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SAFETY EVALUATION REPORT

Docket No. 71-9370
Model No. 380-B
Certificate of Compliance No. 9370
Revision 0

Enclosure 2

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SUMMARY

By application dated April 6, 2016 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML16102A136), as supplemented on October 13, 2016 (ADAMS Accession No. ML16294A260), October 20, 2016 (ADAMS Accession No. ML16301A022), June 9, 2017 (ADAMS Accession No. ML17165A437), and September 11, 2017 (ADAMS Accession No. ML17258A069), the National Nuclear Security Administration (hereafter, NNSA or the applicant), requested that the U.S. Nuclear Regulatory Commission (NRC) approve the Model No. 380-B package as a Type B(U)-96 package for the transport of non-fissile radioactive sealed sources contained in either shielded devices or shielded source containers. Quantities of fissile materials less than 15 grams are also allowed.

The packaging consists of a package body; a closure lid, a personnel barrier, and impact limiters. Unless otherwise noted, all elements are made of Type 304 stainless steel (SS) in conformance with American Society for Testing Materials (ASTM) A240 (ASTM, 2015a). The package is designed to be transported singly, with its longitudinal axis vertical, by ground, air, or by water in accordance with the exclusive use regulations. The Model No. 380-B package provides leaktight containment of the radioactive contents under all normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

NRC staff reviewed the application, including relevant information in the attachment to the application, using the guidance in NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material,” (NRC, 1999). Based on the statements and representation in the application, as supplemented, and the conditions listed below, the staff concludes that the package meets the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) Part 71, “Packaging and Transportation of Radioactive Material.”

1.0 GENERAL INFORMATION

1.1 Package Description

Section 1.2.1 of the application described the Model No. 380-B package, when loaded and prepared for transport, as 118.2 inches (in.) tall, 100 inches in diameter (over the upper and lower impact limiter), and weighing a maximum of 67,000 pounds (lbs.). Section 1.2.1 of the application also identified the empty packaging weight as 55,000 lbs. The applicant designed the Model No. 380-B package as a Type B(U)-96 package for transporting a variety of radioactive sources and irradiation devices (shielded devices) containing radioactive sources which are either sealed or encapsulated. Unless otherwise noted, the applicant fabricated the package using various forms of ASTM Type 304 SS to construct the Model No. 380-B package components.

1.1.1 **Packaging**

The application described the following Model No. 380-B package components:

(1) Cask assembly (package assembly) which included the following components:

a. Cask body
b. Closure lid
c. Thermal shield

(2) Personnel barrier

(3) Inner cover

(4) Impact limiters.

1.1.1.1 Cask Assembly (Package Assembly)

The package assembly consisted of a shielded package (also described in the application as a "cask") body and closure lid which is bolted to the package body in the transport configuration. The applicant used austenitic SS as the material of construction for all structural components of the package body. The application described the package assembly, without impact limiters, as a cylinder 68-1/8 in. long with a diameter of 57-½ in.

(a) Cask Body

The cask body included:

(i) a 1-½ in. thick Type 304 SS inner shell;

(ii) a 1-¾ in. thick Type 304 SS outer shell;

(iii) a 6-½ in. thick lead shield cast-in-place through the upper end structure and solidified between the inner shell and the outer shell;

(iv) an upper-end structure consisting of an O-ring and 36 tapped holes which accommodate the closure lid bolts; and

(v) a lower-end structure consisting of a 2-½ in. thick inner plate which is filled with 6 inches of lead sheets packed firmly in place prior to welding a 1-½ in. thick outer plate to the inner plate.

The concentric inner and outer shells formed the annulus for the 6-½ inch thick lead shield. An upper end structure that included an O-ring sealing surface and 36 1-½ 6UNC-2B tapped holes for the lid closure bolts comprised the top of the cask body. The applicant either forged, cast, or machined the package body.

(b) Closure Lid

The applicant either forged, cast, or machined the closure lid which consisted of a 2-½ in. thick inner plate filled with 6 inches of lead and covered with a 1-½ in. thick outer plate. The lid had 36 through holes with counter bores to recess and protect the socket head closure bolts. The mating surface of the lid featured a step relief located at the bolt circle. This relief prevented prying loads from being applied to the closure bolts by precluding any contact between the lid and the body outside the bolt circle.

(c) Thermal Shield

The applicant used a 0.105-inch (12 gauge) Type 304 stainless steel thermal shield between the upper and lower impact limiters. Sheet 4 of drawing 1916-02-02-SAR depicted the thermal shield as separated from the outer cask shell by 0.105-inch (12 gauge) stainless steel strips and three 0.102-0.105-inch (10 AWG) diameter stainless steel wire rings wrapped around the outer shell with 4 inch spacing. The offset thermal shield provided an approximate 1/10 inch air gap between the cask outer shell and environmental conditions.

1.1.1.2 Personnel Barrier

Section 1.2.1.3 of the application described the personnel barrier as consisting of two equal assemblies of expanded SS sheets and 0.105 in. (12 gauge) SS perimeter strips. The personnel barrier limited access to the cask body between the impact limiters allowing the dose rates on the side of the package to meet the NCT requirements. The applicant designed the personnel barrier to be removable and to be secured with either padlocks, pins or both.

1.1.1.3 Inner Cover

Section 1.2.1.4 of the application described the inner cover as a ½-in. thick SS plate with a 2 in. wide by 1-½ in. thick reinforcing ring welded to the outer perimeter of the SS plate bottom. The inner cover included ½ - 13UNC SS screws with rotating retainers to anchor it to the inner shell of the cask assembly. The inner cover served as an exclusion zone in the NCT shielding evaluation.

1.1.1.4 Impact Limiters

Section 1.2.1.2 of the application described the two Model No. 380-B impact limiters as 100 in. diameter and 43 in. long with a 16.8 in. conical section towards the outer end. Each impact limiter also included:

(a) both an outer and an inner cylindrical shell, each fabricated from ¼ in. thick Type 304 SS,

(b) a ½ in. thick inner flat plate,

(c) polyurethane foam that provided energy absorption during NCT and HAC as well as thermal protection during the HAC fire, and

(d) three, reinforced, 5/8 – 11UNC threads on both the top end and inner surface of the impact limiters for lifting of the impact limiter only.

Twelve bolts made from ASTM A564, Type 630, Condition H1100 precipitation hardened SS (ASTM, 2013) with 1-1/4 – 7UNC threads and a 1.1 inch diameter shank attached the impact limiters to the package body.

1.2 Contents

The applicant designed the Model No. 380-B package to transport non-fissile sealed and encapsulated radioactive sources in the form of either shielded devices or shielded source containers. The applicant identified the maximum activity of the package contents as shown in Table 1.3-1 below and the maximum allowed decay heat as 205 watts (205W) per package.

Table 1.3-1 Maximum Activity of Payload Source Nuclides

Nuclide	Maximum Activity Ci
^{60}Co	7,702
^{137}Cs	40,675
^{192}Ir	33,333
^{90}Sr	30,606
^{226}Ra (no Be) [4]	1,101
^{226}Ra Be [4]	4.67

Notes to Table 2:
1. Physical form of all nuclides is solid material in a sealed capsule.
2. The maximum activity listed is the maximum for a single nuclide in the Model No. 380-B. For combinations of different nuclides, lower activity limits apply as discussed in Chapter 5, “Shielding Evaluation,” of the application.
3. The maximum activity is 16,431*A_2 per Section 5.5.3, “A_2 Calculation,” of the application.
4. Impurities may include oxygen, carbon, sulfur, bromine (hydrous), and chlorine (hydrous and anhydrous).

The applicant used either metallic, polyurethane foam, or wood dunnage materials to block all contents in position for shipment in the Model No. 380-B package. The applicant stated that the dunnage would prevent unwanted motion during NCT, and that these materials did not provide a safety function. The applicant indicated that all contents of the package are dry and that the only potential source of water vapor was the moisture normally present in wood dunnage. The applicant accounted for moisture normally present in wood in both the NCT and the HAC maximum pressure analyses. The staff confirmed that the package loading procedures verify that both the contents and the package interior are free of moisture.

Table 1.3-2 Maximum Weight of Inner Container Contents

Component	Maximum Weight (lbs.)
Device(s)	10,000
Dunnage	2,000

The staff reviewed the description of the package and contents and concluded that it meets the requirements of 10 CFR Part 71.

1.3 Drawings

The applicant constructed the packaging in accordance with the following NNSA drawings:

a. 1916-02-01-SAR, “LANS 380-B Package Assembly,” sheets 1-2, Revision 0.

b. 1916-02-02-SAR, “LANS 380-B Cask Assembly,” sheets 1-6, Revision 2.

c. 1916-02-03-SAR, “LANS 380-B Impact Limiter Assembly,” sheets 1-4, Revision 1.

The staff reviewed the drawings and found they adequately represented the package. The drawings included dimensions, dimensional tolerances, package markings, materials of construction, and the codes and standards used to design the package. The drawings contained standard symbols for welding and nondestructive examination consistent with American Welding Society (AWS) 2.4 (AWS, 2014).

2.0 STRUCTURAL EVALUATION

The objective of this review is to verify that the structural performance of the Model No. 380-B package design has been adequately evaluated in accordance with Subpart E, “Package Approval Standards” for all packages and the tests specified under NCT and HAC to meet the requirements of 10 CFR Part 71.

2.1 Description of Structural Design

2.1.1 Structural Design Features

The applicant identified the main structural components of the Model 380-B package as follows:

(1) the lead-shielded cask body assembly,

(2) the package lid, and

(3) the impact limiters.

Section 1.1 of this SER included a description of the Model No. 380-B package features.

The applicant designed the two impact limiters to protect the package from the impact loads of a package drop scenario. Drawing No. 1916-02-03-SAR of the application presented impact limiter design details, including the following:

(1) the ¼-in. thick cylindrical shell enclosure,

(2) the ½-in. inner flat plate, and

(3) the 16 pounds per cubic foot (lb/ft^3) of polyurethane foam.

The impact limiters overlapped the cask body, one each at the package top and bottom ends, and each measured 100 in. in diameter and 43 in. long overall. Twelve 20-in. long by 1-¼ in.

diameter attachment bolts made from ASTM A564, Type 630, Condition H1100 precipitation hardened SS bar stocks secured the impact limiter to the cask body. As shown on Drawing No. 1916-02-03-SAR, the applicant designed individual attachment bolts to be threaded at one end into a boss welded to an inner flat plate internal to the impact limiter and fastened to a lug welded to the external shell of the cask body at the other end.

2.1.2 Design Criteria

Section 2.1.2 of the application presented the structural design criteria for the Model No. 380-B package. Satisfying the design criteria ensured that the following 10 CFR Part 71.51 safety requirements are met:

(1) no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging during NCT, and

(2) no escape of radioactive material exceeding a total amount of one A_2 in one week and no external dose rate exceeding 1 rem per hour (1 rem/hr.) at one meter from external package surfaces during HAC.

For the structural design, the applicant identified the package as a Category I container per NUREG/CR-3854, "Fabrication Criteria for Shipping Containers," with the following component classifications:

(1) Containment structures

ASME Boiler and Pressure Vessel Code (ASME B&PV Code), Section III, "Rules for Construction of Nuclear Facility Components, Division I, Subsection NB – Class I Components." This applied to the cask body containment boundary elements, including the lower end structure, the inner shell and the upper end structure as well as the cask closure lid main structure and the closure bolts which were designed in accordance with the guidance of NUREG/CR-6007, "Stress Analysis of Closure Bolts for Shipping Casks."

(2) Non-containment structures

ASME B&PV Code, Section III, "Rules for Construction of Nuclear Facility Components, Division I, Subsection NF – Supports." To perform an effective structural evaluation, the applicant used the design by analysis stress analysis approach of Subsection NB for the cask body non-containment elements, including the outer shell, lid outer plate, and bottom outer plate.

The applicant designed the impact limiters using energy-absorbing polyurethane foam to absorb the impact energy by crushing during the cask free drops. The applicant demonstrated the impact limiter performance through ½-scale certification test unit (CTU) drop tests that showed the impact limiters:

(1) limit impact loads exerted on the package components,

(2) prevent the cask body and lid from a "hard" landing onto an essentially unyielding surface, and

(3) remain attached to the cask body with sufficient structural integrity subsequent to the HAC free drop and puncture drop events.

The applicant noted that all contents (i.e., shielded devices) are placed into the Model No. 380-B package for shipment and blocked in position using either metallic structures, polyurethane foam, or wood dunnage materials to prevent unwanted motion during NCT.

2.1.3 Structural Acceptance Criteria

The applicant demonstrated the package structural performance primarily by computer analyses. The applicant calculated impact loads with a finite element analysis (FEA) impact limiter model and benchmarked the FEA method of evaluation using data obtained from ½-scale CTU drop tests.

The applicant used acceptance criteria in accordance with Regulatory Guide 7.6, “Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels,” to evaluate NCT and HAC allowable stresses for the cask body assembly FEA. The applicant also used loads and load combinations in accordance with Regulatory Guide 7.8, “Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material.” These loads and loading combinations included heat, cold, pressure, vibration, and free drop for NCT and free drop for HAC.

Section 2.1.2.3 of the application presented structural performance criteria for miscellaneous structural failure modes, including brittle fracture, fatigue and buckling. Section 2.1.2.3.2 of the application evaluated the Model No. 380-B package against the ASME Code, Section III, NB-3222.4(d) cyclic operation provisions. Considering normal operating cycles of package loading and unloading, the applicant demonstrated adequate fatigue resistance of the package to ensure a minimum 25 year service with up to 50 shipments per year.

Section 2.1.2.3.3 of the application noted that the cask body inner and outer shells are evaluated for structural stability in accordance with the interaction equations of ASME Code Case N-284-4. Appendix Section 2.12.6 of the application provided buckling analysis details based on the stress analysis results of Section 2.6.4, “Increased External Pressure,” Section 2.6.7, “Free Drop (NCT)”, Section 2.7.1, “Free Drop (HAC)”, and Section 2.7.6, “Immersion – All Packages.” The analysis details demonstrated that the buckling capabilities of the inner and outer shells adequately satisfied the ASME B&PV Code, Level A and Level D service conditions factor of safety provisions. For NCT (Service Level A), the applicant employed the required factor of safety of 2.0, and for HAC (Service Level D), the applicant employed the required factor of safety of 1.34.

2.1.4 Weights and Centers of Gravity

Table 2.1-2, “380-B Package Component Weights,” of the application listed weights of major components of the package. Section 2.1.3 of the application noted that the center of gravity (CG) of the package is located 58.9 inches from the bottom outside surface of the external impact limiter for a package with a maximum gross weight of 67,000 lbs.

2.1.5 Codes and Standards

Section 2.1.4 of the application summarized the codes and standards used to design the Model No. 380-B package. SER Section 2.1.2 above discussed use of the codes and standard.

2.1.6 General Considerations for Package Structural Evaluation

The applicant evaluated the structural performance of the package by analysis and by testing. For the evaluation by analysis, the applicant used both FEA and closed-form solutions. For the evaluation by testing, half-scale packaging drop test results confirmed the design adequacy of the impact limiters and provided test data suitable for benchmarking the impact limiter FEA model as well as for calculating bounding cask deceleration g-loads and impact limiter deformations. Staff reviewed the general considerations for the package structural evaluation with respect to evaluation by analysis and by testing, including the use of test data to benchmark the impact limiter FEA model, and provided their evaluation in the following sections.

2.1.6.1 Evaluation by Analysis

2.1.6.1.1 Finite Element Analysis Codes

Sections 2.12.4 1 and 2.12.5.2 of the application presented details of the two general-purpose, commercially available FEA codes, ANSYS and LS-DYNA, used by the applicant to perform package structural evaluations. The applicant used ANSYS to perform quasi-static stress analyses of the Model No. 380-B system components including the cask body and cask lid. The applicant used the explicit dynamic analysis code, LS-DYNA, to determine impact limiter deformations and rigid body decelerations for the package free drop tests onto an essentially unyielding surface. After showing that the LS-DYNA decelerations correlated conservatively with the equivalent prototype test results, the applicant then used the LS-DYNA decelerations in the ANSYS stress analyses of the Model No. 380-B system components including the cask body and cask lid.

2.1.6.1.2 Finite Element Analysis Models

Appendix Section 2.12.4.1 of the application discussed the ANSYS finite element modeling of the Model No. 380-B cask body and closure lid. The ANSYS finite element model consisted of the upper and lower end structures, the inner shell, the outer shell, the bottom outer plate, and closure lid. The applicant chose to model the cask shell and closure lid plates using SOLID185 bricks. The applicant modeled both the closure lid bolts and the closure lid using BEAM4 elements and also modeled interface elements using both CONTA173 and TARGE170 contact elements. The applicant developed a half-symmetry model configuration which is depicted in Figure 2.12.4-1.

Appendix Section 2.12.5.2 of the application presented the Model No. 380-B package half-symmetry LS-DYNA finite element model with the prototypical impact limiter modeled in detail; however, the applicant chose not to model the cask body, the cask lid, and payload explicitly. The applicant modeled the cask body as a rigid hollow cylinder with closed ends and represented the payload as a solid cylinder. Figure 2.12.5-1 of the application depicted the LS-DYNA model.

Because LS-DYNA simulations of large deformation impact limiter responses can be sensitive to the finite element modeling approach implemented, the applicant demonstrated that their FEA approach was conservative by benchmarking their analytical results against test data. Appendix Sections 2.12.3 and 2.12.5 of the application presented the test results and evaluations, respectively, for the CTU which is a half-scale construction of the Model No. 380-B package. In SER Section 2.1.5.2.2, the staff evaluated the applicant's benchmarking of the LS-DYNA impact limiter analysis approach. The staff reviewed the modeling approaches and concluded that they are acceptable because they use common practices for analyzing cask body structural components.

2.1.6.2 Evaluation by Test

The applicant performed the 30-ft free-drop and the 40-in. puncture-drop tests of the half-scale CTUs to demonstrate the general structural integrity of the impact limiter and their attachment to the cask. Additionally, the applicant used the drop test results to benchmark the LS-DYNA finite element analysis approach from which impact limiters crush depths and rigid-body decelerations of the cask body were conservatively calculated for the packaging.

2.1.6.2.1 Half-Scale Cask Certification Test Unit Drop Tests

Appendix Sections 2.12.2 and 2.12.3 of the application described the test plans and test results, respectively, of the half-scale CTUs for the 30-foot end, the 30-foot CG-over-corner, and the 30-foot side free drops as well as four 40-inch puncture drops at various impact limiter locations. Table 2.12.3-2 of the application delineated the use of four CTUs, each associated with either new or drop-damaged impact limiters, for the drop test sequence. The application also described the use of four accelerometers for recording cask drop response time histories. The applicant used a cutoff frequency of 500-Hz to filter the raw data and to obtain rigid-body decelerations of the cask body.

Appendix Section 2.12.3.4 reported the maximum decelerations measured for the end drop, CG-over-corner and side drop CTU configurations which are summarized in Table 2.1-1 below. Staff reviewed these maximum decelerations together with the recorded time-history responses to assess the applicant's benchmark of the impact limiter LS-DYNA finite element modeling approach and provided their assessment in SER Section 2.1.6.2.2.

Table 2.1-1 Tested Maximum Decelerations - 1/2-Scale CTUs, 30-ft Drop

	Accelerometer No.				**Average**
Drop Orientation/Measurement Direction	***1***	***2***	***3***	***4***	
D1, End Drop/Cask Axial	156g	152g	153g	159g	155g
D2, CG Over Corner Drop/Normal to Drop Pad	lost	87g	106g	107g	98g
D3,Side Drop/Cask Transverse	118g	119g	117g	122g	119g

The staff reviewed the tests conducted and determined that the test results, including the maximum rigid-body decelerations and corresponding response pulse durations and shapes, are adequately reduced. The tests confirmed the impact limiter would remain attached to the cask body and the deformation capability of the impact limiters would prevent a hard landing by the cask on an essentially unyielding surface during a cask free drop accident.

2.1.6.2.2 Benchmark of Impact Limiter Finite Element Analysis Model

Appendix Section 2.12.3 of the application presented the half-scale CTU test results used to benchmark the impact limiter FEA modeling as well as demonstrate impact limiter performance which include remaining attached to the cask body after the free drop.

As noted in Appendix Section 2.12.5.2 of the application, the LS-DYNA finite element model included both a full scale and a half-symmetry impact limiter model. However, the applicant modeled neither the cask body, the cask lid nor the payload explicitly. The applicant represented the cask body by a rigid hollow cylinder with closed ends and the payload by a solid cylinder. Appendix Section 2.12.5.3.3 of the application summarized the following material model selections:

(i) *mat_plastic_kinematic for Type 304 SS,

(ii) *mat_plastic_kinematic for A564 Type 630 Condition H1100 steel,

(iii) *mat_rigid for cask, payload, and drop pad, and

(iv) *mat_crushble_foam for polyurethane foam.

Figures 2.12.5-24 through 2.12.5-26 of the application compared the calculated decelerations with the tested prototypical equivalent, rigid-body, deceleration time histories of the CTUs for the three free drop tests. The time-history response plots compared the three most dominant response quantities: the maximum deceleration, the pulse duration and the pulse shape. The staff noted that the area enclosed by the horizontal time axis and the single-pulse response curve provide a good estimate of the total impact limiter energy dissipation. The tested and simulated responses correlated well with those shown in the plots. Therefore, in aggregate, the comparison plots indicated the capability of the LS-DYNA FEA models to simulate the cask free drop response. On this basis, the staff concluded with reasonable assurance that the LS-DYNA modeling, as implemented by the applicant, is capable of conservatively calculating the impact limiter deformations and the rigid cask body decelerations.

Table 2.1-2 below compared the calculated and tested maximum impact limiter deformations as well as the corresponding cask rigid body decelerations. The calculated impact limiter deformations demonstrated that the LS-DYNA model can conservatively calculate the deformations. Similarly, they demonstrated that the calculated decelerations, which are considered in the quasi-static structural analyses of the cask body components in Sections 2.12.4 and 2.12.6 of the application, are conservative.

Table 2.1-2 Benchmark Results Comparison

Results	D1 Cold End Drop	D2 Warm CG Over Corner Drop	D3 Warm Side Drop
Max. Deceleration, Test	78g	49g	60g
Maximum Deceleration, Benchmark	83.7g	49.4g	60.7g
Percent Less	-6.8%	-0.8%	-1.2%
Max. Crush, Test	5.44 in	11.86 in	7.10 in
Max Crush, Benchmark	6.01 in	13.53 in	10.38 in
Percent Less	-1.5%	-12.34%	-31.60%

2.2 Mechanical Properties of Materials

The staff conducted a comprehensive review of the materials listed in the bill-of-materials and the application. Table 2.2-1 through Table 2.2-6 of the application showed both the strength and material properties used in the Model No. 380-B package structural analyses. Tables 2.2-1 and 2.2-2 of the application listed the mechanical properties of wrought and forged Type 304 SS respectively. The staff compared the mechanical properties listed in Tables 2.2-1 and 2.2-2 of the application to the mechanical properties listed in the ASME B&PV Code, Section II, Part D, (ASME, 2011) and confirmed the values listed for the properties below were appropriate:

a. yield strength,

b. ultimate strength,

c. design stress intensity,

d. elastic modulus, and

e. thermal expansion coefficients.

The staff determined that the specifications and temperature dependent mechanical properties, including yield strength, tensile strength, allowable strength, modulus of elasticity, and coefficient of thermal expansion conform to ASME Code, Section II, Part D (ASME, 2011). The staff found the materials properties information provided by the applicant for the Model No. 380-B package components acceptable.

2.2.1 Bolts

Table 3.2-3 of the application listed the mechanical properties of the ASTM A564, grade 630, Condition H1100 bolts. The staff compared the mechanical properties listed in Table 2.2-3 of the application to the mechanical properties listed in the ASME B&PV Code, Section II, Part D, (ASME, 2011) and confirmed the values listed for the properties below were appropriate:

(1) yield strength,

(2) ultimate strength,

(3) design stress intensity,

(4) elastic modulus, and

(5) thermal expansion coefficients.

The staff determined that the specifications and temperature dependent mechanical properties, including yield strength, tensile strength, allowable strength, modulus of elasticity, and coefficient of thermal expansion, conform to ASME B&PV Code, Section II, Part D (ASME, 2011). The staff determined that the allowable strength (equivalent to the design stress intensity) for the ASTM A564 Grade 630 bolts is consistent with the guidance in NUREG/CR-6007 (Mok et al., 1992). The applicant provided mechanical properties for the ASTM A564 Grade 630 bolts up to temperatures of 800°F (427°C) to assess bolt performance under HAC. The staff determined that, while the maximum impact limiter attachment bolt temperatures under HAC exceed the ASME code maximum temperature limits for this material, a reduction of the mechanical properties of the bolts is of no consequence because the time at elevated temperatures is less than the time required for the mechanical properties to degrade.

2.2.2 Shielding Material

Table 2.2-4 of the application listed the lead shielding mechanical properties. These properties met either ASTM B29 (any grade) (ASTM, 2014), or Federal Specification QQ-L-171e grade A or C (GSA, 1957) specifications. The staff compared the mechanical properties listed in Table 2.2-4 of the application with the mechanical properties listed in WADC Technical Report 5.7-.695 (Tietz, 1958) and NUREG/CR-0481 (Rack and Knorovsky, 1978). The staff confirmed that the values listed in the application for tensile yield strength, tensile ultimate strength, tensile proportional load elastic modulus and thermal expansion coefficient are consistent with reported values in Tietz (1958) as well as Rack and Knorovsky (1978).

2.2.3 Brass

SAR Table 2.2-5 provided the yield strength and ultimate strength for the ASTM B16 C36000 Temper H02 brass (ASTM 2015b) used for the test and vent port plugs. The staff compared the mechanical properties listed in Table 2.2-5 of the Model No. 380-B application to the values listed in ASTM B16 for UNS C36000 brass in the H02 condition and found that the material properties at room temperature were accurate with respect to the ASTM standard. Staff compared the properties at elevated temperature to properties of leaded brasses with similar compositions originally prepared by the International Copper Development Council (CIDEC) and published by the Copper Development Association (CDA). The staff found that significant decreases in tensile and yield strength were generally not observed at temperatures less than 200°C (392°F). The staff also reviewed general information on brass properties published by the CDA which states "[t]he strength of brasses is substantially retained at temperatures up to around 200ºC and reduces by only about 30% at 300ºC." (CDA, 2005) Because the highest temperature for the brass test and vent port plugs is 400°F (204°C), the staff determined that the mechanical properties provided for the ASTM B16 brass are acceptable to account for the material properties under NCT and HAC conditions.

2.2.4 Radiation Effects on Materials

Section 2.2.3 of the application discussed the effects of radiation. The applicant stated that the radiation associated with the source payload will not affect either the containment or other safety components comprising the Model No. 380-B package because unshielded sources are not transported in the Model No. 380-B package. In addition, the applicant identified that safety significant materials sensitive to radiation dose are either located outside of the package's heavy shielding (e.g., the polyurethane foam in the impact limiters), or are replaced on an annual basis (e.g., the butyl rubber containment seal). After reviewing the information presented in the application, staff determined there will be no harmful radiation effects on the packaging and that the requirements of 10 CFR 71.43(d) are satisfied.

2.3 Fabrication

The applicant fabricated the Model No. 380-B package main components, including the impact limiter shells, thermal shield, and personnel barrier, from Type 304 SS in various product forms. For impact energy absorption, the applicant used polyurethane foam. Other materials performing a structural function included ASTM B16 UNS C36000 brass alloy (for the test and vent port plugs), and ASTM A564, Type 630, Condition 1100 SS for the closure bolts and impact limiter bolts. The applicant used butyl rubber to fabricate the containment O-ring seal, and plastic to fabricate the fire-consumable vent plugs in the foam cavities. The applicant designed the Model No. 380-B package using the codes and standards summarized in Table 2.3-1 below.

Table 2.3-1 Summary of Design Codes and Standards for the Main Components of the Model No. 380-B Packaging.

Packaging Component	Packaging Sub-component	Design Codes and Standards (Section 1.2.1, "Packaging," of the Application)
Cask Assembly	Package Body and Lid	ASTM A182 (forged)
		ASTM A240, Type 304 (Machined)
	Inner Shell, Outer Shell, Bottom Outer Plate, and Lid Outer Plate	ASTM A240, Type 304
	Lead Shielding (Gamma Shielding)	ASTM B29 lead or optionally, from lead per Federal Specification QQ-L-171E, Grade A or C
	Socket Head Closure Bolts	ASTM A564, Type 630, Condition H1100
	Bolts (Electroless Nickel)	SAE-AMS 2404, Revision F, Class 1, or MIL-DTL-26074 Rev. F Class 1 Grade B
Impact Limiters	Upper And Lower Impact Limiters	ASTM Type 304 SS
	Attachment Bolts	ASTM A564, Type 630, Condition H1100
Personnel Barrier	Sheet And Perimeter Strips	ASTM Type 304 SS
Inner Cover	SS Plate	ASTM Type 304 SS

2.3.1 Brittle Fracture

In Section 2.1.2.3.1, “Brittle Fracture,” of the application, the applicant noted that, with the exception of the closure bolts, all structural components of the Model No. 380-B package are fabricated from austenitic SS. Therefore, the applicant determined that a brittle fracture evaluation is not required because austenitic SS does not undergo a ductile-to-brittle transition in the temperature range of interest (i.e., down to -40 ºF). The applicant stated that the closure bolts are fabricated from ASTM A564, Type 630, Condition H1100 precipitation hardened SS bolting material and cited Section 5 of NUREG/CR-1815 (Holman and Langland, 1981) as justification that brittle fracture is not a failure mode of concern.

The staff reviewed the information provided in the application and the NUREG/CR-1815 section cited (Holman and Langland, 1981). The staff noted that the guidance in NUREG/CR-1815 states:

> “Bolts are generally not considered as fracture critical components because multiple load paths exist and because bolted systems are designed to be redundant. In other words, failure of one or more bolls can be tolerated since failure normally does not lead to penetration or rupture of the container. However, in cases where a particular bolt is determined to be a fracture critical component, the toughness requirements for that bolt should be specified at the same category level as other components of the system.”

The staff also reviewed the available information on the effects of thermal treatments on the fracture and impact toughness of precipitation hardened (PH) 17-4 SS such as ASTM A564, Type 630. Sunder et al. (1967) showed that the Charpy V-notch impact strength of 17-4 PH SS at −40°F (−40°C) increases with heat treatment. Sunder et al. (1967) reported the Charpy V-notch impact strength of 17-4 PH SS at −40°F (−40°C) to be 40 foot pound (ft-lb) for the H1025 condition, and for the H1150 condition, Sunder et al. (1967) reported the Charpy V-notch impact strength increased to 76 ft-lb. Based on the data from Sunder et al. (1967), the staff determined that brittle fracture is not a failure mode of concern for the ASTM A564, Type 630, bolts.

The staff determined that brittle fracture of the structural components of the Model No. 380-B package is not a failure mode of concern, since structural components of the Model No. 380-B package are constructed from austenitic SS which does not undergo a ductile-to-brittle transition in the temperature range of interest [i.e., down to −40 °C (−40 °F)].

2.4 General Standards for All Packages

2.4.1 Minimum Package Size

The impact limiters and personnel barrier diameter of 100 inches proved to be the minimum dimension of the Model No. 380-B package which exceeds the specified requirement of 4 inches. Therefore, the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper Indicating Feature

Section 2.4.2 of the application described the tamper-indicating feature for the package. The applicant passed an electronic security monitor cable through holes cross-drilled in the impact limiter attachment lugs to detect any tampering. The cable crossed the upper impact limiter attachment bolt heads which cannot be accessed without interrupting the remotely monitored current in the cable. The application also stated that an optional tamper-indicating lockwire placed across at least one of the upper impact limiter attachment brackets would indicate evidence of tempering. Therefore, staff determined that the requirement of 10 CFR 71.43(b) is satisfied.

2.4.3 Positive Closure

Section 2.4.3 of the application stated that the upper impact limiter prevents the Model No. 380-B package from being opened unintentionally because, after it is attached using 12 1-1/4 in. diameter bolts, it blocks access both to the lid closure bolts and to the vent port. This satisfies the requirements of 10 CFR §71.43(c) for positive closure.

2.4.4 Chemical and Galvanic Reactions

Section 2.2.2 of the application, "Chemical, Galvanic, or Other Reactions," specified that the materials from which the package is fabricated, along with the contents of the package, should not cause significant chemical, galvanic, or other reactions in an air or water environment. The applicant further indicated that the Model No. 380-B package materials have been previously used, without incident, transporting similar payloads in radioactive material packages such as the Model Nos. RH-TRU 72-B (NRC Docket No. 71-9212) and the BRR (BEA Research Reactor) package (NRC Docket No. 71-9341).

As discussed in Section 8.1.5.1 of the application, the applicant utilized a rigid, closed-cell (non-water absorbent) polyurethane foam that is free of halogens and chlorides.

The applicant stated that:

(1) the brass alloy vent port plug is very corrosion resistant,

(2) any damage that could occur to the material is easily detectable during the loading and unloading of the Model No. 380-B package, and

(3) the alloy steel closure bolts, which are plated with corrosion-resistant nickel plating, can be readily inspected at each use for the presence of corrosion.

The applicant utilized optional alloy steel thread inserts which are plated for protection against corrosion. The containment O-ring seal butyl elastomer material, which is organic in nature, contained no corrosives that would either react with or adversely affect the integrity of the Model No. 380-B package SS containment boundary.

The staff concluded that, during normal operation, the Model No. 380-B package internals will not be subject to continuous or frequent exposure to moisture and that any water intrusion is not likely to occur in great quantities. Because both the number of and the galvanic potential between the different metals used by the applicant to fabricate the Model No. 380-B package is low, the applicant asserted that the conditions required to create the possibility of galvanic corrosion is small. Furthermore, visual inspections of the payload cavity at various timed intervals provided reasonable assurance that significant corrosion would not occur. Staff determined that the combination of a successful radioactive material packaging history combined with the successful use of these fabrication materials in similar industrial environments will ensure that any chemical, galvanic, or other type of reactions will not compromise the Model No. 380-B package integrity.

2.5 Lifting and Tie-Down Standards for All Packages

The Model No. 380-B package design incorporated no structural features integral to the package which serve an as a lifting or tie-down device. Therefore, the requirements of 10 CFR 71.45(a)(1) and 10 CFR 71.45(b)(1) do not apply.

2.6 Normal Conditions of Transport

2.6.1 Heat

2.6.1.1 Pressures and Temperatures

Table 3.1-1 of the application, “Maximum NCT and HAC Temperatures,” identified the maximum cask body component temperature as less than 150°F. Table 3.1-2 of the application reported a maximum cavity pressure of 7.0 pounds per square inch gauge (psig), and the applicant conservatively set the maximum normal operating pressure (MNOP) at 10 psig for the purpose of demonstrating compliance with the preliminary determination requirements of 10 CFR 71.85 which requires first use testing of the packaging containment system at 150% of the MNOP. However the applicant used a design pressure of 25 psig for the cask containment boundary evaluation which is significantly higher than either the maximum calculated cavity pressure or the MNOP.

2.6.1.2 Differential Thermal Expansion

The application noted that the Model No. 380-B package does not include a lodgment, basket, or other internal structure. Since the package internals consisted of shielded devices located within the payload cavity by means of either nonstructural dunnage or blocking with specified minimum clearances, the applicant asserted that differential thermal expansion is not of concern for the contents. The applicant also noted that thermal expansion was not of concern for the cask inner shell because the thermal gradient across the shell thickness was less than 10°F which is relatively small.

2.6.1.3 Stress Calculations and Comparison with Allowable Stresses

For the packaging design pressure of 25 psig, the applicant calculated a primary membrane-plus-bending stress intensity of 14,333 psi. Compared to a primary membrane stress allowable of 20,000 psi, the 14,333 psi primary membrane-plus-bending stress intensity of 14,333 corresponded to a margin of safety of 0.4 which is positive and therefore acceptable.

Section 2.6.1.2.2 of the application evaluated the stresses in the inner shell by considering different thermal expansion coefficients between the SS and the lead gamma shielding resulting from the lead cooling. The applicant evaluated the structural performance of the inner shell using closed-form solutions to estimate a bounding external pressure of 225 psi. Section 2.6.1.3.2 identified that the maximum overall stress intensity due to pressure and lead shrinkage loading was 14,139 psi. Compared to the secondary stress allowable of 60,000 psi, the 14,139 psi corresponded to a margin of safety of 3.24 which is positive and therefore acceptable.

2.6.1.4 Closure Bolts

Section 2.6.1.5 of the application discussed design details of the lid configuration which prevented both a lateral force and a prying moment from being applied to the shanks of the 36 1-1/2 6UNC-2A bolts. Using a bolting torque of 950 ft-lb and a nut factor of 0.15, the applicant calculated a bolt tensile preload of 50,667 lbs. per bolt. When the applicant combined a differential thermal expansion bolt tensile force of 7,259 lbs. with the calculated bolt tensile preload of 50,667 lbs., the applicant determined a margin of safety of 0.72 for the bolt average tensile force evaluation which is positive and therefore acceptable. When accounting for the residual shear stress associated with the bolt torque, the applicant calculated a safety margin of 0.99 based on a stress intensity limit of 99.5 ksi. Since the safety margin of 0.99 is positive, staff finds it acceptable,

The stress analyses and the margins of safety evaluated above provide reasonable assurance for the staff to conclude that the Model No. 380-B package would not experience adverse thermal stresses under hot conditions. This satisfies the requirements of 10 CFR 71.71(c)(1) for the hot condition.

2.6.2 Cold

The applicant evaluated the package for the cold condition of -40 °C (-40 ºF). In recognizing that lead would contract further at lower temperatures, Section 2.6.2 of the application repeated the hot condition inner shell stress analysis performed in Section 2.6.1 for the NCT cold condition to calculate a maximum sustainable interface pressure of 376 psi between the lead shielding and the inner shell. This results in an inner shell membrane stress of 4,951 psi. Compared to the primary membrane stress allowable of 20,000 psi, the 4,951 psi corresponds to a margin of safety of 3.04 which is positive and therefore acceptable.

Because the coefficient of thermal expansion of the closure lid material is slightly larger than that of the bolting material, the applicant evaluated the reduction in closure bolt preload occurring at the NCT cold condition. Assuming a room temperature of 70ºF and using the bolt preload of 45,333 lb., the applicant calculated a preload reduction of 19% which is adequate to maintain the compression of the containment O-ring under the cold condition.

On the basis of the evaluation above, the application meets the 10 CFR 71.71(c)(2) cold condition requirements.

2.6.3 Reduced External Pressure

Section 2.6.3 of the application evaluated the effect of a reduced external pressure of 3.5 psig per 10 CFR 71.71(c)(3). Considering the calculated cavity pressure of 7.0 psig, the applicant noted that the effective pressure of 21.7 psig is bounded by the 25 psig design pressure used in analyzing the packaging containment boundary. Therefore, a reduced external pressure will not reduce the package effectiveness in compliance with the requirements of 10 CFR71.71(c)(3).

2.6.4 Increased External Pressure

Section 2.6.4 of the application considered both the lead shrinkage fabrication stress of 376 psi and other related initial conditions to obtain a combined external pressure of 400.8 psig applied to the cask inner shell. Therefore, the applicant selected an upper bound pressure of 410 psig on the cask inner shell to calculate a maximum stress intensity of 5,052 psi. Compared to the membrane stress allowable of 20,000 psi, the maximum stress intensity of 5,052 psi corresponded to a margin of safety of 2.96 which is positive and therefore acceptable. These analytical results demonstrated that the package is sufficiently robust in a cold environment with increased external pressure.

Appendix Section 2.12.6.2 of the application performed a bounding buckling evaluation of the cask inner shell which encompassed the increased external pressure condition. Using the methodology of ASME Code Case N-284-4, “Metal Containment Shell Buckling Design Methods,” the applicant employed a factor of safety of 2.0 applicable to the increased external NCT pressure with all the interaction check values, including the maximum value of 0.45, being less than unity as required. Thus, the applicant demonstrated that the increased external pressure load case is not of concern.

The above results demonstrate, in aggregate, that the package satisfies the structural requirements of 10 CFR 71.71(c)(4) for increased external pressure condition.

2.6.5 Vibration

Section 2.6.5 of the application considered the ANSI Standard N14.23, “Design Basis for Resistance to Shock and Vibration of Radioactive Material Packaging Greater Than One Ton in Truck Transport,” to evaluate the effect of a 2g vertical vibration amplitude on the cask structural performance. For Type 304 SS, at a temperature of 150^{o}F, the applicant determined the allowable stress amplitude to be 13,300 psi for 10^{11} vibration cycles. The applicant determined that, when the closure lid is subject to the 2g vibration at the maximum calculated stress of 247.7 psi, the corresponding fatigue stress margin of safety is 52.9.

On the basis of the above stress margin of safety, the applicant demonstrated that fatigue of the Model No. 380-B package due to transportation vibration is not of concern for meeting the requirement of 10 CFR 71.71(c)(5) for vibration condition.

2.6.6 Water Spray

Because of the materials of construction, the applicant asserted, and staff confirmed, that the water spray of 10 CFR 71.71(c)(6) is unnecessary.

2.6.7 Free Drop

Appendix Section 2.12.5.6.1 of the application adapted the benchmarked LS-DYNA FEA models discussed in SER Section 2.1.6.2.2 to perform 16 design simulations of the package undergoing the 1-ft NCT and 30-ft HAC free drops. The applicant accomplished this by varying the following:

(1) the impact limiter foam strength for temperatures of either -40^{o}F or 160^{o}F as applicable,

(2) the side, CG-over-corner and end drop orientations for NCT, and

(3) the side, CG-over-corner, end, 10^{o} slapdown, and 20^{o} slapdown drop orientations.

Table 2.12.5-10 of the application summarized the simulated acceleration and crush results for the NCT free drops. The applicant calculated a maximum rigid body acceleration of 33.8g for the NCT end drop. The applicant also calculated a side drop maximum of 18.3g for NCT.

Section 2.6.7 of the application discussed the FEA performed by the applicant. For the FEA, the applicant performed a quasi-static stress analysis of the cask body assembly using the ANSYS model reviewed in SER Section 2.1.6.1.2 for all NCT drop orientation. The applicant employed an acceleration of 35g in the FEA for all NCT drop orientations. This value bounded the maximum 33.8g acceleration discussed in the paragraph above. For the NCT cask body stress analyses, the applicant considered a dynamic load factor of 1.15 which is based conservatively on the single-pulse amplification of the rigid body acceleration modal properties associated with the relatively flexible closure lid. As shown in Table 2.6-3 of the application, the margins of safety are 0.61, and 0.31 for the NCT cask top-down and side drops, respectively.

On the basis of the stress margins of safety reviewed above, the staff concludes that there is no reduction of effectiveness and the Model No. 380-B package meets the requirements of 10 CFR 71.71(c)(7) for free drop test.

2.6.8 Corner Drop

Section 2.6.8 of the application noted that the 10 CFR 71.71(c)(8) corner drop requirement only applies to rectangular fiberboard or wood packages less than 100 lbs. Therefore, this condition is not applicable to this Model No. 380-B package.

2.6.9 Compression

Section 2.6.9 of the application noted that the Model No. 380-B package exceeds the weight limit of 11,000 lb. Therefore, the staff concludes that the 10 CFR 71.71(c)(9) compression test is unnecessary.

2.6.10 Penetration

In Section 2.6.10 of the application, the applicant also determined that a minimum material thickness of 0.015 inches is needed to prevent a 1.25 inch diameter, hemispherical ended, 13-lb. bar, dropped vertically from a height of 40 inches, from penetrating either the impact limiter shell casing or the thermal shield on the outside of the cold cask. Since this thickness is less than the 0.25 in. thick impact limiter shell casing and the 0.105 in. thick thermal shield, the applicant determined that this test is unnecessary.

On the basis of the evaluation above, the staff concludes that the test requirements of 10 CFR71.71(c)(10) is unnecessary.

2.7 Hypothetical Accident Conditions

2.7.1 Free Drop

As noted in SER Section 2.6.1, the LS-NYDA simulation calculated a maximum deceleration of 92.8g for the HAC free drops. Since the drop testing indicated no hard landing of the ½-scale CTU onto the target, staff determined that the impact limiter HAC performance is acceptable.

Table 2.12.5-11 of the application summarized the simulated acceleration and crush results for the HAC free drops. The applicant calculated a maximum rigid body deceleration of 92.8g for the HAC end drop. The applicant also calculated a side drop maximum of 88.9g for HAC. The applicant performed FEA of the HAC drops similar to those performed for the NCT free drops but with load combinations appropriate to the HAC. As discussed in Section 2.7.1.2 of the application, the applicant selected a bounding 100g to evaluate the following under HAC:

(1) cask body stress,

(2) closure bolt stress,

(3) lead slump performance, and

(4) buckling strength.

For the HAC cask body stress analyses, the applicant also used a dynamic load factor of 1.15. Table 2.7-2 of the application listed the calculated minimum margins of safety for different stress categories corresponding to the top and bottom end drops as well as the side drop. For the containment boundary, the applicant determined minimum margins of safety of 1.10 and 0.39 for the membrane and membrane-plus-bending stresses respectively.

In evaluating the closure lid bolts, the applicant used the loads associated with the HAC top-down end drop, the 1.15 dynamic load factor and the 150°F at-temperature stress allowable of 98,000 psi. The applicant computed the closure lid bolt minimum margin of safety to be 0.59 for the cask closure lid bolts. In evaluating lead slump from the HAC, the applicant determined the end drop to be bounding. The applicant evaluated the impact forces acting on the lead gamma shield that had the potential to reconfigure the lead in the direction of the end drop. The evaluations showed that the total gap associated with the maximum axial lead slump is 0.36 inches.

For the buckling evaluation of the cask inner shell, the applicant calculated an axial stress of 8,695 psi but conservatively employed a value of 9,000 psi. Using a factor of safety of 1.34 corresponding to ASME B&PV Code, Service Level D performance, the applicant calculated in Appendix Section 2.12.6 of the application a maximum interaction check value of 0.4387. Since this value is less than unity, staff finds it acceptable.

On the basis of the margins of safety reviewed above, the staff concludes that there is no reduction of effectiveness of the Model No. 380-B package and that the package meets the free drop requirements of 10 CFR 71.71(c)(7).

2.7.2 Crush

Since the Model No. 380-B package weight exceeds 1,100 lb., the crush test specified in 10 CFR 71.73(c)(2) does not apply.

2.7.3 Puncture

Section 2.7.3 of the application evaluated the package structural performance under the HAC puncture tests. For the four puncture tests on the impact limiters, the applicant performed three of them, P1, P2 and P4, on the damaged impact limiters of the half-scale CTU per the 10 CFR 71.73(c) sequential testing provision following the 30-ft free drop. The applicant performed the fourth test, P3, in anticipation of submitting the Model No. 380-B package design for certification by foreign competent authorities per the International Atomic Energy Agency regulations. Therefore, the staff only based their findings on drop tests P1, P2 and P4.

The test designated as P1 attempted to create the potential worst-case damage in the vicinity of the closure lid vent port in preparation for the thermal evaluation. The test designated as P2 followed the 30-ft CG-over-corner drop to create the potential worst-case damage in the area of the closure lid elastomer containment seal. The applicant performed this test also in preparation for the thermal evaluation. The applicant performed test P4 after the 30-ft side drop of the package to evaluate potential weakening of the corner joint between the cylindrical side shell and the flat annular shell of the impact limiter resulting from impact limiter deformation. However, because the damage inflicted by test P4 was not bounding compared to tests P1 and P2, the applicant ignored the results.

Section 2.7.3.2 of the application evaluated puncture of the cask body used the Nelms' Equation which is a commonly accepted method to determine the puncture resistance of lead-backed SS shells. The applicant determined that, for a package weighing 67,000 lb. undergoing a puncture drop of 40 in., the required outer shell thickness is 0.94 in. Since the outer shell thickness is 1.75 in., this corresponds to a margin of safety of 0.86. Since this value is positive, staff determined that it is acceptable.

On the basis of the review above, the staff concludes that the package structural performance meets the puncture test the requirements of 10 CFR 71.73(c)(3).

2.7.4 Thermal

2.7.4.1 Summary of Temperature and Pressures

Tables 3.1-1 of the application listed the maximum calculated package component temperatures resulting from the HAC fire event. For the package structural evaluation, however, the applicant used a temperature of 700°F which bounded all the listed temperatures for determining the allowable at-temperature stresses. This corresponded to an at-temperature ultimate strength of 59,200 psi for Type 304 SS of the cask body as shown in Table 2.2-2 of the application. For the A564, grade 630, Condition H1100 closure bolts, the applicant used an at-temperature ultimate strength of 128,400 psi as shown in Tables 2.2-3 of the application. Although Table 3.1-2 reported the calculated cavity pressure of 66.2 psig, the applicant used a conservative pressure of 100 psig for the packaging containment evaluation.

2.7.4.2 Differential Thermal Expansion

The applicant stated in Section 2.7.4.2, "Differential Thermal Expansion," of the application that the Model No. 380-B package does not include a lodgment, basket, or other internal structure. Therefore, the applicant asserted that differential thermal expansion is not of concern because the Model No. 380-B payload consists of shielded devices that are located within the payload cavity by non-structural dunnage or blocking.

The staff reviewed the packaging cross-section, dimensions, and exploded views shown in Figures 1.2-2 to 1.2-4 of the application. Staff also reviewed Table 3.1-1 of the application for maximum NCT and HAC temperatures. Based upon a review of the information presented, staff confirmed that no significant thermal gradient exists and thermal expansion is not a concern for the Model No. 380-B package.

2.7.4.3 Stress Calculations

Although the applicant calculated a peak internal pressure of 66.2 psi, Section 2.7.4.3 of the application showed that a conservative cavity pressure of 100 psi was used to perform the cask stress analyses. In addition, Section 2.7.4.3 of the application showed that a peak internal temperature of 700°F was assumed in performing the cask stress analyses even though a peak temperature of 643°F was calculated for the closure lid. Using these assumed values, the applicant calculated a maximum overall stress intensity of 12,677 psi due to the bolt preload stress concentration. Since this stress intensity is less than the 700°F at-temperature membrane stress intensity limit of 37,920 psi for Type 304 SS, the applicant asserted that it was unnecessary to identify the individual stress components. Therefore, using the maximum overall stress intensity of 12,677 psi, the applicant calculated a margin of safety of 1.99 for the cask which is positive and therefore acceptable.

The 100 psi cavity pressure produced an axial force of 4,922 lb. on each of the 36 closure lid bolts. Since this axial force is bounded by the bolt preload force of 50,667 lb. identified in Section 2.6.1.5 of the application, the applicant used the bolt preload force and the at-temperature stress allowable of 89,890 psi to calculate a margin of safety of 1.39 for the closure lid bolts. The applicant also calculated the extreme range of stresses per the guidance in Paragraph C.7 of Regulatory Guide 7.6. Using an allowable stress of 870,000 psi, the applicant calculated a corresponding margin of safety of 1.54. The positive margins demonstrate that the closure bolts are not of concern for the HAC fire event.

On the basis of the review above, the staff concludes that the package structural performance meets the thermal test requirements of 10 CFR 71.73(c)(4).

2.7.5 Immersion – Fissile Material

Since the package contents do not include fissile material, the requirements of 10 CFR 71.73(c)(5) do not apply.

2.7.6 Immersion - All Packages

In SER Section 2.6.4, "Increased External Pressure," the applicant demonstrated that the package is capable of resisting an external pressure of 410 psi. Since this pressure enveloped the 21.7 psi associated with immersion under a head of 50 ft. of water, the Model No. 380-B package met the immersion test requirements of 10 CFR 71.73(c)(6) for all packages.

2.7.7 Deep Immersion

Since the contents are less than 10^5 A_2, the special requirements for Type B packages in 10 CFR 71.61 do not apply.

2.8 Evaluation Findings

The staff reviewed documentation provided by the applicant including detailed calculation packages and test results to confirm that statements presented by the applicant are accurate and within acceptable engineering practices. Based on a review of the statements, representations, and supplemental calculations in the application, the staff finds that the structural design has been adequately described and evaluated and that the package has adequate structural integrity to meet the requirements of 10 CFR Part 71.

3.0 THERMAL

The purpose of this evaluation is to verify that the Model No. 380-B package:

1) provides adequate protection against the thermal tests specified in 10 CFR Part 71, and

2) meets the thermal performance requirements of 10 CFR Part 71 under NCT and HAC.

3.1 Description of Thermal Design

3.1.1 Thermal Design Features

The applicant stated in Section 3.1.1, "Design Features," of the application that the Model No. 380-B package consists of three principal components: a lead-shielded package body, a bolted closure lid and upper and lower impact limiters. The package design incorporated a personnel barrier which is installed between the impact limiters prior to transport, and a thermal shield which covered most, but not all, of the outer shell between the impact limiters. The applicant designed the package body with a large thermal mass-to-surface area ratio capable of absorbing the high heat flux generated during the HAC fire event and limiting the temperature rise within the interior of the package.

The applicant minimized residual gaps between the lead and the steel shells using a controlled lead pour procedure. In the NCT thermal analysis, the applicant assumed a uniform gap existed between the outer radius of the side wall lead and the inner radius of the outer shell to minimize heat transfer out of the package. However, in the HAC thermal analysis, the applicant modeled full contact between the outer radius of the side wall lead and the inner radius of the outer shell to maximize the heat flow from the fire to the package. The thermal shield provided significant shielding of the outer shell from the high heat fluxes associated with the HAC fire accident event. For the impact limiters, the applicant encased the "insulation-like" polyurethane foam, which absorbs a majority of the heat energy by decomposition during the HAC event, in a SS shell.

3.1.2 Contents Decay Heat

The applicant stated in Section 3.1.2, "Content's Decay Heat," of the application that the Model No. 380-B package is designed for a maximum decay heat of 205W. The applicant's thermal analyses assumed that 100% of the decay heat is deposited on the inner shell. To produce bounding temperatures, the applicant distributed the entire decay heat flux over the least possible inner shell area depending on the type of dunnage used. For metal and wooden timber dunnage, the applicant assumed that the entire heat flux was distributed over the underside of the inner cover and approximately 14 inches of the inner shell at the top of the cask. For foam and plywood dunnage, the applicant assumed that this dunnage would enclose the ends of the shielded device and distribute the heat flux on the radial inner shell surfaces directly opposite the shielded device.

The staff reviewed Section 1.2, “Package Description,” and Section 3.1, “Description of Thermal Design,” of the application and concluded that the Model No. 380-B package thermal design features are well described and that distribution of the content’s decay heat on the package cavity is appropriate to obtain bounding component temperatures.

3.1.3 Summary Tables of Maximum Temperatures and Pressure

For NCT evaluations, Section 3.1.3 and Table 3.1-1 of the application demonstrated that the accessible surface temperature of the Model No. 380-B package remains below the maximum 185°F permitted by 10 CFR 71.43(g) for exclusive use shipment when transported in a 100°F environment with no insolation. Information included in Table 3.3-1 indicated that the maximum component temperature is 181°F and that significant thermal margins exist for all package components. The applicant also provided information on the maximum pressures during NCT in Section 3.1.4 and Table 3.1-2 of the application. The applicant stated that, based on an assumed fill gas temperature of 70 °F at one atmosphere, the maximum pressure rise under NCT will be 7.0 psig. Based on this calculated NCT pressure, the applicant conservatively set the MNOP at 10 psig.

For HAC evaluations, Section 3.1.3 and Table 3.1-1 of the application demonstrated that the maximum accessible surface temperature of the Model No. 380-B package is 643°F with the exception of the thermal shield and the impact limiter attachment bolts. However, as shown in Table 3.4-1 and Table 3.4-2 of the application, significant thermal margins existed for all package components and non-metallic contents under HAC. The applicant also provided information on the maximum pressures during HAC in Section 3.1.4 and Table 3.1-2 of the application. The applicant stated that based on an assumed fill gas temperature of 70°F at one atmosphere, the maximum pressure rise under HAC will be 66.2 psig. Based on this calculated HAC pressure, the applicant conservatively assumed the HAC pressure to be 100 psig.

3.2 Material Properties and Component Specifications

The applicant presented the Model No. 380-B package material properties and specifications in Section 3.2, “Material Properties and Component Specifications,” of the application. The applicant listed the thermal properties of packaging materials in Table 3.2-1 of the application and thermal properties of air in Tables 3.2-2 of the application.

The staff reviewed Section 3.2 as well as Tables 3.2-1 and 3.2-2 of the application for the material properties of contents and packaging components. The staff determined that the material properties, emissivity data, absorption data and component specifications used in the thermal analysis were acceptable.

3.3 General Considerations

3.3.1 Flammable Gas Generation

The applicant stated in Appendix 5.5.4, “Gas Generation due to Radiolysis,” of the application that both flammable and non-flammable gases can be generated in the Model No. 380-B package due to radiolysis of non-metallic dunnage. Using a conservative G-value of 4.5 for wood, the applicant performed gas generation calculations and determined that the largest volume of flammable gas generated in one year is approximately 0.02 liters which is much less than the smallest void volume of 4.6 liters for the Model No. 380-B package which exists between the inner cover and the package lid. The applicant estimated gas generation within the

Model No. 380-B package as 0.4% in one year which is less than the 5% limit by volume discussed in NUREG-1609 [3]. Therefore, the applicant stated that the pressure resulting from radiolysis of the dunnage from the package contents is not of concern.

The staff reviewed the assumptions and calculations described in Appendix 5.5.4 of the application and confirmed that the G-value of 4.5 for wood bounds the 1.6 G-value for water. Therefore, staff found the applicant's flammable gas generation evaluation acceptable and determined that flammable gas generation is not a significant issue for the Model No. 380-B package.

3.4 Normal Conditions of Transport

3.4.1 Heat and Cold

The applicant evaluated the thermal performance of the Model No. 380-B package using the computer codes 3-D Thermal Desktop and SINDA/FLUENT. The applicant modeled NCT heat transfer assuming radiation heat transfer with an emissivity value of 0.8, natural convection heat transfer using a heat transfer coefficient of 5W per square meter Celsius (W/m^2-^oC), heat flux from solar insolation, an internal decay heat of 205W, and an ambient temperature of 100°F. As prescribed by 10 CFR 71.71(c)(1), the applicant applied the 24-hour averaged insolation as an hourly average.

The staff reviewed Section 3.1," Description of Thermal Design," of the application and confirmed that the assumptions, boundary conditions, and thermal parameters used for the NCT thermal model are acceptable per the thermal phenomena justification and guidelines of NUREG-1609[3].

3.4.2 Maximum Normal Operating Pressure

In Section 3.3.2, "Maximum Normal Operating Pressure," of the application, the applicant estimated the MNOP assuming no payload outgassing, ideal gas expansion and wood dunnage outgassing due to evaporation of the moisture content in the wood. Using these assumptions, the applicant calculated a MNOP of 7.0 psig for the predicted bulk gas temperature of 232°F under NCT hot conditions due to a 4.4 psig pressure rise from ideal gas expansion of the bulk cavity gas pressure and a 2.6 psig increase from the saturation pressure of water in the wood dunnage.

The staff reviewed the pressure calculation provided in Section 3.3.2 of the application and determined that the calculated pressure rise of 7.0 psig is bounded by the MNOP of 10 psig. The staff confirmed that the pressure rise under NCT is not a significant issue because the NCT pressure rise of 7.0 psig is bounded both by the MNOP of 10 psig and by the maximum design pressure of 25 psig.

3.4.3 Maximum Temperatures

For the Model No. 380-B package loaded with a shielded device, the applicant calculated maximum package component temperatures under NCT and provided them in Table 3.1-1 of the application. For both the cavity gas atmosphere and the inner shell, the applicant calculated temperatures of 232^oF and 133^oF respectively. The applicant determined that the maximum lead shield temperature occurred at the lid. The applicant calculated the maximum lead temperature to be 136^oF which is below the allowable limit of 620^oF. For the containment seal, the applicant calculated a maximum temperature of 133°F which is below the allowable limit of 250°F.

The staff reviewed Table 3.1-1 of the application and determined that the predicted temperature of each component is below the maximum allowable temperature limit under NCT hot conditions, and the maximum accessible surface temperature under NCT is 103°F which is less than the 185°F (or 85°C) permitted by 10 CFR 71.43(g) for an exclusive use shipment when transported in a 100°F ambient temperature with no insolation.

The applicant summarized the predicted package component temperatures (e.g., inner shell, closure lid, lead, thermal shield, main containment seal, impact limiter, maximum accessible surface, etc.) under NCT hot conditions with no insolation, NCT hot conditions with insolation and NCT cold conditions in Tables 3.3-1 and 3.3-2 of the application.

The staff reviewed Section 3.3, “Thermal Evaluation for Normal Conditions of Transport,” of the application and the NCT temperatures shown in Tables 3.3-1 and 3.3-2 of the application and confirmed that the resulting NCT package component temperatures, including lead and closure seals, are below the allowable limits.

3.5 Hypothetical Accident Conditions

3.5.1 Initial Conditions

As described in Section 3.4.1, “Initial Conditions,” of the application, the applicant developed a thermal model of the Model No. 380-B package under HAC as follows:

(1) worst-case damage from the potential HAC free drops and puncture drop,

(2) a horizontal package orientation for a fully engulfing fire,

(3) loss of personnel barrier and the sheet covering the impact limiter recess cavities before the fire event,

(4) a loss of 2.7 inches of polyurethane foam from the impact limiter due to thermal decomposition, and

(5) an initial temperature distribution from NCT steady state analysis under 100^{o}F ambient, insolation, and open style payload dunnage heat load distribution.

The staff found the assumptions mentioned above acceptable since these lead to higher initial temperatures of the package components and maximize heat input to the package during the HAC fire.

3.5.2 Fire Test Conditions

As stated in Section 3.4.2, “Fire Test Conditions,” of the application, the applicant used a flame temperature of 1475°F and an effective flame emissivity of 1.0 to simulate the hydrocarbon fuel/air fire event. The applicant also employed convection heat transfer coefficient between the package and the environment based on an average gas velocity of 10 meters per second (m/s), which is equivalent to a heat transfer coefficient of 15 W/m^2-°C, during the 30-minute fire transient. After the 30 minute fire transient, the applicant based the heat transfer coefficient on still air. In addition the applicant assumed an ambient temperature of 100°F and full insolation following the 30-minute fire.

The staff reviewed the assumptions, boundary conditions and parameters used for the HAC thermal analysis, and determined that they are both acceptable and consistent with NUREG-1609[3]. The staff finds that the applicant's HAC thermal evaluation meets the thermal requirements of 10 CFR 71.73.

3.5.3 Maximum Temperatures and Pressure

The applicant calculated the peak HAC temperatures of the inner shell, the closure lid, the closure lid bolts, the lead shield, the main containment seals and the thermal shield. The applicant presented the maximum temperatures in Table 3.4-1 of the application. The applicant also presented the temperature limits, data sources, and safety margins of non-metallic content materials in Table 3.4-2 of the application. In addition, Figure 3.4-7 of the application depicted the time dependent temperature of each component both during the 30-minute fire and during the post-fire cooldown. Based on the safety margins provided in Tables 3.4-1 and 3.4-2, the applicant stated that the peak HAC temperatures of Model No. 380-B package components, non-metallic contents and non-metallic materials are below the allowable temperature limits during the HAC fire.

The staff reviewed Section 3.4, "Thermal Evaluation for Hypothetical Accident Conditions," of the application and temperature results provided in Tables 3.4-1 and 3.4-2 as well as Figures 3.4-1 thru 3.4-7 of the application for the HAC fire and the post-fire cool-down. The staff confirmed that the packaging component, non-metallic contents and non-metallic material temperatures calculated from the HAC thermal analyses remained below the allowable limits during the 30-minute fire transient and the post-fire cooldown.

The applicant stated in Section 3.4.3, "Maximum Temperatures and Pressure," that:

(1) the minimum thermal margin occurs for the vent port sealing washer approximately 2 minutes after the end of the fire with a predicted peak temperature of 392°F;

(2) this peak temperature is 8°F below the 400°F short-term limit for the butyl rubber vent port sealing washer; and

(3) although the vent port sealing washer is near the limit of 400°F, it's above 350°F for only 20 minutes as illustrated in Figure 3.4-7 of the application.

The staff reviewed Section 3.4.3 and determined that the margin of 8°F is acceptable because the butyl rubber seal material has been proven to meet the leaktight criteria after tests of 430°F for one hour and 400°F for eight hours as discussed in Section 3.2.3, "Component Specifications," of the application [4].

<u>Impact of Loss of Polyurethane Foam</u>

The applicant stated in Appendix 3.5.4, "Last-A-Foam Response under HAC," that the polyurethane foam in the Model No. 380-B package has a density of 16 lb./ft^3 with a ±15% manufacturing tolerance (i.e., 13.6 to 18.4 lb./ft^3). The applicant also stated that a maximum recession depth of 2.7 inch was expected for foam having a density of 13.6 lb/ft^3. Therefore, the applicant asserted that any virgin foam with a thickness exceeding approximately 3.2 inches (i.e., 2.7 inches + 0.5 inches) prior to the fire would prevent any significant temperature rise on the backside of the foam after a 30-minute fire event because the polyurethane foam can mitigate heat transfer to the package by a variety of mechanisms (e.g., low thermal conductivity, self-extinguishment, endothermic dissociative mechanisms from polymer to gas, and intumescent char).

Based upon information provided in Appendix 3.5.4 of the application and RAI response [5], the staff confirmed the applicant's assertion that 2.7 inches of polyurethane is sufficient to predict the bounding safety related component temperatures in the HAC fire event given that the polyurethane foam has 16 lb/ft^3 with a ±15% tolerance and that the damage to the impact limiters during the HAC free drop and puncture events will not cause a chimney effect.

Maximum HAC Pressures

In Section 3.4.3.1, "Maximum HAC Pressure" of the application, the applicant assumed the maximum HAC pressure would occur using of wood dunnage due to the presence of water in the wood dunnage. By combining the water saturation pressure of 60 psia with a pressure rise of 6.2 psig, which was determined assuming ideal gas expansion, the applicant calculated a maximum HAC pressure of 66.2 psig. Therefore, the applicant assumed a peak HAC pressure of 100 psig when wood dunnage is used as stated in Section 3.4.3.1 of the application. After reviewing the pressure calculation provided in Section 3.4.3.1 of the application, the staff confirmed the calculated maximum HAC pressure of 66.2 psig and determined that the assumed HAC pressure is acceptable.

3.6 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the applicant adequately described and evaluated the thermal design of the package and that the thermal performance of the package meets the thermal standards of 10 CFR Part 71.

4.0 CONTAINMENT

The purpose of the containment review is to verify that both the design and the performance of the Model No. 380-M package satisfies the containment requirements of 10 CFR Part 71 under NCT and HAC.

4.1 Description of the Containment System

The applicant stated in Section 4.1.1 of the application that the containment boundary of the Model No. 380-B package includes the inner shell, the lower and upper end structures, the containment O-ring seal, the closure lid, the vent port plug including sealing washer and plug, and the vent port drill access hole plug and weld as shown in Figure 4.1-1 of the application. The applicant asserted that the Model No. 380-B package provides a leaktight containment which is defined as a leakage rate less than 1×10^{-7} reference cubic centimeters per second (ref-cm^3/sec) per ANSI N14.5 – 2014 [8].

Because the containment welds are full penetration welds which are volumetrically inspected to ensure structural and containment integrity, the applicant stated in Section 4.1 of the application that the vent port is the only containment penetration. Section 4.1.4 of the application identified that all containment boundary welds are inspected by liquid dye penetrant on the final pass in accordance with the ASME B&PV Code. The applicant also noted in Section 8.1.4 of the application that all containment boundary welds would be confirmed as leaktight.

The staff reviewed Section 4.1, “Description of Containment System,” and confirmed that the information presented there agreed with the Model No. 380-B package containment boundary shown in Figure 4.1-1, and Drawing No. 1916-02-02 (sheets 1-6) of the application.

4.1.1 Containment Boundary

The applicant stated that the Model No. 380-B package containment boundary consisted of the following elements:

(1) the lower end structure,

(2) the inner shell,

(3) the upper end structure (including lead pour hole plug and welds),

(4) the containment O–ring seal (the inner elastomer seal in the closure lid),

(5) the closure lid main structure,

(6) the vent port in the closure lid including elastomer sealing washer and brass port plug, and

(7) the vent port drill access hole plug and weld.

Figure 4.1-1 of the application showed the containment boundary. The staff reviewed the containment boundary description and the containment boundary figure provided by the applicant and found both acceptable.

4.1.1.1 Containment Penetrations

The applicant identified that the vent port is the only containment penetration. The applicant located the vent port in a steel block welded to the upper flange as depicted in Figure 4.1-1 of the application. The applicant designed and tested the vent port to ensure “leaktight” sealing integrity. The staff reviewed the containment penetration discussion provided by the applicant and found it acceptable.

4.1.1.2 Seals

The applicant stated that the elastomeric portion of the containment boundary includes the following:

(a) a nominally 3/8 inch diameter O–ring face seal located in the inner groove of the closure lid, and

(b) a seal washer sealing element (an O–ring integrated with a SS washer) for the vent port.

The applicant stated that the seals are made using a butyl elastomer compound suitable for continuous use between temperatures of at least -40 ºF and 250 ºF. Section 8.1.5.2 of the application included additional information on the butyl rubber O-rings acceptance tests.

The staff reviewed the seal information provided by the applicant and finds this information acceptable.

4.1.1.3 Welds

The applicant identified all structural welds used in the containment boundary as full penetration welds and stated that they are volumetrically inspected to ensure their integrity. The applicant noted that the weld joining the inner shell to the upper end forging is ultrasonically inspected in accordance with the ASME B&PV Code, Subsection NB, Article NB–5000, and Section V, Article 4, and that the weld joining the inner shell to the lower end forging is radiographically inspected in accordance with the ASME B&PV Code, Subsection NB, Article NB–5000, and Section V, Article 2. The applicant also noted that all containment boundary welds are inspected using liquid dye penetrant on the final pass in accordance with the ASME B&PV Code, Subsection NB, Article NB–5000, and Section V, Article 6. Finally, the applicant also identified that all containment boundary welds are confirmed to be leaktight as discussed in Section 8.1.4, "Fabrication Leakage Rate Tests."

4.1.1.4 Closure

To close the package, the applicant used 36 1-½ 6UNC socket head cap screws tightened between 850-950 ft-lb. In Chapter 2 of the application, the applicant showed that the closure lid cannot be detached by either internal pressure, NCT events, or HAC events. The upper impact limiter, which is attached to the package using twelve, 1-¼ 7UNC socket head cap screws tightened to 280-340 ft-lb completely covered the closure lid including the vent port which prevents inadvertently opening the containment. Figure 4.1-1 of the application showed the vent port, which is the only containment penetration, located in a steel block welded to the upper flange. The applicant designed and tested the vent port to ensure the leakage rate does not exceed 1 x 10^{-7} ref-cm^3/s, per ANSI N14.5 (i.e., a leaktight sealing integrity). The staff finds the discussion of the containment penetrations acceptable.

4.2 General Considerations

The applicant stated in Section 5.5.4, "Gas Generation due to Radiolysis," of the application that the shielded devices will be shored within the Model No. 380-B package using either wood, polyurethane foam or metallic dunnage. Since hydrogen and other gases may be generated due to radiolysis of non-metallic dunnage, the applicant performed gas generation analyses using a gamma G-value to determine if hydrogen and other flammable gases comprise less than 5% by volume of the total gas inventory within any confined volume during a one year time period as specified in Section 3.5.4.2 of NUREG-1609[3]. The applicant only used a gamma G-value because alpha and beta radiation will not escape the shielded device. The applicant performed the analyses assuming gas generation with Cobalt-60 (^{60}Co), a strong gamma emitter, since it is representative of the other radioactive isotopes that may be transported within the Model No. 380-B package. The applicant provided G values of water and wood, which are based on the experimental results provided in the CH-TRU Payload Appendices [29], in Table 5.5-3 of the application.

The applicant used a conservative G value of 4.5 (flammable gas in wood) and calculated the energy absorption in the wood using a Monte Carlo N-Particle (MCNP) model. The applicant then calculated the number of gas molecules using the formula listed in Section 5.5.4 of the application. In Table 5.5-6 of the application, the applicant identified the minimum void volumes required to remain below 5% flammable gas in one year as 0.057, 0.20, and 0.40 liters for small, medium and large devices respectively. Since the total void volume inside the cavity of the Model No. 380-B package will typically be much larger than the smallest void volume of 4.6 liters, which exists between the inner cover and the package lid, staff determined that there is a large safety margin for flammable gas concentrations.

The staff reviewed Section 5.5.4 of the application and determined using a G value of 4.5 is acceptable. The staff also reviewed the MCNP model and determined the energy deposition calculation is acceptable. Therefore, the staff determined that the applicant's analysis of gas generation due to radiolysis is acceptable.

4.3 Containment under Normal Conditions of Transport (Type B Packages)

The applicant stated in Section 4.2, "Containment Under Normal Conditions of Transport," of the application that the structural and thermal evaluations presented in Section 2.6, "Normal Conditions of Transport," and Section 3.3, "Thermal Evaluation for Normal Conditions of Transport," demonstrate that there is no release of radioactive materials from the Model No. 380-B package per the leaktight definition of ANSI N14.5 - 2014 under the NCT tests described in 10 CFR 71.71.

The applicant predicted the maximum NCT hot temperatures for the Model No. 380-B package closure seals to be 123°F for metal and wooden timber dunnage as shown in Table 3.3-1 and 131°F for foam and plywood dunnage as shown in Table 3.3-2 of the application. The predicted maximum NCT closure seal temperature of 131°F is below the allowable temperature limit of 250°F for butyl rubber under NCT.

The staff reviewed the thermal model descriptions and the NCT temperatures of the containment components, including the closure seals, shown in Tables 3.3-1 and 3.3-2 of the application. The staff confirmed that the maximum NCT temperatures for all containment components are below the required temperature limits. Therefore, the staff finds that the containment effectiveness of the closure seals is maintained for NCT and the Model No. 380-B package meets the NCT containment requirements in compliance with 10 CFR 71.71 and 71.51(a)(1).

4.4 Containment under Hypothetical Accident Conditions (Type B Packages)

The applicant stated in Section 4.3, "Containment Under Hypothetical Accident Conditions," of the application that the structural and thermal evaluations presented in Section 2.7, "Hypothetical Accidents," and Section 3.4, "Thermal Evaluation for Hypothetical Accident Conditions," demonstrate that there is no release of radioactive materials from the Model No. 380-B package per the leaktight definition of ANSI N14.5 - 2014 under the HAC tests described in 10 CFR 71.73(c)(4). As shown in Table 3.4-1 of the application, the applicant predicted the peak HAC temperature of the closure seals to be 301°F which is below the allowable HAC temperature limit of 400°F for butyl rubber seals.

The staff reviewed the HAC containment component temperatures, including closure seals, and confirmed the peak HAC component temperatures for all containment components are below the required temperature limits as shown in Table 3.4-1 of the application. Therefore, the staff finds that the containment effectiveness of the closure seals is maintained for HAC and the Model No. 380-B package meets the HAC containment requirements in compliance with 10 CFR 71.73(c)(4) and 71.51(a)(2).

4.5 Leakage Rate Tests for Type B Packages

The applicant stated in Section 4.4.1, "Fabrication Leakage Rate Tests," of the application that, consistent with guidelines of ANSI N14.5 – 2014, the Model No. 380-B package containment boundary is leakage rate tested to the leaktight criteria of 1.0 x 10^{-7} ref-cm^3/sec during fabrication. In accordance with the 2014 version, the applicant committed to ensuring that personnel with the level of training specified in Reference 5 of the standard (*Recommended Practice No. SNT-TC-1A*, American Society for Nondestructive Testing, Inc.) will participate in the development and execution of the specific leakage rate test procedures for the Model No. 380-B package.

The applicant stated in Section 4.4.2, "Maintenance/Periodic Leakage Rate Tests," of the application that, for both the containment O-ring and the vent port seal, a periodic leakage rate test is performed at least annually and a maintenance leakage rate test is performed either after replacing a damaged containment seal or after repairing the sealing surface. The applicant noted in Section 4.4.2 of the application that both periodic and maintenance leakage rate tests are performed per ANSI N14.5 - 2014 to verify the containment seal leakage rate does not exceed 1.0 x 10^{-7} ref-cm^3/sec.

The applicant described in Section 4.4.3, "Preshipment Leakage rate Tests," of the application that the containment O-ring seal and the vent port sealing washer are leakage rate tested to 1.0 x 10^{-3} ref-cm^3/sec per ANSI N14.5 - 2014. The applicant committed to perform a pre-shipment leakage rate test at the time of shipment. However, the applicant indicated that either the maintenance or the periodic leakage rate tests may be performed at the time of shipment instead of the tests described in Section 7.4, "Preshipment Leakage Rate Test," of the application if necessary.

The staff reviewed Section 4.4, "Leakage Rate Tests for Type B Packages," of the application and found the leakage rate test descriptions acceptable. Staff confirmed that the fabrication, maintenance, and periodic leakage rate tests will be performed on the entire containment boundary of the Model No. 380-B package in accordance with the guidelines of Sections 7.3, 7.4, and 7.5 of ANSI N14.5 – 2014. Staff also confirmed that, prior to shipment, the containment O-ring seal and the vent port seal are leakage rate tested per Section 7.6 of ANSI N14.5 – 2014.

4.6 Evaluation Findings

The staff reviewed the containment sections of the Model No. 380-B package application request and concluded that the Model No. 380-B package has been described and evaluated to demonstrate that it satisfies the containment requirements of 10 CFR Part 71, the package is leak-tight and the package meets the requirements of 10 CFR 71.51(a)(1) for NCT and 10 CFR 71.51(a)(2) for HAC.

Based on a review of the statements and representations in the application, the staff concludes that the containment design has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR Part 71.

5.0 SHIELDING EVALUATION

The purpose of this evaluation is to verify that the Model No. 380-B package shielding provides adequate protection against direct radiation from its contents and to verify that the package design meets the external radiation requirements of 10 CFR Part 71 under NCT and HAC.

5.1 Description of Shielding Design

5.1.1 Design Features

The staff reviewed the General Information chapter (Chapter 1) of the application and the information in the Shielding chapter (Chapter 5) of the application. Section 1.2.1.1 of the application provided shielding details. The applicant designed the Model No. 380-B package with a thick-wall to provide significant gamma radiation shielding. The staff confirmed that the applicant adequately described the dimensions, tolerances and densities of the lead and the steel gamma shielding of the Model No. 380-B package. The applicant asserted that hydrogenous neutron shielding is not necessary and included none in the package design.

The applicant designed the Model No. 380-B package to transport shielded devices. Shielded devices, including shielded source containers, contained either a sealed source or a group of sealed sources encased in shielding material and surrounded by a steel shell which provides structure for the shielded device. Table 1.2-1 of the application listed the nuclides that will be transported in the Model No. 380-B package. The applicant identified the physical form of all nuclides as solid material in a sealed capsule and identified oxygen, carbon, sulfur, and hydrous bromine as well as both hydrous and anhydrous chlorine as non-radioactive impurities. The applicant requested no fissile material, including plutonium, as authorized contents. The applicant identified the maximum decay heat limit for the Model No. 380-B package as 205W and provided the total activity to reach 205W in Table 5.2.7 of the application.

The applicant indicated that, after placing all shielded devices into the Model No. 380-B package for shipment, the shielded devices are blocked in position using either metallic, polyurethane foam, or wood dunnage materials to prevent unwanted motion under NCT. The applicant also indicated that the dunnage does not provide a safety function.

5.1.2 Summary Table of Maximum Radiation Levels

The staff reviewed the calculated dose rates in Tables 5.4-2 thru 5.4-7, 5.4-10, and 5.4-11 of the application and determined that the values are within the limits of 10 CFR 71.47 and 10 CFR 71.51 for both NCT and HAC. The applicant selected the activity limits for the isotopes such that computed dose rates are 95% of the NCT regulatory limits for open vehicles under exclusive use (i.e., the maximum dose rate on the inaccessible package surface beneath the personnel barrier is 950 mrem/hr, the maximum dose rate on both the accessible package surfaces and the personnel barrier is 190 mrem/hr, and the maximum dose rate 2 m from the vehicle side is 9.5 mrem/hr). For the accessible package surfaces, the applicant calculated a maximum dose rate of 138.5 mrem/hr, which is below the regulatory limit of 200 mrem/hr, and demonstrated that the dose rate in any occupied location is less than 1.6 mrem/hr.

5.2 Radiation Source Specifications

Table 5.2-1 of the application summarized the allowable source nuclides which may be loaded into the Model No. 380-B package. Although these nuclides may emit either alpha or beta radiation, only the gamma and neutron emissions from the source nuclides contributed to the dose rate. The applicant also indicated that actinides may be mixed with an (α, n) target nucleus such as beryllium. For the Model No. 380-B package, the applicant determined that the Co-60 activity is limited by the dose rate. The applicant developed separate MCNP models for the following sources: Co-60, Cesium-137 (^{137}Cs), Strontium-90 (^{90}Sr), Iridium-192 (^{192}Ir), Radium-226 (^{226}Ra) (gamma), ^{226}Ra with a chlorine target (neutron), and ^{226}Ra with a beryllium target (neutron). The applicant took limited self-shielding credit for Co-60.

The applicant limited the decay heat of the Model No. 380-B package to 205W, and computed the decay heat per Ci for each isotope using ORIGEN-S. The applicant provided the total activity to reach 205W in Table 5.2-7 of the application. The decay heat values included daughter products. For both ^{137}Cs and ^{90}Sr, the applicant conservatively included 1 Ci of metastable Barium-137, and 1 Ci of Yttrium-90 respectively. Although the decay heat for ^{226}Ra increased slowly with time and peaked after approximately 80 years of decay, the applicant conservatively reported the ^{226}Ra decay heat at 80 years of decay as the peak value. The applicant's calculations demonstrated that, for all isotopes other than Co-60, the heat load governed the activity limit rather than dose rate.

The applicant also used the ORIGEN-S module of the SCALE code version 6 (SCALE6/ORIGEN-S) to estimate the gamma and neutron source terms. However, there was an error in the SCALE6/ORIGEN-S data libraries for ^{192}Ir and SCALE6/ORIGEN-S cannot be used to determine the gamma source for this isotope. Therefore, for this isotope only, the applicant used SCALE44/ORIGEN-S to estimate the gamma source term.

The staff performed confirmatory analyses for the source terms using ORIGEN-ARP as part of the SCALE6.1 depletion code and obtained results which were in good agreement with those generated by the applicant.

5.2.1 Gamma Source

Tables 5.2-2 thru 5.2-6 of the application showed the allowable gamma source nuclides for 1 Ci. The applicant provided details of each gamma source including their gamma energies and the decay heat. Table 5.2-7 of the application included the decay heat for each isotope to be loaded in the Model No. 380-B package.

5.2.2 Neutron Source

The applicant based the values in Table 5.2-8 of the application, which summarized the neutron sources generated by ^{226}Ra via (α,n) reactions, on 1 Ci of ^{226}Ra. The applicant used the ORIGEN-S module of the SCALE code package, version 6, to calculate the neutron sources. The applicant modeled the ^{226}Ra either as a compound or as a mixture with beryllium.

Because some radium sources contained trace elements of oxygen, carbon, sulfur, bromine, hydrous chlorine or anhydrous chlorine, the applicant developed models with ^{226}Ra as one of the following compounds: $RaSO_4$, hydrous $RaBr_2$, hydrous $RaCl_2$, anhydrous $RaCl_2$, or $RaCO_3$. Since bromine is not an (α,n) target material, only hydrous $RaBr_2$ would produce neutrons due to the presence of ^{17}O and ^{18}O. The applicant determined that the neutron production of hydrous $RaCl_2$ bounded the neutron production of the other compounds.

Because beryllium generates more neutrons than any other target material, the applicant treated radium beryllium mixtures separately. In their model, the applicant assumed that the radium beryllium mixture is infinitely dilute (i.e.; the beryllium mass is 1,000 times greater than the ^{226}Ra mass). This assumption conservatively increased the neutron production of the radium beryllium mixture

5.3 Shielding Model

5.3.1 Configuration of Shielding and Source

The applicant analyzed all allowable Model No. 380-B package shielding and source configurations using the MCNP computer code. The applicant took no shielding credit for either the dunnage which secures the shielded devices within the Model No. 380-B package, or the substantial shielding surrounding the shielded devices. In the MCNP models, the applicant located the source at the position resulting in the maximum dose rates. The source locations considered in the MCNP models included the bottom corner, the upper corner, and the side of the package cavity. Tables 5.4-2 to 5.4-7 presented the dose rate results for these different locations. These tables showed that, in general, the maximum dose rates were located at the inner wall of the package because the distance to the side of the package was shortest at this location.

Because all sources are sealed and encapsulated, the applicant stated that the source itself remains intact during NCT and HAC, and prevented exposure of the packaging materials to a strong radiation field during NCT. For all isotopes other than ^{60}Co, the applicant conservatively modeled the content as a point source. This method took no credit either for the source encapsulation materials or for self-shielding provided by the source material. Because the ^{60}Co activity is limited by dose rate, the applicant took limited self-shielding credit for this isotope by modeling the ^{60}Co as a solid cylinder of cobalt metal. Using the specific activity of 1,100 Ci/g from Table A-1 of 10 CFR 71, the applicant calculated the minimum mass of a 7,500 Ci source to be 6.8 g (i.e., 7500/1100 = 6.8). Using a mass of 6.8 g and a density of 8.9 grams per cubic centimeter (g/cm^3), the applicant calculated that the smallest theoretical volume of a 7,500 Ci ^{60}Co source is 6.8/8.9 = 0.76 cm^3. Assuming the cylindrical ^{60}Co source had a height equal to its diameter, the applicant modeled the ^{60}Co source as a cylinder 0.98 cm high and 0.98 cm in diameter. Staff determined this representation is conservative because no self-shielding credit is taken either for inert materials in the cobalt matrix or encapsulation materials. The applicant developed separate MCNP models for the following sources: ^{60}Co, ^{137}Cs, ^{90}Sr, ^{192}Ir, ^{226}Ra (gamma), ^{226}Ra with a chlorine target (neutron), and ^{226}Ra with a beryllium target (neutron).

The applicant explicitly modeled all package features relevant to the shielding analysis including streaming paths such as the gap between the lid and the package wall as well as all interfaces between steel and lead components. The staff confirmed that the dimensions used in the MCNP code were appropriate for the package geometry including the streaming paths.

5.3.2 Material Properties

As described in Section 5.3.2 of the application, the applicant developed the MCNP models using SS, lead, polyurethane foam, and cobalt metal with the following densities:

(1) Type 304 SS with a density of 7.94 g/cm^3 (496 lb/ft^3) for the Model No. 380-B shell and other structural components;
(2) Lead (pure) with a density of 11.35 g/cm^3 (709 lb/ft^3)
(3) Polyurethane foam with a density of 0.224 g/cm^3 (14 lb/ft^3)
(4) Solid metallic Co-60, modeled as a small cylinder, with a density 8.9 g/cm^3.

Staff confirmed that the applicant used these material properties in the MCNP input files.

5.3.3 Methods

Staff reviewed and evaluated the shielding evaluation methods used by the applicant. The applicant developed a model for each of the following sources: ^{60}Co, ^{137}Cs, ^{90}Sr, ^{192}Ir, ^{226}Ra (gamma), ^{226}Ra with a chlorine target (neutron), and ^{226}Ra with a beryllium target (neutron) and modeled the source isotope as either a single point source or a line source as applicable. The applicant used MCNP5 v1.51 to compute dose rates for a 1 Ci source and scaled the results to obtain source strengths that resulted in dose rates which were 95% of the regulatory dose-rate limits. The applicant investigated three general locations for the point source:

(1) Bottom of the package at the package inner diameter (bottom corner),

(2) Mid-height of the package cavity at the package inner diameter, and

(3) Top of the package at the package inner diameter.

The applicant primarily calculated dose rates using radial mesh tallies. Because the source was always located at the inner diameter of the cavity, the applicant focused the mesh tallies on a segment 10 degrees wide that was centered on the source. For ^{60}Co, ^{137}Cs, ^{90}Sr, and ^{192}Ir, the applicant only computed dose rates due to gamma radiation. However, because ^{226}Ra has both a gamma and neutron component, the applicant explicitly computed each. The applicant ignored secondary gamma radiation due to neutron capture because the Model No. 380-B package does not utilize a hydrogenous neutron shield.

Because the NCT models included the inner cover, the inner cover constrained the source in these models and the applicant modeled the source near the lid. The applicant calculated NCT dose rates for ^{60}Co, ^{137}Cs, ^{90}Sr, ^{192}Ir, ^{226}Ra with chlorine and ^{226}Ra with beryllium using mesh tallies located at the inaccessible package side, package side at the impact limiter radius, at the top impact limiter flat surface, on the bottom impact limiter flat surface, and 2 m from the side of a standard trailer; i.e., 102-in. wide. Because the dose rate limits for the side of the trailer were the same for the side of the package, the package side dose rates bounded the trailer surface dose rates making it unnecessary to compute the trailer surface dose rates explicitly.

The applicant only calculated HAC dose rates for ^{60}Co and ^{226}Ra (with beryllium) because they were dose-rate-limited sources. In the HAC calculations, the applicant used mesh tallies to compute the dose rates 1 m from the package body and modeled the source in the bottom corner, side, and top corner of the Model No. 380-B package cavity. For the HAC models, the applicant omitted the inner cover because it is assumed to be damaged and located the source at the bottom of the lid next to the package inner diameter (top corner).

5.3.4 Input and Output Data

The applicant provided sample ORIGEN-S and MCNP input files in Appendix 5.5.2 of the application.

The applicant stated that the Monte Carlo uncertainty associated with the limiting dose rate location is less than 5% for ^{60}Co and ^{226}Ra. Because the Model No. 380-B package is designed to shield a strong ^{60}Co source, the Model No. 380-B package provides more shielding protection than necessary for the lower-energy ^{137}Cs, ^{90}Sr, and ^{192}Ir sources. Although the Monte Carlo uncertainty is approximately 10% for the limiting dose rates associated with ^{137}Cs and ^{90}Sr, and as high as approximately 40% for ^{192}Ir, further refinement of the method proved unnecessary because dose rates computed by the applicant for ^{137}Cs, ^{90}Sr, and ^{192}Ir were essentially zero since these isotopes are limited by heat load.

5.3.5 Flux-to-Dose Rate Conversion

For this analysis, the applicant used ANSI/ANS-6.1.1-1977 flux-to-dose rate conversion factors obtained from the MCNP User's Manual, Tables H.1 and H.2, which have been converted to provide results in mrem/hr rather than rem/hr. The applicant provided these conversion factors in Table 5.4-1 of the SAR.

5.4 Normal Conditions of Transport

5.4.1 NCT Analysis

The applicant designed the package to be transported vertically, centered on an open trailer, with only one package transported per shipment. Therefore, the applicant evaluated the NCT dose rate limits against the exclusive use transportation dose rates identified in 10 CFR 71.47: 1,000 mrem/hr on the inaccessible package surfaces beneath the personnel barrier, 200 mrem/hr on the accessible surfaces of the package, 200 mrem/hr on the surface of the trailer, and 10 mrem/hr at a distance of 2 m from the surface of the trailer.

In addition, the regulations also limited the dose rates to 2 mrem/hr in any occupied location with the exception of private carriers if exposed personnel wear radiation dosimetry devices. The applicant performed hand calculations to demonstrate this dose rate limit is met. The applicant estimated the occupied location (i.e., the driver of the vehicle) to be at least 25 feet from the centerline of the package. The applicant used the following distances to show compliance with the occupied location dose rate limit: X1 = 0 cm (i.e., the package centerline), X2 = 48.16 cm (i.e., the location of the source at the inner diameter of the package), X3 = 329.54 cm (i.e., 2 m from the vehicle side), and X4 = 762 cm (i.e., the occupied location). Therefore, the applicant calculated the distance from the source to the 2 m dose rate location as R1 = X3 – X2 = 281.38 cm, and the distance from the source to the occupied location as R2 = X4 – X2 = 713.84 cm.

Since all of the sources behave essentially as point sources, the dose rate decreased by the square of the distance from the source. The applicant's hand calculations demonstrated that the dose rate 2 m from the side of the vehicle is less than10 mrem/hr, and because the applicant took no additional shielding credit for items outside the package, the applicant determined that the occupied location dose rate cannot exceed 1.6 mrem/hr (i.e., $10\times(281.38/713.84)^2$). Therefore, the applicant demonstrated that the occupied location dose rate limit is met if the 10 mrem/hr at 2 m dose rate limit is met.

The applicant analyzed each isotope to ensure compliance with the regulatory limits.

5.4.1.1 ^{60}Co Analysis

The applicant developed two cases for the source in the top corner because the inner cover prevents the source from being located in the corner immediately adjacent to the lid. Figure 5.4-2 of the application illustrated the two source locations. When the source is in the "top right" position, there is a streaming path through the lid/body interface gap, but radially the gamma must traverse lead to exit the package. In the "top left" position there is no lid gap streaming but there is a path through the joint that does not include lead. Table 5.4-2 of the application summarized the maximum mesh tally results for the 8 source locations.

5.4.1.2 ^{137}Cs Analysis

The applicant stated that a limited analysis was performed for ^{137}Cs, which emits radiation with much weaker energies compared to ^{60}Co, because the Model No. 380-B package more shielding protection than necessary for this isotope. Therefore, decay heat rather than dose rate limited this isotope to an activity of 40,675 Ci as shown in Table 5.2-7.

5.4.1.3 ^{90}Sr Analysis

The applicant stated that a limited analysis was performed for ^{90}Sr, which emits radiation with much weaker energies compared to ^{60}Co, because the Model No. 380-B package provides more shielding protection than necessary for this isotope. Therefore, decay heat rather than dose rate limited this isotope to an activity of 30,606 Ci as shown in Table 5.2-7.

5.4.1.4 ^{192}Ir Analysis

The applicant stated that a limited analysis was performed for ^{192}Ir, which emits radiation with much weaker energies compared to ^{60}Co, because the Model No. 380-B package provides more shielding protection than necessary for this isotope. Therefore, decay heat rather than dose rate limited this isotope to an activity of 33,333 Ci as shown in Table 5.2-7.

5.4.1.6 ^{226}Ra (Beryllium) Analysis

The applicant stated that ^{226}Ra is the only nuclide listed in Table 5.2-1 that generates both neutrons (via (α,n) reactions) and gammas. To determine the dose rates for this content, the applicant generated separate neutron and gamma input files and summed the results. The target material with which ^{226}Ra is mixed determined the quantity of neutrons generated.

The applicant computed dose rates for a 1 Ci ^{226}Ra source with beryllium and scaled the results until 95% of a regulatory dose rate limit was achieved. For this source, the inaccessible package surface dose rate proved limiting (950 mrem/hr). Table 5.4-7 of the application reported dose rates for 4.67 Ci of ^{226}Ra mixed with beryllium. The accessible maximum surface dose rate is 122.1 mrem/hr, and the maximum dose rate 2 m from the side of the vehicle is 7.9 mrem/hr. Because the dose rate is almost entirely due to neutron radiation, the dose rates peaked next to the source location.

5.4.1.5 ^{226}Ra Analysis

If beryllium is not the target material, the bounding compound proved to be $RaCl_2$. Table 5.4-6 of the application reported the dose rates for this isotope.

Table 5.4-8 summarized the activity limits for the Model No. 380-B package with a single source type. Note that ^{60}Co and ^{226}Ra (with beryllium) are limited by dose rate while the remaining isotopes are limited by heat load.

5.5 Hypothetical Accident Conditions

No reduction in the effectiveness of the Model No. 380-B package shielding occurred as a result of HAC testing. For HAC, the applicant modeled all impact limiter foam as a void to simulate potential fire damage. The applicant also assumed the inner cover to be damaged and omitted it from the model. This assumption allowed the source to move to the top corner of the lid where lid streaming is the most severe. Figures 5.4-1 and 5.4-2 of the application showed the MCNP models as well as the top and side source locations respectively. Also, the MCNP HAC models accounted for lead slump as described in Section 2.7.1.2 of the application.

5.6 Evaluation Findings

The staff reviewed the description of the package design features related to shielding and the source terms, and the methods and instructions for determining the contents. The staff also reviewed the shielding analyses, the assumptions and approximations used in the analyses as presented in the shielding safety analysis, and the results of the analysis, presented in the application, the maximum dose rates for NCT and HAC to determine that the reported values were below the regulatory limit in 10 CFR 71.47 and 71.51 for a non-exclusive use package.

Based on its review of the statements and representations provided in the application, the staff has reasonable assurance that the shielding evaluation is consistent with the appropriate codes and standards for shielding analyses and NRC guidance, and that the shielding design of the Model No. 380-B package, with the content's limits as determined from the instructions for determining allowable content and the loading table in Chapter 7 of the application.

6.0 CRITICALITY

The applicant designed this package to ship sealed sources of ^{60}Co, ^{137}Cs, ^{90}Sr, ^{226}Ra, ^{192}Ir, ^{226}Ra with beryllium and ^{226}Ra without beryllium. The total fissile mass limit for the Model No. 380-B package is 15 grams. This quantity of fissile material is fissile exempt. Therefore, a criticality evaluation is not necessary.

7.0 PACKAGE OPERATIONS

The purpose of this evaluation is to verify that the operating controls and procedures of the Model No. 380-B package meet the requirements of 10 CFR Part 71.

7.1 Package Loading

The staff reviewed the package loading instructions. Chapter 7 of the application included loading and unloading instructions based on the type of payload. The applicant provided procedures for preparing the Model No. 380-B package for loading. These procedures included a description of the components that must be removed in sequential order to gain access to the package cavity.

7.2 Loading of Contents

Section 7.1.2 provided the main steps for loading the contents into the Model No. 380-B package. Some of these steps included lifting and moving package components, installing seals, verifying that the package cavity is clean and dry, and verifying that payload limits are not exceeded. The procedures required inspecting the seals and sealing surfaces for damage prior to installation as well as specifying torque values for the package closure bolts.

7.3 Preparation for Transport

Staff reviewed the procedures for preparing the Model No. 380-B package for transport. These included procedures for

1) attaching and torqueing the upper impact limiter attachment bolts,
2) installing a tamper-indicating device,
3) installing the personnel barrier,
4) installing tie-downs
5) monitoring external radiation, and
6) determining surface contamination.

The applicant stated in Section 7.4, "Pre-shipment Leakage Rate Test," of the application that, prior to shipment, the pre-shipment leakage rate test would be performed following the guidelines of ANSI N14.5 – 2014 to confirm proper assembly of the package. The staff confirmed that the pre-shipment leakage rate test using the gas pressure rise method for the Model No. 380-B package is appropriate and that the criteria of no detectable leakage in excess of 1.0×10^{-3} ref-cm^3/s is consistent with ANSI N14-5 – 2014 guidelines.

In addition, the preparation procedures included the requirements to complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172 and package marking in accordance with 10 CFR 71.85(c) and Subpart D of 49 CFR 172.

7.4 Package Unloading

Section 7.2 of the application included the unloading procedures. These procedures included checks to record the condition of the tamper indicating devices. The procedures for opening the package referenced the procedures for the preparation for loading. After the impact limiter and package closure lid are removed, the procedures directed the user to attach a sealing surface protector and to secure it to the package body. Then, the user removed the inner cover lid to gain access to the package payload in accordance with the procedures. After removing the dunnage and payload, the procedures described how to reinstall the removed components in sequential order including the torque specification for bolts.

7.5 Preparation of Empty Package for Transport

The applicant specified that it would follow the requirements of 49 CFR 173.428 when preparing an empty Model No. 380-B package for transport.

7.6 Evaluation Findings

Based on a review of the statements and representations in the application, the staff concludes that the operating procedures meet the requirements of 10 CFR Part 71 and that these procedures are adequate to assure the package will be operated in a manner consistent with its evaluation for approval.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM REVIEW

The purpose of this evaluation is to verify that the acceptance tests and maintenance program of the Model No. 380-B transport package meet the requirements of 10 CFR Part 71.

8.1 Acceptance Tests

8.1.1 Visual Inspections and Measurements

The applicant committed to measuring and visually inspecting each Model No. 380-B package to ensure that it is assembled in accordance with the licensing drawings. Appendix 1.3.3, "Packaging General Arrangement Drawings," included drawing requirements for the Model No. 380-B package. The applicant also committed to making the findings required by 10 CFR 71.85, "Preliminary Determinations" prior to first use of the Model No. 380-B package.

8.1.2 Weld Examinations

The applicant committed to identifying and recording the locations, types, and sizes of all welds to ensure compliance with the drawings in Appendix 1.3.3, "Packaging General Arrangement Drawings." The applicant stated all welds would be visually examined per AWS D1.6 [18], and summarized the weld examinations performed on each Model No. 380-B package in Table 8.1-1.

The applicant specified the following examinations for confinement welds:

(1) For the Inner and outer shell longitudinal seam welds, as well as the inner shell to lower end structure weld, radiographic testing per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 2 and liquid penetrant testing of the final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

(2) For the inner shell to upper end structure weld, ultrasonic testing per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 4 and PT of the final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

(3) For the vent port drill access hole plug weld in the closure lid and the lead pour access hole plug weld in the upper end structure, liquid penetrant testing on the final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

For non-confinement welds, the applicant specified the follow examinations:

(1) For outer shell to upper and lower end structure welds, ultrasonic testing per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 4 and liquid penetrant testing on final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

(2) For bottom outer plate and lid outer plate welds, liquid penetrant testing on final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

(3) For all other non-containment welds, except seal welds, liquid penetrant testing on the final pass per ASME B&PV Code, Subsection NB, Article NB-5000, and Section V, Article 6.

8.1.3 Structural and Pressure Tests

Since the MNOP of the Model No. 380-B package was set at 10 psig as stated in Section 3.3.2 of the application, the ASME B&PV Code, Subsection NB required the containment boundary be pressure tested to 150% of the MNOP (i.e., a test pressure of 15 psig) to ensure that it is leaktight. The applicant stated in Section 8.1.3 of the application that the Model No. 380-B package is pressure tested to 125% of the design pressure of 25 psig (i.e., a pressure of 31.25 psig) per the requirements of ASME B&PV Code, Subsection NB, Article NB-6220. The applicant also stated that, following pressure testing of the containment boundary, both welds directly related to the pressure testing and accessible base material adjacent to the welds shall be visually inspected for plastic deformation or cracking in accordance with AWS D1.6, and liquid penetrant inspected per ASME B&PV Code, Subsection NB, Article NB–5000, and Section V, Article 6, as delineated on the drawings in Appendix 1.3.3, “Packaging General Arrangement Drawings”. The applicant stated that any indications of cracking or distortion shall be recorded and evaluated in accordance with the cognizant quality assurance (QA) program.

The staff reviewed Sections 3.3.2 and 8.1.3 of the application and determined that, because the 31.25 psig pressure test on the Model No. 380-B containment boundary is greater than the required test pressure of 15 psig (150% of MNOP), the requirements of 10 CFR 71.85(b) are satisfied.

The applicant incorporated no lifting devices that require load testing into the package design. Therefore, the applicant performed no structural tests on the package.

8.1.4 Fabrication Leakage Rate Tests

Section 8.1.4 of the application stated that, during fabrication, the containment boundary is leakage rate tested consistent with the guidelines dictated in Section 7.3 of ANSI N14.5 - 2014. The applicant performed these leakage rate tests to confirm the containment boundary leakage rate for the Model No. 380-B package does not to exceed 1 x 10^{-7} ref-cm^3/s air.

The applicant stated in Section 8.1.4, “Fabrication Leakage Rate Tests,” of the application that the fabrication leakage rate testing is performed both prior to, and following, lead installation because of the potential for the lead to prevent helium gas from reaching the surface of the containment boundary. During fabrication, the applicant leakage rate tested the containment boundary with four separate tests: (1) the containment body structure prior to lead installation, (2) the closure lid structure prior to lead installation, (3) the containment boundary and containment O-ring after lead installation, and (4) the vent port sealing washer. The applicant performed these four tests in two stages: prior to lead installation and after lead installation. The applicant performed all tests in accordance with ANSI N14.5 - 2014. The applicant indicated that tests 1, 2 and 3 would follow the guidelines in Section A.5.3 (Gas Filled Envelope – Gas Detector) and that test 4 would follow the guidelines in Section A.5.4 (Evacuated Envelope – Gas Detector) of ANSI N14.5 - 2014.

The staff reviewed Section 8.1.4 of application and confirmed that the 2-stage fabrication leakage rate testing is both necessary and acceptable due to the potential for the lead to prevent helium gas from reaching the surface of the containment boundary in accordance with ANSI N14.5 - 2014.

8.1.5 Component and Material Tests

The applicant discussed acceptance tests for the polyurethane foam and the butyl rubber O-rings in Section 8.1.5 of the application. In addition, the applicant considered the impact limiter characteristics critical for the structural and thermal performance of the package. Section 8.1.5 of the application included acceptance tests for the materials of construction and manufacturing processes associated with these components.

The applicant identified general requirements for the polyurethane foam including major chemical constituents, verification of proper storage by the supplier, impact limiter shell preparation, foam installation as well as both pour and test records. The applicant also identified physical characteristics of a foam batch including leachable chlorides (EPA method 300.0, Pfaff, 1993), thermal conductivity (ASTM C518, 2015c), and specific heat (ASTM E1269, 2011). The applicant provided a description of the foam flame retardancy testing. The applicant also described the physical characteristics for a foam pour including density and compressive stress measurements. The applicant stated that test samples from each foam pour shall be tested in accordance with ASTM D1621, “Standard Test Method for Compressive Properties of Rigid Cellular Plastics,” (ASTM, 2011). The staff reviewed the materials testing for the polyurethane foam and determined that the test methods identified by the applicant are appropriate to evaluate the required physical properties of the impact limiter polyurethane foam.

The applicant stated that the butyl rubber O-rings will conform to ASTM D2000 (ASTM, 2012) and identified physical characteristics of the butyl rubber containment O-ring seals as well as the sealing washers determined by lot based on the acceptance tests. These included testing for the material’s durometer (ASTM D2240), tensile strength and elongation (ASTM D412), heat resistance (ASTM D573), compression set (ASTM D395), cold temperature resistance (ASTM D2137) and cold temperature resiliency (ASTM D1329). The staff reviewed the materials testing for the butyl rubber containment O-ring seals and sealing washers and determined that the test methods identified by the applicant are appropriate to evaluate the required physical properties of these components.

Section 8.1.5 of the application described the component and material tests. Section 8.1.5.1 of the application, "Polyurethane Foam," presented details of the acceptance tests for this material. Table 2.2-6 of the application, "Nominal Material Properties of 16 lb/ft^3 Polyurethane Foam," included room-temperature crush properties of the polyurethane foam component. Section 8.1.5.2 described the required propertied for the Butyl rubber O-rings. The staff also reviewed the additional materials selected for the package and determined that they were acceptable and provided reasonable assurance for package safety.

8.1.6 Shielding Tests

The applicant indicated that the poured lead shielding integrity shall be confirmed via gamma scanning using a ^{60}Co gamma source positioned within the package cavity. The applicant committed to use a ^{60}Co gamma source of sufficient strength to provide a dose reading on the cask surface which is not only above the background dose, but also within the calibrated range of the measuring equipment. The applicant stated that the shielding would be evaluated in accordance with the guidance in NUREG\CR-3854, Section 3.2.1, and that the ^{60}Co source strength shall be recorded at the time of the test. The applicant also stated that the type of gamma sensor used for measurements shall be recorded and all equipment shall be calibrated per the manufacturer's instructions. In addition, the applicant stated that the gamma scanning shall be performed according to a written procedure using a grid pattern with a maximum grid size of four inches square, and that the acceptance criteria for each grid square will be established using the dose rate results of the analytical shielding model.

8.1.7 Thermal Tests

The applicant stated in Section 8.1.7 of the application that a thermal test is not required for the Model No. 380-B package because the thermal evaluations presented in Chapter 3 of the application are based on well-established heat transfer properties, heat transfer methodologies and demonstrate large thermal margins for all components. After reviewing the thermal evaluations, staff found that they included acceptable thermal margins for the low decay heat load of 205W of the proposed contents, employed conservative assumptions, and used appropriate heat transfer properties. Therefore, based upon a review of the information provided, staff determined that thermal testing for the Model No. 380-B package need not be performed because the information provided by the applicant demonstrates compliance with 10 CFR Part 71 regulatory requirements.

8.2 Maintenance Program

8.2.1 Structural and Pressure Tests

The applicant asserted, and the staff confirmed, that structural tests are unnecessary to ensure the continued performance of the package.

8.2.2 Maintenance/Periodic Leakage Rate Tests

To ensure a leaktight condition (i.e., leakage rate less than $1x10^{-7}$ ref-cm^3/s), the applicant stated in Section 8.2.2, "Maintenance/Periodic Leakage Rate Tests," of the application that the containment O-ring seal and the vent port sealing washer of the Model No. 380-B package shall be tested using the Evacuated Envelope – Gas Detector method, as described in Section A.5.4 of ANSI N14.5 - 2014 either after every twelve months, or after performing maintenance on the Model No. 380-B package (e.g., after seal replacement or sealing area repair). The staff reviewed Section 8.2 of application and determined that both the maintenance and the periodic leakage rate testing procedures are acceptable as described in Section 8.2.2 of the application.

8.2.3 Component and Material Tests

Section 8.2 of the application summarized the maintenance requirements of the Model No. 380-B package components. The maintenance program included periodic testing, inspection, and replacement schedules, and included items such as fasteners, seals, sealing areas, and the impact limiters. The staff found that visual inspections at various timed intervals provide reasonable assurance against material degradation that may occur.

8.2.4 Thermal Tests

The applicant asserted and the staff confirmed that thermal tests are unnecessary to ensure the continued performance of the package.

8.3 Evaluation Findings

Based on review of the statements and representations in the Model No. 380-B package application, the staff concludes that the acceptance tests for the packaging component temperatures, the package pressures, and the heat transfer features meet the requirements of 10 CFR Part 71 and that the maintenance program is adequate to assure packaging performance during its service life.

9.0 QUALITY ASSURANCE

The applicant, an organization under the U.S. Department of Energy (DOE), supplemented their certificate of compliance request with a letter that described QA programs which satisfy the requirements of 10 CFR Part 71, Subpart H. The Los Alamos National Laboratory (LANL) Operations Support–Packaging and Transportation (OS-PT) organization provided QA oversight and AREVA provided technical support for the Model No. 380-B package. DOE Order 460.1C, “Packaging and Transportation Safety,” contained the QA requirements for using NRC-certified packages. The applicant intended to operate the Model No. 380-B package under LANL SD330, “Los Alamos National Laboratory Quality Assurance Program” which established the LANL QA program requirements for site-wide implementation and which served as the basis for LANL QA program acceptability. LANL SD330 implemented the full scope of requirements stated in DOE Order 414.ID, Quality Assurance (current contractual version) which constitutes compliance with the nuclear safety QA criteria required by 10 CFR 830, Subpart A, “Quality Assurance Requirements.” AREVA, with QA oversight by the LANL OS-PT organization, acted on behalf of the packaging owner as the Design Agency to provide design, licensing documentation, and certification expertise. The Design Agency determined the package's safety-related items and the appropriate QA level. A Table within the applicant’s supplemental QA letter depicted how the 10 CFR 71, Subpart H requirements are addressed within both the LANL QA program and the AREVA QA program for the Model No. 380-B package. The applicant indicated that the package users would adhere to their QA programs. As this package is originally certified in the United States, staff finds that it meets the NRC QA requirements.

10.0 REFERENCES

1. (ASME, 2010a) American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, 2010 Edition, Division 1, Section III, Subsection NB, "Class 1 Components."

2. (ASME, 2010b) American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, 2010 Edition, Division 1, Section V, "Nondestructive Examination, Article 4, Ultrasonic Examination Methods for Welds."

3. (NRC, 1999) U. S. Nuclear Regulatory Commission. NUREG-1609, "Standard Review Plan for Transportation Packages for Radioactive Material," March 31, 1999.

4. (NNSA, 2016a) Al-Daouk, Ahmad M., National Nuclear Security Administration's (NNSA), letter to U.S. Nuclear Regulatory Commission (Attn: Document Control Desk), April 6, 2016, ADAMS Accession Nos. ML16102A136 and ML16112A158.

5. (NNSA, 2016b) Al-Daouk, Ahmad M., National Nuclear Security Administration's (NNSA), letter to U.S. Nuclear Regulatory Commission (Attn: Document Control Desk), October 13, 2016, ADAMS Accession No. ML16294A260.

6. (NNSA, 2016c) Schwendenman, Kathy, National Nuclear Security Administration's (NNSA), email to Garcia Santos, Norma, U.S. Nuclear Regulatory Commission, October 20, 2016, ADAMS Accession No. ML16301A022.

7. (NNSA, 2017) Al-Daouk, Ahmad M., National Nuclear Security Administration's (NNSA), letter to U.S. Nuclear Regulatory Commission (Attn: Document Control Desk), June 9, 2017, ADAMS Accession Nos. ML17165A437 and ML17170A287.

8. (ANSI, 2014) American National Standards Institute (ANSI), ANSI N14.5-2014, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment" New York, NY.

9. (ASME, 2011) American Society of Mechanical Engineers (ASME) Boiler and Pressure (B&PV) Code, 2010—Addenda 2011. New York, NY.
   Section II, "Materials,"
   Section III, "Rules for Construction of Nuclear Facility Components." Division 1, "Metallic Components"; Subsection NB through NH, and Appendices,
   Section V, "Nondestructive Examination."
   Section IX, "Welding, Brazing, and Fusing Qualifications."

10. (ASTM 2011) ASTM International, ASTM: E1269 – 11-2011, “Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry,” West Conshohocken, PA

11. (ASTM 2012) ASTM International, ASTM D2000 – 12-2012, “Standard Classification System for Rubber Products in Automotive Applications,” West Conshohocken, PA.

12. (ASTM 2013) ASTM International, ASTM A564/A564M – 13-2013, “Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes,” West Conshohocken, PA.

13. (ASTM, 2014) ASTM International, ASTM B29 – 14-2014, “Standard Specification for Refined Lead,” West Conshohocken, PA.

14. (ASTM, 2015a) ASTM International, ASTM A240/A240M − 15-2015, “Standard Specification for Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications,” West Conshohocken, PA.

15. (ASTM, 2015b) ASTM International, ASTM B16/B16M − 10-2015, “Standard Specification for Free-Cutting Brass Rod, Bar and Shapes for Use in Screw Machines,” (Reapproved 2015), West Conshohocken, PA.

16. (ASTM, 2015c) ASTM International, ASTM C518 – 15-2015, “Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus,” Designation, West Conshohocken, PA.

17. (AWS, 2012) American Welding Society (AWS), AWS A2.4-2012, “Standard Symbols for Welding, Brazing, and Nondestructive Examination,” 7th Edition.

18. (AWS, 2017) American Welding Society, AWS D1.6, “Structural Welding Code-Stainless Steel,” 3rd Edition American Welding Society, 2017.

19. (CDA, 2005) Copper Development Association (CDA), “The Brasses properties & applications,” CDA Publication No. 117, Hertfordshire, UK.

20. (GSA, 1957) General Services Administration (GSA), “Federal Specification – Lead Pig,” QQ-L-171e, U.S. Government Printing Office, May 27, 1957.

21. (Holman and Langland, 1981) Holman, W.R. and R.T. Langland, NUREG/CR-1815, UCRL-53013, “Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick,” Livermore, CA: Lawrence Livermore National Laboratory, 1981.

22. (Mok et. al 1992) Mok, G.C., L.E. Fischer, and S.T. Hsu, NUREG/CR-6007/UCRL-ID-110637, “Stress Analysis of Closure Bolts for Shipping Casks,” Livermore, CA: Lawrence Livermore National Laboratory, April 1992.

23. (NRC, 1999) U.S. Nuclear Regulatory Commission, NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material,” Initial Report, March 1999.

24. (Pfaff, 1993) Pfaff, J.D, “Determination of Inorganic Anions by Ion Chromatography,” Method 300.0, Revision 2.1, Cincinnati, OH: U.S. Environmental Protection Agency, August 1993.

25. (Rack and Knorovsky, 1978) Rack, H.J., and G.A. Knorovsky, NUREG/CR-0481/SAN D77-1872, ”An Assessment of Stress-Strain Data Suitable for Finite-Element Elastic-Plastic Analysis of Shipping Containers,” Springfield, VA: U.S. Department of Commerce, National Technical Information Service, September 1978.

26. (Slunder et. al, 1967) Slunder, C.J., A.F. Hoenie, and A.M. Hall, NASA TM X-53578, “Thermal and Mechanical Treatments for Precipitation Hardenable Stainless Steels and Their Effect on Mechanical Properties NASA Technical Memorandum,” Huntsville, AL: George C. Marshall Space Flight Center, February 20, 1967.

27. (Tietz, 1958) Tietz, T.E., WADC Technical Report 57-695, "Determination of the Mechanical Properties of a High Purity Lead and a 0.058 % Copper-Lead Alloy," ASTIA Document No. 15116, Menlo Park, CA: Stanford Research Institute, April, 1958.

28. (WHC, 1994) Westinghouse Hanford Company, WHC-SD-RTG-TRP-002, “Radioisotope Thermoelectric Generator Transportation System Packaging O-Ring Material Elevated Temperature,” Revision 0.

29. CH-TRU Payload Appendices, Revision 3, December 2007.

CONDITIONS

The certificate of compliance includes the following condition(s) of approval:

Condition No. 5.(a)(2), “Description,” describes the package and identifies the maximum package weight.

Condition No. 5.(a)(3), “Drawings,” contains the latest revision of the licensing drawings to which the package must be fabricated.

Condition No. 5.(b)(1), “Type and Form of Material,” lists the sources authorized for transport in the Model No. 380-B package.

Condition No. 5.(b)(2), “Maximum Quantity of Material,” contains the curie limits for the sources authorized for transport in the Model No. 380-B package.

Condition No. 5.(b)(3), “Maximum Weight of Contents,” specifies the maximum weight of the contents authorized for transport in the Model No. 380-B package.

Condition No. 5.(b)(4), “Maximum Decay Heat,” lists the maximum decay heat of 205W per package.

Condition No. 6 specifies that “plutonium sources are not permitted for transport.”

Condition No. 7 specifies that “americium sources are not permitted for transport.”

Condition No. 8 requires that the operating procedures and the maintenance and acceptance tests listed in Chapter Nos. 7 and 8 of the application, respectively, are followed.

The references section contains the original application and the supplements provided as part of the review process.

CONCLUSIONS

Based on the statements and representations contained in the application, as supplemented, and the conditions listed above, the staff concludes that the design has been adequately described and evaluated, and the Model No. 380-B package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9370, Revision 0,
on November XX, 2017