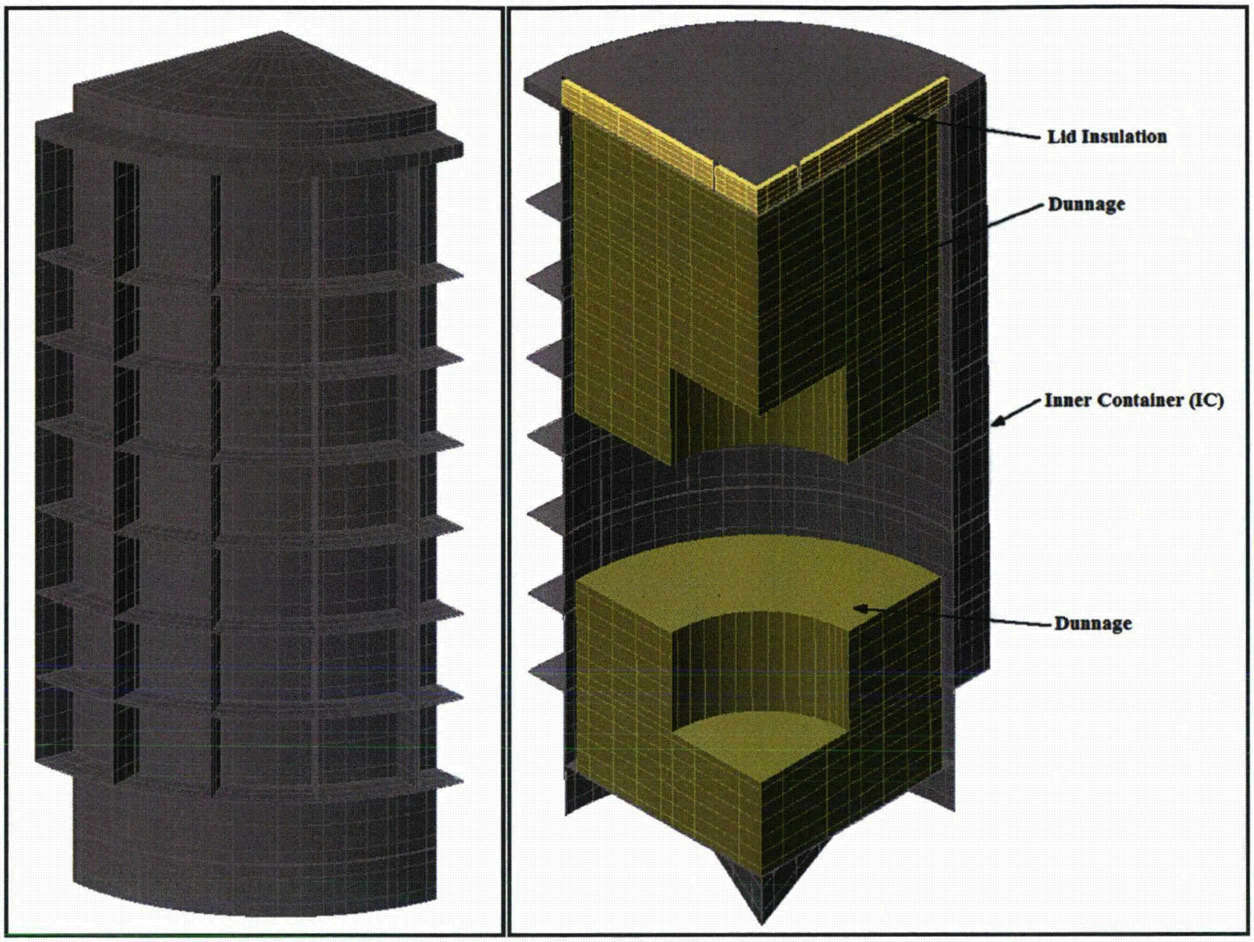


Figure 3.5-10 – Alternate Views of Thermal Model for Inner Container (IC)

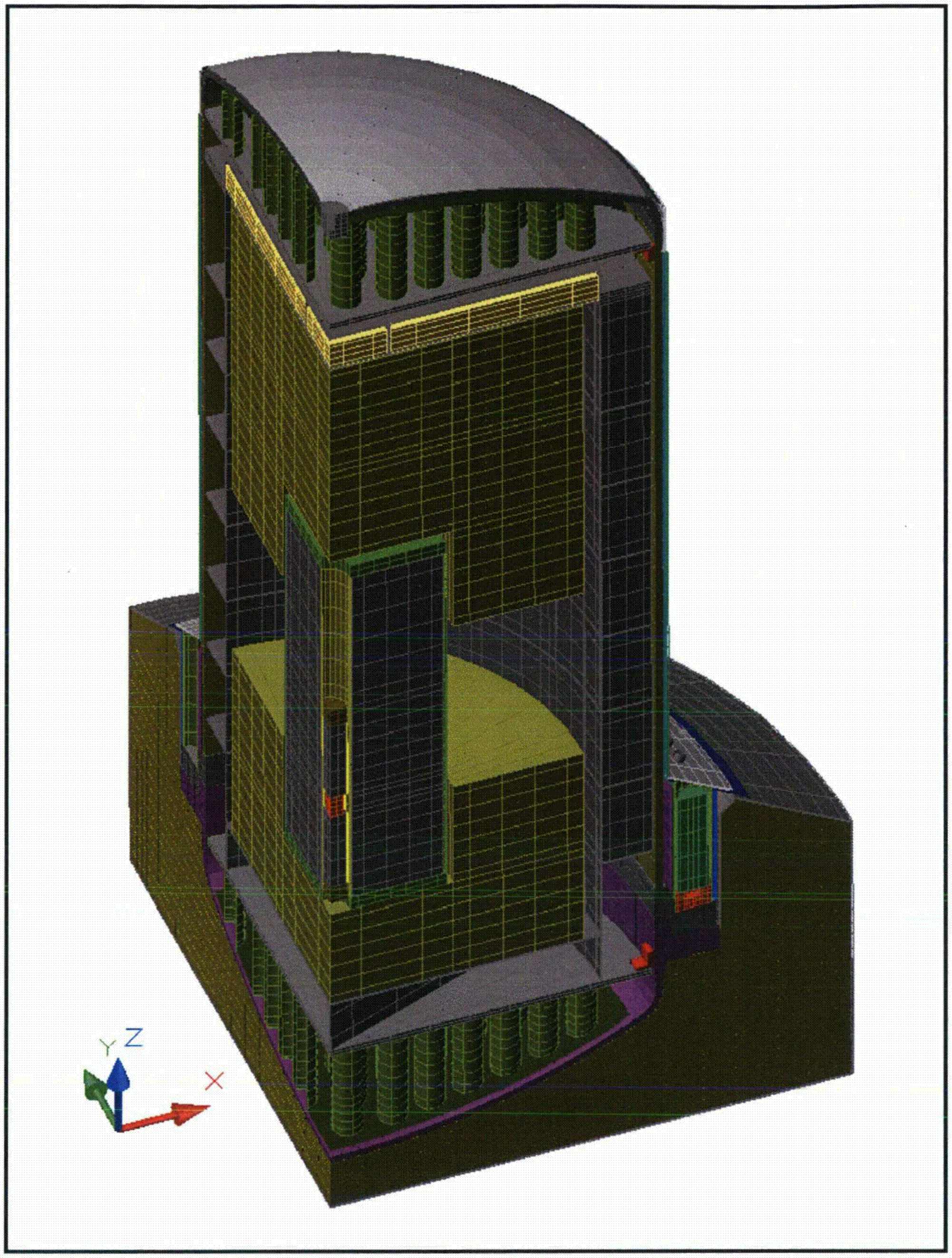


Figure 3.5-11 – Combined Modeling of 435-B Packaging with SD Payload

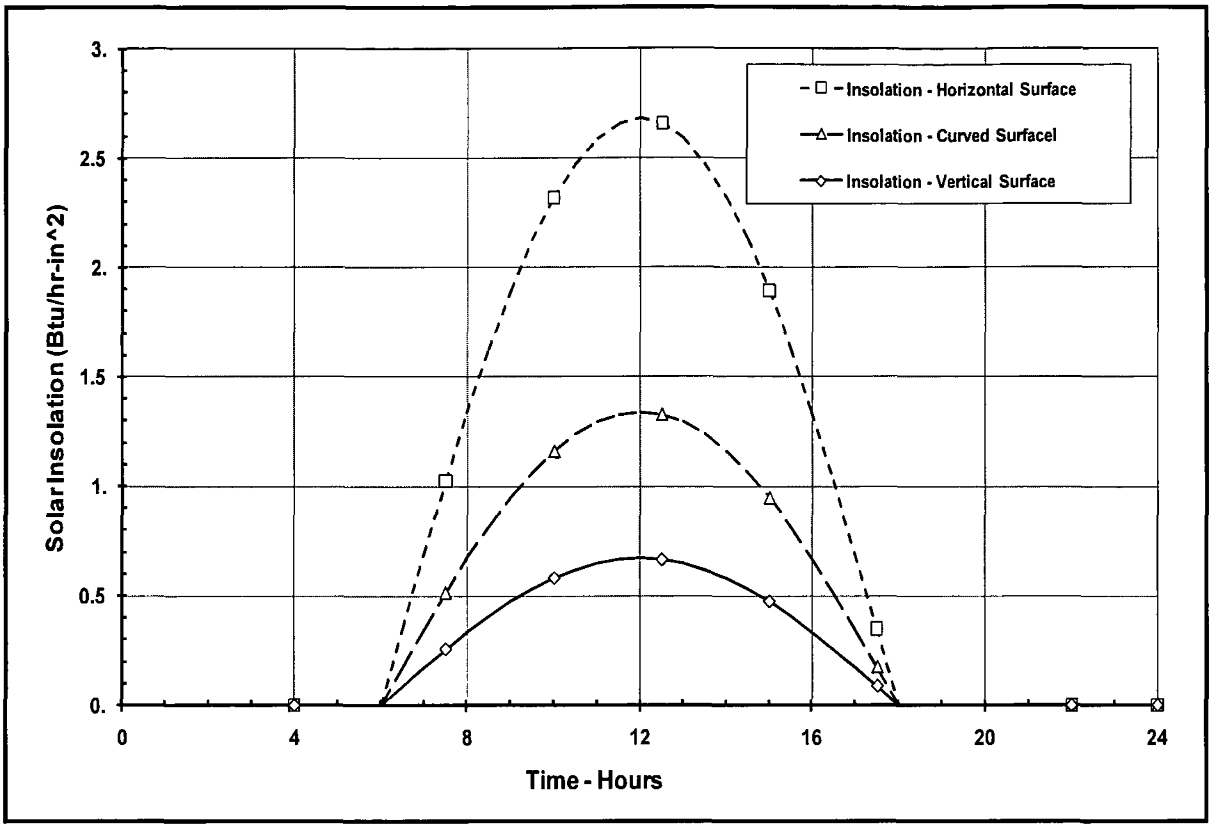


Figure 3.5-12 – Diurnal Cycle for Insolation

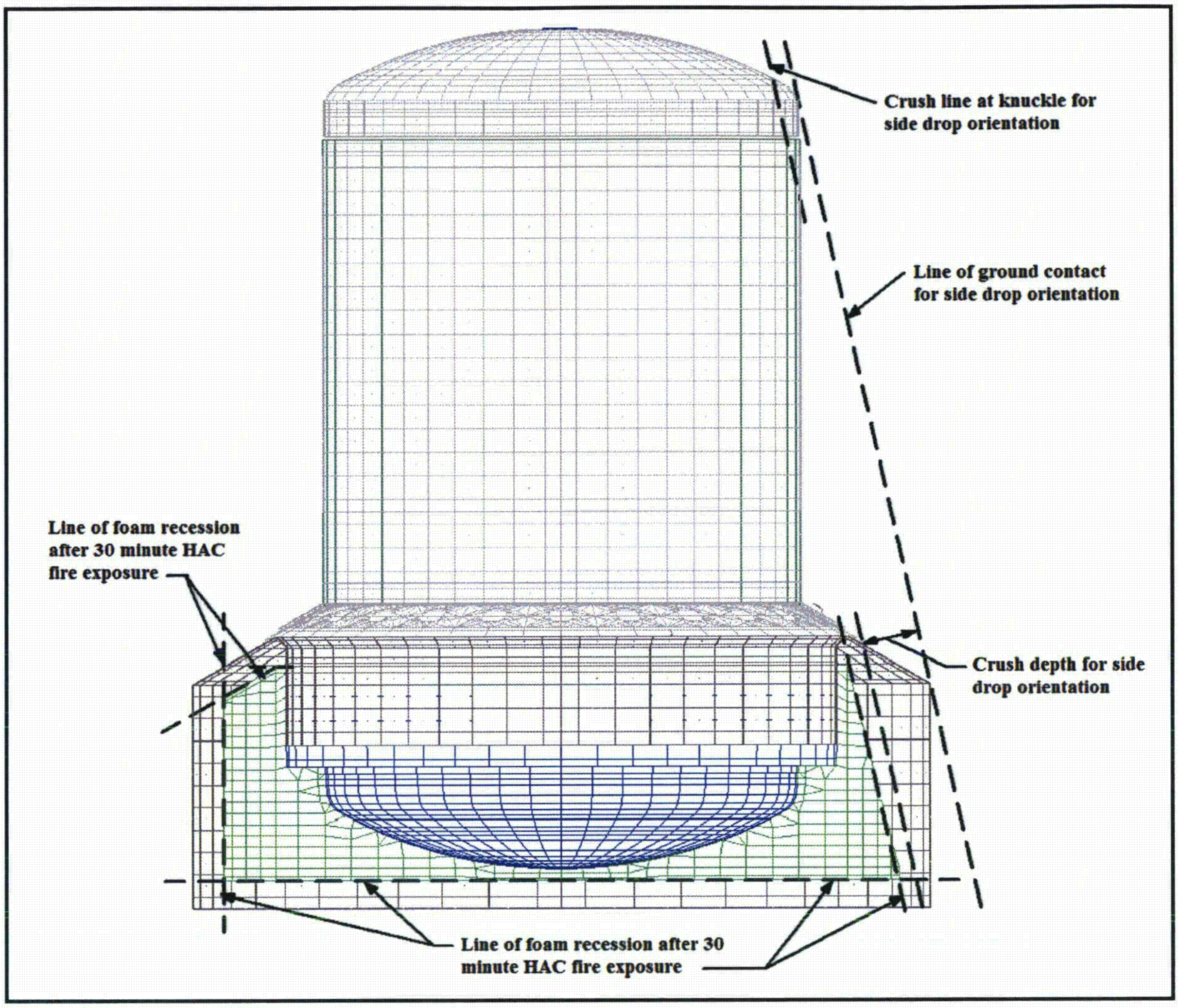


Figure 3.5-13 – HAC Side Drop Damage Modeling

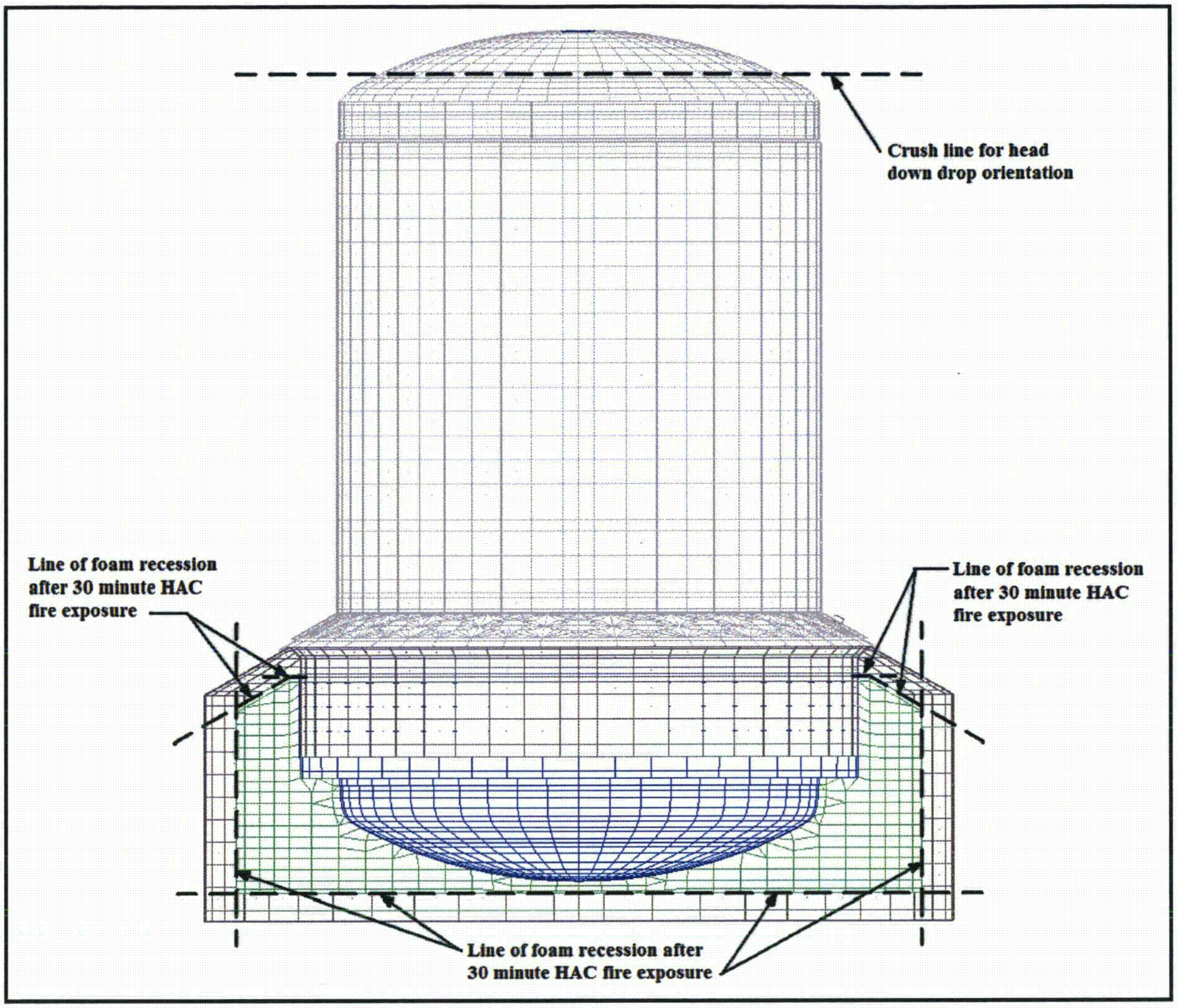


Figure 3.5-14 – HAC Head Down Drop Damage Modeling

3.5.4 'Last-A-Foam' Response under HAC Conditions

The General Plastics LAST-A-FOAM® FR-3700 rigid polyurethane foam [5] used in the impact limiters has been used for numerous transportation packages. The FR-3700 formulation is specially designed to allow predictable impact-absorption performance under dynamic loading, while also providing a significant level of thermal protection under the HAC conditions. Upon exposure to fire temperatures, this proprietary foam decomposes into an intumescent char that swells and tends to fill voids or gaps created by free drop or puncture bar damage. This thermal decomposition absorbs a significant amount of the heat transferred into the foam, which is then expelled from the impact limiters as a high temperature gas. Because the char has no appreciable structural capacity and will not develop unless there is space available, the char will not generate stresses within the adjacent package components. Without available space the pyrolysis gases developed as a result of the charring process will move excess char mass out through the vent ports and prevent its buildup. Only as the charring process continues and space becomes available will the char be retained, filling the available space and plugging holes at the surface of the impact limiters. The thermal decomposition process does not alter or cause a chemical reaction within the adjacent materials.

The mechanisms behind the observed variations in the thermal properties and behavior of the FR-3700 foam at elevated temperatures are varied and complex. A series of fire tests [6 and 7] conducted on 5-gallon cans filled with FR-3700 foam at densities from 6.7 to 25.8 lb/ft^3 helped define the expected performance of the foam under fire accident conditions. Under the referenced fire tests, one end of the test article was subjected to an open diesel fueled burner flame at temperatures of 980 to 1,200°C (1,800 to 2,200 °F) for more than 30 minutes. A thermal shield prevented direct exposure to the burner flame on any surface of the test article other than the hot face. Each test article was instrumented with thermocouples located at various depths in the foam. In addition, samples of the foam were subjected to thermogravimetric analysis (TGA) to determine the thermal decomposition vs. temperature. The exposure temperatures for the TGA tests varied from 70 to 1,500 °F, and were conducted in both air and nitrogen atmospheres. The result for the nitrogen environment (see Figure 3.5-15) is more representative of the low oxygen environment existing within the impact limiter shells encasing the foam. These test results indicate that the following steps occur in the thermal breakdown of the foam under the level of elevated temperatures reached during the HAC fire event:

- Below 250 °F, the variation in foam thermal properties with temperature is slight and reversible. As such, fixed values for specific heat and thermal conductivity are appropriate.
- Between 250 and 500 °F, small variations in foam thermal properties occur as water vapor and non-condensable gases are driven out of the foam. As such, fixed values for specific heat and thermal conductivity are also appropriate for this temperature range. Further, the observed changes are so slight that the same thermal properties used for temperatures below 250 °F may also be used to characterize the thermal performance of the foam between 250 and 500 °F.
- Between 325 and 435 °F, a foam weight reduction of approximately 2% (see Figure 3.5-15) will occur as water vapor and/or the gas used as the blowing agent is lost.

- Irreversible thermal decomposition of the foam begins as the temperature rises above 500 °F and increases non-linearly with temperature. Based on the TGA testing (see Figure 3.5-15), approximately 2/3's of this decomposition occurs over a narrow temperature range centered about 670 °F.
- The decomposition is accompanied by vigorous out-gassing from the foam and an indeterminate amount of internal heat generation. The internal heat generation arises from the gases generated by the decomposition process that are combustible under piloted conditions. However, since the decomposition process is endothermic, the foam will not support combustion indefinitely. Further, the out-gassing process removes a significant amount of heat from the package via mass transport.
- The weight loss due to out-gassing not only has direct affect on the heat flux into the remaining virgin foam, but changes the composition of the resulting foam char since the foam constituents are lost at different rates. This change in composition affects both the specific heat and the thermal conductivity of the foam char layer.
- As temperature continues to rise, the developing char layer begins to take on the characteristics of a gas-filled cellular structure where radiative interchange from one cell surface to another becomes the dominant portion of the overall heat transfer mechanism. This change in heat transfer mechanisms causes the apparent heat conductivity to take on a highly non-linear relationship with temperature.
- Finally, at temperatures above 1,250 °F, the thermal breakdown of the foam is essentially completed and only about 5 to 10% of the original mass is left. In the absence of direct exposure to a flame or erosion by the channeling of the outgas products through the foam, the char layer will be the same or slightly thicker than the original foam depth. This char layer will continue to provide radiative shielding to the underlying foam material.

Since the thermal decomposition of the foam is an endothermic process, the foam is self-extinguishing and will not support a flame once the external flame source is removed. However, the gases generated by the decomposition process are combustible and will burn under piloted conditions. A portion of these generated gases can remain trapped within the charred layer of the foam after the cessation of the HAC fire event and continue to support further combustion, although at a much reduced level, until a sufficient time has passed for their depletion from the cell structure. This extended time period is typically from 15 to 45 minutes.

The sharp transition in the state of the foam noted in Figure 3.5-15 at or about 670 °F can be used to correlate the observed depth of the foam char following a burn test with the occurrence of this temperature level within the foam. The correlation between the foam recession depth and the foam density, as compiled from a series of tests, is expressed by the relation:

$$y = -0.94581 - 11.64 \times \log_{10}(x)$$

where y = the recession depth, cm

x = foam density (g/cm^3)

Based on this correlation, the recession depth expected for the nominal 15 pcf density foam used in the packaging is estimated to be 2.5 inches. The loss of foam could increase to a depth of approximately 2.8 inches for foam fabricated at the low end of the density tolerance (i.e., 12.75 pcf).

It should be noted that these results assume that the foam is enclosed within a steel shell with surface openings that are approximately 0.3 ft^2 or smaller. The presence of the steel enclosure helps shield the foam from the heat flux of a HAC fire event and helps contain the foam char that is generated. The same is true if a layer of 0.25" thick Lytherm paper is placed between the foam and the steel enclosure. Proprietary test results with and without a layer of Lytherm paper indicates that the foam loss for 8 pcf foam was reduced by approximately 11%.

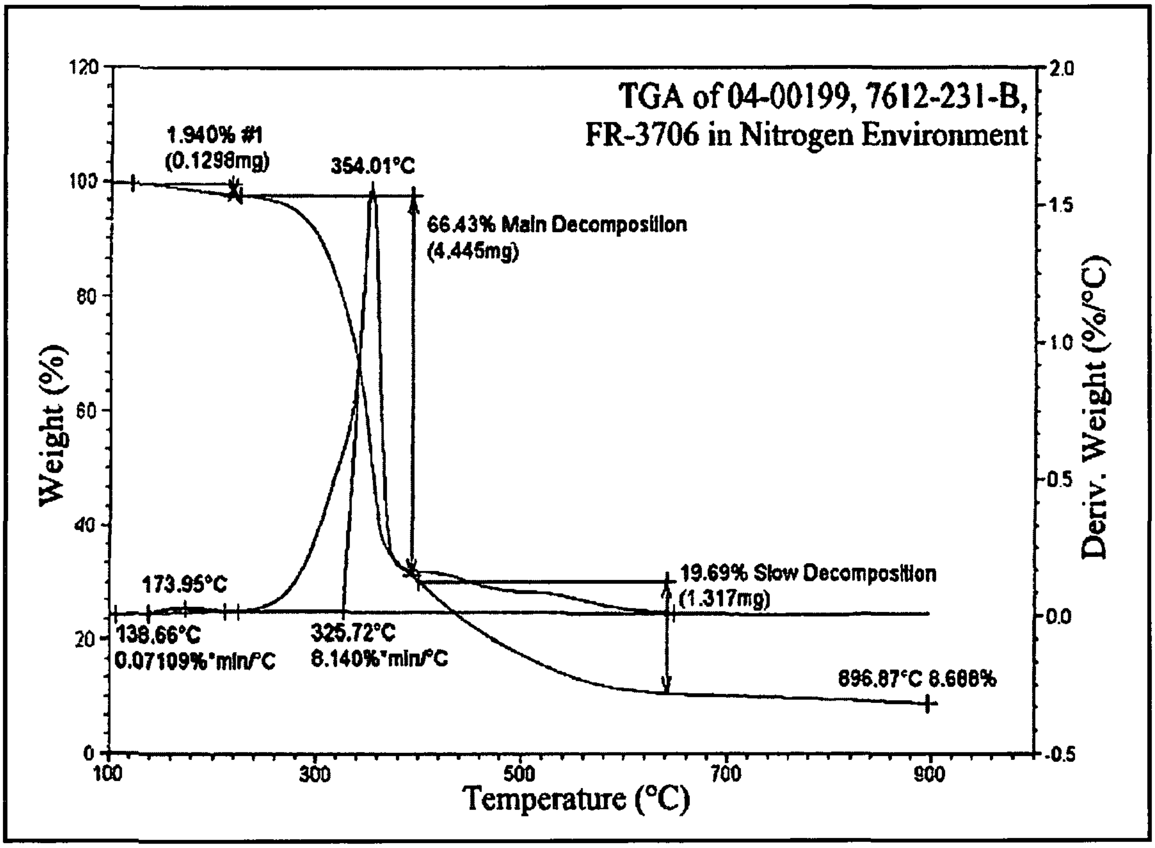


Figure 3.5-15 – TGA Analysis of Foam Decomposition in Nitrogen Environment

4.0 CONTAINMENT

4.1 Description of the Containment System

4.1.1 Containment Boundary

The 435-B package provides a single level of leaktight containment, defined as a leakage rate of less than 1×10^{-7} reference cubic centimeters per second (ref–cm^3/s), air, per ANSI N14.5 [1]. The containment boundary of the 435-B package consists of the following elements. Unless noted, all elements are made of ASTM Type 304 stainless steel in various product forms. A full description of the packaging is given in Section 1.2.1, *Packaging*.

- The upper torispherical head and upper body assembly lifting boss
- The cylindrical side shell
- The upper flange (attached to the upper body assembly)
- The lower flange (attached to the lower body assembly)
- The lower torispherical head
- The containment elastomer O-ring seal
- The vent port block and brass vent port plug in the upper flange including elastomer sealing washer

The containment boundary is shown in Figure 4.1-1.

4.1.2 Containment Penetrations

The vent port is the only containment penetration. The vent port is located in a steel block welded to the upper flange, as shown in Figure 4.1-1. The vent port is designed and tested to ensure leaktight sealing integrity, i.e., a leakage rate not exceeding 1×10^{-7} ref–cm^3/s, per ANSI N14.5.

4.1.3 Seals

The elastomeric portion of the containment boundary is comprised of a nominally 3/8–inch diameter, bore-type O–ring seal located in the upper groove in the lower flange, and a seal washer sealing element (an O–ring integrated with a stainless steel washer) for the vent port. The seals are made using a butyl elastomer compound suitable for continuous use between the temperatures of -65 °F and 250 °F [2], and capable of much higher temperatures during the HAC fire case transient. Further discussion of the thermal performance capabilities of the butyl rubber seals is provided in Appendix 2.12.5, *Containment Seal Performance Tests*.

Two O–ring seals are provided in the lower body flange: the upper seal is containment, and the lower forms an annular space for leakage rate testing of the containment seal. The leakage rate tests used for various purposes are summarized in Section 4.4, *Leakage Rate Tests for Type B Packages*, and described in detail in Chapter 8, *Acceptance Tests and Maintenance Program*.

The containment seal will retain adequate compression to afford a seal in the worst case condition. The nominal diameter of the containment seal (upper) groove is:

$$D_g = 45.74 - 2(1.2\times\tan(5) + 0.265) = 45.0 \text{ inches}$$

where the flange outer diameter is 45.74 inches, the height of the upper groove centerline is 1.2 inches above the flange joint, the flange tapers at an angle of 5°, and the groove depth is 0.265 inches. See Detail G on drawing 1916-01-01-SAR, sheet 4. The O-ring minimum length is 44.10 inches, minus 1%, or:

$$D_{OR} = 44.10 \times 0.99 = 43.66 \text{ inches}$$

The maximum stretch of the containment seal is therefore:

$$S = \frac{D_g - D_{OR}}{D_{OR}} \times 100 = 3.1\,\%$$

The minimum stretch is 1%, using the O-ring maximum length of 44.10 × 1.01 = 44.54 inches. From the Parker O-ring Handbook [6], the observed cross-section reduction caused by this amount of stretch is 2.5% for the maximum stretch case, and 1.0% for the minimum stretch case. The O-ring diameters are:

$$d_{Min} = (0.375 - 0.007) \times (1 - 0.025) = 0.359 \text{ inches}$$

$$d_{Max} = (0.375 + 0.007) \times (1 - 0.010) = 0.378 \text{ inches}$$

where the O-ring cross section is 0.375 ± 0.007 inches.

The inner diameter of the mating surface of the upper body assembly is 45.765 ± 0.007 or 45.772 inches maximum. The corresponding diameter of the base flange component is 45.740 ± 0.007, or 45.733 inches minimum. The maximum radial clearance between the two assembled flanges is therefore:

$$gap_{Max} = 45.772 - 45.733 = 0.039 \text{ inches.}$$

This assumes that the upper flange is shifted the maximum radial amount relative to the lower flange. The minimum gap, which occurs 180° away from the maximum gap, is equal to zero.

The depth of the groove which contains the seal is 0.265 ± 0.005, or g_{Max} = 0.270 inches, and g_{Min} = 0.260 inches.

The compression range of the O-ring seal is:

$$C_{Min} = \frac{d_{Min} - g_{Max} - gap_{Max}}{d_{Min}} \times 100 = 13.9\,\%$$

$$C_{Max} = \frac{d_{Max} - g_{Min}}{d_{Max}} \times 100 = 31.2\,\%$$

Where C_{Max} and C_{Min} are the maximum and minimum compressions that the containment O-ring seal will experience. As shown in Appendix 2.12.5, *Seal Performance Tests*, the butyl rubber used in the 435-B has been successfully tested using compression values as low as 10%.

4.1.4 Welds

All butt welds used in the containment boundary (including any welds used to join plates prior to forming) are full penetration welds, and are radiograph and liquid penetrant inspected to ensure structural and containment integrity. Radiographic inspection is in accordance with the ASME Code, Subsection NB, Article NB-5000, and Section V, Article 2 [3] and liquid penetrant inspection on the final pass in accordance with the ASME Code, Subsection NB, Article NB-5000, and Section V, Article 6 [4]. The fillet weld between the vent port block and the lower flange and the full penetration groove weld which closes off the vent port machining access hole (see Section M-M on drawing 1916-01-01-SAR, sheet 6) are liquid penetrant inspected on the final pass in accordance with the ASME Code, Subsection NB, Article 5000, and Section V, Article 6. All containment boundary welds are confirmed to be leaktight as discussed in Section 8.1.4, *Fabrication Leakage Rate Tests*.

4.1.5 Closure

The package closure is made using (24) 1-1/4-7 UNC socket head cap screws tightened to 300 ± 30 ft-lb. As shown in Chapter 2, *Structural Evaluation*, the closure lid cannot become detached by any internal pressure, NCT, or HAC events. The closure joint is protected by the impact limiter, which is integral with the lower body assembly. The bolt heads and the vent port are covered by the rain shield. Thus, the containment openings cannot be inadvertently opened.

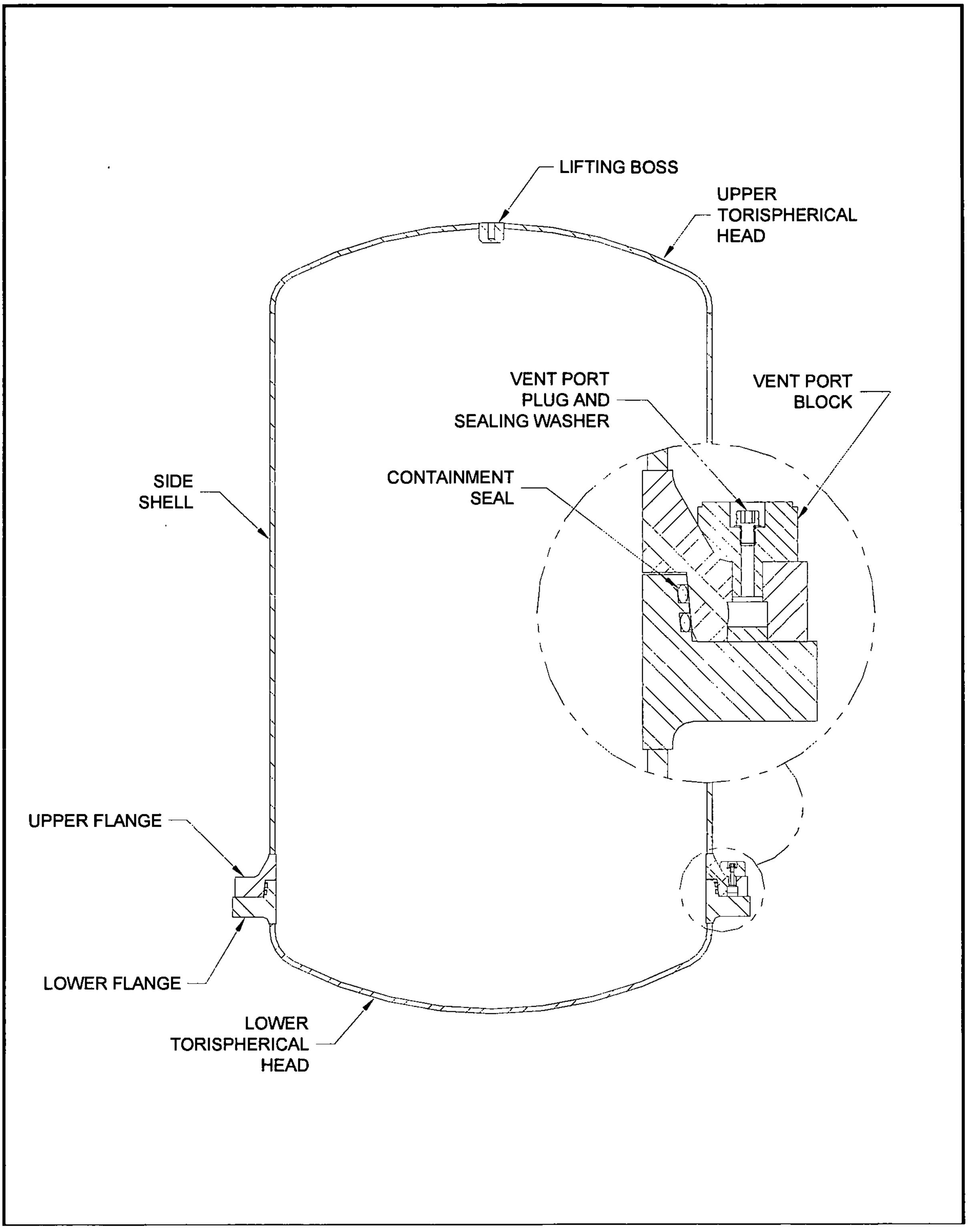


Figure 4.1-1 – 435-B Package Containment Boundary

4.2 Containment Under Normal Conditions of Transport

The results of the NCT structural and thermal evaluations presented in Sections 2.6, *Normal Conditions of Transport*, and 3.3, *Thermal Evaluation Under Normal Conditions of Transport*, respectively, demonstrate that there is no release of radioactive materials per the "leaktight" definition of ANSI N14.5 under any of the NCT tests described in 10 CFR §71.71 [5].

4.3 Containment Under Hypothetical Accident Conditions

The results of the HAC structural and thermal evaluations performed in Sections 2.7, *Hypothetical Accident Conditions*, and 3.4, *Thermal Evaluation Under Hypothetical Accident Conditions*, respectively, demonstrate that there is no release of radioactive materials per the "leaktight" definition of ANSI N14.5 under any of the hypothetical accident condition tests described in 10 CFR §71.73.

4.4 Leakage Rate Tests for Type B Packages

4.4.1 Fabrication Leakage Rate Tests

During fabrication, the containment boundary is leakage rate tested as described in Section 8.1.4, *Fabrication Leakage Rate Tests*. The fabrication leakage rate tests are consistent with the guidelines of Section 7.3 of ANSI N14.5. This leakage rate test verifies the containment integrity of the 435-B packaging to a leakage rate not to exceed 1×10^{-7} ref–cm^3/s, air.

4.4.2 Maintenance/Periodic Leakage Rate Tests

In the 12-month period prior to shipment, or at the time of damaged containment seal replacement or sealing surface repair (whichever is sooner), the containment O–ring seal and the vent port sealing washer are leakage rate tested as described in Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*. The maintenance/periodic leakage rate tests are consistent with the guidelines of Section 7.4 of ANSI N14.5. This test verifies the sealing integrity of the containment seals to a leakage rate not to exceed 1×10^{-7} ref–cm^3/s, air.

4.4.3 Preshipment Leakage Rate Tests

Prior to shipment of the loaded 435-B package, the containment O–ring seal and the vent port sealing washers are leakage rate tested per Section 7.4, *Preshipment Leakage Rate Test*. The preshipment leakage rate tests are consistent with the guidelines of Section 7.6 of ANSI N14.5. This test verifies the sealing integrity of the containment seals to a leakage rate sensitivity of 1×10^{-3} ref–cm^3/s, air.

The maintenance/periodic leakage rate tests, described in Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*, may be performed as an option, in lieu of the preshipment leakage rate tests.

4.5 Appendix

4.5.1 References

1. ANSI N14.5–1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute (ANSI), Inc.
2. Rainier Rubber Company, Seattle, WA.
3. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*, and Section V, *Nondestructive Examination*, Article 2, *Radiographic Examination*, 2010 Edition.
4. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*, and Section V, *Nondestructive Examination*, Article 6, *Liquid Penetrant Examination*, 2010 Edition.
5. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 01–01–11 Edition.
6. Parker O–ring Handbook, ORD–5700, Parker-Hannifin Corporation, Cleveland, OH, © 2007.

5.0 SHIELDING EVALUATION

The 435-B package is used to transport radioactive sources in the Long Term Storage Shield (LTSS) or shielded devices containing their sources (devices). The shielding analysis for the LTSS for a variety of source isotopes is presented in the main body of Chapter 5.0, *Shielding Evaluation*. The shielding analysis for the devices is presented in Appendix 5.5.3, *Shielded Device Evaluation*.

5.1 Description of Shielding Design

5.1.1 Design Features

The 435-B package itself offers little shielding. The outer shell of the 435-B is 0.5-in thick steel. The shielding is provided primarily by the LTSS, which features 85.8 mm lead shielding on the ends and 244 mm lead shielding on the sides. Sources are loaded into four recesses within the LTSS. The sources are sealed within one of five special form capsules of differing length. Each special form capsule is loaded into a large source drawer, which features tungsten shielding at each end. The large source drawer is 21.5-in long and 2.5-in in diameter. The length of the tungsten shielding is dependent upon the length of special form capsule utilized, and the tungsten length ranges between 88.5 and 214 mm.

In addition, the LTSS may be used with the T80/T780 drawer. The T80 and T780 drawers are physically identical. Like the large source drawer, they are 21.5-in long and 2.5-in in diameter. For the T80 drawer, the shielding on each side of the source is 9.2-in of lead. For the T780 drawer, the shielding may be either lead, tungsten, or depleted uranium.

As demonstrated by the certification testing documented in Appendix 2.12.3, *Certification Test Report*, the LTSS does not experience any significant damage which could reduce its effectiveness or which could lead to a release of the sources from the shield.

5.1.2 Summary Table of Maximum Radiation Levels

The number of possible LTSS loading scenarios can vary over a large range. Therefore, a simplified method is employed to compute dose rates for single isotopes, and then the dose rate from any arbitrary combination of isotopes may be calculated using a sum of fractions rule. Using this approach, the maximum surface and 1 m dose rates are conservatively limited to 190 mrem/hr and 9.5 mrem/hr, respectively, which are less than the normal condition of transport (NCT) limits for non-exclusive use transportation of 200 mrem/hr on the package surface and 10 mrem/hr at 1 m from the package surface. Therefore, the transport index (TI) will not exceed 9.5.

Under hypothetical accident conditions (HAC), there is no damage to the LTSS, LTSS lodgment, or 435-B package that affects dose rates. Because there is no change to the shielding under HAC, the HAC dose rates are the same as the NCT dose rates at 1 m, or 9.5 mrem/hr. This is significantly less than the limit of 1000 mrem/hr.

The LTSS loading methodology used to ensure compliance with the dose rate limits is summarized in Section 5.4.5, *LTSS Loading Methodology*.

5.2 Source Specification

Source terms are determined for a number of isotopes, which are summarized in Table 5.2-1. These isotopes may be either alpha or beta emitters, although from a shielding standpoint, only the corresponding gamma and neutron emissions contribute to the dose rate. The actinides may also be mixed with an (α,n) target nucleus, such as beryllium. The decay heat of the 435-B package is limited to 200 watts. Therefore, each nuclide is also limited to 200 watts. In most cases, the gamma and neutron source terms are computed by the ORIGEN-S module of the SCALE6 code package [3].

5.2.1 Gamma Source

Co-60

Co-60 is a beta/gamma emitter. The decay of Co-60 is sufficiently simple to be treated explicitly. Each decay of Co-60 results in two gammas, with energies of 1.173 and 1.332 MeV [1]. The gamma source for 1 Ci of Co-60 is provided in Table 5.2-2.

An ORIGEN-S case is developed for 1 Ci of Co-60 in order to determine the decay heat. For 1 Ci of Co-60, the decay heat is 0.01542 watts. Therefore, the Co-60 activity is limited to 12,970 Ci for the maximum decay heat of 200 watts.

Cs-137

Cs-137 is a beta/gamma emitter. The decay of Cs-137 is sufficiently simple to be treated explicitly. The decay of Cs-137 emits a 0.662 MeV gamma with an 85% probability [1]. The gamma source for 1 Ci of Cs-137 is provided in Table 5.2-3.

Cs-137 quickly reaches equilibrium with its daughter product, Ba-137m. Therefore, to conservatively compute the decay heat, equal activities of both Cs-137 and Ba-137m are input to ORIGEN-S, and a maximum decay heat is computed at time zero. For 1 Ci of Cs-137/Ba-137m, the decay heat is 5.0400E-03 watts.

Sr-90

Sr-90 decays to Y-90, and both are beta/gamma emitters. Sr-90 reaches equilibrium with Y-90 after approximately 20 days. To conservatively compute the source term and decay heat, 1 Ci of both Sr-90 and Y-90 are input to ORIGEN-S. For 1 Ci of Sr-90/Y-90, the decay heat is 6.6980E-03 watts. The gamma source is extracted from the ORIGEN-S output and is provided in Table 5.2-4 for 1 Ci.

Ra-226

Ra-226 is an alpha/gamma emitter. The gamma source input files are developed using ORIGEN-S. The Ra-226 gamma source for a decay time from 0.1 to 10 years is provided in Table 5.2-5 for 1 Ci. The gamma sources for the energy groups that are primary contributors to the dose rate (0.6 to 2.5 MeV) peak at approximately 0.3 years of decay. The gamma source for the lower energy groups continue to increase slowly after 0.3 years, but these energy groups do not contribute to the dose rate. Therefore, the source at a decay time of 0.3 years is used in the shielding calculations.

The decay heat increases slowly with time and peaks after approximately 80 years of decay, with a maximum value of 0.1862 watts for 1 Ci.

The alpha radiation will lead to a neutron source when mixed with an (α,n) target nucleus, such as beryllium. The neutron source is discussed in Section 5.2.2, *Neutron Source*.

Am-241

Am-241 is an alpha/gamma emitter and results in little gamma radiation. Am-241 sources are relatively pure, with an Am-241 content of approximately 0.997 g per gram of metal [5]. A representative distribution is provided in Table 5.2-6, taken from Table 16 of [5]. The maximum 435-B activity of 1,000 Ci Am-241 equates to 291.5 g. Based on the information in Table 5.2-6, for 291.5 g Am-241, the total plutonium mass is limited to approximately 0.98 g, which is significantly less than the fissile exemption limit of 15 g per 10 CFR 71.15(b).

The Am-241 gamma source is computed for pure Am-241 because the impurities are negligible. The gamma source for 1 Ci Am-241 listed in Table 5.2-7 is computed at time zero. The gamma source is quite weak at the energies that contribute to the dose rate. For 1 Ci of Am-241, the decay heat is 0.03337 watts.

The alpha radiation will lead to a neutron source when mixed with an (α,n) target nucleus, such as beryllium. The neutron source is discussed in Section 5.2.2, *Neutron Source*.

Pu-238

Pu-238 is an alpha/gamma emitter and results in little gamma radiation. A Pu-238 sealed source is typically ~80% Pu-238 and ~20% other plutonium isotopes. The quantity of Pu-238 is limited for transport by the mass of fissile plutonium that may be present as an impurity. A representative distribution is provided in Table 5.2-8, taken from Table 4 of [5]. The fissile isotopes Pu-239, Pu-241, and U-235 are limited to a total of 15 g per 10 CFR 71.15(b). The total fissile mass per gram of plutonium is 0.168 g per Table 5.2-8. For the 435-B limit of 75 g Pu-238 (including impurities), the total fissile mass is $(75)(0.168) = 12.6 \text{ g} < 15 \text{ g}$.

The gamma source is computed using ORIGEN-S and is listed in Table 5.2-9 on a per gram basis. The plutonium impurities are neglected because the gamma source and decay heat are maximized for pure Pu-238, as the half-life of Pu-238 is relatively short. This source is computed at time zero. For 1 g of Pu-238, the decay heat is 0.56773 watts.

The alpha radiation will lead to a neutron source when mixed with an (α,n) target nucleus, such as oxygen. The neutron source is discussed in Section 5.2.2, *Neutron Source*.

Pu-239

Pu-239 is an alpha/gamma emitter and results in little gamma radiation. The total mass of fissile isotopes is limited to 15 g per 10 CFR 71.15(b). However, sources containing Pu-239 will have other non-fissile plutonium impurities. Representative distributions for Pu-239 in sealed sources may be found in Table 10 of [5] and Table 2 (Reconciled Values) of [6]. These distributions are reproduced in Table 5.2-10 as isotopic sets #1 and #2. ORIGEN-S models are developed for both sets of isotopics. Because Pu-241 is a beta emitter and decays to Am-241, which is a minor gamma emitter, the Pu-241 is conservatively modeled as Am-241.

The gamma source computed using both sets of isotopics is provided in Table 5.2-11 on a per gram basis. Isotopic set #2 results in a larger gamma source, although the gamma source is small in either case. The gamma source for isotopic set #2 is used in the shielding calculations. The source is computed at time zero. For 1 g of Pu-239 (including impurities), the decay heat is 0.00307 watts.

The alpha radiation will lead to a neutron source when mixed with an (α,n) target nucleus, such beryllium. The neutron source is discussed in Section 5.2.2, *Neutron Source*.

Ir-192

Ir-192 is a beta/gamma emitter. There is an error in the SCALE6/ORIGEN-S data libraries for Ir-192 and SCALE6/ORIGEN-S cannot be used to determine the gamma source for this isotope. Therefore, for this isotope only, SCALE44/ORIGEN-S [4] is used to compute the gamma source term. The gamma source is provided in Table 5.2-12 for 1 Ci and is computed at time zero. For 1 Ci of Ir-192, the decay heat is 0.00615 watts.

Se-75

Se-75 is a beta/gamma emitter. The gamma source term is computed using ORIGEN-S and is provided in Table 5.2-13 for 1 Ci Se-75. The source term is computed at time zero. For 1 Ci of Se-75, the decay heat is 0.00241 watts.

Decay Heat per Ci or Gram

The maximum decay heat for each source is listed in the individual sections above. However, it is useful to summarize the maximum decay heat for each isotope per either Ci or gram to facilitate the scenario in which different source isotopes are combined in the same LTSS. These data are presented in Table 5.2-14.

5.2.2 Neutron Source

Neutron sources are generated by Ra-226, Am-241, Pu-238, and Pu-239. These sources are generated by both (α,n) reactions and spontaneous fission, although the spontaneous fission component is negligible compared to the (α,n) component for the nuclides under consideration. Target nuclides that result in an (α,n) source include oxygen, beryllium, and chlorine. The ORIGEN-S module of the SCALE6 code package is used to calculate the neutron sources. Quantities are input in grams rather than curies because the target nuclides are not radioactive.

Ra-226

Ra-226 sources exist either as a radium/beryllium mixture, or as radium with trace amounts of oxygen, carbon, sulfur, bromine, or chlorine (hydrous or anhydrous). Because the trace elements contain (α,n) target nuclides, it is conservatively assumed that the trace elements are present as compounds $RaSO_4$, $RaBr_2$, $RaCl_2$ + water, $RaCl_2$ (anhydrous), $RaCO_3$, or $RaSO_3$. The masses of the target elements are computed based on the chemical formulas provided. For $RaCl_2 + H_2O$, the H_2O mass is arbitrarily selected as five times the $RaCl_2$ mass, although adding water simply decreases the neutron source magnitude. For the Ra/beryllium mixture, an infinitely dilute mixture is conservatively assumed (infinite dilution is defined as a beryllium mass 1000 times greater than the Ra-226 mass). Bromine is not an (α,n) target isotope, so $RaBr_2$ does not generate neutrons.

The results for 1 Ci are summarized in Table 5.2-15. The maximum neutron source occurs for a decay time of 0.3 years. RaBe is by far the largest neutron source. Beryllium generates more neutrons than any other target material, and the infinite dilution assumption also increases the beryllium neutron source. Of the non-Be target compounds, $RaCl_2$ (anhydrous) has the largest neutron source. Therefore, $RaCl_2$ (anhydrous) is used to bound all non-Be targets, and RaBe is treated separately.

Am-241

Am-241 sources exist either as an americium/beryllium mixture, or as americium with trace amounts of oxygen or chlorine. Because the trace elements contain (α,n) target nuclides, it is conservatively assumed that the trace elements are present as compounds AmO_2 or AmCl. The masses of the target elements are computed based on the chemical formulas provided. For the Am/beryllium mixture, an infinitely dilute mixture is conservatively assumed (infinite dilution is defined as a beryllium mass 1000 times greater than the Am-241 mass).

The neutron sources are summarized in Table 5.2-16 for a 1 Ci source. The sources are computed at time zero. AmO_2 and AmCl result in similar neutron sources, while the AmBe source is orders of magnitude larger. AmCl may be used to bound AmO_2, and AmBe is treated separately.

Pu-238

Pu-238 sources exist as plutonium with a trace amount of oxygen. Because oxygen is an (α,n) target nuclide, it is conservatively assumed that the trace oxygen is present as the compound PuO_2. Although a Pu-238 source contains other isotopes of plutonium, the total plutonium mass is conservatively modeled as pure Pu-238 for the neutron source calculation to maximize the activity. The Pu-238 source is provided in Table 5.2-17 for 1 g Pu-238. The source is computed at time zero.

Pu-239

Pu-239 sources exist as either $PuBe_{13}$ or plutonium with a trace amount of oxygen. Because oxygen is an (α,n) target nuclide, it is conservatively assumed that the trace oxygen is present as the compound PuO_2. The plutonium contains impurities with half-lives much shorter than Pu-239, and the neutron source strength is sensitive to the impurity content. Therefore, two different plutonium isotopic sets are used, as listed in Table 5.2-10. Pu-239 sources are treated as either PuO_2 or $PuBe_{13}$. The neutron sources for PuO_2 and $PuBe_{13}$ for each of the two isotopic sets are presented in Table 5.2-18.

The Pu-241 impurity is a beta emitter and decays to Am-241, which is an alpha emitter. Therefore, the neutron source strength increases with time as the Am-241 concentration increases. To simplify the calculation, the Pu-241 impurity is conservatively input as Am-241, and the source is computed at time zero.

For both PuO_2 and $PuBe_{13}$, isotopic set #2 results in a more conservative neutron source than set #1 and is used in subsequent dose rate calculations. Because the $PuBe_{13}$ neutron source is significantly larger than the PuO_2 neutron source, these compounds are treated separately in subsequent dose rate calculations.

Table 5.2-1 – Allowable Source Nuclides

Nuclide	Radiation Type	435-B Limit
Co-60	Gamma	12,970 Ci
Cs-137	Gamma	14,000 Ci
Sr-90	Gamma	1,000 Ci
Ra-226 (no Be)	Neutron and Gamma	20 Ci
Ra-226Be	Neutron and Gamma	1.3 Ci
Am-241 (no Be)	Neutron and Gamma	1000 Ci
Am-241Be	Neutron and Gamma	6.6 Ci
Pu-238 (no Be)	Neutron and Gamma	75 g plutonium
Pu-239 (no Be)	Neutron and Gamma	15 g plutonium
Pu-239Be	Neutron and Gamma	15 g plutonium
Ir-192	Gamma	200 Ci
Se-75	Gamma	80 Ci

Table 5.2-2 – Gamma Source, 1 Ci Co-60

Line Energy (MeV)	Gamma Source (γ/s)
1.173	3.7E+10
1.322	3.7E+10

Table 5.2-3 – Gamma Source, 1 Ci Cs-137

Line Energy (MeV)	Gamma Source (γ/s)
0.662	3.145E+10

Table 5.2-4 – Gamma Source, 1 Ci Sr-90

E_{upper} (MeV)	Gamma Source (γ/s)
5.00E-02	1.603E+10
1.00E-01	5.603E+09
2.00E-01	3.909E+09
3.00E-01	1.282E+09
4.00E-01	9.361E+08
6.00E-01	6.294E+08
8.00E-01	2.853E+08
1.00E+00	1.218E+08
1.33E+00	7.182E+07
1.66E+00	1.359E+07
2.00E+00	2.438E+06
2.50E+00	1.252E+05
Total	2.888E+10

Table 5.2-5 – Gamma Source (γ/s), 1 Ci Ra-226

E_{upper} (MeV)	0.1 y	0.3 y	0.5 y	0.7 y	1.0 y	3.0 y	5.0 y	10.0 y
5.00E-02	1.430E+10	**1.439E+10**	1.446E+10	1.453E+10	1.463E+10	1.529E+10	1.591E+10	1.729E+10
1.00E-01	1.356E+10	**1.359E+10**	1.360E+10	1.360E+10	1.362E+10	1.371E+10	1.379E+10	1.396E+10
2.00E-01	4.267E+09	**4.277E+09**	4.283E+09	4.289E+09	4.298E+09	4.354E+09	4.407E+09	4.524E+09
3.00E-01	1.229E+10	**1.231E+10**	1.231E+10	1.231E+10	1.231E+10	1.232E+10	1.232E+10	1.233E+10
4.00E-01	1.483E+10	**1.485E+10**	1.485E+10	1.484E+10	1.484E+10	1.484E+10	1.484E+10	1.482E+10
6.00E-01	1.353E+09	**1.355E+09**	1.356E+09	1.356E+09	1.356E+09	1.359E+09	1.362E+09	1.367E+09
8.00E-01	1.874E+10	**1.877E+10**	1.876E+10	1.876E+10	1.876E+10	1.874E+10	1.873E+10	1.869E+10
1.00E+00	2.222E+09	**2.224E+09**	2.224E+09	2.224E+09	2.224E+09	2.222E+09	2.220E+09	2.216E+09
1.33E+00	9.685E+09	**9.695E+09**	9.695E+09	9.695E+09	9.690E+09	9.685E+09	9.675E+09	9.655E+09
1.66E+00	4.921E+09	**4.927E+09**	4.926E+09	4.926E+09	4.925E+09	4.921E+09	4.917E+09	4.906E+09
2.00E+00	8.210E+09	**8.220E+09**	8.220E+09	8.220E+09	8.220E+09	8.210E+09	8.205E+09	8.185E+09
2.50E+00	3.136E+09	**3.140E+09**	3.140E+09	3.140E+09	3.139E+09	3.137E+09	3.134E+09	3.127E+09
3.00E+00	4.949E+07	**4.955E+07**	4.955E+07	4.954E+07	4.954E+07	4.949E+07	4.945E+07	4.934E+07
4.00E+00	1.183E+07	**1.185E+07**	1.185E+07	1.185E+07	1.185E+07	1.184E+07	1.183E+07	1.180E+07
5.00E+00	6.715E+00	**6.720E+00**	6.725E+00	6.735E+00	6.745E+00	6.835E+00	6.920E+00	7.140E+00
6.50E+00	1.935E+00	**1.937E+00**	1.938E+00	1.940E+00	1.943E+00	1.969E+00	1.994E+00	2.057E+00
8.00E+00	2.461E-01	**2.464E-01**	2.465E-01	2.468E-01	2.472E-01	2.504E-01	2.536E-01	2.616E-01
1.00E+01	3.284E-02	**3.288E-02**	3.290E-02	3.293E-02	3.299E-02	3.342E-02	3.385E-02	3.491E-02
Total	1.076E+11	**1.078E+11**	1.081E+11	1.089E+11	1.096E+11	1.099E+11	1.102E+11	1.106E+11

Table 5.2-6 – Representative Radionuclide Distribution for Am-241 Sealed Sources

Nuclide	Grams per Gram of Source Material
Am-241	9.97E-01
Pu-238	2.05E-06
Pu-239	2.75E-03
Pu-240	5.55E-04
Pu-241	3.97E-05
Pu-242	1.19E-05
U-234	1.14E-11
U-235	1.43E-09
U-238	5.71E-07
Cs-137	7.78E-10
Sr-90	4.46E-10

Table 5.2-7 – Gamma Source, 1 Ci Am-241

E_{upper} (MeV)	Gamma Source (γ/s)
5.00E-02	8.740E+09
1.00E-01	1.056E+10
2.00E-01	7.342E+06
3.00E-01	2.863E+05
4.00E-01	4.595E+05
6.00E-01	3.389E+04
8.00E-01	2.707E+05
1.00E+00	2.393E+03
1.33E+00	9.774E+01
1.66E+00	2.215E-35
2.00E+00	3.447E+01
2.50E+00	1.809E+01
3.00E+00	9.079E+00
4.00E+00	6.683E+00
5.00E+00	1.694E+00
6.50E+00	4.896E-01
8.00E+00	6.264E-02
1.00E+01	8.444E-03
Total	1.931E+10

Table 5.2-8 – Representative Radionuclide Distribution for Pu-238 Sealed Sources

Nuclide	Grams per Gram of Plutonium
Pu-238	8.03E-01
Pu-239	1.61E-01
Pu-240	2.63E-02
Pu-241	6.90E-03
Pu-242	2.33E-03
Am-241	2.84E-04
U-234	3.40E-09
U-235	4.25E-07
U-238	1.70E-04
Cs-137	2.31E-07
Sr-90	1.33E-07

Table 5.2-9 – Gamma Source, 1 g Pu-238

E_{upper} (MeV)	Gamma Source (γ/s)
5.00E-02	3.984E+10
1.00E-01	3.231E+07
2.00E-01	2.179E+07
3.00E-01	2.193E+04
4.00E-01	1.896E+02
6.00E-01	2.589E-03
8.00E-01	3.271E+05
1.00E+00	4.328E+04
1.33E+00	9.917E+03
1.66E+00	1.419E-13
2.00E+00	1.679E+03
2.50E+00	9.696E+02
3.00E+00	5.381E+02
4.00E+00	4.583E+02
5.00E+00	1.451E+02
6.50E+00	5.499E+01
8.00E+00	1.022E+01
1.00E+01	2.087E+00
Total	3.989E+10

Table 5.2-10 – Representative Radionuclide Distribution for Pu-239 Sealed Sources

Nuclide	Isotopic Set #1, Based on [5], Grams per Gram of Plutonium	Isotopic Set #2, Based on [6], Grams per Gram of Plutonium
Pu-238	1.48E-04	1.50E-04
Pu-239	9.32E-01	9.26E-01
Pu-240	6.50E-02	6.75E-02
Pu-241①	2.44E-03	6.20E-03
Pu-242	3.62E-04	3.30E-04
Am-241	2.84E-04	2.50E-04
U-234	3.40E-09	-
U-235	4.25E-07	-
U-238	1.70E-04	-
Cs-137	2.31E-07	-
Sr-90	1.33E-07	-

①Modeled as Am-241 in ORIGEN-S.

Table 5.2-11 – Gamma Source, 1 g Pu-239 (includes impurities)

E_{upper} (MeV)	Isotopic Set #1 Gamma Source (γ/s)	Isotopic Set #2 Gamma Source (γ/s)
5.00E-02	1.705E+08	**2.831E+08**
1.00E-01	9.933E+07	**2.343E+08**
2.00E-01	2.989E+05	**3.925E+05**
3.00E-01	1.764E+04	**2.120E+04**
4.00E-01	9.993E+04	**1.051E+05**
6.00E-01	3.337E+04	**3.357E+04**
8.00E-01	4.559E+03	**8.013E+03**
1.00E+00	5.455E+01	**8.520E+01**
1.33E+00	7.580E+01	**7.933E+01**
1.66E+00	1.961E-13	**1.787E-13**
2.00E+00	3.151E+01	**3.295E+01**
2.50E+00	1.887E+01	**1.971E+01**
3.00E+00	1.083E+01	**1.129E+01**
4.00E+00	9.600E+00	**1.000E+01**
5.00E+00	3.195E+00	**3.322E+00**
6.50E+00	1.266E+00	**1.315E+00**
8.00E+00	2.456E-01	**2.547E-01**
1.00E+01	5.175E-02	**5.363E-02**
Total	2.703E+08	**5.179E+08**

Table 5.2-12 – Gamma Source, 1 Ci Ir-192

E_{upper} (MeV)	Gamma Source (γ/s)
5.00E-02	1.994E+09
1.00E-01	3.602E+09
2.00E-01	3.023E+08
3.00E-01	1.271E+10
4.00E-01	3.736E+10
6.00E-01	2.055E+10
8.00E-01	3.031E+09
1.00E+00	1.095E+08
1.33E+00	1.926E+07
1.66E+00	4.233E+05
Total	7.969E+10

Table 5.2-13 – Gamma Source, 1 Ci Se-75

E_{upper} (MeV)	Gamma Source (γ/s)
5.00E-02	7.414E+09
1.00E-01	2.034E+09
2.00E-01	2.530E+10
3.00E-01	3.375E+10
4.00E-01	2.878E+09
6.00E-01	1.729E+09
8.00E-01	1.196E+06
1.00E+00	5.585E+04
Total	7.310E+10

Table 5.2-14 – Decay Heat per Ci or Gram

Isotope	Decay Heat	Unit
Co-60	1.5420E-02	Watts/Ci
Cs-137	5.0400E-03	Watts/Ci
Sr-90	6.6980E-03	Watts/Ci
Ra-226	1.8620E-01	Watts/Ci
Am-241	3.3370E-02	Watts/Ci
Pu-238	5.6773E-01	Watts/g
Pu-239	3.0873E-03	Watts/g
Ir-192	6.1500E-03	Watts/Ci
Se-75	2.4100E-03	Watts/Ci

Table 5.2-15 – Ra-226 Neutron Sources, 1 Ci Ra-226

Neutron Sources (n/s)						
E_{upper} (MeV)	$RaSO_4$	$RaSO_3$	$RaCl_2$	$RaCl_2+H_2O$	$RaCO_3$	RaBe
1.30E-06	9.865E-09	8.180E-09	**0.000E+00**	1.742E-08	9.015E-09	**0.000E+00**
1.86E-06	8.485E-07	7.040E-07	**0.000E+00**	1.498E-06	7.755E-07	**0.000E+00**
3.06E-06	1.839E-06	1.525E-06	**7.775E-06**	3.773E-06	1.681E-06	**0.000E+00**
1.07E-05	1.513E-05	1.255E-05	**1.400E-04**	3.609E-05	1.383E-05	**0.000E+00**
2.90E-05	1.094E-04	9.080E-05	**7.920E-04**	2.452E-04	1.769E-04	**0.000E+00**
1.01E-04	5.130E-04	4.259E-04	**4.651E-03**	1.212E-03	8.770E-04	**0.000E+00**
5.83E-04	6.440E-03	5.345E-03	**7.085E-02**	1.608E-02	1.528E-02	**0.000E+00**
3.04E-03	8.895E-02	7.385E-02	**8.715E-01**	2.147E-01	1.903E-01	**8.645E-01**
1.50E-02	1.058E+00	8.780E-01	**9.855E+00**	2.518E+00	2.137E+00	**4.925E+01**
1.11E-01	2.353E+01	1.953E+01	**3.207E+02**	6.280E+01	4.392E+01	**2.243E+03**
4.08E-01	1.168E+02	9.695E+01	**2.676E+03**	3.852E+02	2.193E+02	**3.164E+04**
9.07E-01	2.344E+02	1.945E+02	**9.215E+03**	1.034E+03	3.655E+02	**2.966E+05**
1.42E+00	3.638E+02	3.022E+02	**1.024E+04**	1.329E+03	3.947E+02	**4.062E+05**
1.83E+00	4.596E+02	3.819E+02	**5.675E+03**	1.186E+03	4.280E+02	**2.484E+05**
3.01E+00	2.224E+03	1.847E+03	**2.197E+03**	4.041E+03	2.040E+03	**1.395E+06**
6.38E+00	1.605E+03	1.331E+03	**0.000E+00**	2.832E+03	2.820E+03	**6.640E+06**
2.00E+01	3.004E-01	2.489E-01	**0.000E+00**	5.340E-01	3.805E+02	**4.720E+06**
Total	5.030E+03	4.174E+03	**3.034E+04**	1.087E+04	6.695E+03	**1.374E+07**

Table 5.2-16 – Am-241 Neutron Sources, 1 Ci Am-241

Neutron Sources (n/s)			
E_{upper} (MeV)	AmO_2	AmCl	AmBe
1.30E-06	3.953E-11	**3.953E-11**	**3.953E-11**
1.86E-06	1.426E-10	**1.426E-10**	**1.426E-10**
3.06E-06	3.831E-10	**3.831E-10**	**3.831E-10**
1.07E-05	3.985E-09	**3.985E-09**	**3.985E-09**
2.90E-05	1.635E-08	**1.635E-08**	**1.635E-08**
1.01E-04	1.678E-04	**2.319E-04**	**1.161E-07**
5.83E-04	1.741E-03	**1.040E-02**	**1.755E-06**
3.04E-03	1.723E-02	**1.065E-01**	**6.515E-02**
1.50E-02	2.166E-01	**1.449E+00**	**3.304E+00**
1.11E-01	4.277E+00	**5.799E+01**	**1.470E+02**
4.08E-01	2.018E+01	**3.039E+02**	**5.816E+03**
9.07E-01	4.156E+01	**1.031E+03**	**7.359E+04**
1.42E+00	5.809E+01	**4.599E+02**	**1.002E+05**
1.83E+00	7.920E+01	**4.072E-02**	**5.915E+04**
3.01E+00	4.075E+02	**8.694E-02**	**3.323E+05**
6.38E+00	2.036E+02	**7.866E-02**	**1.497E+06**
2.00E+01	8.728E-03	**8.728E-03**	**8.535E+05**
Total	8.146E+02	**1.854E+03**	**2.922E+06**

Table 5.2-17 – Pu-238 Neutron Source, 1 g Pu-238

E_{upper} (MeV)	Neutron Source (n/s)
1.30E-06	3.009E-07
1.86E-06	1.088E-06
3.06E-06	2.935E-06
1.07E-05	3.065E-05
2.90E-05	1.259E-04
1.01E-04	2.171E-03
5.83E-04	3.891E-02
3.04E-03	4.687E-01
1.50E-02	5.487E+00
1.11E-01	1.102E+02
4.08E-01	5.507E+02
9.07E-01	1.164E+03
1.42E+00	1.485E+03
1.83E+00	1.687E+03
3.01E+00	7.677E+03
6.38E+00	4.063E+03
2.00E+01	4.440E+01
Total	1.679E+04

Table 5.2-18 – Pu-239 Neutron Sources, 1 g Pu-239 (including impurities)

	Neutron Sources (n/s)			
E_{upper} (MeV)	Isotopic Set #1 PuO_2	Isotopic Set #2 PuO_2	Isotopic Set #1 PuBe	Isotopic Set #2 PuBe
1.30E-06	2.467E-08	**2.485E-08**	8.267E-09	**8.553E-09**
1.86E-06	8.213E-08	**8.280E-08**	2.998E-08	**3.102E-08**
3.06E-06	1.941E-07	**1.961E-07**	8.107E-08	**8.387E-08**
1.07E-05	1.564E-06	**1.589E-06**	8.493E-07	**8.787E-07**
2.90E-05	5.215E-06	**5.325E-06**	3.493E-06	**3.614E-06**
1.01E-04	3.455E-05	**3.752E-05**	2.483E-05	**2.569E-05**
5.83E-04	4.706E-04	**5.061E-04**	3.755E-04	**3.885E-04**
3.04E-03	5.469E-03	**5.846E-03**	7.580E-03	**8.267E-03**
1.50E-02	6.155E-02	**6.603E-02**	2.260E-01	**2.548E-01**
1.11E-01	1.290E+00	**1.379E+00**	8.860E+00	**1.010E+01**
4.08E-01	7.207E+00	**7.660E+00**	3.141E+02	**3.617E+02**
9.07E-01	1.465E+01	**1.561E+01**	3.801E+03	**4.398E+03**
1.42E+00	1.626E+01	**1.744E+01**	4.684E+03	**5.493E+03**
1.83E+00	1.428E+01	**1.559E+01**	2.649E+03	**3.127E+03**
3.01E+00	4.755E+01	**5.343E+01**	1.685E+04	**1.957E+04**
6.38E+00	2.339E+01	**2.647E+01**	6.311E+04	**7.520E+04**
2.00E+01	9.047E-01	**9.360E-01**	3.687E+04	**4.378E+04**
Total	1.256E+02	**1.386E+02**	1.283E+05	**1.519E+05**

5.3 Shielding Model

5.3.1 Configuration of Source and Shielding

Models of the 435-B package and contents are developed in the MCNP5 computer program [2] for all allowable configurations of source and shielding. The objective is to determine the source activity for each nuclide within an LTSS that results in dose rates near the regulatory limit. Once these activity limits are known, the dose rate for any combination of different isotopes may be conservatively estimated using a sum of fractions rule. The details of the individual calculations and development of the sum of fractions rule is presented in Section 5.4, *Shielding Evaluation*. This section presents the geometry of the source and shielding that is common to the various models.

The LTSS is transported inside the LTSS lodgment, which is situated inside the 435-B cavity. The LTSS lodgment is not modeled explicitly in MCNP because it offers little axial or radial shielding, although credit is taken for the LTSS lodgment for axial placement of the LTSS within the package. The bottom of the LTSS is placed 8.5-in from the bottom of the package (8.0-in lodgment bottom piece plus 0.5-in lodgment support plate; the 0.5-in rubber pad is neglected). The 435-B is artificially shortened in the MCNP models so that the distance from the top of the LTSS to the inner top of the 435-B is 17.3-in (16.8-in for lodgment top piece plus 0.5-in lodgment top plate). Therefore, the LTSS is simultaneously modeled at both the bottom and top of the package, and no models are required in which the LTSS shifts axially.

The LTSS lodgment is transported inside the 435-B package. Key dimensions used in the MCNP model are listed in Table 5.3-1, and the model geometry is shown in Figure 5.3-1. As noted in the previous paragraph, the height of the 435-B is intentionally reduced in the model compared to the actual value. This is achieved by reducing the cavity length. The upper and lower internal impact limiters are conservatively modeled as void, although credit is taken for the 0.5-in impact limiter aluminum plates that form the top and bottom of the cavity. The outer shell of the package is stainless steel and includes the thermal shield below the torispherical head (the thermal shield on the torispherical head is neglected). Polyurethane foam fills the external impact limiter. Details of the flanges that connect the upper and lower package assemblies are conservatively ignored and modeled as foam.

The LTSS is the primary shield and is dimensioned on Figure 5.3-2. The key dimensions used to develop the LTSS models are listed in Table 5.3-2, and the model geometry is shown in Figure 5.3-3. The LTSS drawer barrel contains four recesses, and drawers containing sources are inserted into each recess. The drawer barrel rotates to facilitate source loading and is located inside the liner tube weldment. Steel cover plates are located on each end of the liner tube weldment. The ends of the liner tube weldment are covered with lead-shielded flanges. The LTSS also has thick lead shielding on the side between the liner tube and outer shell. The radial lead thickness is conservatively reduced by 7 mm to account for tolerances. The lead thickness in the shielded flange (both upper and lower) is conservatively reduced by the index cap penetration depth of 10 mm. This reduction is conservative because the index cap would be associated with only one drawer. Also, the index plate and index pivot plates contain a hole associated with only one drawer, although this hole is modeled with each drawer to maintain model symmetry. These modeling assumptions result in conservative dose rates.

The LTSS has two basic configurations: Large source drawers (LDs) and the T80/T780 drawer. The LD and T80/T780 drawer shall not be mixed within the same LTSS.

LD Configuration: Each of the four LTSS recesses shall be filled with either an LD or a shield drawer (no empty recesses). A shield drawer is a large source drawer body nominally filled with a tungsten shield plug. Five different LDs are available to accommodate the various sources. In general, the different LDs cannot be mixed within an LTSS because they do not provide equivalent shielding. The allowed combinations of LDs are defined in Table 5.3-3. For any of the allowed combinations, an LD may be replaced with a shield drawer because a shield drawer is more heavily shielded than an LD.

There are five LDs of various tungsten shielding lengths (LD-74, -150, -200, -250, and -325) and five NLM 52s special form capsules of various lengths to fit within the LDs (NLM 52-74, -150, -200, -250, and -325). Other special form or non-special form capsules may be used that have the same length, diameter, and at least as much radiation attenuation as the NLM-52 capsule series, although the NLM 52 nomenclature is used in the following discussion for convenience. The sources are located inside the NLM 52 special form capsules, and only one source nuclide type is allowed per NLM 52. In most cases, one NLM 52 is transported per LD, although two NLM 52-74s may be transported inside an LD-150.

Co-60 and Cs-137 may be either short cylinder (point) or pencil (line) sources, while the remaining source nuclides are point sources. Only point sources are allowed in the NLM 52-74, and only line sources are allowed in the NLM 52-250 and -325. The NLM 52-150 and -200 may contain either point or line sources. The allowable combinations of LDs, NLM 52s, and source types are summarized in Table 5.3-4.

MCNP models are developed for all allowable combinations of LDs and source nuclides. Each MCNP model contains either 1 Ci (or 1 g) of source nuclide in a single LD, while the three remaining LDs are modeled without sources. No credit is taken for self-shielding of the source or encapsulation material. Point sources are modeled as a sphere of radius 1 mm (to aid in visualization), and line sources are modeled as a cylinder of radius 1 mm with the lengths provided in Table 5.3-4.

Models are developed for different source locations within the capsules to maximize the dose rates due to streaming effects. Eight (x,y) source locations are utilized, as shown on Figure 5.3-4. The sources are placed either at the top or bottom of the capsule to maximize the dose rate through the ends of the LTSS. The source placement for the NLM 52-74 capsule is shown in Figure 5.3-5 for Location 1 at the top of the capsule.

Dimensions for the five NLM 52 capsules are provided in Table 5.3-5. The model geometry of a representative NLM 52 capsule is shown in Figure 5.3-6.

The LD features tungsten shielding at the ends. Dimensions of the LD and tungsten inserts are provided in Table 5.3-6. Small deviations of actual and as-modeled dimensions are noted in Table 5.3-6. These differences are small and may be neglected. The model geometry of a representative LD is shown in Figure 5.3-6.

T80/T780 Configuration: Each of the four LTSS recesses shall be filled with either a T80/T780 drawer or a shield drawer (no empty recesses). A shield drawer is a drawer body nominally filled with a tungsten shield plug. The T80/T780 contains a Co-60 point source with a maximum activity of 12,970 Ci. No other sources are authorized for this drawer. The dimensions of the

T80/T780 drawer are shown in Figure 5.3-7 and are determined by physically cutting a drawer in half and measuring the dimensions. The MCNP model geometry of the T80/T780 is consistent with this figure.

The T80 and T780 drawers are physically identical. Like the large source drawer, they are 21.5-in long and 2.5-in in diameter. In the center is a 1.1-in diameter cross-drilled hole that accepts a source capsule. The drawers are made of brass with a wall thickness of 0.2-in and a stainless steel end thickness of 0.8-in. For the T80 drawer, the shielding on each side of the source is 9.2-in of lead. For the T780 drawer, the shielding may be either lead, tungsten, or depleted uranium, although this shielding is conservatively modeled as lead in MCNP.

5.3.2 Material Properties

Type 304 stainless steel with a density of 7.94 g/cm^3 is used for the 435-B shell, LTSS structural members, LD structure, and NLM 52 capsules. The Type 304 composition is provided in Table 5.3-7 and is obtained from the SCALE6 User's Manual [3].

Tungsten with a density of 17 g/cm^3 is used as a shield material in the LD. It is modeled as pure.

Lead with a density of 11.35 g/cm^3 is used as a shield material in the LTSS. It is modeled as pure.

Polyurethane foam with a density of 14 pounds per cubic foot (pcf) (0.224 g/cm^3) is modeled in the lower assembly of the 435-B. This bounds the actual density of 15 pcf. The foam composition utilized is provided in Table 5.3-8.

Aluminum with a density of 2.7 g/cm^3 is used in the 435-B internal impact limiter plates that form the top and bottom of the 435-B cavity. It is modeled as pure.

The T80/T780 drawer is similar to an LD, although the primary shielding material is lead rather than tungsten. The T80/T780 drawer tube is modeled as brass with a density of 8.07 g/cm^3, and the composition of brass is provided in Table 5.3-9 [7].

Table 5.3-1 – Key 435-B Dimensions

Component	Actual Dimension (in)	As-Modeled Dimension (in)
Shell inner diameter	43.5	Same
Shell thickness	0.5	Same
Side thermal shield thickness	0.165 (=0.06+0.105)	Same
Upper/Lower head thickness	0.5	Same
Upper/Lower head height	~9.0	Same
Cavity height	60.3	58.99
Overall package height	83.2	81.59
Upper/Lower internal impact limiter plate thickness	0.5	Same
Impact limiter outer diameter	70	Same
Impact limiter shell thickness	0.25	Same

Table 5.3-2 – Key LTSS Dimensions

Component	Actual Dimension (mm)	As-Modeled Dimension (mm)
Side lead thickness (max)	244 (=678/2-190/2)	237
Shielded flange lead thickness	85.8	76
Shielded flange lead outer diameter	216	Same
Shielded flange insert thickness	10	Same
Shielded flange thickness	32	Same
Side shell thickness	6	Same
Drawer inner diameter	64	Same
Drawer barrel outer diameter	169.75	Same
Liner tube outer diameter	190	Same
Liner tube inner diameter	171	Same
Liner tube assembly flange outer diameter	330	Same
Liner tube assembly flange thickness	74 (=19+55)	Same
Index pivot and pivot plate thickness	20	Same
Index pivot and pivot plate hole diameter	64	Same
Index pivot and pivot cover plate thickness	18	Same

Table 5.3-3 – Allowable LD Configurations

Configuration①	Recess 1	Recess 2	Recess 3	Recess 4
A	LD-74	LD-74	LD-74	LD-74
B	LD-150	LD-150	LD-150	LD-150
C	LD-200	LD-200	LD-200	LD-200
D	LD-250	LD-250	LD-250	LD-250
E	LD-325	LD-325	LD-325	LD-325
AB	LD-74	LD-150	LD-150	LD-150
BC	LD-150	LD-150	LD-200	LD-200
BD	LD-250	LD-150	LD-150	LD-150

①Any number of LDs may be replaced with a shield drawer.

Table 5.3-4 – Authorized Payload Special Form Capsule Sources and Nuclides

Drawer Model	Special Form Capsule Model	Authorized Source Geometry and Dimensions	Authorized Nuclides
LD-74	NLM 52-74	Point source	All nuclides in Table 5.2-1
LD-150	NLM 52-150	Point source	All nuclides in Table 5.2-1
		Line source, length ≥ 60 mm	Co-60 and Cs-137
LD-150	Two (2) NLM 52-74s	Point source	All nuclides in Table 5.2-1
LD-200	NLM 52-200	Point source	All nuclides in Table 5.2-1
		Line source, length ≥ 136 mm	Co-60 and Cs-137
LD-250	NLM 52-250	Line source, length ≥ 186 mm	Co-60 and Cs-137
LD-325	NLM 52-325	Line source, length ≥ 236 mm	Co-60 and Cs-137

Table 5.3-5 – NLM 52 Special Form Capsule Dimensions

Component	Actual Dimension (mm)	As-Modeled Dimension (mm)
Cylinder length NLM 52-74	74	Same
Cylinder length NLM 52-150	150	Same
Cylinder length NLM 52-200	200	Same
Cylinder length NLM 52-250	250	Same
Cylinder length NLM 52-325	325	Same
Outer diameter	52	Same
Inner diameter	47.3	Same
End cap thickness	8	Same

Table 5.3-6 – Large Source Drawer Dimensions

Component	Actual Dimension (mm)	As-Modeled Dimension (mm)
Tungsten length LD-74	214	Same
Tungsten length LD-150	176	Same
Tungsten length LD-200	151	Same
Tungsten length LD-250	126	Same
Tungsten length LD-325	88.5	Same
Tungsten outer diameter	51.85	53
Overall drawer length	547.80	548
Top end thickness	20	Same
Bottom end thickness	19.62 (=547.80-528.18)	20
Outer diameter	62.94	63
Inner diameter	54 (max)	53

Table 5.3-7 – SS304 Composition

Component	Wt.%
C	0.08
Si	1.0
P	0.045
Cr	19.0
Mn	2.0
Fe	68.375
Ni	9.5
Density = 7.94 g/cm^3	

Table 5.3-8 – Foam Composition

Component	Wt.%
C	60
O	24
N	12
H	4
Density = 0.224 g/cm^3	

Table 5.3-9 – Brass Composition

Component	Wt.%
Fe	0.0868
Cu	66.5381
Zn	32.5697
Sn	0.2672
Pb	0.5377
Density = 8.07 g/cm^3	

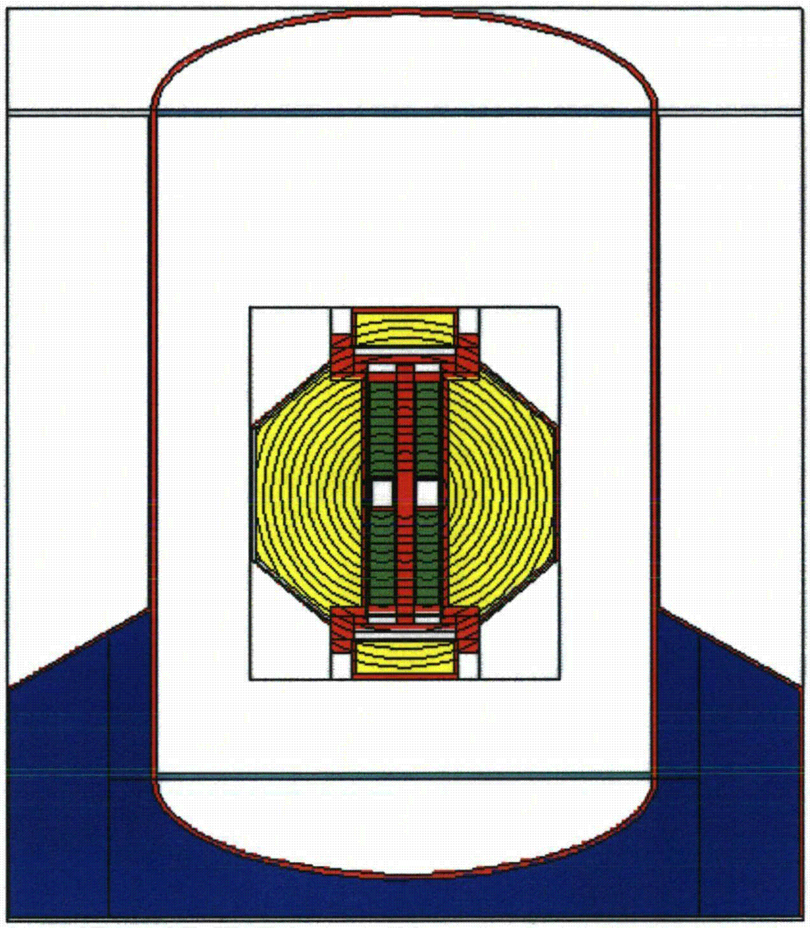


Figure 5.3-1 – 435-B with LTSS

Security Related Information
Figure Withheld Under 10 CFR 2.390

Dimensions are in mm.

Figure 5.3-2 – LTSS Dimensions

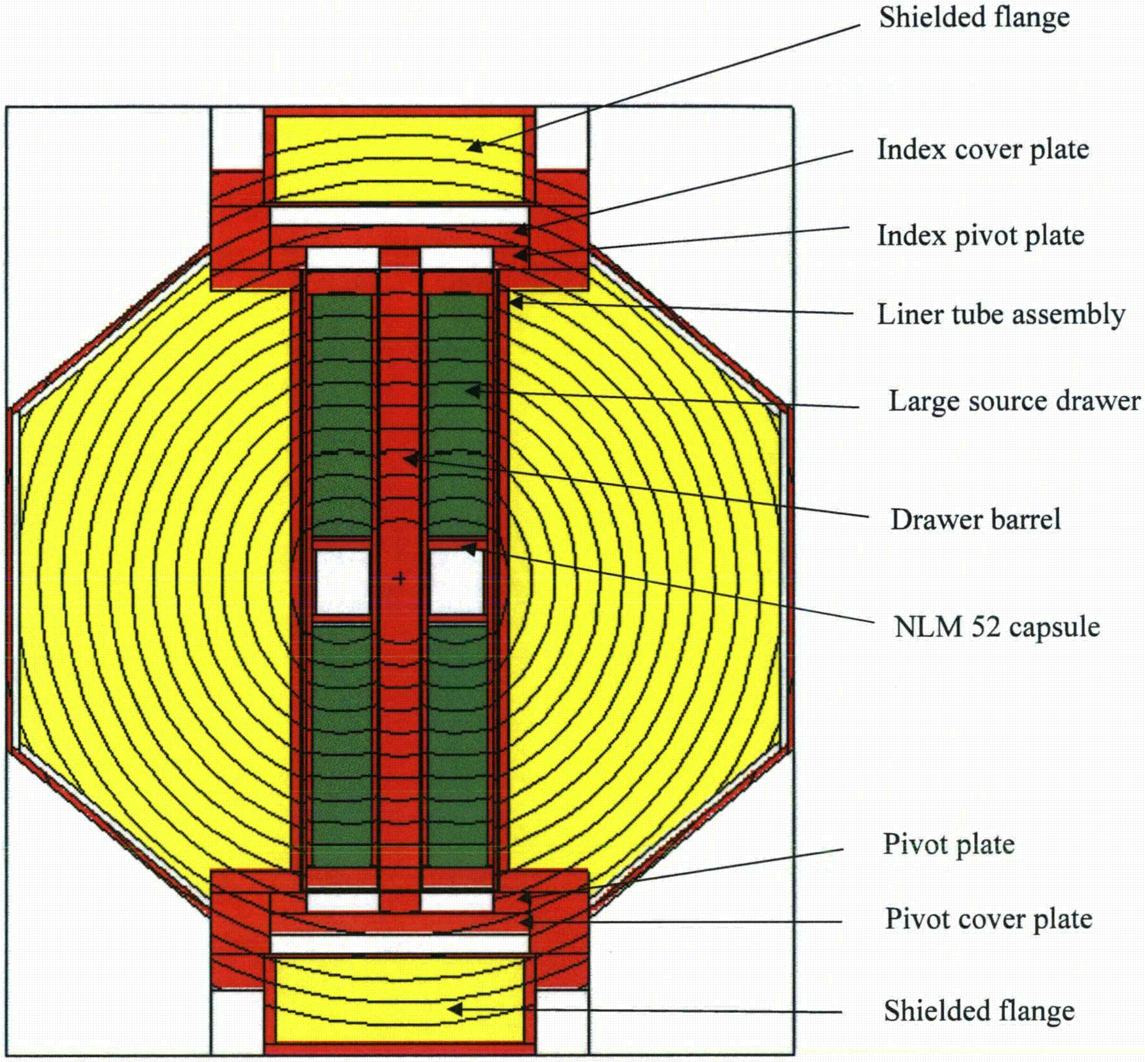


Figure 5.3-3 – LTSS with LD-74/NLM 52-74

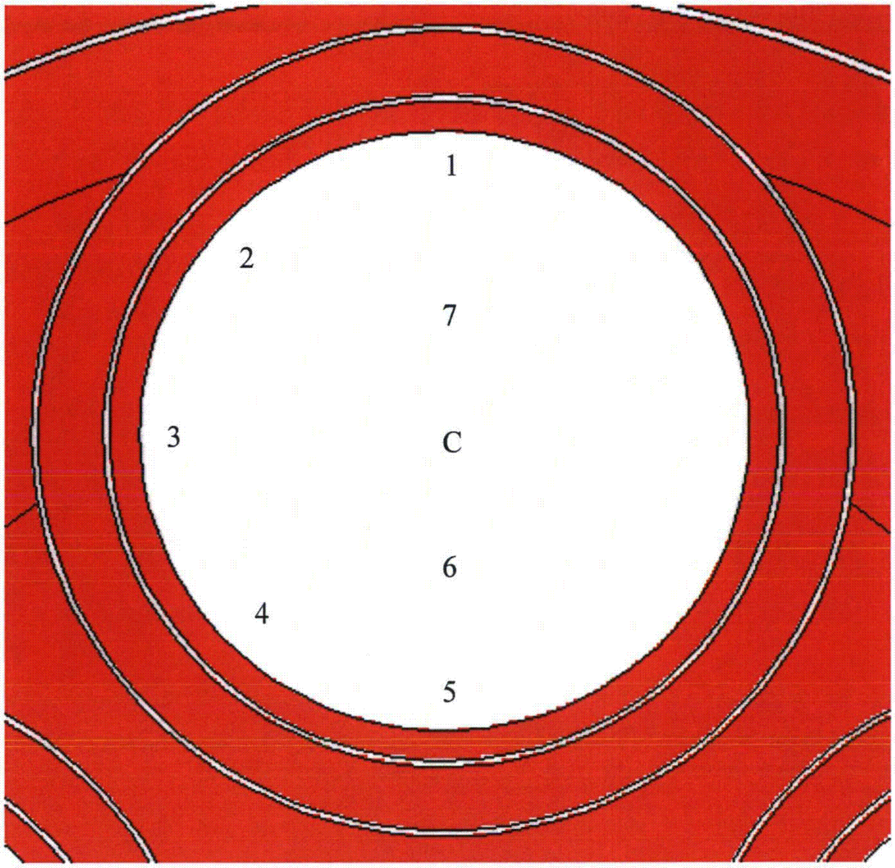


Figure 5.3-4 – Source Locations (x,y)

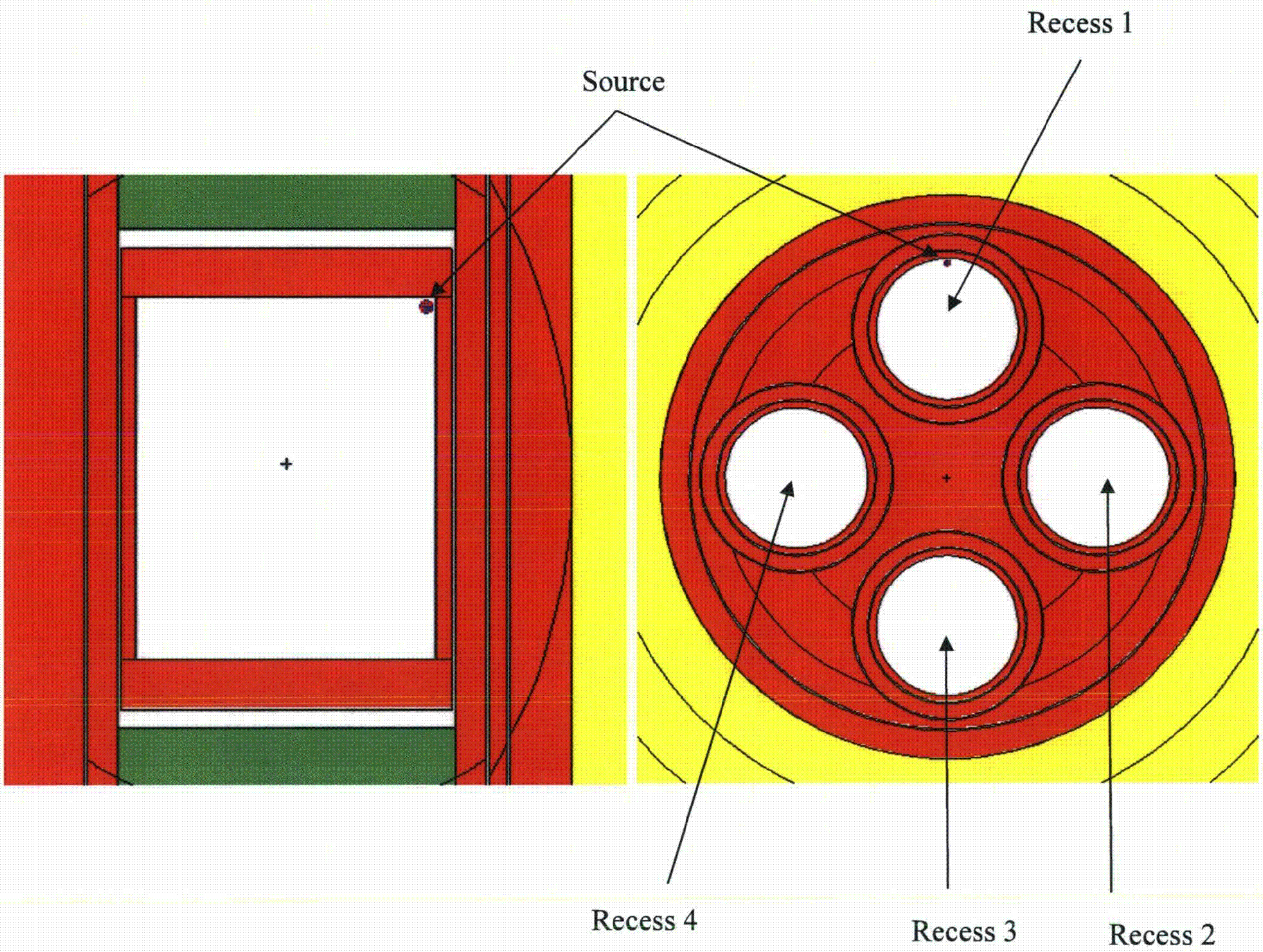


Figure 5.3-5 – Point Source in NLM 52-74 Capsule, Location 1, Top

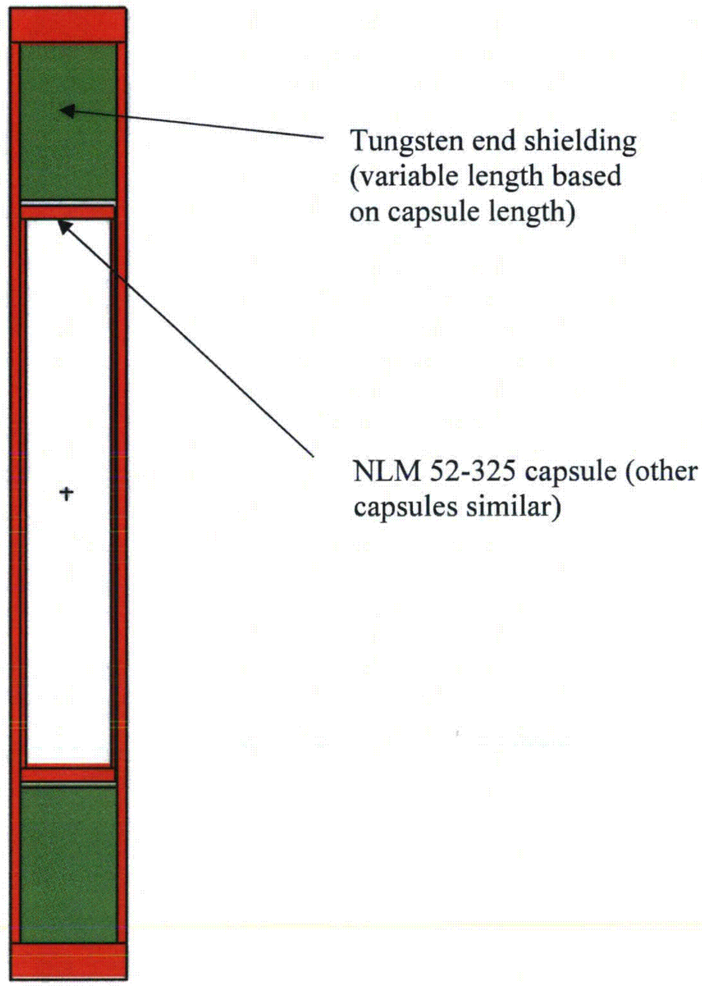
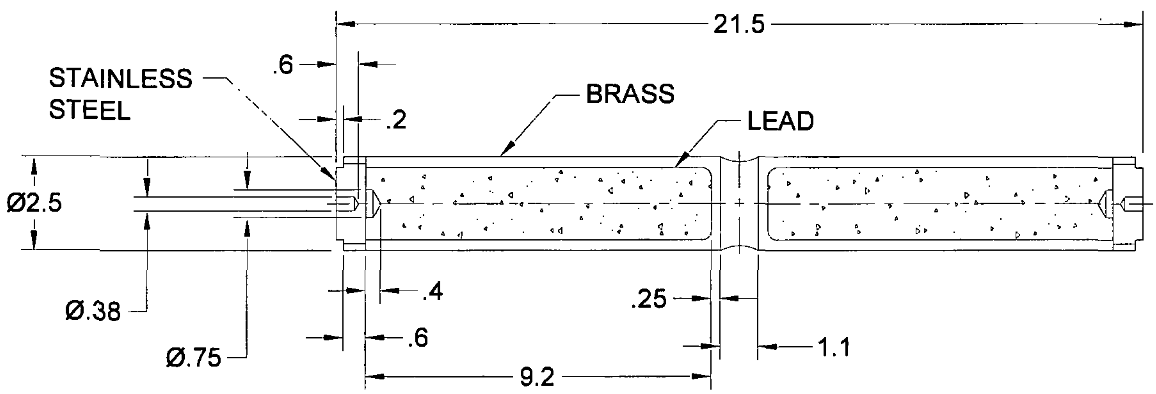


Figure 5.3-6 – Large Source Drawer with NLM 52-325 Capsule



Dimensions are in inches

Figure 5.3-7 – T80/T780 Drawer

5.4 Shielding Evaluation

5.4.1 Methods

MCNP5 v1.51 is used for the shielding analysis [2]. MCNP5 is a standard, well-accepted shielding program utilized to compute dose rates for shielding evaluations. A three-dimensional model is developed that captures all of the relevant design parameters of the 435-B package and contents. Dose rates are calculated by tallying the neutron and gamma fluxes over volumes of interest and converting these fluxes to dose rates.

In an actual LD shipping configuration, the LTSS may contain a different source isotope in each of the four recesses. For example, recess 1 could contain Co-60, recess 2 could contain Cs-137, recess 3 could contain Sr-90, and recess 4 could contain AmBe. Because an unlimited combination of sources and source activities within an LTSS is possible, it is not feasible to directly compute dose rates for all possible LTSS loading scenarios. Rather, a simplified approach is used in which each MCNP model is conservatively reduced to a single isotope in a single recess. The source is modeled with a strength of 1 Ci (or 1 g for the plutonium sources), and the dose rate is computed on the surface and 1 m from the surface of the 435-B.

Once the maximum dose rates from a 1 Ci source are known, the source activity is determined for each nuclide that results in dose rates near the regulatory limits. For non-exclusive use transportation, the dose rate is limited to 200 mrem/hr on the surface of the package and 10 mrem/hr at a distance of 1 m from the surface of the package. These limits are conservatively reduced to 190 mrem/hr and 9.5 mrem/hr at the surface and 1 m, respectively. The activities $A_{surface}$ and A_{1m} that result in dose rates near the regulatory limits are then:

$$A_{surface} = 190/D_{max\ surface}$$

$$A_{1m} = 9.5/D_{max\ 1m}$$

where $D_{max\ surface}$ is the maximum surface dose rate for a 1 Ci source, and $D_{max\ 1m}$ is the maximum 1 m dose rate for a 1 Ci source. The activity limit A_i for isotope *i* is then the lesser of $A_{surface}$ and A_{1m}. For the 435-B, A_{1m} always bounds $A_{surface}$. In many cases A_i violates heat load limits or administrative activity limits for the package. Therefore, the A_i value is simply a theoretical activity limit based *only* on shielding requirements.

A_i values are computed for each isotope in each of the allowed configurations of LD and source type, as defined in Table 5.3-3 and Table 5.3-4. Once the A_i values are known, the maximum possible dose rate for any arbitrary combination of nuclides in the LTSS may be determined by using a sum of fractions rule. Using a sum of fractions rule, the total dose rate may be estimated as the sum of the dose rate contribution from each individual source.

As a simple example, if A_i = 5,000 Ci results in a 1 m dose rate of 9.5 mrem/hr, then if 1,000 Ci of this isotope is present in each of the four recesses, the maximum total 1 m sum of fractions is 1000/5000*4 = 0.8, or a dose rate of (0.8)(9.5) = 7.6 mrem/hr. *This 7.6 mrem/hr dose rate is conservative because the result is mathematically equivalent to placing all of the sources in the same LD, which is not possible.* In reality, each of the four sources would be in a different LD and a different recess, and the true maximum would be less than 7.6 mrem/hr at 1 m because the maximum dose rate from each source would not typically be at the same (x,y,z) location in space. Therefore, the sum of fractions method is inherently conservative.

The approach taken is to model each source isotope as a single point (or line, as applicable) in an LD. Also, models are developed with the sources in different locations within an NLM 52 to find the maximum dose rate, as the dose rate is sensitive to streaming effects for the gamma emitters. Mesh tallies are placed at the top, bottom, and side surfaces of the 435-B, as well as 1 m from these surfaces. Because the top surface of the 435-B is curved and the mesh tally is flat, the top surface mesh tally is placed as close to the top of the package as possible. The 1 m top tally is located 1 m from the axial center of the 9-in head (i.e., the axial center of the head is approximately 4.5-in below the top of the head) to bring this dose location closer to the package surface, as the 1 m top dose rate is often limiting. The bottom mesh tally is at the bottom surface of the impact limiter, and the 1 m bottom tally is located 1 m from this surface. The top and bottom mesh tallies are rectangular 32x32 grids, with mesh dimensions of 10 cm x 10 cm. Therefore, the top and bottom mesh tallies extend approximately 1 m from the side surface of the side thermal shield.

The side cylindrical mesh tally is located next to the side thermal shield. The dose rates beside the impact limiter surface are not tallied with a mesh because the dose rate will be lower here due to the larger distance from the source. The side surface mesh tally begins at the bottom of the side thermal shield and extends upward 140 cm axially in 10 cm increments. The mesh 1 m from the package side is located 0.95 m from the surface of the side thermal shield, and is conservatively brought 0.05 m closer to the package surface to account for potential non-concentricity of the package internals. The mesh tally 1 m from the side of the package begins 1 m below the bottom of the package and extends axially approximately 1 m above the top of the package in 10 cm increments. The side surface mesh tallies have 36 angular segments to capture the circumferential variation of the dose rate, since the dose rate is higher at the side of the package nearest where the source is placed.

For the neutron emitters, secondary gammas are not computed because there is no hydrogenous neutron shielding material that would lead to significant secondary gammas. The secondary gamma dose rate is at least two orders of magnitude less than the neutron dose rate, and this is demonstrated by comparing the neutron and secondary gamma dose rates for the $RaCl_2$ source. Also, the only neutron emitter that results in non-negligible primary gammas is Ra-226. The primary gammas for the other neutron emitters result in gamma dose rates many orders of magnitude below the neutron dose rate.

For the T80/T780 configuration, a similar approach is used, although the method is greatly simplified because there is only one type of drawer and only one source type (Co-60). Therefore, it is sufficient to develop only a single geometric model with the source in several locations within the drawer.

5.4.2 Input and Output Data

Sample ORIGEN-S and MCNP input files are provided in Appendix 5.5.2, *Sample Input Files for LTSS Evaluation*. A large number of input and output files are generated for this analysis due to the large number of configurations and sources.

Problem convergence is accelerated by dividing the LTSS into layers and splitting the particles as particles traverse outwardly through these layers. The Monte Carlo uncertainty associated with the limiting dose rate location is typically less than 5%. Ir-192 and Se-75 have rather poor statistics because the source energies are weak for the amount of shielding present, indicating that there is essentially no dose rate from these isotopes. Therefore, the activity limits for Ir-192 and Se-75 are conservatively reduced by at least an order of magnitude from the calculated values.

5.4.3 Flux-to-Dose Rate Conversion

ANSI/ANS-6.1.1-1977 flux-to-dose rate conversion factors are used in this analysis. These are obtained from the MCNP User's Manual [2], Tables H.1 and H.2, although these values have been converted to provide results in mrem/hr rather than rem/hr. These conversion factors are provided in Table 5.4-1.

5.4.4 External Radiation Levels

NCT

NCT dose rates are computed at the surface and 1 m from the surface of the 435-B package for each of the sources listed in Table 5.2-1 and configurations listed in Table 5.3-3 and Table 5.3-4. Mesh tallies are used to determine the maximum dose rate for a unit source (1 Ci or 1 g), as described in Section 5.4.1, *Methods*.

In all cases, the 1 m dose rates are more limiting than the surface dose rates. Due to streaming effects, the gamma dose rate is sensitive to the location of the source within the LD. Therefore, cases are run with the source in several different locations within the LD to determine the limiting configuration. The A_i activity limit for each isotope, which is essentially the activity that results in a 1 m dose rate of 9.5 mrem/hr, is summarized in Table 5.4-6.

The limiting dose rate location for the gamma emitters is typically 1 m from the top of the package at an off-center location due to streaming through the steel structural members. The limiting dose rate location for the neutron emitters is 1 m from the side of the package next to the source because this is the shortest distance to the source. While the gamma emitter A_i values may change dramatically for the various LDs, the A_i values for the neutron emitters are relatively constant for the various LDs, as the LTSS contains no hydrogenous neutron shielding material.

Ir-192 and Se-75 result in essentially no dose rate due to the low gamma energies and large thickness of gamma shielding material. Therefore, the A_i values for Ir-192 and Se-75 are conservatively reduced by at least an order of magnitude from the computed values and are listed as constants in Table 5.4-6.

The T80/T780 analysis is performed only for a point source of Co-60 and is separate from the LD analysis presented above. The minimum A_i = 39,339 Ci for the T80/T780. This exceeds the Co-60 activity limit of the package of 12,970 Ci. Therefore, up to 12,970 Ci of Co-60 may be transported per 435-B and may be divided in any manner between the four T80/T780 drawers.

HAC

Drop testing, discussed in Section 2.12.3, *Certification Test Report*, showed negligible damage to the LTSS, LTSS lodgment, and 435-B package. Therefore, there is essentially no difference between the NCT and HAC shielding configurations. Because the methodology is developed to result in a 1 m dose rate of 9.5 mrem/hr, the HAC dose rate at 1 m will not exceed 9.5 mrem/hr. This is significantly less than the limit of 1000 mrem/hr.

5.4.5 LTSS Loading Methodology

The following is a concise summary of how to apply the results of this shielding evaulation when loading an LTSS. There are two allowable contents for the LTSS. Content 1 utilizes the T80/T780 source drawer and a Co-60 source. Content 2 utilizes the standard source drawer and the nuclides listed in Table 5.4-2. This summary is also provided in Chapter 7.0, *Package Operations*.

Limits for Content 1: The T80/T780 source drawer may contain up to the Table 5.4-2 limit of Co-60 (i.e., 12,970 Ci) in one to four drawers in any distribution. T80/T780 source drawers (Content 1) may not be mixed with large source drawers (Content 2) within the LTSS. Any of the four recesses in the LTSS that is not loaded with a T80/T780 drawer must be loaded with a shield drawer.

Limits for Content 2: There are seven steps in qualifying Content 2 for the LTSS.

1. **Basic Radionuclide Limits.** Verify that the total activity of each isotope to be transported in the LTSS does not exceed the basic radionuclide limits given in Table 5.4-2 or the limits specified in the special form capsule certificate, ZA/NLM52/S, or other special form capsules, if used.
2. **Fissile Mass Limit.** Verify that the total fissile mass within the LTSS does not exceed 15g. The fissile mass is equal to:

$$\text{Fissile mass (g)} = A + 0.2 \times B + 0.001 \times C$$

   where:

   A equals the total grams of plutonium in all Pu-239 sources
   B equals the total grams of plutonium in all Pu-238 sources
   C equals the curies of americium in all Am-241 sources

3. **Plutonium By Air Exclusion.** NO PLUTONIUM SOURCES ARE PERMITTED FOR SHIPMENT OF THE 435-B BY AIR. AMERICIUM GREATER THAN 200 CURIES SHALL NOT BE SHIPPED BY AIR. Note: The 200 Ci limit on americium is due to the potential trace quantities of plutonium in an americium source. Up to an A_2 quantity of plutonium may be present in ~230 Ci of americium. Therefore, this value is conservatively rounded down to 200 Ci.
4. **Decay Heat Limit.** Verify that the total heat load is less than or equal to 200 watts. If only a single isotope is to be shipped in the LTSS, this is ensured by step 1 above. If multiple isotopes are to be transported, the total watts shall be calculated by multiplying the activity of each isotope by the heat generation rate found in Table 5.4-3.
5. **Physical Form Restrictions.** Verify that the source physical form and isotope comply with the requirements delineated in Table 5.4-4.
6. **Drawer Configuration Restrictions.** Verify that the drawer configuration to be transported is allowed per Table 5.4-5. NOTE: Any recesses in the LTSS that are not needed to carry sources must be given a shield drawer.
7. **Dose Rate Limits.** Verify the selected loading does not violate the dose rate limits using the following equation:

$$\sum_{i=1}^{n} \frac{S_i}{A_i} \leq 1 \qquad (\leq 0.3 \textit{ for commercial aircraft transport})$$

where:

S_i is the activity of each source in Ci (g Pu for Pu sources)
A_i is the appropriate value from Table 5.4-6 for each drawer for the configuration used (A – E, AB, BC, BD)

NOTE: ONLY ONE NUCLIDE TYPE MAY BE PLACED IN A SINGLE CAPSULE.

Examples are provided below.

Example 1:
Recess 1: LD-74 with 7,000 Ci Cs-137, point source
Recess 2: LD-74 with 5,000 Ci Cs-137, point source
Recess 3: LD-74 with 2,000 Ci Co-60, point source
Recess 4: LD-74 with 3,000 Ci Co-60, point source

Step 1: The total Cs-137 (12,000 Ci) and Co-60 (5,000 Ci) are less than the limits in Table 5.4-2.
Step 2: No plutonium or americium, does not apply.
Step 3: No plutonium or americium, air transport allowed.
Step 4: The total power is 138 watts $\leq$ 200 watts based on Table 5.4-3.
Step 5: Physical form restrictions in Table 5.4-4 are met.
Step 6: The drawer configuration is consistent with Configuration A in Table 5.4-5.
Step 7: Table 5.4-6 Configuration A limits apply. The sum of fractions = 0.15 $\leq$ 1.0.

Therefore, this shipment is allowed by air (including commercial aircraft), land, or sea transport.

Example 2:
Recess 1: LD-150 with two NLM52-74 capsules. The first capsule has 1,000 Ci Co-60 and the second capsule has 1,000 Ci Sr-90
Recess 2: LD-150 with 5,000 Ci Cs-137, line source
Recess 3: LD-150 with 2,000 Ci Co-60, point source
Recess 4: LD-150 with 2 Ci AmBe

Step 1: The total Cs-137 (5,000 Ci), Co-60 (3,000 Ci), Sr-90 (1,000 Ci) and AmBe (2 Ci) are less than or equal to the limits in Table 5.4-2.
Step 2: Fissile mass = 0.001*2 = 0.002 g $\leq$ 15 g.
Step 3: Americium < 200g, air transport allowed.
Step 4: The total power is 78 watts $\leq$ 200 watts based on Table 5.4-3.
Step 5: Physical form restrictions in Table 5.4-4 are met.
Step 6: The drawer configuration is consistent with Configuration B in Table 5.4-5.
Step 7: Table 5.4-6 Configuration B limits apply. The sum of fractions = 0.83 $\leq$ 1.0.

Therefore, this shipment is allowed by air (not commercial aircraft), land or sea transport.

Example 3:
Recess 1: LD-74 with 15 g Pu in a Pu-238O_2 source
Recess 2: LD-74 with 15 g Pu in a Pu-238O_2 source

Recess 3: LD-74 with 2 g Pu in a Pu-239O_2 source
Recess 4: LD-74 with 2 g Pu in a Pu-239Be source

Step 1: The total Pu in the Pu-238 source (30 g) and total Pu in the Pu-239 source (4 g) are less than the limits in Table 5.4-2.
Step 2: The total fissile material in the package is 30 g*0.2 + 4 g = 10 g ≤ 15 g.
Step 3: Due to the presence of plutonium, air transport is not permitted.
Step 4: The total power is 17 watts ≤ 200 watts based on Table 5.4-3.
Step 5: Physical form restrictions in Table 5.4-4 are met.
Step 6: The drawer configuration is consistent with Configuration A in Table 5.4-5.
Step 7: Table 5.4-6 Configuration A limits apply. The sum of fractions = 0.04 ≤ 1.0.

Therefore, this shipment is allowed by land or water transport.

Example 4:
Recess 1: LD-74 with 14,000 Ci Cs-137 point source
Recess 2: LD-150 with 5,000 Ci Co-60 line source
Recess 3: LD-150 with 1 Ci RaBe source
Recess 4: LD-150 with 2 Ci AmBe source

Step 1: The totals for each isotope are less than or equal to the limits in Table 5.4-2.
Step 2: Fissile mass = 0.001*2 = 0.002 g ≤ 15 g.
Step 3: Americium < 200g, air transport allowed.
Step 4: The total power is 148 watts ≤ 200 watts based on Table 5.4-3.
Step 5: Physical form restrictions in Table 5.4-4 are met.
Step 6: The drawer configuration is consistent with Configuration AB in Table 5.4-5.
Step 7: Table 5.4-6 Configuration AB limits apply. The sum of fractions = 1.5 > 1.0. Therefore, this shipment is **not** allowed.

This shipment is not allowed due to violation of the dose rate limit (Step 7).

Table 5.4-1 – Flux-to-Dose Rate Conversion Factors

E (MeV)	Neutron Factors (mrem/hr)/(n/cm²/s)	E (MeV)	Neutron Factors (mrem/hr)/(n/cm²/s)
2.50E-08	3.67E-03	0.5	9.26E-02
1.00E-07	3.67E-03	1.0	1.32E-01
1.00E-06	4.46E-03	2.5	1.25E-01
1.00E-05	4.54E-03	5.0	1.56E-01
1.00E-04	4.18E-03	7.0	1.47E-01
0.001	3.76E-03	10.0	1.47E-01
0.01	3.56E-03	14.0	2.08E-01
0.1	2.17E-02	20.0	2.27E-01
E (MeV)	**Gamma Factors (mrem/hr)/(γ/cm²/s)**	**E (MeV)**	**Gamma Factors (mrem/hr)/(γ/cm²/s)**
0.01	3.96E-03	1.4	2.51E-03
0.03	5.82E-04	1.8	2.99E-03
0.05	2.90E-04	2.2	3.42E-03
0.07	2.58E-04	2.6	3.82E-03
0.1	2.83E-04	2.8	4.01E-03
0.15	3.79E-04	3.25	4.41E-03
0.2	5.01E-04	3.75	4.83E-03
0.25	6.31E-04	4.25	5.23E-03
0.3	7.59E-04	4.75	5.60E-03
0.35	8.78E-04	5.0	5.80E-03
0.4	9.85E-04	5.25	6.01E-03
0.45	1.08E-03	5.75	6.37E-03
0.5	1.17E-03	6.25	6.74E-03
0.55	1.27E-03	6.75	7.11E-03
0.6	1.36E-03	7.5	7.66E-03
0.65	1.44E-03	9.0	8.77E-03
0.7	1.52E-03	11.0	1.03E-02
0.8	1.68E-03	13.0	1.18E-02
1.0	1.98E-03	15.0	1.33E-02

Table 5.4-2 – Basic 435-B Limits

Source	Maximum Quantity per 435-B
Co-60	12,970 Ci
Cs-137	14,000 Ci
Sr-90	1,000 Ci
Ra-226 (excluding Ra-226Be)①	20 Ci
Ra-226Be①	1.3 Ci
Am-241 (excluding Am-241Be)②	1000 Ci
Am-241Be②	6.6 Ci
Pu-238 (excluding Pu-238Be)③	75 g Pu
Pu-239 or Pu-239Be③	15 g Pu
Ir-192	200 Ci
Se-75	80 Ci

①Impurities may include oxygen, carbon, sulfur, bromine, and chlorine (hydrous or anhydrous).
②Impurities may include oxygen and chlorine.
③Impurities may include oxygen. The total fissile mass limit for the 435-B is 15 g.

Table 5.4-3 – Watts per Source Unit

Isotope	watts/unit
Co-60	1.5420E-02 watts/Ci
Cs-137①	5.0400E-03 watts/Ci
Sr-90②	6.6980E-03 watts/Ci
Ra-226③	1.8620E-01 watts/Ci
Am-241	3.3370E-02 watts/Ci
Pu-238	5.6773E-01 watts/g
Pu-239	3.0873E-03 watts/g
Ir-192	6.1500E-03 watts/Ci
Se-75	2.4100E-03 watts/Ci

①Includes Ba-137m.
②Includes Y-90.
③Includes decay products.

Table 5.4-4 – Authorized Payload Special Form Capsule Sources and Nuclides

Drawer Model	Special Form Capsule Model	Authorized Source Geometry and Dimensions	Authorized Nuclides
LD-74	NLM 52-74	Point source	All nuclides in Table 5.4-2
LD-150	NLM 52-150	Point source	All nuclides in Table 5.4-2
		Line source, length ≥ 60 mm	Co-60 and Cs-137
LD-150	Two (2) NLM 52-74s	Point source	All nuclides in Table 5.4-2
LD-200	NLM 52-200	Point source	All nuclides in Table 5.4-2
		Line source, length ≥ 136 mm	Co-60 and Cs-137
LD-250	NLM 52-250	Line source, length ≥ 186 mm	Co-60 and Cs-137
LD-325	NLM 52-325	Line source, length ≥ 236 mm	Co-60 and Cs-137

Table 5.4-5 – Allowable Drawer Configurations

Configuration①	Recess 1	Recess 2	Recess 3	Recess 4
A	LD-74	LD-74	LD-74	LD-74
B	LD-150	LD-150	LD-150	LD-150
C	LD-200	LD-200	LD-200	LD-200
D	LD-250	LD-250	LD-250	LD-250
E	LD-325	LD-325	LD-325	LD-325
AB	LD-74	LD-150	LD-150	LD-150
BC	LD-150	LD-150	LD-200	LD-200
BD	LD-250	LD-150	LD-150	LD-150

①Any number of LDs may be replaced with a shield drawer.

Table 5.4-6 – A_i Activity Limits

Isotope	Cfg. A LD-74	Cfg. B LD-150	Cfg. C LD-200	Cfg. D LD-250	Cfg. E LD-325
Co-60 point (Ci)	34400	5800	1800	NA	NA
Co-60 line (Ci)	NA	11800	6500	2600	530
Cs-137 point (Ci)	3.50E+07	3.30E+06	6.40E+05	NA	NA
Cs-137 line (Ci)	NA	8.50E+06	3.90E+06	9.80E+05	1.00E+05
Sr-90 (Ci)	1.60E+07	3.20E+06	1.00E+06	NA	NA
Am-241 (no Be) (Ci)	14800	14200	14200	NA	NA
Am-241Be (Ci)	6.6	6.5	6.4	NA	NA
Ra-226 (no Be) (Ci)	720	680	530	NA	NA
Ra-226Be (Ci)	1.3	1.3	1.3	NA	NA
Pu-238 (no Be) (g Pu)	1300	1300	1300	NA	NA
Pu-239 (no Be) (g Pu)	1.60E+05	1.60E+05	1.50E+05	NA	NA
Pu-239Be (g Pu)	120	120	120	NA	NA
Ir-192 (Ci)	1.00E+05	1.00E+05	1.00E+05	NA	NA
Se-75 (Ci)	1.00E+05	1.00E+05	1.00E+05	NA	NA

	Cfg. AB		Cfg. BC		Cfg. BD	
Isotope	LD-74	LD-150	LD-150	LD-200	LD-150	LD-250
Co-60 point (Ci)	32700	Use Cfg. B Limits	5600	Use Cfg. C Limits	5600	Use Cfg. D Limits
Co-60 line (Ci)	NA		11800		10300	
Cs-137 point (Ci)	3.30E+07		3.30E+06		3.20E+06	
Cs-137 line (Ci)	NA		7.40E+06		6.90E+06	
Sr-90 (Ci)	1.60E+07		3.20E+06		3.10E+06	
Am-241 (no Be) (Ci)	14600		14100		14100	
Am-241Be (Ci)	6.6		6.4		6.4	
Ra-226 (no Be) (Ci)	720		680		680	
Ra-226Be (Ci)	1.3		1.3		1.3	
Pu-238 (no Be) (g Pu)	1200		1300		1300	
Pu-239 (no Be) (g Pu)	1.60E+05		1.60E+05		1.60E+05	
Pu-239Be (g Pu)	120		120		120	
Ir-192 (Ci)	1.00E+05		1.00E+05		1.00E+05	
Se-75 (Ci)	1.00E+05		1.00E+05		1.00E+05	

5.5 Appendices

5.5.1 References

5.5.2 Sample Input Files for LTSS Evaluation

5.5.3 Shielded Device Evaluation

5.5.1 References

1. Glenn F. Knoll, *Radiation Detection and Measurement*, Second Edition, John Wiley & Sons, 1989.
2. LA-UR-03-1987, *MCNP – A General Monte Carlo N-Particle Transport Code, Version 5*, Los Alamos National Laboratory, April 24, 2003 (Revised 2/1/2008).
3. *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations*, ORNL/TM-2005/39, Version 6, Vols. I-III, January 2009.
4. SCALE4.4, *Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers*, Oak Ridge National Laboratory, September 1998.
5. *Radiological Characterization of Actinide Sealed Source Waste for Disposal at WIPP*, Los Alamos National Laboratory, 2005.
6. LA-UR-09-06701, *Radionuclide Distribution in Plutonium-239 Material Used for Sealed Source Production*, Los Alamos National Laboratory.
7. PNNL-15870, Rev. 1, *Compendium of Material Composition Data for Radiation Transport Modeling.*

5.5.2 Sample Input Files for LTSS Evaluation

Sample ORIGEN-S input file for AmBe neutron source:

```
'This SCALE input file was generated by
'OrigenArp Version  5.1.01 March 22, 2007
#origens
0$$ a11 71 e t
Decay Case
3$$ 21 1 1 27 a16 2 a33 18 e t
35$$ 0 t
54$$ a8 1 a11 2  e
56$$ a2 7 a10 0 a13 2 a15 3 a17 2 e
57** 0 a3 1e-05 e
95$$ 0 t
Case 1
0 MTU
60** 0.1 0.3 1 3 10 30 100
61** f0.05
65$$
'Gram-Atoms   Grams   Curies   Watts-All   Watts-Gamma
 3z   1   0   0   1 0 0  1 0 0   3z   6z
 3z   1   0   0   1 0 0  1 0 0   3z   6z
 3z   1   0   0   1 0 0  1 0 0   3z   6z
81$$ 2 0 26 1 a7 200 e
82$$ 2 2 2 2 2 2 2 e
83**
 1.0000000e+07 8.0000000e+06 6.5000000e+06 5.0000000e+06 4.0000000e+06
 3.0000000e+06 2.5000000e+06 2.0000000e+06 1.6600000e+06 1.3300000e+06
 1.0000000e+06 8.0000000e+05 6.0000000e+05 4.0000000e+05 3.0000000e+05
 2.0000000e+05 1.0000000e+05 5.0000000e+04 1.0000000e+04 e
84**
 2.0000000e+07 6.3763000e+06 3.0119000e+06 1.8268000e+06
 1.4227000e+06 9.0718000e+05 4.0762000e+05 1.1109000e+05 1.5034000e+04
 3.0354000e+03 5.8295000e+02 1.0130000e+02 2.9023000e+01 1.0677000e+01
 3.0590000e+00 1.8554000e+00 1.3000000e+00 1.1253000e+00 1.0000000e+00
 8.0000000e-01 4.1399000e-01 3.2500000e-01 2.2500000e-01 1.0000000e-01
 5.0000000e-02 3.0000000e-02 1.0000000e-02 1.0000000e-05 e
 73$$ 952410 40000
74** 291.5 3e5
75$$ 2 4
t
56$$ f0 t
end
```

Sample MCNP input file for LTSS evaluation, Co-60 point source, LD-074:

```
LANL-B
c
c     LANL-B Package
c
10    1 -7.94  10 -11 -35                      imp:p=1.5e7 $ base sheet
11    1 -7.94  (60 -61 31 -35):(34 -35 11 -61) imp:p=1.5e7 $ cone sheet
12    0        -50 -12                         imp:p=1.5e7 $ inside head
13    1 -7.94  50 -51 -12                      imp:p=1.5e7 $ lower head
14    1 -7.94  30 -31 12 -17                   imp:p=5.8e6 $ shell
15    5 -2.7   12 -13 -30                      imp:p=1.5e7 $ bottom
```

```
16    2 -0.224 11 -12 51 -33                      imp:p=1.5e7 $ foam
17    2 -0.224 31 -33 12 -60                      imp:p=1.5e7 $ foam
18    2 -0.224 33 -34 11 -60                      imp:p=1.5e7 $ foam
19    5 -2.7   16 -17 -30                         imp:p=1.5e7 $ top plate
20    0        13 -16 -30 fill=3(0 0 97.014)      imp:p=1     $ cavity
21    1 -7.94  61 -16 31 -32                      imp:p=5.8e6 $ thermal shields
22    1 -7.94  52 -53 17                          imp:p=1.5e7 $ top head
23    0        17 -52                             imp:p=1     $ inside top
24    0        32 -35 61 -16                      imp:p=1     $ side air
25    0        16 -17 31 -35                      imp:p=1     $ side air sliver
26    0        17 -18 53 -35                      imp:p=1     $ top air
27    0        (-10:18:35) 70 -71 -72             imp:p=1     $ 1m
28    0        (-70:71:72) 73 -74 -75             imp:p=1     $ 2m
99    0        -73:74:75                          imp:p=0
c
c     Universe 1: Large Source Drawer
c
100   0        102 -103 -110      fill=2          u=1 imp:p=1 $ cavity
101   0        101 -102 -110      fill=6          u=1 imp:p=1 $ bottom W
102   0        103 -104 -110      fill=6          u=1 imp:p=1 $ top W
104   1 -7.94  100 -101 -111      fill=5          u=1 imp:p=1 $ bottom cap
105   1 -7.94  104 -105 -111      fill=5          u=1 imp:p=1 $ top cap
106   1 -7.94  101 -104 110 -111  fill=5          u=1 imp:p=1 $ cladding
107   0        -100:105:111                       u=1 imp:p=1
c
c     Universe 2: NLM 52
c
200   0        201 -202 -210                      u=2 imp:p=1 $ cavity
201   1 -7.94  201 -202 210 -211 fill=5           u=2 imp:p=1 $ cladding
202   1 -7.94  200 -201 -211     fill=5           u=2 imp:p=1 $ end cap
204   1 -7.94  202 -203 -211     fill=5           u=2 imp:p=1 $ end cap
205   0        -200:203:211                       u=2 imp:p=1
c
c     Universe 3: LTSS
c
300   1 -7.94  300 -301 -302 303 304 305 306 fill=5 u=3 imp:p=1
301   0        300 -301 -303 fill=1(1)             u=3 imp:p=1 $ top drawer
302   0        300 -301 -304 fill=1(2)             u=3 imp:p=1 $ left drawer
303   0        300 -301 -305 fill=1(3)             u=3 imp:p=1 $ bottom drawer
304   0        300 -301 -306 fill=1(4)             u=3 imp:p=1 $ right drawer
c
305   0        (-300:301:302) 322 -325 -330        u=3 imp:p=1 $ gap to liner
306   1 -7.94  323 -324 330 -331  fill=5           u=3 imp:p=1 $ liner tube
307   1 -7.94  330 -333 322 -323  fill=5           u=3 imp:p=1 $ bottom liner
308   1 -7.94  332 -333 320 -322  fill=5           u=3 imp:p=1 $ bottom liner
309   1 -7.94  321 -322 -332 303 304 305 306 fill=5 u=3 imp:p=1 $ bottom
pivot
310   0        321 -322 -303                       u=3 imp:p=1 $ bottom pivot
311   0        321 -322 -304                       u=3 imp:p=1 $ bottom pivot
312   0        321 -322 -305                       u=3 imp:p=1 $ bottom pivot
313   0        321 -322 -306                       u=3 imp:p=1 $ bottom pivot
314   1 -7.94  328 -321 -332      fill=5           u=3 imp:p=1 $ bottom extra
315   0        320 -328 -332                       u=3 imp:p=1 $ bottom air
316   1 -7.94  330 -333 324 -325  fill=5           u=3 imp:p=1 $ top liner
317   1 -7.94  332 -333 325 -327  fill=5           u=3 imp:p=1 $ top liner
318   1 -7.94  325 -326 -332 303 304 305 306 fill=5 u=3 imp:p=1 $ top pivot
```

```
319   0        325 -326 -303                          u=3 imp:p=1 $ top pivot
hole
320   0        325 -326 -304                          u=3 imp:p=1 $ top pivot
hole
321   0        325 -326 -305                          u=3 imp:p=1 $ top pivot
hole
322   0        325 -326 -306                          u=3 imp:p=1 $ top pivot
hole
323   1 -7.94  326 -329 -332      fill=5              u=3 imp:p=1 $ top extra
324   0        329 -327 -332                          u=3 imp:p=1 $ top air
c
330   1 -7.94  343 -320 -335       fill=5             u=3 imp:p=1 $ bottom end
331   3 -11.35 341 -343 -334       fill=4             u=3 imp:p=1 $ bottom end
332   1 -7.94  340 -341 -335       fill=5             u=3 imp:p=1 $ bottom end
333   1 -7.94  341 -343 334 -335   fill=5             u=3 imp:p=1 $ bottom end
334   1 -7.94  342 -320 335 -333   fill=5             u=3 imp:p=1 $ bottom end
335   0        340 -342 335 -333                      u=3 imp:p=1 $ bottom end
336   1 -7.94  327 -344 -335       fill=5             u=3 imp:p=1 $ top end
shield
337   3 -11.35 344 -346 -334       fill=4             u=3 imp:p=1 $ top end
shield
338   1 -7.94  346 -347 -335       fill=5             u=3 imp:p=1 $ top end
shield
339   1 -7.94  344 -346 334 -335   fill=5             u=3 imp:p=1 $ top end
shield
340   1 -7.94  327 -345 335 -333   fill=5             u=3 imp:p=1 $ top end
shield
341   0        345 -347 335 -333                      u=3 imp:p=1 $ top end
c
350   3 -11.35 (333 -354 -361 362 -363 -364):
               (323 -324 331 -333) fill=4             u=3 imp:p=1  $ side lead
351   0        354 -353 -355 -356 359 -360            u=3 imp:p=1  $ side gap
352   0        333 -354 -355 359 361                  u=3 imp:p=1  $ bottom gap
353   0        333 -354 -356 -360 363                 u=3 imp:p=1  $ bottom gap
354   1 -7.94  333 -353 356 -351 -358      fill=5 u=3 imp:p=1  $ side steel
top
355   1 -7.94  353 -352 -350 -351 357 -358 fill=5 u=3 imp:p=1  $ side steel
356   1 -7.94  333 -353 -350 355 357       fill=5 u=3 imp:p=1  $ side steel
c
360   0        -340:347:352                           u=3 imp:p=1
361   0         333 -352 351 -347                     u=3 imp:p=1
362   0         333 -352 350  340                     u=3 imp:p=1
c
c     Universe 4: Splitting universe for lead
c
400   3 -11.35  -400     u=4 imp:p=1
401   3 -11.35  400 -401 u=4 imp:p=2.5
402   3 -11.35  401 -402 u=4 imp:p=6.3
403   3 -11.35  402 -403 u=4 imp:p=15.6
404   3 -11.35  403 -404 u=4 imp:p=39.1
405   3 -11.35  404 -405 u=4 imp:p=97.7
406   3 -11.35  405 -406 u=4 imp:p=244
407   3 -11.35  406 -407 u=4 imp:p=610
408   3 -11.35  407 -408 u=4 imp:p=1525
409   3 -11.35  408 -409 u=4 imp:p=3815
410   3 -11.35  409 -410 u=4 imp:p=9537
411   3 -11.35  410 -411 u=4 imp:p=2.4e4
```

```
412   3 -11.35  411 -412 u=4 imp:p=6.0e4
413   3 -11.35  412 -413 u=4 imp:p=1.5e5
414   3 -11.35  413 -414 u=4 imp:p=3.7e5
415   3 -11.35  414 -415 u=4 imp:p=9.3e5
416   3 -11.35  415 -416 u=4 imp:p=2.3e6
417   3 -11.35  416 -417 u=4 imp:p=5.8e6
418   3 -11.35  417      u=4 imp:p=1.5e7
c
c     Universe 5: Splitting universe for steel
c
500   1 -7.94  -400      u=5 imp:p=1
501   1 -7.94  400 -401 u=5 imp:p=2.5
502   1 -7.94  401 -402 u=5 imp:p=6.3
503   1 -7.94  402 -403 u=5 imp:p=15.6
504   1 -7.94  403 -404 u=5 imp:p=39.1
505   1 -7.94  404 -405 u=5 imp:p=97.7
506   1 -7.94  405 -406 u=5 imp:p=244
507   1 -7.94  406 -407 u=5 imp:p=610
508   1 -7.94  407 -408 u=5 imp:p=1525
509   1 -7.94  408 -409 u=5 imp:p=3815
510   1 -7.94  409 -410 u=5 imp:p=9537
511   1 -7.94  410 -411 u=5 imp:p=2.4e4
512   1 -7.94  411 -412 u=5 imp:p=6.0e4
513   1 -7.94  412 -413 u=5 imp:p=1.5e5
514   1 -7.94  413 -414 u=5 imp:p=3.7e5
515   1 -7.94  414 -415 u=5 imp:p=9.3e5
516   1 -7.94  415 -416 u=5 imp:p=2.3e6
517   1 -7.94  416 -417 u=5 imp:p=5.8e6
518   1 -7.94  417      u=5 imp:p=1.5e7
c
c     Universe 6: Splitting universe for tungsten
c
600   4 -17.0  -400      u=6 imp:p=1
601   4 -17.0  400 -401 u=6 imp:p=2.5
602   4 -17.0  401 -402 u=6 imp:p=6.3
603   4 -17.0  402 -403 u=6 imp:p=15.6
604   4 -17.0  403 -404 u=6 imp:p=39.1
605   4 -17.0  404 -405 u=6 imp:p=97.7
606   4 -17.0  405 -406 u=6 imp:p=244
607   4 -17.0  406 -407 u=6 imp:p=610
608   4 -17.0  407 -408 u=6 imp:p=1525
609   4 -17.0  408 -409 u=6 imp:p=3815
610   4 -17.0  409 -410 u=6 imp:p=9537
611   4 -17.0  410 -411 u=6 imp:p=2.4e4
612   4 -17.0  411 -412 u=6 imp:p=6.0e4
613   4 -17.0  412 -413 u=6 imp:p=1.5e5
614   4 -17.0  413 -414 u=6 imp:p=3.7e5
615   4 -17.0  414 -415 u=6 imp:p=9.3e5
616   4 -17.0  415 -416 u=6 imp:p=2.3e6
617   4 -17.0  416 -417 u=6 imp:p=5.8e6
618   4 -17.0  417      u=6 imp:p=1.5e7

c
c    Package
c
10   pz  0        $ bottom of package
11   pz  0.635    $ bottom plate
```

```
12   pz  32.004   $ bottom of inner support
13   pz  33.274   $ bottom of cavity
16   pz  183.106  $ top of cavity
17   pz  184.376  $ top of top plate
18   pz  207.3    $ top of model
30   cz  55.245   $ shell inner
31   cz  56.515   $ shell outer
32   cz  56.9341  $ outer thermal shields
33   cz  66.04    $ foam interface
34   cz  88.265   $ base sheet inner
35   cz  88.9     $ base sheet outer
50   ell 0 0 32.004  0 0 21.59 -55.245 $ lower head inner
51   ell 0 0 32.004  0 0 22.86 -56.515 $ lower head outer
52   ell 0 0 184.376 0 0 21.59 -55.245 $ upper head inner
53   ell 0 0 184.376 0 0 22.86 -56.515 $ upper head outer
60   kz  103.0298 3.0 -1
61   kz  103.7630 3.0 -1
70   pz -100      $ bottom 1m
71   pz  295.8    $ top 1m (measured from the axial middle of the head)
72   cz  156.9341 $ side 1m
73   pz -200      $ bottom of model
74   pz  410      $ top of model
75   cz  256      $ side of model
c
c    Large Source Drawer
c
100  pz -27.4     $ bottom of drawer
101  pz -25.4     $ bottom of lower tungsten
102  pz -4.0      $ top of lower tungsten
103  pz  4.0      $ bottom of upper tungsten
104  pz  25.4     $ top of upper tungsten
105  pz  27.4     $ top of drawer
110  cz  2.65     $ IR
111  cz  3.15     $ OR
c
c    NLM 52
c
200  pz -3.7      $ bottom
201  pz -2.9      $ bottom cap
202  pz  2.9      $ top cap
203  pz  3.7      $ top
210  cz  2.365    $ IR
211  cz  2.6      $ OR
c
c    LTSS
c
300  pz -27.575 $ bottom of drawer barrel
301  pz  27.575 $ top of drawer barrel
302  cz  8.4875 $ outer surface of drawer barrel
303  c/z 0 5.0 3.2  $ drawer 1
304  c/z -5.0 0 3.2 $ drawer 2
305  c/z 0 -5.0 3.2 $ drawer 3
306  c/z 5.0 0 3.2  $ drawer 4
320  pz -33.15 $ liner tube assembly bottom
321  pz -29.65 $ pivot flange
322  pz -27.65 $ liner tube assembly recess
323  pz -25.75 $ liner tube assembly
```

```
324  pz  25.75 $ liner tube assembly
325  pz  27.65 $ liner tube assembly recess
326  pz  29.65 $ pivot flange
327  pz  33.15 $ liner tube assembly top
328  pz -31.45 $ extra bottom plate
329  pz  31.45 $ extra top plate
330  cz  8.55  $ liner tube IR
331  cz  9.5   $ liner tube OR
332  cz  11.25 $ recess IR
333  cz  16.5  $ liner tube assembly OR
334  cz  10.8  $ end shield lead
335  cz  11.75 $ end shield OR
340  pz -42.15 $ bottom end shield
341  pz -41.15 $ bottom end shield
342  pz -36.35 $ bottom end flange
343  pz -33.55 $ bottom end
344  pz  33.55 $ top end
345  pz  36.35 $ top end flange
346  pz  41.15 $ top end shield
347  pz  42.15 $ top end shield
350  kz -43.8489 1.4203   $ bottom shell outer
351  kz  43.8489 1.4203   $ top shell outer
352  cz  34.5             $ side shell outer
353  cz  33.9             $ side shell inner
354  cz  33.2             $ gap in lead
355  kz -43.0666 1.4203   $ bottom shell inner
356  kz  43.0666 1.4203   $ top shell inner
357  pz -43.8489          $ ambiguity surface for 350
358  pz  43.8489          $ ambiguity surface for 351
359  pz -43.0666          $ ambiguity surface for 355
360  pz  43.0666          $ ambiguity surface for 356
361  kz -42.1528 1.4203   $ bottom lead gap
362  pz -42.1528          $ ambiguity surface for 361
363  kz  42.1528 1.4203   $ top lead gap
364  pz  42.1528          $ ambiguity surface for 363
c
c    Splitting
c
400  so 5.5
401  so 7.5
402  so 9.5
403  so 11.5
404  so 13.5
405  so 15.5
406  so 17.5
407  so 19.5
408  so 21.5
409  so 23.5
410  so 25.5
411  so 27.5
412  so 29.5
413  so 31.5
414  so 33.5
415  so 35.5
416  so 37.5
417  so 39.5
c
```

```
c    Tally surfaces
c
2000 cz 7.5
2001 cz 22.5
2002 cz 37.5
2003 cz 52.5
2004 cz 67.5
2005 cz 82.5
2006 cz 97.5
2007 cz 112.5
2008 cz 127.5
2009 cz 142.5
c
2050 pz -90.5
2051 pz -75.5
2052 pz -60.5
2053 pz -45.5
2054 pz -30.5
2055 pz -15.5
2056 pz -0.5
2057 pz 14.5
2058 pz 29.5
2059 pz 44.5
2060 pz 59.5
2061 pz 74.5
2062 pz 89.5
2063 pz 104.5
2064 pz 119.5
2065 pz 134.5
2066 pz 149.5
2067 pz 164.5
2068 pz 179.5
2069 pz 194.5
2070 pz 209.5
2071 pz 224.5
2072 pz 239.5
2073 pz 254.5
2074 pz 269.5
2075 pz 284.5
c
2100 pz 52.4

mode p
m1     6000   -0.08      $ SS304
       14000  -1.0
       15031  -0.045
       24000  -19
       25055  -2
       26000  -68.375
       28000  -9.5
m2     6000   -0.6       $ foam
       8000   -0.24
       7000   -0.12
       1000   -0.04
m3     82000 1           $ lead
m4     74000 1           $ tungsten
m5     13027 1           $ al
```

```
c
*tr1   0  5 0
*tr2  -5  0 0  90   0 90  180  90 90
*tr3   0 -5 0 180  90 90   90 180 90
*tr4   5  0 0  90 180 90    0  90 90
c
sdef  cel=d1 pos=0 2.264 2.799 erg=d3 rad=0.1 wgt=7.4e10 $ 1 Ci Co-60
si1   L 20:301:100:200
sp1   1
#     si3   sp3
      L     d
      1.173 0.5
      1.332 0.5
c
c    Tallies
c
c      ansi/ans-6.1.1-1977 flux-to-dose, photons (mrem/hr)/(p/cm**2/s)
de0         0.01   0.03   0.05   0.07   0.10   0.15   0.20   0.25   0.30
            0.35   0.40   0.45   0.50   0.55   0.60   0.65   0.70   0.80
            1.00   1.40   1.80   2.20   2.60   2.80   3.25   3.75   4.25
            4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
            13.0   15.0
df0         3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
            8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
            1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
            5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
            1.18-2 1.33-2
c
fc12    Bottom Surface
f12:p   10
fs12   -2000 -2001 -2002 -2003 -2004 -2005
c
fc22    Top Surface
f22:p   53
fs22    -2000 -2001 -2002 -2003
c
fc32    Side surface (primary)
f32:p   32
fs32    -2061 -2062 -2063 -2064 -2065 -2066 -2067 -2068
c
fc42    Side surface (base) (last junk)
f42:p   35
fs42    -2057 -2058 -2059 -2100
c
fc52    Side surface (base conical)
f52:p   61
fs52    -2004 -2005
c
fc62    Bottom 1m Surface
f62:p   70
fs62    -2000 -2001 -2002 -2003 -2004 -2005 -2006 -2007 -2008 -2009
c
fc72    Top 1m Surface
f72:p   71
fs72    -2000 -2001 -2002 -2003 -2004 -2005 -2006 -2007 -2008 -2009
c
fc82    Side 1m surface
```

```
f82:p   72
fs82    -2050 -2051 -2052 -2053 -2054 -2055 -2056 -2057 -2058 -2059
        -2060 -2061 -2062 -2063 -2064 -2065 -2066 -2067 -2068 -2069
        -2070 -2071 -2072 -2073 -2074 -2075
c
c       A rectangular mesh tally is placed at the top surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh14:p geom=xyz origin=-160 -160 207.3
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=208.3
            kints=1
c
c       A rectangular mesh tally is placed 1m from the top,
c       The 1 m location is measured from the center of the head.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh24:p geom=xyz origin=-160 -160 296.8
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=298.8
            kints=1
c
c       A rectangular mesh tally is placed at the bottom surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh34:p geom=xyz origin=-160 -160 -1
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=0
            kints=1
c
c       A rectangular mesh tally is placed 1m from the bottom surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh44:p geom=xyz origin=-160 -160 -101
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=-99
            kints=1
c
c          A cylindrical mesh tally is placed around the package surface.
c          Circumferentially there are 36 segments,
c          each 10 degrees wide.  Theta=0 corresponds to the positive y-axis.
c          radius=i
c          axial=j
c          circumferential=k
c
```

```
fmesh54:p   geom=cyl origin=0 0 70 axs=0 0 1 vec=0 1 0
            imesh=56.94 57.94
            iints=1 1
            jmesh=140
            jints=14
            kmesh=1
            kints=36
c
c          A cylindrical mesh tally is placed around the package
c          0.95 m from the surface of the package.
c          Circumferentially there are 36 segments,
c          each 10 degrees wide.  Theta=0 corresponds to the positive y-axis.
c          radius=i
c          axial=j
c          circumferential=k
c
fmesh64:p   geom=cyl origin=0 0 -100 axs=0 0 1 vec=0 1 0
            imesh=150.9 152.9
            iints=1 1
            jmesh=400
            jints=40
            kmesh=1
            kints=36
c
prdmp   j j 1 2
ctme    2940 $ 60*7*7 for 7 CPUs
c nps     100
```

5.5.3 Shielded Device Evaluation

The 435-B package has been designed to transport a variety of devices containing sources, including laboratory irradiators and teletherapy heads. These devices are further subdivided into Group 1 and Group 3, as defined in Chapter 1.0, *General Information.* The Gammacell 3000 (GC-3000) is selected to bound all Group 1 devices. The shielding analysis is performed on the GC-3000 since it has a smaller minimum shielding distance compared to the other types in Group 1. It is designed to use an external, removable auxiliary shielding component which is not shipped with the unit and not credited in the analysis. The Gammacell 40 (GC-40) is the only device in Group 3. The dose rates are shown to be below the regulatory limits for each device.

5.5.3.1 Description of Shielding Design

5.5.3.1.1 Design Features

The 435-B package itself offers little shielding. The outer shell of the 435-B is 0.5-in thick steel. The shielding is provided primarily by the devices and varies widely between devices. Two specific devices are addressed in this analysis, the GC-3000 and GC-40.

The GC-3000 is heavily shielded with lead. The lead thickness through the top lead plug is approximately 3-in. Additional shielding at the top is provided by a source holder that features approximately 2.35-in steel shielding. The minimum side lead thickness is approximately 4.5-in.

The GC-40 is also heavily shielded with lead. The GC-40 drawer provides approximately 5.75-in axial lead shielding and 1.3-in axial steel shielding. The GC-40 is highly asymmetrical in shape and in the transport position provides several inches of lead shielding.

As demonstrated by the certification testing documented in Appendix 2.12.3, *Certification Test Report*, and as supplemented by analyses in Section 2.7.1.6, *Structural Evaluation of the Shielded Devices*, the devices do not experience any significant damage which could reduce their effectiveness or which could lead to a release of the sources from the shields.

5.5.3.1.2 Summary Table of Maximum Radiation Levels

The dose rates are limited to 200 mrem/hr on the surface of the package and 10 mrem/hr at a distance of 1 m from the package for non-exclusive use transportation. Dose rates are computed for a Group 1 device (GC-3000) with a 3,840 Ci Cs-137 pencil source and for the Group 3 device (GC-40) with a 2,250 Ci Cs-137 point source. Normal condition of transport (NCT) dose rates are provided in Table 5.5.3-1 and Table 5.5.3-2 for the GC-3000 and GC-40, respectively.

Because the GC-3000 bounds the GC-40 under NCT based on the results in Table 5.5.3-1 and Table 5.5.3-2, hypothetical accident condition (HAC) dose rates are computed only for the GC-3000. The HAC dose rates are computed at a distance of 1 m from the surface of the package and are provided in Table 5.5.3-3. The HAC dose rates are negligible compared to the limit of 1000 mrem/hr.

Table 5.5.3-1 – GC-3000 NCT Dose Rates (Non-exclusive use)

	Package Surface (mrem/hr)			1 m from Package Surface (mrem/hr)		
	Top	Side	Bottom	Top	Side	Bottom
Gamma	6.7	18.6	0.4	0.8	1.6	0.04
Neutron	0	0	0	0	0	0
Total	6.7	18.6	0.4	0.8	1.6	0.04
Limit	200			10		

Table 5.5.3-2 – GC-40 NCT Dose Rates (Non-exclusive use)

	Package Surface (mrem/hr)			1 m from Package Surface (mrem/hr)		
	Top	Side	Bottom	Top	Side	Bottom
Gamma	0.3	1.4	0.4	0.04	0.1	0.06
Neutron	0	0	0	0	0	0
Total	0.3	1.4	0.4	0.04	0.1	0.06
Limit	200			10		

Table 5.5.3-3 – Bounding HAC Device Dose Rates

	1 m from Package Surface (mrem/hr)		
	Top	Side	Bottom
Gamma	0.8	2.6	0.04
Neutron	0	0	0
Total	0.8	2.6	0.04
Limit	1000		

5.5.3.2 Source specification

5.5.3.2.1 Gamma source

Sources contain only Cs-137. The decay of Cs-137 is sufficiently simple to be treated explicitly. The decay of Cs-137/Ba-137m emits a 0.662 MeV gamma with an 85% probability [1].

The activities for the GC-3000 and GC-40 are given in Table 1.2-2. The GC-3000 contains up to 3,048 Ci Cs-137, although the maximum activity for Group 1 is 3,840 Ci Cs-137 for both the Gammator M38 and GC-1000. Because the intent is to bound all Group 1 devices with the GC-3000 analysis, the larger 3,840 Ci activity is modeled in the GC-3000. Therefore, the as-modeled gamma source for the GC-3000 is 3840*0.85*3.7E+10 = 1.208E+14 γ/s.

The GC-40 contains up to 4,200 Ci Cs-137. However, only the upper or lower module of a GC-40 will be transported within the 435-B, and the maximum activity within a module is

2,250 Ci. Therefore, the as-modeled gamma source for the GC-40 is 2250*0.85*3.7E+10 = 7.076E+13 γ/s.

5.5.3.2.2 Neutron source

No neutron sources are utilized.

5.5.3.3 Shielding Model

5.5.3.3.1 Configuration of Source and Shielding

The GC-3000 transports pencil sources. It is assumed in this calculation that the GC-3000 source has a radius of 0.5 cm and length of approximately 24 cm, which is the length of the source capsule cavity. The GC-40 transports non-pencil sources, which are modeled as a point (radius of 0.1 cm to aid visualization). No credit is taken for self-shielding within the source for either the GC-3000 or GC-40.

Models of the 435-B package, GC-3000 or GC-40 device, and GC-3000 or GC-40 drawer are developed in the MCNP5 computer program [2]. The geometries of the GC-3000 and GC-40 have been determined by physically cutting the devices in half and measuring the dimensions. These measurements are provided in Figure 5.5.3-1 through Figure 5.5.3-5. The dimensions used in the MCNP models are consistent with these dimensions. For convenience, all steel is modeled as stainless steel, although some items, such as the GC-3000 and GC-40 shells, are carbon steel. This simplification has no impact on the results.

Each device is transported inside the inner container (IC). The IC is not modeled explicitly in MCNP because it offers little axial or radial shielding, although credit is taken for radial placement of the device within the package. The devices are positioned within the IC using blocking, which will radially center the device within the package cavity during normal conditions. Because the blocking may place the source axial location up to the axial center of the package cavity, cases are conservatively developed with the devices at the top or bottom of the package cavity, which will bound the actual configuration. In the actual configuration, a device is offset from the top and bottom of the package cavity by several inches due to the IC lid and bottom structures.

The IC is transported inside the 435-B package. The 435-B MCNP model is described in Section 5.3.1, *Configuration of Source and Shielding*. The normal conditions of transport (NCT) MCNP models for the GC-3000 and GC-40 are shown in Figure 5.5.3-6 through Figure 5.5.3-9. The large cavity shown on the left side of the GC-3000 in Figure 5.5.3-1 is absent in the MCNP models because even with this feature, there is less lead on the right half of the device. Also, the ends of the GC-40 drawer are modeled as brass for simplicity, although the ends are stainless steel per Figure 5.5.3-5. This simplification has a negligible impact on the results.

Hypothetical accident condition (HAC) models are developed only for the GC-3000 and are shown in Figure 5.5.3-10. Under HAC, testing has shown negligible deformation of the 435-B package. Therefore, the dimensions of the 435-B in the HAC model are the same as the NCT model. The foam is conservatively modeled as void in the HAC models. Damage to the blocking, resulting from the HAC impact, is assumed to allow the device to relocate within the IC. Although the IC itself is not significantly damaged, any radial spacing provided by the IC is not credited, and the device is placed against the inner wall of the 435-B.

As shown in Section 2.7.1.6, *Structural Evaluation of the Shielded Devices*, the devices are not damaged under HAC, the sources remain secure in the shielded position, and that lead melt or lead displacement does not occur. Therefore, the devices are modeled as undamaged in the HAC models.

5.5.3.3.2 Material Properties

Stainless steel 304 with a density of 7.94 g/cm^3 is modeled for the 435-B shell and device structural members. The stainless steel composition is provided in Section 5.3.2, *Material Properties*. Carbon steel items, such as the GC-3000 and GC-40 shells, are modeled as stainless steel for convenience. This has no effect on the results.

Lead with a density of 11.35 g/cm^3 is modeled as a shield material in the GC-3000 and GC-40. It is modeled as pure.

Polyurethane foam with a density of 14 pounds per cubic foot (pcf) (0.224 g/cm^3) is modeled in the lower assembly of the 435-B. This bounds the actual density of 15 pcf. The foam composition is provided in Section 5.3.2, *Material Properties*.

Aluminum with a density of 2.7 g/cm^3 is modeled in the 435-B internal impact limiter plates that form the top and bottom of the 435-B cavity. It is modeled as pure.

The cladding and ends of the GC-40 drawer is modeled as brass with a density of 8.07 g/cm^3. The brass composition is provided in Section 5.3.2, *Material Properties*.

Security Related Information
Figure Withheld Under 10 CFR 2.390

Figure 5.5.3-1 – GC-3000 (x-z view)

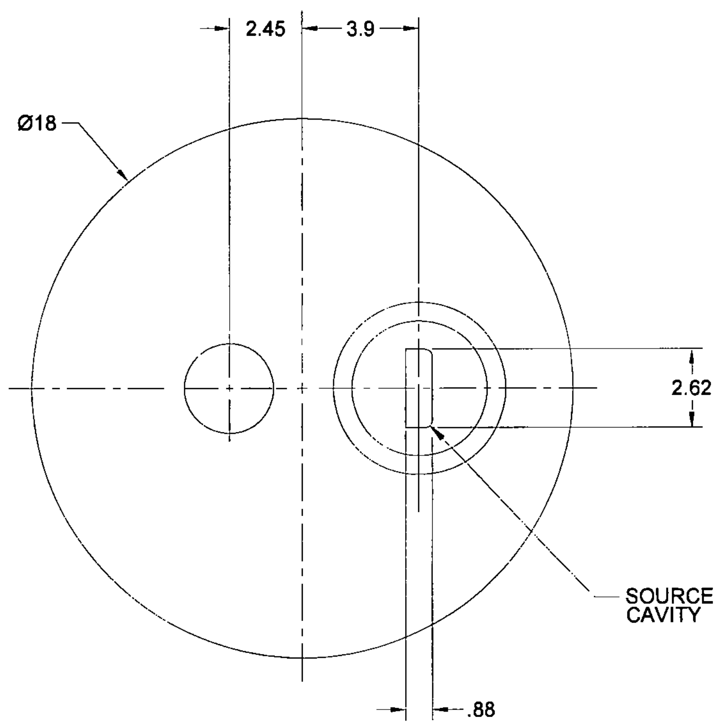


Figure 5.5.3-2 – GC-3000 (x-y view)

Security Related Information
Figure Withheld Under 10 CFR 2.390

Figure 5.5.3-3 – GC-3000 Source Capsule and Holder

Security Related Information
Figure Withheld Under 10 CFR 2.390

Figure 5.5.3-4 – GC-40

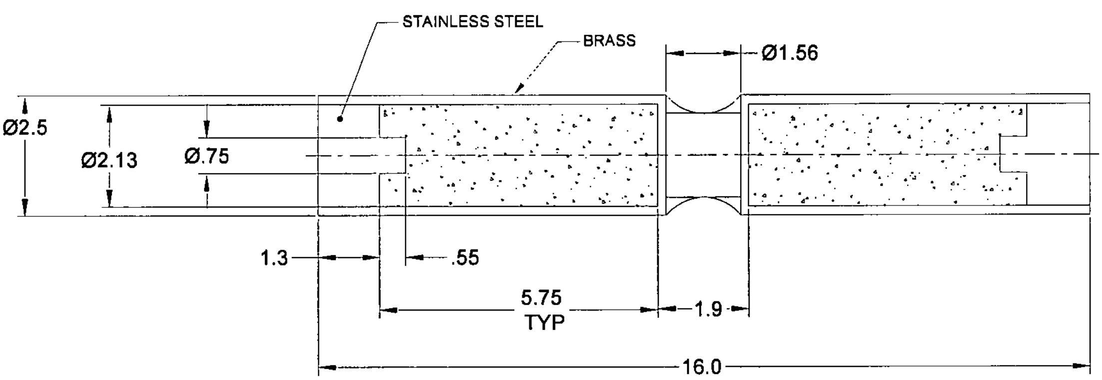


Figure 5.5.3-5 – GC-40 Drawer

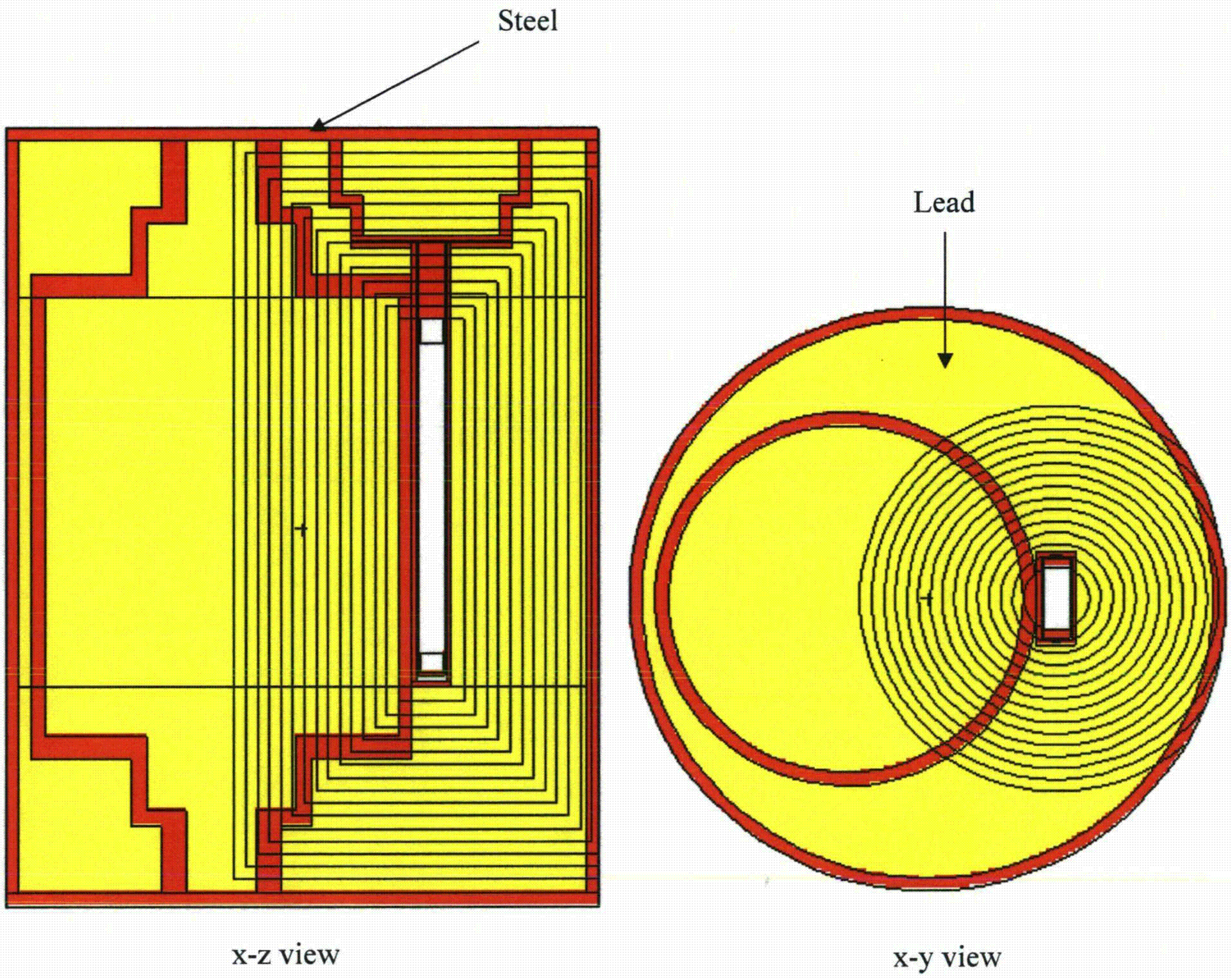
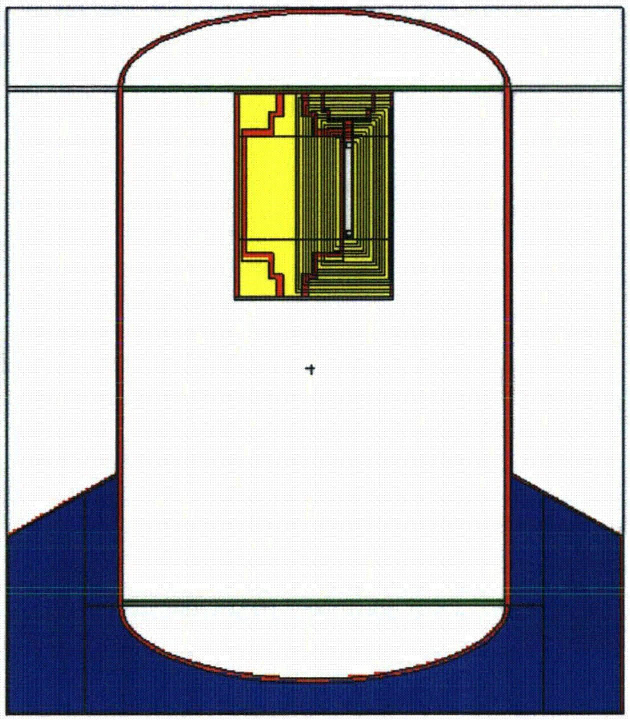
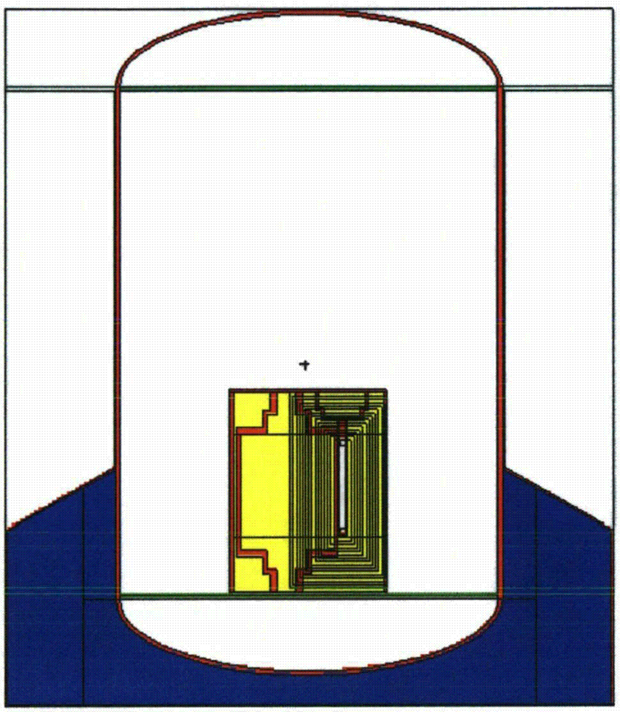


Figure 5.5.3-6 – GC-3000 MCNP Model



Shifted up



Shifted down

Figure 5.5.3-7 – NCT 435-B with GC-3000 MCNP Models

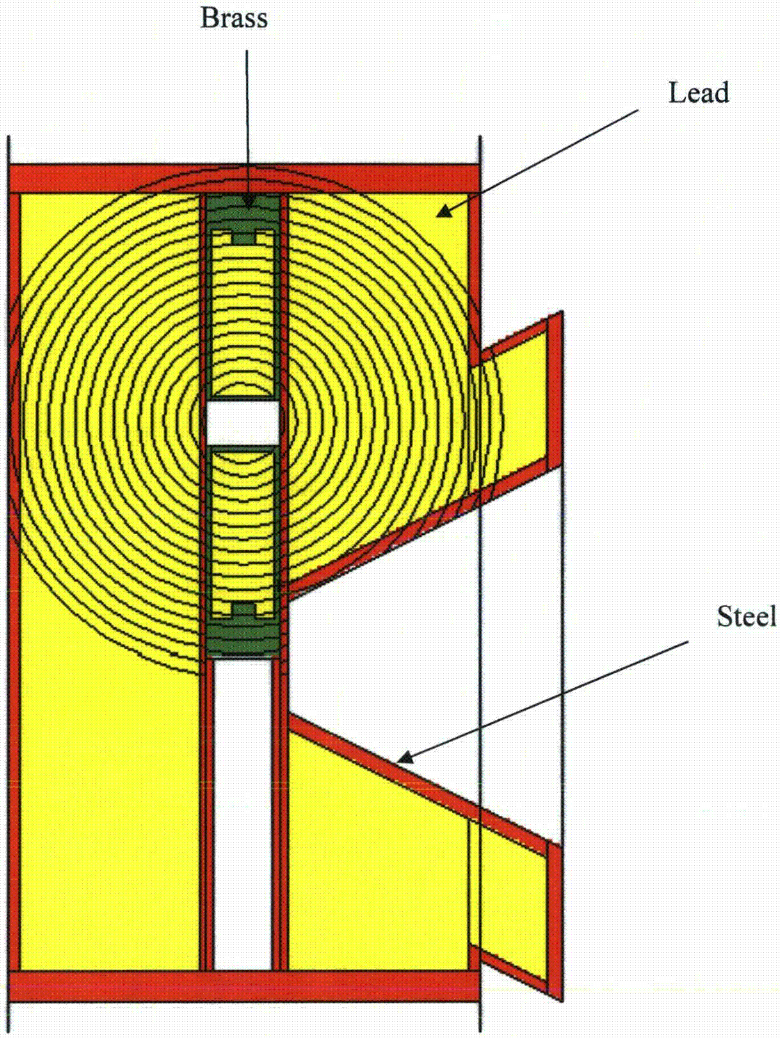
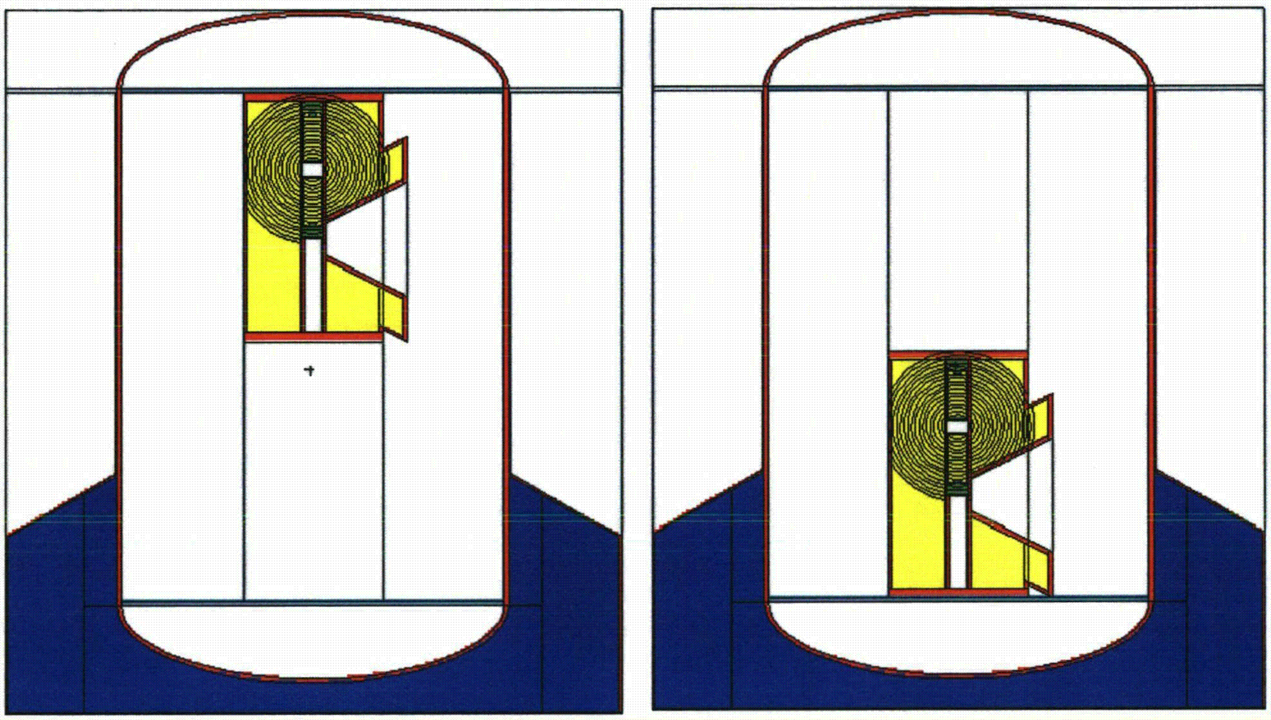
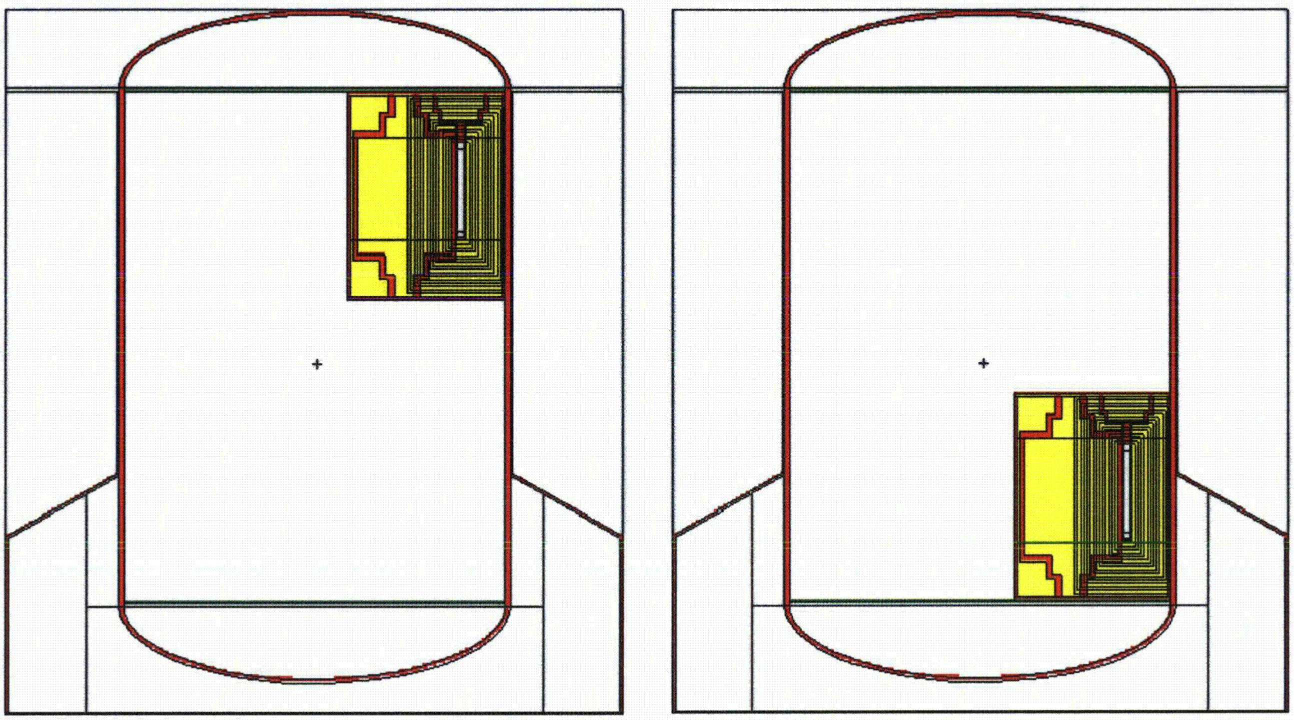


Figure 5.5.3-8 – GC-40 MCNP Model



Shifted up   Shifted down

Figure 5.5.3-9 – NCT 435-B with GC-40 MCNP Models



Shifted up

Shifted down

Figure 5.5.3-10 – HAC 435-B with GC-3000 MCNP Models

5.5.3.4 Shielding Evaluation

5.5.3.4.1 Methods

MCNP5 v1.51 is used for the shielding analysis [2]. MCNP5 is a standard, well-accepted shielding program utilized to compute dose rates for shielding licenses. A three-dimensional model is developed that captures all of the relevant design parameters of the 435-B package and contents. Dose rates are calculated by tallying the gamma fluxes over surfaces (or volumes) of interest and converting these fluxes to dose rates.

Mesh tallies are placed at the top, bottom, and side surfaces of the 435-B, as well as 1 m from these surfaces. Because the top surface of the 435-B is curved and the mesh tally is flat, the top surface mesh tally is placed as close to the top of the package as possible. The 1 m top tally is located 1 m from the axial center of the 9-in head (i.e., the axial center of the head is approximately 4.5-in below the top of the head) to bring this dose location closer to the package surface. The bottom mesh tally is at the bottom surface of the impact limiter, and the 1 m bottom tally is located 1 m from this surface. The top and bottom mesh tallies are rectangular 32x32 grids, with mesh dimensions of 10 cm x 10 cm. Therefore, the top and bottom mesh tallies extend approximately 1 m from the side surface of the side thermal shield.

The side cylindrical mesh tally is located next to the side thermal shield. The dose rates beside the impact limiter are not tallied with a mesh because the dose rate will be lower here due to the larger distance from the source. The side surface mesh tally begins at the bottom of the side thermal shield and extends 140 cm axially in 10 cm increments. The mesh 1 m from the package side is located 0.95 m from the surface of the side thermal shield, and is conservatively brought 0.05 m closer to the package surface to account for potential non-concentricity of the package internals. The mesh tally 1 m from the side of the package begins 1 m below the bottom of the package, and extends axially approximately 1 m above the top of the package in 10 cm increments. The side surface mesh tallies have 36 angular segments to capture the circumferential variation of the dose rate, since the dose rate is higher at the side of the package nearest where the source is placed.

5.5.3.4.2 Input and Output Data

A sample input file is provided in Appendix 5.5.3.5.2, *Sample Input File for Shielded Device* . Problem convergence is accelerated by dividing the device into layers and splitting the particles as particles traverse outwardly through these layers. The Monte Carlo uncertainty associated with the limiting dose rate location is less than 5%.

5.5.3.4.3 Flux-to-Dose Rate Conversion

Flux to dose rate conversion factors are defined in Section 5.4.3, *Flux-to-Dose Rate Conversion.*

5.5.3.4.4 External Radiation Levels

Dose rates are computed at the surface and 1 m from the surface of the 435-B package using mesh tallies, as described in Section 5.5.3.4.1, *Methods*. For non-exclusive use transportation, the dose rate is limited to 200 mrem/hr on the surface of the package and 10 mrem/hr at a distance of 1 m from the surface of the package.

The limiting dose rate results are summarized in Table 5.5.3-4 and Table 5.5.3-5 for the GC-3000 and GC-40, respectively. In all cases, the dose rates are far below the limits of 200 mrem/hr on the surface and 10 mrem/hr at a distance of 1 m from the surface.

It is apparent from the GC-3000 and GC-40 dose rates that the GC-3000 results in higher dose rates than the GC-40. Therefore, an HAC evaluation is performed only for the GC-3000. Dose rates at 1 m are computed using the same mesh tallies used in the NCT analysis. HAC results are provided in Table 5.5.3-6. Dose rates are negligible compared to the limit of 1000 mrem/hr.

Table 5.5.3-4 – NCT Dose Rate Results, GC-3000

Tally Location	GC-3000 Location	Dose Rate (mrem/hr)	σ	Limit (mrem/hr)
Top Surface	Shifted up	6.7	1.4%	200
Bottom Surface	Shifted down	0.4	7.1%	
Side Surface	Shifted up	18.6	2.6%	
Tally Location	**GC-3000 Location**	**Dose Rate (mrem/hr)**	**σ**	**Limit (mrem/hr)**
1m Top	Shifted up	0.8	2.9%	10
1m Bottom	Shifted down	0.04	5.7%	
1m Side	Shifted up	1.6	3.3%	

Table 5.5.3-5 – NCT Dose Rate Results, GC-40

Tally Location	GC-40 Location	Dose Rate (mrem/hr)	σ	Limit (mrem/hr)
Top Surface	Shifted up	0.3	1.1%	200
Bottom Surface	Shifted down	0.4	2.4%	
Side Surface	Shifted up	1.4	1.6%	
Tally Location	**GC-40 Location**	**Dose Rate (mrem/hr)**	**σ**	**Limit (mrem/hr)**
1m Top	Shifted up	0.04	2.5%	10
1m Bottom	Shifted down	0.06	5.6%	
1m Side	Shifted up	0.1	2.1%	

Table 5.5.3-6 – HAC Dose Rate Results, GC-3000

Tally Location	GC-3000 Location	Dose Rate (mrem/hr)	σ	Limit (mrem/hr)
1m Top	Shifted up	0.8	2.7%	1000
1m Bottom	Shifted down	0.04	4.3%	
1m Side	Shifted up	2.6	2.9%	

5.5.3.5 Appendices to Shielded Device Evaluation

5.5.3.5.1 References for Shielded Device Evaluation

1. Glenn F. Knoll, *Radiation Detection and Measurement*, Second Edition, John Wiley & Sons, 1989.
2. LA-UR-03-1987, *MCNP – A General Monte Carlo N-Particle Transport Code, Version 5*, Los Alamos National Laboratory, April 24, 2003 (Revised 2/1/2008).

5.5.3.5.2 Sample Input File for Shielded Device Evaluation

Sample case GC3000_UP1:

```
LANL-B
c
c      LANL-B Package
c
10     1 -7.94  10 -11 -35                        imp:p=1.5e7 $ base sheet
11     1 -7.94  (60 -61 31 -35):(34 -35 11 -61)  imp:p=1.5e7 $ cone sheet
12     0        -50 -12                           imp:p=1.5e7 $ inside head
13     1 -7.94  50 -51 -12                        imp:p=1.5e7 $ lower head
14     1 -7.94  30 -31 12 -17                     imp:p=5.8e6 $ shell
15     5 -2.7   12 -13 -30                        imp:p=1.5e7 $ bottom
16     2 -0.224 11 -12 51 -33                     imp:p=1.5e7 $ foam
17     2 -0.224 31 -33 12 -60                     imp:p=1.5e7 $ foam
18     2 -0.224 33 -34 11 -60                     imp:p=1.5e7 $ foam
19     5 -2.7   16 -17 -30                        imp:p=1.5e7 $ top plate
20     0        13 -16 -30 fill=1(0 0 122.1)      imp:p=1     $ cavity
21     1 -7.94  61 -16 31 -32                     imp:p=5.8e6 $ thermal shields
22     1 -7.94  52 -53 17                         imp:p=1.5e7 $ top head
23     0        17 -52                            imp:p=1     $ inside top
24     0        32 -35 61 -16                     imp:p=1     $ side air
25     0        16 -17 31 -35                     imp:p=1     $ side air sliver
26     0        17 -18 53 -35                     imp:p=1     $ top air
27     0        (-10:18:35) 70 -71 -72            imp:p=1     $ 1m
28     0        (-70:71:72) 73 -74 -75            imp:p=1     $ 2m
99     0        -73:74:75                         imp:p=0
c
c      Universe 1: GC-3000
c
100    0        103 -106 127 -128 131 -132 fill=2(9.906 0 18)  u=1 imp:p=1
101    1 -7.94  100 -101 -151                             fill=5 u=1 imp:p=1
102    1 -7.94  101 -112 150 -151                         fill=5 u=1 imp:p=1
103    1 -7.94  112 -113 -151                             fill=5 u=1 imp:p=1
104    3 -11.35 (111 -112 -122):(107 -111 -120)           fill=4 u=1 imp:p=1
105    1 -7.94  102 -103 126 -129 130 -133                fill=5 u=1 imp:p=1
106    1 -7.94  103 -106 126 -129 130 -133 #100           fill=5 u=1 imp:p=1
107    1 -7.94  (107 -110 120 -121):
                (110 -111 120 -123):(111 -112 122 -123)   fill=5 u=1 imp:p=1
108    1 -7.94  106 -107 -121                             fill=5 u=1 imp:p=1
109    1 -7.94  (-126:129:-130:133) 114 -106 -121         fill=5 u=1 imp:p=1
110    1 -7.94  (109 -112 140 -141):(108 -109 140 -143):
                (105 -108 142 -143):(104 -105 142 -144)   fill=5 u=1 imp:p=1
113    3 -11.35 (104 -108 -142):(108 -112 -140)           fill=4 u=1 imp:p=1
114    3 -11.35 104 -112 -150 #100 #104 #106 #107 #108
```

```
                                #109 #110 #113        fill=4 u=1 imp:p=1
115   3 -11.35 101 -102 -150 #116                     fill=4 u=1 imp:p=1
116   1 -7.94  (140 -141 101 -116):(141 -142 115 -116):
               (142 -143 115 -118):(143 -144 117 -118):
               (145 -144 118 -102)                    fill=5 u=1 imp:p=1
117   3 -11.35 (-126:129:-130:133) 102 -104 -150 #118  fill=4 u=1 imp:p=1
118   1 -7.94  102 -104 145 -144                      fill=5 u=1 imp:p=1
199   0        -100:151:113                                  u=1 imp:p=1
c
c     Universe 2: Pencil Holder
c
200   0        206 -207 201 -202 209 -210      u=2 imp:p=1 $ cavity
201   1 -7.94  205 -208 209 -210 212 -200      u=2 imp:p=1 $ bottom
202   0        200 -201 -211                   u=2 imp:p=1 $ hole
203   0        202 -203 -211                   u=2 imp:p=1 $ hole
204   1 -7.94  200 -201 205 -208 209 -210 211  u=2 imp:p=1 $ bottom w/ hole
205   1 -7.94  201 -202 205 -206 209 -210      u=2 imp:p=1 $ side
206   1 -7.94  201 -202 207 -208 209 -210      u=2 imp:p=1 $ side
207   1 -7.94  202 -203 205 -208 209 -210 211  u=2 imp:p=1 $ top w/ hole
208   1 -7.94  205 -208 203 -220 209 -210      u=2 imp:p=3 $ top
209   1 -7.94  205 -208 220 -221 209 -210      u=2 imp:p=9 $ top
210   1 -7.94  205 -208 221 -222 209 -210      u=2 imp:p=27 $ top
211   1 -7.94  205 -208 222 -223 209 -210      u=2 imp:p=81 $ top
212   1 -7.94  205 -208 223 -224 209 -210      u=2 imp:p=243 $ top
213   1 -7.94  205 -208 224 -204 209 -210      u=2 imp:p=729 $ top
214   0        -205:208:-212:204:-209:210      u=2 imp:p=1
c
c     Universe 4: Splitting universe for lead
c
400   3 -11.35  -400 460 -430                 u=4 imp:p=1
401   3 -11.35  (400:430:-460) -401 -431 461 u=4 imp:p=3
402   3 -11.35  (401:431:-461) -402 -432 462 u=4 imp:p=9
403   3 -11.35  (402:432:-462) -403 -433 463 u=4 imp:p=27
404   3 -11.35  (403:433:-463) -404 -434 464 u=4 imp:p=81
405   3 -11.35  (404:434:-464) -405 -435 465 u=4 imp:p=243
406   3 -11.35  (405:435:-465) -406 -436 466 u=4 imp:p=729
407   3 -11.35  (406:436:-466) -407 -437 467 u=4 imp:p=2187
408   3 -11.35  (407:437:-467) -408 -438 468 u=4 imp:p=6561
409   3 -11.35  (408:438:-468) -409 -439 469 u=4 imp:p=2e4
410   3 -11.35  (409:439:-469) -410 -440 470 u=4 imp:p=6e4
411   3 -11.35  (410:440:-470) -411 -441 471 u=4 imp:p=1.8e5
412   3 -11.35  (411:441:-471) -412 -442 472 u=4 imp:p=5.3e5
413   3 -11.35  (412:442:-472) -413 -443 473 u=4 imp:p=1.6e6
414   3 -11.35  (413:443:-473) -414 -444 474 u=4 imp:p=4.8e6
415   3 -11.35  (414:444:-474)                u=4 imp:p=1.4e7
c
c     Universe 5: Splitting universe for steel
c
500   1 -7.94  -400 460 -430                 u=5 imp:p=1
501   1 -7.94  (400:430:-460) -401 -431 461 u=5 imp:p=3
502   1 -7.94  (401:431:-461) -402 -432 462 u=5 imp:p=9
503   1 -7.94  (402:432:-462) -403 -433 463 u=5 imp:p=27
504   1 -7.94  (403:433:-463) -404 -434 464 u=5 imp:p=81
505   1 -7.94  (404:434:-464) -405 -435 465 u=5 imp:p=243
506   1 -7.94  (405:435:-465) -406 -436 466 u=5 imp:p=729
507   1 -7.94  (406:436:-466) -407 -437 467 u=5 imp:p=2187
508   1 -7.94  (407:437:-467) -408 -438 468 u=5 imp:p=6561
```

```
509   1 -7.94  (408:438:-468) -409 -439 469 u=5 imp:p=2e4
510   1 -7.94  (409:439:-469) -410 -440 470 u=5 imp:p=6e4
511   1 -7.94  (410:440:-470) -411 -441 471 u=5 imp:p=1.8e5
512   1 -7.94  (411:441:-471) -412 -442 472 u=5 imp:p=5.3e5
513   1 -7.94  (412:442:-472) -413 -443 473 u=5 imp:p=1.6e6
514   1 -7.94  (413:443:-473) -414 -444 474 u=5 imp:p=4.8e6
515   1 -7.94  (414:444:-474)               u=5 imp:p=1.4e7

c
c    Package
c
10   pz  0        $ bottom of package
11   pz  0.635    $ bottom plate
12   pz  32.004   $ bottom of inner support
13   pz  33.274   $ bottom of cavity
16   pz  183.106  $ top of cavity
17   pz  184.376  $ top of top plate
18   pz  207.3    $ top of model
30   cz  55.245   $ shell inner
31   cz  56.515   $ shell outer
32   cz  56.9341  $ outer thermal shields
33   cz  66.04    $ foam interface
34   cz  88.265   $ base sheet inner
35   cz  88.9     $ base sheet outer
50   ell 0 0 32.004  0 0 21.59 -55.245 $ lower head inner
51   ell 0 0 32.004  0 0 22.86 -56.515 $ lower head outer
52   ell 0 0 184.376 0 0 21.59 -55.245 $ upper head inner
53   ell 0 0 184.376 0 0 22.86 -56.515 $ upper head outer
60   kz  103.0298 3.0 -1
61   kz  103.7630 3.0 -1
70   pz -100      $ bottom 1m
71   pz  295.8    $ top 1m (measured from the axial middle of the head)
72   cz  156.9341 $ side 1m
73   pz -200      $ bottom of model
74   pz  410      $ top of model
75   cz  256      $ side of model
c
c    GC-3000
c
100  pz 0.0001    $ bottom of GC3000
101  pz 0.9652
102  pz 17.1958
103  pz 17.526
104  pz 47.625
105  pz 49.53
106  pz 52.07
107  pz 52.5272
108  pz 53.467
109  pz 54.737
110  pz 54.7878
111  pz 55.7022
112  pz 59.9948
113  pz 60.96     $ top of GC3000
114  pz 51.6128
115  pz 6.223
116  pz 7.493
117  pz 11.43
```

```
118  pz 13.335
c
120  c/z 9.906 0 5.2578 $ source side
121  c/z 9.906 0 6.1722
122  c/z 9.906 0 6.8453
123  c/z 9.906 0 7.7597
126  px 8.4328          $ source slot
127  px 8.763
128  px 11.049
129  px 11.3792
130  py -3.6322
131  py -3.302
132  py  3.302
133  py  3.6322
c
140  c/z -6.223 0 2.7178 $ chamber side
141  c/z -6.223 0 4.6482
142  c/z -6.223 0 5.715
143  c/z -6.223 0 6.985
144  c/z -6.223 0 14.6553
145  c/z -6.223 0 13.5856
c
150  cz 21.8948
151  cz 22.86
c
c    Holder
c
200  pz 0.3302
201  pz 1.8542
202  pz 26.1112
203  pz 28.0162
204  pz 33.9852 $ top
205  py -3.175
206  py -2.413
207  py 2.413
208  py 3.175
209  px -1.0478
210  px 1.0478
211  cz 0.889   $ hole
212  pz 0.0002
220  pz 29
221  pz 30
222  pz 31
223  pz 32
224  pz 33
c
c    Splitting
c
400  c/z 9.906 0 2.5
401  c/z 9.906 0 3.4
402  c/z 9.906 0 4.3
403  c/z 9.906 0 5.2
404  c/z 9.906 0 6.1
405  c/z 9.906 0 7.0
406  c/z 9.906 0 7.9
407  c/z 9.906 0 8.8
408  c/z 9.906 0 9.7
```

```
409  c/z 9.906 0 10.6
410  c/z 9.906 0 11.5
411  c/z 9.906 0 12.4
412  c/z 9.906 0 13.3
413  c/z 9.906 0 14.2
414  c/z 9.906 0 15.1
c 415  c/z 9.906 0 17.5
c 416  c/z 9.906 0 18.5
c 417  c/z 9.906 0 19.5
c
430  pz 46
431  pz 47
432  pz 48
433  pz 49
434  pz 50
435  pz 51
436  pz 52
437  pz 53
438  pz 54
439  pz 55
440  pz 56
441  pz 57
442  pz 58
443  pz 59
444  pz 60
c
460  pz 16
461  pz 15
462  pz 14
463  pz 13
464  pz 12
465  pz 11
466  pz 10
467  pz 9
468  pz 8
469  pz 7
470  pz 6
471  pz 5
472  pz 4
473  pz 3
474  pz 2
c
c    Tally surfaces
c
2000 cz 7.5
2001 cz 22.5
2002 cz 37.5
2003 cz 52.5
2004 cz 67.5
2005 cz 82.5
2006 cz 97.5
2007 cz 112.5
2008 cz 127.5
2009 cz 142.5
c
2050 pz -90.5
2051 pz -75.5
```

```
2052 pz -60.5
2053 pz -45.5
2054 pz -30.5
2055 pz -15.5
2056 pz -0.5
2057 pz 14.5
2058 pz 29.5
2059 pz 44.5
2060 pz 59.5
2061 pz 74.5
2062 pz 89.5
2063 pz 104.5
2064 pz 119.5
2065 pz 134.5
2066 pz 149.5
2067 pz 164.5
2068 pz 179.5
2069 pz 194.5
2070 pz 209.5
2071 pz 224.5
2072 pz 239.5
2073 pz 254.5
2074 pz 269.5
2075 pz 284.5
c
2100 pz 52.4

mode p
m1     6000   -0.08      $ SS304
       14000  -1.0
       15031  -0.045
       24000  -19
       25055  -2
       26000  -68.375
       28000  -9.5
m2     6000   -0.6       $ foam
       8000   -0.24
       7000   -0.12
       1000   -0.04
m3     82000 1           $ lead
m5     13027 1           $ al
c
sdef  cel=d1 pos=0 0 13.9827 erg=d3 rad=d2 ext=d4 axs=0 0 1 wgt=1.208e14 $ 3840 Ci Cs-137
si1    L 20:100:200
sp1    1
si2    0.5
si4    12.1
#      si3   sp3
       L     d
       0.662 1
c
c    Tallies
c
c      ansi/ans-6.1.1-1977 flux-to-dose, photons (mrem/hr)/(p/cm**2/s)
de0         0.01    0.03    0.05    0.07    0.10    0.15    0.20    0.25    0.30
            0.35    0.40    0.45    0.50    0.55    0.60    0.65    0.70    0.80
            1.00    1.40    1.80    2.20    2.60    2.80    3.25    3.75    4.25
```

```
           4.75   5.00   5.25   5.75   6.25   6.75   7.50   9.00   11.0
           13.0   15.0
df0        3.96-3 5.82-4 2.90-4 2.58-4 2.83-4 3.79-4 5.01-4 6.31-4 7.59-4
           8.78-4 9.85-4 1.08-3 1.17-3 1.27-3 1.36-3 1.44-3 1.52-3 1.68-3
           1.98-3 2.51-3 2.99-3 3.42-3 3.82-3 4.01-3 4.41-3 4.83-3 5.23-3
           5.60-3 5.80-3 6.01-3 6.37-3 6.74-3 7.11-3 7.66-3 8.77-3 1.03-2
           1.18-2 1.33-2
c
fc12    Bottom Surface
f12:p   10
fs12   -2000 -2001 -2002 -2003 -2004 -2005
c
fc22    Top Surface (last junk)
f22:p   53
fs22    -2000 -2001 -2002 -2003
c
fc32    Side surface (primary)
f32:p   32
fs32    -2061 -2062 -2063 -2064 -2065 -2066 -2067 -2068
c
fc42    Side surface (base) (last junk)
f42:p   35
fs42    -2057 -2058 -2059 -2100
c
fc52    Side surface (base conical)
f52:p   61
fs52    -2004 -2005
c
fc62    Bottom 1m Surface
f62:p   70
fs62    -2000 -2001 -2002 -2003 -2004 -2005 -2006 -2007 -2008 -2009
c
fc72    Top 1m Surface
f72:p   71
fs72    -2000 -2001 -2002 -2003 -2004 -2005 -2006 -2007 -2008 -2009
c
fc82    Side 1m surface
f82:p   72
fs82    -2050 -2051 -2052 -2053 -2054 -2055 -2056 -2057 -2058 -2059
        -2060 -2061 -2062 -2063 -2064 -2065 -2066 -2067 -2068 -2069
        -2070 -2071 -2072 -2073 -2074 -2075
c
c       A rectangular mesh tally is placed at the top surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh14:p geom=xyz origin=-160 -160 207.3
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=208.3
            kints=1
c
c       A rectangular mesh tally is placed 1m from the top,
c       The 1 m location is measured from the center of the head.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
```

```
fmesh24:p geom=xyz origin=-160 -160 296.8
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=298.8
            kints=1
c
c       A rectangular mesh tally is placed at the bottom surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh34:p geom=xyz origin=-160 -160 -1
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=0
            kints=1
c
c       A rectangular mesh tally is placed 1m from the bottom surface.
c       The grid is 32x32, and each square is 10 cm x 10 cm
c
fmesh44:p geom=xyz origin=-160 -160 -101
            imesh=160
            iints=32
            jmesh=160
            jints=32
            kmesh=-99
            kints=1
c
c          A cylindrical mesh tally is placed around the package surface.
c          Circumferentially there are 36 segments,
c          each 10 degrees wide.  Theta=0 corresponds to the positive y-axis.
c          radius=i
c          axial=j
c          circumferential=k
c
fmesh54:p   geom=cyl origin=0 0 70 axs=0 0 1 vec=0 1 0
            imesh=56.94 57.94
            iints=1 1
            jmesh=140
            jints=14
            kmesh=1
            kints=36
c
c          A cylindrical mesh tally is placed around the package
c          0.95 m from the surface of the package.
c          Circumferentially there are 36 segments,
c          each 10 degrees wide.  Theta=0 corresponds to the positive y-axis.
c          radius=i
c          axial=j
c          circumferential=k
c
fmesh64:p   geom=cyl origin=0 0 -100 axs=0 0 1 vec=0 1 0
            imesh=150.9 152.9
            iints=1 1
            jmesh=400
```

```
            jints=40
            kmesh=1
            kints=36
c
prdmp   j j 1 2
ctme    2940
```

6.0 CRITICALITY EVALUATION

Based on the provisions of 10 CFR 71.15(b) [1], the 435-B package contents are exempt from classification as fissile material. The maximum content of fissile material in the 435-B is 15g. There is an adequate mass of steel in the packaging, neglecting any other materials, to satisfy the requirements of 10 CFR 71.15(b). Therefore, a criticality evaluation is not required.

6.1 References

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 01–01–11 Edition.

7.0 PACKAGE OPERATIONS

The 435-B packaging consists of four major components: the Lower Body Assembly, or base (1916-01-01-SAR, Assembly A2), the Upper Body Assembly, or bell (1916-01-01-SAR, Assembly A3), the Lodgment (1916-01-02-SAR), and the Inner Container, or IC (1916-01-03-SAR). Both the bell and the base include an Internal Impact Limiter Assembly (1916-01-01-SAR, Assembly A4), which are not removed during normal operation. The single external impact limiter is part of the base and is not separable. Reference to specific 435-B packaging components may be found in Appendix 1.3.3, *Packaging General Arrangement Drawings*.

7.1 Procedures for Loading the Package

This section delineates the procedures for loading a payload into the 435-B packaging.

7.1.1 General Lifting and Handling

1. The 435-B package is lifted only from the bottom using a pallet. The threaded hole in the top of the bell is not to be used for lifting the package.
2. After the 24 closure bolts have been removed, the bell is lifted off of the base using the 3/4-10 UNC threaded hole in the top of the bell.
3. The bell must be set down on a smooth, clean surface free of grit, such as paper or plastic sheet.
4. With the bell removed, the base may be moved either using the pallet, or by making use of the threaded closure bolt holes. The maximum depth of penetration into the threaded holes from the flange surface must not exceed 2.5 inches. Use caution not to damage the machined flange surface or the O-rings, if installed, and do not apply any loads to the vertical portion of the flange that contains the O-ring grooves.
5. Perform all operations in a clean work area. Before lifting the payload or the bell over the base, ensure that the lower surfaces are free of debris.

7.1.2 Loading of Contents

The 435-B payload consists either of the Long Term Storage Shield (LTSS), transported using the lodgment (see drawing 1916-01-02-SAR) or any of the devices listed in Table 1.2-2 using the Inner Container (IC) (see drawing 1916-01-03-SAR).

7.1.2.1 Loading the LTSS into the 435-B

1. Remove the 5, 1/2-13UNC socket head cap screws (SHCS) from each half of the rain shield (total of 10 bolts).
2. Remove the vent port insulation cylinder and seal test port insulation cylinder from the vent port and seal test port access tubes, respectively.
3. Remove the 24, 1-1/4-7UNC socket head cap screws from the bell flange. The bolt heads feature holes that may be used with wire hooks to lift the bolts out of the tubes.
4. Using the lift point at the top, remove the bell.

5. Ensure that the LTSS has been loaded according to the procedure delineated in Section 7.1.4, *Loading and Preparing the LTSS for Transport.*
6. The LTSS may be loaded into the lodgment before placing it in the 435-B packaging. Optionally, the LTSS may be loaded into the lodgment with the lodgment in place in the packaging.
7. Remove the 8, 1/2-13UNC bolts which connect the upper and lower halves of the lodgment.
8. Lift off the upper lodgment half. For convenience, lifting shackles may optionally be retained in storage locations found near the lifting holes.
9. Remove the LTSS from its storage base and upright it so that its longitudinal axis is essentially vertical.
10. Lift the LTSS using hoist rings or equivalent mounted in the two M16 threaded holes located in the LTSS lifting blocks.
11. Place the LTSS into the lodgment lower half, taking care to align the hinge on the LTSS with the associated clearance cutouts in the ribs in the lower half. Ensure that the lower end of the LTSS is approximately centrally placed and seated on the thick rubber pad at the bottom of the lodgment.
12. Remove the lifting load from the LTSS. Temporary spacers or equivalent may be used between the LTSS and the lodgment, if necessary, in order to keep the LTSS essentially vertical after removal of the lifting load. The two hoist rings may be left in place in the LTSS.
13. Lower the upper half of the lodgment over the LTSS using the index marks to align the ribs in the correct orientation. Ensure that the three toggle clamps are open, and that they pass freely over the top end of the LTSS.
14. Install the 8, 1/2-13UNC bolts in the clevises which connect the lodgment upper half and lower half. Tighten the hex locknuts only to contact with the clevises.
15. Close each of the three toggle clamps. Adjust each clamp as necessary so that a similar clamping force is applied by each clamp. If used, remove temporary spacers.
16. Using the lifting holes provided in two opposite ribs of the upper lodgment, lift the loaded lodgment assembly over the package base. Before passing over the base, ensure that the bottom of the lodgment is free of loose debris.
17. Using the centering guides located on the lower internal impact limiter, lower the lodgment into position on the base. Ensure that the lower surface of the lodgment is resting flat on the base.
18. Visually inspect both main containment O-ring seals and the mating surfaces on the bell. If damage is present that is sufficient to impair containment integrity (e.g., cuts, tears, and/or joint separation in the O-ring, or scratches or dents in the sealing surfaces), replace the seals and/or repair the damaged surfaces per Section 8.2.3.2, *Sealing Area Routine Inspection and Repair*.
19. As an option, remove and sparingly apply vacuum grease to the O-ring seals and/or sealing surfaces, and reinstall the O-rings into the grooves in the base flange.

20. Remove and visually inspect the vent port and seal test port plugs and associated sealing washers and mating surfaces on the flange. If damage is present that is sufficient to impair containment integrity (e.g., cuts, tears, and/or separation of the O-ring from the metal washer, or scratches or dents in the sealing surfaces), replace the seals and/or repair the damaged surfaces per Section 8.2.3.2, *Sealing Area Routine Inspection and Repair*.
21. Reinstall the vent port and seal test port plugs and sealing washers. Do not tighten at this time.
22. If not already present, install seal surface protector(s) on the bell, and optionally, install seal protector(s) on the base.
23. Verify that no foreign material has entered the packaging cavity during loading.
24. Lower the bell over the lodgment. When the bell bottom edge is several inches below the widest part of the lodgment, remove the bell seal surface protector(s) and base seal protector(s), if used. Continue to lower the bell into position on the base, using the alignment marks and the alignment pins. Before losing sight of the base O-ring seals, visually determine that no debris is present on the O-ring seals.
25. Coat closure bolt threads and washer surfaces with a low-halogen, nickel based nuclear grade lubricant prior to assembly. Re-coating is not required if an adequate coat exists. Install the 24 closure bolts, and using a crossing pattern, tighten to 270 – 330 ft-lb torque.
26. Preshipment leakage rate testing of the main containment O-ring seal and vent port sealing washer shall be performed according to the following criteria:
    a. If the main containment (upper) O-ring seal has been replaced or the corresponding sealing surface repaired, or if the vent port plug or sealing washer has been replaced or the mating sealing surface repaired, the leakage rate tests shall be performed according to Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*.
    b. If the criteria of step (a) above do not apply, as an option, preshipment leakage rate testing may be performed according to Section 7.4, *Preshipment Leakage Rate Test*.
27. After preshipment leakage rate testing is complete and associated equipment has been removed, ensure that the vent port plug and seal test port plug are tightened to 48 – 60 in-lb torque.
28. Install a port insulation cylinder in the vent port access tube and in the seal test port access tube. Note that both cylinders are identical.
29. Install the two halves of the rain shield using 5 each, 1/2-13UNC bolts, tightened to 22 – 28 ft-lb torque. Optionally, a weather seal may be used with the rain shield, or nuclear-grade duct tape may be used to cover the rain shield or tube sheet-to-impact limiter joints.
30. Install tamper-indicating lockwire in two adjacent rain shield bolts. Both bolts must be located on the same rain shield half.

7.1.2.2 Loading the Inner Container (IC) into the 435-B

1. Remove the 5, 1/2-13UNC socket head cap screws (SHCS) from each half of the rain shield (total of 10 bolts).

2. Remove the vent port insulation cylinder and seal test port insulation cylinder from the vent port and seal test port access tubes, respectively.
3. Remove the 24, 1-1/4-7UNC socket head cap screws from the bell flange. The bolt heads feature holes that may be used with wire hooks to lift the bolts out of the tubes.
4. Using the lift point at the top, remove the bell.
5. Prepare a shielded device for transport per the procedural steps in Section 7.1.2.2.1, *Preparing Group 1 Devices for Transport*, or Section 7.1.2.2.2, *Preparing Group 3 Devices for Transport*.
6. Remove the six, 1-8UNC bolts holding the lid to the IC, and remove the lid using the three, ½-13UNC lifting holes located near the perimeter of the lid top surface.
7. Load the shielded device into the IC.
    a. Prepare the blocking/dunnage. Dunnage shall be structural metal such as aluminum, stainless steel, or carbon steel in a welded or bolted configuration, or it may be made from blocks of polymeric foam. Polymeric foam dunnage shall be rigid, closed-cell, and have a decomposition temperature greater than or equal to 400 °F. The total weight of all dunnage material must be less than or equal to 500 lb.
    b. Ensure that the cavity of the IC is clean and dry and free of foreign material. Protect from entry of precipitation.
    c. Place the lower dunnage, as needed, into the bottom of the IC.
    d. Place the shielded device into the IC with its axis vertical.
        i. The dunnage shall be configured to locate the axis of the device approximately along the axis of the IC.
        ii. The CG of the device (alternately, the center of the device) must be placed at or below the mid-height of the IC (i.e., no more than 26.5 inches from the bottom floor of the IC).
        iii. If using polymeric foam as dunnage, ensure that at least 50% of the side axial height of the device is not covered by dunnage material. This restriction does not apply to metallic dunnage.
    e. Place the upper dunnage, as needed, into the IC.
8. Replace the IC lid and install the six, 1-8UNC bolts, flat washers, and nuts, applying a torque of 170 to 210 ft-lb. Since the bolts are zinc plated, lubrication of the threads is optional.
9. Using the three, ½-13UNC lifting holes in the IC lid, lift the IC over the package base. Before passing over the base, ensure that the bottom of the IC is free of loose debris.
10. Using the centering guides located on the lower internal impact limiter, lower the IC into position on the base. Ensure that the lower surface of the IC is resting flat on the base.
11. Visually inspect both main containment O-ring seals and the mating surfaces on the bell. If damage is present that is sufficient to impair containment integrity (e.g., cuts, tears, and/or joint separation in the O-ring, or scratches or dents in the sealing surfaces), replace the seals

and/or repair the damaged surfaces per Section 8.2.3.2, *Sealing Area Routine Inspection and Repair*.

12. As an option, remove and sparingly apply vacuum grease to the O-ring seals and/or sealing surfaces, and reinstall the O-rings into the grooves in the base flange.
13. Remove and visually inspect the vent port and seal test port plugs and associated sealing washers and mating surfaces on the flange. If damage is present that is sufficient to impair containment integrity (e.g., cuts, tears, and/or separation of the O-ring from the metal washer, or scratches or dents in the sealing surfaces), replace the seals and/or repair the damaged surfaces per Section 8.2.3.2, *Sealing Area Routine Inspection and Repair*.
14. Reinstall the vent port and seal test port plugs and sealing washers. Do not tighten at this time.
15. If not already present, install seal surface protector(s) on the bell, and optionally, install seal protector(s) on the base.
16. Verify that no foreign material has entered the packaging cavity during loading.
17. Lower the bell over the IC. When the bell bottom edge is several inches below the IC top, remove the bell seal surface protector(s) and base seal protector(s), if used. Continue to lower the bell into position on the base, using the alignment marks and the alignment pins. Before losing sight of the base O-ring seals, visually determine that no debris is present on the O-ring seals.
18. Coat closure bolt threads and washer surfaces with a low-halogen, nickel based nuclear grade lubricant prior to assembly. Re-coating is not required if an adequate coat exists. Install the 24 closure bolts, and using a crossing pattern, tighten to 270 – 330 ft-lb torque.
19. Preshipment leakage rate testing of the main containment O-ring seal and vent port sealing washer shall be performed according to the following criteria:
    a. If the main containment (upper) O-ring seal has been replaced or the corresponding sealing surface repaired, or if the vent port plug or sealing washer has been replaced or the mating sealing surface repaired, the leakage rate tests shall be performed according to Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*.
    b. If the criteria of step (a) above do not apply, as an option, preshipment leakage rate testing may be performed according to Section 7.4, *Preshipment Leakage Rate Test*.
20. After preshipment leakage rate testing is complete and associated equipment has been removed, ensure that the vent port plug and seal test port plug are tightened to 48 – 60 in-lb torque.
21. Install a port insulation cylinder in the vent port access tube and in the seal test port access tube. Note that both cylinders are identical.
22. Install the two halves of the rain shield using 5 each, 1/2-13UNC bolts, tightened to 22 – 28 ft-lb torque. Optionally, a weather seal may be used with the rain shield, or nuclear-grade duct tape may be used to cover the rain shield or tube sheet-to-impact limiter joints.
23. Install tamper-indicating lockwire in two adjacent rain shield bolts. Both bolts must be located on the same rain shield half.

7.1.2.2.1 Preparing Group 1 Devices for Transport

1. Identify the shielded device and ensure that the model number matches one of the model numbers listed under Group 1 in Table 1.2-2.
2. Remove all components that are not necessary to the shielding function or to the source retention function, such as stands, cabinets, enclosures, electrical hardware, motors, or any other auxiliary or unnecessary equipment. Remove the auxiliary (external) shield component from the GC-3000. Lifting loops may be left intact.
3. The maximum weight of the device must be less than or equal to 3,500 lb.
4. The rotating sample chamber (aka the rotor) must be mechanically fixed in position with the sample chamber facing outward.
5. Inspect the device for damage to the body assembly and to structural components that contain the lead shielding or retain the source in a safe position. Identify any cracks, voids, or corrosion that is significantly deeper than the surface. Visually inspect the weld that retains the shield plug for cracks, damage, or significant corrosion. Any flaws of this kind disqualify the device for transport.
6. Perform a radiation survey of the entire device surface. The dose rate must be less than 200 mrem/hr on the surface and less than 10 mrem/hr at a distance of one meter from the surface. Failure to meet this requirement disqualifies the device for transport.
7. The Group 1 device is now ready for placement in the inner container.

7.1.2.2.2 Preparing Group 3 Devices for Transport

1. The only Group 3 device defined and eligible for transport in the 435-B is the Gammacell-40, also known as the Exactor, or as the GC-40.
2. Remove all components that are not necessary to the shielding function or to the source retention function, such as stands, cabinets, enclosures, electrical hardware, motors, or any other auxiliary or unnecessary equipment.
3. The maximum weight must be less than or equal to 3,500 lb.
4. A fully configured GC-40 contains two separate shielded devices, the upper head and the lower head. Only one device shall be transported at a time.

To prepare the upper head:

5. Disassemble the upper head from the sample chamber. Inspect the device for damage to the body assembly and to structural components that contain the lead shielding or retain the source in a safe position. Identify any cracks, voids, or corrosion that is significantly deeper than the surface. Any flaws of this kind disqualify the device for transport.
6. The source must be located in the storage position and held in place by a shipping fixture placed in the drawer opening.
7. A retaining plate must be fastened to each end of the head using four socket head cap screws meeting the tensile strength requirements of ASTM F837 (stainless steel) or ASTM A574 (alloy steel) or better.

8. Perform a radiation survey of the entire device surface. The dose rate must be less than 200 mrem/hr on the surface and less than 10 mrem/hr at a distance of one meter from the surface. Failure to meet this requirement disqualifies the device for transport.
9. The upper head is now ready for placement in the inner container.

To prepare the lower head:

10. Disassemble the sample chamber from the top of the lower head. Remove the lower head from any base to which it may be attached.
11. Using appropriate equipment, cut off the steel framework which is welded to the lower head. Leave approximately one to two inches of the plate material still attached. Do not damage the shell of the head.
12. The maximum weight must be less than or equal to 3,500 lb.
13. Inspect the device for damage to the body assembly and to structural components that contain the lead shielding or retain the source in a safe position. Identify any cracks, voids, or corrosion that is significantly deeper than the surface.
14. The source must be located in the storage position and held in place by a shipping fixture placed in the drawer opening.
15. A retaining plate must be fastened to each end of the head using four socket head cap screws meeting the tensile strength requirements of ASTM F837 (stainless steel) or ASTM A574 (alloy steel) or better.
16. Perform a radiation survey of the entire device surface. The dose rate must be less than 200 mrem/hr on the surface and less than 10 mrem/hr at a distance of one meter from the surface. Failure to meet this requirement disqualifies the device for transport.
17. The lower head is now ready for placement in the inner container.

7.1.3 Preparation of the 435-B Package for Transport

1. Cover the threaded hole in the top of the bell by mechanical means, such as a bolt, per drawing 1916-01-01-SAR.
2. Place the 435-B package and pallet onto the conveyance.
3. Install the tie–down assembly over the top of the impact limiter, and secure to the conveyance. Ensure that chocks (horizontal restraints) are properly installed on the conveyance.
4. Monitor external radiation for the package per the requirements of 49 CFR §173.441 [2].
5. Determine that surface contamination levels for the package is per the requirements of 10 CFR §71.87(i) [1] and 49 CFR §173.443 [2].
6. Determine the transport index for the package per the requirements of 49 CFR §173.403 [2].
7. Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172 [3].
8. 435-B package marking shall be in accordance with 10 CFR §71.85(c) [1] and Subpart D of 49 CFR 172 [3]. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Package placarding shall be in accordance with Subpart F of 49 CFR 172.

7.1.4 Loading and Preparing the LTSS for Transport

The LTSS is loaded and prepared for transport in the 435-B package in three steps: 1) Qualifying a payload for transport (Section 7.1.4.1), 2) Preparing large source drawers (Section 7.1.4.2), and 3) Loading drawers into the LTSS (Section 7.1.4.3).

7.1.4.1 Qualifying a Payload for Transport

INTRODUCTORY INFORMATION

The LTSS may transport two content types: *Content 1* is the T80/T780 source drawer containing a Co-60 source.

Content 2 (the subject of the following paragraphs) is the large source drawer containing end shield plugs and a capsule, which, in turn, contains a radioactive source. Content 2 sources must be placed in capsules for loading into the LTSS. There are five different special form capsules that may be used, differing only in length: NLM 52-74, NLM 52-150, NLM 52-200, NLM 52-250, or NLM 52-325, which are 74 mm, 150 mm, 200 mm, 250 mm, and 325 mm long, respectively. The special form capsule is certified by the South African Competent Authority under certificate number ZA/NLM52/S. Other special form or non-special form capsules may be used that have the same length, diameter, and at least as much radiation attenuation as the NLM-52 capsule series. The NLM 52 nomenclature is used in the following discussion for convenience. When loaded with a special form capsule, the large source drawer is designated accordingly. For example, a large source drawer loaded with a NLM 52-250 special form capsule is designated the large source drawer 250, or LD-250. With the exception of the LD-150, a large source drawer contains a single special form capsule, centered between two equal-length tungsten end shield plugs. The LD-150 may contain either a NLM 52-150 or two NLM 52-74s. The longer the capsule, the shorter the end shield plugs. The end shield plugs nominally fill the space not taken by the special form capsule.

Sources are differentiated into two physical forms: pencil and short cylinder. All pencil sources are allowed to contain only one of two isotopes: Co-60 or Cs-137. Short cylinder sources may contain any of the isotopes in Table 7.1-1. The special form capsules must contain only the isotopes and physical form combinations delineated in Table 7.1-3. Each capsule must contain only one isotope type, but may contain multiple sources having the same isotope. Any of the four recesses in the LTSS that is not loaded with a large source drawer must be loaded with a shield drawer. An empty recess is not permitted.

There are eight configurations of large source drawers that are permitted in the LTSS, depending on the contents of the drawer and the arrangement of the drawers in the four recesses in the LTSS. These configurations are designated A, B, C, D, E, AB, BC, and BD. All of the single-letter designations specify a single large source drawer type in each of the four recesses. For example, configuration C is for an LD-200 in each recess. All of the two-letter designations specify a certain combination of drawers in the four recesses. For example, configuration BC specifies an LD-150 in recesses 1 and 2, and an LD-200 in recesses 3 and 4. The configurations are completely defined in Table 7.1-4. Note that a shield drawer may be substituted for any loaded drawer in any of the configurations. Note: a shield drawer is a large source drawer nominally filled with a tungsten plug.

The following procedure identifies the activity that may be transported in the LTSS and its distribution among the four recesses in the LTSS. At the conclusion of this process, it will be established:

a. The configuration of each drawer (LD-*xx*) in each recess (configurations A – E, AB, BC, BD)
b. The isotope and form of each source to be placed in each special form capsule (pencil, short cylinder, Co-60, Cs-137, etc.)
c. The activity in each capsule and the total in the LTSS.

Note: the exclusion of a quantity of americium greater than 200 Ci from air transport (see step 3 below) is due to the trace content of plutonium in americium.

Examples of acceptable source loadings in the LTSS are given in Appendix 7.5.1, *LTSS Loading Examples*.

PROCEDURAL REQUIREMENTS

Limits for Content 1: The T80/T780 source drawer may contain up to the Table 7.1-1 limit of Co-60 (i.e., 12,970 Ci) in one to four drawers in any distribution. T80/T780 source drawers (Content 1) may not be mixed with large source drawers (Content 2) within the LTSS. Any of the four recesses in the LTSS that is not loaded with a T80/T780 drawer must be loaded with a shield drawer.

Limits for Content 2: There are seven steps in qualifying Content 2 for the LTSS.

1. **Basic Radionuclide Limits.** Verify that the total activity of each isotope to be transported in the LTSS does not exceed the basic radionuclide limits given in Table 7.1-1 or the limits specified in the special form capsule certificate, ZA/NLM52/S, or other special form capsules, if used.
2. **Fissile Mass Limit.** Verify that the total fissile mass within the LTSS does not exceed 15g. The fissile mass is equal to:

$$\text{Fissile mass (g)} = A + 0.2 \times B + 0.001 \times C$$

where:

A equals the total grams of plutonium in all Pu-239 sources
B equals the total grams of plutonium in all Pu-238 sources
C equals the curies of americium in all Am-241 sources

3. **Plutonium By Air Exclusion.** NO PLUTONIUM SOURCES ARE PERMITTED FOR SHIPMENT OF THE 435-B BY AIR. TOTAL AMERICIUM GREATER THAN 200 CURIES SHALL NOT BE SHIPPED BY AIR.
4. **Decay Heat Limit.** Verify that the total heat load is less than or equal to 200 watts. If only a single isotope is to be shipped in the LTSS, this is ensured by step 1 above. If multiple isotopes are to be transported, the total watts shall be calculated by multiplying the activity of each isotope by the heat generation rate found in Table 7.1-2.
5. **Physical Form Restrictions.** Verify that the source physical form and isotope comply with the requirements delineated in Table 7.1-3.

6. **Drawer Configuration Restrictions.** Verify that the drawer configuration to be transported is allowed per Table 7.1-4. NOTE: Any recesses in the LTSS that are not needed to carry sources must be given a shield drawer.
7. **Dose Rate Limits.** Verify the selected loading does not violate the dose rate limits using the following equation:

$$\sum_{i=1}^{n} \frac{S_i}{A_i} \leq 1 \qquad (\leq 0.3 \text{ for commercial aircraft transport})$$

where:

S_i is the activity of each source in Ci (g Pu for Pu sources)
A_i is the appropriate value from Table 7.1-5 for each drawer for the configuration used (A – E, AB, BC, BD)

NOTE: ONLY ONE NUCLIDE TYPE MAY BE PLACED IN A SINGLE CAPSULE.

7.1.4.2 Preparing Large Source Drawers

Large source drawers shall be prepared for loading as follows. Operations shall take place in a hot cell or equivalent, consistent with site ALARA rules.

1. The capsule to be placed into the large source drawer must be either the NLM 52 special form capsule or another special form or non-special form capsule that has the same length, diameter, and at least as much radiation attenuation as the NLM-52 capsule series. Verify that the capsule has been closed and prepared for shipping in accordance with a written procedure.
2. Verify that only source material that conforms to all of the limits, restrictions, and controls specified in Section 7.1.4.1, *Qualifying a Payload for Transport*, have been placed into the capsule.
3. Place the special form capsule into a large source drawer. The special form capsule shall be centrally located between two tungsten shield plugs. The tungsten end shield plug lengths shall be utilized according to Table 7.1-3. Note: when using two NLM 52-74s in lieu of one NLM 52-150, use the end shield plugs for the NLM 52-150.
4. Thread in the end cap of the large source drawer until fully seated and secure with a set screw. The large source drawer is now designated a LD-*xx*, where *xx* corresponds to the length of the special form capsule that was placed inside, e.g., LD-250.
5. Alternately, the end cap of the large source drawer may be threaded in and secured after the drawer body has been placed into the LTSS.
6. Proceed to Section 7.1.4.3, *Loading Drawers into the LTSS.*

7.1.4.3 Loading Drawers into the LTSS

The LTSS may be loaded either inside a hot cell, mated to the outside of a hot cell, mated to another LTSS, or mated to a shielded device containing a loaded drawer(s). The order of the steps below may be altered in accordance with site safety requirements.

1. Prepare the LTSS to receive a source drawer by opening the end doors and removing the security plates.

2. Place the LTSS in a hot cell. Alternately, mate it to a hot cell, to another LTSS, or to another device containing a loaded drawer.
3. Rotate the barrel to place a recess in the load/unload position.
4. Place a loaded drawer (LD-*xx* or T80/T780 drawer) into the recess in the LTSS.
    a. The contents of the drawer must be in accordance with Section 7.1.4.1, *Qualifying a Payload for Transport*, and the drawer must be prepared in accordance with Section 7.1.4.2, *Preparing Large Source Drawers*.
    b. Do not mix LD-*xx* drawers with T80/T780 drawers.
    c. If not already done, thread in the drawer end cap and secure with a set screw.
5. Rotate the barrel to the next recess and repeat with the next drawer or shield drawer.
6. Repeat until all the cavities of the LTSS are filled with either loaded drawers or shield drawers.
7. Separate the LTSS from any other equipment, if mated.
8. Install security plates on each end of the LTSS.
9. Close the end doors and fasten to the LTSS with eight, M16 socket head cap screws, tightened to 60 – 70 N-m (44 – 52 ft-lb).

Table 7.1-1 – Basic 435-B Limits

Source	Maximum Quantity per 435-B
Co-60	12,970 Ci
Cs-137	14,000 Ci
Sr-90	1,000 Ci
Ra-226 (excluding Ra-226Be)①	20 Ci
Ra-226Be①	1.3 Ci
Am-241 (excluding Am-241Be)②	1000 Ci
Am-241Be②	6.6 Ci
Pu-238 (excluding Pu-238Be)③	75 g Pu
Pu-239 or Pu-239Be③	15 g Pu
Ir-192	200 Ci
Se-75	80 Ci

①Impurities may include oxygen, carbon, sulfur, bromine, and chlorine (hydrous or anhydrous).
②Impurities may include oxygen and chlorine.
③Impurities may include oxygen. The total fissile mass limit for the 435-B is 15 g.

Table 7.1-2 – Watts Per Source Unit

Isotope	watts/unit
Co-60	1.5420E-02 watts/Ci
Cs-137①	5.0400E-03 watts/Ci
Sr-90②	6.6980E-03 watts/Ci
Ra-226③	1.8620E-01 watts/Ci
Am-241	3.3370E-02 watts/Ci
Pu-238	5.6773E-01 watts/g
Pu-239	3.0873E-03 watts/g
Ir-192	6.1500E-03 watts/Ci
Se-75	2.4100E-03 watts/Ci

①Includes Ba-137m.
②Includes Y-90.
③Includes decay products.

Table 7.1-3 – Authorized Payload Special Form Capsule Sources and Nuclides

Drawer Model	End Shield Length, mm	Special Form Capsule Model	Authorized Source Shape and Dimensions	Authorized Nuclides
LD-74	214	NLM 52-74	Short cylinder	All nuclides in Table 7.1-1
LD-150	176	NLM 52-150	Short cylinder	All nuclides in Table 7.1-1
			Pencil source, len. ≥ 60 mm	Co-60 and Cs-137
LD-150	176	Two NLM 52-74s	Short cylinder	All nuclides in Table 7.1-1
LD-200	151	NLM 52-200	Short cylinder	All nuclides in Table 7.1-1
			Pencil source, len. ≥ 136 mm	Co-60 and Cs-137
LD-250	126	NLM 52-250	Pencil source, len. ≥ 186 mm	Co-60 and Cs-137
LD-325	88.5	NLM 52-325	Pencil source, len. ≥ 236 mm	Co-60 and Cs-137

Table 7.1-4 – Allowable Drawer Configurations

Configuration①	Recess 1	Recess 2	Recess 3	Recess 4
A	LD-74	LD-74	LD-74	LD-74
B	LD-150	LD-150	LD-150	LD-150
C	LD-200	LD-200	LD-200	LD-200
D	LD-250	LD-250	LD-250	LD-250
E	LD-325	LD-325	LD-325	LD-325
AB	LD-74	LD-150	LD-150	LD-150
BC	LD-150	LD-150	LD-200	LD-200
BD	LD-250	LD-150	LD-150	LD-150

①Any number of LDs may be replaced with a shield drawer.

Table 7.1-5 – A_i Activity Limits

Isotope	Cfg. A LD-74	Cfg. B LD-150	Cfg. C LD-200	Cfg. D LD-250	Cfg. E LD-325
Co-60 point (Ci)	34400	5800	1800	NA	NA
Co-60 line (Ci)	NA	11800	6500	2600	530
Cs-137 point (Ci)	3.50E+07	3.30E+06	6.40E+05	NA	NA
Cs-137 line (Ci)	NA	8.50E+06	3.90E+06	9.80E+05	1.00E+05
Sr-90 (Ci)	1.60E+07	3.20E+06	1.00E+06	NA	NA
Am-241 (Ci) (no Be)	14800	14200	14200	NA	NA
Am-241Be (Ci)	6.6	6.5	6.4	NA	NA
Ra-226 (Ci) (no Be)	720	680	530	NA	NA
Ra-226Be (Ci)	1.3	1.3	1.3	NA	NA
Pu-238 (g Pu) (no Be)	1300	1300	1300	NA	NA
Pu-239 (g Pu) (no Be)	1.60E+05	1.60E+05	1.50E+05	NA	NA
Pu-239Be (g Pu)	120	120	120	NA	NA
Ir-192 (Ci)	1.00E+05	1.00E+05	1.00E+05	NA	NA
Se-75 (Ci)	1.00E+05	1.00E+05	1.00E+05	NA	NA

	Cfg. AB		Cfg. BC		Cfg. BD	
Isotope	LD-74	LD-150	LD-150	LD-200	LD-150	LD-250
Co-60 point (Ci)	32700	Use Cfg. B Limits	5600	Use Cfg. C Limits	5600	Use Cfg. D Limits
Co-60 line (Ci)	NA		11800		10300	
Cs-137 point (Ci)	3.30E+07		3.30E+06		3.20E+06	
Cs-137 line (Ci)	NA		7.40E+06		6.90E+06	
Sr-90 (Ci)	1.60E+07		3.20E+06		3.10E+06	
Am-241 (Ci) (no Be)	14600		14100		14100	
Am-241Be (Ci)	6.6		6.4		6.4	
Ra-226 (Ci) (no Be)	720		680		680	
Ra-226Be (Ci)	1.3		1.3		1.3	
Pu-238 (g Pu) (no Be)	1200		1300		1300	
Pu-239 (g Pu) (no Be)	1.60E+05		1.60E+05		1.60E+05	
Pu-239Be (g Pu)	120		120		120	
Ir-192 (Ci)	1.00E+05		1.00E+05		1.00E+05	
Se-75 (Ci)	1.00E+05		1.00E+05		1.00E+05	

7.2 Procedures for Unloading the Package

This section delineates the procedures for unloading a payload from the 435-B packaging. The requirements in Section 7.1.1, *General Lifting and Handling*, must be observed when unloading the packaging.

7.2.1 Removal of Contents

7.2.1.1 Unloading the LTSS

1. Disconnect the 435-B package tie–downs and remove them from the package.
2. Record the condition of the tamper–indicating lockwires, then remove them.
3. Remove the 5, 1/2-13UNC socket head cap screws (SHCS) from each half of the rain shield (total of 10 bolts).
4. Remove the vent port insulation cylinder and seal test port insulation cylinder from the vent port and seal test port access tubes, respectively.
5. Connect a vent port tool to the vent port. Connect a gas sampling device to the vent port tool.
6. Loosen and remove the vent port plug using the vent port tool so that a gas sample may be extracted from the cavity.
7. Following verification of no contamination in the gas sample, vent the cavity to atmosphere to equalize cavity pressure.
8. Remove the 24, 1-1/4-7UNC socket head cap screws from the bell flange. The bolt heads feature holes that may be used with wire hooks to lift the bolts out of the tubes.
9. Using the lift point at the top, remove the bell. Use care not to allow contact of the bell sealing surface with any object capable of scratching the surface, or use a seal surface protector before lifting the bell above the LTSS.
10. The lodgment with the LTSS may be removed from the package base for unloading, or may be unloaded without removing it from the package base.
11. Remove the 8, 1/2-13UNC bolts which connect the upper and lower halves of the lodgment.
12. Release the three toggle clamps. Temporary spacers or equivalent may be used between the LTSS and the lodgment, if necessary, to control the position of the LTSS after release of the toggle clamps.
13. Lift off the lodgment upper half, ensuring that the toggle clamps clear the LTSS.
14. Lift the LTSS out of the lodgment lower half using hoist rings or equivalent mounted in the two M16 threaded holes located in the LTSS lifting blocks. Ensure that the LTSS clears the lodgment lower half as it is being lifted.
15. Replace the upper half of the lodgment using the index marks to align the ribs in the correct orientation.
16. Install the 8, 1/2-13UNC bolts in the clevises which connect the lodgment upper half and lower half. Tighten the hex locknuts only to contact with the clevises.

17. If the lodgment was removed from the package base, replace it using the lifting holes provided in two opposite ribs of the upper lodgment. Using the centering guides located on the lower internal impact limiter, lower the lodgment into position on the base. Before passing over the base, ensure that the bottom of the lodgment is free of loose debris.
18. Lower the bell into position on the base, using the alignment marks and the alignment pins.
19. Coat closure bolt threads and washer surfaces with a low-halogen, nickel based nuclear grade lubricant prior to assembly. Re-coating is not required if an adequate coat exists. Install the 24 closure bolts, and using a crossing pattern, tighten to 270 – 330 ft-lb torque.
20. Install and tighten the vent port plug to 48 – 60 in-lb torque.
21. Install the vent port insulation cylinder in the vent port access tube and the seal test port insulation cylinder in the seal test port access tube. Note that both cylinders are identical.
22. Install the two halves of the rain shield using 5 each, 1/2-13UNC bolts, tightened to 22 – 28 ft-lb torque. Optionally, a weather seal may be used with the rain shield, or nuclear-grade duct tape may be used to cover the rain shield or tube sheet-to-impact limiter joints.
23. Place the 435-B package and pallet onto the conveyance.
24. Cover the threaded hole in the top of the bell by mechanical means, such as a bolt, per drawing 1916-01-01-SAR.
25. Install the tie–down assembly over the top of the impact limiter, and secure to the conveyance. Ensure that chocks (horizontal restraints) are properly installed on the conveyance.

7.2.1.2 Unloading the Inner Container (IC)

1. Disconnect the 435-B package tie–downs and remove them from the package.
2. Record the condition of the tamper–indicating lockwires, then remove them.
3. Remove the 5, 1/2-13UNC socket head cap screws (SHCS) from each half of the rain shield (total of 10 bolts).
4. Remove the vent port insulation cylinder and seal test port insulation cylinder from the vent port and seal test port access tubes, respectively.
5. Connect a vent port tool to the vent port. Connect a gas sampling device to the vent port tool.
6. Loosen and remove the vent port plug using the vent port tool so that a gas sample may be extracted from the cavity.
7. Following verification of no contamination in the gas sample, vent the cavity to atmosphere to equalize cavity pressure.
8. Remove the 24, 1-1/4-7UNC socket head cap screws from the bell flange. The bolt heads feature holes that may be used with wire hooks to lift the bolts out of the tubes.
9. Using the lift point at the top, remove the bell. Use care not to allow contact of the bell sealing surface with any object capable of scratching the surface, or use a seal surface protector before lifting the bell above the IC.

10. Using the three, ½-13 UNC holes in the lid of the inner container, lift the IC off from the package base.
11. Remove the six, 1-8UNC bolts from the lid of the inner container, and remove the lid.
12. Remove the blocking/dunnage and the shielded device from the inner container.
13. Optionally, replace the blocking/dunnage for the return shipment.
14. Replace the lid on the IC and tighten the six, 1-8UNC bolts to a torque of 170 – 210 ft-lb.
15. Using the three, ½-13 UNC holes in the lid of the inner container, replace the IC on the package base. Using the centering guides located on the lower internal impact limiter, lower the IC into position on the base. Before passing over the base, ensure that the bottom of the IC is free of loose debris.
16. Lower the bell into position on the base, using the alignment marks and the alignment pins.
17. Coat closure bolt threads and washer surfaces with a low-halogen, nickel based nuclear grade lubricant prior to assembly. Re-coating is not required if an adequate coat exists. Install the 24 closure bolts, and using a crossing pattern, tighten to 270 – 330 ft-lb torque.
18. Install and tighten the vent port plug to 48 – 60 in-lb torque.
19. Install the vent port insulation cylinder in the vent port access tube and the seal test port insulation cylinder in the seal test port access tube. Note that both cylinders are identical.
20. Install the two halves of the rain shield using 5 each, 1/2-13UNC bolts, tightened to 22 – 28 ft-lb torque. Optionally, a weather seal may be used with the rain shield, or nuclear-grade duct tape may be used to cover the rain shield or tube sheet-to-impact limiter joints.
21. Cover the threaded hole in the top of the bell by mechanical means, such as a bolt, per drawing 1916-01-01-SAR.
22. Place the 435-B package and pallet onto the conveyance.
23. Install the tie–down assembly over the top of the impact limiter, and secure to the conveyance. Ensure that chocks (horizontal restraints) are properly installed on the conveyance.

7.3 Preparation of an Empty Package for Transport

Previously used and empty 435-B packagings shall be prepared and transported per the requirements of 49 CFR §173.428 [2].

7.4 Preshipment Leakage Rate Test

After the 435-B package is assembled and prior to shipment, leakage rate testing shall be performed to confirm proper assembly of the package following the guidelines of Section 7.6, *Preshipment Leakage Rate Test*, and Appendix A.5.2, *Gas Pressure Rise*, of ANSI N14.5 [4].

7.4.1 Gas Pressure Rise Leakage Rate Test Acceptance Criteria

In order to demonstrate containment integrity in preparation for shipment, no leakage shall be detected when tested to a sensitivity of 1×10^{-3} reference cubic centimeters per second (ref–cm^3/s) air, or less, per Section 7.6 of ANSI N14.5, *Preshipment Leakage Rate Test*.

7.4.2 Determining the Test Volume and Test Time

1. Assemble a leakage rate test apparatus that consists of, at a minimum, the components illustrated in Figure 7.4–1, using a calibrated volume with a range of 6 – 31 cubic inches, and a calibrated pressure transducer with a minimum sensitivity of 100 millitorr. Connect the test apparatus to the test volume (i.e., the seal test port, or vent port insert, as appropriate).
2. Set the indicated sensitivity on the digital readout of the calibrated pressure transducer, ΔP, to, at a minimum, the resolution (i.e., sensitivity) of the calibrated pressure transducer (e.g., ΔP = 1, 10, or 100 millitorr sensitivity).
3. Open all valves (i.e., the vent valve, calibration valve, and vacuum pump isolation valve), and record ambient atmospheric pressure, P_{atm}.
4. Isolate the calibrated volume by closing the vent and calibration valves.
5. Evacuate the test volume to a pressure less than the indicated sensitivity on the digital readout of the calibrated pressure transducer or 1.0 torr, whichever is less.
6. Isolate the vacuum pump from the test volume by closing the vacuum pump isolation valve. Allow the test volume pressure to stabilize and record the test volume pressure, P_{test} (e.g., P_{test} < 1 millitorr for an indicated sensitivity of 1 millitorr).
7. Open the calibration valve and, after allowing the system to stabilize, record the total volume pressure, P_{total}.
8. Knowing the calibrated volume, V_c, calculate and record the test volume, V_t, using the following equation:

$$V_t = V_c\left(\frac{P_{atm} - P_{total}}{P_{total} - P_{test}}\right)$$

9. Knowing the indicated sensitivity on the digital readout of the calibrated pressure transducer, ΔP, calculate and record the test time, t, using the following equation:

$$t = \Delta P(1.32)V_t$$

7.4.3 Performing the Gas Pressure Rise Leakage Rate Test

1. Isolate the calibrated volume by closing the calibration valve.

2. Open the vacuum pump isolation valve and evacuate the test volume to a pressure less than the test volume pressure, P_{test}, determined in Step 6 of Section 7.4.2, *Determining the Test Volume and Test Time*.
3. Isolate the vacuum pump from the test volume by closing the vacuum pump isolation valve. Allow the test volume pressure to stabilize and record the beginning test pressure, P_1. After a period of time equal to "t" seconds, determined in Step 9 of Section 7.4.2, *Determining the Test Volume and Test Time*, record the ending test pressure, P_2. To be acceptable, there shall be no difference between the final and initial pressures such that the requirements of Section 7.4.1, *Gas Pressure Rise Leakage Rate Test Acceptance Criteria*, are met.
4. If, after repeated attempts, the O–ring seal fails to pass the leakage rate test, replace the damaged seal and/or repair the damaged sealing surfaces per Section 8.2.3.2, *Sealing Area Routine Inspection and Repair*. Perform verification leakage rate test per the applicable procedure delineated in Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*.

7.4.4 Optional Preshipment Leakage Rate Test

As an option to Section 7.4.3, *Performing the Gas Pressure Rise Leakage Rate Test*, Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*, may be performed.

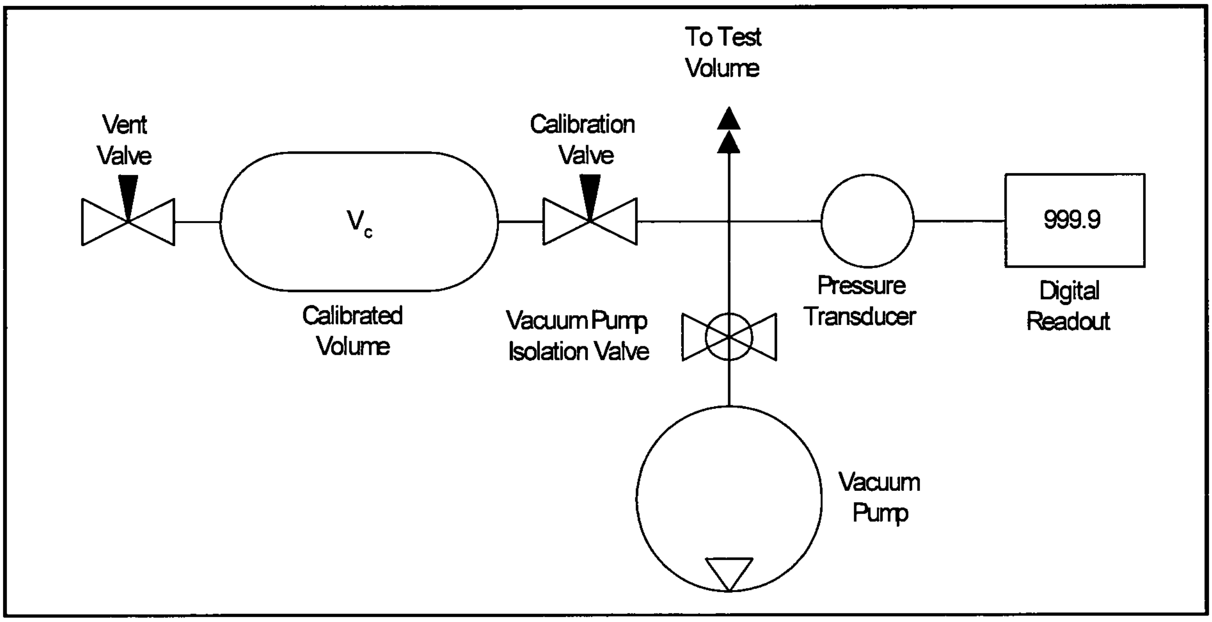


Figure 7.4-1 – Pressure Rise Leakage Rate Test Schematic

7.5 Appendix

7.5.1 LTSS Loading Examples

Example 1:
Recess 1: LD-74 with 7,000 Ci Cs-137, point source
Recess 2: LD-74 with 5,000 Ci Cs-137, point source
Recess 3: LD-74 with 2,000 Ci Co-60, point source
Recess 4: LD-74 with 3,000 Ci Co-60, point source

Step 1: The total Cs-137 (12,000 Ci) and Co-60 (5,000 Ci) are less than the limits in Table 7.1-1.
Step 2: No plutonium or americium, does not apply.
Step 3: No plutonium or americium, air transport allowed.
Step 4: The total power is 138 watts ≤ 200 watts based on Table 7.1-2.
Step 5: Physical form restrictions in Table 7.1-3 are met.
Step 6: The drawer configuration is consistent with Configuration A in Table 7.1-4.
Step 7: Table 7.1-5 Configuration A limits apply. The sum of fractions = 0.15 ≤ 1.0.

Therefore, this shipment is allowed by air (including commercial aircraft), land, or sea transport.

Example 2:
Recess 1: LD-150 with two NLM52-74 capsules. The first capsule has 1,000 Ci Co-60 and the second capsule has 1,000 Ci Sr-90
Recess 2: LD-150 with 5,000 Ci Cs-137, line source
Recess 3: LD-150 with 2,000 Ci Co-60, point source
Recess 4: LD-150 with 2 Ci AmBe

Step 1: The total Cs-137 (5,000 Ci), Co-60 (3,000 Ci), Sr-90 (1,000 Ci) and AmBe (2 Ci) are less than or equal to the limits in Table 7.1-1.
Step 2: Fissile mass = 0.001*2 = 0.002 g ≤ 15 g.
Step 3: Americium ≤ 200 Ci, air transport allowed.
Step 4: The total power is 78 watts ≤ 200 watts based on Table 7.1-2.
Step 5: Physical form restrictions in Table 7.1-3 are met.
Step 6: The drawer configuration is consistent with Configuration B in Table 7.1-4.
Step 7: Table 7.1-5 Configuration B limits apply. The sum of fractions = 0.83 ≤ 1.0.

Therefore, this shipment is allowed by air (not commercial aircraft), land or sea transport.

Example 3:
Recess 1: LD-74 with 15 g Pu in a Pu-238O_2 source
Recess 2: LD-74 with 15 g Pu in a Pu-238O_2 source
Recess 3: LD-74 with 2 g Pu in a Pu-239O_2 source
Recess 4: LD-74 with 2 g Pu in a Pu-239Be source

Step 1: The total Pu in the Pu-238 source (30 g) and total Pu in the Pu-239 source (4 g) are less than the limits in Table 7.1-1.

Step 2: The total fissile material in the package is 30 g*0.2 + 4 g = 10 g ≤ 15 g.
Step 3: Due to the presence of plutonium sources, air transport is not permitted.
Step 4: The total power is 17 watts ≤ 200 watts based on Table 7.1-2.
Step 5: Physical form restrictions in Table 7.1-3 are met.
Step 6: The drawer configuration is consistent with Configuration A in Table 7.1-4.
Step 7: Table 7.1-5 Configuration A limits apply. The sum of fractions = 0.04 ≤ 1.0.

Therefore, this shipment is allowed by land or sea transport.

<u>Example 4:</u>
Recess 1: LD-74 with 14,000 Ci Cs-137 point source
Recess 2: LD-150 with 5,000 Ci Co-60 line source
Recess 3: LD-150 with 1 Ci RaBe source
Recess 4: LD-150 with 2 Ci AmBe source

Step 1: The totals for each isotope are less than or equal to the limits in Table 7.1-1.
Step 2: Fissile mass = 0.001*2 = 0.002 g ≤ 15 g.
Step 3: Americium ≤ 200 Ci, air transport allowed.
Step 4: The total power is 148 watts ≤ 200 watts based on Table 7.1-2.
Step 5: Physical form restrictions in Table 7.1-3 are met.
Step 6: The drawer configuration is consistent with Configuration AB in Table 7.1-4.
Step 7: Table 7.1-5 Configuration AB limits apply. The sum of fractions = 1.5 > 1.0. Therefore, this shipment is **not** allowed.

This shipment is not allowed due to violation of the dose rate limit (Step 7).

7.5.2 References

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 01–01–11 Edition.
2. Title 49, Code of Federal Regulations, Part 173 (49 CFR 173), *Shippers–General Requirements for Shipments and Packagings*, 10–01–11 Edition
3. Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 10–01–11 Edition.
4. ANSI N14.5–1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute (ANSI), Inc.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This section describes the acceptance tests and the maintenance program that shall be used on the 435-B package in compliance with Subpart G of 10 CFR 71 [1].

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85, this section discusses the inspections and tests to be performed prior to first use of the 435-B packaging. Acceptance criteria for all inspections and tests are found either on the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*, or in the sections that follow. Deviations from requirements will be recorded and dispositioned in accordance with the cognizant quality assurance program.

8.1.1 Visual Inspection and Measurements

Each 435-B packaging will be visually inspected and measured to ensure that all of the requirements delineated on the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*, are satisfied. This includes but is not limited to such items as materials, physical arrangement of components, quantities, dimensions, welds, and measurements.

8.1.2 Weld Examinations

The locations, types, and sizes of all welds will be identified and recorded to ensure compliance with the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*. All welds are subject to visual examination per AWS D1.6 [2] or AWS D1.2 for aluminum [18]. All containment boundary welds (those joining the torispherical heads, cylindrical shell, and flanges, including the bell lifting boss and any axial joints) are examined by radiographic inspection in accordance with the ASME Code, Subsection NB, Article NB-5000, and Section V, Article 2 [3]. Containment boundary welds associated with the vent port and all welds subject to radiographic inspection are liquid penetrant inspected on the final pass in accordance with the ASME Code, Subsection NB, Article NB-5000, and Section V, Article 6 [4]. All other welds on the 435-B package, except seal welds, are liquid penetrant inspected on the final pass in accordance with the ASME Code, Subsection NF, Article NF-5000, and Section V, Article 6 [5].

8.1.3 Structural and Pressure Tests

8.1.3.1 Lifting Device Load Testing

The 435-B package is lifted and handled using a pallet, and thus does not contain any lifting devices that require load testing.

8.1.3.2 Containment Boundary Pressure Testing

Since the MNOP equals 5 psig, no pressure test is required by 10 CFR 71.85(b). The 435-B package containment boundary is pressure tested to 125% of the design pressure of 25 psig per the requirements of ASME Code, Subsection NB, Article NB–6220 [6], or a test pressure of 31.25 psig.

Following pressure testing of the containment boundary, welds directly related to the pressure testing and accessible base material adjacent to the welds shall be visually inspected for plastic deformation or cracking in accordance with AWS D1.6, and liquid penetrant inspected per ASME Code, Subsection NB, Article NB–5000, and Section V, Article 6, as delineated on the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*. Indications of cracking or distortion shall be recorded and evaluated in accordance with the cognizant quality assurance program.

Leakage rate testing per Section 8.1.4, *Fabrication Leakage Rate Tests*, shall be performed after completion of pressure testing to verify package configuration and performance to design criteria.

8.1.4 Fabrication Leakage Rate Tests

This section provides the generalized procedure for fabrication leakage rate testing of the containment vessel boundary and vent port penetration during fabrication. Fabrication leakage rate testing shall follow the guidelines of Section 7.3, *Fabrication Leakage Rate Test*, of ANSI N14.5 [7]. Three separate tests comprise the series. Each test shall meet the acceptance criteria delineated in Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria*.

8.1.4.1 Fabrication Leakage Rate Test Acceptance Criteria

1. To be acceptable, each leakage rate test shall demonstrate a "leaktight" leakage rate of 1×10^{-7} reference cubic centimeters per second (ref–cm^3/s), air, or less, per Section 6.3, *Application of Reference Air Leakage Rate* (L_R), of ANSI N14.5.
2. In order to demonstrate the leaktight leakage rate, the sensitivity of the leakage rate test procedure shall be 5×10^{-8} cm^3/s, air, or less, per Section 8.4, *Sensitivity*, of ANSI N14.5.
3. Failure to meet the stated leakage rate shall be recorded and evaluated in accordance with the cognizant quality assurance program.

8.1.4.2 Helium Leakage Rate Testing the Containment Structure Integrity

This leakage rate test verifies the leak tightness of the containment boundary structures, including the lower torispherical head, lower flange, upper torispherical head, cylindrical body, upper flange, and connecting welds.

1. The fabrication leakage rate test shall be performed following the guidelines of Section A.5.3, *Gas Filled Envelope – Gas Detector*, of ANSI N14.5.
2. The upper and lower halves of the containment boundary shall be assembled together for the test. The stage of completion of the 435-B packaging shall be sufficient to support the test.
3. Connect a port tool to the vent port in the upper flange.
4. Install a helium mass spectrometer leak detector (MSLD) to the port tool. Evacuate through the port until the vacuum is sufficient to operate the MSLD.
5. Surround the outer surface of the containment body with an envelope filled with helium gas (99% purity or better) to a minimum concentration of 50%, and to a pressure slightly greater than atmospheric pressure. The final leakage rate shall be adjusted for the helium concentration in the envelope.

6. Perform the helium leakage rate test to the requirements of Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria.* If, after repeated attempts, the containment structure fails to pass the leakage rate test, isolate the leak path and, prior to repairing the leak path and repeating the leakage rate test, record on a nonconformance report and disposition prior to final acceptance in accordance with the cognizant quality assurance program.

8.1.4.3 Helium Leakage Rate Testing the Containment O–ring Seal

1. The fabrication leakage rate test of the 435-B package containment O–ring seal integrity shall be performed following the guidelines of Section A.5.4, *Evacuated Envelope – Gas Detector*, of ANSI N14.5.
2. Assemble the 435-B package with the two O–ring seals installed in the lower flange and the closure bolts tightened. Ensure the vent and seal test ports are installed with their associated sealing washers. Assembly information is given in Appendix 1.3.3, *Packaging General Arrangement Drawings.*
3. Utilizing a port tool, attach a vacuum pump and a source of helium gas, in parallel, to the vent port.
4. Close the valve to the source of helium gas and open the valve to the vacuum pump.
5. Utilizing a port tool, rotate the vent port plug to the open position.
6. Evacuate the system to a 90% vacuum or better (≤ 10% ambient atmospheric pressure). Isolate the vacuum pump from the system.
7. Provide a helium atmosphere inside the evacuated cavity by backfilling with helium gas (99% purity or better) to ambient atmospheric pressure (+1 psi, -0 psi).
8. Utilizing the port tool, rotate the vent port plug to the closed position, and remove the helium–contaminated port tool from the vent port.
9. Install a clean (helium–free) port tool into the seal test port.
10. Attach a helium MSLD to the port tool.
11. Utilizing the port tool, rotate the seal test port plug to the open position.
12. Evacuate the cavity between the containment O–ring seal and the test O–ring seal until the vacuum is sufficient to operate the leak detector per the manufacturer's recommendations.
13. Perform the helium leakage rate test to the requirements of Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria.* If, after repeated attempts, the 435-B package containment O–ring seal fails to pass the leakage rate test, isolate the leak path and, prior to repairing the leak path and repeating the leak test, record on a nonconformance report and disposition prior to final acceptance in accordance with the cognizant quality assurance program.

8.1.4.4 Helium Leakage Rate Testing the Vent Port Sealing Washer

1. The fabrication leakage rate test of the vent port plug sealing washer integrity shall be performed following the guidelines of Section A.5.4, *Evacuated Envelope – Gas Detector*, of ANSI N14.5.
2. Assemble the 435-B package with the two O–ring seals installed in the lower flange and the closure bolts tightened. Ensure the vent and seal test ports are installed with their associated

sealing washers. Assembly information is given in Appendix 1.3.3, *Packaging General Arrangement Drawings*.

3. Verify the presence of a helium atmosphere below the vent port plug sealing washer, as specified above in Steps 3 – 8 of Section 8.1.4.3, *Helium Leakage Rate Testing the Containment O–ring Seal*. Alternatively, perform this test immediately after the containment O-ring seal test.
4. Install a clean (helium-free) port tool into the vent port.
5. Attach a helium MSLD to the port tool.
6. Evacuate the cavity above the vent port plug sealing washer until the vacuum is sufficient to operate the leak detector per the manufacturer's recommendations.
7. Perform the helium leakage rate test to the requirements of Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria*. If, after repeated attempts, the vent port plug sealing washer fails to pass the leakage rate test, isolate the leak path and, prior to repairing the leak path and repeating the leak test, record on a nonconformance report and disposition prior to final acceptance in accordance with the cognizant quality assurance program.

8.1.5 Component and Material Tests

8.1.5.1 Polyurethane Foam

This section establishes the requirements and acceptance criteria for installation, inspection, and testing of the rigid, closed–cell polyurethane foam utilized within the 435-B packaging impact limiter. These requirements apply only to the nominally 15 lb/ft^3 foam used in the external impact limiter, since the performance of this material is important to the structural and thermal evaluations of the packaging. These requirements do not apply to the nominally 30 lb/ft^3 foam blocks used in the upper body assembly, because these components are used primarily as spacing material, and their structural and thermal performance is not critical.

8.1.5.1.1 Introduction and General Requirements

The polyurethane foam used within the 435-B packaging is comprised of a specific "formulation" of foam constituents that, when properly apportioned, mixed, and reacted, produce a polyurethane foam material with physical characteristics consistent with the requirements given in Section 8.1.5.1.2, *Physical Characteristics*. In practice, the chemical constituents are batched into multiple parts (e.g., parts A and B) for later mixing in accordance with a formulation. Therefore, a foam "batch" is considered to be a specific grouping and apportionment of chemical constituents into separate and controlled vats or bins for each foam formulation part. Portions from each batch part are combined in accordance with the foam formulation requirements to produce the liquid foam material for pouring into a component or box. Thus, a foam "pour" is defined as apportioning and mixing the batch parts into a desired quantity for subsequent installation (pouring). Finally, all contiguous pours into a single mold are termed a "bun".

The following sections describe the general requirements for constituent storage, and foam pour and test data records. The major chemical constituents of the foam are: carbon, 50% - 70%, oxygen, 14% - 34%, nitrogen, 4% - 12%, and hydrogen, 4% - 10%.

8.1.5.1.1.1 Polyurethane Foam Constituent Storage

The foam supplier shall certify that the polyurethane foam constituents have been properly stored prior to use, and that the polyurethane foam constituents have been used within their shelf life.

8.1.5.1.1.2 Polyurethane Foam Installation

The foam shall be installed while the longitudinal axis of the impact limiter shell is vertical. The walls of the shell where the liquid foam material is to be installed shall be between 55 °F and 95 °F prior to foam installation. Measure and record the shell temperature to an accuracy of ±2 °F.

In the case of multiple pours into a single impact limiter, the cured level of each pour shall be measured and recorded to an accuracy of ±1 inch.

Measure and record the weight of liquid foam material installed during each pour to an accuracy of ±10 pounds.

All test samples shall be poured into disposable containers at the same time as the actual pour it represents, clearly marking the test sample container with the pour date and a unique pour identification number. All test samples shall be cut from a larger block to obtain freshly cut faces. Prior to physical testing, each test sample shall be cleaned of superfluous foam dust.

8.1.5.1.1.3 Polyurethane Foam Pour and Test Data Records

A production pour and testing record shall be compiled by the foam supplier during the foam pouring operation and subsequent physical testing. Upon completion of production and testing, the foam supplier shall issue a certification referencing the production record data and test data pertaining to each foamed component. At a minimum, relevant pour and test data shall include:

- formulation, batch, and pour numbers, with foam material traceability, and pour date,
- instrumentation description, serial number, and calibration due date,
- pour and test data (e.g., date, temperature, dimensional, and/or weight measurements, compressive stress, etc., as applicable), and
- technician and Quality Assurance/Quality Control (QA/QC) sign–off.

8.1.5.1.2 Physical Characteristics

The following subsections define the required physical characteristics of the polyurethane foam material.

Testing for the various polyurethane foam physical characteristics is based on a "formulation", "batch", or "pour", as appropriate, as defined in Section 8.1.5.1.1, *Introduction and General Requirements*. The physical characteristics determined for a specific foam formulation are relatively insensitive to small variations in chemical constituents and/or environmental conditions, and therefore include physical testing only for leachable chlorides, thermal conductivity, and specific heat. Similarly, the physical characteristics determined for a batch are only slightly sensitive to small changes in formulation and/or environmental conditions during batch mixing, and therefore include physical testing only for flame retardancy. Finally, the physical characteristics determined for a pour are also only slightly sensitive to small changes in formulation and slightly more sensitive to variations in environmental conditions during pour mixing, and therefore include physical testing for density and compressive stress.

8.1.5.1.2.1 Physical Characteristics Determined for a Foam Formulation

8.1.5.1.2.1.1 Leachable Chlorides

The leachable chloride physical characteristic shall be determined once for a particular foam formulation. If multiple components are to utilize a specific foam formulation, then additional physical testing, as defined below, need not be performed.

1. The leachable chlorides test shall be performed using an ion chromatograph (IC) apparatus. The IC measures inorganic anions of interest (i.e., chlorides) in water. Description of a typical IC is provided in EPA Method 300.0 [8]. The IC shall be calibrated against a traceable reference specimen per the IC manufacturer's operating instructions.
2. One test sample shall be taken from a pour for each foam formulation. The test sample shall be a cube with dimensions of 2.00 ±0.06 in.
3. Place the test sample in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test sample. Measure and record the room temperature to an accuracy of ±2 °F.
4. Obtain a minimum of 550 mL of distilled or de–ionized water for testing. The test water shall be from a single source to ensure consistent anionic properties for testing control.
5. Obtain a 400 mL, or larger, contaminant free container that is capable of being sealed. Fill the container with 262 ±3 mL of test water. Fully immerse the test sample inside the container for a duration of 72 ±3 hours. If necessary, use an inert standoff to ensure the test sample is completely immersed for the full test duration. Seal the container prior to the 72–hour duration.
6. Obtain a second, identical container to use as a "control". Fill the control container with 262 ±3 mL of the same test water. Seal the control container prior to the 72–hour duration.
7. At the end of the test period, measure and record the leachable chlorides in the test water per the IC manufacturer's operating instructions. The leachable chlorides in the test water shall not exceed one part per million (1 ppm).
8. Should leachable chlorides in the test water exceed 1 ppm, measure and record the leachable chlorides in the test water from the "control" container. The difference in leachable chlorides from the test water and "control" water sample shall not exceed 1 ppm.

8.1.5.1.2.1.2 Thermal Conductivity

1. The thermal conductivity test shall be performed using a heat flow meter (HFM) apparatus. The HFM establishes steady state unidirectional heat flux through a test specimen between two parallel plates at constant but different temperatures. By measurement of the plate temperatures and plate separation, Fourier's law of heat conduction is used by the HFM to automatically calculate thermal conductivity. Description of a typical HFM test method is provided in ASTM C518 [9]. The HFM shall be calibrated against a traceable reference specimen per the HFM manufacturer's operating instructions.
2. Three test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the HFM manufacturer's operating instructions.

3. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.
4. Measure and record the necessary test sample parameters as input data to the HFM apparatus per the HFM manufacturer's operating instructions.
5. Perform thermal conductivity testing and record the measured thermal conductivity for each test sample following the HFM manufacturer's operating instructions.
6. Determine and record the average thermal conductivity of the three test samples. The numerically averaged thermal conductivity of the three test samples shall be within the range between 0.22 and 0.34 (BTU–in)/(hr–ft^2–°F).

8.1.5.1.2.1.3 Specific Heat

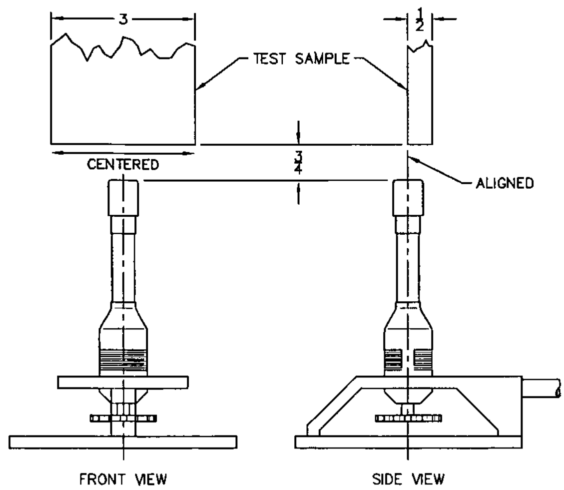
1. The specific heat test shall be performed using a differential scanning calorimeter (DSC) apparatus. The DSC establishes a constant heating rate and measures the differential heat flow into both a test specimen and a reference specimen. Description of a typical DSC is provided in ASTM E1269 [10]. The DSC shall be calibrated against a traceable reference specimen per the DSC manufacturer's operating instructions.
2. Three test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the DSC manufacturer's operating instructions.
3. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.
4. Measure and record the necessary test sample parameters as input data to the DSC per the DSC manufacturer's operating instructions.
5. Perform specific heat testing and record the measured specific heat for each test sample following the DSC manufacturer's operating instructions.
6. Determine and record the average specific heat of the three test specimens. The numerically averaged specific heat of the three test samples shall be within the range between 0.28 and 0.42 Btu/lb_m–°F.

8.1.5.1.2.2 Physical Characteristics Determined for a Foam Batch

Polyurethane foam material physical characteristics for flame retardancy shall be determined once for a particular foam batch based on the batch definition in Section 8.1.5.1.1, *Introduction and General Requirements*. If single or multiple components are to utilize a single foam batch, then additional flame retardancy testing, as defined below, need not be performed for each foam pour.

Polyurethane foam shall be tested for flame retardancy as follows:

1. Three test samples shall be taken from a pour from each foam batch. Each test sample shall be a rectangular prism with nominal dimensions of 0.5 inches thick, 3.0 inches wide, and a minimum length of 8.0 inches. In addition, individual sample lengths must not be less than the total burn length observed for the sample when tested.
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.



3. Install an approximately 3/8–inch, or larger, Bunsen or Tirrill burner inside an enclosure of sufficient size to perform flame retardancy testing. Adjust the burner flame height to 1½ ±1/4 inch. Verify that the burner flame temperature is 1,550 °F, minimum.
4. Support the test sample with the long axis oriented vertically within the enclosure such that the test sample's bottom edge will be 3/4 ±1/8 inch (see adjacent figure) above the top edge of the burner.
5. Move the burner flame under the test sample for an elapsed time of 60 ±2 seconds. As illustrated, align the burner flame with the front edge of the test sample thickness and the center of the test sample width.
6. Immediately after removal of the test sample from the burner flame, measure and record the following data:
   a. Measure and record, to the nearest second, the elapsed time until flames from the test sample extinguish.
   b. Measure and record, to the nearest second, the elapsed time from the occurrence of drips, if any, until drips from the test sample extinguish.
   c. Measure and record, to the nearest 0.15 inch, the burn length following cessation of all visible burning and smoking.
7. Flame retardancy testing acceptance is based on the following criteria:
   a. The numerically averaged flame extinguishment time of the three test samples shall not exceed fifteen seconds.
   b. The numerically averaged flame extinguishment time of drips from the three test samples shall not exceed three seconds.
   c. The numerically averaged burn length of the three test samples shall not exceed 6.0 in.

8.1.5.1.2.3 Physical Characteristics Determined for a Foam Pour

8.1.5.1.2.3.1 Density

Polyurethane foam material physical characteristic for density shall be determined for each foam pour based on the pour definition in Section 8.1.5.1.1, *Introduction and General Requirements.*

1. Three test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with minimum nominal dimensions of 1.0 inch thick (T) × 2.0 inch wide (W) × 2.0 inch long (L).
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the weight of each test sample to an accuracy of ±1 gram.

4. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.03 in.
5. Determine and record the room temperature density of each test sample utilizing the following formula:

$$\rho_{foam} = \frac{\text{Weight, g}}{453.6\ \text{g/lb}_m} \times \frac{1{,}728\ \text{in}^3/\text{ft}^3}{\text{T} \times \text{W} \times \text{L},\ \text{in}^3},\ \text{lb}_m/\text{ft}^3$$

6. Determine and record the average density of the three test samples. The numerically averaged density of the three test samples shall be within ±15% of the specified nominal foam density, i.e., within the range of 12.7 to 17.3 lb_m/ft^3 for a nominal 15 lb_m/ft^3 foam.

8.1.5.1.2.3.2 Compressive Stress

1. Three test samples shall be taken from each foam pour. Each test sample shall be a rectangular prism with minimum nominal dimensions of 1.0 inch thick (T) × 2.0 inch wide (W) × 2.0 inch long (L). The thickness dimension shall be the parallel–to–rise direction (for the perpendicular–to–rise direction, see below).
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.03 inch.
4. Compute and record the surface area of each test sample by multiplying the width by the length (i.e., W × L).
5. Place a test sample in a Universal Testing Machine. Lower the machine's crosshead until it touches the test sample. Set the machine's parameters for the thickness of the test sample.
6. Determine and record the average parallel–to–rise compressive stress of the three test samples from each batch pour for each foam density. As shown in Table 8.1-1, the average parallel–to–rise compressive stress for each foam pour shall be the nominal compressive stress ±15% at strains of 10%, 40%, and 70%.
7. Determine and record the average parallel–to–rise compressive stress of all test samples from each foamed component. As shown in Table 8.1-1, the average parallel–to–rise compressive stress for all foam pours used in a single bun shall be the nominal compressive stress ±10% at strains of 10%, 40%, and 70%.
8. Data for compressive stress in the perpendicular–to–rise direction shall be obtained in an identical manner, using three additional test samples, except that the thickness dimension of the test samples shall be perpendicular to the foam rise direction. As shown in Table 8.1-2, the average perpendicular–to–rise compressive stress for each foam pour shall be the nominal compressive stress ±15% at strains of 10%, 40%, and 70%. As further shown in Table 8.1-2, the average perpendicular–to–rise compressive stress for all foam pours used in a single bun shall be the nominal compressive stress ±10% at strains of 10%, 40%, and 70%.

8.1.5.2 Butyl Rubber O–rings

Physical characteristics of the butyl rubber containment O–ring seals and sealing washers for the following parameters shall be determined for each lot based on the following acceptance tests. All material shall conform to the following ASTM D2000 [11] designation:

M4AA710 A13 B13 F17 F48 Z Trace Element.

8.1.5.2.1 Durometer

The durometer of each lot of the butyl rubber material shall be determined in accordance with ASTM D2240 [12]. Each lot of butyl rubber material shall have a hardness of 70 ±5 Shore A durometer (i.e., within the range of 65 to 75 Shore A durometer).

8.1.5.2.2 Tensile Strength and Elongation

The tensile strength of each lot of the butyl rubber material shall be determined in accordance with ASTM D412 [13]. Each lot of butyl rubber material shall have a minimum tensile strength of 10 MPa and a minimum elongation of 250%.

8.1.5.2.3 Heat Resistance

The heat resistance of each lot of the butyl rubber material shall be determined in accordance with ASTM D573 [14]. Each lot of butyl rubber material shall experience a maximum 10 Shore A durometer hardness increase, a maximum reduction in tensile strength of 25%, and a maximum reduction in ultimate elongation of 25%, when tested at 70 °C.

8.1.5.2.4 Compression Set

The compression set of each lot of the butyl rubber material shall be determined in accordance with Method B of ASTM D395 [15]. After 22 hours at 70 °C, each lot of butyl rubber material shall have a maximum compression set of 25%.

8.1.5.2.5 Cold Temperature Resistance

The cold temperature resistance of each lot of the butyl rubber material shall be determined in accordance with Method A, 9.3.2 of ASTM D2137 [16]. After 3 minutes at -40 °C, each lot of butyl rubber material shall be non–brittle.

8.1.5.2.6 Cold Temperature Resiliency

The cold temperature resiliency of each lot of the butyl rubber material shall be determined in accordance with the TR–10 test of ASTM D1329 [17]. Each lot of butyl rubber material shall be resilient at a test temperature of -50 °C or less.

8.1.6 Shielding Integrity Tests

The 435-B does not include any components whose primary purpose is shielding. Therefore, tests to demonstrate the integrity of shielding components are not required.

8.1.7 Thermal Tests

Tests to demonstrate the heat transfer capability of the packaging are not required because the thermal evaluations presented in Chapter 3, *Thermal Evaluation,* are based on well established heat transfer properties and methodologies and demonstrate relatively large thermal margins for all components. As such, the uncertainties in the predicted temperature levels are small. Further, since the thermal modeling incorporates several conservative assumptions, it is expected that the peak temperatures achieved will be less than predicted. See Chapter 3, *Thermal Evaluation,* for further discussions.

Table 8.1-1 – Compressive Strength (psi) Parallel–to–Foam Rise at 65°F to 85°F

Strain	Minimum		Nominal	Maximum	
	Nom. –15%	Nom. –10%		Nom. +10%	Nom. +15%
10%	535	566	629	692	723
40%	641	679	754	829	867
70%	2,248	2,381	2,645	2,910	3,042

Table 8.1-2 – Compressive Strength (psi) Perpendicular–to–Foam Rise at 65°F to 85°F

Strain	Minimum		Nominal	Maximum	
	Nom. –15%	Nom. –10%		Nom. +10%	Nom. +15%
10%	513	543	603	663	693
40%	654	692	769	846	884
70%	2,287	2,422	2,691	2,960	3,095

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the 435-B packaging.

8.2.1 Structural and Pressure Tests

No structural or pressure tests are necessary to ensure continued performance of the packaging.

8.2.2 Maintenance/Periodic Leakage Rate Tests

This section provides the generalized procedure for maintenance/periodic leakage rate testing of the containment boundary penetrations during routine maintenance, or at the time of seal replacement or sealing area repair. Maintenance leakage rate testing shall follow the guidelines of Section 7.4, *Maintenance Leakage Rate Test*, and Section 7.5, *Periodic Leakage Rate Test*, of ANSI N14.5.

Maintenance/periodic leakage rate testing shall be performed on the main O–ring seal and the vent port sealing washer in accordance with Section 8.2.2.1, *Helium Leakage Rate Testing the Containment O–ring Seal* and 8.2.2.2, *Helium Leakage Rate Testing the Vent Port Sealing Washer*. Each leakage rate test shall meet the acceptance criteria delineated in Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria.*

8.2.2.1 Helium Leakage Rate Testing the Containment O–ring Seal

1. The maintenance/periodic leakage rate test of the 435-B package containment O–ring seal integrity shall be performed following the guidelines of Section A.5.4, *Evacuated Envelope – Gas Detector*, of ANSI N14.5.
2. Assemble the 435-B package with the two O–ring seals installed in the lower flange and the closure bolts tightened. Ensure the vent and seal test ports are installed with their associated sealing washers. Assembly information is given in Appendix 1.3.3, *Packaging General Arrangement Drawings*.
3. Utilizing a port tool, attach a vacuum pump and a source of helium gas, in parallel, to the vent port.
4. Close the valve to the source of helium gas and open the valve to the vacuum pump.
5. Utilizing a port tool, rotate the vent port plug to the open position.
6. Evacuate the system to a 90% vacuum or better (≤ 10% ambient atmospheric pressure). Isolate the vacuum pump from the system.
7. Provide a helium atmosphere inside the evacuated cavity by backfilling with helium gas (99% purity or better) to ambient atmospheric pressure (+1 psi, -0 psi).
8. Utilizing the port tool, rotate the vent port plug to the closed position, and remove the helium–contaminated port tool from the vent port.
9. Install a clean (helium–free) port tool into the seal test port.
10. Attach a helium MSLD to the port tool.
11. Utilizing the port tool, rotate the seal test port plug to the open position.

12. Evacuate the cavity between the containment O–ring seal and the test O–ring seal until the vacuum is sufficient to operate the leak detector per the manufacturer's recommendations.
13. Perform the helium leakage rate test to the requirements of Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria.* If, after repeated attempts, the 435-B package containment O–ring seal fails to pass the leakage rate test, isolate the leak path and, prior to repairing the leak path and repeating the leak test, record on a nonconformance report and disposition prior to final acceptance in accordance with the cognizant quality assurance program.

8.2.2.2 Helium Leakage Rate Testing the Vent Port Sealing Washer

1. The maintenance/periodic leakage rate test of the vent port plug sealing washer integrity shall be performed following the guidelines of Section A.5.4, *Evacuated Envelope – Gas Detector*, of ANSI N14.5.
2. Assemble the 435-B package with the two O–ring seals installed in the lower flange and the closure bolts tightened. Ensure the vent and seal test ports are installed with their associated sealing washers. Assembly information is given in Appendix 1.3.3, *Packaging General Arrangement Drawings.*
3. Verify the presence of a helium atmosphere below the vent port plug sealing washer, as specified above in Steps 3 – 8 of Section 8.2.2.1, *Helium Leakage Rate Testing the Containment O–ring Seal.* Alternatively, perform this test immediately after the containment O-ring seal test.
4. Install a clean (helium-free) port tool into the vent port.
5. Attach a helium MSLD to the port tool.
6. Evacuate the cavity above the vent port plug sealing washer until the vacuum is sufficient to operate the leak detector per the manufacturer's recommendations.
7. Perform the helium leakage rate test to the requirements of Section 8.1.4.1, *Fabrication Leakage Rate Test Acceptance Criteria.* If, after repeated attempts, the vent port plug sealing washer fails to pass the leakage rate test, isolate the leak path and, prior to repairing the leak path and repeating the leak test, record on a nonconformance report and disposition prior to final acceptance in accordance with the cognizant quality assurance program.

8.2.3 Component and Material Tests

8.2.3.1 Fasteners

All threaded components shall be visually inspected before installation for deformed or stripped threads. Damaged threaded components shall be repaired or replaced prior to further use. The threaded components to be visually inspected include the closure bolts, vent port plug, the test port plug, and the rain shield attachment bolts.

8.2.3.2 Sealing Area Routine Inspection and Repair

Before each use and at the time of seal replacement, containment sealing surfaces shall be visually inspected for damage that could impair the sealing capabilities of the packaging. Perform visual surface finish inspections for the base O–ring grooves, the mating sealing area on the bell, and the surfaces that mate with the sealing washer in the vent port. Damage shall be repaired prior to further use (e.g., using emery cloth or other surface finishing techniques) to restore the sealing surfaces to the value specified on the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*.

Upon completion of any surface finish repairs, perform a leakage rate test per Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*.

8.2.3.3 Impact Limiter

Before each use, the external impact limiter shell shall be inspected for tears or perforations and for the presence of the fire–consumable plastic plugs. The internal impact limiters shall be inspected for proper installation and to ensure that the ⅜-16 UNC SHCS are intact and tightened to the value specified in drawing 1916-01-01-SAR, flag note 34. Any damage shall be repaired prior to further use.

8.2.3.4 Seals

The containment boundary O–ring seal and the vent port sealing washer shall be replaced within the 12–month period prior to shipment or when damaged (whichever is sooner), per the size and material requirements delineated on the drawings in Appendix 1.3.3, *Packaging General Arrangement Drawings*. Following seal replacement and prior to a loaded shipment, the new seals shall be leakage rate tested to the requirements of Section 8.2.2, *Maintenance/Periodic Leakage Rate Tests*.

8.2.4 Thermal Tests

No thermal tests are necessary to ensure continued performance of the 435-B packaging.

8.3 Appendix

8.3.1 References

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 01–01–11 Edition.
2. ANSI/AWS D1.6/D1.6M:2007, *Structural Welding Code–Stainless Steel*, American Welding Society (AWS).
3. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*, and Section V, *Nondestructive Examination*, Article 2, *Radiographic Examination*, 2010 Edition.
4. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*, and Section V, *Nondestructive Examination*, Article 6, *Liquid Penetrant Examination*, 2010 Edition.
5. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NF, *Supports*, and Section V, *Nondestructive Examination*, Article 6, *Liquid Penetrant Examination*, 2010 Edition.
6. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, *Rules for Construction of Nuclear Facility Components*, Division 1 – Subsection NB, *Class 1 Components*, Article NB–6220, 2010 Edition.
7. ANSI N14.5–1997, *American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment*, American National Standards Institute (ANSI), Inc.
8. EPA Method 300.0, Revision 2.2 (October 1999), *Determination of Inorganic Anions by Ion Chromatography*, U.S. Environmental Protection Agency.
9. ASTM C518–04, *Standard Test Method for Steady–State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus*, American Society for Testing and Materials (ASTM).
10. ASTM E1269, *Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry*, American Society for Testing and Materials (ASTM).
11. ASTM D2000–05, *Standard Classification System for Rubber Products in Automotive Applications*, American Society for Testing and Materials (ASTM).
12. ASTM D2240–05, *Standard Test Method for Rubber Property – Durometer Hardness*, American Society for Testing and Materials (ASTM).
13. ASTM D412–98a(2002)e1, *Standard Test Methods for Vulcanized Rubber and Thermoplastic Rubbers and Thermoplastic Elastomers – Tension*, American Society for Testing and Materials (ASTM).
14. ASTM D573–04, *Standard Test Method for Rubber – Deterioration in an Air Oven*, American Society for Testing and Materials (ASTM).

15. ASTM D395–03, *Standard Test Methods for Rubber Property – Compression Set,* American Society for Testing and Materials (ASTM).
16. ASTM D2137–94(2000), *Standard Test Methods for Rubber Property – Brittleness Point of Flexible Polymers and Coated Fabrics,* American Society for Testing and Materials (ASTM).
17. ASTM D1329–02, *Standard Test Method for Evaluating Rubber Property – Retraction at Lower Temperatures (TR Test),* American Society for Testing and Materials (ASTM).
18. ANSI/AWS D1.2/D1.2M:2008, *Structural Welding Code–Aluminum*, American Welding Society (AWS).

9.0 QUALITY ASSURANCE

The design, procurement, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair and modification of components of Type B and AF packaging is controlled at the Los Alamos National Laboratory (LANL) by the LANL Type B and Fissile Radioactive Materials Quality Assurance Plan (QAP). The LANL Quality Assurance Functional Organizational Chart (Figure 9.0-1) shows the organizational structure and lines of authority for various functions associated with the use of LANL-owned Type B Packages.

This chapter defines the Quality Assurance (QA) requirements and methods of compliance applicable to the 435-B package. The QA requirements for packaging established by the NRC are described in Subpart H of 10 CFR Part 71 (10 CFR 71). Subpart H is an 18-criteria QA program based on ANSI/ASME NQA-1. Guidance for QA programs for packaging is provided by NRC Regulatory Guide 7.10. The QA requirements of DOE for the use of NRC certified packaging are described in DOE Order 460.1C.

The technical services, i.e., licensing documentation, design, and certification expertise for the 435-B package shall be provided by AREVA Federal Services, LLC, with QA oversight by the LANL Operations Support-Packaging and Transportation (OS-PT) organization. AREVA has an established QA program qualified to 10 CFR 71 Subpart H, and DOE Order 414.1D and documented on the LANL Institutional Evaluated Suppliers List (IESL).

In addition to 10 CFR71 Subpart H requirements, LANL organizations must also comply with LANL's institutional Quality Assurance Plan for Type B and fissile radioactive materials, i.e., P&T-PLAN-028, *LANL Type B and Fissile Radioactive Materials Quality Assurance Plan (QAP),* as well as SD330, *Los Alamos National Laboratory Quality Assurance Program.*

P&T-PLAN-028 is applicable to all LANL organizations that use, lease, borrow or procure the design and fabrication services of a Type B container. For LANL organizations, P&T-PLAN-028, hereby described as QAP, invokes each of the requirements of Subpart H of 10 CFR Part 71, and the LANL institutional QA requirements of SD330. P&T-PLAN-028 also requires LANL users of Type B packaging to have in place a QA program that meets the intent of 10CFR 71, Subpart H. The LANL Type B and Fissile Radioactive Materials QAP demonstrates compliance with both 10CFR 71 Subpart H and the SD 330 requirements, and govern LANL organizations operations for Type B packaging.

LANL Quality Assurance Program (SD330) is the approved institutional description of the overall quality management system that provides a level of confidence that both its business management and technical processes are effective and efficient. It is issued under the authority of the Laboratory Director and reflects the values of LANL senior management. It is consistent with requirements of the prime contract and LANL Governing Policies on performance, safety, and safeguards and security, and it promotes compliance with federal, state, and local regulations and codes.

SD 330 establishes the LANL quality assurance program requirements for site-wide implementation and is to serve as the basis for LANL quality assurance program acceptability. It is designed such that implementation of the full scope of requirements as stated in DOE Order 414.1D, Quality Assurance (current contractual version), constitutes compliance to nuclear safety quality assurance criteria required by 10 CFR 830, Subpart A, *Nuclear Safety*

Management Quality Assurance Requirements. The requirements of SD330 apply to all Laboratory work, whether it is performed by employees, subcontractors or suppliers, through the flow down of requirements prescribed in implementing procedures and procurement documents/contracts.

The 435-B packaging is designed and built to transport radioactive sources which are contained in the Long Term Storage Shield (LTSS) or other authorized payload containers; and must be approved by the NRC for the shipment of radioactive material in accordance with the applicable provisions of the DOT, described in 49 CFR 173, Subpart I - Class 7 (Radioactive) Materials. Procurement, design, fabrication, assembly, testing, maintenance, repair, modification, and use of the 435-B package are all done under QA programs that meet all applicable NRC and DOE QA requirements.

The DOE Field Offices for shipping and receiving sites inspect and approve the respective shipper's and receiver's QA programs for equivalency to the NRC's QA program requirements in Subpart H of 10 CFR 71. Non-DOE users of the 435-B package may only use it when approved to do so by the NRC.

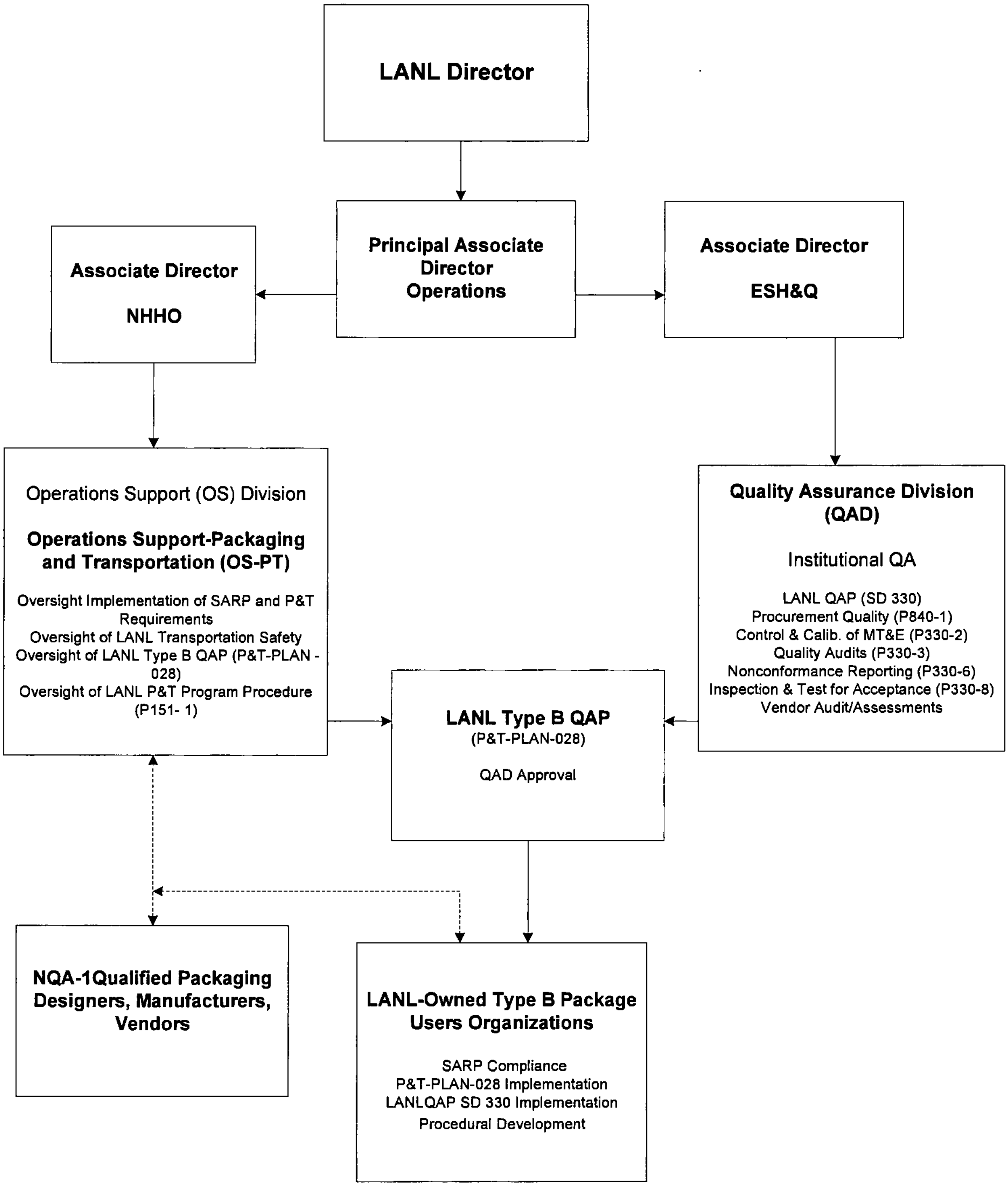


Figure 9.0-1 LANL Quality Assurance
Functional Organizational Chart

Figure 9.0-1 – LANL Quality Assurance Functional Organization Chart

9.1 Quality Assurance Organization (10 CFR 71.103)

The structure of each organization and the assignment of responsibility for each function the organization performs with respect to packaging shall ensure the (1) specified quality requirements are achieved and maintained by those who have been assigned the responsibility for performing the work and (2) conformance to established requirements is verified by individuals and groups not directly responsible for performing the work. The persons or organization responsible for verifying quality shall report through a management hierarchy so that required authority and organizational freedom, including sufficient independence from influences of cost and schedule, are provided.

All organizations involved with the packaging shall establish a formal organizational structure and prepare organization charts identifying each organizational element that functions under the QA program such as: engineering, procurement, inspection, testing and quality assurance.

Requirements shall be established by all organizations involved with the packaging to ensure that designated QA individuals have the responsibility and authority to stop unsatisfactory work and the processing, delivery or installation of nonconforming material. This authority shall be delineated in writing.

All organizations that may be involved with the packaging shall be required to document a formal QA plan and organization that complies with the stated requirements of this chapter.

9.1.1 DOE LANL – Packaging Owner

DOE-LANL is the 435-B Packaging Owner and Applicant. The LANL owner organization of the package is Off-Site Recovery Program (OSRP). The owner organization that accepts the packaging from the supplier documents that the packaging is acceptable for use in accordance with the Certificate of Compliance, and maintains the package records as required by this chapter of the SAR. The owner may delegate the performance of these responsibilities.

9.1.2 Packaging Design Authority

LANL organization Operations Support-Packaging and Transportation (OS-PT) is the Design Authority (DA) for the 435-B package. The DA is responsible for the design and use of the packaging, as well as changes to, and final acceptance of the package design. The DA may delegate any of these activities to others as long as they retain the responsibilities. The DA is also responsible for securing regulatory concurrence and interpretation of the SAR and/or Certificate of Compliance (CoC).

9.1.3 Packaging Design Agency

AREVA Federal Services, LLC, with QA oversight by the LANL Operations Support-Packaging and Transportation (OS-PT) organization, is the LANL Contractor acting on behalf of the packaging owner to provide design, licensing documentation, and certification expertise. The Design Agency determines the packages safety-related items and their appropriate level of Quality Assurance effort according to the NRC Guide 7.10. The Design Agency may delegate any of these activities as long as they retain the responsibilities.

9.1.4 Packaging Users

A package User ships and receives materials in that specific packaging. LANL Off-Site Recovery Program (OSRP) and DOE Complex-Wide Users are responsible for the QA controls necessary to ensure that the certified packages and their use, maintenance, and testing meet the requirements of this Safety Analysis Report (SAR) and the Certificate of Compliance.

9.2 Quality Assurance Program (10 CFR 71.105)

The LANL Type B and Fissile Radioactive Materials Quality Assurance Plan (P&T-PLAN-028 QAP) establishes the QA program requirements for programs, projects, and activities related to Type B packaging and transportation. P&T-PLAN-028 QAP describes the Type B packaging requirements for LANL and fulfills the requirements for a transportation QA plan as required by 10 CFR 71, Subpart H for the 435-B packaging. Table 9.2-1 depicts how the requirements of 10 CFR 71, Subpart H are addressed within the LANL QA program.

The LANL/OS-PT/OSRP management is responsible for ensuring implementation of operational requirements as defined within the QA program as well as the requirements of this SAR including design, procurement, fabrication, inspection, testing, maintenance, and modifications. Procurement documents are to reflect applicable requirements from 10 CFR 71, Subpart H, ASME NQA-1 and the QA program.

LANL/OS-PT/OSRP management assesses the adequacy and effectiveness of the QA program to ensure effective implementation inclusive of objective evidence and independent verification, where appropriate, to demonstrate that specific project and regulatory objectives are achieved.

All LANL personnel and contractors are responsible for effective implementation of the QA program within the scope of their responsibilities. Personnel responsible for inspection and testing are to be qualified, as appropriate, through minimum education and/or experience, formal training, written examination and/or other demonstration of skill and proficiency. Objective evidence of qualifications and capabilities are to be maintained as required.

QA training shall be routinely given to project personnel to ensure that personnel can fulfill design, inspection, fabrication, maintenance and operation requirements. Records of attendance at each training session shall be maintained by the organization conducting the training session. Quality-affecting personnel are instructed in the proper implementation of procedures concerning design, fabrication, operation, maintenance, inspection and quality assurance requirements for the 435-B package.

9.2.1 QA Levels

Materials and components of the 435-B are designed, procured, fabricated, assembled, and tested using a graded approach under a 10 CFR 71, Subpart H equivalent QA Program. Under that program, the categories critical to safety are established for all 435-B packaging components and subcomponents. These defined quality categories consider the impact to safety if the component were to fail or perform outside design parameters. The graded quality category results for each component and subcomponent of the 435-B are shown in Table 9.2-2.

The extent of quality effort given to an activity or packaging component shall be controlled by the quality level assigned and the attendant QA requirements. Table 9.2-3 identifies the level of QA effort for package activities appropriate for each quality category element. Activities associated with procurement, fabrication, handling, shipping, storing, cleaning, assembly, inspection, testing, operation, maintenance, repair and modification of the packaging as well as the individual packaging components shall be based upon a graded approach identified in 10 CFR 71.101 (defined in NRC Regulatory Guide 7.10, Appendix A) and shall be assigned quality levels based on the following definitions:

Graded Quality Category A Items:

These items and services are critical to safe operation and include structures, components, and systems whose failure could directly result in a condition adversely affecting public health and safety. The failure of a single item could cause loss of primary containment leading to a release of radioactive material beyond regulatory requirements, loss of shielding beyond regulatory requirements, or unsafe geometry compromising criticality control.

Graded Quality Category B Items:

These items and services have a major impact on safety and include structures, components, and systems whose failure or malfunction could indirectly result in a condition adversely affecting public health and safety. The failure of a Category B item, in conjunction with the failure of an additional item, could result in an unsafe condition.

Graded Quality Category C Items:

These items and services have a minor impact on safety and include structures, components, and systems whose failure or malfunction would not significantly reduce the packaging effectiveness and would not be likely to create a situation adversely affecting public health and safety.

Quality is maintained during the life of the packaging by specific inspections and verifications associated with maintenance and packaging use. Packaging maintenance is delineated in Chapter 8.2, *Maintenance Program*. Prior to each use, the packaging shall comply with the SAR drawings given in Appendix 1.3.3, *Packaging General Arrangement Drawings*, and the maintenance program as required by the USNRC Certificate of Compliance. The package shall be operated according to the operating procedures delineated in Chapter 7, *Package Operations*, as required by the USNRC Certificate of Compliance. Note that the operating procedure used for packaging operations may be more detailed than the procedural outline provided in Chapter 7.

Table 9.2-1 - QA Program Requirement Cross-mapping

10 CFR 71 Subpart H Requirement	Title	LANL QA Program Section	AREVA QAP Section	Description	Application to LANL Implementation	Application to AREVA Implementation
1 (71.103)	QA Organization	2.0	1.0	Identifies organizations and their relationships in performance of activities affecting quality.	Applicable	Applicable
2 (71.105)	QA Program	3.0	2.0	Describes basic methods for establishing a documented QA program that implements requirements of 10 CFR 71, Subpart H.	Applicable	Applicable
3 (71.107)	Package Design Control	4.0	3.0	Describes design control measures established for structures, systems, and components.	Applicable	Applicable
4 (71.109)	Procurement Document Control	5.0	4.0	Describes procedures for ensuring that applicable regulatory requirements, design bases, and other requirements necessary to ensure adequate quality are suitably included or referenced in documents for procurement of material and services.	Applicable	Applicable
5 (71.111)	Instructions, Procedures, and Drawings	6.0	5.0	Describes documentation of instructions, procedures, or drawings to ensure that safety criteria have been met. Also describes QA review and concurrent processes.	Applicable	Applicable

10 CFR 71 Subpart H Requirement	Title	LANL QA Program Section	AREVA QAP Section	Description	Application to LANL Implementation	Application to AREVA Implementation
6 (71.113)	Document Control	7.0	6.0	Describes documents to be maintained by the QA program and how those documents may be changed, reviewed, approved, and issued.	Applicable	Applicable
7 (71.115)	Control of Purchased Material, Equipment, and Services	8.0	7.0	Describes procurement planning, sources, bids, evaluations, awards, performance control, verification activities, control of nonconformance's, and records.	Applicable	Applicable
8 (71.117)	Identification and Control of Materials, Parts, and Components	9.0	8.0	Describes procedures to track materials to prevent the use of incorrect or defective items.	Applicable	Applicable
9 (71.119)	Control of Special Processes	10.0	9.0	Describes procedures to monitor special processes such as welding, radiography, and heat-treating.	Applicable	Applicable
10 (71.121)	Internal Inspection	11.0	10.0	Describes the planning and use of inspection procedures, instructions, and checklists.	Applicable	Applicable

10 CFR 71 Subpart H Requirement	Title	LANL QA Program Section	AREVA QAP Section	Description	Application to LANL Implementation	Application to AREVA Implementation
11 (71.123)	Test Control	12.0	11.0	Describes requirements and procedures for testing materials in accordance with original design and testing requirements. Also ensures that the test results are documented and evaluated by qualified individuals.	Applicable	Applicable
12 (71.125)	Control of Measuring and Test Equipment	13.0	12.0	Describes procedures for ensuring that measuring and test equipment is properly calibrated and appropriate actions should the equipment be out of calibration.	Applicable	Applicable
13 (71.127)	Handling, Storage, and Shipping Control	14.0	13.0	Describes procedures for ensuring that containers and packaging are preserved, prepared, released, and delivered in good condition.	Applicable	Applicable
14 (71.129)	Inspection, Test, and Operating Status	15.0	14.0	Describes methods for the identification of the inspection, test, and operating status of items including the application/removal of tags, markings, or stamps.	Applicable	Applicable

10 CFR 71 Subpart H Requirement	Title	LANL QA Program Section	AREVA QAP Section	Description	Application to LANL Implementation	Application to AREVA Implementation
15 (71-131)	Nonconforming Materials, Parts, or Components	16.0	15.0	Describes the identification, segregation, disposition, and evaluation of items that do not conform to design and construction criteria.	Applicable	Applicable
16 (71-133)	Corrective Action	17.0	16.0	Described procedures for identifying, reporting, and obtaining corrective actions from suppliers for defective material.	Applicable	Applicable
17 (71-135)	Quality Assurance Records	18.0	17.0	Describes the establishment of quality assurance records, content, indexing and classification, and appropriate methods for storage, preservation, and safekeeping.	Applicable	Applicable
18 (71.137)	Audits	19.0	18.0	Describes internal and external audit programs applicable to both in-house and major suppliers.	Applicable	Applicable

Table 9.2-2 - QA Categories for Design and Procurement of 435-B Subcomponents

Component	Subcomponent	Category
Containment Boundary	Upper & Lower Flange	A
	Cylindrical Shell	A
	Upper & Lower Torispherical Heads	A
	Lifting Boss	A
	Vent and Test Port Blocks	A
	3/8-in Thick Vent Port Closure Plate	A
Vessel Closure	Closure Bolts	A
	Washers	B
	Vent and Test Port Plugs	A
Seals	Containment O-ring Seal	A
	Test O-ring Seal	C
	Vent Port Sealing Washer	A
	Test Port Sealing Washer	C
Thermal Shield	Sheet Material	B
	Wire	B
Upper Body Assembly	Closure Bolt Access Tubes	B
	Tube Sheet	B
	Outer Sheet (51.5-in OD)	B
	Insulation Sheet	B
	Insulation Retention Sheet	B
	Polyurethane Foam (Blocks, 30 lb/ft^3)	B
	Plastic Melt Plugs	C
	Rain Shield Bolt Bosses	B
	Internal Impact Limiter Clips & Bolts	B
Lower Body Assembly	Impact Limiter Shell	B
	Insulation Sheet	B
	Centering Ring (1-in high)	B
	Bolt Hole Closure Cups	C
	Guide Pins	C
	Polyurethane Foam (Poured, 15 lb/ft^3)	B
	Plastic Melt Plugs	C
	Half Coupling	C
	Internal Impact Limiter Locator Clips & Bolts	B

Component	Subcomponent	Category
Internal Impact Limiter (Upper and Lower)	Aluminum Plate	B
	Crush Tubes, Tube Inner Plates, & Attachment Screws	B
	Tube Stabilizer Sheet	B
Rain Shield	Rain Shield Sheets, Attachment Bolts, & Washers	B
LTSS Lodgment	Aluminum Plate, Bar, Angle, & Pipe	B
	Rubber, Toggle Clamps, Fasteners	C
Inner Container	Plate, Sheet, Bar	B
	Fasteners	C
Miscellaneous	Vent and Test Port Insulation Cylinders	B
	Weld Filler Metal	A
	Closure Bolt Lubricant	C
	Thread Locking Compound (optional)	C
	Vacuum Grease (optional)	C

Table 9.2-3 - Level of Quality Assurance Effort per QA Element

QA Element	Level of QA Effort	QA Category A	QA Category B	QA Category C
1	QA Organization			
	• Organizational structure and authorities defined	X	X	X
	• Responsibilities defined	X	X	X
	• Reporting levels established	X	X	X
	• Management endorsement	X	X	X
2	QA Program			
	• Implementing procedures in place	X	X	
	• Trained personnel	X	X	
	• Activities controlled	X	X	
3	Design			
	• Control of design process and inputs	X	X	X
	• Control of design input	X	X	X
	• Software validated and verified	X	X	X
	• Design verification controlled	X	X	X
	• Quality category assessment performed	X	X	X
	• Definition of commercial or generic item (off-the-shelf) not related to A or B component			X
4	Procurement Document control			
	• Complete traceability	X	X	
	• Qualified suppliers list	X	X	
	• Commercial grade dedicated items acceptable	X	X	
	• Off-the-shelf item			X
5	Instructions, Procedures, and Drawings			
	• Must be written and controlled	X	X	
	• Qualitative or quantitative acceptance criteria	X	X	
6	Document Control			
	• Controlled issuance	X	X	
	• Controlled changes	X	X	
	• Procurement documents	X	X	X

QA Element	Level of QA Effort	QA Category A	QA Category B	QA Category C
7	Control of Purchased Material, Equipment, and Services			
	• Source evaluation and selection plans	X	X	
	• Evidence of QA at supplier	X	X	
	• Inspections at supplier, as applicable	X	X	
	• Receiving inspection	X	X	
	• Objective proof that all specifications are met	X	X	
	• Audits/surveillances at supplier facility, as applicable	X	X	
	• Incoming inspection for damage only			X
8	Identification and Control of Material, Parts, and Components			
	• Positive identification and traceability of each item	X	X	
	• Identification and traceable to heats, lots, or other groupings	X	X	
	• Identification to end use drawings, etc.			X
9	Control of Special Processes			
	• All welding, heat treating, and nondestructive testing done by qualified personnel	X	X	
	• Qualification records and training of personnel	X	X	
	• No special processes			X
10	Inspection			
	• Documented inspection to all specifications required	X	X	
	• Examination, measurement, or test of material or processed product to assure quality	X	X	
	• Process monitoring if quality requires it	X	X	
	• Inspectors must be independent of those performing operations	X	X	X
	• Qualified inspectors only	X	X	X
	• Receiving inspection	X	X	X
11	Test Control			
	• Written test program	X	X	
	• Written test procedures for requirements in the package approval	X	X	
	• Documentation of all testing and evaluation	X	X	
	• Representative of buyer observes all supplier acceptance tests if specified in procurement documents	X		
	• No physical tests required			X
12	Control of Measuring and Test Equipment			
	• Tools, gauges, and instruments to be in a formal calibration program	X	X	
	• Only qualified inspectors	X	X	
	• No test required			X

QA Element	Level of QA Effort	QA Category		
		A	B	C
13	Handling, Storage, and Shipping			
	• Written plans and procedures required	X	X	
	• Routine handling			X
14	Inspection, Test, and Operating Status			
	• Individual items identified as to status or condition	X	X	X
	• Stamps, tags, labels, etc., must clearly show status	X	X	X
	• Visual examination only			X
15	Nonconforming Materials, Parts, or Components			
	• Written program to prevent inadvertent use	X	X	X
	• Nonconformance to be documented and closed	X	X	X
	• Disposal without records			X
16	Corrective Action			
	• Objective evidence of closure for conditions adverse to quality	X	X	X
17	QA Records			
	• Design and use records	X	X	
	• Results of reviews, inspections, test, audits, surveillance, and materials analysis	X	X	
	• Personnel qualifications/certifications	X	X	
	• Records of fabrication, acceptance, and maintenance retained throughout the life of package	X	X	X
	• Record of package use kept for three years after shipment	X	X	
	• All records managed by written plans for retention and disposal	X	X	
	• Procurement records	X	X	X
18	Audits			
	• Written plan of periodic audits	X	X	X
	• Lead auditor certified	X	X	

9.3 Design Control (10 CFR 71.107)

Design and modifications to the 435-B shall be controlled by design reviews, analyses or testing using documented procedures. In addition, any changes or modifications to the packaging design that vary from the approved certified configuration or specifications shall be subject to NRC approval. No changes shall be made to the SAR or design without formal approval of the NRC certifying official. Procedures are established to control design activities to ensure the following occur:

- Competent engineering personnel, independent of design activities, perform design verification. Verification may include design reviews, alternate calculations, or qualification testing. Qualification tests are conducted in accordance with approved test programs or procedures.
- Design interface controls will be established and adequate.
- Design, specification, and procedure changes will be reviewed and approved in the same manner as the original issue. In a case where a proposed design change potentially affects licensed conditions, the LANL Type B Packaging Quality Assurance Program shall ensure that licensing considerations have been reviewed and are complied with or otherwise reconciled by amending the license.
- Design errors and deficiencies will be documented, with corrective action to prevent recurrence.
- Applicable design codes and standards pertinent to modifications or additions to be made shall be identified.
- The design process shall be documented. Necessary modifications shall be documented in an amended SAR. Changes to the design shall not be implemented without review and approval from the Nuclear Regulatory Commission.
- Design reviews shall be performed for all category A and B components and subcomponents (Table 9.2-2). Design adequacy shall be verified by persons other than those who designed the item or by prototype testing.
- A design control system shall be established for packaging design and modification.

Quality assurance category levels for design and fabrication control of the 435-B are listed in Table 9.2-2. Classification of components into quality levels assures that critical parameters of a given component are reviewed in a manner consistent with their importance to safety. Critical dimensions with tolerances and standards shall be shown on the specifications and drawings for each component. Inspections shall be conducted by other than those who performed the activity to verify conformance of a packaging related item or activity to identified standards and requirements. The applicable design codes and standards are identified on the design drawings and in the Manufacturing and Material Specifications provided in Chapter 1, *General Information.*

Computer programs used for design analysis or verification will be controlled in accordance with approved procedures. These procedures will provide for verification of the accuracy of computer results and for the assessment and resolution of reported computer program errors.

9.4 Procurement Document Control (10 CFR 71.109)

Purchasers of packagings and replacement items shall use a graded QA approach. As noted in Table 9.2-2, the "A" items are critical to safe operation and are subject to the most stringent quality controls.

Procurement documentation specifications shall contain the applicable requirements including, as appropriate, standards, specifications, codes, documentation and any other special conditions. Specifications prescribe the necessary inspections, tests and other pertinent QA considerations as well as packaging, shipping and handling requirements. Procurement specification documents shall serve as the principal technical documents for the procurement of materials, spare parts, components, subcomponents, equipment or services to be used in the design, fabrication, assembly, testing, maintenance, repair, modification and use of the packaging.

The initiator of the purchase requisition or order is responsible for including the applicable QA requirements on the requisition and for obtaining proper approval signatures. Suppliers are evaluated to assess the supplier's capability to meet the QA requirements specified in the procurement documents. Also, where sub-tier suppliers are involved, the QA provisions appropriate to these procurements are specified. The extent of the supplier's or sub-tier supplier's QA program depends on the particular item or service being procured.

The Design Authority, which is responsible for packaging design, shall approve the procurement specifications issued for all new packagings and associated components. A new packaging shall be fabricated by a supplier that has been evaluated and approved in accordance with a DOE-approved QA program. Before fabrication begins, the supplier shall have a QA program in place that includes those elements of NQA-1 specified by the Design Authority QA, the LANL QA, and the purchase requisition initiator's QA organization.

Each of the package user organizations shall have a documented, approved quality assurance program which shall be supplemented with detailed procedures and instructions as required, to ensure adequate control for preparing safety related procurement documents. Safety related procurement documents shall be reviewed to determine that appropriate quality requirements are identified.

The 435-B package owner will be responsible for initiating procurement actions for packaging spare parts and maintenance services from a supplier with a 10 CFR 71, Subpart H QA Program, as appropriate. Implementing procedures will provide the logic process for determining Quality Levels used in procurement of equipment and subcontracting of services. Procedures shall be in place to ensure processes address document preparation and document control, and management of records meeting regulatory requirements. Procurement records must be kept in a manner that satisfies regulatory requirements.

9.5 Instructions, Procedures, and Drawings (10 CFR 71.111)

Activities concerning loading, unloading, leak-rate testing and shipping shall be prescribed by documented instructions, procedures, or drawings of a type appropriate to the circumstances and shall be accomplished in accordance with these instructions, procedures, or drawings. Appropriate quantitative or qualitative acceptance criteria, including sequential setups, technical constraints, etc. for determining that important activities have been satisfactorily accomplished shall also be documented. QA oversight shall be included within these documents according to such factors as quality level imposed and the complexity, importance, and special nature of the activity affecting quality. Procedures are issued as controlled documents.

Personnel must receive appropriate training in the procedural requirements on the basis of the particular aspects of the procedure in which they are involved. Chapter 7, *Package Operations*, provides specific information governing loading and unloading procedures for these packagings. Chapter 8, *Acceptance Tests and Maintenance Program*, provides specific information governing acceptance tests, inspections, and maintenance activities associated with these packagings.

Compliance with these approved instructions, procedures and drawings is mandatory for Shipper/Receiver organization personnel.

9.5.1 Preparation and Use

Activities concerning loading and shipping are performed in accordance with written operating procedures developed by the user and approved by the package custodian. Packaging first-time usage tests, sequential loading and unloading operations, technical constraints, acceptance limits, and references are specified in the procedures. A pre-planned and documented inspection will be conducted to ensure that each loaded package is ready for delivery to the carrier.

9.5.2 Operating Procedure Changes

Changes in operating procedures that affect the process must be reviewed and approved by the same organization that performed the initial review and approval, or by qualified responsible organizations.

9.5.3 Drawings

Drawings are shown in Appendix 1.3.3, *Packaging General Arrangement Drawings*. Implementation of design revisions is discussed in Section 9.3, *Design Control*.

9.6 Document Control (10 CFR 71.113)

All documents used to accomplish and/or verify quality-related activities shall be controlled. Package users are responsible for establishment, development, review, approval, distribution, revision, and retention of their documents. Documents requiring control, the level of control, and the personnel responsibilities and training requirements are to be identified.

Packaging documents to be controlled include as a minimum:

- Operating procedures
- Maintenance procedures
- Inspection and test procedures
- Loading and unloading procedures
- Preparation for transport procedures
- Repair procedures
- Design specifications
- Fabrication records
- Drawings of packaging and components
- SAR and occurring supplements
- Special process specifications and procedures
- QA Program Manuals/Plans, etc.

Requirements shall ensure changes to documents, which prescribe activities affecting quality, are reviewed and approved by the same organization that performed the initial review and approval, or by qualified responsible organizations. Documents that prescribe activities affecting quality are to be reviewed and approved for technical adequacy and inclusion of appropriate quality requirements prior to approval and issuance. Measures are taken to ensure that only current documents are available at the locations where activities affecting quality are performed prior to commencing the work. Revisions are handled in a like manner as the original issue. Only the latest revisions must be available for use. Documentation received from the supplier for each package must be filed by package serial number. These documents are to be retained in the user's facility.

9.7 Control of Purchased Material, Equipment, and Services (10 CFR 71.115)

Established procedures ensure that purchased materials, equipment and services conform to procurement document requirements. The procurement process for the packaging incorporates the graded approach defined in Appendix A of Regulatory Guide 7.10.

The procurement of replacement parts shall be done under a QA program that meets the requirements of 10CFR71, Subpart H. Procurement documentation specifications shall contain the applicable requirements including, as appropriate, standards, specifications, codes, documentation, and any other special conditions. Specifications prescribe the necessary inspections, tests and other pertinent QA considerations as well as packaging, shipping, and handling requirements.

Only evaluated and approved suppliers/manufacturers may supply packagings. The suppliers must submit a copy of their administrative procedural controls and a Manufacturing and Inspection (M&I) Plan for the Design Agency review and approval prior to the start of fabrication. The Design Agency and the purchaser use the M&I Plan to establish witness and hold points to be observed during the manufacture of the packagings. The supplier's QA program must address the requirements of NQA-1, with the exception of Design Control.

The supplier's M&I Plan shall address the following items as required in the procurement specifications:

- material certifications including traceability of materials
- welding procedure specifications and welding procedure qualification records
- welder qualification records and process qualification
- types of inspections and tests to be performed and by whom
- nondestructive examination (NDE) procedures
- NDE personnel qualification records
- weld inspection records
- NDE reports
- dimensional inspection reports
- cleaning procedures
- procedures for controlling nonconformances
- manufacturing and test procedures
- monitoring methods, equipment, and personnel for special processes qualifications of individuals involved in the QA work for these packagings

9.8 Identification and Control of Materials, Parts, and Components (10 CFR 71.117)

Items that require protection to ensure their intended use or that have unique characteristics must be identified and controlled throughout fabrication, assembly and storage. Traceability of these controlled items must be ensured. Each LANL User is responsible for identifying these items and the level of control to be maintained. Any packaging component not meeting the specifications shall have a Nonconformance Report (NCR) issued against it and shall be tagged and segregated until the disposition of the NCR has been adequately determined and implemented. Replacement parts must be identified, in a like manner as the original, to ensure correct usage. The requirements for identification and control of material, parts, and components consist of the following elements:

- Implementing procedures are established to identify and control materials, parts, and components. These procedures assure identification of items by appropriate means during fabrication, installation, and use of the items and prevent the inadvertent use of incorrect or defective items.
- Requirements for identification are established during the preparation of procedures and specifications.
- Methods and location of identification are selected to not adversely affect the quality of the item(s) being identified.
- Items having limited shelf or operating life are controlled to prevent their inappropriate use.

Control and identification must be maintained either directly on the item or within documents traceable to the item to ensure that only correct and acceptable items are used. When physical identification is not practical, other appropriate means of control must be established such as bagging, physical separation, or procedural control. Each packaging unit shall be assigned a unique serial number after fabrication or purchase. All documentation associated with subsequent storage, use, maintenance, inspection, acceptance, etc., must refer to the assigned serial number. Verification of acceptance status is required prior to use. Items that are not acceptable must be controlled accordingly. Control of nonconforming items is addressed in Section 9.15, *Nonconforming Materials, Parts or Components*.

9.9 Control of Special Processes (10 CFR 71.119)

Requirements shall be established and implemented for the control of special processes used in the fabrication, modification and repair of the packaging. These processes shall include welding, non-destructive testing and other processes special to a specific packaging as identified in the application for packaging certification. Special processes shall be performed in accordance with approved written procedures. Personnel who perform special processes shall be formally trained, qualified, and/or certified. Qualification records of procedures and personnel shall be filed and kept current by the organization which performs the special process. The welding and weld inspection requirements shall be in accordance the ASME, Boiler and Pressure Vessel Code, Section III, Subsection NB, as specified on the engineering drawings.

9.10 Internal Inspection (10 CFR 71.121)

The packaging is required to undergo fabrication inspections by the supplier and independent inspections by individuals acting on behalf of the purchaser. Supplier inspections (as defined in the M&I Plan) are designed to ensure that an accepted packaging or item conforms to the tested and certified design criteria. The supplier is required to submit an M&I Plan for approval prior to the start of fabrication. Approvers of the M&I Plan include the Design Agency and QA (e.g. LANL User QA). The M&I Plan is used as a tool for establishing witness and hold points. The M&I Plan details how fabrications and inspections are to be performed and describes the qualifications of the suppliers and inspectors. Inspections shall be documented and the results shall be delivered to the purchaser along with the packaging. The M&I Plan establishes methods, equipment, and personnel qualifications. Supplier conformance with the requirements of the M&I Plan is verified and monitored by the Design Agency and LANL User Representative.

Independent inspection activity shall be performed by qualified inspectors. The activities performed during the inspection shall include verification of conformance with accept/reject criteria, completion of prerequisites, personnel qualification, and equipment calibration. Inspections shall be performed upon receipt of the packaging, prior to first usage (implemented by LANL User procedures), and annually. Post-loading inspections including leak testing shall be performed prior to shipment in all cases.

Procedures shall be established to ensure that inspectors are qualified and/or certified in accordance with applicable codes and standards. The procedures require that the inspection personnel certifications are kept current and that inspection personnel are independent from individuals performing the activity being inspected.

The inspections to be performed by qualified and/or certified personnel shall include the inspections or examinations included in Chapter 7, *Package Operations*, and in Chapter 8, *Acceptance Tests and Maintenance Program*. Required inspections and examinations are reported as part of the packaging documentation record.

9.11 Test Control (10 CFR 71.123)

The Design Agency with QA oversight by the LANL Operations Support-Packaging and Transportation (OS-PT) organization are required to ensure applicable test programs, including prototype qualification tests, production tests, proof tests, and operational tests in accordance with written procedures are performed by the supplier prior to delivering packaging. The Supplier's QA program should also establish measures to ensure that modifications, repairs, and replacements are tested in accordance with the original design and testing requirements.

9.11.1 Procedures

The Supplier QA program shall establish measures to ensure that test prerequisites identified in the appropriate design disclosures (e.g., instrument calibrations, monitoring to be performed, mandatory hold points, etc.) are properly translated into test procedures.

9.11.2 Acceptance Tests

Acceptance tests shall include the following considerations:

- structural integrity leak-tightness (on containment vessel as well as auxiliary equipment and shield tanks)
- component performance for valves, gaskets, and fluid transport devices
- shielding integrity
- thermal integrity

9.11.3 Maintenance Tests

Maintenance tests are to be established to ensure that packages remain usable and free of excessive radiation and contamination. Qualified and responsible individuals are to document, evaluate, and assess the acceptability of all test results

9.11.4 Results

Test results are to be documented, evaluated, and maintained as QA records. These records should be readily available if questions arise concerning operational aspects of the packaging. Quality records of test results conducted by the Supplier/manufacturer shall be submitted to LANL packaging purchasers upon delivery of the packaging, and shall be reviewed during the receipt inspection process.

Computer programs shall be validated and verified to demonstrate the capability of the computer program to produce valid. results. Software errors shall be reviewed and evaluated for impact on outputs.

9.12 Control of Measuring and Test Equipment (10 CFR 71.125)

Measuring and Test Equipment (M&TE) is defined as devices or systems used to calibrate measure, gage, test, or inspect, in order to control and validate acquired data and to verify conformance to specified requirements. Calibration procedures, vendor manuals, and the SAR detail the requirements for M&TE calibration (including frequency and maintenance), the use of appropriate standards and organizational responsibilities for establishing, implementing, and ensuring the effectiveness of a calibration program.

Type B packaging suppliers, owners, and users, shall ensure that measurement and test equipment is calibrated, adjusted, and maintained at prescribed intervals during each phase of package development, including fabrication, testing and prior to use. Calibration equipment shall be labeled or identified to indicate the planned date of its next calibration, with retrievable records maintained. Calibration standards must be traceable to national standards. In those cases where recognized standards do not exist, the user and/or vendor must document the alternative basis used for calibration. M&TE identified in the SAR for use that requires calibration shall be identified at the time of procurement. The requirements for control of measuring and test equipment shall consist of the following elements:

- Implementing procedures shall be established to assure that tools, gages, instruments and other measuring and testing devices (M&TE) used in activities affecting quality are properly controlled, calibrated and adjusted to maintain accuracy within required limits.
- M&TE are calibrated at scheduled intervals against certified standards having known valid relationships to national standards. If no national standards exist, the basis for calibration shall be documented. Calibration intervals are based on required accuracy, precision, purpose, amount of use, stability characteristics and other conditions that could affect the measurements.
- Calibrations are to be performed in accordance with approved written procedures. Inspection, measuring and test equipment are to be identified to indicate calibration status.
- M&TE are to be identified, labeled or tagged indicating the next required calibration due date, and traceable to calibration records.
- If M&TE is found to be out of calibration, an evaluation shall be performed and documented regarding the validity of inspections or tests performed and the acceptability of items inspected or tested since the previous acceptable calibration. The current status of M&TE is to be recorded and maintained. Any M&TE that is consistently found to be out of calibration shall be repaired or replaced.

Special calibration and control measures on rules, tape measures, levels and other such devices are not required where normal commercial practices provide adequate accuracy.

9.13 Handling, Storage, and Shipping Control (10 CFR 71.127)

The LANL Owner, User and/or Applicant shall develop written operating procedures from the procedural requirements presented in Chapter 7, *Package Operations*, to address handling and storage of the packaging components. These procedures must identify appropriate information regarding environment, temperature, cleaning, and preservation as applicable to meet design requirements. Limited-life components must be addressed in these procedures to assure replacement within the required period of time. The procedural controls shall apply to the life cycle of the packaging from initial fabrication through the maintenance and repair aspects. These measures shall apply to complete units as well as spare and replacement parts. Procurement documents shall require that items (spare and replacement parts) be controlled in accordance with supplier developed procedures which adequately address handling, storage and shipping controls.

Requirements for handling, storage and shipping shall be implemented to preclude damage, loss or deterioration. Technical specifications shall be prepared to define such requirements and provide for their accomplishment. Handling, storage and shipping of the package shall be in accordance with Chapter 7, *Package Operations*.

Empty packages, following usage, must be checked and decontaminated if required. Each package must be inspected, reconditioned, or repaired, as appropriate, in accordance with approved written procedures before storing or loading. Empty 435-B packagings are to be tagged with "EMPTY" labels and stored in designated protected areas in order to minimize environmental effects on the containers. New and unused 435-B packagings do not require an "EMPTY" label.

9.14 Inspection, Test, and Operating Status (10 CFR 71.129)

Each LANL User shall perform or coordinate the maintenance on each packaging in accordance with a procedure that outlines and records each step in preparation of the packaging for shipment. Details are provided in Chapter 7, *Package Operations*. Details regarding maintenance activities are provided in Chapter 8, *Acceptance Tests and Maintenance Program*. The inspection, test, and operating status of any packaging shall be identified clearly by using status indicators (i.e., tags) or records traceable to the individual units.

Requirements shall be established to ensure that the status of inspections, tests and operating conditions, including maintenance activities, is known by organizations responsible for assurance of quality of the 435-B.

9.15 Nonconforming Materials, Parts, or Components (10 CFR 71.131)

9.15.1 Identification

Procedures shall be established to identify and document any nonconforming item or activity. If the inspection identifies an out of conformance item or activity, the Purchaser/LANL User documents the nonconformance and recommends one of several disposition options: "repair," "rework," "reject" or "use-as-is." The Purchaser/LANL User is responsible for obtaining approval of the LANL Design Authority and Design Agency, as appropriate, of the nonconformance dispositions of "repair" or "use-as-is." Copies of all documentation shall be sent to the Design Authority and Design Agency for trending purposes.

9.15.2 Segregation

Nonconforming items must be identified, tagged, segregated where practical, and placed in controlled areas until disposition is complete. Where it is impractical to place the nonconforming item in a controlled area, methods shall be established to identify and segregate the item.

9.15.3 Disposition

The evaluation for disposition of the nonconformance may include the following:

- Rework: The process by which an item is made to conform to original requirements by completion or correction.
- Repair: The process of restoring a nonconforming characteristic to a condition such that the capability of an item to function reliably and safely is unimpaired, even though that item still does not conform to the original requirements (technical justification required).
- Use-as-is: A disposition permitted for a nonconforming item when it can be established that the item is satisfactory for its intended use (technical justification required).
- Reject: Action taken to eliminate a nonconforming item from its specified use (scrap, return to supplier, etc.).

In all cases of action, final disposition of nonconformance must be identified and documented, and the documentation must be maintained as a QA record. Nonconformances shall be documented and tracked from the identification process through the resolution and disposition of corrective action. Procedures shall be required of the packaging fabricator that address the identification and control of nonconformances and include the initiation and processing of nonconformance reports by personnel through follow-up and closure. Nonconforming items may include hardware and raw materials.

Nonconforming activities include fabrication, contracted services, and day-to-day operations by personnel. Nonconforming items and services may result from a subcontractor's activities or activities by a service organization. All items affected by the nonconformance shall be tagged or segregated, and removed from use until the nonconformance has been appropriately resolved and closed. Should an item or the shipping package itself require rework or repair, the acceptability of the nonconforming item shall be re-inspected against the original requirements after the designated rework or repair.

9.16 Corrective Action (10 CFR 71.133)

Conditions adverse to quality shall be identified and corrected as soon as practical. In order to prevent recurrence of a nonconformance, the causes of the nonconformance shall be promptly identified. The identification, cause of the condition, and corrective action taken shall be documented and reported to appropriate levels of management. The package User QA organization shall ensure that the corrective action has been implemented and is effective.

The LANL Corrective Action program addresses significant conditions adverse to quality requirements for corrective action, and consists of the following elements:

- Occurrence Reporting and Processing Systems
- QA Stop Work Process
- QA Audits/Surveillances
- Management Assessments
- Integrated Safety Management Evaluations
- Issues and Corrective Management Policy
- Nonconformance Reporting policy
- Lessons Learned Reports
- Documentation on a Corrective Action Reports (CARs), or equivalent

9.17 Quality Assurance Records (10 CFR 71.135)

A record is a completed document that furnishes evidence of the quality of items and/or activities affecting quality. QA records shall furnish documentary evidence that the tasks affecting quality are performed as planned. Records shall include, but are not limited to reports, analyses, data, computer codes, specifications, instructions, change orders and modifications, nonconformance results, contract documents, procedures, inspection and test data, audit results, maintenance and shipping records. Reviews shall be conducted at the completion of each project to determine receipt of adequate records. Table 9.17-1 itemizes these applicable QA records and designates the retention periods. The container owner shall maintain all lifetime records. The requirements for quality assurance records are further addressed in LANL Records Management Policy, 10CFR 71.91 and 10CFR 71.135.

9.17.1 Generating Records

Package user documents designated as QA records must be:

- Legible
- Completed to reflect the work accomplished and relevant results or conclusions
- Signed and dated or otherwise authenticated by authorized personnel.

QA records should be placed in a records storage area as soon as is feasible to avoid loss or damage. Individual package QA records must be generated and maintained for each package by the package serial number.

9.17.2 Receipt, Retrieval and Disposition of Records

The container owner has overall responsibility for records management for the 435-B. Package users are responsible for maintaining records while they are in process and for providing completed records to the container owner organization for document control. A receipt control system shall be established, and records maintained in-house or at other locations are to be identifiable and retrievable and not disposed of until prescribed conditions are satisfied.

Designated storage facilities are constructed to minimize the risks of damage or destruction to the QA records from natural causes, such as extreme temperatures; moisture from rain, snow, or high humidity; insects; mold; or fire. Security systems and facility activity classifications shall be established to prevent access to records by unauthorized personnel. Records are to be available for inspection upon request.

Table 9.17-1 - Quality Assurance Records

Quality Assurance Record	Retention Period
Design and Fabrication Drawings	LOP+
Test Reports	LOP+
Independent Design Review Comments	LOP+
Safety Analysis Report for Packaging	LOP+
Vendor Manufacturing and Inspection Plan	LOP+
Material Test Report of Certification of Materials	LOP+
Welding Specifications and Procedures	LOP+
Procedure Qualification Record	LOP+
Welder or Welding Operator Qualification Tests	LOP+
Record of Qualification of Personnel Performing Radiographic and PT Reports	LOP+
Weld Radiographs	LOP+
Liquid Penetrant Reports	LOP+
Dimensional Inspection Report for All Features	LOP+
Structural Test Reports (by Vendor)	LOP+
Leakage Test Reports (by Vendor and annual)	LOP+
Leakage Test Reports (Acceptance)	LOP+
Visual and Dimensional Inspection upon Receipt of Packaging	LOP+
Leak Testing Personnel Qualification Records	S+
Package Loading Procedure	S+
Leak Test Results (post loading)	S+
Unloading Procedure	S+
Preparation of Empty Package for Transport	S+
Maintenance Procedures	LOP+
Repair Procedures	LOP+
Procurement Specifications	LOP+
Audit Reports	LOP+
Personnel Training and Qualification Documentation	LOP+
Maintenance Log	LOP+
Corrective Action Reports	LOP+
Nonconformance Reports (and resolutions)	LOP+

Quality Assurance Record	Retention Period
Incident Reports per 10 CFR 71.95	LOP+
Preliminary Determinations per 10 CFR 71.85	S+
Routine Determinations per 10 CFR 71.87	S+
Shipment Records per 10 CFR 71.91(a), (b), (c), (d)	S+
LOP+ Lifetime of packaging plus 3 years S+ Shipping date plus 3 years	

9.18 Audits (10 CFR 71.137)

Audits related to the packaging shall be conducted by the QA organization of the user. The QA organization shall identify the lead auditor and audit team from designated, qualified personnel. Individuals shall be qualified based on training, examination and experience. Audit personnel shall understand the activities they are reviewing and shall not have direct responsibility for the activities being audited. Audit teams shall be responsible for preparing audit checklists, conducting the audit in accordance with the audit plan, good audit practice, and documenting the results in a final audit report.

Internal audits of the active and applicable elements of the QA Plan such as design, modification, operations, maintenance, and shipment will typically be conducted on an annual basis. If a package is not in use, audits may be suspended until such time that the package is in use again.

External audits of quality assurance programs and plans of major suppliers or major contractors shall be conducted on a triennial basis. The 3-year period shall begin with the performance of an audit when sufficient work is in progress to demonstrate implementation of a quality assurance plan having the required scope for procurements placed during the 3-year period.

The User organization QA officer shall evaluate audit results for indications of adverse trends that could affect quality. When results of such assessments so indicate, appropriate corrective action will be implemented.

The User organization QA officer shall follow up on audit findings to assure that appropriate corrective actions have been implemented and directs the performance of re-audits when deemed necessary.