Department of Energy
Washington, DC 20585

Office of Facility Safety Analysis, EH-32

SAFETY EVALUATION REPORT
Model No. UC-609 Shipping Package
Docket No. 87-19-9932

SUMMARY

Based on the statements and representation in the Reference Safety Analysis Report for Packaging (SARP), the EH-32 staff has concluded that the Model No. UC-609 Shipping Package design meets the requirements of DOE Order 5480.3, 10 CFR Part 71, 49 CFR Part 173 and IAEA Safety Safety Series No. 6, 1973 Revised Edition (As Amended).

REFERENCE

Safety Analysis Report on Model No. UC-609 B(U) DOE Shipping Package, Report UCRL-ID-111494, Revision dated May 1993, Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550.

DRAWINGS

The Model No. UC-609 Shipping Package is defined by the following Lawrence Livermore National Laboratory drawings:

Shipping Container Assembly, AAA92-102223, Rev. 0C; Containment Vessel Assembly, AAA75-113083, Rev. 0F; Containment Vessel Cover Assembly, AAA91-109841, Rev. 0B; Container Insulation Cover Assembly, AAA77-104161, Rev. 0C; Drum Assembly, AAA91-107485, Rev. 0A; and Valve Assembly, AAA91-109803, Rev. 0A.

1. GENERAL

The general information and drawings presented in the reference were reviewed by the staff and found acceptable. The Model No. UC-609 Shipping Package is adequately described by the above assembly and attendant drawings which provide specifications for the materials of construction, component dimensions, location, size, and type of weld joints on the packaging. Nameplate information complies with regulatory requirements and tamper-indicating seals are installed on the container.

The Model No. UC-609 Shipping Package is a Type B(U) container for shipping any form of tritium, except activated luminous paint, and is also a Category I container as defined in NRC Regulatory Guide 7.11. The containment boundary shall therefore be designed and fabricated to the requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Division 1, Subsection NB.

The total gross weight of the fully loaded container is 226.8 kg (500 lb). The container can be shipped as non-exclusive use highway transport or by air, rail, or water.

This Technical Review Report (TRR) directly evaluates and assesses the integrity of the vessel and components that comprise the containment boundary along with the permanent internal components and also evaluates the ability of the drum container to provide protection to the containment vessel during the normal conditions of transport and hypothetical accident conditions defined by DOE Order 5480.3 and 10 CFR Part 71.

1.1 Description

1.1.1 Packaging

The external dimensions of the drum serving as the outer container are a maximum diameter of 63.5 cm (25 in) and a total height of 138.4 cm (54.5 in). The inner containment vessel has a diameter of 45.7 cm (18 in) and a height of 111.9 cm (44.06 in).

The outer container is comprised of a right circular cylindrical drum with a flat cover and bottom fabricated from 14 gauge (0.19 cm) ASTM A 240 type 304 stainless steel to the dimensional requirements of Military Standard MS 27683. Four rolled stiffening ridges in the drum body and the top and bottom rolled lips are also fabricated to MS 27683. The cover is secured to the top lip of the drum with eight (8) ASTM A 240 type 304 stainless steel J-shaped brackets 5.1 cm (2 in) wide by 0.48 cm (0.188 in) thick. These brackets are secured to ASTM A 240 type 304 stainless steel blocks welded to the drum cover by eight (8) 3/8-16 x 0.75 inch (1.9 cm) corrosion resisting steel bolts fabricated to the Military Standard Material Specification MS 35307. The cover is secured without the use of a locking ring or gasket.

The drum is lined with ASTM C 208 roof-grade Celotex cellulosic fiber insulation board. The drum body insulation consists of 10.2 cm (4 in) thick Celotex cut into annular disks which form a 7.2 cm (2.85 in) thick cylinder that fills the space between the drum and containment vessel. The top and bottom of this containment vessel cavity within the drum is insulated with solid disks of Celotex 8.6 and 9.4 cm (3.38 and 3.69 in) thick respectively. The insulation disks at the top of the drum are supported by a disk made from non-structural, 1.3 cm (0.5 in) thick interior grade plywood. The plywood disk forms the top inside surface of the containment vessel cavity within the drum and rests on the annular disks lining the drum sides. A bottle-cap shaped heat shield made from 0.08 cm (0.032 in) thick ASTM A 240 type 304 stainless steel is cemented to the outside surface of the drum-top Celotex with a Military Specification MIL-A-46106 Silicone adhesive. This stainless steel cap completely covers the top of the Celotex and extends 3.8 cm (1.5 in) down the side of the insulation. A 61 cm (24 in) diameter by 1.3 cm (0.5 in) thick disk of alumina-silica ceramic fiber blanket (Cerafelt) produced by Thermal Ceramics Company is placed between the stainless steel cap and the drum cover. The insulating blanket is primarily used to fill any gap between the drum cover and Celotex insulation. The ceramic fiber blanket also provides thermal protection to the top layer of Celotex. However, similar thermal protection to the Celotex at the sides and bottom of the packaging is not provided.

The container does not have a gasket between the cover and the drum and is also vented to prevent over-pressure during the hypothetical accident thermal event by four (4) 0.64 cm (0.25 in) diameter holes equally spaced around the drum body 5.1 cm (2 in) below the top rolled lip. These holes are sealed weather-tight during normal conditions of transport with pressure-sensitive adhesive tape made to the Federal Specification PPP-T-0097. The tape provides a weather-tight seal over the temperature range of -54 to +65°C (-65 to +150°F). This tape will burn-off during the hypothetical accident thermal event allowing the drum to vent.

The containment vessel boundary consists of a right circular cylinder with dished semi-elliptical heads. The top head contains a bolted flange closure that is welded onto the semi-elliptical head. The body of the containment vessel is fabricated from 0.32 cm (0.125 in) thick ASTM A 240 type 316 stainless steel sheet and is formed into a right circular cylinder 45.7 cm (18 in) in diameter by 77.3 cm (30.45 in) long. 10 gauge (0.34 cm) thick ASME style semi-elliptical heads are welded to the body. The overall length of the vessel including the cylinder and heads is 111.9 cm (44.06 in).

The removable cover in the top head consists of a flange welded to the dished part of a semi-elliptical head. The cover flange is machined from 3.81 cm (1.5 in) thick ASTM A 240 type 316 stainless steel plate. The mating vessel flange is machined from 4.45 cm (1.75 in) thick ASTM A 240 type 316 stainless steel plate and provides a 25.4 cm (10 in) diameter access opening into the containment vessel. The flanged cover is sealed to the body by eight (8) 3/8-24 x 1.14 in (2.9 cm) A 286 alloy steel bolts fabricated to the Aerospace Material Specification (AMS) 5726. A 0.20 cm (0.080 in) thick ASTM B 152 H01 temper (quarter hard) copper gasket provides the primary seal. A secondary seal is provided by an O-ring made from 70 durometer silicone rubber to AMS 3304. The cover flange contains a leak test port between the primary copper gasket and the secondary O-ring seal. The port is sealed with a type 316 stainless steel Cajon VCR connector, soft nickel Cajon gasket, and blind nut after acceptance testing.

The removable cover of the containment vessel contains a type 316 stainless steel NUPRO bellows valve that is a part of the containment boundary. The purpose of the valve is to pressurize the vessel with helium prior to shipment. The valve is located at the center of the cover and is welded to

1.2 Contents

The packaging is designed to transport up to 150 grams of tritium in any form. The limits on the contents of the Model No. UC-609 Shipping Package are as follows.

The tritium shall be contained in a storage vessel within the containment vessel. The maximum weight of the contents placed in the containment vessel shall not exceed 54.4 kg (120 lb). The maximum internal pressure of the containment vessel shall not exceed 760 kPa gauge at 145°C (110 psig at 293°F). The maximum tritium content shall not exceed 150 grams (48 watts decay heat load). The contents shall be in a form to allow evacuation of the containment vessel to 21 kPa (3 psia), then back-filled with helium to pass the assembly verification leakage test at 760 kPa (110 psig). The O_2 content shall be less than 5% by volume of the gas in the containment vessel. Noncorrosive metallic load distributing disks 25.08 ±0.08 cm (9.875 ±0.03 in) diameter at least 1.27 cm (0.5 in) thick shall be fixed to either end of the contents. The contents and disks shall be less than the nominal 79 cm (31 in) long cavity by 0.32 to 0.48 cm (0.125 to 0.188 in) and less than or equal to the diameter of the load distributing disks. Contents that can cause chemical or galvanic reactions with the containment boundary or activated luminous paint are not allowed.

2. STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The main component of the Model No. UC-609 Shipping Package is the containment vessel which surrounds a tritium storage vessel and is in turn surrounded by an outer stainless steel drum. The space between the tritium storage vessel and the containment vessel is maintained by an engineered packing material layer of aluminum honeycomb. The space between the containment vessel and the steel drum is maintained by an impact absorbing layer constructed of annular segments of Celotex and a plywood disk. In this design, the honeycomb protects the containment vessel against impact damage from the tritium storage vessel and distributes the impact forces that would otherwise be concentrated forces from the storage device to the containment vessel during the shock loadings of the 9 m (30 ft) drop. Similarly the Celotex absorbs the energy of a 9 m (30 ft) drop impact between the containment vessel and the impacted unyielding surface. The plywood disk distributes the force from the top ring of the containment vessel to the Celotex. The drum is designed to remain closed through the 9 m (30 ft) drop and provide a barrier against direct exposure of the Celotex or plywood to the 800°C (1,475°F) environment of a subsequent hypothetical accident thermal event. The internal metal thermal shield provides additional protection for the Celotex at the drum closure location. Any overpressurization of the drum is prevented by four 0.64 cm

(0.25 in) diameter vent holes near the top of the drum covered by adhesive tape which burns away.

The containment vessel is a relatively thin, 0.32 cm (0.125 in) nominal thickness, shell closed by a bolted flange closure with a copper gasket engaged by steel knife edges machined into the flange surfaces. The closure flanges are rigid rings when compared to the shell, on the order of 6 or 7 cm^2 (1 in^2) in cross section through each flange, and are rigidly joined by eight (8) 3/8 inch bolts. The leakage integrity of this vessel under severe mechanical and thermal loading conditions is achieved by special design features as follows. The closure components are made of materials which have matching coefficients of thermal expansion, 16.2 for the steel, 16.7 for the bolts and 16.9 for the copper, each in units of $10^{-6}/^{\circ}C$ (9.0, 9.3 and 9.4 x $10^{-6}/^{\circ}F$), thus avoiding differential thermal expansion problems. The flanges are compact being only about 4 cm (1 in) by 5 cm (2 in) in cross section, insulated from direct thermal exposure, and in contact over a large surface area with a high bearing stress, thus precluding the development of any significant thermal gradients. Although the vessel design results in some toroidal twisting of the flanges when the vessel is pressurized, the seal has passed leakage tests when subjected to pressures of about three times the maximum normal operating pressure. Analytical results corroborate this experimental finding.

The SARP states that the containment vessel was constructed according to the rules of the ASME B&PV Code, Section VIII, Division 1 with additional requirements to make the fabrication, examination, and testing technically equivalent to the requirements of Section III, Division 1, Subsection NB. The staff reviewed the construction drawings and specifications in the SARP and concurs that the Model No. UC-609 Shipping Package satisfies the requirements of Subsection NB of the ASME B&PV Code.

2.1.2 Design Criteria

The design criteria section of the SARP lists the mechanical and environmental loadings that govern the design of the Model No. UC-609 Shipping Package. The design criteria used for the containment vessel are based on the release rate requirements for contents given in 10 CFR §71.51 and the structural design and fabrication rules in the ASME B&PV Code, Section III, Division 1, Subsection NB. ASME B&PV Code allowable stress intensities for the containment vessel shell, head, and flange material are listed in the SARP. Allowable stress intensities equivalent to those of the ASME B&PV Code are also provided for the A 286 alloy steel bolting material. The containment vessel design was verified in the SARP by analysis and physical testing. The packaging design and design criteria have been reviewed by the staff and found to be acceptable. The design criteria used in the confirmatory analysis were the same as described above.

The containment vessel bolting is made from an A 286 AMS 5726 alloy steel. This bolting material is acceptable because it is identical to the ASME B&PV Code Section III, Class 1 bolting material specification SA-453 Grade 660 except that the AMS 5726 material has mechanical properties enhanced by work strengthening. The containment vessel shell and heads are made from ASTM A 240 Type 316 stainless steel sheet. The flanges are made from ASTM A 240 Type 316 stainless steel plate. The NUPRO bellows valve is made from type 316 stainless steel, the valve body, bonnet, seat insert, stem and handle are made from type 316 stainless steel which meets the material certification requirements of Section III of the ASME B&PV Code. None of these materials are susceptible to brittle fracture at the minimum temperatures of -40°C (-40°F) expected during transport. Therefore, protection against brittle fracture of the structural components comprising this packaging is not necessary.

The general properties of Celotex are given in the SARP in Section 2.3 and the specific inelastic stress strain curve used for the impact analysis is given in the SARP in Appendix 2-B. For purposes of the confirmatory review the staff used force displacement test data for Celotex provided in "Y/EN-4120 - Packaging Materials Properties Data" by M. S. Walker. This data is also the source material for some of the analyses provided in the SARP. However, the stress strain curves generated in the confirmatory review differ somewhat from those presented in the SARP. The specific shape of the stress strain curves used has a strong influence on the results of the analyses.

The staff found the material properties provided in the SARP to be acceptable. These properties are in agreement with those published in technical reports, standards, or handbooks.

2.4 General Standards for All Packages

The requirements of 10 CFR §71.43 are met as described below.

2.4.1 Minimum Package Size

For the Model No. UC-609 Shipping Package, the smallest overall dimension, as shown in Figure 1.1 of the SARP, is 63.5 cm (25 in) which is larger than the 10 cm (4 in) minimum specified in 10 CFR §71.43(a).

2.4.2 Tamperproof Feature

Detail C of the Shipping Container Assembly drawing AAA92-102223, Rev. 0C in the SARP shows that two (2) of the drum bolt heads have holes for the installation of tamper indicating security seal wires.

2.4.3 Positive Closure

The Model No. UC-609 Shipping Package includes a containment vessel securely closed by a cover with eight (8) bolts, enclosed in an drum with a bolted closure cover. This configuration prevents unintentional opening of the containment system as required by 10 CFR §71.43(c).

2.4.4 Chemical and Galvanic Reactions

The Model No. UC-609 Shipping Package has been in service since 1978 and the SARP reports that there has been no indication of any chemical or galvanic reaction between any of the materials used in this packaging. Any potential for such problems would have resulted in observable evidence of reactions during inspections after these many years of service. The staff concluded that the materials used in the Model No. UC-609 Shipping Package construction are compatible with each other and no chemical or galvanic reactions would be expected between the materials which are in contact in this packaging.

2.4.5 Valve Standards

The standards for valves in 10 CFR §71.45(e) state "A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage." The fill valve at the top of the containment vessel is protected against unauthorized operation by the valve housing. The 10 CFR §71.45(e) leakage retention requirements for valve enclosures are satisfied by the valve housing as explained in the containment evaluation in Section 4.

The valve housing has been evaluated in the structural confirmatory review by noting the SARP reports pressure testing of the enclosure to 3,450 kPa (500 psi) with measured displacements remaining linear, indicating no permanent deformation and stresses remaining below the elastic limit. The displacement of 0.033 cm (13 mils) at 2,760 kPa (400 psi) reported in the SARP corresponds to a computed displacement between 0.033 cm (13 mils) to 0.041 cm (16 mils), depending for the assumption made for the effective diameter of the valve housing, obtained in the confirmatory evaluation based on elastic behavior of the housing structure. This testing shows that there is a safety factor of at least 5 in the design, which is acceptable based on general engineering practice, which is the only criterion available for this evaluation since there is no criterion for valve enclosures in the applicable regulations. The effect of high and low temperature conditions on the valve housing has been evaluated and found to be acceptable because all of the components of the housing are made of the same material thus avoiding differential thermal expansion when temperatures change slowly and uniformly.

The valve itself is protected against direct mechanical loadings by the valve housing as noted in Section 2.7.1. However, deceleration loadings need to be considered separately. In the staff confirmatory evaluation, the stress on the connection of the valve to the containment vessel cover were evaluated for an enveloping deceleration level of 9.8 km/s^2 (1,000 g) and were found to be below yield, which is acceptable. Individual components of the valve are much too light to be affected by a drop impact acceleration.

The valve stem was evaluated for the effect of forces generated by an excessive torque applied to the valve handle. The torque on handle is specified in the SARP as "hand tight" and the staff determined that, using an extreme torque of 2.7 N-m (2 ft-lb) applied at the approximately 2.5 cm (1 in) diameter knurled round valve handle, the valve stem stresses remain below yield. Under this torque, the force in the stem would be at the elastic buckling strength of the stem and so the stem would maintain a constant maximum seating force on the valve seat over a wide range of twist applied to the valve handle. Buckling of the valve stem is not a possible failure mode because the stem is confined by an enclosing helical spring contained in the valve bellows thus limiting the elastic buckling displacement range. Based on the above evaluations the confirmatory review determined that the valve is acceptable.

2.5 Lifting and Tie-down Standards

Lifting and tie-down requirements in 10 CFR §71.45 are specifically identified as applying only to devices that are a structural part of the package. The 226.8 kg (500 lb) Model No. UC-609 Shipping Packages are handled by conventional drum handling equipment and do not have lifting or tie-down devices that are a structural part of the packaging. The package does not have any features that could be used for lifting in an unintended manner. The drum cover brackets, which could conceivably have been used to tie the package down in an unintended manner, have been modified in the present design so that these brackets no longer provide a protrusion that could be used as an attachment for a tie-down sling. Therefore the lifting and tie-down requirements in 10 CFR §71.45 are met.

2.6 Normal Conditions of Transport

2.6.1 Heat

The response of the Model No. UC-609 Shipping Package to the normal conditions of transport heat environment is evaluated and discussed in the thermal evaluation in Section 3. The increase in pressure due to heatup of the material inside the containment vessel is reported in the SARP as 600 kPa gauge (87 psig). However, to conservatively use one enveloping pressure for evaluation purposes, the SARP uses 760 kPa gauge (110 psig) as a reference design pressure. At this pressure, the SARP reports that containment shell stress design margins are about 2.5 and that the computed stress intensities reach at most 42% of the ASME B&PV Code allowable levels. The SARP also reports that, at nominal room temperatures, pressure testing to over three (3) times the design pressure was conducted without leakage. In addition, periodic pressure proof testing performed at 1,380 kPa gauge (200 psig) followed by leak testing according to ANSI N14.5-1987, indicates that the packaging meets containment requirements at the pressures associated with the normal conditions of transport high temperature.

Staff confirmatory analysis determined that the maximum pressure developed under normal conditions of transport is 650 kPa gauge (94 psig). An axisymmetric thick shell finite element model was constructed and run using the ALGOR Code working with 760 kPa gauge (110 psig) as a reference internal pressure. The resulting maximum stress intensity at the surface of the containment vessel shell was found to be 107 MPa (15.5 ksi). This stress component is classified as an ASME B&PV Code primary local membrane plus general bending stress with a stress intensity limit of 1.5 S_m, or 207 MPa (30 ksi) for SA 240 type 316 stainless steel plate. Although the containment vessel is designated as a sheet form, the stress limits for plate form are used since the ASME B&PV Code does not provide a specific limit for the sheet form of this material. The use of the plate form limits is conservative since the sheet form limits would be higher. General primary membrane stress intensities were evaluated and found to be 59 MPa (8.5 ksi) and the corresponding ASME B&PV Code limit is 138 MPa (20 ksi). The primary bending membrane stress intensities are below 90 MPa (13 ksi) with the ASME B&PV Code limit at 207 MPa (30 ksi). Staff confirmatory analysis determined that other ASME B&VP Code stress limits are met with much larger margins. So the design margins, defined as the excess of the allowable stress intensity over the computed stress intensity as a percentage of the computed stress intensity, are over 95% in all cases. The reference design pressure of 760 kPa (110 psig) was used for the above computations. Using 650 kPa (94 psig), the maximum pressure actually computed in the thermal evaluation in Section 3, the design margins are over 125%.

Staff Evaluation of Containment Vessel Shell Stresses For Normal Conditions of Transport

Stress Category	Stress Intensity MPa (ksi)	ASME Limit MPa (ksi)	Design Margin
General Primary Membrane	59 (8.5)	138 (20)	135 %
General Primary Bending	90 (13.0)	207 (30)	130 %
Local Membrane plus Primary Bending	107 (15.5)	207 (30)	95 %

The effect of the 760 kPa gauge (110 psig) reference pressure on the copper ring sealing surface has been evaluated as follows. The 760 kPa gauge (110 psig) pressure results in a force of 42 kN (9.5 kips) pushing up against the cover. Using standard bolting analysis, the force applied to the cover by the bolts, which is also the force on the flange faces, is computed to be 342 kN (76.8 kips). Hence, the 760 kPa gauge (110 psig) pressure results in a 12% reduction in the contact force between the two flanges, but produces no change in the forces or strains in the bolts. Based on this 12% reduction, the safety factor against separation of the closure due to overstressing of the bolts is 8. In the confirmatory evaluation, the distortion of the flanges due to the 760 kPa gauge (110 psig) containment vessel internal pressure, based on the elasticity of the flanges and the vessel, was investigated using an ALGOR axisymmetric thick shell finite element model. The analysis found that relative displacements at the knife edges would be completely prevented due to the stiffness of the copper gasket itself. Even with a model taking very little credit for the stiffness of the copper gasket, displacements on the order of only 2.5 microns (0.1 mil) vertically were computed, well within the elastic displacement capabilities of the 2.0 mm (80 mil) thick copper ring gasket. The strain capacity at the yield point for quarter hard copper gasket is about 0.002 or about 4 microns (0.16 mil) in 2.0 mm (80 mil). The validity of the ALGOR finite element models was established by computing the shell stresses due to pressure at locations away from shell discontinuities. The general shell stresses calculated with ALGOR were found to match corresponding stresses computed using handbook formulas.

The staff confirmatory analysis concludes that the containment vessel closure has an adequate margin against relative displacements that could result in any separation at the copper gasket for the 760 kPa gauge (110 psig) reference pressure used in the computations as an envelope for the maximum pressure under the normal conditions of transport high temperature environment.

The maximum stresses in the containment vessel closure bolts occur under the normal conditions of transport high temperature environmental conditions. The SARP computes these stresses and reports that the applicable stress limits, as delineated in the design criteria section, are met. The general tensile bolt stress is computed as 750 MPa (109 ksi) with the applicable ASME B&PV Code limit at 786 MPa (114 ksi) and the bolt surface stress intensity with the residual bolt torque shear stress taken into account is 910 MPa (132 ksi) with the ASME B&PV Code limit at 1,180 MPa (171 ksi). The maximum possible residual bolt torque, which is half of the initial bolting torque of 61 N-m (45 ft-lb), was used in this analysis. The computations in the SARP are the result of several revisions in the selection of bolting geometry, materials, and computational methods. The SARP computational results are in agreement with the confirmatory computations performed by the staff to within 1%. The staff confirmatory analysis considered more details than the SARP analysis considered, including the bolt to flange stiffness ratio and differential thermal expansion. The bolts meet the requirements of Section III of the ASME B&PV Code and the bolt stresses do not exceed yield.

The staff confirmatory analysis reported in the thermal evaluation in Section 3, concludes that under normal conditions the maximum thermal gradient will be 0.15°C/cm (0.7°F/in) and will be found in the containment vessel shell. This results in stresses on the order of 140 kPa (20 psi) which is insignificant.

Finally, differential thermal expansion effects due to increased temperature for components other than bolts were reviewed by the staff and found to be insignificant since the materials have coefficients of thermal expansion that are identical or very close to each other as noted previously.

Based on the staff evaluations described, the structural performance requirements for the heat environment for normal conditions of transport specified in 10 CFR §71.71(c)(1) are satisfied. Containment requirements will be met at the 760 kPa gauge (110 psig) pressure associated with the heat environment as discussed in the containment evaluation in Section 4.

2.6.2 Cold

The SARP shows that the requirements for normal conditions of transport at the cold temperature specified in 10 CFR §71.71(c)(2) are satisfied, based on a specific series of tests consisting of leak testing performed while cycling between nominal room temperature and the specified -40°C (-40°F) temperature at a pressure of 720 kPa gauge (105 psig). The staff reviewed this series of tests, and on the basis of the data presented in the SARP, concurs with the conclusions reached in the SARP. The low temperature will not be detrimental to the behavior of the packaging components outside the containment vessel since the packaging is assembled with generous dimensional tolerances. Therefore, the packaging components will not be affected by thermal expansion or contraction. The behavior of the materials will not be affected to the extent that analysis results would be invalidated. The stainless steels used for the containment vessel and bolts provide excellent ductility and toughness at low temperatures. Thus, the staff concludes that the low temperatures encountered during normal conditions of transport will not affect the integrity of the packaging containment.

2.6.3 Reduced External Pressure

Reduced external pressure associated with normal conditions of transport as specified in 10 CFR §71.71(c)(3) imposes a differential internal pressure of about 76 kPa (11 psi) on the containment vessel. The pressure due to high temperature, discussed in Section 2.6.1, was computed as 600 kPa gauge (87 psig) in the SARP and as 650 kPa gauge (94 psig) in the confirmatory evaluation. So the 760 kPa gauge (110 psig) used in the vessel and bolting analysis has sufficient margin to accommodate the additional 76 kPa (11 psi) due to reduced external pressure.

A 76 kPa (11 psi) pressure differential across the drum would be vented since there is no seal between the cover and the drum. Staff review indicates that any slight pressure that may develop will be relieved by a small, inconsequential deformation of the cover, which is acceptable.

2.6.4 Increased External Pressure

The 140 kPa (20 psia) absolute pressure required by 10 CFR §71.71(c)(4) results in a differential external pressure of at most 38 kPa (5.5 psi). Increased internal pressures generated by the contents will decrease this differential external pressure. This pressure will have no effect on the drum since the cover is not sealed to the drum. For the containment vessel, calculations presented in the SARP, and calculations performed by the staff during the confirmatory review, show that the external pressure is only 3 to 5% of the pressure allowed by the ASME B&PV Code for the geometry of the containment vessel. The exact percentage depends on the specific equations used for the buckling calculations. The 3 to 5% range is based on linear elastic buckling of the shell alone without the benefit of the aluminum honeycomb bonded to the vessel. The honeycomb will increase the allowable pressure substantially. Therefore, buckling of the containment vessel due to external pressure is not a concern.

2.6.5 Vibration

The bolted closure of the drum resists vibration by means of the specified 27 N-m (20 ft-lb) bolt torque on the eight (8) nominal 3/8 inch drum closure bolts. The containment vessel is closed with eight (8) nominal 3/8 inch bolts torqued to 61 N-m (45 ft-lb). Staff confirmatory review found these torques to be adequate considering the overall design and function of the closure configuration. In addition, the SARP reports that specific vibration tests have been performed on prototype Model No. UC-609 Shipping Packages followed by leak tests that indicate acceptable leakage.

2.6.6 Water Spray

The SARP states that the package is impervious to water spray. In addition, the packaging materials used are not significantly changed by the presence of water. Staff confirmatory evaluation indicates that the drum will not admit water during a water spray test and that the packaging materials would continue to perform their safety function even if exposed to water.

2.6.7 Free Drop

For packages less than 5,000 kg (11,000 lb) in weight, the normal condition of transport drop test height specified in 10 CFR §71.71(c)(7) is 1.2 m (4 ft). After being subjected to the drop test, the package must satisfy the 10 CFR §71.43(f) requirements of no dispersal, no increase in radiation levels and no decrease in effectiveness of the packaging. Radiation levels are not significant for the Model No. UC-609 Shipping Package and the external radiation level calculations are not significantly affected by the packaging materials. Packaging effectiveness in terms of establishing a geometry for criticality requirements is not an issue since no fissile material is transported. Thus, relative to the normal conditions of transport tests, the Model No. UC-609 Shipping Package has only one function, namely to provide containment of the contents.

The SARP addresses the normal free drop requirements by referring to the hypothetical accident 9 m (30 ft) drop evaluations and stating that the Model No. UC-609 Shipping Package meets the containment levels required for the normal conditions when subjected to the much more severe drop heights of the hypothetical accident conditions. The SARP reports leak testing results that indicate the normal conditions of transport containment requirements are met after the hypothetical accident 9 m (30 ft) drop tests. Since the normal condition of transport containment requirements are met after the hypothetical accident condition drop, the containment requirements will also be met after the much less severe 1.2 m (4 ft) normal conditions of transport drop. No other quantitative criteria apply, so the conclusion that the normal conditions requirements will be met following the normal conditions drop height of 1.2 m (4 ft), is valid.

The 9 m (30 ft) drop tests referred to above were not performed at the -29 to 38°C (-20 to 100 °F) range of temperatures specified in 10 CFR §71.71(b); however, as noted in Section 2.6.2 above, the stainless steels used for the containment vessel and bolts provide excellent ductility and toughness at low temperatures so the packaging will retain its performance characteristics at reduced temperatures. The staff evaluation concludes that the packaging meets all requirements after a normal conditions of transport drop.

2.6.8 Corner Drop

The corner drop conditions do not apply to packages exceeding 100 kg (220 lb) in weight.

2.6.9 Compression

The SARP refers to testing that shows that the 10 CFR §71.71(c)(9) compression test requirements are met. For the confirmatory review, the staff noted that, in the past, various comparable packagings using similar drums have been found to meet these requirements both by analysis and by test. In addition, the Celotex alone is capable of supporting the compression weight specified in the regulations. Therefore the staff concludes that the compression test requirements are met.

2.6.10 Penetration

The SARP refers to testing that shows the 10 CFR §71.71(c)(10) penetration test results in an small, insignificant dent in the drum. Impact of the 6 kg (13 lb) penetration bar dropped 1 m (40 in) will not result in damage that could affect the performance of this package. Therefore, the staff concludes that the penetration test requirements are met.

2.7 Hypothetical Accident Conditions

2.7.1 Free Drop

The 10 CFR §71.73(c)(1) hypothetical accident 9 m (30 ft) free drop test condition affects two aspects of the Model No. UC-609 Shipping Package performance. First, sufficient protection must be provided by the drum and Celotex structure so that the containment vessel will still satisfy the containment requirements after the 9 m (30 ft) drop impact. Second, the drum must provide sufficient confinement and protection of the Celotex so that, during the hypothetical accident thermal event, the Celotex will be sufficiently protected from the 800°C (1,475°F) environment to prevent unacceptably high containment vessel temperatures. The latter aspect will be discussed first.

The SARP addresses the 9 m (30 ft) free drop by reference to prototype testing in which a 9 m (30 ft) drop test was performed followed by a puncture bar drop test and then followed by a furnace thermal test, as required by 10 CFR §71.73(c). The thermal test is discussed in the thermal evaluation in Section 3. The orientation selected for the 9 m (30 ft) drop was the oblique orientation with the center of gravity of the package over the top edge. This orientation is the one most likely to open a gap in the outer packaging and provide exposure of internal components such as Celotex to the hypothetical accident thermal event. The drop did in fact result in slight separation, about 0.3 cm (0.125 in), between the cover and the lip of the drum, but this location is protected by an internal metal heat shield. The tests referred to here were performed on a prototype packaging which used a carbon steel drum while the present packaging uses stainless steel. Results for a stainless steel drum would be the same since the elastic deformation modulus is the same for both materials and the material yield strength is approximately the same. Relative to the behavior of the drum, the drop test is performed to determine if the drum material will tear. However, tearing is less likely for stainless steel than for carbon steel because the ductility of the stainless steel is higher. Also, as noted previously in Section 2.6.7, the 9 m (30 ft) drop tests were not performed at the -29 to 38°C (-20 to 100 °F) range of temperatures specified in 10 CFR §71.73(b). However, the stainless steels used for the containment vessel and bolts provide excellent ductility and toughness at low temperatures so the packaging will retain its performance characteristics at reduced temperatures.

Confirmatory review relied on a 9 m (30 ft) oblique drop analysis performed for similar drum packaging. For that packaging, a non-linear finite element analysis carried out using the ANSYS Code indicated the possibility of a small opening with dimensions comparable to the 0.3 cm (0.125 in) gap several inches long, observed in the Model No. UC-609 Shipping Package 9 m (30 ft) drop test discussed above. Possible consequences of this damage and performance expectations based on extensive drum type packaging thermal testing are discussed in the thermal evaluation in Section 3.

To address the other aspect of the 9 m (30 ft) drop test, namely that the drum and Celotex structure provide sufficient impact protection for the containment vessel so that containment will be maintained after the 9 m (30 ft) drop, the SARP presents actual prototype drop test data for two orientations and shows analytically that other orientations result in damage that is less severe. The two orientations for which drop tests were performed were an oblique drop with the center of gravity over the impact point on the top edge of the drum and a side drop with the axis of the drum in the horizontal orientation. The oblique drop resulted in crushing of the edge of the drum to a maximum depth of about 10.2 cm (4 in) and no visually detected deformation of the containment vessel. The side drop resulted in a 2.5 cm (1 in) deep indentation in the drum as well as a visually detectable indentation on the containment vessel of less than 2.5 cm (1 in). For both cases, no leakage from the containment vessel was measured to a sensitivity of 1×10^{-10} std cm^3/s helium, which is much less than the leak tight regulatory requirement.

Other orientations, in particular the top end down and the bottom end down orientations, were evaluated in the SARP by comparison of analytical results for these orientations with corresponding data for the oblique case. Analytical modeling was used to derive the deformations of the containment vessel for the oblique drop orientation and then using the same techniques to compute the deformations for the top end down drop orientation. The analysis was performed by the DYNA3D finite element method code using a constitutive relationship developed originally for crushable foam to define the Celotex behavior. Strains of the containment vessel shell in the vicinity of the juncture with the closure flange for the end drop orientation were substantially smaller than the comparable strains for the oblique drop orientation, so the SARP concludes that the leaktightness performance for the end drop orientation will also be better and the containment requirements will be met. The end drop orientation is a concern for the containment evaluation, but not for the thermal evaluation. Even though the end drop orientation results in an drum crushing depth that is much smaller than for the oblique drop orientation, the smaller crushing depth is associated with higher internal deceleration loadings and thus higher forces on the containment vessel closure. Since the load distribution in the end drop orientation is completely uniform and is in the direction that compresses the seal, this orientation is less likely to result in seal leakage than the tested oblique orientation. However, the loading to the semi-ellipsoidal end shell of the containment vessel is potentially most severe for end drop orientation. The comparison presented in the SARP as described above demonstrates by analysis, on the basis of a comparison of computed strains, that semi-ellipsoidal end shell stress for the end drop orientation is less severe than for the oblique drop orientation.

The confirmatory evaluation for the hypothetical 9 m (30 ft) drop considered the end orientation to be the critical orientation with respect to satisfying containment requirements. Deceleration levels that the containment vessel will experience were computed using a one dimensional non-linear dynamic analysis developed as an iterative PC spreadsheet analysis. The most important parameter for this analysis is the stress strain behavior of the Celotex. Therefore, several numerical representations of this behavior were used, including the data given in the SARP as well as the original Celotex compression test data from which the SARP data was derived. This analysis results in a force of 350 kN (78 kips) applied axially to the containment vessel. The local flexibility of the drum cover and drum cylinder loaded by an impact to the closure brackets, was then incorporated in the overall one dimensional dynamic model. A separate force displacement curve was developed for this local flexibility by constructing a linear three dimensional thin shell model for the ALGOR finite element code. This modification to the analysis produced a smaller effect than expected, resulting in a force reduction from 350 kN (78 kips) to 330 kN (74 kips).

Since the 330 kN (74 kip) force is compressive, this force will not lead to separation of the sealing surfaces. However, the stresses in the vessel shell need to be considered. To determine these stresses a finite element model of the containment vessel was constructed using linear material and axisymmetric solid elements, again using the ALGOR code. The general membrane stresses in the shell were computed to be less than 70 MPa (10 ksi), and this stress level was verified with a simple statics computation. The ASME B&PV Code allowable is 330 MPa (48 ksi). Other results from the finite element shell analysis are that the general shell bending stresses are no more than 290 MPa (42 ksi) which is less than the 414 MPa (60 ksi) ASME B&PV Code limit for this stress. The local peak stresses at the shell to closure flange interface are less than 470 MPa (68 ksi). Local peak stresses are not limited under the ASME B&PV Code Section III Class 1 rules for loads that are applied only once rather than resulting from repeated cycles of loading.

Staff Evaluation of Containment Vessel Shell Stresses
For a 9 m (30 Ft) End Drop

Stress Category	Stress Intensity MPa (ksi)	ASME Limit MPa (ksi)	Design Margin
General Primary Membrane	70 (10)	330 (48)	380 %
General Primary Bending	290 (42)	414 (60)	42 %
Local Membrane plus Primary Bending	470 (68)	unlimited	unlimited

The end drop orientation discussed above was of major concern in the confirmatory evaluation because this orientation results in the highest deceleration levels and also because, for this drop orientation, prototype drop testing followed by leak testing was not performed.

Other drop orientations were considered in the confirmatory evaluation, namely the oblique drop orientation and the side drop orientation, for which the SARP does present prototype drop test data. For the side orientation the SARP reports crushing depths of about 2.5 cm (1 in) for the drum plus about 0.32 cm (0.125 in) for the containment vessel. The combined crushing depth would correspond to an average deceleration level of 3,140 m/s^2 (320 g), although sustained peak deceleration levels could be twice that. Using a composite coefficient of friction for stainless steel on stainless steel and stainless steel on copper of 0.5 and the cover weight of 10 kg (22 lb), the bolting force needed to prevent any cover slippage relative to the vessel during a side drop would be 62 kN (14 kips). The bolt preload of 343 kN (77 kips) yields a safety factor of 5.5, providing conservatism for a possible higher sustained peak deceleration level, a lower coefficient of friction or a larger participation of other factors in the effective mass of the cover that is being decelerated. For the oblique orientation, the SARP reports a prototype drop test crushing depth of about 10.2 cm (4 in) corresponding to a deceleration level of only 880 m/s^2 (90 g) which is enveloped, with a wide margin, by the deceleration levels for the two component orientations considered above. The valve and valve enclosure were evaluated for deceleration loadings as discussed in Section 2.4.5 and were found to be below yield, which is acceptable. Based on the above evaluations, the staff concludes that the Model No. UC-609 Shipping Package meets the 10 CFR Part 71 requirements following a hypothetical 9 m (30 ft) drop.

2.7.2 Puncture

The SARP addresses the puncture test by presenting prototype test data for the 1 m (40 in) drop to a puncture bar conducted according to the requirements of 10 CFR §71.73(c)(2). The test, using the midpoint of the side of the drum as the impact location, resulted in a dent in the drum with a maximum depth of 2.5 cm (1 in) which is of no consequence to the various performance requirements in 10 CFR §71.52(2). There was no deformation of the containment vessel.

In general, staff confirmatory review considers a puncture bar impact, as defined by 10 CFR §71.73(c)(2), as potentially affecting compliance with requirements in three ways. First, the puncture bar can damage functional components, such as closure brackets or valves that may be out of the reach in a 9 m (30 ft) drop to a flat surface. For the Model No. UC-609 Shipping Package, any components subject to puncture bar impact are also exposed to impact in the 9 m (30 ft) drop to a flat surface so this is not a concern. Specifically, a prototype 9 m (30 ft) drop to a flat surface impacting the closure brackets has been performed, and this drop envelops the 1 m (40 in) drop to a puncture bar. The valve at the top of the containment vessel will not be reached in the puncture drop since the depth of puncture bar penetration is at most 2.5 cm (1 in) while the valve is protected by the valve housing plus 10 cm (4 in) of Celotex.

Second, for some packagings, the puncture bar impact can cause high deceleration levels to internal components of the package. However, for the Model No. UC-609 Shipping Package, any potential impact point for the 1 m (40 in) puncture bar drop is also a potential impact point for the 9 m (30 ft) drop, so the puncture bar impact will be enveloped by the 9 m (30 ft) drop impact.

The third general concern is that the surface of the packaging may be breached in the impact with the puncture bar, or an opening from another drop may be enlarged, resulting in increased damage during the hypothetical accident thermal event. For the Model No. UC-609 Shipping Package, a breach of the drum appears to be the most serious of the three concerns since the puncture bar impact could potentially propagate a gap in the drum which could have resulted from a prior 9 m (30 ft) drop. However, a breach cannot occur because the only drop orientation that can produce a gap in the outer packaging is the oblique drop to the top edge which results in a slight separation at the drum closure. The Celotex in the area of the drum closure is protected from any heat flux through the gap between the lid and the drum by a special metal heat shield provided in that area. Any subsequent orientation for a drop to a puncture bar will either tend to close this gap, if the impact is on the cover, or will involve a drop orientation with an impact tangential to the drum surface for which most of the drop energy will be dissipated in rotating the package rather than in further opening the gap in the drum. On this basis, the staff confirmatory review concludes that a puncture bar impact will not significantly affect the performance of the Model No. UC-609 Shipping Package.

2.7.3 Thermal

The hypothetical accident thermal event results in pressures and temperatures that can affect the performance of the packaging structures. As reported in the thermal evaluation in Section 3, the maximum pressure that can be developed in the containment vessel is less than 760 kPa gauge (110 psig). The discussion in Section 2.6.1 addresses this pressure and shows that the regulatory requirements for this packaging will be met for this pressure. The SARP addresses the differential thermal expansion and the thermal gradients that will develop during the thermal event by reporting test data for a prototype containment vessel subjected to these thermal conditions and leak tested with acceptable leakage. Specifically, the test subjected the vessel to a thermal gradient with the top of the vessel at 145°C (293°F) and the rest of the vessel at nominal room temperature, with the vessel internal pressure at 830 kPa gauge (121 psig). These test conditions envelope the conditions predicted for a hypothetical accident thermal event. Staff confirmatory review verified the expected temperature and pressure conditions as discussed in the thermal evaluation in Section 3, and concluded that no significant structural deformations will result from these conditions, as discussed in Sections 2.6.1 and 2.1.1.

The staff confirmatory analysis reported in the thermal evaluation in Section 3, concludes that, for the hypothetical accident thermal event, the maximum thermal gradient will be 9.6°C/cm (44°F/in) and will be found in the containment vessel shell. This gradient results in stresses below 7 MPa (1 ksi) which are acceptable. The thermal gradient through the vessel closure flanges will be lower than the 9.6°C/cm (44°F/in) maximum noted above. Gradients less than 2.4°C/cm (11°F/in) were computed. Resulting stresses could be higher than the 7 MPa (1 ksi) noted above because the closure flanges are much thicker than the shell. However, the staff estimates that the stresses will still be less than 14 MPa (2 ksi), even considering the material thickness through the flanges and the low stiffness provided by the thin shell restraining the flanges. The 14 MPa (2 ksi) stress is less than 10% of the allowable stress. In addition, the adequacy of the vessel under these thermal gradients is verified by the prototype containment vessel thermal gradient testing described above.

During the hypothetical accident thermal event, the steel drum reaches temperatures that exceed the maximum temperatures at which the steel can be allowed to support pressure or mechanical loads. However, the drum is not expected to provide pressure restraint or load carrying capacity during a thermal event. The drum will continue to surround the Celotex since the drum retains at least 10% of its strength. The development of any pressure inside the drum is precluded by the vent holes, the absence of a gasket between the lid and the drum, as well as by the fact that any significant pressure would cause enough deformation of the cover to result in venting through the drum to cover interface.

2.7.4 Immersion - Fissile Material

The Model No. UC-609 Shipping Package will have no fissile contents so this item is not applicable.

2.7.5 Immersion - All Packages

The 10 CFR §71.73(c)(5) hypothetical accident requirement for a 15 m (50 ft) immersion will affect the Model No. UC-609 Shipping Package only to the extent that the hydrostatic pressure will affect the structures of the packaging. The water itself does not result in any reduction in compliance with the regulatory performance requirements subsequent to the hypothetical accident tests. The hydrostatic pressure effect is less than 4 times the increased external pressure capacity requirement discussed in Section 2.6.4 for the containment vessel for which a factor of 20 to 30 design margin was determined. On this basis, the containment vessel will meet the 15 m (50 ft) immersion test with a factor of 5 design margin. The drum is not affected by the hydrostatic pressure because the vent holes are expected to allow water entry thus preventing external overpressurization. Should water not enter fast enough to equilibrate the external pressure, any significant overpressure will cause enough deformation of the cover to result in pressure relief through the drum to cover interface. Thus the packaging is acceptable under the 15 m (50 ft) immersion conditions.

2.7.6 Summary of Damage

The structural damage expected to result from the hypothetical accident test sequence is the crushing of the drum and supporting Celotex in the area of impact to a depth of between 2.5 and 10 cm (1 and 4 in) depending on the location of the impact caused by the 9 m (30 ft) drop. Internally no damage will result to the closure flanges but, for a side drop orientation, some superficial denting, consisting of a flattening of the containment vessel shell to a depth of less than 2.5 cm (1 in), may occur. The damage after the thermal event consists of charring of the Celotex to a depth of about 4 cm (1.5 in), leaving more than 2.5 cm (1 in) of un-charred Celotex surrounding the containment vessel at all points. This damage is an acceptable consequence of the hypothetical accident thermal event.

The staff concludes that the Model No. UC-609 Shipping Package structural features have been designed adequately and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 5480.3 have been met.

3. THERMAL EVALUATION

3.1 Discussion

Analyses and tests have been used in the SARP to evaluate the package performance during normal conditions of transport and the hypothetical accident test conditions specified in 10 CFR §71.71(c) and 10 CFR §71.73(c)(3), respectively.

The results of the staff confirmatory analysis agree with those presented in the SARP that, for a maximum loading of 150 g (25 moles) of tritium, the total decay heat source in the package will be 48 watts.

3.2 Summary of Thermal Properties of Materials

The thermal properties of the packaging components have been adequately listed in the SARP. The staff conclude that values listed are in agreement with those published in technical reports, standards, or handbooks. The references for the data cited are also provided in the SARP.

3.3 Technical Specifications of Components

The protection to the containment vessel during a hypothetical accident thermal event is provided primarily by the Celotex disks and rings fabricated per ASTM C 208 inside the drum and surrounding the containment vessel. The insulation cover assembly inside the top of the drum is composed of two (2) Celotex disks with a total thickness of 8.9 cm (3.5 in) and a 1.3 cm (0.5 in) thick interior grade plywood disk. A 0.076 cm (0.03 in) thick type 304 stainless steel heat shield covers and protects the top Celotex and plywood disks from the hypothetical accident thermal event environment if a slight gap exists between the drum and cover. Another 10.2 cm (4 in) thick Celotex ring is attached to the plywood disk at the bottom. A 1.3 cm (0.5 in) thick alumina-silica ceramic fiber blanket (Cerafelt) disk is then placed between the insulation cover assembly and the drum cover.

Celotex is an acceptable material for thermal insulation because the furnace tests, performed at the Savannah River Plant and reported in "Drum and Board-Type Insulation Over-packs of Shipping Packages for Radioactive Materials", by E. E. Lewallen, Report DP-1292, E. I. Du Pont De Nemours & Co., July 1972, have shown that Celotex, in a severely air-restricted environment, chars at temperatures above 141°C (285°F) and provides thermal protection through sacrificial decomposition during a hypothetical accident thermal event. Therefore, the allowable temperature for Celotex is 141°C (285°F).

The Cerafelt has a recommended maximum temperature limit, given in Reference 8, Section 3.6 of the SARP, of 1,300°C (2,372°F). The charring and release of combustible gases in wood, per the Encyclopedia of Material Science and Engineering, Volume 7, Editor Michael B. Bever, occurs in the temperature range of 200 to 280°C (392 to 536°F). Since the thermal properties of these two materials are acceptable at temperatures higher than that of the Celotex, the limiting allowable temperature for the thermal insulation is 141°C (285°F).

The major components of the containment boundary are the vessel, cover, fill valve and copper gasket. The containment vessel and cover are fabricated from ASTM A 240 type 316 stainless steel. The fill valve is a type 316 stainless steel NUPRO bellows valve with an operating temperature range of -62 to 316°C (-80 to 600°F), as given in the NUPRO technical specification "H and HK Series Bellows Sealed Valves", Report N-390-4, dated April, 1991. The gasket is fabricated from ASTM B 152 H01 copper sheet. From the data, given in "Machine Design, Seals Reference Issue", June 1964, the copper gasket has a continuous exposure temperature limit of 316°C (600°F). Military Specification MIL-A-46106A Silicone adhesive is used to attach the aluminum honeycomb to the inner surface of the containment vessel and has a safe working temperature limit of 200°C (392°F). The allowable temperature of 145°C (293°F), specified in the SARP for the vessel, cover and fill valve, is acceptable because this temperature is lower than the safe working temperature limits of 200°C (392°F) for the Silicone adhesive and 316°C (600°F) for the fill valve and copper gasket. This allowable temperature further assures that the aluminum honeycomb will stay attached to the containment vessel under both normal conditions of transport and hypothetical accident conditions.

3.4 Thermal Evaluation for Normal Conditions of Transport

3.4.1 Thermal Model

The performance evaluation of the Model No. UC-609 package with a decay heat load of 48 watts, presented in the SARP, is based on test data and analysis. The thermal test was performed with a prototype package in a temperature controlled room. A resistance wire, attached to the vessel carrier, was used to simulate different heat loads. The package was allowed to reach a thermal equilibrium before recording the temperatures of the package.

The analysis, presented in the SARP for the normal conditions of transport with insolation, was performed in 1977 before the present regulatory requirement for the solar heat load was applicable. A two-dimensional axisymmetric model of the package and the TRUMP computer code were used to predict the temperatures of a package exposed to the sun. The analysis was performed with a daily insolation of 2.05×10^7 J (1.95×10^4 Btu) and an ambient temperature varying sinusoidally between 54.4°C (130°F) and 26.7°C (80°F) over a 24 hour cycle. The solar heat load represented the mid-summer desert conditions in the continental U.S., but is 20% less than that presently required by 10 CFR §71.71(c)(1). The model is acceptable because the package geometry is axisymmetrical and the thermal resistance between the containment and storage vessels, used in the analysis, was computed from the temperature data recorded in the thermal test. The TRUMP code, developed in 1966, is a well used program and the validation state of the code, as described in the DOE Packaging Review Guide (1987), is considered excellent.

The SARP analysis for the normal conditions of transport with 38°C (100°F) ambient temperature and no insolation was carried out by applying an energy balance at the package surface. The analysis provides a conservative prediction because all 48 watts of the heat load was assumed to flow out through the cylindrical side of the package.

The staff confirmatory analyses used a two-dimensional axisymmetric model of the package, a decay heat load of 48 watts, an ambient temperature of 38°C (100°F) and the HEATING6 module of the SCALE-3 computer code. The analyses were performed for the package both in the shade and in the sun. For the package in the sun, the daily insolation of 3.35×10^7 J/m^2 (2.95×10^3 Btu/ft^2) and 1.67×10^7 J/m^2 (1.47×10^3 Btu/ft^2), as required by 10 CFR §71.71(c) for flat horizontal and curved surfaces, respectively, were used.

3.4.2 Maximum Temperatures

The results of the SARP and staff analyses, together with the allowable temperature limits, are presented in the following table. The component temperatures listed are the predicted peak values.

Summary of Peak Temperatures During Normal Conditions of Transport

Component	SARP °C (°F)	Staff °C (°F)	Allowable °C (°F)
Outer Accessible Drum Surface in Shade	43 (109)	42 (108)	50 (122)
Celotex	76 (169)	103 (218)	141 (285)
Copper Gasket	76 (169)	103 (218)	145 (293)
Fill Valve	76 (169)	104 (219)	145 (293)
Containment Vessel	76 (169)	104 (219)	145 (293)

The allowable temperature for the accessible surface of the package in shade is taken from the requirement in 10 CFR §71.43(g) for a non-exclusive use shipment. The allowable temperatures of 141°C (285°F) for the Celotex and 145°C (293°F) for the containment system are arrived at as discussed earlier in Section 3.3. The acceptability of the containment system to meet the requirements of 10 CFR §71.51 at 145°C (293°F) is discussed in the containment evaluation in Section 4.

The SARP analysis predicts lower temperatures than that of the staff because, the solar heat load in the SARP analysis, as stated earlier, is 20% less than that required by 10 CFR §71.71(c)(1). Furthermore, the staff performed a conservative analysis by assuming all of the circumferential area of the packaging was facing solar radiation.

For the normal conditions of transport with an ambient temperature of 38°C (100°F) and the package in the shade, the packaging complies with the accessible surface temperature limit of 50°C (122°F) for a non-exclusive use shipment as required by 10 CFR §71.43(g).

The predicted peak temperatures of the components of the packaging are all lower than the allowable temperatures for normal conditions of transport by an acceptable margin.

3.4.3 Minimum Temperatures

The minimum temperature of the package with no internal heat load will be -40°C (-40°F) when exposed to an ambient temperature of -40°C (-40°F) in still air and shade. This condition is the coldest regulatory environment required by 10 CFR §71.71 (c)(2). The effects of low temperature on the structural properties and leakage rate of tritium are evaluated and discussed in the structural and containment evaluations in Sections 2 and 4, respectively.

3.4.4 Maximum Internal Pressures

The staff has reviewed the SARP procedures used to calculate the internal pressure of the containment vessel for all of the allowable packaging contents and agrees with the conclusion that the maximum pressure in the containment vessel will be for the case when the packaging contents are the maximum allowable 150 g (25 moles) of tritium gas.

The SARP and staff pressure analyses for the package containing tritium gas are based upon the following assumptions. The tritium in the storage vessel has leaked into the containment vessel. The gas mixture in the containment vessel obeys perfect gas laws. Some of the tritium has decayed into helium-3. The amount of decay is calculated on the assumption that the transit and wait period will be one year or less.

Since there is no gasket between the drum and the cover, the pressure differential across the drum boundary will be relatively small.

The maximum internal pressures for the containment vessel from the SARP and staff analyses together with the allowable pressure are shown in the following table.

Peak Containment Vessel Internal Pressures During
Normal Conditions of Transport

SARP	Staff	Allowable
600 kPa gauge (87 psig)	648 kPa gauge (94 psig)	760 kPa gauge (110 psig)

The allowable pressure of 760 kPa gauge (110 psig), specified in the SARP for the containment vessel, is acceptable because this pressure is lower than the periodically performed proof and leak tests at 1,380 kPa gauge (200 psig) and 920 kPa gauge (133 psig), respectively. The acceptability of the containment boundary to meet the requirements of 10 CFR §71.51 at 760 kPa gauge (110 psig) is discussed in the containment evaluation in Section 4.

The staff prediction of pressure is higher than that of the SARP analysis because the temperatures predicted in the staff analysis are higher. However, the predicted peak pressures in both analyses are lower than the allowable pressure limit.

3.4.5 Maximum Thermal Stresses

The maximum temperature gradient predicted by the staff analysis during normal conditions of transport will be 0.153°C/cm (0.7°F/in) and will occur at the lower corner of the containment vessel. The stresses resulting from the temperature gradient and pressure loadings are evaluated and discussed in the structural evaluation in Section 2.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The results in the SARP and the results from the staff confirmatory analyses show that, for normal conditions of transport, the Model No. UC-609 package component temperatures and containment pressure will remain below the allowable limits. The results also show that the package surface temperature meets the thermal requirements of 10 CFR §71.43(g).

3.5 Hypothetical Accident Thermal Evaluation

3.5.1 Thermal Model

Thermal tests and analysis are used in the SARP to predict the maximum temperature and pressure of the containment system under a hypothetical accident thermal event. The leakage test of the containment boundary, heated to 145°C (293°F) and pressurized to 834 kPa gauge (121 psig), is then used to show that the package meets the requirements of 10 CFR §71.51(a)(2).

The thermal test was conducted in 1977 on a full scale prototype package without the heat source. The package was first subjected to drop and puncture tests and then inserted for 30 minutes in a furnace preheated to 800°C (1,475°F). Tempilabels that permanently change color within the indicated range were mounted on the surface of the containment vessel to record the maximum temperatures achieved during the test. The package maximum temperatures were then calculated conservatively by adding the effect of a 48 watt heat source to the measured peak temperatures. The effect of the heat source on package temperatures was calculated with the two-dimensional axisymmetric model of the package and using the TRUMP computer program.

Since the thermocouples had failed and the heat fluxes to the package were not measured during the furnace test, the staff can not judge whether the test was conducted to the present heat flux requirement of 10 CFR §71.73(c)(3). However, by linearly adding the temperature effect of the heat source to the measured temperatures has made the SARP predicted peak temperatures acceptable for the reasons discussed in Section 3.5.3.

The staff confirmatory analysis used a two-dimensional axisymmetric model of the packaging. To account for the damage from the drop and puncture tests, the model assumed the top and bottom ends of the packaging were crushed by 2.5 cm (1.0 in) and the outer radii of Celotex and drum were reduced by 0.25 cm (0.1 in). The analyses were performed using the HEATING6 module of the SCALE-3 computer code.

3.5.2 Package Conditions and Environment

The test results, presented in the SARP and verified and discussed in the structural evaluation in Section 2, show that the maximum damage from the side drop, corner drop and puncture events will be the flattening of the drum to a depth of 2.5 cm (1 in), crushing of the corner to a depth of 7.6 cm (3 in), and indenting of the drum to a depth of 2.5 cm (1 in), respectively. In the final tests performed on the prototype package with a carbon steel drum, there was no tearing of the drum and only a slight separation, about 0.3 cm (0.125 in), between the cover and the lip of the drum. The separation, as discussed in the structural evaluation in Section 2, will also be about 0.3 cm (0.125 in) in the present packaging that uses a stainless steel drum. This separation will have inconsequential impact on the hypothetical accident thermal event because the internal metal heat shield, between the drum and Celotex, protects the internal components and prevents the Celotex from being directly exposured to the hypothetical accident environment.

3.5.3 Package Temperatures

The results of the SARP and staff analyses, together with the allowable temperatures, are presented in the following table.

Summary of Peak Temperatures During the Hypothetical Accident Thermal Event

Component	SARP °C (°F)	Staff °C (°F)	Allowable °C (°F)
Copper Gasket	141 (285)	103 (217)	145 (293)
Fill Valve	141 (285)	101 (213)	145 (293)
Containment Vessel	141 (285)	131 (268)	145 (293)

The SARP predicted peak temperatures are higher than that of the staff for the following reason. A furnace test on a package with no heat source starts with lower initial package temperatures than those that would be present in a package with an internal heat source. The SARP then computed the peak package temperatures by adding the temperature rise from the furnace test on a package with no heat source to the temperatures that would have resulted from a package at 38°C (100°F) containing a 48 watt heat source. Also, during a hypothetical accident thermal event, the heat flux to and the temperature rise in a package are higher when the initial package temperatures are lower. The SARP therefore determined a higher temperature rise as a result of the 30 minutes of exposure to 800°C (1,475°F) than that computed in the staff analysis for a package with an internal heat source.

The SARP predicts 141°C (285°F) as the peak temperature for the containment boundary. 141°C (285°F) is the temperature at which Celotex begins to degrade and char. The SARP prediction therefore implies that, during a 30 minute hypothetical accident thermal event, the Celotex will char through a depth of 7.2 cm (2.85 in) and the charring front will reach the containment vessel. However, the photograph of the Celotex rings, after the 30 minute furnace test and included on page 34 of the report in Appendix 2-B of Chapter 2 of the SARP, shows that more than 2.5 cm (1 in) of un-charred Celotex surrounds the containment vessel at all points indicating that the maximum charring depth was only 4.8 cm (1.85 in). Also, the Savannah River Plant furnace test for 30 minutes at 800°C (1,475°F) has shown that the average charring depth of Celotex would be 4.4 cm (1.75 in). The effect of the 48 watt heat load, considered in the SARP prediction, is therefore high because this higher temperature is equivalent to an additional charring of 2.5 cm (1 in) of Celotex or to an additional 15 minutes of exposure to the 800°C (1,475°F) hypothetical accident thermal event environment. The SARP predicted peak temperatures are therefore higher than expected.

The SARP and staff confirmatory analyses show that during the hypothetical accident thermal event, the component temperatures remain below the allowables. The containment vessel temperature margin, 14°C (25°F), between the allowable and staff predicted temperatures assures that the containment vessel remains below 145°C (293°F), the temperature at which the containment boundary, according to the test results presented in Appendix 2-B of the SARP and discussed in the containment evaluation in Section 4, is shown to meet the requirements of 10 CFR §71.51(a)(2).

3.5.4 Maximum Internal Pressures

For the hypothetical accident thermal event internal pressure analyses, the SARP and staff used the same procedure that was used for the normal conditions of transport. The results of the SARP and staff confirmatory analyses, together with the allowable pressure, are shown in the following table.

Peak Containment Vessel Internal Pressures During the Hypothetical Accident Thermal Event

SARP	Staff	Allowable
730 kPa gauge (106 psig)	710 kPa gauge (103 psig)	760 kPa gauge (110 psig)

The SARP and staff confirmatory analyses show that during the hypothetical accident thermal event, the containment vessel pressure remains below the allowable. Furthermore, as discussed in the containment evaluation in Section 4, the containment boundary at a pressure of 760 kPa gauge (110 psig) meets the release requirement of 10 CFR §71.51(a)(2).

The Model No. UC-609 Shipping Package has four 0.64 cm (0.25 in) diameter holes to vent the Celotex decomposition gases generated during a hypothetical accident thermal event. The adhesive tape used to cover these vent holes and make the package weather tight burns away during the hypothetical accident thermal event. The furnace tests at the Savannah River Plant have shown that the clearance between the drum and cover provides an additional vent area of 0.013 cm^2/cm (0.005 in^2/in) of circumference. The results of the staff confirmatory analysis found that the total vent area, 3.80 cm^2 (0.59 in^2) from the drum cover clearance and the four (4) vent holes, is adequate to prevent the Celotex decomposition gases from building up pressure inside the drum. This total vent area for the package, which contains 50 kg (110 lb) of Celotex, corresponds to 0.076 cm^2/kg (0.0054 in^2/lb) of Celotex and is more than the recommended value of 0.071 cm^2/kg (0.005 in^2/lb) of Celotex based on the furnace tests results at the Savannah River Plant.

The vent holes in the Model No. UC-609 package are located in the top sidewall of the drum. This location of the vent holes is acceptable because the furnace tests at the Savannah River Plant have observed less smoldering, lower inner container temperatures, and no bulging of the drum for the packages with vent holes in the top sidewall of the drum than for the packages with other vent holes locations.

3.5.5 Maximum Thermal Stresses

The staff analysis predicts that the maximum temperature gradient, during a hypothetical accident thermal event, will be 9.62°C/cm (44°F/in) and will occur at the lower corner of the containment vessel. The stresses resulting from the temperature gradient and pressure loadings are evaluated and discussed in the structural evaluation in Section 2.

3.5.6 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

The SARP has demonstrated and the staff analyses have confirmed that the package will comply with the performance requirements of 10 CFR §71.51(a)(2) under the hypothetical accident test conditions specified in 10 CFR §71.73.

3.6 Conclusion

The staff concludes that the Model No. UC-609 Shipping Package thermal features have been designed adequately and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 5480.3 have been met.

4. CONTAINMENT EVALUATION

The Model No. UC-609 Shipping Package is designed to ship any form of tritium except activated luminous paint. The radioactive contents are limited to no more than 150 g (25 moles) of tritium, which corresponds to 1,455,000 Ci. This quantity represents 1,455 A_2 values for tritium as a compressed or uncompressed gas, adsorbed on a solid carrier, and tritiated water, and 72,750 A_2 values for all other forms of tritium.

The containment boundary of the Model No. UC-609 Shipping Package consists of the body and cover of the containment vessel fabricated from ASTM A 240 type 316 stainless steel together with the ASTM B 152 H01 copper gasket, the type 316 stainless steel NUPRO bellows valve, associated welds, and eight (8) A 286 alloy cover bolts fabricated to the AMS 5726. The body is made by welding formed semielliptical heads to each end of a rolled and welded sheet cylinder. Access into the vessel is through a 25.4 cm (10 in) ID flange that is welded onto one head. The cover assembly consists of a mating flange welded to a semielliptical head and closes the opening. All joints are full penetration welds made by the tungsten inert gas process according to ASME B&PV Code, Section III, Subsection NB or equivalent. The eight (8) cover bolts are torqued to 61 N-m (45 ft-lb) and securely close the containment boundary satisfying the requirement in 10 CFR §71.43(c) of a "containment system securely closed by a positive fastening device which cannot be opened unintentionally".

The only penetration into the containment boundary is through a bellows fill valve that is welded onto the bottom half of a two-piece valve housing. The fill valve and valve housing bottom are then welded into the center of the cover assembly. Three containment boundary welds are required to seal the bellows fill valve/valve housing penetration to the domed head. First, a short piece of tubing is welded to the seat side of the fill valve. Then, the valve/tube assembly is in turn welded to a boss on the housing base. Finally, a weld is performed on the inside of the cover between the housing boss and the domed head of the cover.

The release criteria for the containment boundary is leaktightness as defined by ANSI N14.5-1987 as air leakage not to exceed 1×10^{-7} std cm^3/s at an upstream pressure of 101 kPa (1 atm abs) and a downstream pressure of 1 kPa (0.01 atm abs) or less. The release requirements of 10 CFR §71.51 for both the normal and hypothetical accident conditions of transport have been shown in the SARP to be satisfied by a combination of testing and analysis which includes tritium permeation through the stainless steel containment vessel and the copper gasket. The conclusions presented in the structural and thermal evaluations, Sections 2 and 3, based upon confirmatory analyses of the packaging, demonstrate that the normal and hypothetical accident conditions do not reduce the effectiveness of the containment boundary of the package. In particular, the staff considers the release from the package acceptable because the thermal confirmatory analysis determined that the maximum seal temperature and pressure will be less than the 145°C (286°F) and 834 kPa gauge (121 psig) pressure used in the Elevated Temperature Leak Test on page 44 in Appendix 2-B of the SARP. This test verified that the leakage rate of the containment closure seal remained less than 1×10^{-7} std cm^3/s helium when exposed to this high temperature and pressure environment.

The containment boundary assembly verification tests measure the leakage through the copper gasket closure seal, by means of the leak test port, and the leakage through the fill valve, which is closed hand tight. Based on acceptable, long term operating performance, prototype design verification tests, and staff confirmatory review in the structural evaluation in Section 2, the staff is not concerned with changes in valve seat or closure seal leakage during all transport conditions. The bellows portion of the valve is not tested since the bellows is not a part of the containment boundary. The containment assembly verification leakage tests indicate that the combination of the closure seal and fill valve meet the regulatory leak tight criteria.

The valve housing provides the leakage and protection required of a valve enclosure in 10 CFR §71.43(e). The upper part of the valve housing is removable for access to the fill valve. An enclosed 70 durometer ethylene propylene elastomer O-ring seal, made to ASTM D 2000 M3BA708A14B13F17 material specification, is compressed by screwing together the valve housing upper half onto the fixed lower half to form a seal. Proof and leakage tests were performed on the seal of a prototype valve housing as reported on page 48 in Appendix 2-B of the SARP. These tests indicated that the seal performed satisfactorily at evidently nominal room temperature but tests were not performed to verify high or low temperature seal performance. However, high and low temperature seal performance is found to be acceptable in the structural evaluation in Section 2 because the valve housing will not deform causing a change in the leakage rate during the normal conditions of transport. Normally, a valve enclosure is expected to meet the same leak tight criteria as the containment boundary. However, with the tritium contents in this package, permeation leakage rate through the ethylene propylene O-ring seal becomes an important factor.

Both the SARP and staff analyses calculated the tritium permeation leakage rate through the ethylene propylene O-ring valve housing cover seal as 2.5×10^{-5} std cm^3/s at 23°C and 4.0×10^{-4} std cm^3/s at 150°C, and 2.5×10^{-5} std cm^3/s at 23°C and 1.1×10^{-4} std cm^3/s at 150°C, respectively. These permeation leakage rates alone violate the leaktight criteria of a valve enclosure. The staff considers the high tritium permeation leakage through the valve housing seal to be acceptable since the intent of the requirement for a valve enclosure in 10 CFR §71.43(e) was to prevent visible leakage from the valve during transport. Double containment is not required.

The acceptance and assembly verification leakage tests of the valve housing are performed at a pressure of less than 101.3 kPa (14.7 psia), rather than at the maximum allowable 760 kPa (110 psig) pressure of the containment boundary. This testing is acceptable to show that the valve housing will retain any leakage but is not necessary for this package since the tritium permeation leakage rates will predominate.

An assembly verification leakage test of the containment boundary is performed at the maximum normal operating pressure for the particular contents shipped with a leakage criteria of 1×10^{-7} std cm^3/s helium after the copper gasket is replaced with a new copper gasket prior to each shipment. The ANSI N14.5-1987 definition of leaktight as 1×10^{-7} std cm^3/s air corresponds to a leakage of 1.96×10^{-7} cm^3/s helium at standard leakage conditions [(SLC); 25°C and 1 atm abs]. During the assembly verification leakage test in the SARP, the closure seal and the fill valve seat are tested at a pressure less than the acceptance leakage test pressure.

The SARP leakage criterion of 1×10^{-7} std cm^3/s helium is more restrictive by a factor of two compared to leaktightness which corresponds to a leakage of 1.96×10^{-7} cm^3/s helium at SLC. This more restrictive criterion more than accounts for the error in the leakage measurement caused by the evacuation of the containment vessel to 20.7 kPa (3 psia) and the subsequent back fill with helium during the leakage tests. The staff conservatively calculates that the resultant measured leakage will be ~94% of the true helium leakage because the gas inside is actually a mixture of helium and air.

The initial integrated acceptance leakage test and the five year periodic leakage test are performed at a sensitivity sufficient to demonstrate leaktightness of the entire containment boundary. The helium gas used in the assembly verification leakage test of the containment boundary remains in the package during shipment limiting the O_2 to less than 5% by volume thus eliminating the possibility of an hydrogen explosion breaching the containment boundary in accordance with the gas concentration requirements of NRC I&E Notice #84-72.

The staff concludes that the containment boundary of the Model No. UC-609 Shipping Package will not release radioactive material in excess of the regulatory limits allowed by NRC regulations and DOE Orders under both normal conditions of transport and hypothetical accident conditions and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 5480.3 have been met.

5. SHIELDING EVALUATION

The radioactive contents of the Model No. UC-609 Shipping Package are limited to 150 g (25 moles) of tritium in any form enclosed in a 0.32 cm (0.125 in) thick stainless steel containment vessel with a maximum decay heat generation of 48 watts. Since tritium is a weak beta emitter and does not emmit penetrating gamma rays, the containment vessel alone provides adequate shielding to meet all of the requirements of 10 CFR §§71.47 and 71.51.

The staff concludes that the Model No. UC-609 Shipping Package will be within the dose rate limits allowed by federal regulations and DOE Orders under both normal conditions of transport and hypothetical accident conditions and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Order 5480.3 have been met.

6. CRITICALITY EVALUATION

Since the allowable contents of the Model No. UC-609 Shipping Package are limited to any form of tritium, a non-fissionable material, criticality is not possible.

7. OPERATING PROCEDURES EVALUATION

The operating procedure requirements presented in Chapter 7 of the SARP for the Model No. UC-609 Shipping Package provide specific guidance for:

1.) loading, closure, and preshipment checks,
2.) receiving checkout, opening, and unloading, and
3.) empty packaging preparations.

Each container must first be inspected and discrepancies corrected before being used. The inspection and repair criteria are put forth in Section 8.2.3 of the SARP.

Radiation surveys are prescribed at two points of the loading process. The first ensures that the empty packaging was not contaminated during storage to protect the loading and handling personnel and the second ensures compliance with shipping regulations.

Assembly verification leakage testing is required as part of the operating procedures described in Chapter 7 of the SARP. Step 15 of Section 7.1 specifies the requirements for the assembly verification leakage test based on a mass spectrometer leak detector with a sensitivity of 1×10^{-8} cm^3/s helium. The acceptance criteria specifies that any detected leakage equal to or less than 1×10^{-7} std cm^3/s helium is acceptable.

The staff concludes that the operating procedure requirements presented in the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR 71, 49 CFR 173 and DOE Order 5480.3 have been met.

8. ACCEPTANCE TESTS AND MAINTENANCE PROGRAM EVALUATION

The requirements for acceptance tests to be performed on each Model No. UC-609 Shipping Package prior to first use and after third use are presented in Section 8.1 of the SARP. These tests include:

1.) visual inspection,
2.) structural and pressure tests, and
3.) leak testing.

The maintenance program used to ensure continued performance of the packaging is described in Section 8.2 of the SARP. This program includes:

1.) structural and pressure tests,
2.) leak tests, and
3.) subsystem maintenance.

Chapter 8 of the SARP includes leakage tests to be performed before first use, after third use and every five years on the containment boundary. The tests require sensitivities of 1×10^{-8} cm^3/s helium to assure that the containment criteria of 1×10^{-7} cm^3/s helium is satisfied.

The maintenance program also includes a replacement schedule and shelf life for parts such as seals, and guidance on how components should be repaired.

The staff concludes that the acceptance tests and maintenance program requirements presented in Chapter 8 of the SARP are acceptable and will provide reasonable assurance that the regulatory requirements of 10 CFR 71, 49 CFR 173 and DOE Order 5480.3 have been met.

9. QUALITY ASSURANCE EVALUATION

The requirements for a Quality Assurance (QA) Plan presented in the QA Chapter 9 of the SARP have been reviewed and found to meet the QA requirements of

10 CFR 71, Subpart H. These QA requirements provide sufficient control over all items and quality-affecting activities that are important-to-safety as applied to the design, procurement, fabrication, testing, operation, maintenance, modification and repair of the Model No. UC-609 Shipping Package. The QA requirements are based on a graded approach as described in 10 CFR §71.101. In addition, based on the contents of the package, which exceed 30,000 Ci, the containment boundary components must be designed, fabricated, and tested in accordance with ASME B&PV Code, Section III, Subsection NB as recommended by NUREG/CR-3854, "Fabrication Criteria for Shipping Containers", and NRC Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches". The graded approach in the QA Chapter includes an important-to-safety Q-list for each item and quality-affecting activity and is graded based on the design function of the item relative to the safety and performance requirements for the complete shipping package. The Q-list uses three QA levels with associated definitions for each. The QA level of each important-to-safety item is based on the specific criteria, and the necessary level of QA requirements is invoked for each item. The QA requirements assure that the Model No. UC-609 Shipping Package is designed, fabricated, and tested in accordance with the drawings identified in Appendix 1-A of the SARP. In addition, the QA Chapter requires the user to invoke the same level of QA requirements for the use, maintenance, and repair of the packaging as is required for the procurement, fabrication and acceptance testing of the original packaging. The QA levels for important-to-safety items and activities are based on the following definitions:

1. QA Level 1 (Critical)

   Items or quality-affecting activities whose failure or malfunction will directly result in an unacceptable condition of containment, shielding, or subcriticality.

2. QA Level 2 (Major)

   Items or quality-affecting activities whose failure or malfunction could indirectly result in an unacceptable condition of containment, shielding, or subcriticality. An unsafe condition could result only if the failure of a QA Level 2 item occurred in conjunction with the failure of another QA Level 2 item.

3. QA Level 3 (Minor)

   Items whose failure or malfunction will not reduce the packaging effectiveness and will not result in an unacceptable condition of containment, shielding, or subcriticality.

After determining the applicable QA level, the appropriate level of QA effort for design, procurement, fabrication, testing, operations, maintenance, modification and repair activities is determined from the 18 QA elements identified in 10 CFR 71, Subpart H and ASME-NQA-1. The 18 elements identified in the SARP are organization; quality assurance program; design control; procurement document control; instructions, procedures, and drawings; document control; control of purchased material, equipment, and services; identification and control of material, parts, and components; control of special processes; inspection control; test control; control of measuring and test equipment; handling, shipping and storage control; inspection, test and operating status; control of nonconforming materials, parts, or components; corrective action; QA records; and QA audits.

The QA Chapter of the SARP includes independent verification of fabrication and operational activities considered to be critical in satisfying the regulatory requirements for containment, shielding, and subcriticality as identified in 10 CFR Part 71. The independent verifications include the dimensions of all Q-flagged items identified on fabrication drawings, final bolt torquing of the containment vessel closure, acceptance leakage tests prior to first use and after the third use, assembly verification leakage tests before each shipment, periodic leakage tests at least every five (5) years or whenever any repairs or changes in components, except for the copper gasket, are made to the containment boundary.

The staff concludes that the QA requirements presented in the SARP are in conformance with the established criteria in Subpart H of 10 CFR Part 71 and will assure that any design, procurement, fabrication, testing, inspection, operations, maintenance, modification, or repair of the Model No. UC-609 Shipping Package will be accomplished in accordance with the requirements presented in the SARP and will provide reasonable assurance that the regulatory requirements of 10 CFR Part 71, 49 CFR Part 173 and DOE Orders 5480.3 and 1540.2 have been met.

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Date: AUG 12 1993