CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATION NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE	PAGES
9403	0	71-9403	USA/9403/B(U)-96	1 OF	5

2. PREAMBLE

a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."

b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION.

c. ISSUED TO (Name and Address)

NAC International
2 Sun Court, Suite 220
Peachtree Corners, GA 30092

d. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

NAC International Volunteer Package Safety Analysis Report", Revision No. 0, dated April 2025.

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No: Volunteer

(2) Description

The Volunteer packaging is comprised of a cask assembly, with identical upper and lower impact limiters, and internal support structures for specific contents to be shipped.

The packaging has three (3) different length configurations (i.e., long, standard, and short) of 266.5-inch, 254.5-inch, and 206.5-inch, respectively. The cask cavity dimensions of the long, standard, and short cask configurations are Ø 26.5-inch by 180.5-inch, Ø 26.5-inch by 168.5-inch, and Ø 26.5-inch by 120.5-inch, respectively.

The cask body consists of a 1.25-inch-thick stainless-steel inner shell, surrounded by a 4.54-inch-thick (minimum) lead gamma shield and a 2.25-inch-thick stainless-steel outer shell. The outside of the cask body weldment, between the end regions that are covered by the impact limiters, is covered by a 1/8-inch-thick stainless-steel thermal shield that is offset from the outer shell by 1/8-inch-thick spacers and a wire wrap to create an insulating air gap.

The top and bottom ends of the cask assembly both include a total thickness of 9.0 inches of stainless steel. The inner shell is welded to a stainless-steel flange at the top end and a stainless-steel inner bottom plate (forging) at the bottom end.

5.(a)(2) Description (continued)

The outer shell is welded to the stainless-steel flange at the top end and a stainless-steel outer bottom forging at the bottom end. The inner bottom plate fits within a machined 3.0-inch-deep pocket on the inside of the outer bottom forging to provide 9.0 inches of stainless-steel shielding on the bottom end.

The cask lid is a 9.0-inch-thick stainless-steel stepped design, secured to the cask body weldment by twenty-four (24) 1½-inch diameter bolts.

The cask assembly includes a vent port in the cask lid and a drain port in the flange, both sealed with identical port covers that are secured to the cask assembly by three (3) 7/8-inch diameter bolts.

Elastomeric cask containment seals are used on the cask lid and port cover plates for all cask configurations except for tritium producing burnable absorber rod (TPBAR) contents, which use metallic containment seals. Elastomeric test O-ring seals are provided outside the containment seals for leak testing.

All package configurations have an 86.0-inch outside diameter, excluding impact limiter lift lugs and support angles. The cask assembly diameter is 43.0-inch at the top and bottom ends where the impact limiters are attached, and 43.5-inch in the region between the upper and lower impact limiters (excluding the upper and lower trunnions). The overall length of the long, standard, and short cask assemblies is 198.5-inch, 186.5-inch, and 138.5-inch, respectively.

The packaging is equipped with identical cylindrical cup-shaped upper and lower impact limiters that fit over the respective ends of the cask assembly. Each impact limiter secured to the cask assembly by eight (8) 1-inch diameter threaded retaining rods, washer plates, and hex nuts. The impact limiters are constructed from Type 304 stainless-steel shells that completely encase the internal balsa wood cores and protect them from the external environment. Each impact limiter assembly is Ø 86.0-inch by 49.0-inch long, with a Ø 43.4-inch by 15.0-inch-deep pocket that fits over the end of the cask assembly.

The maximum weight of the contents and internal support structures is 11,500 lbs. for all cask configurations. The maximum gross weight of the package for the long, standard, and short configurations is approximately 84.4 kip, 80.5 kip, and 64.8 kip, respectively.

5.(a)(3) Drawings

The package shall be constructed and assembled in accordance with the following NAC International Drawing numbers:

Drawing No.	Revision	Drawing Title
70000.38-L100	1P	Packaging Assembly, Volunteer
70000.38-L110	1P	Cask Assembly, Volunteer
70000.38-L115	2P	Port Cover Assembly, Volunteer
70000.38-L116	1P	Port Cover Assembly, Metal Seal, Volunteer
70000.38-L120	2P	Cask Body Weldment, Volunteer
70000.38-L130	3P	Cask Lid Assembly, Volunteer
70000.38-L131	2P	Cask Lid Assembly, Metal Seal, Volunteer
70000.38-L141	0P	Impact Limiter, Volunteer
70000.38-L150	0P	Shield Liner Assembly, Volunteer
70000.38-L160	0P	TPBAR Basket Assembly, Volunteer
70000.38-L165	0P	TPBAR Spacer, Volunteer
70000.38-L166	0P	TPBAR Bearing Plate, Volunteer
70000.38-L167	0P	Basket Extension Assembly, TPBAR, Volunteer

5(b) Contents

(1) Type and Form of Material

(a) Irradiated Hardware: Radioactive material in the form of neutron activated metals or metal oxides in solid form, and/or contaminated non-fuel bearing reactor accelerator components, intact, segmented, and/or sized reduced, and contained inside a shield liner assembly.

(b) Vitrified High-Level Waste (HLW): Radioactive waste material confined within a solidified borosilicate glass matrix and contained inside a sealed stainless-steel HLW canister with a welded closure.

(c) TPBARs: Production TPBARs in consolidation canisters.

5(b) Contents of Packaging

(2) Maximum quantity of material per package:

(a) Irradiated Hardware

(i) Maximum Co-60 activity of 30,000 Ci.

(ii) Maximum heat load of 470 thermal watts per package.

(b) Vitrified HLW

i) Maximum combined total activities of all gamma and neutron-emitting isotopes not exceeding 474 Ci/kg and 2.15 Ci/kg, respectively. Maximum combined total activity density of Ba-137m and Cs-137 not to exceed 350 Ci/kg.

ii) Maximum linear heat generation rate of 25.2 watts per inch of canister length, and maximum total heat load not to exceed 4.79 kW for a 15-foot long HLW canister and 2.75 kW for a 10-foot long HLW canister.

(c) TPBAR

i) Up to 4 consolidation canisters, each with no more than 300 TPBARs, not to exceed 1,200 TPBARs total per shipment and no more than two (2) pre-failed TPBAR per shipment.

ii) Average tritium content shall not exceed 1.5g per TPBAR.

iii) Minimum cooling time of 60 days.

iv) Maximum decay heat of 2.75 watts per TPBAR and 3.30 kW per package.

(d) Plutonium contents in quantities greater than 0.74 TBq (20 Ci) must be in solid form.

(e) Fissile content shall meet 10 CFR 71.15 fissile exempt limits

5(c) Criticality Safety Index (CSI): 0 (Not Applicable).

6. In addition to the requirements of Subpart G of 10 CFR Part 71, the package shall:

(a) Be prepared for shipment and operated in accordance with the Operating Procedures in Chapter 8, and

(b) Be tested and maintained in accordance with the Acceptance Tests and Maintenance Program in Chapter 9 of the application.

7. Additional operating requirements of the package include:

   (a) Transport by air is not authorized.

   (b) The package is transported in an exclusive-use conveyance only.

8. The package must be marked with Package Identification Number USA/9403/B(M)-96 for shipments of TPBAR contents.

9. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

10. Expiration Date: May 31, 2030.

REFERENCES

NAC International Volunteer Package Safety Analysis Report" Revision No. 0 dated April 2025.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

YOIRA DIAZ-SANABRIA

Digitally signed by YOIRA DIAZ-SANABRIA
Date: 2025.04.30 16:58:55 -04'00'

Yoira Diaz-Sanabria, Chief
Storage and Transportation Licensing Branch
Division of Fuel Management
Office of Nuclear Material Safety
and Safeguards

Date: April 30, 2025

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION REPORT
Docket No. 71-9403
Model No. Volunteer Package
Certificate of Compliance No. 9403
Revision No. 0

EVALUATION

By letter dated May 20, 2024 (Agencywide Documents Access and Management System Accession No. ML24142A453), as supplemented on August 22, 2024 (ML24235A548), February 25, 2025 (ML25056A217), March 7, 2025 (ML25065A238), and April 2, 2025 (ML25092A169), April 8, 2025 (ML25098A240), and April 16, 2025 (ML25107A109) NAC International (NAC or the applicant) submitted an application for a certificate of compliance (CoC) for the Model No. Volunteer transportation package.

The U.S. Nuclear Regulatory Commission (NRC) staff performed its review of the application and associated safety analysis report (SAR) to the Volunteer package utilizing the guidance provided in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material."

1.0 GENERAL INFORMATION

1.1 Packaging

The Volunteer packaging is comprised of a cask assembly, with identical upper and lower impact limiters, and internal support structures for specific contents to be shipped.

The packaging has three different length configurations (i.e., long, standard, and short) of 266.5-inch, 254.5-inch, and 206.5-inch, respectively. The cask cavity dimensions of the long, standard, and short cask configurations are Ø 26.5-inch by 180.5-inch, Ø 26.5-inch by 168.5-inch, and Ø 26.5-inch by 120.5-inch, respectively.

The cask body consists of a 1.25-inch-thick stainless steel inner shell, surrounded by a 4.54-inch-thick (minimum) lead gamma shield and a 2.25-inch-thick stainless steel outer shell. The outside of the cask body weldment, between the end regions that are covered by the impact limiters, is covered by a 1/8-inch-thick stainless-steel thermal shield that is offset from the outer shell by 1/8-inch-thick spacers and a wire wrap to create an insulating air gap.

The top and bottom ends of the cask assembly both include a total thickness of 9.0 inches of stainless steel. The inner shell is welded to a stainless-steel flange at the top end and a stainless steel inner bottom plate (forging) at the bottom end.

The outer shell is welded to the stainless-steel flange at the top end and a stainless-steel outer bottom forging at the bottom end. The inner bottom plate fits within a machined 3.0-inch-deep pocket on the inside of the outer bottom forging to provide 9.0 inches of stainless-steel shielding on the bottom end.

The cask lid is a 9.0-inch-thick stainless steel stepped design, secured to the cask body weldment by 24 1½-inch diameter bolts.

The cask assembly includes a vent port in the cask lid and a drain port in the flange, both sealed with identical port covers that are secured to the cask assembly by three 7/8-inch diameter bolts.

Elastomeric cask containment seals are used on the cask lid and port cover plates for all cask configurations except for tritium producing burnable absorber rod (TPBAR) contents, which use metallic containment seals. Elastomeric test O-ring seals are provided outside the containment seals for leak testing.

All package configurations have an 86.0-inch outside diameter, excluding impact limiter lift lugs and support angles. The cask assembly diameter is 43.0-inch at the top and bottom ends where the impact limiters are attached, and 43.5-inch in the region between the upper and lower impact limiters (excluding the upper and lower trunnions). The overall length of the long, standard, and short cask assemblies is 198.5-inch, 186.5-inch, and 138.5-inch, respectively.

The packaging is equipped with identical cylindrical cup-shaped upper and lower impact limiters that fit over the respective ends of the cask assembly. Each impact limiter secured to the cask assembly by eight 1-inch diameter threaded retaining rods, washer plates, and hex nuts. The impact limiters are constructed from Type 304 stainless steel shells that completely encase the internal balsa wood cores and protect them from the external environment. Each impact limiter assembly is Ø 86.0-inch by 49.0-inch long, with a Ø 43.4-inch by 15.0-inch-deep pocket that fits over the end of the cask assembly.

The maximum weight of the contents and internal support structures is 11,500 pounds (lbs.) for all cask configurations. The maximum gross weight of the package for the long, standard, and short configurations is approximately 84.4 kip, 80.5 kip, and 64.8 kip, respectively.

1.2 Contents

The NAC Volunteer contents are discussed in SAR section 1.2.2 and state that the acceptable radioactive contents include irradiated hardware in shield liner assemblies, vitrified high-level waste (HLW) in canisters, and TPBAR consolidation canisters (CCs). The general specifications for all radioactive contents are that the:

1. The NAC Volunteer package is designed for Type B quantity of radioactive material that may exceed $3000A_2$,

2. All packaging configurations are designed for a maximum payload weight of 11,500 lbs, including the weight of the contents, internal support structures and any shoring and/or dunnage, and

3. All contents are non-fissile or fissile exempt (i.e., meeting at least one of the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) 71.15(a) through (f)).

1.3 Drawings

The package shall be constructed and assembled in accordance with the following NAC International Drawing numbers and titles:

70000.38-L100, Revision 1P	Packaging Assembly, Volunteer
70000.38-L110, Revision 1P	Cask Assembly, Volunteer
70000.38-L115, Revision 2P	Port Cover Assembly, Volunteer
70000.38-L116, Revision 1P	Port Cover Assembly, Metal Seal, Volunteer
70000.38-L120, Revision 2P	Cask Body Weldment, Volunteer
70000.38-L130, Revision 3P	Cask Lid Assembly, Volunteer
70000.38-L131, Revision 2P	Cask Lid Assembly, Metal Seal, Volunteer
70000.38-L141, Revision 0P	Impact Limiter, Volunteer
70000.38-L150, Revision 0P	Shield Liner Assembly, Volunteer
70000.38-L160, Revision 0P	TPBAR Basket Assembly, Volunteer
70000.38-L165, Revision 0P	TPBAR Spacer, Volunteer
70000.38-L166, Revision 0P	TPBAR Bearing Plate, Volunteer
70000.38-L167, Revision 0P	Basket Extension Assembly, TPBAR, Volunteer

1.4 Evaluation Findings

The staff reviewed the general design information. Based on its review, the staff concludes that the information presented in this section of the application provides an adequate basis for the evaluation of the Volunteer package against the requirements in 10 CFR Part 71 for each technical discipline.

2.0 STRUCTURAL EVALUATION

The objective of the structural evaluation is to verify that the applicant has adequately evaluated the structural performance of the package (packaging together with contents) and demonstrated that it meets the regulations in 10 CFR Part 71, “Packaging and Transportation of Radioactive Material.”

2.1 Structural Design

2.1.1 Description of Structural Design

The Volunteer is a Type B(U)-96 transportation package for irradiated hardware and vitrified HLW contents. However, it is designated Type B(M)-96 for TPBAR contents.

The Volunteer package consists of a cask assembly, equipped with identical upper and lower impact limiters, and internal support structures for specific contents. The package includes three

(3) different length configurations (i.e., long, standard, and short) and designed to transport irradiated hardware, vitrified HLW, and TPBAR radioactive contents. All package configurations have an 86.0-inch outside diameter (OD), excluding the impact limiter lift lugs and support angles. The length of the long, standard, and short packages, with impact limiters attached, are 266.5-inch, 254.5-inch, and 206.5-inch, respectively. The cask assembly is 43.0 inches in diameter at the top and bottom ends where the impact limiters are attached and in the region between the upper and lower impact limiters (excluding the upper and lower trunnions, and thermal shield). The overall length of the long, standard, and short cask assemblies is 198.5-inch, 186.5-inch, and 138.5-inch, respectively. The cask cavity dimensions of the long, standard, and short cask configurations are 26.5-inch diameter by 180.5-inch, 168.5-inch, and 120.5-inch, respectively.

The cask body radial construction consists of a stainless steel inner shell, surrounded by a lead gamma shield and a stainless steel outer shell. The top and bottom ends of the cask assembly both include a total thickness of 9.0 inches of stainless steel. The inner shell is welded to a stainless steel flange at the top end and a stainless steel inner bottom plate (forging) at the bottom end. The outer shell is welded to the stainless steel flange at the top end and a stainless steel outer bottom forging at the bottom end. The inner bottom plate fits within a machined 3.0-inch deep pocket on the inside of the outer bottom forging to provide 9.0 inches of stainless steel shielding at the bottom end. The cask lid is 9.0-inch-thick stainless steel stepped configuration secured to the cask body weldment by 24 bolts. The cask assembly also includes a vent port in the cask lid and a drain port in the flange, both sealed with identical port covers that are secured to the cask assembly by three bolts. Elastomeric cask containment seals are used on the cask lid and port cover plates for all cask configurations except for TPBAR contents, which use metal containment seals. The inner O-rings on the closure lid and the vent and drain port covers are components of the cask containment boundary, whereas the outer O-rings are for the purpose of leakage rate testing only.

The package is equipped with identical cylindrical cup-shaped upper and lower impact limiters that fit over the respective ends of the cask assembly. Each impact limiter is secured to the cask assembly by eight retaining rods, washer plates, and hex nuts. The impact limiters are constructed from stainless steel shells that completely encase the internal balsa wood cores and protect them from the external environment. Each impact limiter assembly has a deep pocket that fits over the end of the cask assembly.

The package includes internal support structures for radioactive contents. Irradiated hardware contents must be packaged in a shield liner assembly (SLA) and TPBAR CCs must be packaged in a TPBAR basket assembly. The TPBAR basket assembly and the shield liner assembly are not relied upon for criticality control. These assemblies act as a structural support that are designed and fabricated in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC), section III, division 1, subsection NF.

The SLA is a stainless steel cylindrical shell assembly and functions as a secondary container to facilitate the loading and unloading of irradiated hardware contents into and out of the cask assembly and minimizes contamination of the cask cavity. The SLA includes three different lengths that are sized to fit within the cavity of the long, standard, and short casks for transport. All three SLA configurations are identical with respect to the cross-section dimensions, shell support features, and top and bottom end details; they vary only by the overall length.

The TPBAR basket assembly is only used with the standard cask configuration and consists of an open-ended internal support structure for TPBAR CC contents. The TPBAR basket assembly can be configured in two ways with additional internal support components including a bearing plate that is bolted to the inside surface of the cask lid at the top end, or an aluminum extension plate that is bolted to the top end of the TPBAR basket and TPBAR spacers that are placed on top and around the bail handle of the TPBAR CC. The structural function of the TPBAR basket assembly is to provide four cells into which TPBAR CCs can be loaded, maintain the axial position of the TPBAR CC and retain its shielding configuration.

The user-supplied sealed stainless-steel canister with a welded closure holds the vitrified HLW contents during transport. The canisters for HLW contents have a nominal 24-inch OD, a minimum 3/8-inch nominal shell thickness, and a maximum nominal overall length of 180 inches and 120 inches for a long and short configuration, and are transported in the long cask and short cask, respectively. The user supplied canister is not credited in the structural and containment evaluations of the Volunteer package.

The maximum weight of the contents and internal support structure is 11.5 kip for all cask configurations. The maximum gross weight of the package for the long, standard, and short configurations is approximately 84.4 kip, 80.5 kip, and 64.8 kip, respectively.

The applicant provided licensing drawings with tolerances, dimensions, material designation, and associated standards. Component descriptions and the arrangement of components relative to each other were detailed by the applicant. The applicant described the weight of the package with and without its contents in table 2.1-5 of the Volunteer SAR. The overall physical dimensions of the package were shown in the listed drawings in SAR section 1.6.2. The package is designed to be lifted vertically using a lifting device connected to the two diametrically opposed upper trunnions located on the outer shell of the cask assembly.

The NRC staff reviewed the package structural design description and concludes that the contents of the application satisfy the applicable requirements of 10 CFR 71.31(a)(1), 10 CFR 71.31(a)(2), and 10 CFR 71.33.

2.1.2 Design Criteria

The applicant discussed the design criteria for the package structural evaluation in SAR section 2.1.2. The structural analyses of the package are performed for the applicable normal condition of transport (NCT) tests, hypothetical accident condition (HAC) tests, and the special requirements for Type B packages containing more than 10^5 A_2. The load combinations of initial conditions used for the package structural evaluation of each NCT and HAC test are based on table 1 of Regulatory Guide (RG) 7.8, Revision 1. The stresses in the package structural components are calculated for the NCT and HAC load combinations and compared to the allowable stress design criteria developed in accordance with RG 7.6, Revision 1. The allowable stress design criteria are based on the “design-by-analysis” approach of the ASME BPVC section III, division 1, subsections NB, and NF, 2013 edition using elastic-system analysis with Level A Limits for NCT and Level D Limits for HAC. In accordance with Regulatory Position 1 of RG 7.6, the values of the material properties used in the structural analysis correspond to the appropriate temperatures at the respective loading condition. In accordance with Regulatory Position 5 of RG 7.6, the elastic-plastic buckling analyses of the cask assembly are used to show that structural instability will not occur under NCT and HAC. Based on the review of the proposed design criteria the NRC staff concludes that they are appropriate for the intended purpose and are properly applied.

2.1.3 Codes and Standards for Package Design

The package containment system is designed and fabricated in accordance with the applicable requirements of the ASME BPVC, section III, division 1, subsection NB. The non-containment structural components of the package, including the internal support structures, are designed and fabricated in accordance with the applicable requirements of the ASME BPVC section III, division 1, subsection NF. The material standards used for the package comply with American Society for Testing and Materials (ASTM) and ASME BPVC section II, part D, for the package. The applicant used the LS-DYNA (Version 971 R11.1) computer program for load drop simulation analyses and the ANSYS (Version 16.2) computer program to develop finite element method models and perform structural analyses. The applicant designed the lifting attachments of the Volunteer package in accordance with the requirements of NUREG-0612 and American National Standards Institute (ANSI) N14.6 for special lifting devices for critical lifts.

The applicant selected codes and standards that are appropriate for Category I container contents based on the guidance provided in RG 7.6 and NUREG/CR-3854. Based on the review of the proposed codes and standards, the NRC staff concludes that they are appropriate for the intended purpose and are properly applied.

2.2 General Requirements

2.2.1 Minimum Package Size

The minimum package dimension is greater than 4-inch; thus, the NRC staff finds that the package satisfies the requirements of 10 CFR 71.43(a) for minimum size.

2.2.2 Tamper-Indicating Feature

The closure of the package is facilitated by wire cable tamper-indicating seals or similar devices (SAR appendix 1.6.2, Drawing No. 70000.38-L100, Items 8 and 9) that are attached to the upper impact limiter attachments after it is installed such that they cannot be removed without damaging the tamper-indicating seals or the package. The location of the seal and its materials of construction minimize the potential for accidental damage during transport of the package. The NRC staff reviewed the package tamper-indicating feature description and its locations, and finds that the package satisfies the requirements of 10 CFR 71.43(b) for a tamper-indicating feature.

2.2.3 Positive Closure

Positive closure of the package is facilitated by the cask lid bolts, port cover bolts and closure seals. The package containment system is evaluated for internal pressure loads that arise during NCT and HAC in SAR section 2.6 and section 2.7 respectively. The results of the NCT and HAC stress analyses are used to evaluate the containment seal integrity based on the separation of the surface contact elements at the location of the cask lid containment seal. The evaluations demonstrate that the lid bolts and port cover bolts satisfy the applicable allowable stress design criteria, and that the containment seal remains intact under NCT and HAC. Hence, the package containment system satisfies the positive closure requirements of 10 CFR 71.43(c). The NRC staff reviewed the package closure analysis and finds that the package satisfies the requirements of 10 CFR 71.43(c) for positive closure.

2.2.4 Package Valve

Other than the cask assembly lid closure and port cover closures, there are no penetrations to the containment system, and no valves, or pressure relief devices of any kind exist in the package. The NRC staff reviewed the package closure description of the package and finds that it satisfies requirements of 10 CFR 71.43(e).

2.3 Lifting and Tie-Down

2.3.1 Lifting Devices

The applicant describes lifting and handling of the package in calculation 70000.38-2107, "Volunteer Cask Lifting and Tiedown Analysis," Revision 2, and in SAR section 2.5.1. The two diametrically opposed upper trunnions welded to the outer shell of a cask assembly are designed to support the cask during lifting, upending and downending operations. The two diametrically opposed lower trunnions are designed as pivot points for the cask upending and downending operations. The lifting attachments of the package are designed in accordance with the requirements of NUREG-0612 and ANSI N14.6 for critical lift devices that bound the requirements of 10 CFR 71.45.

Based on the applicant's calculations, the maximum combined stresses in the lifting attachments (i.e., lifting trunnions and their welds to the outer shell) are shown to have factors of safety greater than six compared to the material yield strength and greater than 10 compared to the material ultimate tensile strength. Under excessive loading, the results show that the lifting attachments would fail at the base of the lifting trunnion shoulder outside the outer shell and not impair the ability of the package to meet the other requirements of 10 CFR Part 71 Subpart E, thereby satisfying the overload requirement of 10 CFR 71.45(a).

The NRC staff reviewed the lifting analyses for the package and concludes that it satisfies the requirements of 10 CFR 71.45(a) for lifting.

2.3.2 Tie-Down Devices

The applicant describes the package tie-down arrangement in calculation 70000.38-2107, "Volunteer Cask Lifting and Tiedown Analysis," Revision 2, and in SAR section 2.5.2. The lower trunnions are secured to the transport skid such that they resist the full 10g longitudinal load, whereas the upper/lifting trunnions are free to slide in the longitudinal direction to allow for free differential thermal expansion between the package and the skid. The 5g lateral load is resisted by the upper trunnion and lower trunnion on the side in the direction of the lateral load. The 2g vertical load is resisted by all four trunnions. When subjected to the combined loading in all three directions, the stresses in the trunnions and their attachments to the cask body do not exceed the yield strength of the materials in accordance with the requirements of 10 CFR 71.45(b)(1). The lowest factors of safety against yielding in the upper and lower tiedown attachments is 2.5. In addition, under excessive loading, the results show that the upper and lower tiedown attachments would fail at locations outside the outer shell and not impair the ability of the package to meet the other requirements of 10 CFR Part 71 Subpart E, thereby satisfying the overload requirement of 10 CFR 71.45(b)(3).

The NRC staff reviewed the tie-down analyses for the package and concludes that they satisfy the requirements of 10 CFR 71.45(b) for tie-down.

2.4 General Considerations for Structural Evaluation of the Package

The structural evaluation of the package is performed by analysis using computational modeling software and classical closed form solutions (hand calculations). The ANSYS and LS-DYNA computer programs are used for the structural evaluation of the packaging. The LS-DYNA computer program and modeling methodology for free drop tests are benchmarked by comparison to a similar NAC CY-STC package and its ¼-scale model physical drop tests as described further in section 2.4.3 of this safety evaluation report (SER).

Specifically, the applicant analyzes a sequence of free drops for the NCT and HAC with various package orientations to determine the rigid body responses (accelerations, deformations) of the package in calculation 70000.38-2201, "LS-DYNA drop analyses of Volunteer Balsa wood impact limiter," Revision 0, and as described in SAR section 2.6, "Normal Condition of Transportation," and section 2.7," Hypothetical Accident Conditions." Based on the results of the drop analyses, dynamic load factors (DLF) and equivalent static acceleration factors for the NCT and HAC free drops are established in calculation 70000.38-2204, "Dynamic Load Factors and Equivalent Static Accelerations for Volunteer Cask with Balsa Wood Impact Limiter," Rev. 0. The DLFs and equivalent static acceleration factors are summarized in SAR table 2.13-5 and section 2.13.3 and used for the structural evaluation of the cask and internal components in subsequent stress analyses. The staff finds that the analytic techniques used for the structural evaluation comply with guidance provided in RG 7.9, as supplemented by NUREG-2216. The NRC staff reviewed the method of the package evaluation to demonstrate compliance with the NCT and HAC test requirements and finds it acceptable to satisfy the requirements of 10 CFR 71.41(a).

2.4.1 LS-DYNA Model

The applicant used the LS-DYNA explicit dynamic program to simulate response of the Volunteer package to the NCT free drop, HAC free drop, and HAC puncture tests. Three separate models, shown in SAR figure 2.13-2, are used to evaluate the long, standard, and short cask configurations for a range of free drop orientations and thermal conditions. Full- scale, half symmetry models are developed of the package using an ANSYS preprocessing routine. The LS-DYNA finite element model is a ½-symmetry model that includes the cask and contents, which are modeled as a rigid body, and the upper and lower impact limiters, which include the stainless-steel shell weldment, balsa wood end core and side core, and the retaining rods that attach the impact limiters to the ends of the cask assembly. Certain packaging features are not modeled, such as the upper and lower trunnions and thermal shield, that are not important for the deformation response of the impact limiters or the rigid-body dynamic response of the package. However, the mass of the components that are not modeled are included in the cask assembly model.

The model of the cask and internals, shown in SAR figure 2.13-3, uses 8-node solid elements, whereas the model of the impact limiters, shown in figure 2.13-4, uses 4-node shell elements for the various plates of the shell weldment and solid homogeneous elements for the balsa wood end and side cores. The retaining rods that attach the impact limiters to the ends of the cask assembly are modeled as beam elements. For the NCT and HAC free drop analyses, the impact target is modeled as a rigid flat surface. For the HAC puncture drop analyses, the puncture bar is added between to the impact target and the package, as shown in SAR figure 2.13-5 and figure 2.13-6. Contact surfaces are modeled between the impact limiter cores and shell weldment, between the impact limiter shell weldment and cask body, and between the impact limiter shell weldments and impact target or puncture bar surfaces. A lower-bound sliding coefficient of friction is conservatively modeled for all contact surfaces.

The impact limiter shell weldments, retaining rods, and mild steel puncture bar are all modeled using elastic-plastic true stress-strain (multi-linear) material models based on their respective material properties at temperatures of -40°F and 200°F. The impact limiter balsa wood end and side cores are modeled using the LS-DYNA crushable foam material model with stress strain properties based on testing of balsa wood performed both parallel and perpendicular to the wood grain direction at temperatures of -40°F and 200°F for strain rates of 0 sec^{-1} (static) and 25 sec^{-1} (dynamic). The compressive strength of the balsa wood at an angle to the grain direction is determined using Hankinson's formula. The cold stress-strain curves for balsa wood are conservatively increased by an additional 10 percent to provide upper-bound (i.e., hard) crush properties that typically result in the highest package peak rigid-body acceleration loads. The hot stress-strain curves for balsa wood are conservatively decreased by an additional 10 percent to provide lower-bound (i.e., soft) crush properties that typically result in the largest impact limiter deformation and the greatest potential to "bottom-out".

The material properties of the steel and balsa wood used in the LS-DYNA models are provided in SAR chapter 7. For each free drop condition evaluated, the package model is positioned directly above the target in the impact orientation of interest, and the initial impact velocity corresponding to the drop height is applied to the model.

In calculation 70000.38-2201, the applicant documents the energy balance time-history results for the NCT and HAC drop conditions, which shows that all the initial kinetic energy is converted into strain energy due to crushing of the impact limiter. The hourglass energy plotted in the system energy plots of the calculation show essentially zero. The sliding energy remains positive throughout the impact, which indicates proper behavior of the model contact interfaces. Based on the review of the calculation and plots, the NRC staff finds that the hourglass energy relative to internal energy is low and that the LS-DYNA modeling approach of the drop cases is acceptable.

The NRC staff reviewed the approach of developing the LS-DYNA models and concludes that it is appropriately modeled and acceptable to provide an accurate structural response for the package under NCT free drop, HAC free drop, and HAC puncture testing conditions as required by 10 CFR 71.41(a).

2.4.2 ANSYS Model

The applicant used the ANSYS computer program to generate a three-dimensional (3-D) model of the Volunteer package and determine its response to NCT and HAC. The ANSYS code performed an equivalent static analysis with bounding g-loads calculated using the LS-DYNA dynamic analysis. Most of the stress analyses of the Volunteer cask are performed using the ANSYS finite element computer program and the full-scale finite element models that include ¼-symmetry and ½-symmetry finite element models. The ¼-symmetry model is intended to be used for load conditions that include uniform radial loads, such as internal or external pressure loads, axial loads (e.g., end drops), axisymmetric temperature gradients, and bolt preload. The ½-symmetry models, which are generated by symmetry reflection of the ¼-symmetry models, are intended to be used for evaluation of conditions that include transverse loads, such as side drops, corner drops, and slapdown impacts, etc.

The finite element models of the cask assembly represent all the major packaging components, including the inner bottom plate, inner shell, bolt flange, cask lid, lid bolts, bottom forging, outer shell, and gamma shield. The upper and lower impact limiters and the contents are not included in the ¼-symmetry finite element model but are accounted for separately in the applied loads used in the stress analyses. The ½-symmetry finite element models include support shells that react transverse loads (e.g., side drop) at the impact limiter overhang regions at the top and bottom ends of the cask. The simulation of the model includes applied loads and boundary conditions. The calculated stress intensities are compared to appropriate ASME code allowable stresses and the margins of safety are calculated.

The NRC staff reviewed the approach of developing the ANSYS model and concludes that it is appropriately modeled and acceptable to provide accurate structural analyses results for the package under NCT and HAC test conditions as required by 10 CFR 71.41 (a).

2.4.3 Benchmarking and Validation

The applicant describes the benchmark analysis of the LS-DYNA code for the drop analysis of the Volunteer package in appendix G of the Calculation 70000.38-2201, and SAR section 2.13.1.2.1, to demonstrate that it accurately predicts the non-linear response of the impact limiter assembly and the rigid-body response of the package under free drop conditions. The applicant describes that the LS-DYNA model had previously been validated for the CY-STC package design based on the 30-foot (9-m) drop tests of a ¼-scale model of the CY-STC package. As shown in SAR figure 2.13-1, the applicant demonstrated that the acceleration time-histories from the LS-DYNA simulations for the HAC side and HAC end drops for the CY-STC package agree well with the corresponding measured responses from physical ¼-scale model drop tests of the CY-STC package.

The applicant uses comparison of the Volunteer and the CY-STC packages relevant design features and previous benchmark analysis of the CY-STC package to confirm that the LS-DYNA software and modeling methodology employed for the CY-STC package can accurately predict the dynamic response of the Volunteer package for the free drop tests. The crushable wood cores of the impact limiter are represented in the model using LS-DYNA's crushable foam material model. The LS-DYNA benchmark analysis compares the results of the computer simulations to the measured response from ¼-scale-model physical drop tests of the NAC CY-STC package.

The applicant compares the relevant Volunteer package design features that affect its structural response to drop events to the CY-STC package design features. This comparison shows similarities between the cask assembly configurations and their mass center of gravity locations, upper and lower impact limiters configurations, and their material and attachment design including shear relief pockets. Based on these similarities, and after scale factors adjustment for the differences in the mass and core stiffnesses as shown in SAR table 2.13-1, the applicant establishes that the structural response of the Volunteer impact limiters to free drop loading agrees well with the results of the Volunteer drop analyses, which is similar to that of the CY-STC impact limiters that have been benchmarked based on the ¼-scale drop testing.

Based on the review of the methodology and the close correlation of the results, the NRC staff concludes that the benchmark evaluation for the LS-DYNA is acceptable for use in the design and analysis of the Volunteer package to ensure the model accurately provides structural responses to meet the requirements of 10 CFR 71.41(a).

2.5 Normal Conditions of Transport

The acceptance criteria used by the applicant for the NCT is to demonstrate that the cask lid and port cover closures remain secured and that the cask containment is not breached during the NCT.

2.5.1 Heat

The applicant states that the package ambient temperature conditions correspond to an ambient temperature of 38°C (100°F) with solar insolation. This matches the 38°C ambient temperature required by 10 CFR Part 71. Thus, the NRC staff concludes that the ambient heat requirements for the package satisfy the standards of 10 CFR 71.71(c)(1).

2.5.2 Design Pressures and Temperatures

SAR section 3.3 describes the results of the NCT heat thermal evaluation that shows the standard cask configuration with TPBAR contents experiences the highest overall peak temperatures. SAR table 3.3-2 provides the maximum temperatures of the cask assembly components. The applicant uses the bounding design temperature distribution conservatively as shown in SAR figure 2.6-1 for the cask assembly stress analysis in calculation 70000.38-2105, "Volunteer Cask Assembly Stress and Buckling Analysis" Rev. 4, which considers the maximum temperatures of 300°F at the top and bottom ends of the cask cavity and 325°F on the inside surface of the inner shell. This also results in larger temperature differentials through the cask bottom end, top end, and side wall. As discussed in SAR section 2.6.1.4, the results of the NCT heat cask assembly stress analysis show that the maximum stresses in all components of the cask assembly due to the design temperature distribution bound those from the generic (i.e., bounding heat flux) and TPBAR temperature distributions calculated in SAR chapter 3, Thermal Evaluation.

As shown in SAR table 3.1-6 and table 16 of the calculation 70000.38-2105, the maximum internal pressures for the NCT heat and cold conditions are 460 psig and 403 psig, respectively. Upper-bound design internal pressure loads of 575 psig and 490 psig are conservatively used for the cask assembly stress analysis for hot and cold conditions, respectively, per table 16 of the calculation 70000.38-2105. The design pressures for NCT heat conservatively envelope the maximum calculated NCT pressure for 2 pre-failed rods and, assuming 100 percent failure of the remaining rods, including the pressure differential of 11.2 psi due to reduced external pressure load of 3.5 psi. Based on the review of the results from SAR thermal evaluation and structural analyses input, the NRC staff concludes that the design temperatures and pressures are appropriately considered in the cask structural evaluations to meet the requirements of 10 CFR 71.71(b).

2.5.3 Differential Thermal Expansion

The applicant considers differential thermal expansion of the package as described in section 2.6.1.2 of the application. The effects of differential thermal expansion of the cask assembly materials are accounted for in the NCT heat finite element analysis. For the thermal expansion between the cask cavity and the cask internal support structure (SLA), the applicant evaluates it using hand calculations, conservatively considering an upper-bound temperature of 400°F for the SLA, and for a lower bound temperature of 70°F for the cask assembly. The nominal axial and radial gaps between the SLA and the cask cavity are 0.75-inch and 0.25-inch, respectively, for all three cask configurations. The calculation results show that differential thermal expansion between the cask cavity and SLA are less than the available axial and radial clearances. Therefore, the shield liner assembly will expand freely within the cask cavity.

The differential thermal expansion between the TPBAR basket assembly and the cask cavity are evaluated, considering an upper-bound temperature of 400°F for the TPBAR basket, and 300°F for the cask shell. The nominal axial and radial gaps between the TPBAR basket and the cask cavity are 0.69-inch and 0.25-inch, respectively. The results show that differential thermal expansions between the basket and cask cavity are less than the available axial and radial clearances. Therefore, the TPBAR basket assembly will expand freely within the cask cavity.

In addition, the applicant evaluates differential thermal expansion between the TPBAR basket divider plates and the slotted grooves in the TPBAR basket weldment and demonstrates that the TPBAR basket divider plates expand freely under the worst case NCT and HAC conditions. Similarly, the differential radial expansion between the cask lid and TPBAR bearing plate, and between the TPBAR basket assembly and the upper flange of the TPBAR basket extension assembly, have been shown to be acceptable based on the sufficient clearances available at the bolted connections between the two components.

Based on the review of the evaluation and results, the NRC staff finds that the interfacing package components are free to expand without any constraints under the worst-case thermal conditions, and concludes this analysis is acceptable to satisfy requirements of 10 CFR 71.71(c)(1).

2.5.4 Cold

The applicant uses the temperature -40°F to perform a drop test evaluation and uses material properties at this temperature. The NRC staff reviewed the cold temperature requirements for the package and concludes that they satisfy the standards of 10 CFR 71.71(c)(2).

2.5.5 Reduced External Pressure

In accordance with 10 CFR 71.71(c)(3), the package is designed to withstand the effects of a reduced external pressure of 3.5 psia (18.2 psig). The cask assembly is designed to ASME section III, subsection NB, for a reduced external pressure of 3.5 psia and an internal design pressure of 575 psig and 490 psig for hot and cold conditions, respectively. Hence, the greatest pressure difference between inside and outside of the containment system is applied for the design.

The results of the applicant's analysis for the NCT reduced external pressure demonstrated that the package containment system satisfies the ASME allowable stress design criteria. As a result, the NRC staff concludes that the package satisfies the standards of 10 CFR 71.71(c)(3) for reduced external pressure.

2.5.6 Increased External Pressure

In accordance with 10 CFR 71.71(c)(4), the package is designed to withstand the effects of an increased external pressure of 20 psia. The applicant designed the cask assembly for an increased external pressure of 5.3 psig (increased above 14.7 psia atmospheric pressure) and an internal pressure of 0 psig.

As stated in SAR section 2.6.4, the water immersion evaluation for an external pressure of 290 psi is significantly higher than the increased external pressure of 5.3 psig. Since the cask assembly is designed to a higher value of external pressure (290 psi), the NRC staff concludes that the package satisfies the standards of 10 CFR 71.71(c)(4).

2.5.7 Vibration and Fatigue

According to the requirements of 10 CFR 71.71(c)(5), the package is subjected to vibration normally incident to transport. The package is transported in a horizontal orientation, and supported by the upper and lower trunnions of the cask assembly.

The applicant describes in SAR section 2.6.5 that because the peak longitudinal and transverse accelerations for truck and rail transport are so low due to vibrations, they are insignificant, and a bounding NCT vibration load of 2g vertical is used for the NCT vibration evaluation. The primary concern for NCT vibration is fatigue failure of the package, specifically in the regions of the upper and lower trunnions and adjacent regions of the cask outer shell that support the package under routine transportation conditions. The applicant determines the stresses in the upper and lower trunnions and cask outer shell due to a 2g vertical vibration load using the same ½-symmetry 3-D finite models used for the tiedown analyses, which result in the maximum stress of 9.2 ksi at the base of the trunnion shoulder, significantly less than the ASME code allowable stress. The results of the NCT vibration stress analysis are considered in the fatigue evaluation of the cask that is presented in SAR section 2.1.2.4 and discussed in the following paragraph of this SER. The package thus complies with the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) when subjected to the NCT vibration test specified in 10 CFR 71.71(c)(5).

The applicant describes in SAR section 2.1.2.4.1 that consideration of fatigue in the packaging structural components is not required if the conditions stipulated in ASME NB-3222.4(d)(1) through (6) are met. The applicant evaluates these conditions conservatively based on the assumption that the package will be used for 20 years of service and be used for one shipment per week, for a total of 1,040 shipments. Based on this evaluation, the applicant demonstrates that the conditions stipulated in NB-3222.4(d)(1) through (6) are met, and therefore, analysis of the package structural components for cyclic service is not required. However, the applicant performs the fatigue analysis of bolts per the ASME section III NB-3232.3 to determine their maximum numbers of loading cycles (i.e. installation and removal). For the cask closure bolts and port cover bolts, the applicant documents the results of a fatigue analysis in SAR section 2.1.2.4.2 and 2.1.2.4.3 and Calculation 70000.38-2110, Revision 1. The results of the fatigue analysis show that the cask closure bolts and port cover bolts satisfy the fatigue design criteria of ASME NB-3232.3 for maximum 2745 NCT cyclic loading. As a result, the applicant adds the maintenance requirement to replace the cask lid cover bolts and port cover bolts after 2,500 cycles (i.e., 1250 shipments based on two cycles per shipment) or sooner in SAR section 9.2.3.3. The NRC staff reviewed the vibration and fatigue requirements for the package and bolts and concluded that they satisfy the evaluation requirement of 10 CFR 71.71(c)(5).

2.5.8 Water Spray

In accordance with the requirements of 10 CFR 71.71(c)(6), the package must be subjected to a water spray that simulates exposure to rainfall of approximately 2 in/hour for at least 1 hour. The applicant stated that the cask assembly is isolated from the quenching effects of the water spray by the upper and lower impact limiter assemblies and the thermal shield, which insulates the cask assembly from sudden environmental changes. The NRC staff considers that the effects of the water spray test are not significant for the structural design of a large cask like the Volunteer package. As a result, the NRC staff finds that the water spray test will not impair the package and concludes that it satisfies the standards of 10 CFR 71.71(c)(6).

2.5.9 Free Drop

The applicant evaluates three different NCT free drop impact orientations. These include end drop, end corner drop, and side drop as shown in SAR figure 2.6-3. As described in SAR appendix 2.13.2, the LS-DYNA explicit finite element analysis computer program is used to perform dynamic analyses of the Volunteer package for a range of NCT free drop conditions, including enveloping cold and hot cases for the short, standard and long cask configurations. The cold and hot conditions correspond to impact limiter temperatures of -40^{0}F and 200^{0}F, respectively. The temperature of 200°F bounds the balsa average temperatures per the analyzed NCT heat conditions. However, some localized sections in contact with the cask outer surfaces experience elevated balsa temperatures. The sensitivity study in appendix J of the calculation 70000.38-2201 confirms that using properties at a bounding maximum temperature of 280°F at selected sections of the balsa will maintain clearance between the upper trunnion and impact plane for the side drop and the slapdown. Further, this study concludes that localized elevated balsa temperatures, which exceed the 200°F temperature considered for material properties, do not have a significant impact on the crush performance of the Volunteer impact limiters.

The NCT free drop is evaluated for the heaviest content weight of 11,500 lbs., which includes the weight of the internal support structures. All NCT free drop conditions, except for the hot NCT end drop case for the long cask configuration, are based on the cold drop conditions with the upper-bound crush strength properties of the impact limiter materials, which produces the highest peak rigid-body accelerations loads. The hot NCT end drop case for the long cask demonstrates that under the maximum crush conditions (i.e., softest impact limiter and highest package mass) the stepped geometry at the end of the impact limiter balsa wood end core does not create an abrupt change in stiffness that produces higher loads than the governing cold NCT end drop for the short cask. For each condition evaluated, the resulting rigid-body acceleration time histories of the cask assembly are used to determine the DLF and equivalent static acceleration load for each NCT free drop orientation, as described in SAR section 2.13.3. For each NCT free drop impact orientation, detailed stress analyses of the cask assembly and internal support structures demonstrate that the applicable allowable stress design criteria for NCT are satisfied, the structural components do not buckle or collapse under the worst-case NCT free drop load combinations, and that the containment seal is maintained. Also, for the NCT end and side drop orientations, the permanent deformation of the cask's lead gamma shield (i.e., lead slump) is evaluated for the full range of load combinations to determine the maximum gaps to be considered in the NCT shielding analysis.

The structural evaluation of the packaging for the NCT end, side, and corner drop impacts are described in SAR sections 2.6.7.1, 2.6.7.2, and 2.6.7.3, respectively. The stress analyses use proper material allowable stress intensities from the ASME section III, subsection NB for the cask assembly components, and subsection NF for the internal structures. For the cask assembly, excluding the lid bolts, the lowest factor of safety is 1.18 for primary membrane stress intensity in the inner shell for load combination NS3 (i.e., long/cold NCT side drop with minimum internal pressure). The lowest factor of safety in the lid bolts is 1.05 for load combination NCT1 (i.e., long/hot NCT top corner drop with minimum internal pressure). The minimum factors of safety for primary membrane and primary membrane plus bending stress intensities in the port cover bolts for the NCT free drop load combination are 1.90 and 2.80, respectively. The results of the limit/collapse load buckling analysis for the Volunteer cask NCT end drop demonstrate that the minimum required factor of safety of 1.50 against collapse is provided, which demonstrates the cask shell structural stability under compression loads. For the shield liner assembly, the lowest factor of safety is 1.35 for bearing stress at the end and center supports for the NCT side drop. For the TPBAR basket, the lowest factor of safety is 1.05 for bearing stress on the ends of the divider plates for the NCT end drop.

The results of the package structural analysis for NCT free drop conditions demonstrate that the package satisfies the applicable allowable stress and structural stability design criteria, and that the containment seal is maintained during and following NCT free drop impacts. The NCT free drop does not result in any plastic deformation of the package structural components. A maximum ¼-inch axial gap is developed at the end of the lead gamma shield due to the combined effects of lead slump from the NCT end drop and differential thermal expansion between the lead and the surrounding steel weldment. This gap is accounted for in the NCT shielding evaluation, as discussed in SAR chapter 5.

Based on the review of the analyses methods and the results, the NRC staff concludes that sufficient design margin exists for the cask assembly and internal structural components as the calculated factors of safety (i.e. allowable parameter/actual parameter) are greater than 1.0. The NRC staff concurs with the applicant's structural assessment and concludes that the package satisfies the requirements of 10 CFR 71.71(c)(7).

2.5.10 Compression

In accordance with 10 CFR 71.71(c)(9), packages weighing up to 11,000 pounds must be subjected to a compressive load. The gross weight of the Volunteer package, including the contents weight, exceeds 11,000 lbs. Therefore, the package is not evaluated for the compression test. The NRC staff concludes that the compression test requirements of 10 CFR 71.71(c)(9) do not apply to the Volunteer package.

2.5.11 Penetration

In accordance with 10 CFR 71.71(c)(10), the package must be subjected to an impact of the hemispherical end of a vertical steel cylinder of 1.25-inch diameter and weighing 13 lbs., that is dropped from a height of 40 inches onto the exposed surface of the package that is expected to be most vulnerable to puncture. The NRC staff finds that the Volunteer package is large in size and does not have any vulnerable location on the package surface (e.g., an unprotected valve); therefore, the package does not need to be evaluated for a penetration test. The NRC staff concludes that it satisfies the standards of 10 CFR 71.71(c)(10).

2.5.12 Conclusion for NCT

The NRC staff reviewed the structural performance of the Volunteer package under NCT required by 10 CFR 71.71 and concludes that there will be no substantial reduction in the effectiveness of the package that would prevent it from satisfying the requirements of 10 CFR 71.51(a)(1).

2.6 Hypothetical Accident Conditions

The structural evaluation for HAC is based on sequential application of the HAC tests specified in 10 CFR 71.73(c) to determine the cumulative effect on the package, in accordance with 10 CFR 71.73(a). As discussed in section 2.5 of this SER, no significant package damage results from the NCT tests of 10 CFR 71.71. Thus, the evaluation of the package for the HAC test sequence is performed starting with an undamaged specimen. The package is evaluated for the most unfavorable initial conditions specified in 10 CFR 71.73(b). The HAC load combinations considered in the structural evaluation are developed in accordance with RG 7.8 and summarized in section 2.1.2.1.

2.6.1 Free Drop

In accordance with 10 CFR 71.73(c)(1), the Volunteer package is evaluated for a free drop of 30-feet (9-m) onto a flat, essentially unyielding, horizontal surface. The applicant evaluates the Volunteer package for a wide range of HAC free drop impact orientations to determine the maximum peak rigid-body acceleration loads for both hot and cold drops to be considered in the package structural analysis. As presented in SAR section 2.13.2, the applicant performs dynamic analyses using LS-DYNA computer program to determine the dynamic response of the cask body assembly for the applicable free drops for HAC conditions.

As discussed in SAR section 2.13.3, the applicant determines equivalent static accelerations based on the peak rigid body accelerations of the cask from the LS-DYNA drop analyses results and associated DLFs. Based on the equivalent static accelerations as summarized in SAR table 2.13-6, bounding design accelerations for the HAC are defined and used in the subsequent structural analyses. The cold and hot drop conditions are evaluated in combination with maximum and minimum internal design pressure and maximum bolt preload.

The applicant evaluates the Volunteer package stresses for several different HAC free drop orientations, as shown in SAR figure 2.7-1. These include bottom and top end drops, bottom and top corner drops, horizontal side drops, and oblique drop slapdown impacts at angles of 10°, 15°, and 20° from horizontal. The structural evaluation for the HAC end drop, side drop, corner drop, oblique drop slapdown impacts are described in SAR sections 2.7.1.1, 2.7.1.2, 2.7.1.3, and 2.7.1.4, respectively. The stress analyses use proper material allowable stress intensities from the ASME section III, subsection NB for the cask assembly components, and subsection NF for the internal structures. For the cask assembly, excluding the lid bolts, the lowest factor of safety is 1.07 for primary membrane stress intensity in the outer shell for load combination HBC1 (i.e., long/hot HAC bottom corner drop with minimum internal pressure). The lowest factor of safety in the lid bolts is 1.34 for load combination HTC1 (i.e., long/hot HAC top corner drop with minimum internal pressure). The minimum factors of safety for primary membrane stress intensity in the port cover bolts for the HAC free drop load combination is 2.84. The results of the HAC free drop plastic instability analysis demonstrate that the cask assembly satisfies the plastic instability acceptance criteria (i.e., the maximum HAC drop load does not exceed 0.7PI, where PI is the plastic instability load).

For the shield liner assembly structure, the lowest factor of safety is 1.17 for shear stresses in the lid alignment/shear pin for the HAC slapdown drop. For the TPBAR basket structure, the lowest factor of safety is 1.11 for average shear stress in the side shield-to-flange groove weld for the HAC slapdown drop. In response to the request for HLW canister structural evaluation, the applicant clarified in the SAR section 2.1.1.3 that the user supplied vitrified HLW canister is loaded directly into the cask assembly without having a need for an internal support structure. Further, the user supplied canister is not credited in the structural evaluation of the Volunteer packaging, nor in the containment evaluation.

The results of the HAC free drop analysis also show that the maximum plastic strains in the impact limiter shell weldment and retaining rods resulting from the HAC free drops are 110 percent and 30 percent, respectively, which are lower than the respective failure strains of 120 percent and 51 percent. Thus, the HAC free drop does not tear or perforate the outer skin of the impact limiter to expose the balsa wood core and does not result in any failure of the impact limiter retaining rods.

The results of the package structural analysis for HAC free drop conditions demonstrate that the package satisfies the applicable allowable stress and structural stability design criteria for accident conditions, no significant permanent deformation occurs (except for lead slump), containment seal is maintained following the HAC free drop impact, and the package maintains its structural stability. A maximum 0.85-inch axial gap is developed at the end of the lead gamma shield due to the combined effects of lead slump from the HAC free drop and differential thermal expansion between the lead and the surrounding steel weldment. This gap is accounted for in the HAC shielding evaluation, as discussed in SAR chapter 5.

Based on the review of the analyses methods and results, the NRC staff concludes that sufficient design margin exists for the cask assembly components, the closure bolts and the internal structures components as the calculated factors of safety (i.e. allowable stress/actual stress) are greater than 1.0. The NRC staff finds the package structural assessment acceptable and concludes that it satisfies the free drop requirements of 10 CFR 71.73 (c)(1).

2.6.2 Crush

The crush test of 10 CFR 71.73(c)(2) is required only when the specimen has a mass not greater than 1100 lbs. (500 kg). This test is not applicable since the package weighs more than 1100 lbs.

2.6.3 Puncture

The applicant considers the three most damaging orientations that could damage key components of the package. The applicant performs the puncture drop test sequence following the HAC free drop test in accordance with 10 CFR 71.73(a). Therefore, the package damage resulting from the HAC free drop is considered in the HAC puncture drop evaluation. The applicant evaluates the orientation where the HAC puncture test could damage the cask bottom end (i.e., bottom forging) and cask top end (i.e., cask lid, lid bolts, and closure seal region). In addition, potential deformation of the cask outer shell and lead gamma shield resulting from a side puncture impact is considered for evaluation, and a corner puncture impact is evaluated to determine the maximum damage to the impact limiter shell. All HAC puncture impact cases are evaluated for the maximum allowable content. The stress analyses of the cask assembly for puncture impact cases are performed by the applicant using the 3-D ¼-symmetry ANSYS finite element model. The puncture cases are summarized in SAR section 2.7.3 and tables 2.7-10 through 2.7-12. The results show that the minimum factor of safety for primary membrane and primary membrane plus bending stress intensities in the cask assembly structural components (excluding the lid bolts) are 1.15 and 1.13, respectively. The minimum factor of safety for primary membrane stress intensity in the lid bolts is 1.57.

The NRC staff reviewed the analysis and results in SAR section 2.7.3 and finds that the HAC puncture impact stresses in the outer shell of the cask and lid bolts are below the applicable Service Level D allowable stress intensity limits of ASME BPVC section III. The maximum stress intensities throughout the cask assembly due to the side puncture impact are lower than the yield strength, except locally in the outer shell region directly over the puncture bar, it exceeds the yield strength, and some local plastic deformation occurs. But it does not perforate the outer shell, which is approximately 1.8 times thicker than the thickness required to prevent perforation from the side puncture impact. The analysis results show that the HAC side puncture impact deforms the outer shell inward by approximately 0.85-inch, where the lead thickness is reduced by approximately 0.97-inch. This lead/steel deformation due to the side puncture accident is accounted for in the HAC shielding evaluation, as discussed in SAR chapter 5. In addition, the results show that the cask closure seal maintains leaktight containment, and no significant permanent deformation of cask assembly will result. Therefore, the NRC staff concludes that the package satisfies the puncture requirements of 10 CFR 71.73(c)(3).

2.6.4 Thermal

In accordance with 10 CFR 71.73(c)(4), the package is designed to withstand a 30-minute fire with the flame temperature of 1,475°F (800°C). In SAR section 2.7.4, the applicant describes the structural evaluation for the HAC thermal loading. The results of the HAC thermal evaluation described in SAR section 3.4 show that the standard cask configuration with TPBAR contents experiences the highest overall peak temperatures during the fire transient. The results of the thermal analysis show that the peak temperature of the containment seals for all cask configurations remain below their respective temperature limits. The corresponding maximum internal pressure load on the cask assembly, conservatively based on a maximum of 2 pre-failed TPBARs, 1.5g tritium per TPBAR, and 100 percent event-failed rods, is 495 psig. An upper-bound HAC design internal pressure load of 600 psig is conservatively used for the stress analysis of the cask assembly.

As discussed in SAR section 2.7.4.2, the internal support structures are designed with sufficient radial and axial clearances to the cask cavity to allow free thermal expansion during the HAC thermal tests. As discussed in SAR section 2.6.1.2, the bounding temperature differential used for the NCT heat differential thermal expansion evaluation is larger than the maximum temperature differential between the internal support structures and the cask cavity for the HAC thermal conditions.

The applicant summarized the maximum stress intensity in the cask components and the cask closure bolts for the HAC pressure loading as shown in SAR table 2.7-13. The results show that the minimum factor of safety for primary membrane and primary membrane plus bending stress intensities in the cask assembly structural components (excluding the lid bolts) are 2.09 and 2.89, respectively. The minimum factor of safety for primary membrane stress intensity in the lid bolts is 1.36. In addition, the results of the HAC pressure stress analysis show that no significant separation of the cask lid sealing surface results from HAC pressure loading. Thus, containment will be maintained under HAC pressure loading, and there will be no loss or dispersal of radioactive contents.

The NRC staff reviewed the statements presented by the applicant and relevant portions of the structural and thermal evaluations and found them acceptable. Additional detailed reviews and safety evaluations by the NRC staff on the applicant's thermal evaluations are provided in chapter 3.0 of this SER.

2.6.5 Immersion - Fissile Material

The Volunteer package is not authorized to transport fissile material. Thus, the requirements of 10 CFR 71.73(c)(5) do not apply.

2.6.6 Immersion - All Packages

In accordance with 10 CFR 71.73(c)(6), an undamaged package is subjected to a water pressure equivalent to immersion under a head of water of at least 50 feet (15 m) or an equivalent external pressure load of 36.4 psi (21.7 psi gauge +14.7). The package design is bounded by the 290 psi for external pressure as required by 10 CFR 71.61, which exceeds the external pressure load of 36.4 psi. As a result, the NRC staff concludes that it satisfies the standards of 10 CFR 71.73(c)(6).

2.6.7 Air Transport Accident Conditions for Fissile Material

Air transport of the package is not permitted and as a result, the requirements of 10 CFR 71.55(f) do not apply.

2.6.8 Immersion - Special Requirement for Type B Packages Containing More Than 10^5 A_2

The requirements of 10 CFR 71.51(d) and 10 CFR 71.61 apply. The applicant considered the deep-water pressure of 290 psig per 10 CFR 71.61 on the cask external surface and modeled it with a maximum bolt preload to evaluate the stresses in the cask assembly. The evaluation results in SAR table 2.7-14 show that the minimum factors of safety are greater than 10 for the cask assembly components, except for the closure bolts. The cask closure bolts minimum factor of safety is 2.5 for the primary membrane plus bending stress. The results of the finite element analysis demonstrate compliance with the accident condition allowable stress design criteria. In addition, the results demonstrate that no plastic deformation of the lid bolts or seal region results, and that water in-leakage is prevented. Based on the review of the cask assembly analysis and the results to meet the special immersion requirements, the NRC staff concludes that the package satisfies the immersion-special requirements of 10 CFR 71.51(d) and 10 CFR 71.61.

2.6.9 Air Transport of Plutonium

The requirements of 10 CFR 71.74 do not apply since the package does not contain plutonium.

2.6.10 Fuel Rods

The authorized contents of the package include TPBARs in consolidation canisters. The greatest potential for damage of the TPBARs is buckling resulting from an HAC end drop that could result in the release of tritium from the TPBARs into the cask cavity. The applicant describes in SAR section 2.11 that the bounding internal pressures for NCT and HAC are conservatively calculated based on 2 pre-failed TPBARs per shipment and 100 percent failure of the remaining TPBARs, respectively as discussed in SAR sections 3.3.2 and 3.4.3.2. The assumed failure of 100 percent of the TPBARs is conservative in terms of both internal pressure and flammability as discussed in section 4.5.2, and therefore, the structural evaluation of the TPBARs is not required.

The NRC staff reviewed the statements presented by the applicant and relevant portions of the structural, thermal and containment evaluations and finds that the internal pressures and flammability events have been evaluated with conservative assumptions of either 100 percent failed fuel rods or no failed fuel rods, and concludes that the structural evaluation of fuel rods is not required.

2.6.11 Conclusion for HAC

The NRC staff concludes that structural performance of the Volunteer package meets the HAC requirements of 10 CFR 71.73 and has the structural integrity to satisfy the containment and shielding requirements for a Type B package. The Volunteer package is not authorized to transport fissile material, and therefore, does not have to meet fissile package requirements.

2.7 Evaluation Findings:

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

3.0 THERMAL EVALUATION

3.1 Review Objectives

The objective of the NRC staff review of Volunteer transport package is to verify that the thermal performance of the package has been adequately evaluated for the tests specified under NCT and HAC and that the package design satisfies the thermal requirements of 10 CFR Part 71. This case is also reviewed to determine whether the package fulfills the acceptance criteria listed in section 3 of NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel and Radioactive Material."

3.2 Description of the Thermal Design

3.2.1 Design Features

The Volunteer packaging consists of a cask assembly with identical impact limiters on its top and bottom ends. In addition, internal support structures are used inside the cask cavity with some of the contents. The cask assembly consists of a body weldment and bolted cask lid. The cask body has a steel-lead-steel sidewall construction with integral upper (lifting) trunnions and lower (rotation) trunnions attached to the outer shell, and a thermal shield outside the outer shell to insulate the package from the effects of the HAC thermal test. The cask assembly's containment vessel provides thermal properties necessary to protect the contents. The cask body weldment is comprised of an inner shell, inner bottom plate, bolt flange, outer shell, bottom forging, with each constructed from mild austenitic stainless steel. Chemical copper lead is poured into the annular cavity between the inner and outer shells.

The impact limiters consist of a stainless-steel shell assembly that is filled with balsa wood cores. A layer of ceramic fiber paper (fire block) is included around the inside pocket of the impact limiter, captured between the inner shell plates and the balsa wood cores, for added insulation of the top and bottom ends of the cask assembly during the HAC thermal test.

The package content includes: 1) Vitrified HLW (in a borosilicate glass monolith) inside a sealed canister, 2) Irradiated hardware, such as reactor internals, non-fuel components, and other Greater Than Class C (GTCC) waste packaged in a shield liner, and 3) TPBARs in CCs.

3.2.2 Thermal Design Criteria

Several thermal design criteria are established by the applicant for the Volunteer transport package to ensure that the package meets all its functional and safety requirements. These criteria are listed below:

- 10 CFR 71.71(c)(1), requires that no loss of effectiveness shall result if the package is subjected to an ambient temperature of 100°F in sunlight.

- Consistent with 10 CFR 71.43(g) the maximum temperature of the accessible packaging surfaces in the shade is limited to 185°F.

- The NCT ambient temperature is -40°F per 10 CFR 71.71(c)(2).
- The maximum temperature achieved during the HAC thermal test must not challenge the package containment boundary.

3.2.3 Content's Decay Heat

SAR table 3.1-1 provides a summary of the packaging contents and its respective design heat loads.

3.2.4 Summary Tables of Temperatures

The summary tables of key package component temperatures for NCT and HAC (SAR tables 3.1-4 and 3.1-5) were reviewed. The temperatures are consistently presented throughout the SAR for NCT and HAC. For the hypothetical accident conditions, the applicant presented the pre-fire, during-fire, and post-fire component temperatures. All components remain below their material property limits (specified in SAR table 3.1-2). Calculated and design temperature limits for the package components were reviewed and found to be consistent throughout the SAR.

3.2.5 Summary Tables of Maximum Pressures

The summary table of maximum internal pressures in the cask cavity for NCT and HAC (calculated as described in SAR sections 3.3.2 and 3.4.3.2, respectively), is provided in SAR table 3.1-6. Chapter 2 of the SAR uses bounding internal pressure loads of 490 psig and 575 psig for NCT cold and hot conditions, respectively. For the HAC thermal test, a bounding design pressure of 600 psig is used. Calculated and design pressure limits for the package were reviewed and found to be consistent throughout the SAR.

The staff reviewed the description of Volunteer transportation package thermal design and finds it acceptable. The staff reviewed the temperature and pressure design limits and calculated temperatures and pressures for the package and found them to be acceptable and consistent in the SAR.

3.3 Material Properties and Component Specifications

3.3.1 Material Properties

The package application provided material thermal properties such as thermal conductivity, density, specific heat, and emissivity for all modeled components of the package. All material thermal properties are included in chapter 7 of the SAR. The staff found these properties acceptable. The thermal properties used for the analysis of the package were appropriate for the materials specified and for the conditions of the cask required by 10 CFR Part 71 during normal and accident conditions.

3.3.2 Component Specifications

The application provided component thermal technical specifications for the Volunteer packaging and contents. The applicant provided temperature ranges for the different materials. These ranges assure that the cask can be operated safely provided the thermal specifications for these materials are not exceeded.

The staff reviewed the thermal properties used for the package analyses and determined that they were appropriate for the materials specified and for the package conditions required by 10 CFR Part 71 during NCT and HAC. The staff reviewed the component specifications for the Volunteer package and determined that the specifications were sufficiently clear to be evaluated as part of the thermal evaluation results.

3.4 Thermal Evaluation under Normal Conditions of Transport

3.4.1 Thermal Models

The applicant used ANSYS finite element analysis (FEA) methods to perform steady-state heat transfer analyses, to evaluate the thermal performance of the package for the NCT. ANSYS is a FEA program with capabilities to predict heat transfer phenomena in two and three dimensions. The applicant developed FEA thermal models for each of the package contents such as vitrified HLW in sealed canisters, TPBARs in consolidation canisters, and irradiated hardware in shield liner assemblies. The applicant also developed a FEA thermal for assuming a bounding heat flux and not modeling the package contents. The purpose of the thermal analyses performed using this model was to evaluate the thermal performance of the long, standard, and short cask configurations for upper-bound content heat loads for a generic shipping configuration that includes a personnel barrier. The design heat load for the irradiated hardware content is significantly less than the heat load used in the model for vitrified HLW content. Therefore, maximum temperatures for the HLW content and the standard canister from the HLW model are bounding for the irradiated hardware content and the shield liner, respectably. A description of the FEA thermal models that included the different contents is provided below.

TPBAR Thermal Model

The applicant's 3-D half symmetry thermal model includes the loaded cask assembly, top and bottom impact limiters, the aluminum enclosure (cover), the carbon steel deck (floor) of the shipping skid, and air surrounding the package inside the aluminum enclosure. Heat is transferred through the cask assembly and impact limiters of the model by a combination of conduction and radiation. From the outer surface of cask body and impact limiters, heat is transferred by conduction, natural convection, and radiation to the inner surfaces of the aluminum enclosure and the shipping skid deck. At the exterior surface of the aluminum enclosure and the outer (bottom) surface of the shipping skid deck, heat is transferred by natural convection and radiation. Each loaded consolidation canister is modeled as a homogeneous region with effective thermal properties determined using a two-dimensional (2-D) ANSYS model of a 17×17 array of TPBAR rods surrounded by helium gas. Solar insolation is applied to the sides and top surfaces of the aluminum enclosure in accordance with 10 CFR Part 71.

Vitrified HLW Thermal model

The applicant's 3-D half symmetry thermal model includes the loaded cask assembly, the top and bottom impact limiters, and vitrified HLW canister contents. A loaded canister containing glass is modeled inside the cask cavity surrounded by air. The vitrified HLW canister is modeled as a right-circular cylindrical shell with end plates, filled with vitrified waste. The external heat load to the package is based on the insolation conditions identified in 10 CFR 71.71. The convection heat transfer coefficient is calculated based on referenced correlations, assuming an ambient temperature of 100°F.

The staff reviewed the applicant's description of the Volunteer transport package thermal models and determined that the application is consistent with guidance provided in NUREG-2216, section 3.4.5, "Thermal Evaluation Under Normal Conditions of Transport." Therefore, the staff concludes that the description of the thermal models is acceptable and meets the requirements of 10 CFR Part 71.

3.4.2 Heat and Cold

The applicant performed steady state analysis using the Volunteer thermal model without insolation to determine the accessible surface temperature in the shade. Boundary conditions at 100 °F and no insolation are considered in the package thermal model to calculate the maximum accessible surface temperature under the shade. The applicant calculated a maximum accessible surface temperature for the Volunteer transport package which is less than the allowable limit. In accordance with 10 CFR 71.43(g), the maximum temperature of the accessible packaging surfaces in the shade is limited to 185°F (85°C). Therefore, this regulatory requirement is met for all package contents.

For the TPBAR content model configuration, the applicant performed steady state analyses using the 3-D half-symmetry FEA models for both the NCT hot case (100°F ambient with solar insolation) and the cold case (-40°F ambient with no solar insolation). The maximum temperatures for TPBAR cladding and key package components for both the hot and cold cases are presented in SAR table 3.3-2. The maximum TPBAR cladding temperature is well below the allowable temperature limit specified in SAR table 3.3-2. The package component temperatures are below their allowable temperatures for NCT.

For the Vitrified HLW content model configuration, the applicant performed steady state analyses using the 3-D half-symmetry FEA models for both the NCT hot case (100°F ambient with solar insolation) and the cold case (-40°F ambient with no solar insolation). The maximum temperatures for the canister content (vitrified HLW or irradiated hardware) and key package components for both hot and cold cases are presented in SAR table 3.3-3. The maximum temperature of the canister content is well below the allowable temperature limit specified in SAR table 3.3-3. The package component temperatures are below their allowable temperatures for NCT.

3.4.3 Maximum Normal Operating Pressure

For a payload of 1200 TPBARs, the applicant considered three contributors to the cask internal pressure: 1) rod backfill gases and tritium/helium produced from lithium, 2) water and tritiated water in pre-failed and waterlogged rods, and 3) cask backfill gases. Internal pressures were evaluated for 0 percent rod failure and 100 percent rod failure. Using the NCT condition average gas temperature, the applicant calculated maximum internal pressures of 21.4 psig and 460 psig for 0 percent rod failure and 100 percent rod failure, respectively.

For the Vitrified HLW and irradiated hardware contents, the applicant calculated the maximum internal pressure using the backfill pressure and the maximum average gas temperature in the cask. The cask is backfilled with air at a pressure of 1 atm and temperature of 293 K (68°F). The maximum average gas temperature obtained from the SAR NCT thermal analysis is used for the pressure calculation. The applicant calculated a maximum internal pressure of 6.8 psig for NCT. The applicant stated that the structural evaluation of the cask assembly in chapter 2 of the SAR uses bounding internal pressure loads of 490 psig and 575 psig for NCT cold and hot conditions, respectively.

The staff reviewed the applicant’s analysis of the Volunteer transport package during NCT. Based on the information provided in the application regarding NCT analysis, the staff determines that the application is consistent with guidance provided in section 3.4.5 of NUREG-2216. Therefore, the staff concludes that the NCT analysis is acceptable because the analysis and results satisfy NUREG-2216 and subsequently meets the requirements of 10 CFR Part 71.

3.5 Thermal Evaluation under Hypothetical Accident Conditions

The applicant’s developed model used to perform the HAC thermal analysis represents the package (with different contents as represented in the model for NCT conditions, i.e., vitrified HLW, TPBARs, etc.) with maximum cumulative damage resulting from the sequential application of the 30-foot free drop test and the 40-inch free drop onto 6-inch diameter mild steel bar. Consistent with the analyses for the NCT cases, the applicant used the general-purpose finite element code ANSYS to model and analyze the package for exposure to the HAC thermal test, in accordance with 10 CFR 71.73(c)(4).

3.5.1 Initial Conditions

The initial temperatures for the Volunteer transport package transient model (before the fire accident) are determined using the same boundary conditions for NCT (100°F ambient with insolation) described in the SAR.

3.5.2 Fire Test Conditions

Based on the requirements in 10 CFR 71.73, a fire temperature of 1475°F, fire emissivity of 0.9 and a period of 30 minutes are considered for the fire conditions in the applicant’s thermal model. A bounding forced convection coefficient surface emissivity of 0.8 is considered for the packaging surfaces exposed to fire, based on 10 CFR 71.73. The convection coefficients used in the analyses before and after the fire are the same as those for the analyses of NCT, except that convection film coefficient for a heated plate facing down is applied on the compressed side surface of impact limiters. A convection film coefficient provided in SAND85-0196 “Thermal Measurements in a Series of Large Pool Fires,” Sandia National Laboratories, Albuquerque, NM, August 1987, for cask size comparable to Volunteer is used during the fire period in the analysis. The applicant applied the temperature profile from the steady state analysis for the NCT hot condition as the initial condition of the model for the fire transient analysis. The 30-minute fire analysis is followed by a 36-hour cool down period.

3.5.3 Maximum Temperatures and Pressure

The peak temperatures of the package components are summarized in SAR tables 3.4-1 through 3.4-3 for the bounding heat flux model, TPBAR content model and the vitrified HLW content model, along with the respective temperature limits. These tables also provide the time of occurrence for the maximum value along with the allowable temperature limit. As shown in the tables, the package components remain below their allowable temperatures for the HAC, except for the lead (in SAR tables 3.4-1 and 3.4-2 for the bounding heat flux model and the TPBAR). The applicant stated that the duration of the lead peak temperature exceeding the allowable temperature is short and it occurs in small, localized regions adjacent to the trunnions. The maximum temperatures for TPBAR and the canister content for vitrified HLW or irradiated hardware are well below their temperature limits.

The applicant calculated the cask internal pressures for the HAC thermal test using the methodology outlined in SAR section 3.3.2. For the irradiated hardware and vitrified HLW waste payloads, the applicant calculated a maximum internal pressure (based on an upper-bound average gas of 380°F) of 8.7 psig. For the TPBAR payload, the applicant calculated maximum internal pressures (based on an upper-bound average gas temperature of 430°F) of 24.0 psig for 0 percent rod failure and 494 psig for 100 percent rod failure. The applicant stated that for the HAC thermal test, a bounding design pressure of 600 psig is conservatively used for the structural evaluation.

3.5.4 Maximum Thermal Stresses

Thermal stresses for the Volunteer cask are discussed in chapter 2 of the SAR.

3.5.5 Accident Conditions for Fissile Material Packages for Air Transport

The Volunteer transport package is not designed for air transport.

The staff reviewed the applicant's analysis of the Volunteer transport package during HAC. Based on the information provided in the application regarding HAC analysis, the staff determines that the application is consistent with guidance provided in NUREG-2216, section 3.4.6, "Thermal Evaluation under Hypothetical Accident Conditions." Therefore, the staff concludes that the HAC analysis is acceptable because the analysis and results satisfy NUREG-2216 and subsequently meets the requirements of 10 CFR Part 71.

3.6 Thermal Tests

SAR chapter 9 provides details of the acceptance and maintenance thermal tests for the Volunteer transport package. According to the SAR, the thermal shield on the cask body weldment is designed to maintain an air space in the annulus between the thermal shield and cask outer shell that insulates the cask from the effects of the HAC thermal (fire) test. Therefore, a test that demonstrates that no water leaks into this air space must be performed.

3.7 Findings

F3-1 The staff reviewed the package description and evaluation and found reasonable assurance that they satisfy the thermal requirements of 10 CFR Part 71.

F3-2 The staff reviewed the material properties and component specifications used in the thermal evaluation and found reasonable assurance that they are sufficient to provide a basis for evaluation of the package against the thermal requirements of 10 CFR Part 71.

F3-3 The staff reviewed the methods used in the thermal evaluation and found reasonable assurance that they are described in sufficient detail to permit an independent review, with confirmatory calculations, of the package thermal design.

F3-4 The staff reviewed the accessible surface temperatures of the package as it will be prepared for shipment and found reasonable assurance that they satisfy 10 CFR 71.43(g) for packages transported by exclusive-use vehicle.

F3-5 The staff reviewed the package design, construction, and preparations for shipment and found reasonable assurance that the package material and component temperatures will not extend beyond the specified allowable limits during normal conditions of transport, consistent with the tests specified in 10 CFR 71.71.

F3-6 The staff reviewed the package design, construction, and preparations for shipment and found reasonable assurance that the package material and component temperatures will not exceed the specified allowable short-time limits during hypothetical accident conditions, consistent with the tests specified in 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

The objective of the NRC's containment evaluation is to verify that the applicant has adequately evaluated the performance of transportation packages for radioactive material so that the packages (packaging together with contents) meet the regulations in 10 CFR Part 71, "Packaging and Transportation of Radioactive Material."

4.1 Description of the Containment System

4.1.1 Containment Boundary and Containment System Closure

Section 4.1 of the SAR states that the containment boundary includes the cask body inner weldment (inner shell, inner bottom plate, flange, and all associated seam welds); cask lid and its inner seal; lid port cover (also referred to as the vent port cover) and its inner seal; and drain port cover and its inner seal. There are no package valves or pressure-relief devices, nor does the packaging rely on filters or a mechanical cooling system.

Section 4.1 of the SAR further describes that the cask lid and vent and drain port covers for non-TPBAR (i.e., irradiated hardware contents or vitrified HLW) payload configurations (i.e., cask configurations 1A (long), 1B (long), 2A (standard), 3A (short), and 3B (short)) all use elastomeric (Viton) O-rings. However, for TPBAR contents (i.e., cask configurations 2B-1 and 2B-2 (both standard in length)), metallic seals are used for the containment boundary inner seals.

Section 4.1 of the SAR further describes that in the lid and port covers, dovetail grooves are used for the elastomeric O-rings and rectangular grooves are used for metallic seals. The dimensions of the dovetail grooves for the elastomeric containment (inner) and test (outer) O-rings are based on the specifications in the Parker O-ring Handbook and are located on Drawing Nos. 70000.38-L115 and 70000.38-L130. The materials and the dimensions of the rectangular grooves for the metallic seals are based on the requirements from the seal supplier and the vendor drawing number is located on Drawing Nos. 70000.38-L116 and 70000.38-L131.

Section 4.1 of the SAR also describes that the inner seals of the cask lid and port covers form leaktight containment and the associated outer seals are used to facilitate leakage rate testing of the assembled closures. The cask lid and vent and drain port covers each have an associated leak test port that are also used to facilitate leakage rate testing. There are quick disconnect fittings for each of the vent and drain ports, of which no credit is given for containment.

Section 4.1 of the SAR further describes that the containment vessel is designed, fabricated, examined, tested, and inspected in accordance with the applicable requirements of subsection NB of the ASME Code, 2013 edition with certain exceptions discussed in table 1-3 of the SAR.

Because the entire containment boundary is tested to the ANSI N14.5, “American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment,” leaktight acceptance criteria, $1x10^{-7}$ ref-cm^3/s, it is not necessary to use the radioactive contents to determine the releasable activity, A_2 (refer to 10 CFR 71.4 for the definition of an A_2), and release rate limits for NCT and HAC. The containment boundary leakage rate testing is further described in sections 4.4, 9.1.4, and 9.2.2 of the SAR and section 4.5 of this SER. The applicant provided metallic seal drawings also indicate that the leak rate acceptance criteria target also meets the leaktight acceptance criteria.

The staff verified the following for the containment system and its components:

- All containment system components are shown in the licensing drawings and are listed as quality category A and are in figure 4.1-1 of the SAR.

- The lid, vent port cover, and drain port cover outer seals are for leak testing purposes and can be not important to safety (NITS).

- The lid, vent port cover, and drain port cover test port plugs and seals do not provide a shielding function or a secondary containment function during leak testing or transport and can be NITS.

- Containment system component information presented in the drawings is consistent with the information presented in the structural and thermal evaluation sections of the SAR.

- Lid, vent port, and drain port bolt torque values are provided on licensing drawings (Nos. 70000.38-L110, L130 and L131) and are consistent with those in chapter 8 package loading procedures of the SAR.

- A lid bolt torque pattern is provided on Licensing Drawing Nos. 70000.38-L130 and L131.

- Appendix 2.13.5 of the SAR provides calculations for the closure lid and port cover tensile stress, shear stress, and containment seating force.

The staff finds that the applicant has adequately demonstrated, in chapter 4 of the SAR, that the containment system for the NAC Volunteer package cannot be opened unintentionally or by an internal pressure within the package and therefore, the requirement in 10 CFR 71.43(c) is met.

4.2 General Considerations for Containment Evaluations

As described in section 4.1 of this SER, the entire containment boundary is tested to the ANSI N14.5 leaktight acceptance criteria, $1x10^{-7}$ ref-cm^3/s.

The Technetics Helicoflex spring-energized metallic seal product number was provided on the licensing drawings to uniquely identify the containment boundary seals for the lid, and vent and drain port covers. The spring materials (jacket and liner), and seal and groove dimensions with tolerances were provided on the metallic seal drawings associated with that product number in appendix F of Calculation No: 70000.38-3010 Rev. 3.

The Parker elastomeric O-ring material was provided on the licensing drawings to uniquely identify the containment boundary seals for the lid, and vent and drain ports. Seal and groove dimensions were also provided for the elastomeric containment boundary seals on the licensing drawings.

The staff confirmed the package is vacuum dried and backfilled with helium, an inert environment for TPBARs or instrument grade air (oil free, clean, dry, compressed air for valves and instruments), dry nitrogen, helium, or an inert gas for irradiated hardware contents, as described in sections 8.1.2.1 (wet loading) and 8.1.2.2 (dry loading) of the application.

4.3 Containment Evaluation Under Normal Conditions of Transport

The applicant described in section 4.2.2 of the SAR that under NCT, the package containment system is designed to be leaktight as defined in ANSI N14.5-2014, i.e., there is no leakage greater than $1x10^{-7}$ ref-cm^3/s of air, with a test sensitivity of $5x10^{-8}$ ref-cm^3/s as described for the leakage rate tests (fabrication, periodic, and maintenance) in chapter 9 of the SAR.

The staff verified that the thermal and structural evaluations, presented in the application, demonstrate that there is no release of radioactive material under NCT. The applicant stated, in section 3.3.2 and table 3.3-4 of the application, that the maximum normal operating pressure (MNOP) of the NAC Volunteer package is 6.8 psig for the vitrified HLW and irradiated hardware contents and 460 psig for the TPBAR contents. This is lower than the design internal pressure for the package of 575 psig; therefore, the staff finds the MNOP to be acceptable.

The applicant reported the maximum NCT temperatures for the inner shell, lid, bottom plate, and lid, vent and drain seals in table 3.1-4 of the SAR. The staff confirmed that the NCT containment boundary temperatures do not exceed the temperature limits also presented in table 3.1-4 of the SAR. Therefore, based on the staff's review of the containment boundary temperatures and the associated containment boundary component temperature limits as presented in the application, the staff finds the containment boundary temperatures to be acceptable.

The staff verified that the applicant described throughout section 2.6 of the SAR that there would be no loss or dispersal of radioactive contents, that the applicable allowable stress design criteria are satisfied, the structural components do not buckle or collapse, and the containment seal is maintained based on no seal separation or seal separation that does not exceed the available seal elastic recovery during and following NCT for both the elastomeric O-rings and metallic seals.

The staff concludes that the results of the structural and thermal analyses, as well as the proposed leakage rate testing, conducted during fabrication to the ANSI N14.5 containment leaktight acceptance criterion and before every shipment to the ANSI N14.5 to the acceptance criterion described in sections 4.5.2 and 4.5.4 of this SER, demonstrates compliance with 10 CFR 71.51(a)(1).

4.4 Containment Evaluation Under Hypothetical Accident Conditions of Transport

The applicant described in section 4.3.2 of the SAR that under HAC, the packaging containment system is designed to be leaktight as defined in ANSI N14.5-2014. The staff verified that the thermal and structural evaluations demonstrate no expected release of radioactive material under HAC. The applicant stated, in section 3.4.3.2 of the SAR, that the maximum HAC pressure of the NAC Volunteer package is 8.7 psig for the vitrified HLW and irradiated hardware contents and 494 psig for the TPBAR contents. This is lower than the design internal pressure for the package of 575 psig; therefore, the staff finds the maximum HAC pressure to be acceptable.

The applicant reported the maximum HAC temperatures for the inner shell, lid, bottom plate, and lid, vent and drain seals in table 3.1-5 of the SAR. The staff confirmed that the HAC containment boundary temperatures do not exceed the temperature limits also presented in table 3.1-5 of the SAR. Therefore, based on the staff's review of the containment boundary temperatures and the associated containment boundary component temperature limits as presented in the application, the staff finds the containment boundary temperatures to be acceptable.

The staff verified that the applicant described throughout section 2.7 of the SAR that the cumulative package damage resulting from the HAC test sequence did not result in the escape of radioactive material exceeding a total amount A_2 in one week, that the applicable allowable stress design criteria are satisfied, and the containment seal is maintained based on no seal separation or seal separation that does not exceed the available seal elastic recovery during and following NCT for both the elastomeric O-rings and metallic seals. The applicant also described that there is no plastic deformation of the lid bolts and seal region for the deep water immersion test.

The staff concludes that the results of the structural and thermal analyses, as well as the proposed leakage rate testing to the ANSI N14.5 containment leaktight acceptance criterion, demonstrates compliance with 10 CFR 71.51(a)(2).

4.5 Leakage Rate Tests for Type B Packages

4.5.1 Fabrication Leakage Rate Test

The purpose of the ANSI N14.5 fabrication leakage rate test is to demonstrate that the containment boundary, as fabricated, will provide the required level of containment. As described in sections 4.1 of this SER and 9.1.4 of the SAR, the entire containment boundary is tested to the ANSI N14.5 leaktight acceptance criteria, $1x10^{-7}$ ref-cm^3/s, with additional details, including the test sensitivity of $5x10^{-8}$ ref-cm^3/s, provided in section 9.1.4 of the SAR.

In section 9.1.4 of the SAR the staff verified the applicant described fabrication leakage rate testing performed on the entire containment boundary using gas filled envelope or evacuated envelope leakage rate test methods described in sections A.5.3 and A.5.4 of ANSI N14.5-2014. The staff also verified that the leakage rate test methods can achieve the test sensitivity specified in section 9.1.4 of the SAR by confirming this in ANSI N14.5-2014.

The staff verified that section 9.1.4 of the SAR describes that leakage rate testing procedures are approved by personnel qualified in accordance with the American Society of Nondestructive Testing (ASNT) Recommended Practice. No. SNT-TC-1A as a Level III in leak testing. The staff also verified that section 9.1.4 of the SAR describes that leak testing is performed by personnel in accordance with section 8.5 of ANSI N14.5-2014.

4.5.2 Maintenance Leakage Rate Test

The purpose of the ANSI N14.5 maintenance leakage rate test is to confirm that any maintenance, repair, or replacement of containment boundary components has not degraded the containment system performance, and it is performed prior to returning the package to service. The staff notes that while section 4.4.2 of the SAR describes maintenance leakage rate testing of the seals specifically, maintenance leakage rate testing could be necessary for any containment boundary component after maintenance, repair, or replacement, as described in section 7.4.3 of ANSI N14.5, and as further described in section 9.2.2.1 of the SAR; which the staff finds to be acceptable. The maintenance leakage rate testing is also shown in table 9.2-1 of the SAR for the containment boundary seals.

In section 9.2.2.1 of the SAR the staff verified that the applicant described the use of the gas filled envelope or evacuated envelope maintenance leakage rate test methods from sections A.5.3 and A.5.4 of ANSI N14.5-2014. The staff verified section 9.2.2.1 of the SAR described that maintenance leakage rate testing is performed in accordance with section 7.4 of ANSI N14.5, which describes testing to the reference air leakage rate, L_R, (leaktight in the case of the NAC Volunteer package) acceptance criterion.

The staff verified that section 9.2.2.1 of the SAR describes that maintenance leakage rate testing procedures are approved by personnel qualified in accordance with the ASNT Recommended Practice. No. SNT-TC-1A as a Level III in leak testing. The staff also verified that section 9.2.2.1 of the SAR describes that maintenance leak testing is performed by personnel in accordance with section 8.5 of ANSI N14.5-2014.

4.5.3 Periodic Leakage Rate Test

The purpose of the ANSI N14.5 periodic leakage rate test is to confirm that the containment capabilities of packagings built to an approved design have not deteriorated over an extended period of use. Sections 9.2.2.1 and 9.2.3.1 of the SAR describe that the elastomeric containment boundary seals are to be replaced within 12 months prior to each shipment, which the staff verified is consistent with section 9.4.2.2 of NUREG-2216. Section 9.2.2.1 of the SAR describes that all metallic containment boundary seals are replaced prior to each shipment, which the staff verified is consistent with section 9.4.2.2 of NUREG-2216. The periodic leakage rate testing is also shown in table 9.2-1 of the SAR for the containment boundary seals.

The staff verified that the applicant described the use of the gas filled envelope or evacuated envelope maintenance leakage rate test methods from sections A.5.3 and A.5.4 of ANSI N14.5-2014. The staff verified section 9.2.2.1 of the SAR described that periodic leakage rate testing is performed in accordance with section 7.5 of ANSI N14.5, which describes testing to the L_R (leaktight in the case of the NAC Volunteer package) acceptance criterion. Because the metallic seals are replaced after each use, there is not a periodic leakage rate test for the metallic containment boundary seals; however, the pre-shipment leakage rate test is performed to the ANSI N14.5 maintenance leakage rate test leaktight acceptance criteria and ANSI N14.5 maintenance leakage rate test requirements in section 9.2.2.1 of the SAR.

The staff verified that section 9.2.2.1 of the SAR describes that periodic leakage rate testing procedures are approved by personnel qualified in accordance with the ASNT Recommended Practice. No. SNT-TC-1A as a Level III in leak testing. The staff also verified that section 9.2.2.1 of the SAR describes that periodic leak testing is performed by personnel in accordance with section 8.5 of ANSI N14.5-2014.

4.5.4 Pre-shipment Leakage Rate Test

The purpose of the ANSI N14.5 pre-shipment leakage rate test is to confirm that the containment system is properly assembled for each shipment. The applicant described the ANSI N14.5 pre-shipment leakage rate test in sections 8.1.3 and 9.2.2.2 of the SAR and it is performed before each shipment after the contents are loaded and the containment system is assembled. The staff verified that pre-shipment leakage rate tests are to be performed on all containment seals, as stated in table 9.2-1 of the SAR.

There are differences between the pre-shipment leakage rate test depending on whether the containment boundary includes metallic seals or elastomeric O-rings, and then also depending on whether the elastomeric O-rings are replaced or are not replaced prior to shipment as described below. Section 9.2.2.2 of the SAR described that containment boundary metallic seals are replaced for every shipment and are tested in accordance with the requirements in section 9.2.2.1 of the SAR, which is also specifically the ANSI N14.5 maintenance leakage rate test requirements. Section 9.2.2.2 of the SAR described that containment boundary elastomeric O-rings that are replaced during loading operations require a maintenance leakage rate test (see section 9.2.2.1 of the SAR), which satisfies the ANSI N14.5 requirements of the pre-shipment leakage rate test. Finally, the applicant described in section 9.2.2.2 of the SAR that for the elastomeric O-rings that are not replaced, the pre-shipment leakage rate test methods are the gas pressure drop and gas pressure rise (A.5.1 and A.5.2 from ANSI N14.5-2014). The staff verified section 9.2.2.2 of the SAR described that pre-shipment leakage rate testing is performed to the no detectable leakage acceptance criterion when tested to a sensitivity of $1x10^{-3}$ ref-cm^3/s.

The staff also verified that section 9.2.2.2 of the SAR describes that pre-shipment leakage rate testing procedures are approved by personnel qualified in accordance with the ASNT Recommended Practice. No. SNT-TC-1A as a Level III in leak testing. The staff also verified that section 9.2.2.2 of the SAR describes that pre-shipment leak testing is performed by personnel in accordance with section 8.5 of ANSI N14.5-2014.

4.5.5 Leakage Testing Conclusions

The staff verified that Condition 6(a) of the CoC states, "The package must be loaded and prepared for shipment in accordance with the Package Operations in chapter 8 of the application." The staff also verified that Condition 6(b) of the CoC states, "The package must be tested and maintained in accordance with the Acceptance Tests and Maintenance Program in chapter 9 of the application." The staff concludes that the fabrication, maintenance, periodic, and pre-shipment leakage rate tests verify the integrity of the containment boundary, and that the containment components will maintain their leaktight containment function during transportation operations. The staff concludes that the leakage rate tests are consistent with the guidelines of ANSI N14.5-2014.

4.6 TPBAR Hydrogen Flammability Appendix

The staff reviewed the applicant provided TPBAR hydrogen flammability assessment in section 4.5.2 of the SAR. The assessments were comprised of no event failed rods (i.e., 1198 intact rods and 2 pre-failed rods) and 100 percent failure of the non-pre-failed rods (i.e., 1198 failed rods and 2 pre-failed rods). The staff confirmed that both assessments provided calculations that demonstrated that tritium (as hydrogen) makes up less than 5 percent of the gas by volume for flammability regulations, 10 CFR 71.43(d) and (f).

The applicant also described HAC for fire and provided justification that the hydrogen flammability is mitigated through vacuum drying and helium backfill, and any hydrogen generated is expected to be oxidized before unloading in an air environment where oxygen could be introduced, and therefore, is no longer flammable. The staff finds this justification provided to be acceptable.

In section 4.5.3 of SAR the applicant provided accident conditions seal permeability calculations. The staff confirmed that the calculations provide a bounding evaluation for the potential release of tritium through the port cover and lid metallic seals and the results meet the 10 CFR 71.51(a)(2) release limit during accident conditions. The staff also confirmed based on the normal conditions seal temperatures that the normal conditions potential release of tritium through the port cover and lid metallic seals meets the 10 CFR 71.51(a)(1) release limit during normal conditions of transport.

4.7 Evaluation Findings

F4-1 The staff has reviewed the description and evaluation of the containment system and concludes that:

- the application identifies established codes and standards for the containment system;
- the package includes a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package.

F4-2 The staff has reviewed the applicant's evaluation of the containment system under NCT and concludes that the package is designed, constructed, and prepared for shipment so that under the tests specified in 10 CFR 71.71, "Normal Conditions of Transport," the package satisfies the containment requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) for normal conditions of transport with no dependence on filters or a mechanical cooling system.

F4-3 The staff has reviewed the applicant's evaluation of the containment system under HAC and concludes that the package satisfies the containment requirements of 10 CFR 71.51(a)(2) for HAC, with no dependence on filters or a mechanical cooling system.

Based on review of the statements and representations in the application, the NRC staff concludes that the package has been adequately described and evaluated to demonstrate that it satisfies the containment requirements of 10 CFR Part 71, and that the package meets the containment criteria of ANSI N14.5-2014.

5.0 SHIELDING EVALUATION

The objective of this shielding evaluation is to verify the proposed design of the NAC Volunteer package, as it pertains to shielding, provides adequate protection to immediate area workers and members of the public against direct radiation that is above the regulatory limits stated in 10 CFR 71 for NCT and HAC. NRC staff reviewed this application using the guidance in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material." This is a new transportation package that is required to be transported under exclusive-use controls. The contents to be transported in this package are as follows:

- TPBARs
- Vitrified Waste
- Irradiated Hardware

5.1 Description of Shielding Design

5.1.1 Shielding Design Features

The design of the Volunteer package consists of the inner and outer shell, lead gamma shield, inner bottom plate and outer bottom forging, upper and lower trunnions, lid, and impact limiters. Figure 1-1 of the application shows the assembly of these components. SAR table 5.1-1 presents the key design features of the packaging credited for radiation shielding. The appendices in this application describe the payload-specific design features. The package is required to transport the contents under exclusive-use controls. Neutron shielding is not necessary for the specified radioactive contents. Cask assembly (i.e., body weldment and closure lid), upper and lower impact limiter assemblies, and internal support structures, as applicable, provide gamma shielding. The cask assembly side wall includes a stainless-steel inner shell, a thick lead gamma shield, and a thick stainless steel shield outer shell. In addition, there is a thick thermal shield between the outer shell and the impact limiters, except around the openings for the upper and lower trunnions. The cask assembly top and bottom ends include a thick stainless-steel shield.

The staff verifies that the engineering drawings in section 1.6.2 of the application, "Packaging General Arrangement Drawings," focus on and provide the necessary details for the features of the package and configurations of components that are important in assessing the shielding performance of the package and demonstrating compliance with 10 CFR Part 71 regulations.

5.1.2 Summary Tables of Maximum External Radiation Levels

The applicant states that this package will transport the contents under exclusive-use controls covered by a personnel barrier or in an enclosure. Figure 1-2 of the application shows the personnel barrier or enclosure. The applicant states that all dose rates are below limits, with at least a 5% margin. The bounding dose rates, including the calculated package transport index (TI), are provided in section 5.6.1.3 for Configurations 2B-1 and 2B-2 (TPBAR); section 5.6.2.3 for Configurations 1B and 3B (Vitrified waste); and section 5.6.3.3 for Configurations 1A, 2A, and 3A (Irradiated hardware).

5.2 Radioactive Materials and Source Terms

5.2.1 Source-term Calculation Methods

The applicant used ORIGEN module of the SCALE computer code to convert activity inventories (in Ci or Ci/kg) to gamma and neutron source terms.

5.2.1.1 TPBAR Payload Source Specification

The applicant generated the TPBAR gamma spectrum by decaying and binning the 30-day discharge activity inventory listed in NUREG-2216 for 30 days. The inventory includes the contribution of the end plugs. Table 5.6.1-1 of the application reproduced the activity inventory listed in NUREG-2216 for 30 days. SAR table 5.6.1-2 shows the source energy spectrum from NUREG-2216 decayed for 30 days more for a total of 60 days from discharge. Based on the source energy spectrum, primary energy lines controlling dose rates, those with energy above 0.9 MeV likely to penetrate cask shielding, are the two energy lines associated with Co-60.

Figure 5.6.1-1 of the application shows the TPBAR axial power profile (excluding end plugs). The bottom-end plug represents 6.8 percent of the total TPBAR power; the top-end plug fraction is insignificant. SAR table 5.6.1-3 presents the graphical power profile in figure 5.6.1-1 of the application converted to a numerical profile. The applicant used the trapezoidal rule for the entire power profile to yield a sum of 1.011, which is consistent with adding the end plug source to the balance of the TPBAR. The staff considers this approach acceptable since using trapezoids (known as the "trapezoid rule") allows the applicant to get more accurate approximations than using rectangles. This rule helps in cases when the area under a curve is determined. In such cases, approximations are the best way to find the area, and the better the approximation, the closer you are to the true value. The final gamma source terms used in the calculation were 2.2035E+16 γ/sec.

5.2.1.2 Vitrified Waste Source Specification

The applicant determines the vitrified waste gamma and neutron source terms (per kg basis) using the activity inventory in table 5.6.2-1 of the application using SCALE/ORIGEN (Version 6.2.4). The applicant uses literature reviews of existing contents for the listed inventories. The applicant developed a single worst-case cask loading combining maximum isotope curies from various canisters. SAR tables 5.6.2-2 and 5.6.2-3 show the gamma and neutron spectra, respectively. Those isotopes that produce most of the source expected to penetrate the cask shields are of interest for the gamma spectrum. Staff agreed with the applicant that a cutoff of 0.45 MeV is reasonable for this evaluation. Above this energy, the isotopes that produce 99.68% account for all the maximum dose rates. The isotopes identified for gamma source terms are Cs-137/ Ba-137m, Cs-134, Sr-90/Y-90, Eu-154, and Co-60. For neutron source terms, these are the isotopes: Cm-244, and Pu-238. Both source terms (gamma/neutrons) have a sum of fractions of 99.68%.

5.2.1.3 Irradiated-Hardware Source Specification

The irradiated-hardware gamma source term is determined based on 30,000 Ci of Co-60 using SCALE/ORIGEN. The gamma spectrum for the irradiated-hardware is shown in table 5.6.3-1 of the application. The irradiated hardware heat load is 462.5 W.

5.3 Shielding Model and Model Specifications

5.3.1 Configuration of Source and Shielding

5.3.1.1 TPBAR Payload Shielding Model

The applicant developed the five axial zones of the TPBAR using a number of TPBARs, and the consolidation can inner width and homogenized densities. To determine the fraction of each constituent material for the pellet axial, the applicant uses Zr-4, cladding, and pellet masses. SAR table 5.6.1-6 shows the key design features of the consolidation can, basket, and spacer credited for radiation shielding. The applicant presented VISED (virtual editor for Monte Carlo N-Particle [MCNP]) slices in figure 5.6.1-2 through figure 5.6.1-6 of the application.

The packaging consists of two options for shipment of TPBARs. The first option uses a bearing plate bolted to the bottom of the cask lid without the four TPBAR spacers. The second option uses the four TPBAR spacers and an extension device to the top of the basket. The first option has the maximum axial shift of the TPBARs in the cask cavity. Therefore, the applicant selected this option for the shielding evaluation. The applicant modeled the TPBAR consolidation canister and TPBARs with and without an upward shift in the cask cavity.

5.3.1.2 Vitrified Waste Shielding Model

The applicant developed a model of the hybrid canister with vitrified waste with a given fixed material composition at a fixed density, with a minimum shielding that will provide maximum dose rates, heat load, and curie content. Table 5.6.2-4 of the application shows the parameters of the vitrified waste. The applicant explained that no tolerances are applied because the only significant feature is the canister shell.

The model assumes the thinner shell type of the Savannah River Site canister, and the ASTM/ASME plate typically allows for small under-thickness tolerances.

Based on a cavity length and a source diameter, the applicant yields a vitrified waste mass of 3124 kg. SAR figures 5.6.2-1 and 5.6.2-2 of the application show VISED slices of the vitrified waste configuration. For a U.S. Department of Energy (DOE) standard canister, the maximum axial shift in the tolerance cask cavity is 0.63 inches. As described above, given that canisters are filled with a seal structure at the top, the model offset is less than the actual loaded cask conditions.

The MCNP code tally multipliers are computed as follows:

- Gamma: 9.1569E+12 γ/sec/kg × 3124 kg = 2.8606E+16 γ/sec
- Neutron: 2.0838E+04 n/sec/kg × 3124 kg = 6.5099E+07 n/sec

5.3.1.3 Irradiated hardware Payload Shielding Model

For the shielding model, the applicant used a minimum source weight of 3810 lbs of steel in the long shield liner, yielding a 1.681 g/cm^3 density. The applicant modeled the source as stainless steel 304. The model of the shield liner with irradiated hardware is developed based on the parameters in table 5.6.3-2 of the application. The applicant applied tolerances as described in table 5.6.3-2 of the application. The shield liner is shifted upward when inserted into the cask cavity. The shield liner lid of the top spacer/flange/lid lug will ensure spacing of the source/shield liner to the cask lid and, therefore, lead taper area. The tally multiplier used in the MCNP calculations is taken directly from table 5.6.3-1 of the application (based on 30,000 Ci of Co-60).

5.3.2 Material Properties

SAR table 5.3-3 shows the material properties of the cask shielding. The applicant used the material properties for stainless steel 304, stainless steel 316, and lead from the Pacific Northwest National Laboratory material compendium. The applicant uses Type 304 material properties to model the Type 304L stainless steel, similar to Type 316L from Type 316 properties. The differences in compositions have no impact on the shielding analysis. The payload-specific source material properties are provided in section 5.6.1.2 for Configurations 2B-1 and 2B-2 (TPBAR); section 5.6.2.2 for Configurations 1B and 3B (Vitrified waste); and section 5.6.3.2 for Configurations 1A, 2A, and 3A (Irradiated hardware). For TPBAR, MCNP material descriptions are shown in table 5.6.1-7 of the application. For the vitrified waste, material description is shown in table 5.6.2-5 of the application. For the Irradiated Steel Payload, the tally multiplier is taken directly from table 5.6.3-1 of the application (based on 30,000 Ci of Co-60).

The staff verified that the applicant described and used appropriate material properties in the shielding models for all packaging components, package contents, and conveyance. The staff confirmed that the applicant provided relevant references documenting the materials' properties. The staff also ensured that the shielding model uses the material properties that minimize the shielding effectiveness of these materials.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant utilized multiple assumptions throughout their shielding calculations to provide assurance that the actual dose rates will always be below the calculated dose rates, as well as below regulatory limits. Minimum dimensions are used where applicable. Also manufacturing tolerances are applied to minimize the radial and axial shielding of the cask. The most significant approaches/assumptions are:

1. All dose rate limits are reduced by 5 percent. This provides direct margin to regulatory limits.
2. As noted previously, manufacturing tolerances are applied to minimize the radial and axial shielding of the cask.

The applicant used ORIGEN depletion code from SCALE, version 6.2.4 computer code for the source terms calculations. Also, the applicant used MCNP 6.2 particle transport code for dose rates analysis. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code and is one of the standard codes used in the nuclear industry for calculating dose rates. The staff verified the MCNP input provided by the applicant and found it acceptable.

The applicant uses variance reduction using the weight window option and initialized using the Automated Variance Reduction Generator (ADVANTG) software. This software automates the process of generating variance reduction parameters for continuous energy Monte Carlo simulations of fixed-source neutron, photon, and coupled neutron-photon transport problems using MCNP code. The staff found this approach acceptable because ADVANTG provides a powerful, efficient, and fully automated alternative to traditional methods for generating variance reduction parameters.

5.4.2 Code Input and Out Data

The applicant has submitted a number of input/output cases that were used to generate all the results. According to the applicant, some models were run to increase the run time to allow better convergence. The staff found the convergence to be good (σ<10 percent) for all total dose rates of interest. The applicant states that the tally fluctuation chart and probability density function plot are studied for each MCNP tally to ensure proper tally bin convergence. This, along with a check of the reported fractional standard deviation (σ) for each tally bin and the additional statistical information reported for MCNP tallies, ensures the reliability of all MCNP calculated dose rate results.

5.4.3 Fluence-rate-to-radiation-level Conversion Factors

The flux-to-dose rate conversion factors were provided in section 5.4.3 of the application. The factors were consistent with the guidance provided in NUREG-2216. The specific values are listed in table 5.4-1 of the application.

5.4.4 External Radiation Levels

The applicant states that all dose rates are below limits, with at least 5 percent margin, and all figures have dose rates in units of mSv/hr.

For TPBAR payload, the applicant uses a governing limit of 10 mSv/hr at the radial surface to scale of the radial plots. The applicant also based scaling the NCT axial plots on the surface in order to get maximum and specific dose rates to each surface (top or bottom). The TPBAR consolidation canister and TPBARs are modeled with and without an upward shift in the cask cavity. The application's tables 5.6.1-8 and 5.6.1-9 show maximum TPBAR dose rates. Radial surface and 2-meter dose rates are higher with the upward shift. Bottom dose rates are approximately 60% lower, and top dose rates are approximately 150 percent higher with the upward shift. Package surface, vehicle surface, and radial 2-meter from the plane of transport vehicle dose rate limits are met at a minimum distance (i.e., the 2-meter location is measured using the 8 feet width of the transport vehicle), with the minimum radial margin computed for the NCT 2-meter from vehicle result. When considering axial dose rates, 2 meters from the impact limiter is sufficient to meet the 0.1 mSv/hr limit. The notes in table 5.6.1-8 and table 5.6.1-9 of the application provide the required offsets to occupied locations from the end of the cask.

For Vitrified Waste Payload, the source terms used for the shielding evaluation of the package were developed based on the available data for maximum isotopic densities of vitrified HLW in a DOE standard canister at the Savanah River Site and from the West Valley Demonstration Project. The staff reviewed these references and found them acceptable. The bounding design source terms provided in SAR table 5.6.2-1 of the application. Of the 30 isotopes included in the bounding design source terms, the combined Ba-137m and Cs-137 source terms account for approximately 74 percent of the total activity for gamma-emitting isotopes that produce gamma rays above 0.45 MeV and are the most important contributors to the gamma dose rate on the package exterior. Therefore, in SAR section 1.2.2.2 the maximum quantity of vitrified HLW in a DOE standard canister is limited by the total activities of all gamma and neutron-emitting isotopes and the total activity density of Ba-137m and Cs-137 isotopes in the vitrified HLW contents, consistent with the shielding evaluation. A DOE standard canister with vitrified HLW must satisfy these activity limit requirements to qualify for shipment in the Volunteer package.

The staff verified that the maximum vitrified waste dose rates limits are met, with the minimum radial margin computed for the NCT 2-meter from vehicle result.

For the Irradiated-Hardware payload, a minimum source weight of steel in the long shield liner yields a density of 1.681 g/cm^3. The source is modeled as stainless steel 304. The model of the shield liner with irradiated hardware was developed based on the parameters in table 5.6.3-2 of the application. Tolerances were applied as described in the table. The tally multiplier is taken directly from table 5.6.3-1 (based on 30,000 Ci of Co-60). The staff verified that maximum irradiated hardware dose rates limits are met, with the minimum radial margin computed for the NCT 2-meter from vehicle result. The TI, defined by the maximum NCT 1-meter dose rate, is 27.9. The applicant determined the radial dose rate is bounding.

5.4.5 Conclusions

The staff reviewed the description of the package design features related to shielding and the source terms, and the method and instructions for determining the contents. The staff also reviewed the shielding analyses and performed confirmatory analyses using SCALE/ORIGEN (Version 6.2.4), based on the assumptions and approximations used in the shielding safety analysis, the results of the analysis presented in the application, and the maximum dose rates for NCT and HAC, to determine that the reported values were below the regulatory limits in 10 CFR 71.47 and 71.51 for an exclusive use package.

Overall, for the three contents (TPBAR, Vitrified Waste, and Irradiate-Hardware Payload) to be shipped in this package, the staff verified that the applicant described the dimensions and material properties of the packaging components used in the models are those that maximize the package radiation levels. The dimensions are at the conservative end of their tolerance range, and they are set to minimize in a realistic manner. The staff also verified that the dimensions and other properties of the package contents and sources used in the models are those that maximize the package radiation levels.

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 NAC Volunteer package, with the content's limits as specified in Condition 5(b)(2) of the CoC, meets the regulatory requirements of 10 CFR Part 71.

5.5 References

2. NUREG-2216, Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Materials- Final Report, U.S. Nuclear Regulatory Commission, Spent Fuel Project Office, August 2020.

3. Code of Federal Regulations, “Packaging and Transportation of Radioactive Materials," Part 71, Title 10, April 1996.

4. 10 CFR Part 71, “Packaging and Transportation of Radioactive Material.”

5. NUREG/CR 5502, Engineering Drawings for 10 CFR Part 71 Package Approvals, U.S. Nuclear Regulatory Commission, May 1998.

6. Oak Ridge National Laboratory, “SCALE Code System,” ORNL/TM-2005/39, Version 6.2.4, 2020.

7. Pacific Northwest National Laboratory, "Compendium of Material Composition Data for Radiation Transport Modeling," PNNL-15780, Rev. 2, 2021.

8. Oak Ridge National Laboratory, “ADVANTG—An Automated Variance Reduction Parameter Generator,” ORNL/TM-2013/416, Rev. 1.

6.0 CRITICALITY EVALUATION

The Volunteer package contents are limited to fissile material quantities that meet the exemption standards in 10 CFR 71.15. Therefore, criticality is not a concern for this package.

7.0 MATERIALS EVALUATION

The staff evaluated the material characteristics of the NAC Volunteer design for transportation of irradiated hardware in shield liner assemblies, vitrified HLW in canisters, and TPBAR CCs. The staff used the guidance in NUREG-2216, “Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material,” issued August 2020 and other guidance documents as identified in this chapter to conduct the materials evaluation.

7.1 Drawings

The drawings for the NAC Volunteer components are provided in SAR chapter 1, appendix 1.6.2. The 13 drawings of the NAC Volunteer Package include a Bill of Materials that provides the material specification and the safety category of each component. Material alternatives, fabrication instructions, and additional material property requirements are provided in the drawing details and notes. The staff reviewed the drawings using the guidance in NUREG-2216, NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” issued May 1999, and RG 7.9, “Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material,” for the recommended content of engineering drawings. In addition, the staff used NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety,” issued February 1996, and NRC RG 7.10, "Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material," Appendix A, “A Graded Approach to Developing Quality Assurance Programs for Packaging Radioactive Material,” for guidance on safety classification of transportation packaging components. The staff verified that the drawings included design features considered in the package evaluation, including:

- the containment system
- closure device
- internal supporting or positioning structures
- gamma shielding
- outer packaging
- heat-transfer features
- energy-absorbing features
- lifting and tie-down devices
- personnel barriers

The staff verified that the drawings include the information described in NUREG-2216 and the referenced NRC guidance documents above on the (1) materials of construction, (2) dimensions and tolerances, (3) codes, standards, or other specifications for materials, fabrication, examination, and testing (4) welding specifications, including location and nondestructive examination (NDE), (5) coating specifications and other special material treatments that perform a safety function and (6) specifications and requirements for alternative materials.

The staff determined that the drawings for the package provide the necessary information identified in the NRC guidance documents and the engineering drawings provided by the applicant are consistent with the design and description of the package, in accordance with 10 CFR 71.33, “Package Description.” Therefore, the staff determined that the drawings provided by the applicant were acceptable.

7.2 Codes and Standards

The materials codes and standards are described in SAR section 7.2.2. The NAC Volunteer Package is designed and constructed to ASME BPVC, 2013 Edition (ASME Code). The containment boundary is designed and fabricated to Class 1 in accordance with the ASME BPV Code, section III, division 1, subsection NB. The structural components that are part of the package but do not have a containment function are designed, fabricated, and inspected to ASME BPV Code, section III, division 1, subsection NF. These components include the cask assembly outer shell, bottom forging, thermal shield components, internal support structures, and impact limiter shell and attachments. The alternative provisions to the ASME Code are described in SAR section 1.2.5.

Non-code components such as the impact limiter balsa wood cores, lead gamma shielding, cask lid and port cover seals, and non-pressure retaining plugs and parts are designated non-code in the drawing parts list. The staff reviewed the non-code components in the drawings part list and determined that they are appropriately designated as non-code components not governed by ASME Code. In addition, the staff determined that the applicant has provided the required properties and performance specifications for these components.

The staff reviewed the applicable codes and standards and material specifications for the NAC Volunteer package components. The staff determined that the use of ASME BPV Code, section III, division 1, subsection NB for the containment boundary, subsection NF for structural components without a containment function is consistent with the NRC guidance in NUREG-2216 which references NUREG/CR-3854, “Fabrication Criteria for Shipping Containers.” Table 4.1 of NUREG/CR-3854 provides guidance for use of ASME BPVC section III, division 1, criteria for the fabrication of containment, criticality, and other safety components for Category I containers such as those that transport spent nuclear fuel. The staff reviewed the Code Alternatives identified in SAR section 1.2.5. The staff determined that the applicant described and provided a basis for the code alternatives for the NAC Volunteer transportation package in SAR section 1.2.5.

Therefore, the staff determined that the description of the codes and standards applicable to the NAC Volunteer package provided by the applicant was acceptable in accordance with 10 CFR 71.31(c).

7.3 Weld Design and Inspection

The NAC Volunteer package containment boundary components are shown in Drawings 70000.38-L110, “Cask Assembly, Volunteer”, 70000.38-L120, “Cask Body Weldment, Volunteer,” and 70000.38-L130, “Cask Lid Assembly, Volunteer,” 70000.38-L-131, "Cask Lid Assembly, Metal Seal, Volunteer," 70000.38-L115, “Port Cover Assembly, Volunteer,” 70000.38-L116, “Port Cover Assembly, Metal Seal, Volunteer.”

The welding design and inspections are described in SAR section 7.3 and the drawings in appendix 1.6.2. Containment system welds are designed and examined in accordance with ASME BPV Code section NB-3350 and NB-5000. Non- containment boundary support welds are designed and examined in accordance with ASME BPV Code section NF-3226 and NF-5000.

The welders and welding procedures are qualified in accordance with ASME section IX. NDE specifications and procedures are in accordance with section V of the ASME Code, acceptance criteria in accordance with section III subsections NB and NF as applicable.

The staff evaluated the welding practices and NDE specifications and found them to be in accordance with the applicable ASME Code sections. The staff reviewed the containment welds and finds that they are performed in accordance with ASME Code NB. Also, the staff confirmed that the package will be leak rate tested in accordance with ANSI N14.5. Section A.5.3 or A.5.4, as documented in the Acceptance tests in SAR section 9.1.4. Therefore, the staff finds the specified NDE, which meets the applicable ASME Code Requirements, and the Helium leak rate testing are sufficient to demonstrate the containment satisfies the regulatory requirements of 10 CFR Part 71.85(a). The staff's containment evaluation is documented in chapter 4 of this SER.

The staff reviewed the support welds and finds they are performed in accordance with ASME Code NF. Therefore, the staff finds the support welds to be acceptable because they meet acceptable Code requirements.

The staff reviewed the applicant's inspection criteria and found that ASME Code subsection NB is appropriate for inspecting containment system welds, including the alternatives to the ASME Code as specified in SAR section 1.2.5. ASME Code subsection NF is appropriate for inspecting non-containment structural Support welds including alternatives to the ASME Code as specified in SAR section 1.2.5. Therefore, the staff finds the inspection criteria acceptable.

7.4 Mechanical Properties

The applicant provided a description of the mechanical properties of the packaging materials in SAR section 7.4. The applicant provided tables in chapter 7 of the SAR listing the mechanical properties for the containment boundary, shielding materials, impact limiter materials, and materials used for the structural components of the NAC Volunteer package. The applicant included material properties including elastic modulus, yield strength, ultimate strength, allowable stress intensity and allowable stress as a function of temperature. For ASME BPV Code materials, the applicant cited the material property values included in the ASME BPV Code, section II, part D and provided properties as a function of temperature.

The staff reviewed the material properties provided by the applicant and determined that the applicant provided the appropriate mechanical properties. The staff reviewed ASME BPV Code materials properties as a function of temperature and determined that the properties provided by the applicant were acceptable because they are in accordance with ASME BPV Code, section II, Part D. The staff determined that the temperature ranges for the mechanical properties provided by the applicant bound the range of the packaging component temperatures provided in chapter 3 of the SAR for NCT and HAC conditions. Therefore, the staff determined that the mechanical properties of the materials for the NAC Volunteer package provided by the applicant were acceptable.

7.5 Thermal Properties

The applicant provided thermal properties of the materials in table 7-9 to 7-15, and table 7-19 including specific heat, thermal conductivity, emissivity, and density. The applicant provided values of the thermal properties as a function of temperature obtained from the ASME BPV Code, section II, part D. The staff reviewed the thermal properties provided by the applicant and determined that the thermal properties provided by the applicant were acceptable because they are in accordance with ASME BPV Code, section II, Part D.

7.6 Radiation Shielding

The staff reviewed information provided by the applicant regarding neutron shielding materials for the NAC Volunteer package. The applicant stated that neutron shielding is provided by the austenitic stainless steel and lead that make up the cask along with self-shielding from the payload. Additionally, the applicant stated that the balsa wood in the impact limiters is credited in NCT shielding evaluations only. No polymetric neutron shields are used. The staff found that since no polymetric shielding is used, there is no potential for degradation from aging or potential for the shielding materials to experience changes as a function of temperature including temperature extremes.

The staff reviewed the information provided by the applicant regarding the gamma shielding materials for the NAC Volunteer package. The applicant stated that gamma shielding is primarily provided by the austenitic stainless steel and lead that make up the cask along with self-shielding from the payload, with the material shielding properties described in SAR table 7-16, “Shielding Material Compositions.” The staff verified the material compositions and geometries of the shielding components used to meet the requirements in 10 CFR 71.43(f) and 10 CFR 71.51(a). Therefore, the staff determined that the material compositions and dimensions of the package components credited for radiation shielding are acceptable. The staff’s shielding evaluation is documented in chapter 5 of this SER.

7.7 Criticality Control

The applicant stated that the NAC Volunteer package authorized contents are limited to non-fissile or fissile-exempt radioactive materials. The staff determined that the NAC Volunteer package meets the requirements in 10 CFR 71.15 because the package authorized contents as described in SER section 7.12 are limited to non-fissile or fissile exempt and meet at least one of the paragraphs (a) through (f) of 10 CFR 71.15.

7.8 Corrosion Resistance

The applicant stated that all exposed internal and external surfaces of the NAC Volunteer package are made of austenitic stainless steel, except for the TPBAR extension plate flange plant, which is aluminum. The primary concern is localized corrosion, including pitting and crevice corrosion, or intergranular stress corrosion cracking. Environments that contain chlorides include exposure to road salts during transport and environments with tritium at high pressure as is in the case of the TPBAR cask configuration. The applicant stated that pitting and localized corrosion is addressed by visually inspecting all exposed surfaces of the cask assembly and impact limiters within the 12-month period prior to any shipment for damage or degradation, including pitting corrosion, per SAR section 9.2.3.4. Intergranular stress corrosion cracking (IGSCC) is mitigated by utilizing Type 304 stainless steel with low-carbon content for cask assembly components in contact with the cask cavity.

The staff reviewed the information provided by the applicant regarding the environments and mitigation of corrosion, including pitting, localized and IGSCC. Per NUREG-2216, section 7.4.10.2, interactions may occur with aluminum in contact with steel. The staff found that the applicant has accurately described and addressed corrosion from the environments for the NAC Volunteer transportation package through material selection and inspection procedures and therefore is in accordance with 10 CFR 71.43(d). The staff also found that the applicant has addressed the potential for localized corrosion degradation through maintenance, inspection, and operating procedures as described in SAR chapters 8 and 9.

7.9 Protective Coatings

The applicant states that this is not applicable as there are no protective coatings specified. The staff determined that the NAC Volunteer package is not relying on protective coatings to prevent the effects of corrosion, chemical reactions, or radiation effects.

7.10 Content Reactions

Flammable and Explosive Reactions

The applicant states that the requirements of 10 CFR 71.43(d) related to flammable and explosive reactions are not applicable as the NAC Volunteer package contents are limited to irradiated hardware in shield liner assemblies, vitrified HLW in canisters, and TPBAR consolidation canisters. The irradiated hardware does not generate flammable or explosive gases because the cavity is vacuum dried prior to closure. The vitrified HLW is contained in a sealed stainless steel canister inside the cask cavity and therefore no contact occurs between the alpha emitters in the borosilicate glass matrix and water during transport and thus no flammable gases are generated. As described in SAR section 4.5.2, the tritium content in TPBAR contents is limited to less than 5 percent of the gas in the cask cavity to address flammability concerns.

The staff reviewed SAR section 7.10 and verified that the applicant has demonstrated that the contents will not lead to potentially flammable or explosive conditions for the package contents including irradiated hardware in shield liner assemblies, vitrified HLW in canisters, and TPBAR consolidation canisters.

Content Chemical Reactions, Outgassing, and Corrosion

The applicant evaluated the potential for chemical reactions between the contents and packaging materials, corrosion reactions and the potential for outgassing that could result in an increase in internal pressure. The applicant provided an evaluation to show that chemical reactions, outgassing and corrosion reactions will not occur based on the chemical compatibility of the contents and the packaging materials. The evaluation concluded that the authorized contents are not subject to chemical reactions, outgassing, or corrosion due to the internal environment of the cask during the short duration of the transport.

As described in SER section 7.10, the staff have determined that the contents of the NAC Volunteer package would not result in adverse reactions. Therefore, the staff finds that the NAC Volunteer package meets the requirements of 10 CFR 71.33(b), 10 CFR 71.35(a), and 10 CFR 71.43(d).

7.11 Radiation Effects

The components affected by radiation include the metal parts of the packaging, elastomeric O-rings, balsa wood cores, metallic containment seals, and the packaging fasteners.

The applicant stated that neutron source terms are low and therefore the fluence experienced by the metal parts is orders of magnitude below 10^{17} n/cm^2 where neutron embrittlement begins. The O-rings exposed to gamma energy is very low and the O-rings are visually inspected for damage, degradation, and leak tested prior to each shipment. Additionally, the O-rings are replaced at least yearly during maintenance as stated in SAR chapter 9.

The applicant stated that the balsa wood cores in the impact limiters receive very low levels of fluence and have little impact on its cellulose structure. The applicant based this upon the operating experience of balsa wood used for impact limiters with similar dose and fluence rates in the impact limiter regions.

The applicant stated that the metallic containment seals are unaffected by the very low radiation levels seen over a single shipment and the seals are replaced before every shipment. The applicant stated that the multi-use fluorocarbon polymer O-ring material has radiation resistant properties and even after years of operation results in no changes to the physical properties. Normal wear is the limiting factor affecting the replacement frequency for the elastomeric O-rings.

The staff's review determined that since the fluence is below 10^{17} n/cm^2 where neutron embrittlement begins, the metal parts of the package will not experience a change in mechanical properties as a result of radiation exposure. For the O-rings and metallic seals, the staff found that the radiation expected is below 10^6 rads, the threshold for degradation, and the replacement frequency and visual inspections will ensure adequate performance. For balsa wood, the staff finds that the impact limiters are not expected to receive a level of radiation to its cellulose structure that would impact its performance. Therefore, the staff determined that the NAC Volunteer package will meet the requirements of 10 CFR 71.35(a) and 10 CFR 71.43(d) for radiation effects on susceptible materials.

7.12 Package Contents

The NAC Volunteer contents are discussed in SAR chapter 1, section 1.2.2. Section 1.2.2 and state that the acceptable radioactive contents include irradiated hardware in shield liner assemblies, vitrified HLW in canisters, and TPBAR CCs. The general specifications for all radioactive contents include:

1. The NAC Volunteer package is designed for Type B quantity of radioactive material that may exceed $3000A_2$.

2. All packaging configurations are designed for a maximum payload weight of 11,500 pounds, including the weight of the contents, internal support structures, and any shoring and/or dunnage.

3. All contents are non-fissile or fissile exempt (i.e., meeting at least one of the requirements of 10 CFR 71.15(a) through (f)).

7.12.1 Irradiated Hardware

The applicant stated that the contents 1A, 2A, and 3A are packaged and shipped in long, standard, and short length shield liner assemblies and cask assemblies, respectively. The shield liners may be either dry or wet loaded into air filled casks. They include irradiated and/or contaminated non-fuel bearing (or fissile exempt quantities) metal and/or solid metal oxide waste, such as intact or segmented boiling water reactor control rod assemblies or control rod blades, segmented reactor components, and solid metal greater than Class C (GTCC) waste. The irradiated hardware contents shall be:

1. Radioactive material in the form of neutron activated metals or metal oxides in solid form and/or contaminated non-fuel bearing reactor accelerator components, or

2. Components may be intact, segmented, and/or size reduced (e.g., compacted) to fit within the cavity of the shield liner assembly.

7.12.2 Vitrified HLW Canisters

The applicant stated that the contents 1B and 3B are HLW vitrified in borosilicate glass contained in a stainless steel HLW canister with a welded closure. They are transported in long and short cask configurations, with only one HLW canister per cask cavity per shipment. The vitrified HLW canisters are dry loaded and shipped with air as cask fill gas. The vitrified HLW canister contents shall be:

1. Radioactive waste material confined within a solidified borosilicate glass matrix and contained inside a sealed stainless steel HLW canister with a welded closure.

7.12.3 TPBARs

Content 2B contains TPBARs inside a CC assembly in a standard length cask assembly, with four CCs allowed per shipment and each CC containing no more than 300 production TPBARs, with a maximum of 1,200 TPBAR per shipment.

The staff's review determined that the applicant provided a description of the NAC Volunteer transportation package contents in SAR chapter 1 including the description of NAC Volunteer package in SAR section 1.2.1, and the drawings in SAR appendix 1.6.2. The staff determined that the applicant provided an acceptable description of the contents of the NAC Volunteer transportation package. The staff determined that the applicant provided information that was in accordance with the guidance in NUREG/CR-6407 and NUREG/CR-5502. Therefore, the staff determined that the information provided by the applicant was acceptable.

The staff determined that the applicant identified the contents of the package in accordance with 10 CFR 71.33(b).

7.13 Fresh (Unirradiated) Fuel Cladding

Not applicable.

7.14 Spent Nuclear Fuel

Not applicable.

7.15 Bolting Material

The staff reviewed SAR section 7.15 which describes the bolting material used. The applicant stated that the bolt material for the cask lid and port covers has the same thermal coefficient of expansion as the materials they are used to connect. The applicant also provided the bolt material properties as a function of temperature in table 7-7, "Mechanical Properties of SA-193, Grade B8S, Stainless Steel Bolting Material."

The applicant also stated that the material is not subject to hydrogen embrittlement or general corrosion. The applicant stated that the lid closure bolts are inspected prior to each shipment and if removed the port cover bolts are inspected prior to each shipment. Also, as described in SAR chapter 9, all bolts are required to be inspected within 12 months prior to shipment and per SAR section 9.2.3.3, the cask lid bolts and port cover bolts are replaced after no more than 1,250 shipments to mitigate the potential for fatigue failure.

The staff reviewed the material properties in table 7-7, “Mechanical Properties of SA-193, Grade B8S, Stainless Steel Bolting Material,” for the bolting materials specified in the SAR, describing the strength of the material, Young’s modulus and thermal expansion coefficients. The staff determined that the cask body, bolts, and flange materials are compositionally similar and will not result in galvanic corrosion to these components. The staff confirmed that the applicant identified the materials to be used in bolted connections in accordance with 10 CFR 71.33(a)(5). The staff reviewed SAR chapter 9 and verified that visual inspections of the bolts were part of the periodic maintenance, which would allow for identification of damage or degradation and allow for rework or replacement prior to use.

The staff verified that the NAC Volunteer package meets the requirements of 10 CFR 71.43(d) and that there are expected to be no significant chemical, galvanic, or other reactions among the bolting materials.

7.16 Seals

Metallic Seals

The applicant stated that only Configuration 2B requires metallic containment seals for cask lid and port covers. The applicant stated that the metallic seals for the cask lid have an allowable temperature range of -40°F to 752°F, whereas the metallic seals for the vent and drain port covers have an allowable temperature range of -40°F to 662°F. The maximum metallic seal temperatures for the cask lid and port cover metallic seals under HAC are 310°F and 327°F, respectively.

The staff verified that the reported maximum operating temperatures for the metallic seals do not exceed the stated maximum temperature limits of 662°F and 752°F. The staff further confirmed that the minimum operating temperature limit specified for the seals is -40°F, which complies with 10 CFR 71.71 (c)(2).

Elastomeric O-rings

The applicant stated that for Configurations 1A, 1B, 2A, 3A, and 3B, the cask lid and port cover inner seals utilize elastomeric O-ring. The applicant stated that the O-ring elastomeric have an allowable continuous service temperature range of -40°F to 400°F. The maximum elastomeric O-ring temperature for the cask lid and port cover elastomeric O-rings under HAC is 323°F and 336°F.

The staff verified that the reported maximum operating temperatures for the elastomeric seals do not exceed the stated maximum temperature limit of 400°F. The staff further confirmed that the minimum operating temperature limit specified for the seals is -40°F, which complies with 10 CFR 71.71 (c)(2).

7.17 Findings

F7.1 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.33 because the applicant described the materials used in the transportation package in sufficient detail to support the staff’s evaluation.

F7.2 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.31(c) because the applicant identified the applicable codes and standards for the design, fabrication, testing, and maintenance of the package and, in the absence of codes and standards, has adequately described controls for material qualification and fabrication.

F7.3 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a) because the applicant demonstrated effective materials performance of packaging components under normal conditions of transport and hypothetical accident conditions.

F7.4 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.85(a) because the applicant has demonstrated effective procedural and inspections controls are in place such that cracks, pinholes, uncontrolled voids, or other defects will not develop that could significantly reduce the effectiveness of the packaging.

F7.5 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.43(d) because the applicant demonstrated through materials controls that there will be no significant corrosion, chemical reactions, or radiation effects that could impair the effectiveness of the packaging.

F7.6 The staff reviewed the package and concludes that the applicant met the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a) for Type B packages and 10 CFR 71.15 for fissile exempt limits because the applicant demonstrated that the package will be designed and constructed such that the analyzed geometric form of its contents will not be substantially altered and there will be no loss or dispersal of the contents under the tests for normal conditions of transport.

Based on the NRC staff's review of the statements and representations in the SAR, the NRC staff concludes that the materials used in the NAC Volunteer package design have been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

8.0 OPERATING PROCEDURES

Chapter 8 of the application provides the operating procedures used to load the package, prepare it for transport (section 8.1), unload the package (section 8.2), and prepare the empty package for transport (section 8.3). Basic steps are presented in the order they are generally performed, required to ensure the package is operated in a manner consistent with the requirements of the CoC and the package safety evaluation in SAR chapters 2 through 6. The applicants operating procedures ensure occupational exposure rates are as low as reasonably achievable.

The application makes clear that users are responsible for creating detailed, written procedures based on this chapter 8, the CoC, and any site-specific requirements. These user-specific procedures may include additional safety measures tailored to the contents being transported, such as the handling of TPBARs, which requires specific monitoring and contamination control as per NUREG-2216. Furthermore, licensees must provide advance notification for certain Type B shipments exceeding specified activity limits.

The Volunteer package comes in various configurations, differing mainly in length and payload capacity, accommodating both wet and dry loading and unloading operations. A key distinction in operating procedures lies in the type of containment seals used. Configurations 2B-1 and 2B-2 utilize metallic seals, which require replacement and helium leakage rate testing before each shipment. All other configurations use elastomeric O-rings, which are tested for leakage prior to each shipment without mandatory replacement. Notably, elastomeric O-rings cannot be used for TPBAR shipments due to tritium permeation concerns.

8.1 Package Loading

The Volunteer package is primarily transported by road; however, the package is also authorized for rail or sea transport. The package is required to be transported under exclusive-use controls. The package is transported in a horizontal orientation, secured to a shipping skid by the cask trunnions, and covered by a personnel barrier or in an enclosure.

The applicant stated in SAR sections 8.1.2.1 and 8.1.2.2 that loading operations are performed in a vertical orientation and may be performed in a dry or wet (e.g., pool) environment. Dry-loading operations will be performed in a precipitation-free environment, or measures will be taken to prevent precipitation from entering the package cavities, such as performing loading operations under a protective cover. If standing water collects inside the cask cavity, absorbent materials or another suitable method, such as a vacuum system, will be used to remove the free-standing water from the cask cavity, which may require the contents to be unloaded. Wet-loading operations require vacuum drying from the cask cavity and leakage rate testing. Wet-loading operations are performed using the cask configuration with drainage features. However, dry loading operations may be performed using cask configurations with or without the drainage features. When the cask configuration with the drainage tube is used for dry loading operations, a pre-shipment leakage rate test of the drain port seal is required even if the drain port cover is not removed during loading operations.

The only special equipment required for the loading and unloading operations of the package, other than standard sockets and wrenches for fasteners, equipment used to lift the packaging components, a radioactive contamination detector, and a radiation survey meter, are the pre-shipment backfill and leakage rate testing apparatuses.

Appropriate controls shall be used for all loading and unloading operations to prevent the spread of radioactive contamination and protect personnel from exposure to excessive radiation.

8.2 Preparation for Transport

SAR Section 8.1.1 involves several key steps: verifying the contents' compliance with the CoC; inspecting the packaging and personnel barrier for damage upon receipt; preparing the conveyance; checking and removing any tamper-indicating devices (TIDs); using a crane to remove the personnel barrier and top/bottom impact limiters; removing cask tiedown securement brackets; upending the cask to a vertical position using a lifting yoke; cleaning the cask exterior; removing drainage hole plugs; carefully loosening and removing the cask lid bolts; lifting and moving the lid to a designated area; removing any internal shipping dunnage; inspecting the cask cavity for foreign materials or damage; confirming the correct installation of internal support structures; and, if necessary, removing vent and drain port covers.

Depending on the type of containment seals, specific preparation steps are required. For elastomeric O-rings, this includes visual inspection for damage, cleaning the grooves, and lightly lubricating the O-rings. Damaged containment O-rings necessitate replacement and a maintenance leakage rate test. The elastomeric test O-rings are inspected and lubricated, while the metallic containment seals are always replaced.

SAR section 8.1.2.2 Dry Loading is used for loading and closure installation, often employing remote handling in shielded enclosures or administrative controls. The procedure involves verifying the closure of any secondary containers, carefully lifting and lowering the contents into the cask, and then using rigging to place and bolt the cask lid. For TPBAR contents, a vacuum drying system is used for evacuation and inerting with helium. Vent and drain port covers are then reinstalled and tightened if they were removed.

SAR section 8.1.3 Final Preparation for Transport includes performing pre-shipment leakage rate tests on the cask lid and vent/drain port covers. The type of test depends on whether metallic (maintenance test required) or elastomeric seals (pre-shipment test required) are used. Plugs are then installed in the leak test ports. Before placing the loaded cask on the shipping skid, a contamination survey is performed on accessible external surfaces. The cask is then lifted and positioned on the skid, oriented correctly, and secured with tiedown brackets. Impact limiters are installed on both ends of the cask, with specific torquing procedures for the retaining rods. A TID is installed on the top impact limiter. Final contamination and radiation surveys are conducted to ensure compliance with regulatory limits. The personnel barrier or cover is then installed and secured.

8.3 Evaluation Findings

The NRC staff has reviewed the description of the operating procedures and finds that the package will be prepared, loaded, transported, received, and unloaded in a manner consistent with its design. The NRC staff has reviewed the description of the special instructions to inspect, handle, and to safely open a package and concludes that the procedures for providing the special instructions to the consignee are in accordance with the requirements of 10 CFR 71.89.

F8-1 The NRC staff has reviewed the proposed special controls and precautions for transport, loading, unloading, and handling and the proposed special controls in case of accident or delay, and finds that they satisfy 10 CFR 71.35(c).

F8-2 The NRC staff has reviewed the description of the operating procedures and finds that the package will be prepared, loaded, transported, received, and unloaded in a manner consistent with its design and evaluation for approval.

F8-3 The NRC staff has reviewed the description of the special instructions (if applicable) needed to safely open a package and concludes that the procedures for providing the special instruction to the consignee are in accordance with the requirements of 10 CFR 71.89.

Based on review of the statements and representations in the application, the NRC staff finds that the operating procedures have been adequately described and meet the requirements of 10 CFR Part 71.

9.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

SAR chapter 9 identifies the inspections, acceptance tests and maintenance programs to be conducted on the Model No. Volunteer package and verifies their compliance with the requirements of 10 CFR Part 71.

9.1 Acceptance Tests

Tests in chapter 9 cover critical aspects like:

- Visual Inspections and Measurements: Verifying dimensions and assembly.
- Weld Examinations: Ensuring the integrity of structural welds.
- Hydrostatic Pressure Testing: Confirming the containment system's pressure boundary.
- Fabrication Leakage Rate Testing: to demonstrate that the containment boundary, as fabricated, provides leaktight containment
- Shielding Tests (Gamma Scan): Validating the effectiveness of the gamma shielding.
- Thermal Tests (Bubble Test): Checking the integrity of the thermal shield.

9.2 Maintenance Program

Chapter 9 includes provisions for:

- Periodic Leakage Rate Tests: Replacing seals and conducting tests at specified intervals.
- Pre-shipment Leakage Rate Tests: Ensuring containment integrity before each shipment (for configurations using elastomeric O-rings).
- Component and Material Tests: Regular inspections of sealing surfaces, threaded fasteners, and exposed packaging surfaces.
- Thermal Test: Periodic re-testing of the thermal shield.

9.3 Evaluation Findings

F9-1 The staff has reviewed the identification of the codes, standards, and provisions of the quality assurance (QA) program applicable to the package design and finds that they meet the requirements specified in 10 CFR 71.31(c) and 10 CFR 71.37(b).

F9-2 The staff has reviewed the description of the preliminary determinations for the package before first use and finds that it meets the requirements of 10 CFR 71.85 and 10 CFR 71.87(g).

F9-3 The staff has reviewed the identification of the codes, standards, and provisions of the QA program applicable to maintenance of the packaging and finds that it meets the requirements specified in 10 CFR 71.31(c) and 10 CFR 71.37(b).

F9-4 The staff has reviewed the description of the routine determinations for package use preceding transport and finds that they meet the requirements of 10 CFR 71.87(b) and 10 CFR 71.87(g).

Based on review of the statements and representations in the application, the NRC staff finds that the acceptance tests and maintenance program have been adequately described and meet the requirements of 10 CFR Part 71.

CONDITIONS

In addition to the package description, drawings and contents, the following conditions were included in the CoC:

Condition 6 states that in addition to the requirements of Subpart G of 10 CFR Part 71, the Volunteer package shall:

(a) Be prepared for shipment and operated in accordance with the Operating Procedures in chapter 8, and

(b) Be tested and maintained in accordance with the Acceptance Tests and Maintenance Program in chapter 9 of the application.

Condition 7 states additional operating requirements that include:

(a) Transport by air is not authorized.

(b) The package is transported in an exclusive-use conveyance only.

Condition 8 states that that package must be marked with Package Identification Number USA/9403/B(M)-96 for shipments of TPBAR contents.

Condition 9 states that the package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.

Condition 10 states that the packages expiration date is April 30, 2030.

CONCLUSION

Based on our review, the statements and representations contained in the application, as supplemented, and the conditions listed above, we conclude that the Model No. Volunteer package meets the requirements of 10 CFR Part 71 and has been renewed for a 5-year term.

Issued with Certificate of Compliance No. 9403, Revision No. 0.