

**CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES**

1.	a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE	PAGES
	9377	0	71-9377	USA/9377/B(U)F-96	1 OF	4

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

- | | |
|---|---|
| a. ISSUED TO (Name and Address)
TN Americas LLC
7160 Riverwood Drive, Suite 200
Columbia, MD 21046 | b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION
TN-32 Transportation Cask Safety Analysis Report,
dated June 2024. |
|---|---|

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.: TN-32B

(2) Description:

The TN-32B packaging consists of a spent fuel basket assembly, a containment vessel, a forged steel shell body, a radial neutron shielding, and impact limiters.

Basket

The spent fuel basket consists of a honeycomb-like structure of stainless-steel cells, housing 32 fuel assemblies, separated by aluminum and poison plates that form a sandwich panel. The aluminum plates provide heat conduction paths from the spent fuel assemblies to the cask cavity wall. The poison material provides the necessary criticality control. The opening of the cells is 8.7 in. x 8.7 in., leaving a minimum of 1/8 in. clearance around the fuel assemblies. The overall basket length (160.0 in.) is less than the cask cavity length to allow for thermal expansion and fuel assembly handling.

Containment Vessel

The containment vessel consists of the inner shell and bottom inner plate, shell flange, closure lid outer plate, closure lid bolts, penetration cover plates and bolts, thermocouple lance assemblies and their seals, inner metallic seals of the lid, vent and drain seals. The containment vessel, which maintains an inert atmosphere (helium) in the cask cavity, is 171 inches long, with a wall thickness of 1.5 inch. The

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5. (a)(2) Description (Continued)

cylindrical cask cavity has an inner diameter of 68.8 inches and a length of 163.4 inches. The closure lid outer plate is 4.5 inches thick and is secured to the body by 48 high-strength closure lid bolts.

Body

The packaging body, i.e., a forged steel gamma shield shell, is around the inner shell and the bottom inner plate of the containment vessel. The 8.00 in. thick gamma shield shell and the 8.75 in. thick bottom plate completely surround the containment vessel shell and bottom plate, respectively. A 6.0 in. thick shield plate is also welded to the inside of the 4.5 in. thick lid outer plate, and 2.13 in. thick lance cover plates are placed over the thermocouple lances and welded to the closure lid outer plate.

The radial neutron shielding is enclosed within the welded steel outer shell. Radial neutron shielding is provided by a borated polyester resin compound surrounding the gamma shield shell. The total radial thickness of the resin and aluminum is 4.5 in.

Impact Limiters

The impact limiters, consisting of balsa wood and redwood blocks encased in stainless steel plates, have an outside diameter of 144 in. and an inside diameter of 89 in. The impact limiters, attached to each other using tie-rods, are also attached to the outer shell of the package with bolts. A puncture-resistant steel plate is placed on the cask lid and bolted to the package body prior to mounting the top impact limiter, to provide a smooth contact surface between the closure lid and the top impact limiter, and to protect the thermocouple lance assemblies from puncture.

A transport frame, which is not part of the packaging, is used for tie-down purposes.

The TN-32B package is 263.2 inches long and has a diameter of 144 in. with the impact limiters installed. The package body is 184.3 in. long (with the closure lid installed), and 87.75 in. in diameter. The closure lid is 79.50 in. in diameter. The cask outside diameter including the radial neutron shield is 98.14 in. The cask cavity is 163.38 in. long and 68.80 in in diameter. The total gross weight of the package is 269,000 lb.

5. (a)(3) Drawings

The packaging is fabricated and assembled in accordance with ORANO TN Drawing Nos.:

19885-71-1, Rev. 0	General Arrangement Assembly
19885-71-2, Rev. 0	General Assembly
19885-71-3, Rev. 0	Lid Assembly and Parts List
19885-71-4, Rev. 0	Puncture resistant Plate Assembly

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5. (a)(3) Drawings (continued)

19885-71-5, Rev. 0	Trunnion Details
19885-71-6, Rev. 0	Basket Assembly and Parts List
19885-71-7, Rev. 0	Thermocouple Lance Assembly, Lance Cover Plate
19885-71-8, Rev. 0	General Assembly Impact Limiters
19885-71-9, Rev. 0	Bottom Impact Limiter Assembly
19885-71-10, Rev. 0	Top Impact Limiter Assembly

5. (b) Contents

(1) Type and form of material

(a) Only intact fuel assemblies limited to the following fuel types, with specifications listed in Table 1-2 of the application:

- i. One (1) Westinghouse LOPAR 17×17 fuel assembly with Zirc-4 cladding
- ii. Twelve (12) Westinghouse NAIF 17×17 assemblies with ZIRLO™ cladding
- iii. One (1) Westinghouse NAIF 17x17 assembly with Low SN Zr-4 cladding
- iv. Eighteen (18) AREVA Advanced MK-BW 17×17 assembly with M5™ cladding

(b) Fuel assembly locations and poison rod assembly (PRA) locations shall be as provided in Figure 6-1 of the application.

(c) The maximum combined weight of a fuel assembly and a PRA shall not exceed 1,551 lb.

(d) The maximum initial enrichment of any fuel assembly is 4.55 wt.% ²³⁵U.

(e) The burnup for each assembly is greater than 50,000 MWd/MTU with the fuel burnup data for all 32 fuel assemblies being as provided in Table 1-3 of the application.

(f). The post-irradiation minimum cooling time is 11.6 years and the maximum total decay heat load shall be 25.84 kW, with a maximum of 0.878 kW for any fuel assembly.

(2) Maximum quantity of material per package

32 PWR assemblies as described in 5.b(1) with a combined weight (fuel assemblies and PRAs) not exceeding 50,000 lb.

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5.(c) Criticality Safety Index: 0.0

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

- (a) The package must be prepared for shipment and operated in accordance with the "Operating Procedures" in Chapter 7 of the application, as supplemented.
- (b) Each packaging must be acceptance tested and maintained in accordance with the "Acceptance Tests and Maintenance Program" in Chapter 8 of the application, as supplemented.

7. Transport by air is not authorized.

8. The personnel barrier shall be installed at all times during transport to meet package surface temperature and/or package dose rates requirements.

9. The package shall be transported under exclusive-use.

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

11. Expiration date: July 31, 2029.

REFERENCES

TN Americas LLC, application "TN-32 Transportation Cask Safety Analysis Report" dated June 2024.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

**YOIRA DIAZ-
SANABRIA**

Digitally signed by YOIRA DIAZ-
SANABRIA
Date: 2024.07.02 15:54:08 -04'00'

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

Date: July 2, 2024



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

**SAFETY EVALUATION REPORT
Docket No. 71-9377
Model No. TN-32B Package
Certificate of Compliance No. 9377
Revision No. 0**

SUMMARY

By letter dated August 19, 2021 (Agencywide Documents Access and Management System Package Accession No. ML21231A189, non-public, ML21231A190), TN Americas LLC submitted an application for approval of the Model No. TN-32B package. The application is for a one-time transportation of the DOE-EPRI High Burnup (HBU) Demonstration Project Cask.

The staff accepted the application for a detailed technical review on October 21, 2021 (ML21291A263). On August 19, 2022, the applicant provided partial responses (ML22231B144, non-public), i.e., structural request for additional information (RAI) responses were not included, to staff's RAI dated May 22, 2022. On June 14, 2023, the applicant provided the structural RAI responses.

On November 14, 2023, the applicant provided supplemental information that was requested by staff (ML23318A179) after the review of the RAI responses and the applicant finalized its supplemental responses by letter dated December 5, 2023 (ML23339A062, ML23339A063, non-public, and ML23339A064, non-public). On June 4, 2024, the applicant provided its response to staff's second request for additional information (ML24156A145, non-public) and then resubmitted on June 21, 2024, the public portion of the responses due to a missing enclosure.

TN provided a consolidated application on June 24, 2024: this June safety analysis report (SAR) is referenced in the certificate of compliance (CoC) (ML24176A172, non-public, and ML24176A173, non-public).

The TN-32B cask (loaded with 32 pressurized-water reactor [PWR] high burn up spent fuel assemblies, with four different cladding types, and placed in storage in November 2017 under CoC No. 72-1021) was used to collect confirmatory data on the conditions of high burn up fuel in dry storage. As such, it includes additional penetrations in the cask lid for installed thermocouple lances; the thermocouple lances are maintained in place within the cask during shipment, in order to utilize that instrumentation for further evaluation of the temperatures of the fuel assemblies after transport. In addition, the applicant has designated that the thermocouple lances themselves are part of the containment boundary.

Also, the application does not follow the U.S. Nuclear Regulatory Commission (NRC) guidance in Regulatory Guide (RG) 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material" by taking credit for the heat inside the cask to warm the lid bolts, so that the "effective" lowest service temperature of the bolts is 136 degrees Fahrenheit (°F) (rather than the conventional practice of assuming the bolts will be at the lowest ambient temperature). Because of the known decay heat of the single payload, the lowest temperature of the cask lid

bolts will never reach the regulatory steady-state of -40°F or -20°F ambient temperature for an assumed zero decay heat load. As such, the bolts currently installed and used for storage will be left in place for transportation. The staff confirmed that the thermal model contains sufficient conservatism to justify that the margin cited by the applicant is reasonable. The staff concluded that there is significant margin between the tested temperature and the calculated bolt material temperature to provide a reasonable basis for acceptability for this single duration trip. In addition, the single trip use limits the potential instances where the material could be exposed to cold conditions.

The applicant developed an LS-DYNA model to analyze the performance of the impact limiters under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) and provided the clarifications and/or justifications requested by the staff on (i) the impact limiter shell thicknesses used in the LS-DYNA models, (ii) the occurrence of negative effective plastic strain in the LS-DYNA models, (iii) the use of element erosion for impact limiter materials in the LS-DYNA models, and (iv) the tighter range of wood properties in the one-third scale impact limiter tests (upon which the TN-32B drop simulations are benchmarked).

The impact limiters are secured on the TN-32B package using bolts (which attach the impact limiters to the cask itself) and tie-rods (which connect the impact limiters together). Both bolts and tie-rods are categorized as components that are not subjected to any criteria specified in the American Society of Mechanical Engineers (ASME) boiler and pressure vessel (BPVC) code). The TN-40 scaled drop tests show that there is no tie-rod failure: the impact limiters remained attached to the test unit during the drop tests of the storage cask.

The package was evaluated against the regulatory standards in 10 CFR Part 71, including the general standards for all packages and the performance standards specific to fissile material packages under NCT and HAC. The analyses performed by the applicant demonstrate that the package provides adequate structural and thermal protection to meet the containment, shielding, and criticality requirements after being subject to the tests for NCT and HAC.

Based on the statements and representations in the application, and the conditions listed in the CoC, the NRC staff (the staff) concludes that the package meets the requirements of 10 CFR Part 71.

EVALUATION

1.0 GENERAL INFORMATION

The TN-32B packaging consists of a spent fuel basket assembly, a containment vessel, a forged steel shell body, a radial neutron shielding, and impact limiters. The spent fuel basket consists of a honeycomb-like structure of stainless-steel cells, housing 32 fuel assemblies, separated by aluminum and poison plates that form a sandwich panel. The aluminum plates provide heat conduction paths from the spent fuel assemblies to the cask cavity wall. The poison material provides the necessary criticality control. The opening of the cells is 8.7 inches (in.) x 8.7 in., leaving a minimum of 1/8 in. clearance around the fuel assemblies. The overall basket length (160.0 in.) is less than the cask cavity length to allow for thermal expansion and fuel assembly handling.

The containment vessel consists of the inner shell and bottom inner plate, shell flange, closure lid outer plate, closure lid bolts, penetration cover plates and bolts, thermocouple lance

assemblies and their seals, inner metallic seals of the lid, vent and drain seals. The containment vessel, which maintains an inert atmosphere (helium) in the cask cavity, is 171 in. long, with a wall thickness of 1.5 in. The cylindrical cask cavity has an inner diameter of 68.8 in. and a length of 163.4 in. The closure lid outer plate is 4.5 in. thick and is secured to the body by 48 high-strength closure lid bolts.

The packaging body, i.e., a forged steel gamma shield shell, is around the inner shell and the bottom inner plate of the containment vessel. The 8.00 in. thick gamma shield shell and the 8.75 in. thick bottom plate completely surround the containment vessel shell and bottom plate, respectively. A 6.0 in. thick shield plate is also welded to the inside of the 4.5 in. thick lid outer plate, and 2.13 in. thick lance cover plates are placed over the thermocouple lances and welded to the closure lid outer plate.

The radial neutron shielding is enclosed within the welded steel outer shell. Radial neutron shielding is provided by a borated polyester resin compound surrounding the gamma shield shell. The total radial thickness of the resin and aluminum is 4.5 in.

The impact limiters, consisting of balsa wood and redwood blocks encased in stainless steel plates, have an outside diameter of 144 in. and an inside diameter of 89 in. The impact limiters, attached to each other using tie-rods, are also attached to the outer shell of the package with bolts. A puncture-resistant steel plate is placed on the cask lid and bolted to the package body prior to mounting the top impact limiter, to provide a smooth contact surface between the closure lid and the top impact limiter, and to protect the thermocouple lance assemblies from puncture.

A transport frame, which is not part of the packaging, is used for tie-down purposes.

The TN-32B package is 263.2 in. long and has a diameter of 144 in. with the impact limiters installed. The package body is 184.3 in. long (with the closure lid installed), and 87.75 in. in diameter. The closure lid is 79.50 in. in diameter. The cask outside diameter including the radial neutron shield is 98.14 in. The cask cavity is 163.38 in. long and 68.80 in. in diameter. The total gross weight of the package is 269,000 pounds (lb).

The packaging is fabricated and assembled in accordance with ORANO TN Drawing Nos.:

19885-71-1, Rev. 0	General Arrangement Assembly
19885-71-2, Rev. 0	General Assembly
19885-71-3, Rev. 0	Lid Assembly and Parts List
19885-71-4, Rev. 0	Puncture resistant Plate Assembly
19885-71-5, Rev. 0	Trunnion Details
19885-71-6, Rev. 0	Basket Assembly and Parts List
19885-71-7, Rev. 0	Thermocouple Lance Assembly, Lance Cover Plate
19885-71-8, Rev. 0	General Assembly Impact Limiters
19885-71-9, Rev. 0	Bottom Impact Limiter Assembly
19885-71-10, Rev. 0	Top Impact Limiter Assembly

The package is allowed to transport only the following 32 intact fuel assemblies with specifications listed in Table 1-2 of the application:

- i. One (1) Westinghouse LOPAR 17×17 fuel assembly with Zirc-4 cladding.
- ii. Twelve (12) Westinghouse NAIF 17×17 assemblies with ZIRLO™ cladding.
- iii. One (1) Westinghouse NAIF 17x17 assembly with Low SN Zr-4 cladding.
- iv. Eighteen (18) AREVA Advanced MK-BW 17×17 assembly with M5™ cladding.

The maximum combined weight of a fuel assembly and a poison rod assembly (PRA) shall not exceed 1,551 lb. with their total combined weight (fuel assemblies and PRAs) not exceeding 50,000 lb.

The maximum initial enrichment of any fuel assembly is 4.55 weight percent (wt.%) ²³⁵U. The burnup for each assembly is greater than 50,000 MWd/MTU with the fuel burnup data for all 32 fuel assemblies being as provided in Table 1-3 of the application. The post-irradiation minimum cooling time is 11.6 years and the maximum total decay heat load shall be 25.84 kW, with a maximum of 0.878 kW for any fuel assembly.

2.0 STRUCTURAL AND MATERIALS EVALUATION

2.1 STRUCTURAL EVALUATION

2.1.1 Descriptions of Structural Design

The applicant provided the descriptions of the TN-32B package in section 1.2, “Package Description,” of the SAR. The TN-32B package consists primarily of the containment vessel, fuel basket and impact limiters. The dimensions, materials and tolerances of the components are provided in the licensing drawings in section 1.4.1, “General Arrangement Drawings,” of the SAR. Table 1-1 of the SAR tabulates overall dimensions and weights of the TN-32B cask and Table 1-2 of the SAR presents the nominal design dimensions and specifications for the fuels.

Containment Vessel: The containment vessel within the cask body is comprised of the inner shell, bottom inner plate, shell flange, lid outer plate, lid bolts, cover plates for the vent, drain and thermocouple lance assemblies (TLAs), and seals for the lids, cover plates and TLAs. The containment vessel prevents potential leakage of radioactive material from the cask cavity. The overall containment vessel length is 171.0 in. with a wall thickness of 1.5 in. The containment vessel is designed, fabricated, examined, and tested in accordance with the requirements of Subsection NB of the ASME Boiler and Pressure Vessel (B&PV) Code.

Surrounding the containment vessel is the shield shell which provides both neutron and gamma shielding and is made of aluminum, resin, and steel. The gamma shield is provided around the inner shell and inner bottom plate of the containment vessel by an independent carbon steel shell. The neutron shield is comprised of resin contained in aluminum alloy tubes.

Fuel Basket: The fuel basket is an assembly from several plates. Its main function is to transfer heat while providing neutron absorption to maintain criticality requirements. The basket structure is mainly comprised of stainless-steel boxes (cells) joined by fusion welded stainless-steel plugs and separated by aluminum and neutron poison material (borated aluminum sheets). The aluminum plate and borated aluminum (poison) plate are sandwiched between the

stainless-steel walls of the adjacent boxes. The aluminum plate provides the heat conduction paths from the fuel assemblies to the cask cavity wall, while the poison material provides the necessary criticality control. The overall basket length is 160.0 in., which is less than the cask cavity length to allow for thermal expansion. The basket structure is designed, fabricated, and inspected in accordance with the ASME B&PV Code, Section III, Subsection NB/NF.

Impact Limiters: The impact limiters consist of thin stainless-steel shells that encase balsa and redwood, which are attached to the cask body. They are designed to fit over the trunnions and are connected with 13 tie-rods to keep the impact limiters attached to the cask. Each impact limiter has fusible plugs that melt and relieve excessive internal pressure during the thermal test. The impact limiters have an outside diameter of 144 in., and an inside diameter of 89 in. to accommodate the cask ends.

A general arrangement of the TN-32B cask is shown in Figure 1-1 of the SAR. Centers of gravity of the components such as the cask body, fuel basket, and impact limiters are provided in Table 2-7 of the SAR. The gross weight of the TN-32B cask is 269 kips.

The staff reviewed the structural design descriptions of the package and determined that the contents of the application satisfy the requirements of 10 CFR 71.31(a)(1)(c), 10 CFR 71.31(a)(2), 10 CFR 71.33(a), and 10 CFR 71.33(b).

Identification of Codes and Standards for Package Design

The applicant used the ASME B&PV Code (Reference 3) to design and fabricate most components of the TN-32B package. Specifically, the components of the cask containment vessel (i.e., inner shell, flange, bottom inner plate, lid, lid bolts, lid seals, drain and vent port cover plates, cover plate seals, and bolts) are designed in accordance with the ASME B&PV Code, Section III, Subsection NB. Additionally, the components are designed to meet the requirements of RG 7.6 (Reference 4) and RG 7.8 (Reference 5). Alternatives to the ASME Code are listed in appendix 2.12.13 of the SAR.

In addition, structures such as the shield shell and neutron shield are designed and fabricated according to the ASME Code, Subsection NF, while welding follows Section IX of the ASME Code. The basket is designed according to the ASME Code, Subsection NB/NF. The staff reviewed the codes and standards used for the package design and found them acceptable.

The staff determined that the package satisfies the regulatory requirements of 10 CFR 71.31(c).

2.1.2 General Requirements for all packages

Minimum Package Size

The applicant stated that the overall package dimensions are 263.2 in. in length and 144.0 in. in diameter, which exceed the minimum dimension requirement of 4 in. specified in 10 CFR 71.43(a).

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(a).

Tamper-Indicating Feature

The staff reviewed the package descriptions and confirmed that the only access path into the package is through the closure lid and associated lid closure bolts, which are completely covered. The path is prevented by the presence of the front impact limiter during transport. In addition, a wire security seal is installed in the front impact limiter. The presence of this seal indicates that unauthorized opening of the package has not occurred. This tamper-indication feature meets the requirements of 10 CFR 71.43 (b).

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(b).

Positive Closure

The staff reviewed the package closure descriptions and found that the positive closure of all openings through the containment vessel is accomplished by bolted closures.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(c).

Package Valve

10 CFR 71.43(e) requires that a package valve must be protected against unauthorized operation. The staff reviewed the package descriptions and found that the TN-32B package does not have any valves or other devices whose failure would allow for the escape of radioactive material.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.43(e).

2.1.3 Lifting and Tie-Down Standards

Lifting Devices

The applicant described lifting and handling of the package in sections 1.2.1.4 and 2.5.1 of the SAR. The package has two upper trunnions and two lower trunnions which are welded to the cask body. The lower trunnions are used to upend and rotate the cask while the upper trunnions are used for lifting. The trunnions are designed to a factor of safety (FS) of 6 when compared to yield stress and a FS of 10 when compared to ultimate stress, which are larger than the FS of 3 against yielding as per the regulations of 10 CFR 71.45. The applicant calculated stresses in the trunnions for shear and bending and found them to be less than the allowable stress of the material. The results of the calculations show that the minimum margins of safety (MS) for the yield stress condition are 0.07 and 0.21 for the upper trunnion and lower trunnion, respectively, while the MS for the ultimate stress condition are 0.45 and 0.68 for the upper trunnion and lower trunnion, respectively. The staff reviewed the calculations and found that all of the calculated stresses in both upper and lower trunnions are acceptable for lifting.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 10 CFR 71.45(a).

Tie-Down Devices

The applicant described tie-down devices of the package in sections 1.2.1.4 and 2.5.2 of the SAR. The applicant stated that the longitudinal forces experienced by the transport package are resisted by steel end restraints that react against the impact limiters. The vertical and lateral forces that act on the transport package are restrained by a dual saddle/strap tie-down system. The tie-down straps resist uplifting and lateral overturning forces whereas the saddles react to downward and strap reaction forces. The applicant analyzed the loading condition (Load Step IL-9, cask supported horizontally by skid with 1g down gravity load) in appendix 2.12.2 of the SAR. The stress results from the tie-down load are presented in Table 2.12.2-2 of the SAR. The calculated stresses are less than the lowest yield strength of 30.0 ksi. The staff reviewed the applicant's calculations and concluded that the design of the tie-down system for the package is in compliance with the requirements of 10 CFR 71.45(b).

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.45(b).

2.1.4 General Information for Structural Evaluation

The applicant performed evaluations for the TN-32B package for both NCT and HAC using the finite element (FE) method with the computational modeling programs (ANSYS and LS-DYNA). Physical testing was not done on the TN-32B package. However, the applicant made several comparisons to the licensed TN-40 package to validate computational models of the TN-32B package, where the licensed TN-40 package was previously evaluated by physical model testing and the FE method using the ANSYS and LS-DYNA computer programs (Reference 6).

ANSYS Models

The applicant generated multiple separate FE models to evaluate the structural performance of different components of the TN-32B package. The applicant created an ANSYS FE model consisting of a three-dimensional (3-D) full sector model with appropriate boundaries based on the licensing drawings and used the model for the structural analyses of the TN-32B cask. The model contained the structural components (i.e., lid shield plate, outer plate, shell flange, inner shell, bottom inner plate, shield shell, and the bottom shield). The ANSYS elements (beam, shell, and solid) were used to define the solid bodies of the cask body and components. Contact between components was represented by contact elements. The contact was modeled between surfaces of the closure lid outer plate and shield plate, and between the closure lid plate and shell flange. The contact was also defined between the inner shell and the gamma shield shell cylinder. Bonded contact was defined for the vessel bottom to the shield bottom interface. Temperature distributions from the thermal evaluations in chapter 3 of the SAR were mapped into a structural model node configuration. Buckling analyses were performed assuming a non-linear elastic plastic behavior.

Closure lid bolts were modeled utilizing the beam elements with pre-tension elements that enable accurate modeling of the bolt preload. Welded connections were represented by nodal couplings. Figures 2.12.2-1 and 2.12.2-2 of the SAR present the geometry of the ANSYS model and mesh, and Table 2.12.2-1 lists the major bounding dimensions of the model.

The applicant also created 3-D ANSYS FE models for the fuel basket analyses under NCT and HAC. The NCT model utilized the shell elements for the stainless-steel fuel boxes. For conservatism, the strength of the aluminum and the borated aluminum plates in the basket were

neglected by excluding these from the FE model, but their weights were accounted for by increasing the stainless-steel box material densities. The solid model used in the lateral load evaluation is shown in Figure 2.12.6-3 of the SAR.

The applicant also created a 3-D ANSYS FE model for the fuel basket compartments, aluminum plates, and aluminum rails for HAC. The compartment box walls and peripheral support plates were meshed with the shell (SHELL43, 4-node large strain plastic shell) element and the plugs were meshed with the beam (BEAM188, 3-D linear finite strain beam) elements in the HAC model. Aluminum rails were bolted to the containment shell. Since the bolts are not structural members and their purpose is to secure the rails during fuel loading and fabrication, the bolts were represented by springs. The model, which includes the fuel compartments, aluminum plates, aluminum rails, and fusion welds, was utilized for the lateral load evaluation, and is shown in Figures 2.12.6-5 and 2.12.6-6 of the SAR.

In addition, the applicant analyzed the performance of the fuel rods for side drop using an ANSYS FE model. A single fuel rod was modeled using the pipe (PIPE16) element where the fuel weight was incorporated by adjusting the density of the cladding and was modeled as being constrained laterally at grid spacers. The geometry and model data used in the ANSYS FE model are summarized in Table 2.12.8-1 and Figure 2.12.8-1 of the SAR.

The staff reviewed the model descriptions and found that the ANSYS models are adequately developed to analyze the performance of the TN-32B package under NCT and HAC and concluded that the ANSYS models are acceptable.

LS-DYNA Models

The applicant evaluated structural performance of the fuel cladding for an end drop using the LS-DYNA FE model. The staff reviewed the applicant's LS-DYNA model for a single fuel rod and found that the model is adequately developed to analyze the performance of the fuel cladding under the accident conditions. The LS-DYNA model for end impact of a fuel rod is described with details in appendix 2.12.8 of the SAR. The LS-DYNA model followed the technical approach and methodology described in NUREG-1864 and Reference 7. Additionally, the SAR described a validation of the applicant's LS-DYNA modeling approach by repeating the case results described in NUREG-1864 and Reference 7 for a Babcock & Wilcox 15x15 fuel assembly.

The staff also reviewed the applicant's LS-DYNA model developed to analyze the performance of the impact limiters under NCT and HAC. The LS-DYNA model for the impact limiter analysis is described in appendix 2.12.9 of the SAR. The staff reviewed the model descriptions and analysis in appendix 2.12.9. In addition, the staff also performed a confirmatory analysis for the impact limiters using the applicant's LS-DYNA input files submitted with the application. From the staff's confirmatory analysis, the staff found information that required additional information from the applicant for clarifications or justifications on the applicant's LS-DYNA modeling assumptions, criteria, and analysis. As a result, the staff issued two requests for additional information (RAIs) (References 8 and 9) as following:

- (i) Justify and/or correct the impact limiter shell thicknesses used in the LS-DYNA models,
- (ii) Clarify the balsa material properties used in the LS-DYNA models,
- (iii) Justify and/or correct the occurrence of negative effective plastic strain in the LS-DYNA models,

- (iv) Clarify the tie-rod connection used in the LS-DYNA models,
- (v) Justify the use of element erosion for impact limiter materials in the LS-DYNA models,
- (vi) Justify and/or correct the contact element behavior between impact limiter materials in the LSDYNA models,
- (vii) Explain or correct the discrepancy between the allowable density and moisture content of redwood in the SAR and the tighter range of wood properties in the one-third scale impact limiter tests (upon which the TN-32B drop simulations are benchmarked),
- (viii) Justify the property changes made to the wood materials in the LS-DYNA package models, and
- (ix) Justify the change of allowable for the impact limiter tie-rods.

The applicant submitted responses to the RAIs with clarifications, justifications, corrective actions, and results of the applicant's re-analysis for the impact limiters. Additionally, the applicant also submitted a revised SAR (Revs. 0b, 0c and 0d) based on its RAI responses (References 10, 11 and 12). The staff reviewed the RAI responses and the LS-DYNA model analysis provided in the revised SAR (Revs. 0b through 0d) and found them acceptable. The applicant resolved all technical issues raised by the staff as delineated above, therefore the staff concluded that applicant's LS-DNA models are adequately developed to analyze the performance of the TN-32B package under NCT and HAC.

Conclusion

The staff reviewed the model descriptions and technical information provided in the RAI responses, revised TN-32B SAR, and associated appendices for package modeling and analyses. The staff concluded that the ANSYS and LS-DYNA models are adequately developed to analyze the TN-32B package under NCT and HAC.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.41(a).

2.1.5 Normal Conditions of Transport

The applicant evaluated the TN-32B package for NCT heat, cold, reduced external pressure, increased external pressure, vibration and fatigue, water spray, free drop, corner drop, compression, and penetration as required by 10 CFR 71.71.

Heat

10 CFR 71.71(c)(1) requires that the package be subjected to an ambient temperature of 100°F in still air and insolation.

The applicant performed thermal analyses for the TN-32B package and presented the evaluation findings in chapter 3, "Thermal Evaluation," of the SAR. The staff's detailed safety evaluations on the applicant's thermal analyses are provided in section 3.0, "THERMAL EVALUATIONS," of this SER. The applicant stated that the thermal analyses performed for the TN-32B package were subjected to hot environment conditions (maximum decay heat load of 25.84 kW, ambient temperature of 100°F in still air, and maximum insolation) and the results of the thermal analyses were used to support various aspects of the structural evaluations. The

calculated maximum temperatures for the package components are provided in Tables 3-1 and 3-2 of chapter 3 of the SAR for NCT and HAC, respectively.

The applicant applied the calculated temperatures to the ANSYS FE model as described in appendix 2.12.2 of the SAR. Table 2.12.2-2 of the SAR provides a summary of the calculated load combination stresses for the structural components under NCT. In addition, Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that the heat requirements for the package are met and the components of the TN-32B package are safe and operational.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(1).

Cold

10 CFR 71.71(c)(2) requires that the package be subjected to an ambient temperature of -40°F in still air and shade.

The applicant performed thermal analyses for the TN-32B package subjected to cold environment conditions (ambient temperature -40°F). Temperatures from the thermal analyses of Chapter 3 of the SAR were applied to the ANSYS FE model for the calculation of thermal stresses. Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that the cold requirements for the package are met and the components of the TN-32B package are safe and operational.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(2).

Reduced External Pressure

10 CFR 71.71(c)(3) requires that the package be subjected to a reduced external pressure of 3.5 pounds per square in. absolute (psia).

The applicant evaluated the TN-32B package subjected to a reduced external pressure of 3.5 psia. The ANSYS FE model was used to calculate the stresses of the components and the evaluations are documented in appendix 2.12.2 of the SAR. Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that the reduced pressure as specified in 10 CFR 71.71(c)(3) will not affect the performance of the TN-32B package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(3).

Increased External Pressure

10 CFR 71.71(c)(4) requires that the package be subjected to an external pressure of 20 psia.

The applicant evaluated the package with an external pressure of 20 psia using the ANSYS FE model. The evaluations are documented in appendix 2.12.2 of the SAR. Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that an external pressure of 20 psia will not affect the performance of the TN-32B package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(4).

Vibration and Fatigue

10 CFR 71.71(c)(5) requires that the package be subjected to a vibration normally incident to transport.

The applicant performed vibration and fatigue analyses for the TN-32B package based on the study of the vibration and shock effects in NUREG-766510 (Reference 13). The stresses due to the transport rail car vibration are presented in Table 2.12.2-2 of the SAR. Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that vibration load during a transit will not affect the performance of the TN-32B package.

The applicant also calculated fatigue cycles on the containment boundary from a combination of various events (operating preload, lifting, railcar vibration, rail car shock, test pressure, lifting, temperature, and 1-foot (ft) drop). The cumulative damage factor, n/N (actual cycles/allowable cycles), was calculated for each event and provided the calculated damage factors in section 2.6.12, "Fatigue Analysis of the Containment Boundary," of the SAR. The total cumulative damage factor was found to be 0.097, which is less than 1.0, which indicates that fatigue will not damage the containment boundary of the TN-32B package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(5).

Water Spray

10 CFR 71.71(c)(6) requires that the package must be subjected to a water spray test that simulates exposure to rainfall of approximately 2 in./h for at least 1 hour.

The applicant stated that all exterior surfaces of the TN-32B cask body are metal and, therefore, not subject to soaking or structural degradation from water absorption. The staff reviewed the statement and agreed that the water spray will not impair the package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(6).

Free Drop

10 CFR 71.71(c)(7) requires that the package must be subjected to a free drop through the distance specified in 10 CFR 71.71(c)(7) onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

The applicant performed two 1-ft. drop (end drop and side drop) analyses. The LS-DYNA FE model was used to calculate the stresses of the components and the evaluations are documented in appendix 2.12.9 and Table 2-12 of the SAR. Tables 12-14 through 12-18 of the SAR present a summary of the calculated stress intensity results with the allowable stresses of the components and calculated FS for the NCT load combinations. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that the free drop of the package through the distance specified in 10 CFR 71.71(c)(7) will not affect the performance of the TN-32B package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(7).

Corner Drop

10 CFR 71.71(c)(8) requires that the package must be subjected to a free drop onto each corner of the package in succession, or in the case of a cylindrical package onto each quarter of each rim, from a height of 1 foot (ft.) a flat, essentially unyielding, horizontal surface with a condition that this test applies only to fiberboard, wood, or fissile material rectangular packages not exceeding 110 lbs. and fiberboard, wood, or fissile material cylindrical packages not exceeding 220 lbs.

The applicant stated that the corner drop test does not apply since the TN-32B package has a mass in excess of 220 lb. As a result, 10 CFR 71.71(c)(8) is not applicable.

The staff determined that the regulatory requirements of 10 CFR 71.71(c)(8) are not applicable to the TN-32B package.

Compression

10 CFR 71.71(c)(9) requires that the package weighing up to 11,000 lb. must be subjected, for a period of 24 hours, to a compressive load applied uniformly to the top and bottom of the package in the position in which the package would normally be transported.

The applicant stated that the compression test does not apply since the TN-32B package has a mass of in excess of 11,000 lb. As a result, 10 CFR 71.71(c)(9) is not applicable.

The staff determined that the regulatory requirements of 10 CFR 71.71(c)(9) are not applicable to the TN-32B package.

Penetration

Title 10 CFR 71.71(c)(10) requires that impact of a hemispherical end of a vertical steel cylinder of 1.25 in. diameter and 13 lb. mass, dropped from a height of 40 in. onto the exposed surface of the package that is expected to be most vulnerable to puncture.

The applicant stated that due to lack of external protuberances, the 40 in. drop of a 13 lb. bar has a negligible effect on the TN-32B package. The staff agreed that the TN-32B package is not susceptible to the 13 lb. bar and concluded that the package meets the regulatory requirements of 10 CFR 71.71(c)(10).

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.71(c)(10).

2.1.6 Hypothetical Accident Conditions

The applicant evaluated the TN-32B package for HAC free drop, crush, puncture, thermal, and water immersion as required by 10 CFR 71.73. The applicant evaluated the load combinations per RG 7.8. The load combinations used for the HAC analyses are tabulated in Table 2.21 of the SAR. The stress intensity results of the components are provided in Tables 2.22 through 2.29.

In addition, appendices 2.12.6 and 2.12.8 contain additional details regarding the fuel basket and the fuel (fuel cladding), respectively, for HAC, while appendix 2.12.9 has additional details regarding the impact limiter for HAC.

Free Drop

The applicant analyzed four 30-ft. drops: (i) 90° end drop, (ii) 0° side drop, (iii) 20° slap-down drop, and (iv) center of gravity (CG) over corner drop. The bounding accelerations used for evaluations are provided in section 2.7.1, "30 Foot Free Drop," of the SAR. Appendices 2.12.3 and 2.12.9 document the calculated stresses in the lid bolts and impact limiters, respectively, while appendices 2.12.6 and 2.12.8 document the stress results for the basket and fuel cladding, respectively. Table 2-21 of the SAR provides a summary of load combinations for HAC and Tables 2-22 through 2-29 present the maximum nodal combined stress intensities of the components for the 30-ft. free drop for the HAC load combinations.

End Drop: From Table 2-22, the maximum stress intensity for the end drop is found to be 46.19 ksi. This stress occurs in the closure lid outer plate due to the end drop load combination, where the allowable stress is 65.0 ksi. The calculated FS is about 1.41, which indicates that the TN-32B package is adequately designed and is safe under the HAC end drop.

Side Drop/Slap-down Drop: The applicant utilized an envelope of side drop load and slap-down drop conditions. From Table 2-22, the maximum stress intensity is found to be 42.75 ksi. This stress occurs at the closure lid outer plate due to the side drop load combination, where the allowable is 65.0 ksi. The calculated FS is about 1.52, which indicates that the TN-32B package is adequately designed and is safe under the HAC side and slap-down drops.

Corner Drop: From Table 2-22, the maximum stress intensity for the CG over corner drop is found to be 43.84 ksi. This stress occurs in the closure lid outer plate due to the corner drop combination, where the allowable stress is 65.0 ksi. The calculated FS is about 1.48, which

indicates that the TN-32B package is adequately designed and is safe under the HAC corner drop.

The staff reviewed the applicant's structural analyses for the TN-32B package under the HAC free drop conditions. Based on a review of the applicant's analyses and modeling, the staff found that the HAC free drops will not result in any structural damage to the TN-32B cask, and that the containment function of the cask will be maintained.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(1).

Crush

The applicant stated that the crush test does not apply since the mass of the TN-32B package is in excess of 1,100 lb. As a result, 10 CFR 71.73(c)(2) is not applicable.

The staff determined that the regulatory requirements of 10 CFR 71.73(c)(2) are not applicable to the TN-32B package.

Puncture

The applicant evaluated the puncture drop in section 2.7.4, "Puncture," of the SAR. The applicant identified that one of the most challenging drops is a vertical drop onto the puncture bar on the side walls of the gamma shield shell. The applicant calculated bending and shear stresses of the shield shell under a puncture event and compared them with the allowable stresses. The minimum calculated FS is larger than 1.0, which indicates that the containment boundary of the TN-32B package will not be breached by the puncture. The staff reviewed the analyses and results, and agreed with the applicant's conclusion that there is no damage to the shield shell and that the containment boundary will be maintained under the puncture drop.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(3).

Thermal

The applicant performed thermal analyses of the TN-32B package and presented the evaluation findings in chapter 3, "Thermal Evaluation," of the SAR. The staff's detailed safety evaluations on the applicant's thermal analyses are provided in section 3.0, "THERMAL EVALUATIONS," of this SER.

The applicant described the thermal analyses of the TN-32B package subjected to thermal fire accident case in chapter 3 of the SAR and incorporated them into the structural analyses in appendix 2.12.2 of the SAR. The applicant took the maximum temperature of the containment boundary for HAC as described in chapter 3 of the SAR for the structural analyses. The applicant conservatively used an internal pressure of 100 pounds per square in. guage (psig) instead of the calculated pressure of 31.3 psig in the analyses.

Tables 2-22 through 2-29 of the SAR present the combined stress intensities in the closure lid, penetration sleeves, gamma shield shell, bottom shield plate, bottom inner plate, inner shell, top shield plate and flange. These tables provide the calculated FS above 1.0 when they are compared with the allowable stresses, which indicates that the thermal requirements for the

package are met and the components of the TN-32B package are safe under the HAC thermal conditions.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(4).

Immersion - Fissile Material

The applicant stated that the immersion test for fissile material requirements of 10 CFR 71.73(c)(5) is covered by the requirements of 10 CFR 71.73(c)(6) because the cask body stresses for this immersion condition with a head of water at 3 ft. (1.3 psi [pounds per square in.] external pressure) are bounded by the immersion condition for all packages (water head at least 50 ft., 21.7 psi external pressure). The staff agreed that the requirements of 10 CFR 71.73(c)(5) will be covered by the requirements of the 10 CFR 71.73(c)(6) for the TN-32B package.

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(5).

Immersion - All Packages

As required by 10 CFR 71.73(c)(6), a separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 50 ft. (21.7 psi).

The applicant performed a structural analysis for the immersion test using the ANSYS FE model. The applicant applied a pressure of 290 psi to the TN-32B package as described in appendix 2.12.2 of the SAR. The applied pressure of 290 psi is higher than the required pressure of 21.7 psi specified in 10 CFR 71.73(c)(6). The result of the calculation shows a calculated minimum FS above 1.0, which indicates that the immersion condition for all packages specified in 10 CFR 71.73(c)(6) will not affect the performance of the TN-32B package. The staff reviewed the applicant's evaluations for the immersion test and concluded that the TN-32B package meets the requirements of 10 CFR 71.73(c)(6).

The staff determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(6).

2.1.7 Air Transport Accident Conditions for Fissile Material

The applicant stated that this test does not apply to the TN-32B package since the package will not be transported by air.

The staff determined that the regulatory requirements of 10 CFR 71.55(f) are not applicable to the TN-32B package.

2.1.8 Special Requirements for Type B Packages Containing More than 10^5 A₂

As required by 10 CFR 71.61, a Type B package containing more than 10^5 A₂ must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi for a period of not less than 1 hour without collapse, buckling, or in-leakage of water.

The applicant stated that the TN-32B is a Type B package and contains more than 10^5 A₂ according to 10 CFR 71.61. The applicant performed a structural analysis using the ANSYS FE model. The applicant applied a pressure of 290 psi to the TN-32B package as described in section 2.7.7 and appendix 2.12.2 of the SAR. The result of the analysis shows that the calculated minimum FS is larger than 1.0, which indicates that an external pressure of 290 psi will not affect the performance of the TN-32B package.

The applicant also performed a buckling analysis for this event using an ANSYS FE model. The result of the analysis shows that the TN-32B cask will not buckle under 290 psi external pressure. In addition to the FE analysis, a buckling evaluation following the method of ASME Code Case N-284 was performed and is documented in appendix 2.12.11 of the SAR. This evaluation included the combination of fabrication induced compressive stresses with the compressive stress due to the external pressure of 290 psi. The result of the evaluation shows that the TN-32B design has significant margins of safety when the compressive load of 290 psi was considered.

The staff reviewed the structural evaluations and concluded that the TN-32B package meets the requirements of 10 CFR 71.61.

2.1.9 Air Transport of Plutonium

The applicant stated that the test does not apply to the TN-32B package since the package will not be transported by air.

The staff determined that the regulatory requirements of 10 CFR 71.64 and 71.74 are not applicable to the TN-32B package.

2.1.10 Conclusion for Safety Evaluation

The staff reviewed and evaluated the applicant's statements and representations in the application. Based on the review and evaluations, the staff concluded that the TN-32B transportation package is adequately described, analyzed, and evaluated to demonstrate that its structural capability and integrity meet the regulatory requirements of 10 CFR Part 71.

References

1. "TN Americas LLC Application for Approval of the TN-32 Transportation Package (Docket No. 71-9377)," Orano TN Letter (E-58750), August 19, 2021.
2. 10 CFR Part 71, "Packaging and Transportation of Radioactive Material."
3. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Facility Components," 1992 Edition.
4. U.S. Nuclear Regulatory Commission (NRC), Regulatory Guide 7.6, Revision 1, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," 1978.
5. U.S. NRC, Regulatory Guide 7.8, Revision 1, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," 1989.

6. Orano TN, "TN-40 Transportation Packaging – Safety Analysis Report," Revision 16. Docket No. 07109313.
7. Harold E. Adkins, Jr., Brian J. Koeppel and David T. Tang, "Spent Nuclear Fuel Structural Response when Subject to An End Impact Accident," PVP-Volume 483, Transportation Storage and Disposal of Radioactive Materials, July 25 through 29, 2004, San Diego, CA, USA.
8. U.S. NRC, Letter to Orano TN, "Request for Additional Information for the Review of the Model No. TN-32B Package," dated May 22, 2022.
9. U.S. NRC, Letter to Orano TN, "Second Request for Additional Information for the Review of the Model No. TN-32B Package," dated January 30, 2024.
10. "TN Americas LLC Application for Approval of the TN-32B Transportation Package (Docket No. 71-9377) – Response to Request for Additional Information," Orano TN Letter (E-60963), August 19, 2022.
11. "TN Americas LLC Application for Approval of the TN-32B Transportation Package (Docket No. 71-9377) – Response to Request for Additional Information," Orano TN Letter (E-62226), June 14, 2023.
12. "TN Americas LLC Application for Approval of the TN-32B Transportation Package (Docket No. 71-9377) – Response to Second Request for Additional Information," Orano TN Letter (E-63235), June 4, 2024.
13. U.S. NRC, NUREG 766510, "Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks," 1977.

2.2 MATERIALS EVALUATION

The applicant states that the application for this TN-32B package is for a one-time transportation of the DOE-EPRI High Burnup Demonstration Project Cask. This cask is a unique, dual-purpose cask intended for both storage and transportation. It is a standard TN-32B storage cask modified to insert seven thermocouple lance assemblies into seven specific spent fuel assemblies. This cask is currently licensed for storage only at the North Anna Power Station (NAPS) Independent Spent Fuel Storage Installation (ISFSI). As this cask has already been licensed for storage under 10 CFR Part 72, the staff's review focused on attributes unique to transportation (i.e., items that were not already reviewed under Docket No. 72-16). Details of the staff's storage review can be found in the safety evaluation report (ML17234A539), with section 9.0 containing the specific discussion of the materials evaluation. This referenced report should be considered supplemental to this transportation review, as there is an overlap between the storage and transportation reviews.

The materials review of the TN-32B application was conducted using the guidance in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material," issued August 2020. Additionally, the staff used other NRC guidance documents as identified in the following sections to guide the materials review.

2.2.1 Drawings

The applicant provided drawings for the transportation package including details of the component safety classification, a bill of materials with material specifications for each component, and dimensions of the components with tolerances.

The staff reviewed the drawings using the guidance in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material," NUREG/CR-5502, "Engineering Drawings for 10 CFR Part 71 Package Approvals," issued May 1999, and Regulatory Guide 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 the 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:

- Containment systems
- Closure devices
- Internal supporting or positioning structures
- Neutron absorbing and moderating features affecting criticality
- Neutron shielding
- Gamma shielding
- Outer shell
- Heat-transfer features
- Impact limiters
- Lifting and tie-down devices
- Personnel barriers

The staff verified that the drawings include the information described in NUREG-2216 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.

2.2.2 Materials of Construction

As described in SAR section 1.2 and the licensed drawings, the TN-32B demonstration cask is comprised of a fuel basket assembly, a containment vessel, a gamma shield shell, radial neutron shielding, a set of impact limiters, and a set of upper and lower trunnions.

The fuel basket assembly consists of compartment boxes fabricated from ASME SA-240 type 304 stainless steel, basket plates fabricated from ASME SB-209 type 6061-T6/T651 borated aluminum, peripheral support plates fabricated from SA-240 type 304 stainless steel, and plugs fabricated from American Society for Testing and Materials (ASTM) SA-479 type 304 stainless steel.

The containment vessel consists of an inner shell and inner bottom plate fabricated from ASME SA-203 grade D nickel alloy steel, an inner shell flange fabricated from ASME SA-350 grade LF3 steel, and six basket rails fabricated from ASTM B-221 type 6061-T6 aluminum. The lid assembly of the containment vessel consists of an outer plate fabricated from ASME SA-203 grade D nickel alloy steel, a shield plate fabricated from ASME SA-516 grade 70 carbon steel, and a vent and drain port cover fabricated from ASME SA-240 type 304 stainless steel.

The gamma shield shell consists of a shield shell fabricated from ASME SA-266 grade 2 carbon steel cylindrical forging and a bottom shield fabricated from ASME SA-516 grade 70 carbon steel plate.

The radial neutron shielding consists of aluminum alloy boxes, fabricated from ASTM B221 6063-T5 aluminum, that contain borated polyester resin.

The impact limiters consist of an upper and lower impact limiter consisting of redwood and balsa wood and enclosed in a shell fabricated from ASTM A240 type 304 stainless steel.

The upper and lower trunnions are fabricated from ASME SA-105 steel forgings and the back-up rings are fabricated from ASME SA-516 grade 70 carbon steel.

Per the above discussion, the staff finds that the applicant's description of the materials of construction to be acceptable.

2.2.3 Codes and Standards

As described in SAR section 2.1.2.1.1, ASME B&PV Code Section III, Subsection NB was used in the design, fabrication, examination, and testing of the transportation package containment vessel, to the maximum practical extent. The staff notes that the cited standards are consistent with NRC guidance in NUREG-2216, which states that containment components may be fabricated in accordance with ASME B&PV Code Section III, Subsection NB, "Class 1 Components".

As described in SAR section 2.1.2.2, the basket structure is designed in accordance with ASME BPV Code, Section III, subsection NB and NF, to the maximum extent practicable, and utilizing the stress limits of Subsection NB. The applicant further states that the basket design NCT and HAC stress limits are identical to Subsection NG. The staff notes that the use of NG stress limits is consistent with the guidance in NUREG-2216, which states that fuel basket structures may be designed in accordance with ASME B&PV Code Section III, subsection NG, "Core Supports".

The applicant notes that the neutron poison sheets are not included in the structural analysis and are therefore not required to be ASME BPV Code materials. There is precedent for using materials other than ASME BPV Code materials, and the ASME BPV Code provides material properties for the aluminum alloy used in this package. Furthermore, the applicant states that the ASME BPV Code permits the material to be used in Class 2 or 3 applications. The staff notes that this is common practice and has been found acceptable. Furthermore, this was subject to review as part of the storage application.

As described in SAR section 2.1.2.1.2, the gamma shield shell and neutron shield outer shell were designed, fabricated, and inspected in accordance with the ASME BPV Code Section III,

Subsection NF, to the maximum practical extent. The staff notes that the cited standards are consistent with NRC guidance in NUREG-2216, which states that other safety structures may be fabricated in accordance with ASME B&PV Code Section III, Subsection NF, "Supports".

The staff reviewed the alternatives to the ASME Code discussed in appendix 2.12.13, noted that no changes were made from the previously approved alternatives for storage of the TN-32B cask, and determined that the alternatives provide an acceptable level of quality and safety. The staff determined that the applicant has accurately identified the codes and standards used for the design and construction of the transportation package.

The information provided by the applicant identifies the quality category or safety classification of the component and identifies the applicable Subsection of the ASME BPV Code used in the design and construction. The applicant described and provided a basis for the Code alternatives applicable to the transportation package. Therefore, the staff determined that the description of the codes and standards applicable to the transportation package provided by the applicant was acceptable.

2.2.4 Weld Design and Inspection

As described in SAR section 8.1.2, confinement boundary welds are designed, fabricated, tested, and inspected in accordance with ASME BPV Code Section III, Subsection NB. Acceptance standards are those of article NB-5000. The welding procedures, welders and weld operators were qualified in accordance with section IX of the ASME BPV Code.

As described in SAR section 2.12.6.4, the basket welds are non-code welds via a proprietary fusion welding process, based on ANSI/AWS D.1.3-89, and qualified utilizing the guidance of ASME BPV Code Section IX and Section VIII, appendix 17. The fusion welds are also qualified by testing to include 100 percent (%) visual inspection and mechanical coupon testing from each welding machine, to show that the weld is stronger than the base material.

As described in SAR sections 2.1.2.1.2 and 8.1.2, non-confinement welds are inspected in accordance with ASME BPV, Section III, Subsection NF. Structural welds examination is via liquid penetrant or magnetic particle (MT) methods, in accordance with section V, Article 6 of the ASME B&PV Code. Liquid penetrant and MT acceptance standards are in accordance with Section III, Subsection NF, paragraphs NF-5340 and NF-5350. The welding procedures, welders, and weld operators were qualified in accordance with section IX of the ASME B&PV Code.

The staff notes that the applicant's use of the cited ASME and AWS codes for the design, fabrication, and examination of the TN-32B welds is consistent with the guidance in NUREG-2216. Therefore, the staff finds the welding criteria to be acceptable.

2.2.5 Mechanical Properties of Materials

The applicant provided a description of the mechanical properties of the packaging materials in section 2.2 of the SAR, which included the yield, ultimate, and design stress values, as specified by the ASME BPV Code, section II, Part D for certain materials. Table 2-6 contains mechanical properties for cask materials, Tables 2.12.6-1 and 2-6 contain mechanical properties for the fuel basket, and Tables 2.12.9-2 and 2.12.9-3 contain material properties for the impact limiters.

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. For ASTM or other non-ASME materials, the applicant provided supplemental information

describing the testing methods and results used to determine the mechanical properties of the materials as a function of temperature. For the containment component materials, the applicant provided ductility values from tensile testing, as well as minimum toughness values or specified toughness testing requirements. The staff reviewed these codes and standards, data, and other technical references to verify material mechanical properties.

Additionally, the staff reviewed the material properties and associated acceptance testing for the wood materials used in the impact limiters. Appendix 2.12.10 discusses the impact limiter testing of the TN-40 transportation package, which was used to benchmark the drop analyses of the TN-32B cask as described in appendix 2.12.9. Comparison of the analytical results to the dynamic testing discussed in appendix 2.12.10 confirms the adequacy of the mechanical properties of the impact limiter materials used in the drop analyses. Further discussion on the structural performance of the impact limiters can be found in the structural evaluation of this report. Section 8.1.5.1 describes the acceptance testing for the impact limiter wood, which provides confirmation that the wood materials will have the necessary material properties assumed in the analyses, such as moisture content, density, and compressive strength. The acceptance testing is performed in accordance with ASTM standards, which the staff considers acceptable to provide adequate controls for the material properties of the impact limiter wood.

The staff reviewed the applicant's thermal analysis in chapter 3 of the SAR and determined that the temperature ranges for the mechanical properties provided by the applicant bound the range of the packaging component temperatures for NCT and HAC conditions.

Per the above discussion, the staff finds the mechanical properties used in the applicant's structural analysis to be acceptable.

2.2.6 Thermal Properties of Materials

As described in SAR section 3.2.2, the applicant provided thermal properties of the materials including thermal expansion coefficients, thermal conductivity, and specific heat. The applicant provided values of the thermal properties as a function of temperature obtained from the ASME BPV Code section II Part D, or linearly extrapolated from lower temperatures in the ASME BPV Code for particular materials at higher temperatures. The applicant provided thermal properties for the wood materials based on the US Department of Agriculture Wood Handbook. In addition, the applicant provided emissivity values for the outer surfaces of the package, which are painted white, with the exception of the trunnion bearing surfaces. The staff reviewed these codes and standards and technical references to verify material thermal properties.

The staff reviewed the thermal evaluation in section 3 of the SAR and verified that no thermal limits are exceeded for the packaging components, and thus no degradation is expected in the materials from exceedance of thermal limits.

Per the above discussion, the staff finds the thermal properties used in the applicant's thermal analysis to be acceptable.

2.2.7 Fracture Resistance

The applicant states that the TN-32B demonstration cask material is a ferritic steel (with stainless steel penetration covers) and is therefore subject to fracture toughness requirements in order to ensure ductile behavior at the lowest service temperature of -20°F ambient. The applicant provided interpolated values for the inner shell and bottom inner plates, the shell flange, and the closure lid plate from the values provided in NUREG/CR-3826 and NUREG/CR-1815 for the nil ductility transition temperatures. The staff reviewed the test results

reported by the applicant in section 2.12.5.2 and verified the inner shell and inner bottom plates and the shell flange and closure lid plate materials satisfy the NUREG-recommended fracture arrest criteria.

The applicant also states that the impact limiter bolt material, ASTM A540 Gr B21 Cl 2, is tested to demonstrate Charpy fracture toughness of at least 20 ft-pounds of force (lbf) at -20°F. The tie-rod material, ASTM A193 Gr B7, is tested to demonstrate Charpy impact test energy of at least 35 ft-lbf at -20°F.

The closure lid bolt material, SA-540 Gr B23 Cl 1, was tested at 40°F. The results of this testing are provided in section 2.12.5.2 of the SAR. The applicant states that this meets the intent of ASME BPV Code, section III, Subsection NB, NB-2333, in that a minimum of 25 mils of lateral expansion is exhibited by the material at the "lowest service temperature." It is noted that the applicant takes credit for decay heat loads, which is contrary to the guidance in RG 7.8 "Load Combinations for the Structural Analysis of Shipping Casks".

The applicant states that the temperature of the closure lid bolts under -20°F ambient conditions (the lowest service temperature) would be 136°F with a cask decay heat load of 25.84 kW. Testing at 40°F is far below 136°F, which provides margin between the calculated temperature of the closure lid bolts at the lowest service temperatures and the tested value for the bolt material. The staff confirmed that the thermal model contains sufficient conservatism to justify that the margin cited by the applicant is reasonable.

The staff concluded that there is significant margin between the tested temperature and the calculated bolt material temperature to provide a reasonable basis for acceptability for this single duration trip. In addition, the single trip use limits the potential instances where the material could be exposed to cold conditions.

Per the above discussion, the staff finds that important to safety components have adequate resistance to fracture.

2.2.8 Radiation Shielding

As described in SAR section 1.2.1.2, neutron shielding is provided by a resin compound cast into long slender aluminum boxes placed around the gamma shield shell with a total thickness of 4.52 in.. The staff confirmed that the resin blocks would not be subject to temperatures at or above design limits during NCT.

The applicant provided additional information regarding thermal aging tests performed on similar materials by Transnucleaire, Paris. They also provided information from the European Organization for Nuclear Research, which noted that resin similar to that used in the TN-32B demonstration cask is among the most radiation-resistant of thermosetting resins.

The staff observed that the resin has been found to be acceptable in prior applications and is currently in use in the TN-32, TN-40, and TN-68 casks at several other ISFSI sites domestically, with no evidence of deterioration in the shielding material, which would be detected by the periodic inspections and dose rate measurements.

The SAR provides specification requirements for the composition of the resin. As these characteristics are part of the SAR, formulation of this resin is considered controlled for these specific characteristics, and changes or substitutions would be subject to an amendment.

The applicant described qualification tests of personnel and procedures for mixing and pouring the resin to ensure chemical composition and density requirements were satisfied, as well as a confirmation of lack of voids. Gamma and neutron dose rate measurement requirements after loading and prior to transportation were described, which provide additional assurance that the neutron shielding materials are performing adequately.

As described in SAR section 1.2.1.2, the gamma shielding is provided by a forged steel gamma shield shell, a bottom plate, and a closure lid shield plate. The gamma shield is 8 in. thick surrounding the cask body, 8.75 in. thick on the cask bottom, and 6 in. thick on the closure lid. The staff ensured that the application describes the physical dimensions of the gamma shielding materials, namely that the dimensions of the components are provided in the application and the drawings.

The applicant indicates that these materials were examined by NDE methods to verify no defects existing prior to installation in the assembly. Furthermore, dose rates for both gamma and neutron have been measured and recorded following loading the HBU payload into the cask cavity and prior to storage on the NAPS ISFSI pad. Prior to transport of the cask, gamma and neutron dose rate measurements will be taken over the cask surface to demonstrate the continued performance of the shielding.

The staff notes that these materials are fabricated to ASME BPV code or other industry standard specifications, and therefore there is an expectation of uniform material properties throughout the material section.

Per the above discussion, the staff concludes that the applicant has provided an acceptable description of the radiation shielding materials.

2.2.9 Criticality Control

As described in SAR sections 1.2.1.5 and 8.1.6.2, the basket structure consists of an assembly of stainless-steel cells joined by a proprietary fusion welding process and separated by aluminum and poison plates. The poison plates are made of borated aluminum alloy with a minimum areal density of 10 milligrams (mg)/centimeter (cm)² B-10, with 90% of the boron content credited in the criticality evaluation of SAR chapter 6. SAR section 8.1.6.2 discusses neutron absorber tests conducted on material coupons extracted from the borated aluminum sheets utilized in the basket fabrication.

The staff notes that this is consistent with the guidance in 7.4.7.2 of NUREG-2216, which requires neutron transmission testing to verify the uniformity and effectiveness of the neutron absorber in order to receive 90% credit. Per the above discussion, the staff find the applicants description, fabrication, and minimum poison content to be acceptable.

2.2.10 Corrosion Resistance

The applicant provided a description of operating environments and the effects of these operating environments on the components of the transportation package. The applicant states in section 2.2.2 of the SAR that the TN-32B demonstration cask components are exposed to the following environments:

- During loading, the cask was submerged in pool water, which is borated. The cask was only maintained in the spent fuel pool for approximately 12 hours to load the HBU fuel assemblies. After removing the cask from the pool, water or water vapor was present during installation of the thermocouple lance

assemblies, and the draining and drying process. This process required approximately 36 hours to install the seven thermocouple lance assemblies, drain the cask cavity, and completely dry, evacuate, and backfill the cavity with helium.

- During handling and transport to/storage on the ISFSI pad, the exterior of the cask was exposed to normal environmental conditions of temperature, rain, snow, etc.
- During transportation, the cask cavity is exposed to an inert helium environment. The helium environment does not support chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur. The cask was thoroughly dried by a vacuum drying process, sealed, and backfilled with helium gas during loading in November 2017.
- The radial neutron shielding materials and the aluminum resin boxes are sealed inside the outer shell for normal operations. The resin material is inert after it has cured and does not affect the aluminum boxes or the carbon steel housing.

The applicant states in section 2.4.4.1 of the SAR that the vessel interior cavity surfaces were grit blasted, and then coated with an aluminum metal-spray. Section 1.2.1.1 of the SAR indicates that this is for corrosion protection (and that a stainless-steel overlay was applied to the O-ring seating surfaces for corrosion protection).

The aluminum metal-spray coating is subject to the following service environments:

- After fabrication, the cask was closed and shipped with helium gas in the cask cavity during the extended non-use storage period.
- At fuel loading, borated spent fuel pool water was present in the cavity for 12 hours.
- The cask was vacuum-dried and backfilled with helium gas the planned storage period of 5.87 years, and/or off-site transport.

Section 2.4.4.5 of the SAR states that the stainless steel, borated aluminum, and thermal aluminum spray are negligibly affected by the short-term exposure to borated water during loading.

The staff reviewed the component materials and their service environments, coatings and their inspection and maintenance (see Section 7.11 below), and the use of inert gas backfill and determined that the applicant has adequate corrosion-control measures to prevent degradation of important to safety components.

2.2.11 Protective Coatings

Section 2.4.4.1 of the SAR describes an aluminum metal-spray coating on the containment vessel interior for corrosion protection. The applicant states this coating is not subject to abrasion except for the one-time insertion of the basket into the containment vessel. The staff verified that this coating would not react with the package internal components and contents and would remain adherent and inert when the package is loaded, unloaded, or transported.

Section 2.4.4.2 of the SAR describes the exterior of the cask as carbon steel and states that the exterior surface, with the exception of the trunnion bearing surfaces, was blasted clean and then painted using an epoxy polysiloxane, or equivalent coating.

Section 8.1.1 of the SAR discusses a visual inspection to verify that all specified coatings are applied. Section 2.4.4.2 also discusses visually inspecting the paint prior to immersion of the cask in the spent fuel pool and prior to transport. Prior to shipping off-site, touch-up painting or recoating is performed if the paint has deteriorated.

The drawings reference applying paint in accordance with manufacturer's instructions and/or recommended primer, application technique DFT. Drawing 19885-71-2 notes "all exposed structural carbon steel surfaces shall be blast cleaned as per SSPC Specification SP6 and coated with DuPont Imron 3.5 HG+ high gloss urethane (use recommended primer, application technique and DFT) or Sherwin Williams Acrolon 218 HS acrylic polyurethane (use recommended primer, application technique DFT) or equivalent with written approval from TN Americas". Drawing 19885-71-9 states all exposed surfaces of the impact limiter shall be painted with one primer coat and one finish coat in accordance with manufacturer's instructions. Color: white

Based on the capability of the coatings and paint to protect the metallic surfaces from corrosion and the visual inspection to ensure that coatings remain intact for this single trip, the staff finds the coatings to be acceptable.

2.2.12 Content Reactions

As described in SAR section 2.2.2, the TN-32B demonstration cask was vacuum-dried and backfilled with helium gas and this inert helium environment will be that experienced by the contents during transportation. The applicant stated that because the TN-32B HBU demonstration cask has a bolted closure, there is no source of ignition to result in an explosion or fire.

As described in SAR section 2.4.4.4, Prairie Island's report to the NRC in response to the NRC Bulletin 96-04 demonstrates that galvanic reactions in hydrogen generation are insignificant for the TN-40 cask, which is similar to TN-32B demonstration cask. The staff determined that the applicant's assessment of no content chemical reactions, outgassing, or corrosion reactions for the contents in the package is acceptable because drying and helium backfilling removes water and creates an inert environment inside the package.

Per the above discussion, the staff finds that the applicant's assessment that there will be no content reactions to be acceptable.

2.2.13 Radiation Effects

As described in SAR section 2.2.3, gamma radiation has no significant effect on metals, and the effect of fast neutron irradiation of metals is a function of the integrated fast neutron flux and studies on fast neutron damage in aluminum, stainless steel, and low alloy steels rarely evaluate damage below 10^{17} n/cm² because it is not significant.

The applicant stated that the neutron absorbers, consisting of aluminum with boron added in the form of boron carbide, possess a durability in radiation environments similar to aluminum, which has been demonstrated over many years in service for spent nuclear fuel (SNF) storage systems and transportation casks.

The applicant stated that radiation levels and temperature on the cask exterior surface are not sufficiently high to damage the paint. The applicant states that this is confirmed by dry cask experience. The paint is also subject to routine maintenance and touch-up during the cask storage period and prior to being transported from the ISFSI site.

The applicant stated that there is no significant degradation of the metallic O-ring seals resulting from the effects of long-term exposure to neutron or gamma radiation. The applicant also stated that the radial neutron shield material is a proprietary resin that has been developed and tested for applications, such as the TN-32B HBU demonstration cask. The neutron and gamma fluence expected for this application are below those levels that could degrade the effectiveness of the metallic O-ring and resin material.

The staff reviewed the applicant's analysis using the guidance in NUREG-2216 section 7.4.11. The staff determined that neutron embrittlement of the metal components of the transportation packaging components will not occur over the expected period of use. In addition, the staff determined that the gamma radiation exposure of the neutron shielding resin is insufficient to result in radiation damage over the expected duration of one trip.

Per the above discussion, the staff finds that the analysis provided by the applicant is acceptable and radiation damage of the package components will not occur over the expected period of use.

2.2.14 Package Contents

Details on each of the 32 individual HBU fuel assemblies are provided in chapter 1 of the SAR, including weights, dimensions, fuel density, cooling time, burnup, and decay heat. The staff reviewed the information provided by the applicant to describe the package contents including the description of the transportation package contents provided in SAR section 1.2.2 and the drawings.

Details on fuel material properties are provided in sections 2.12.8.2.1 and 2.12.8.3 of the SAR, including yield strength, tensile strength, elastic modulus and density. The staff compared these materials properties against staff accepted technical reports, such as PNNL-17700, and found them to be adequately justified and bounding for all cladding types provided in chapter 1.

The applicant provided a thermal analysis in SAR chapter 3 to evaluate fuel performance during NCT and HAC. The staff reviewed this analysis and verified that adequate margin is provided to the maximum fuel temperatures that could result in fuel cladding rupture.

Per the above discussion, the staff finds that applicant's description of the chemical and physical form of the package contents to be acceptable and the mechanical properties of the fuel modules are adequate to ensure that the SNF remains in the analyzed configuration under NCT and HAC.

2.2.15 Bolting Material

The staff reviewed the information provided by the applicant pertinent to bolting materials. The closure lid is secured by 48 high-strength closure lid bolts fabricated from SA-540 Gr B23 Cl 1 steel. The impact limiters are secured with eight 1 ½-in. diameter bolts fabricated from ASTM A540 Gr B21 Cl 2 steel. The impact limiters are secured to each other with thirteen 0.5-in. diameter tie rods fabricated from ASTM A193 Gr B7 steel. The applicant provided information in the materials tables consistent with ASME BPV Code section II, Part D for materials properties for the bolting material using ASME materials. The staff reviewed the materials tables for the

bolting materials to assess consistency with NB-2333-1 for appropriate resistance to brittle fracture.

Loctite N-5000 was utilized to coat the threads of the closure lid bolts. The applicant specified plating to be applied to certain bolting materials in the drawings. The applicant has specified the coatings that will be applied to alloy steel bolts, which the staff finds acceptable for corrosion resistance, considering the application. Further, periodic inspections of the bolts are described in section 8.2.3.1 of the SAR as part of the maintenance program, which will allow for identification of damage or degradation and allow for rework or replacement prior to use. As such, the staff considers that the applicant has assessed the effects of corrosion, chemical reactions, and radiation effects on the bolting materials.

The staff reviewed the information provided by the applicant to ensure that potential thermal expansion effects were evaluated for the bolting materials. The staff confirmed that the closure lid bolts, closure lid, and flange have the same coefficient of thermal expansion at 300°F and therefore the closure is not affected by differential thermal expansion. The staff also confirmed that the jacking screws, closure lid, and penetration sleeve also have the same coefficient of thermal expansion, meaning that differential thermal expansion will not generate additional stress on this bolted closure. The staff finds the similarity of coefficients of thermal expansion for interfacing materials in these connections to be acceptable, as materials with the same coefficients will not generate additional stresses on the connection through differential thermal expansion.

Per the above discussion, the staff finds the applicants bolting materials to be acceptable.

2.2.16 Seals

The applicant stated that double metallic O-ring seals are utilized on the closure lid and the nine lid penetrations (drain port, vent port, and seven thermocouple lances). These O-ring seals are Helicoflex HND seals, which the applicant stated possess long-term stability as well as high corrosion resistance. The applicant notes that no significant degradation results from long-term exposure to neutron or gamma radiation for the metallic O-ring seals.

The applicant notes that the metallic seal seating surfaces are a stainless-steel overlay and that the capability of the sealing surfaces was demonstrated by meeting the leaktight acceptance criteria per ANSI N14.5 during fabrication acceptance leakage rate testing and during pre-shipment leakage rate testing during loading of the HBU payload. While in storage, all containment boundary O-ring seals were monitored by the overpressure system to ensure the containment boundary was maintained.

The applicant stated that seals will be replaced once the covers are removed. The metallic seals have a minimum and maximum temperature rating of -40°F and 663°F/842°F respectively, which the staff compared against the information provided on the manufacturer website. The maximum metallic seal temperatures under NCT are 232°F, which are bounded by the maximum temperature rating. The maximum metallic seal temperatures under HAC are 279°F, which are bounded by the maximum temperature rating.

The operating procedures specify installation of a new metallic O-ring seal on the vent port cover and a leakage rate test of the vent port O-ring seal prior to shipment. A pre-shipment high-vacuum test of the inner and outer elastomer O-ring seals on the puncture resistant plate test ports is also performed prior to transport. A leakage rate test of the cask O-ring seals is also performed upon receipt of the package. The applicant states that all new metallic O-ring seals

were installed, and helium leakage rate tested in September 2017 and November 2017 once loaded.

The staff considers this successful testing, coupled with the monitoring that occurred during the storage period, to provide reasonable assurance that the seals will perform their safety function for the duration of this single transport of the cask.

2.2.17 Evaluation Findings

The applicant has met the requirements of 10 CFR 71.33. The applicant described the materials used in the transportation package in sufficient detail to support the staff's evaluation.

The applicant has met the requirements of 10 CFR 71.31(c). 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.

The applicant has met the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a). The applicant demonstrated effective materials performance of packaging components under NCT and HAC.

The applicant has met the requirements of 10 CFR 71.43(d). The applicant has demonstrated that there will be no significant corrosion, chemical reactions, or radiation effects that could impair the effectiveness of the packaging.

The applicant has met the requirements of 10 CFR 71.43(f) and 10 CFR 71.55(d)(2). The applicant has demonstrated that the package will be designed and constructed such that the analyzed geometric form of its contents will not be substantially altered, no loss or dispersal of the contents, and no substantial reduction in the effectiveness of the packaging under the tests for NCT.

The staff concludes that the TN Americas LLC CoC No. 9377 for the DOE-EPRI HBU Demonstration Project Cask adequately considers material properties and material quality controls such that the design is in compliance with 10 CFR Part 71. This finding is reached on the basis of a review that considered the information in the application, the regulation itself, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

The NRC staff concludes, based on review of the statements, and representations in the application, that the materials used in the package design have been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

The objective of the review is to verify that the thermal performance of the TN-32B cask has been adequately evaluated for the tests specified under both NCT and HAC, and that the package design satisfies the thermal requirements of 10 CFR Part 71 while transporting 32 high burnup spent fuel assemblies with a maximum decay heat load of 25.84 kW.

3.1 Description of Thermal Design

3.1.1 Design Features

Section 3.1.1. of the SAR provided a description of the TN-32B cask's thermal design. In section 1.2.1.5 of the SAR, the applicant described the design features for the cask's basket, which consists of a welded assembly of square stainless-steel fuel compartments separated by aluminum and borated aluminum (poison) plates that form a sandwich panel. The applicant states: "Two 0.50-inch-thick aluminum plates that sandwich a 0.040-inch-thick poison plate creates the center panels". Additionally, the applicant states that "the remaining panels consist of stainless steel that sandwich a 0.50-inch-thick aluminum plate."

Heat conduction paths to the basket peripheral plates from the fuel assemblies are provided by the aluminum. The poison plate provides the necessary criticality control. A strong honeycomb-like structure of cell liners that provide the compartments for each of the HBU fuel assemblies serves as the means of construction. A conduction path is formed from the basket to the inner shell due to the aluminum basket rails being bolted to the inner shell. The applicant stated that these thermal design features of the basket allow the heat generated by the fuel assemblies to be conducted efficiently from the basket to the shell.

In section 1.2 of the SAR, the applicant mentions the conduction path created by the aluminum boxes that contain the radial neutron shielding material as another thermal design feature of the cask. The neutron shield is formed using a resin compound cast into long slender aluminum boxes placed around the gamma shield shell and enclosed within a 1/2-in.-thick steel outer shell. The aluminum boxes are designed to fit tightly against the steel gamma shield shell surfaces, thus improving the heat transfer across the neutron shield.

Also, in section 1.2 of the SAR, the applicant describes the design of the steel-encased wood impact limiters. These components are included in the thermal analysis because of their contribution as a thermal insulator. The impact limiters were created to provide protection to the closure lid and bottom regions from the external heat load applied during the HAC thermal event.

The applicant states, in section 3.1.1 of the SAR, that: "A personnel barrier prevents access to the outer surfaces of the cask body during transport. The barrier, which consists of stainless-steel expanded metal attached to a stainless-steel frame, will enclose the cask body between the impact limiters, and has an open area of approximately 75%."

Staff reviewed the design features of the TN-32B cask and determined that the description of the design features provided in the SAR was acceptable and meets the requirements of 10 CFR Part 71.

3.1.2 Content's Decay Heat

For the TN-32B cask, the total decay heat load is 25.84 kW (with a maximum of 0.878 kW/assembly) for 32 HBU fuel assemblies. In section 3.1.2 of the SAR, the applicant stated that the cask geometry of the TN-32B is half symmetric about a vertical plane through the centerline of the cask. The applicant states, in section 3.1.2 of the SAR, that: "...the decay heat load of the fuel loading pattern in the basket is not symmetric about this plane. The maximum element wattage for each corresponding basket location across the symmetry plane is evaluated."

The applicant indicated that the heat load for each fuel element is deposited as volumetric heat generation over the active fuel length. The applicant applied peaking factors to the fuel assembly decay heat profiles as prescribed in NUREG/CR-6801, "Recommendations for Addressing Axial Burnup in PWR Burnup Credit Analyses," and as described in section 3.1.2 of the SAR: "Since all the fuel elements in this package have a burn-up greater than 50 GWd/MTU, the axial peaking factors from Table 2 of NUREG/CR-6801 are utilized in this evaluation."

Because the table used by the applicant applies to fuels with burnups more than 46 GWd/MTU, using these peaking factors is reasonable.

Also, in section 3.1.2 of the SAR, the applicant stated the axial peaking factors were provided through 18 axial data points over the total height of 144 in. (through a conversion from % to in.). Additionally, the applicant stated the following: "The value for the first and last peaking factors (representing 0% and 100% axial height) are not explicitly listed in NUREG/CR-6801, so an approximation based on 90% of the highest and lowest values given in NUREG/CR-6801 are manually iterated until the closest value of the actual power value was achieved. Finally, the average peaking factor is calculated by dividing the area under the curve by the increment length of 14.4 inches."

Staff reviewed the decay heat, the loads mentioned in this section, and confirmed that the applicant followed the guidance provided in NUREG/CR-6801 regarding the axial peaking factors. Staff determined that these values were acceptable and will remain within their respective allowable values or criteria for NCT and HAC, as required in 10 CFR Part 71.

3.1.3 Summary Tables of Temperatures

In section 3.1.3 of the SAR, the applicant describes summary tables 3-1 and 3-2 which provide the calculated cask component temperatures for NCT and HAC, respectively. The applicant completed a set of steady-state thermal analyses utilizing the maximum decay heat load of 25.84 kW, an ambient temperature of 100°F (38 degrees Celsius [°C]) in still air, and maximum insolation. Figure 3-1 of the SAR shows the calculated temperature distribution within the cask body and fuel basket.

The temperature distributions, as calculated in the fuel assemblies and the neutron shield, are shown in Figures 3-2 and 3-3 of the SAR, respectively. Temperature distributions for the impact limiter wood and basket rails are displayed in Figures 3-4 and 3-5 of the SAR. A summary of the calculated cask component temperatures for NCT and HAC are provided in Tables 3-1 and 3-2 of the SAR, respectively.

These summary tables were reviewed and verified by the staff, and it was determined that the packaging and contents' temperatures will remain within their respective allowable values or criteria for NCT and HAC, as required in 10 CFR Part 71.

3.1.4 Summary Tables of Maximum Pressures

In section 3.1.4 of the SAR, the applicant provided the calculated maximum normal operating pressures (MNOP) for both NCT and HAC conditions. The values of each are listed in Table 3.1 below along with where this information might be found in the SAR.

Table 3.1 MNOP for NCT and HAC

Condition	MNOP	Location in the SAR
NCT	30.5 psig	3.3.2
HAC	93.1 psig	3.4.3.2

Therefore, the internal pressure of the TN-32B cask will remain below the design pressure of 100 psig when loaded with the HBU fuel assemblies. These pressures comply with the pressure limits specified in Table 2.1.1 of the SAR and are, therefore, acceptable.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

Discussion of the material properties for the various TN-32B transportation system components is provided by the applicant in section 3.2 of the SAR. A summary of this section of the applicant's SAR, organized by system components, is provided below.

3.2.1.1 Cask Body, Neutron Shield and Closure Lid

In section 3.2.1 of the SAR, the applicant states the following: "The TN-32B HBU demonstration cask is fabricated using nickel alloy steels (predominately SA-350 Gr. LF3 and SA-203 Gr. D) for containment boundary components, carbon steels for gamma shielding components (SA-266 Gr. 2 and SA-516 Gr. 70), and carbon steel for the cask trunnions (SA-105). Neutron shielding is provided by a borated polyester resin compound cast into long, slender aluminum boxes (ASTM B221, 6063-T5) placed around the cask gamma shield shell."

Related to the neutron shield, the applicant states: "The aluminum material utilized to create the radial neutron shield boxes is ASTM B-221, 6063-T5 aluminum. These boxes provide a heat conduction path through the outer neutron shield. The thermal properties for these materials are cited from the ASME B&PV Code. The thermal properties for temperatures above 400°F are linearly extrapolated from those values at lower temperatures (i.e., 70°F to 400°F). This extrapolation is appropriate since Figure 3 of "Study of the Transient Temperature Profiles Induced by Changes of the Welding Parameters during Aluminum Two-Plate Arc Butt-Welding" illustrates that the thermal conductivity of 6063-T5 aluminum material remains relatively constant up to approximately 1,076°F (580°C)"

For the analysis of the HAC fire, the applicant indicates that the solid neutron absorbing polyester resin is considered to decompose completely during the 30-minute fire. The resin is included in the model during the fire and the properties are changed to air for the remaining analyses. Elements representing the resin are given air thermal conductivity during the 30-minute wood char and cooldown time periods.

For the closure lid, the applicant, in section 3.2.1 of the SAR, notes that: "the closure lid is modeled as a continuous plate neglecting the detail of the thermocouple penetrations, closure lid bolts (SA-540 Gr. B23, Cl 1), and the vent/drain penetrations." The applicant further notes that, for the lid, this "modeling approach is conservative since the thermal conductivity of the plate material is higher than the helium or bolting material it replaces, and, therefore, maximizes the temperature around the metallic containment O-ring seals and closure lid bolts."

3.2.1.2 Fuel Assemblies, Basket Rails, and Fuel Basket

The spent fuel assembly thermal properties are also homogenized across the full cross section of each individual basket compartment when filled with helium for ease of computation.

The applicant states that “the aluminum basket rails (ASTM B221, 6061-T6), secured to the cavity wall provide a conduction path from the basket periphery to the cavity wall. The design of the basket allows the heat from the fuel assemblies to be conducted along the aluminum plates to the basket rails, and to be dissipated to the cavity wall.”

The applicant, in section 3.2.1 of the SAR, continued by stating: “The basket is constructed as a laminated type of structure with homogenized thermal properties. The thermal properties for these materials are cited from the ASME B&PV Code. The thermal properties for temperatures above 400°F are linearly extrapolated from those at lower temperatures (70°F to 400°F). This extrapolation is justified because the thermal data in Figure 3.6.2.0 of “Metallic Materials and Elements for Aerospace Vehicle Structures,” illustrates a positive trend for both thermal conductivity and heat capacity for the 6061-T6 aluminum material at higher temperatures”.

The applicant states that the basket is made up of 32 stainless steel (SA-240 Type 304) fuel compartments with aluminum and borated aluminum (poison) plates in between them. Plug welds are used to secure the compartments together to form the basket. As shown in Figure 3-9 of the SAR, the layered basket plates are homogenized in order to provide a single value for thermal properties and simplify the analytical model.

3.2.1.3 Impact Limiters

Stainless steel (ASTM A-240, Type 304) is used to fabricate the impact limiter shell, the properties of which are cited from the ASME B&PV Code. In the thermal model of the impact limiters, the applicant used a homogenized region with bounding material properties for the redwood and balsa wood blocks encased in stainless-steel.

The applicant specified a minimum bounding conductivity value (k_{min}) of 0.0019 BTU/hr-in-°F, which was calculated for a moisture content of 0% and specific gravity of 0.08. The relatively low thermal conductivity value was selected by the applicant to reduce heat transfer out of the impact limiter during NCT evaluations. This approach is considered to be conservative and is therefore acceptable.

In section 3.2.1 of the SAR, the applicant describes the use of a wood thermal conductivity that varies as a function of time for the HAC thermal model. The range of wood thermal conductivities considered is 0.0657 to 0.1768 Btu/hr-in-°F during pre-fire NCT and cool-down period to reduce heat transfer out of the cask.

The applicant states: “The maximum wood thermal conductivity of 0.0379 Btu/hr-in-°F is used during the 30-minute fire and wood char period immediately after the fire to maximize heat transfer into the cask. The elevated temperature of the charred wood maximizes heat flow into the cask by considering the maximum wood thermal conductivity and treating the air gaps within the impact limiter as metal during the smoldering event”.

3.2.1.4 Air, Helium, and Surface Finishes in the Thermal Model

For the application of air and helium in the thermal model, the applicant states, in section 3.1.2 of the SAR that: “The thermal properties for air and helium are derived from curve fits provided in the “Handbook of Heat Transfer”.

Because the thermal conductivity of air varies significantly with temperature, the computer model calculates the thermal conductivity between the package and the ambient as a function of the mean film temperature”.

Further, the applicant addresses the application of thermal radiation on external surfaces of the model in the following way: “Thermal radiation at the external surfaces of the cask is also considered. Except for the trunnions, all the exterior surfaces of the cask and impact limiters are painted white.”

Table 3.2 below provides the material or surface finish, its associated emissivity and the absorptivity used for the radiation heat transfer calculation in the computer model.

Table 3.2 Emissivities and Absorptivities for Materials for Radiation Heat Transfer Calculation

Material	Emissivity	Absorptivity
White Paint	0.92 to 0.96	0.06 to 0.23
Dust and Dirt	0.9	0.3
Soot (after fire)	0.9	0.95
Soot (cooldown)	0.9	1.0
Oxidized Steel	0.79 to 0.94	N/A
Mild Steel	N/A	0.41 to 0.74
Exterior Surface of Cask Trunnion	0.94	0.74

The assumption made for the emissivity of the exterior surface of the cask trunnion is justified because most of the trunnion surfaces are exposed carbon steel surfaces that are subject to wear during cask down-ending and lifting operations.

Staff reviewed the materials, along with the references for each of the materials. Staff found these values and references acceptable for use for the applicant’s thermal analysis and determined that they are appropriate to provide a basis for the thermal evaluation of the package to meet requirements of 10 CFR Part 71.

3.2.2 Component Specifications

In section 3.2.2 of the SAR, the applicant provides specifications for the components of the TN-32B HBU demonstration cask, which include, among other things, the following:

- metallic containment seals.
- puncture resistant plate O-ring seals.
- neutron shield polyester resin.
- thermocouple lance assemblies, and
- the irradiated fuel payload.

The applicant states that “the other materials either have temperature limits above the maximum expected temperatures or are not considered essential to the function of the package.” A summary of the components listed in SAR section 3.2.2 and their maximum allowable temperatures for NCT is provided in Table 3.3. below.

Table 3.3 Components and Maximum Allowable Temperatures for NCT

Component	Maximum Allowable Temperature °F (°C)
Primary lid containment seal (0.260” cross section)	842 (450)
Vent port/drain port/lance assembly seals (0.161” cross section)	669 (354)
Overpressure port seal (0.160” cross section)	663 (351)
Pressure resistant plate Viton® O-ring seal (0.375” cross section)	400 (205)
Thermocouple lance oversheath with a nickel material tube (0.312” diameter)	800 (427)
Neutron shield polyester resin	300 (149)
Accessible Package Surface	185 (85)
Fuel cladding (as stated in NUREG-1536)	752 (400)
Alloy Steel for containment boundary components (i.e., SA-203 Gr. D, SA-350 Gr LF3 and SA-540 Gr. 23 Cl 1 bolts)	650 (343)
Type 304 Stainless steel (Fuel basket and other components)	800 (427)
Type 304 Stainless steel (for components not serving a structural purpose)	2,600 (1,427)
Aluminum (in compliance with ASME B&PV Code)	400 (204)
Impact limiter wood (to maintain structural properties at elevated temperatures)	230 (110)

3.2.2.1 Temperature Limits for Seals

The applicant stated that two metallic type seals are used in the packaging, including the Helicoflex® double metallic (HND 229) and single metallic (HN-200) O-ring seals with silver jacketing are used. Viton® O-ring seals are used in the puncture resistant plate. The applicant states that the maximum allowable temperature is based on the cross-section of the seal.

The applicant further states that the minimum service temperature for all cask components, including seals, is equal or less than -40°F (-40°C). The applicant points out an exception to this is the Viton® O-ring seals utilized for the puncture resistant plate, which have a minimum service temperature rating of 15°F (-26°C). The applicant maintains that this is acceptable because they have calculated, for the -40°F NCT ambient condition, the minimum temperature for the seal area where this seal is deployed to be not less than 120°F (49°C).

The staff agrees with the applicant’s conclusion related to the minimum service temperature of the Viton® O-ring seals utilized for the puncture resistant plate.

3.2.2.2 Component Temperature Limits for HAC

In section 3.2.2 of the SAR, the applicant states that containment boundary components (including the metallic containment O-ring seals) and the fuel cladding perform their safety function within their allowable temperature limits for HAC, as shown in Table 3-2 of the SAR.

The applicant further states that, during and/or following the HAC fire event, the Viton® O-ring seals utilized for the puncture resistant plates are not required to function, therefore, the applicant does not report a temperature limit for these seals.

3.2.2.3 Thermal Properties of Package Components and Materials

The applicant, also in section 3.2.2 of the SAR, provided a series of tables that provided temperature dependent values of properties including: effective density, thermal conductivity and specific heat for the following materials, components, and/or contents of the package:

- PWR fuel assembly,
- aluminum (used for baskets and radial neutron shield boxes),
- Poison plates,
- Stainless Steel SA-240, Type 304 (used for fuel compartments and impact limiter shells),
- low nickel alloy steel SA-203, Gr. D and SA-350, Gr. LF3 (used for the containment shell),
- helium (used for gaps within the cask cavity),
- SA-286 Gr. 2 and SA-516 Gr. 70 Carbon Steel (used for gamma shield shell, outer shell, and closure lid),
- SA-105 (used for the trunnions),
- air,
- wood (used to model the wood core of the impact limiters for NCT and HAC), and
- neutron shielding (a polyester resin).

Staff reviewed the specifications of the materials, their respective references, and the corresponding regulations and determined that these specifications are acceptable as the material used in the fabrication of the TN-32B transportation system will meet the applicable temperature limits and, therefore, meet the requirements of 10 CFR Part 71.

3.3 Thermal Evaluation under NCT

The applicant utilized a thermal analysis model to assess the thermal performance of the TN-32B HBU demonstration cask under NCT. The development, implementation, and results of the ANSYS® finite element analysis (FEA) thermal model, as described by the applicant in section 3.3.1.1 of the SAR, are summarized in the SER sections below.

3.3.1 Heat and Cold

3.3.1.1 Thermal Models

As described in section 3.3.1.1 of the SAR, the ANSYS® model developed by the applicant was a three-dimensional thermal model of the TN-32B cask and basket with HBU fuel contents. The applicant used SOLID70 conducting elements for all cask components, including gaps, while exterior surfaces of the cask were overlaid with SURF152 shell elements to capture convection

heat transfer at the cask surfaces. The applicant states gap heat transfer is modeled as gaseous conduction, with any other modes of heat transfer neglected.

The applicant provides depictions of various aspects of the analysis model in Figures 3-6 through 3-9 of the SAR. The element plots provided in Figures 3-6 to 3-8, show components such as the wood filled impact limiters, trunnions, neutron shield, cask shell, cask bottom plate, cask closure lid, basket, and fuel assemblies.

The applicant states that: “the model simulates the effective thermal properties of the fuel with a homogenized material occupying the volume within the basket where the 144-in. active length of the fuel is stored.” An interference fit is used to assemble the inner shell and the gamma shield shell, which provides thermal contact at the shell interface.

The applicant also states: “The radial neutron shielding consists of 60 long resin filled aluminum boxes placed between the gamma shield shell and the outer shield shell. The aluminum resin boxes are confined between these shells, and butt against the adjacent shells”

The applicant also provides a discussion of the gaps assumed in the analysis model and how and where those gaps were applied.

The applicant, also in section 3.3.1.1, subsection 1 of the SAR, continues the discussion of their analysis model with a description of the fuel basket model, which is integrated into the ANSYS FEA model, and included a detailed discussion of the assumptions for gaps and thermal contact within the model. Specifically, the applicant states that: “The basket structure is composed of 32 stainless steel fuel compartments... sandwiching three regions of aluminum and borated aluminum (poison) plates. The fuel compartments are joined by welded stainless steel plugs that pass through the aluminum and poison plates. The fuel compartments are plug-welded together to form the basket.”

The applicant then, in section 3.3.1.1, subsection 2 of the SAR, provides a discussion of the integration of the impact limiter into the FEA model. The impact limiters are critical because they help determined the maximum accessible surface temperature during NCT. Both the redwood and balsa wood within the impact limiters are modeled as a homogenized region containing bounding material properties. Within this model, gaseous conduction is the mode of heat transfer used.

Specific aspects of the applicant’s modeling approach, including heat dissipation and solar heat load are discussed in SER sections 3.3.1.2 and 3.3.1.3, respectively, below.

3.3.1.2 Heat Dissipation

In section 3.3.1.2 of the SAR, the applicant provides a detailed discussion of how heat removal from the TN-32B package under the transportation conditions defined in 10 CFR Part 71, are calculated and modeled. The applicant mentioned the use of several subroutines (created in ANSYS®) to calculate the natural or “free” convection heat transfer coefficients, using relationships from section 3.3 of the “Handbook of Applied Thermal Design,” (Guyer, 1989), which were applied to the exterior surfaces of the package for NCT conditions.

As described in section 3.3.1.2 of the SAR, the applicant developed the correlations (including the determination of the appropriate Nusselt and Rayleigh numbers for the “laminar” flow regime experienced in the NCT environment) used in the thermal model for natural convection heat

transfer from both vertical and horizontal surfaces using the relationships found in chapter 4 of the “Handbook of Heat Transfer”, 3rd Edition (Rohsenow, Cho, and Harnett, 1998). The values for natural convection heat transfer coefficients from vertical surfaces as well as long, isothermal cylindrical surfaces were also computed using equations from this reference. The applicant also describes applying correction factors for convection from horizontal cylindrical surfaces.

Finally, the applicant also describes heat transfer from the surface of the package via radiation to the ambient environment, defined by a radiation heat transfer coefficient also derived from the previously mentioned reference (Rohsenow, et al., 1988).

The total heat transfer coefficient, a combination of the convective and radiative heat transfer coefficients, was then calculated and applied as a boundary condition to the surfaces of the ANSYS® FEA model for determining surface temperatures under NCT.

Staff reviewed the equations provided by the applicant, along with the references cited. The staff finds this discussion acceptable for thermal evaluation of the TN-32B package under NCT and is therefore in compliance with the requirements in 10 CFR 71.71.

3.3.1.3 Solar Heat Load

The applicant provides a discussion on solar heat load in section 3.3.1.3 of the SAR. The applicant used the values for total insolation, for flat surfaces not transported horizontally, as defined in 10 CFR 71.71(c)(1) for a 12-hour period in a day. The applicant used the daily averaged value (i.e., the regulatory values were averaged over a 24-hour period) and applied that value to the external surfaces of the thermal models as a constant steady state value.

The applicant states that “daily averaging of the solar heat load is justified based on the large thermal inertia of the TN-32B demonstration cask.” The staff agrees with this assertion. The applicant further explains: “The solar heating is limited to the unshaded portions of the package, which is 75% of the total exposed surface area. The model includes the exposed surfaces of the impact limiters and the cask body 45 degrees below the horizontal centerline, as shown in Figure 3-10 [of the SAR]. The inner vertical surfaces of the impact limiters and the cask body receive the full solar heating input (no reduction due to the personnel barrier)”.

The applicant applies emissivity values for the outer surfaces of the TN-32B demonstration cask as provided in “Thermal Radiation Heat Transfer,” 4th Edition (Siegel and Howell, 2002), specifically for the white painted outer surface of the cask, with a slight reduction in the emissivity and absorptivity values taken to account for dust and dirt, as suggested in the above reference.

In section 3.3.1.3, the applicant provides a summary of their calculation of the total solar input which applies the “solar factors” described above to the exposed areas of the package as prepared for transportation. The applicant calculated the exposed area of the cylindrical body and impact limiters as well as that of the inner and outer flat ends of the impact limiters, and then determined the solar thermal input to be applied to the applicable surfaces of the thermal model, adjusting for the half-symmetrical nature of the analysis model, and the assumed absorptivity of the painted surfaces. Finally, the applicant includes appropriate heat flux (on the interior of the package, from the fuel assemblies).

Staff has reviewed this section provided by the applicant and the pertinent calculations. Staff finds the discussion and calculations acceptable given that they used the values from 10 CFR 71.71(c)(1) and will ensure meeting the regulatory requirements of 10 CFR 71.71.

Considering the two previous sections of this SER on Heat Dissipation and Solar Heat Load, the staff finds the modeling approach described by the applicant acceptable for the thermal evaluation of the TN-32B package and that it meets the requirements found in 10 CFR 71.71.

3.3.1.4 Maximum Temperatures

In section 3.3.1.4 of the SAR, the applicant provides a discussion pertaining to the maximum temperatures under the evaluated NCT “hot” scenario. The applicant summarizes the predicted TN-32B demonstration cask temperatures in Table 3-1 of the SAR which shows that the maximum temperature of any structural component associated with the containment is less than 368°F (187°C).

The applicant also reports on the containment seals, the neutron shield resin, fuel cladding and impact limiter wood temperatures.

The applicant stated that the maximum neutron shield resin temperature is below 300°C and no degradation of the neutron shielding is expected.

Staff confirmed that the maximum temperatures reported by the applicant were below the stated material temperature limits with appropriate margin, and therefore in compliance of 10 CFR 71.71.

The applicant provided numerous figures that captured the NCT temperature distributions for the various components of the TN-32B demonstration cask examined in the thermal analysis. A summary of the figures provided by the applicant in the SAR is provided in the table below.

Component	SAR Figure
Overall Temperature Distribution	3-1
Cask Cross-Section at peak fuel temperature	3-2
Neutron Resin	3-3
Impact Limiter Wood (Peak)	3-4
Aluminum Cask Rails	3-5
Aluminum Neutron Resin Boxes	3-12
Basket cross-section at axial location of PCT	3-11

Finally, the applicant provides a reference to a test report on thermal test conducted on the original TN-32 storage cask design which were conducted in early 2000. The applicant states that the thermal test results demonstrated “that the thermal model considers adequately the insulating effect of the neutron shield and the gaps between multiple shells of the casks and bounds properly the uncertainties and imperfections expected in the fabrication of this type of cask”.

3.3.1.5 Maximum Accessible Surface Temperature in the Shade

In section 3.3.1.5 of the SAR, the applicant provides a discussion regarding the maximum accessible surface temperature of the TN-32B package prepared for transportation and when located in the shade. The exclusive use surface temperature limit, found in 10 CFR 71.43(g), is 185°F (85°C); however, the applicant calculated the maximum accessible surface temperature, in the shade and with a 100°F (38°C) ambient, to be 290°F (143°C). As a result, a personnel barrier is required to be installed during the transport of the TN-32B package in order to prevent access to any surfaces of the package that exceed 185°F (85°C).

The applicant states, also in section 3.3.1.5 of the SAR, that the personnel barrier, when installed, surrounds the body of the TN-32B cask between the impact limiters and has an “open area” of approximately 75% to allow for continuous cooling of the cask surfaces. With the personnel barrier installed, the accessible areas of the TN-32B package, as prepared for transportation, include the surface of the personnel barrier and the outermost surfaces (radial and vertical) of the impact limiter.

The applicant then provided a detailed description of how the accessible surface temperatures were calculated. Using the NCT thermal model (without insolation) and a 100°F (37.8°C) ambient, the accessible surfaces of the impact limiters do not exceed 101°F (38°C). The personnel barrier is exposed to thermal radiation and natural convection to the ambient.

The applicant used the radiation equation, shown on page 3-26 of the SAR, to calculate the temperature of the personnel barrier, which turned out to be 176°F, which is less than 185°F (85°C); thus, meeting the accessible surface temperature requirements for an exclusive use shipment as specified in 10 CFR 71.43(g).

Staff reviewed this section and the associative calculations provided by the applicant. Staff finds the description provided acceptable and that the calculations provided demonstrate compliance with the requirements in 10 CFR 71.71.

3.3.1.6 Minimum Temperatures

In section 3.3.1.6 of the SAR, the applicant provided a discussion on their evaluation of minimum temperatures, in which the applicant states that, for a minimum temperature condition of -40°F (-40°C) ambient, components of the package will approach -40°F (-40°C) if the decay heat load of the contents is not credited.

The applicant states that the minimum temperature condition has no adverse effect on the performance of the TN-32B package given that package materials, including package seals and the containment structures, maintain their functions at this temperature.

The applicant, however, conducted thermal analyses at ambient temperatures of -20°F (-29°C) and 40°F (-40°C) while applying the maximum decay heat from the contents and no insolation load. The applicant provides the results of these analyses in Table 3-1 of the SAR, along with the temperature distributions in the package, in Figure 3-13 of the SAR.

While the applicant maintains that “the minimum allowable service temperature for all the TN-32B HBU cask components is equal to or below -40°F (-40°C) ambient”, one exception is noted for the puncture resistant plate Viton® O-rings seals, which the applicant indicates has a minimum service temperature rating of -15°F (-26°C).

The applicant's analysis, however, predicts that the temperature in the seal area of the puncture resistant plate will not be below 119°F (48°C), (refer to Table 3-1 of the SAR). Therefore, for the -40°F (-40°C) ambient NCT cold condition, the applicant maintains that the use of Viton® seals is acceptable.

Staff reviewed this section in the applicant's SAR and finds that the description provided and calculations reviewed were acceptable and comply with the requirements of 10 CFR Part 71.

3.3.1.7 Evaluation of Cask Performance for NCT

In Table 3.1 of the SAR, the applicant provides a summary of the maximum NCT temperatures of the primary components of the TN-32B demonstration cask and concludes that the TN-32B transportation package, as designed meets all applicable temperature requirements. In Table 3.4, below, a summary of the temperatures calculated by the applicant, as well as their maximum allowable values, is provided for selected components of the TN-32B package.

Table 3.4. Cask Components and Their Respective Calculated Temperatures and Maximum Temperatures for NCT

Cask Component	Calculated °F (°C)	Maximum Allowed °F (°C)
Metallic Seals	232 (111))	663 (350.5)
Fuel Cladding	510 (265)	752 (400)
Radial Neutron Shield Resin	298 (148)	300 (149)
Thermocouple Lance	505 (263)	800 (427)

Staff confirmed that the maximum temperatures reported by the applicant were below the material temperature limits with sufficient margin, and therefore in compliance of 10 CFR 71.71.

3.3.2 Maximum Normal Operating Pressure

In section 3.3.2 of the SAR, the applicant provides a description of their evaluation for the MNOP of the TN-32B demonstration cask. Following the loading of the cask, a draining process is initiated, after which the cask is dried and backfilled with helium gas. The cask void volume, which is defined in the Technical Specifications for the TN-32B storage certificate, is specified, by the applicant, as being filled with 2,230 +/- 100 mbar (32.3 psia +/- 1.5 psia) of helium.

The applicant reports that while loading the TN-32B demonstration cask, they recorded an initial backfill pressure of 2,180 mbar (31.6 psia) after a three-day thermal soaking of the cask. The applicant provided a calculation for MNOP, using the measured initial backfill pressure and accounting for fuel rod fill and irradiation gasses, which resulted in a value of 30.5 psig, which is below the design pressure for the TN-32B HBU demonstration cask of 100 psig with the HBU payload. Staff reviewed the value for MNOP and found it consistent with what was listed and found the value acceptable and in compliance with 10 CFR 71.71.

3.4 Thermal Evaluation under HAC

The applicant evaluated the TN-32B demonstration cask design under the HAC sequence found in 10 CFR 71.73. In section 3.4 of the SAR, the applicant notes that the impact limit position on

the top of the cask protects the closure lid, the vent and drain port seals as well as the thermocouple lances from the environment defined by the thermal accident conditions. The applicant developed analysis models to examine the impacts of HAC on the TN-32B transportation package design.

As described in section 3.3.1.1 of the SAR, the applicant made numerous changes to the existing models that were used to examine the thermal performance of the TN-32B transportation package under NCT in order to evaluate the package under HAC. Some of these modifications are described below:

- Deformed impact limiters were added to the model to reflect the post-HAC drop condition.
- The model captured the thermal charring of the wood under HAC conditions.
- The cask surface emissivities were adjusted to reflect the assumed presence of soot and/or package surface oxidation.
- A “zero air gap” contact approach, associated with the cask and impact limiters, was used to maximize heat transfer into the cask during both the fire and wood char events.
- All air gaps in the cask and impact limiter models representing contact resistances were removed and conservatively replaced with thermal conductivity of the adjacent material to maximize the heat flow into the cask.
- Air gaps were restored in the model for the post fire 30-minute charred wood event and eventual 20-hour cool period in order to maximize thermal resistance.

The staff finds that the description of the applicant’s HAC thermal model for the TN-32B demonstration transportation package acceptable and in compliance with 10 CFR 71.73. The implementation of the applicant’s HAC thermal model is described further in the sections below, including a summary of the initial conditions of the HAC model, the fire test conditions applied to the model, and a discussion of the resulting maximum temperatures and pressures for the TN-32B transportation package.

3.4.1 Initial Conditions

In section 3.4.1 of the SAR, the applicant provided additional details on modifications made to the NCT thermal model to simulate the assumed cask conditions prior to and during the HAC fire event. These additional details related to the modifications made are provided below:

- The model included the “worst-case damage” arising from the postulated HAC free and puncture drops, (represented in figures 3-14 and 3-15 of the SAR),
- The results file of the NCT model run at a 100°F (38°C) ambient (with solar insolation and without deformed impact limiters) is used to map nodal temperatures onto the nodes of the HAC model as the pre-fire “initial condition”.

Staff finds the use of these initial conditions acceptable in developing a model that accurately determines the HAC thermal performance of the TN-32B cask comply with 10 CFR 71.73.

3.4.2 Fire Test Conditions

In section 3.4.2 of the SAR, the applicant provides a detailed discussion of the fire test conditions and the analysis model used to address the requirements in 10 CFR 71.73(c). A summary of the applicant's discussion of the modeling of the HAC fire is provided below:

- At the beginning of the HAC fire exposure, the analysis model is fully engulfed in an environment of 1,475°F (800°C) ambient, combined with an effective fire emissivity of 0.9 and package surface emissivity of 0.8, in order to simulate the average flame temperature of a hydrocarbon fuel/air fire event as defined in 10 CFR 71.73(c).
- Heat from the fire environment is transferred to the model of the TN-32B package outer surfaces. The convection heat transfer coefficient is adjusted for the fire environment and combined with the radiation heat transfer coefficient in the form of total heat transfer coefficient, which is applied to the package surface.
- Gaps associated with the cask and impact limiters are applied in the analysis model as described above in section 3.4 of this SER.
- The applicant assumed that the exposed surfaces of the package are soot-covered following the fire, and they apply a solar absorptivity of 1.0 and an emissivity of 0.9 for all package surfaces exposed to the environment during the cool-down period.
- The convection and radiation heat transfer to ambient are adjusted and combined in the form of a total heat transfer coefficient for the post fire cool-down period.
- Solar radiation is applied as a constant heat flux to the outer surfaces of the package, multiplied by the absorptivity factor of the surfaces, to calculate the amount of solar heat flux that each surface absorbs.

Staff finds the use of these fire test conditions acceptable in developing a model that complies with 10 CFR 71.73.

3.4.3 Maximum Temperatures and Pressure

The applicant discusses the results of their HAC analyses in section 3.4.3 of the SAR. The temperature and pressure results are discussed in sections 3.4.3.1 and 3.4.3.2 of the SAR, respectively. A summary of the results presented by the applicant is provided below.

3.4.3.1 Maximum Temperatures

The applicant, in section 3.4.3.1 of the SAR, discuss the maximum temperatures obtained from their thermal models of the TN-32B transportation system for the HAC fire condition. The results are provided in a series of tables as well as displayed visually in several figures. The results provided by the applicant are summarized below.

In Table 3-2 of the SAR, the applicant lists the predicted peak temperatures of selected components of the TN-32B demonstration cask under HAC conditions, including the closure lid, the vent/drain ports, and the TLA seals. The applicant concludes that these components remain below their maximum allowable temperatures and that significant thermal margins exist for all components reported in the table.

The applicant provides a temperature profile for the TN-32B transportation system at the end of the 30-minute hypothetical fire in Figure 3-17 of the SAR. The applicant maintains that the temperature profile obtained shows that the highest temperatures are “limited to narrow regions on the exterior of the cask and impact limiter exterior shell” which, in turn, speaks to the protection afforded to the package body and contents by the neutron shield, gamma shield, and impact limiters given the aforementioned locations of the high temperatures. This outcome is despite what the applicant notes is a “conservative” level of damage applied to the impact limiters in their analysis model.

Similarly, in Figure 3-18 of the SAR, the applicant provides a temperature profile for the TN-32B transportation package at the end of the 30-minute post-fire “smolder” period, which follows the 30-minute HAC fire exposure. The thermal performance of the TN-32B is further represented in Figure 3-19 of the SAR, which provides the temperature profile after a 40-hour cool-down period which follows both the 30-minute HAC fire exposure and the 30-minute post-fire “smolder” period.

The applicant also provided the maximum temperature response profiles for selected package components, including the fuel assemblies, which are illustrated in Figures 3-20 through 3-23 of the SAR. The applicant highlighted the fact that the relatively low temperature rise observed for the fuel assemblies and the cask components over the HAC fire event demonstrated the adequacy of the thermal protection provided for critical components in the package design.

The applicant specifically reported the maximum temperatures of the seals associated with the containment of the TN-32B transportation package, which were all within the prescribed limits for these materials:

- Closure lid-to-flange containment seal: 563°F (295°C).
- Drain/vent port and lance containment seals: 390°F (199°C).
- Overpressure port seal: 384°F (196°F).

Finally, the applicant reported that the predicted maximum fuel cladding temperature was 554°F (290°C), which, the applicant notes, is below the maximum allowable temperature under HAC of 1058°F (570°C).

The applicant concluded that their thermal analysis of the TN-32B demonstration cask design under hypothetical accident conditions meets all applicable thermal requirements found in the regulations in 10 CFR 71.73. The staff reviewed the applicant’s thermal analysis approach the values reported for maximum temperatures and finds that the values are acceptable and that the analysis results are in compliance with the regulations.

3.4.3.2 Maximum Pressure

In section 3.4.3.2 of the SAR, the applicant describes how the peak cask cavity pressure under HAC conditions was estimated. The applicant stated that the maximum pressure was calculated similarly to the MNOP under NCT conditions, as described in section 3.3.2 of the SAR, with the staff’s review of the applicant’s calculation of MNOP being discussed in sections 3.1.4 and 3.3.2 of this SER.

The applicant specifically reported that under the HAC transient, the peak bulk average helium temperature achieved is 457°F (246°C). With a cask void volume filled with 2,180 mbar (31.6 psia) of helium and an initial gas fill temperature of 179 °F (81.7°C), which the applicant notes is the average measured external cask surface temperature at the time of the helium fill.

The applicant accounts for a 100% release of fuel rod fill and irradiation gasses from the fuel rods during HAC in calculating the maximum cavity pressure value of 93.1 psig (642 kPa), which the applicant reports is below the maximum design pressure of 100 psig (689 kPa) with the HBU fuel assembly payload.

Staff reviewed the applicant's calculations for the maximum pressure and found it consistent with what was listed in the SAR and found the value reported by the applicant acceptable and in compliance with 10 CFR 71.73.

3.4.4 Maximum Thermal Stresses

The maximum thermal stresses for HAC conditions are presented in Subsection 2.7.4.2 of Chapter 2 in the SAR.

3.5 Confirmatory Analyses

Staff did not conduct a confirmatory analysis of the TN-32B transportation package; however, the following actions were performed regarding the analyses submitted by the applicant for this package. The staff:

- Reviewed the applicant's thermal models,
- Checked the code input in the calculation packages,
- Confirmed the use of the material properties and boundary conditions,
- Drawings were reviewed to verify the proper geometry dimensions, and
- Verified the material properties in the application that they were referenced and used correctly.

3.6 Evaluation Findings

The staff reviewed the package description, the material properties, the component specifications, and the methods used in the thermal evaluation and found reasonable assurance that they are sufficient to provide a basis for evaluation of the TN-32 HBU package against the thermal requirements of 10 CFR Part 71.

The staff's specific evaluation findings are provided below:

The staff has reviewed the package description and evaluation and concludes that they satisfy the thermal requirements of 10 CFR Part 71. The staff has reviewed the material properties and component specifications used in the thermal evaluation and concludes that they are sufficient to provide a basis for evaluation of the package against the thermal requirements of 10 CFR Part 71.

The staff has reviewed the methods used in the thermal evaluation and concludes that they are described in sufficient detail to permit an independent review of the package thermal design. The staff has reviewed the accessible surface temperatures of the package as it will be

prepared for shipment and concludes that they satisfy 10 CFR 71.43(g) for packages transported by exclusive-use vehicle.

The staff has reviewed the package design, construction, and preparations for shipment and concludes that the package material and component temperatures will not extend beyond the specified allowable limits during NCT consistent with the tests specified in 10 CFR 71.71. The staff has reviewed the package design, construction, and preparations for shipment and concludes that the package material and component temperatures will not exceed the specified allowable short-term limits during hypothetical accident conditions consistent with the tests specified in 10 CFR 71.73.

4.0 CONTAINMENT EVALUATION

As part of the DOE-EPRI HBU Dry Storage Research Project (HDRP), the HBU Demonstration Project Cask (designated as the TN-32B) has been used to collect confirmatory data on the conditions of HBU fuel in dry storage. This is a unique application in that the applicant, under the proposed CoC 9377, Revision 0, seeks NRC certification of the unique TN-32B dry storage cask (which includes additional penetrations in the cask lid for installed thermocouple lances and was used for experimental purposes prior to shipment) as a transportation package for SNF.

It is the applicant's intent to maintain the thermocouple lances in place within the cask during shipment, in order to utilize that instrumentation, following the one-time shipment, for further evaluation of the temperatures of the HBU fuel assemblies in the package, post-shipment. As further described below, the applicant has designated that the thermocouple lances themselves are part of the containment boundary for this design.

The objective of this containment evaluation review is to verify that the TN-32B package design satisfies the containment requirements of 10 CFR Part 71 under NCT and HAC.

4.1 Description of Containment System

The containment system is described by the applicant in sections 1.2.1.1 and 4.1 of the TN-32 Transportation Cask Safety Analysis Report, and the applicant's description is summarized below.

The components making up the containment boundary for the TN-32B transportation cask include the following:

- the inner shell and bottom inner plate,
- shell flange,
- closure lid outer plate,
- vent/drain port covers, and
- thermocouple lance assemblies (TLAs)

The seals and bolts associated with the containment boundary components listed above are also considered containment components.

Figure 1.1 of the applicant's SAR along with drawings 19885-71-2, 19885-71-3, and 19885-71-7, which are provided in appendix 1.4.1 of the SAR, present the overall layout, design, and assembly of the containment boundary and its associated components. The design of the

containment boundary is discussed by the applicant in chapter 2 of the SAR and the containment boundary fabrication requirements (including examination and testing) are further described in chapter 4 of the SAR.

4.1.1 Containment Vessel

In SAR section 1.2.1.1, the applicant describes the purpose and function of the containment vessel of the TN-32B in the following manner: “The containment vessel prevents potential leakage of radioactive material from the cask cavity. It also maintains an inert atmosphere (helium) in the cask cavity. Helium gas assists in heat removal and provides a non-reactive environment to protect fuel assemblies against fuel cladding degradation that might otherwise lead to gross rupture”.

The containment vessel is further described in sections 1.2.1.1 and 4.1.1 of the SAR, and the applicant’s description is summarized below.

Definition of Containment Boundary

The containment boundary of the TN-32B is composed of the following:

1. Inner shell (welded carbon steel cylinder).
2. Bottom inner plate (carbon steel).
3. Closure lid outer plate (carbon steel), closure bolts, and inner metallic O-ring seal.
4. Shell flange (forging).
5. Vent port cover plate, bolts and metallic O-ring seal.
6. Drain port cover plate, bolts and metallic O-ring seal.
7. Thermocouple (TC) lance assembly (with jacking screws) and inner metallic O-ring seal.

Containment Boundary Dimensions

1. Overall containment vessel length: 171 in. (wall thickness: 1.5 in.).
2. Cask cavity (cylindrical) inner diameter: 68.8 in.; length: 163.38 in.
3. Closure lid outer plate thickness: 4.5 in. (secured with 48 closure lid bolts).

Containment Boundary Materials of Fabrication

Components	Material(s) of fabrication
Inner shell, Bottom inner plate, Closure lid outer plate	SA-302 Grade D
Inner shell flange, Thermocouple penetration sleeve forgings	SA-350 Grade LF3
TLA structural materials*	SA-479 Type 304/304L (dual certified) austenitic stainless steel and SB-163/SB-166 Inconel (UNS N06600) annealed
*See SAR Table 2.12.12-3 (Page 2.12.12-20 of the SAR) for additional details	

The applicant states, in section 1.2.1.1 of the SAR, that the cask cavity surfaces are sprayed with an aluminum coating to inhibit corrosion. In addition, a stainless-steel overlay was applied to all surfaces on the cask body, vent, drain, and TLAs, in contact with metallic seals for corrosion protection.

Quality Control and Code of Record for Design, Fabrication, and Testing of Containment Boundary Components

As described by the applicant in SAR sections 1.2.1.1 and 4.1.1, the tasks of design, fabrication, and testing of the TN-32B demonstration cask were completed under TN Americas' Quality Assurance Program (QAP), which has been found to conform to the criteria in found in 10 CFR Part 71, Subpart H (ML18270A116). Similarly, the applicant performed the design, fabrication, and testing of TLAs under the QAP of AREVA, Inc., which was in effect at the time, and which conformed to the criteria in Subpart B of 10 CFR Part 50.

Further, the applicant followed the requirements of the ASME (B&PV Code, to the maximum extent practicable, for the design, fabrication, examination, and testing of the containment vessel of the TN-32B cask. More specifically, the applicant stated that section III, Subsection NB, Article NB-3200 was used for design, while fabrication and examination of the containment vessel was completed in accordance with Subsections NB-2500, NB-4000, and NB-5000 of the ASME B&PV code. Further, the applicant stated that the materials of construction meet the requirements of section III, Subsection NB-2000 and section II, Material Specifications of the ASME B&PV code, or the corresponding ASTM Specifications, with any exceptions noted as ASME code alternatives discussed in appendix 2.12.13 of the SAR.

The applicant also stated, in section 1.2.1.1 of the SAR, that the guidance found in NRC Regulatory Guides 7.6 and 7.8, which address the "Structural Analysis of Shipping Cask Containment Vessels" and "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material", respectively, was applied to the design of the containment vessel.

Finally, in section 4.1.1 of the SAR, the applicant indicates that hydrostatic pressure testing of the assembled containment vessel was done in accordance with the requirements of the ASME B&PV Code, section III, Subsection NB, Article NB-6200, during original fabrication of the cask in 2000, while the TLAs were hydrostatically tested during the lid modification completed in 2017.

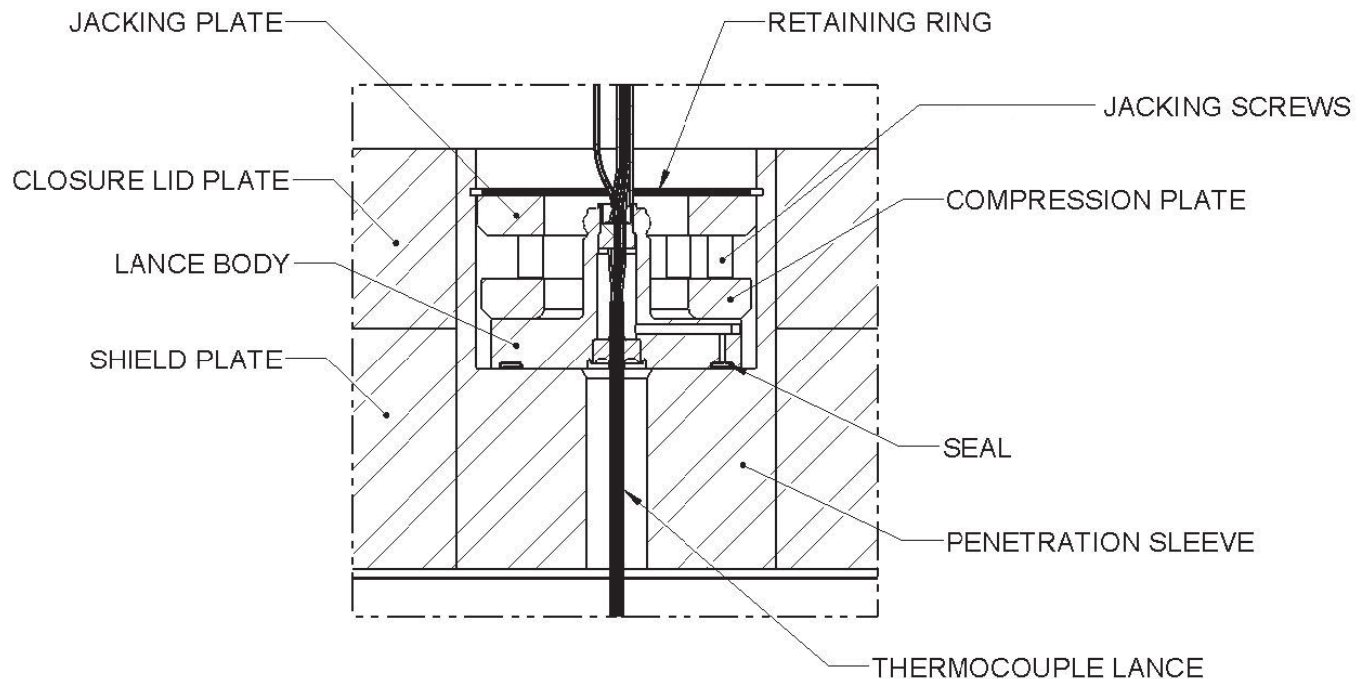
Staff reviewed the information provided by the applicant and finds the description of the containment vessel to be acceptable.

4.1.2 Containment Penetrations

In SAR section 4.1.2, the applicant stated that the closure lid has a total of nine penetrations which represent penetrations through the containment vessel. The vent and drain ports are two of those penetrations with the remaining seven consisting of thermocouple lances extending into spent fuel assemblies in the cask cavity.

Each penetration is provided a double O-ring metallic seal and a mechanical closure and while the vent and drain penetrations feature a bolted cover, while the TLAs are secured via jacking screws and compression plates, as well as a retaining ring (as seen in the diagram below).

Staff reviewed the information provided by the applicant and finds the description of containment penetrations to be acceptable.



4.2 Seals and Welds

The applicant identified the only differences between the containment boundary welds and seals of the TN-32B cask and those of the standard TN-32 dry storage cask, is the addition of the seven thermocouple lance assemblies, including the penetration sleeves.

For the thermocouple closure assembly, the applicant utilized a double metallic, silver-jacketed O-ring seal, which is identical to the seal used for the vent and drain closures previously approved for CoC No. 72-1021 (ML21334A468), and specifically for storage at the North Anna Independent Spent Fuel Storage Installation (ML17234A539).

Because this design feature was previously approved for use as part of the TN-32 storage cask design, staff finds this design feature acceptable for the TN-32B transportation package.

Seals

The applicant described the seals used for the closure of the TN-32B in Section 4.1.3.1 of the SAR. The TN-32B employs Helicoflex® HND metallic silver-jacketed seals (O-rings) on the closure lid as well as each of the nine lid penetrations. SAR Figure 4-2 provides a depiction of the seals, which have an inner spring (made of Inconel X-750 material), a lining that surrounds the spring (made of stainless steel), and a deformable outer jacket (made of silver).

The applicant provides a description of the function of the seal as follows: “The internal spring and lining maintain the necessary rigidity and sealing force and provides some elastic recovery capability. The outer silver jacket provides a ductile material that ensures leak tightness. The jacket also provides a connecting sheet between the inner and outer seals. Holes in this sheet allow for attachment of machine screws, and for communication between the overpressure (OP) port and the space between the seals. This sheet, which is approximately 0.020 in. thick, has insufficient strength to transmit radial forces significant to overcome the axial compressive forces on the seals. The O-ring seal for the OP port is a single metallic seal of a similar design (Helicoflex® HN200).”

The applicant goes on to state that: “The closure lid and penetration seals described above are contained in a groove in the closure lid or the port covers/lance body assemblies. A high level of sealing over the transport period is ensured by utilizing seals in a deformation-controlled design. The deformation of the seals is constant since bolt and jacking screw loads ensure that the mating surfaces remain in metal-to-metal contact. The seal deformation is set by the original O-ring cross section and the depth of the groove. The specified preload has the required force to seat the seals, as demonstrated in appendix 2.12.3.2.2 for the closure lid seal, and appendix 2.12.12.2.2 for the TLA seals.”

The staff has reviewed the aforementioned demonstrations of the specified preload as indicated by the applicant and finds them acceptable, as discussed in chapter 2 of this SER.

In order to ensure adequate surface control of all seating surfaces for the seals, the applicant stated that a stainless-steel overlay is applied to all seating surfaces for metallic seals; this is also true of the TLAs as shown in SAR Figure 4-3. The applicant maintains that surface control of the sealing surfaces contributed to the ability of the seals to successfully pass both fabrication (during cask fabrication) and pre-shipment (during loading of the HBU fuel payload) leakage tests, meeting the leaktight acceptance criteria per ANSI N14.5 (2014).

The applicant further states that at the time of loading the TN-32B, in November of 2017, the cask cavity was backfilled with helium gas and pressurized to above atmospheric pressure to preclude air in-leakage and the seals for the closure lid, port covers, and TC lances were tested for leakage. The applicant reported that the seals were tested to leaktight criteria, i.e., they collectively had a leakage rate of $\leq 1 \times 10^{-7}$ ref cm³/s, in accordance with ANSI N14.5 (2014).

As described by the applicant in SAR section 4.1.3.1, access to the volumes between the double seals in the closure lid, the vent and drain port cover plates, and the thermocouple lances is provided via an OP port, which is not part of the containment boundary, for leakage rate testing purposes.

The applicant further states that monitoring of the performance of the O-ring seals via the OP system during the storage period, indicated that there has not been any leakage from the containment boundary for the duration of the storage period.

The seals described above were reviewed and found acceptable during the review of the storage configuration for the TN-32 design under 10 CFR Part 72 (see chapter 8 of ML17234A539). The seal configuration has not changed between the time the TN-32 storage cask was loaded and the submission of the current application for a 10 CFR Part 71 certificate for transportation, and while the requirements for containment found in 10 CFR Part 71 for transportation are similar to the confinement requirements found in 10 CFR Part 72 for storage, they are not the same; therefore, the system of seals found acceptable for storage requirements

was re-evaluated by the staff based on the containment requirements for transportation found in 10 CFR Part 71 and found acceptable, as documented in this SER.

Welds

The applicant briefly described the closure welds for the TN-32B containment, and the examinations of those welds, in SAR sections 4.1.3.2 and 8.1.2, respectively. A summary of the applicant's description, as provided in the SAR, is as follows:

The containment boundary welds for the of the TN-32B (with the exception of the TLA penetration sleeve welds) are full-penetration welds that include both circumferential welds (such as those that attach the shell flange and bottom inner plate to the inner shell) and longitudinal welds (such as those used on the rolled plate, or shells, that form the cylindrical inner shell). Circumferential welds were used to attach the rolled shells together forming the completed inner shell.

Thermocouple Lance Assembly (TLA) Welds

Each TLA, as described by the applicant in SAR section 4.1.3.2: "...consists of a welded Inconel oversheath that contains nine K-type thermocouples, a reinforcing Inconel oversheath, and a Type 304/304L stainless steel insert that is welded to a Type 304/304L stainless steel body. Except for the square weld that joins the sheath tip plug to the oversheath, the lance containment boundary welds are fillet and partial penetration welds."

The sleeves that penetrate the TN-32B package closure lid and shield plate in order to receive the TLAs are secured to the lid with partial penetration groove welds, which makes them integral to the lid. Execution of the TLA welds and how they are examined is discussed below.

Containment Boundary Weld Classifications and Examinations

The applicant stated, in section 4.1.3.2 of the SAR, that the upper groove weld of the TLA sleeve that attaches the forging "to the closure lid is part of the containment boundary". The applicant further stated that the integrity of the upper groove weld, which, under section NB of the ASME B&PV Code, is classified as a Category C weld, was verified at the time of welding through visual and NDE, "in accordance with section V and the acceptance standards of section NB-5000 of the ASME B&PV Code", utilizing "multi-level liquid PT examination in the root", and on each subsequent weld pass.

The applicant stated that the welds for the TLA assemblies were performed utilizing the gas tungsten arc welding (GTAW) process, and are classified as a Category D under Section III, Subsection NB-3352.4 of the ASME B&PV Code, which specifically permits fillet and partial penetration welds. The applicant further stated that the TLA weld examinations were by a liquid PT process "using acceptance standards that exceeded the acceptance standards of section III, Subsection NB-5352", which, in a response to an RAI from the staff, the applicant clarified, in section 4.1.3.2 of the SAR, the specific acceptance standards used for PT examinations of the TLA containment welds, which the staff confirmed exceed the acceptance standards found in NB-5352.

As stated in sections 4.1.1 and 8.1.3.1 of the SAR, when the TN-32 containment vessel was fabricated in 2000, it was hydrostatically pressure tested (at a pressure of 45 psig) in

accordance with the requirements of the ASME B&PV Code, section III, Subsection NB, Article NB-6200. Weld joints of the containment boundary that were accessible were examined using MT examination for any defects. No defects were reported by the applicant. The applicant further conducted a bubble leakage rate test on the neutron shield enclosure (at 4.4 psig) which included the outer shell, outer shell top and bottom rings, in order to identify potential leak paths through the enclosure welds. No leakage was reported by the applicant.

Later, during fabrication of the TLAs (in 2017), the containment boundaries of the TLAs successfully passed a hydrostatic pressure test (to an external pressure of 3,125 psig) and a helium leakage rate test.

In SAR section 8.1.2, the applicant stated that containment welds for the TN-32B are “designed, fabricated, tested and inspected in accordance with ASME B&PV Code, Section III, Subsection NB.” The applicant reviews ASME code alternatives (regarding the containment vessel) in SAR Appendix 2.12.13 (appendix to chapter 2). Welding of the TN 32B containment was performed, to the maximum extent practical, using processes and personnel qualified in accordance with the ASME B&PV Code.

The applicant further stated that, at the time of fabrication, the base materials and welds for the TN32B were also examined in accordance with the requirements of ASME B&PV Code. Finally, the applicant states, in section 8.1.2, that: “NDE requirements for welds are specified on the drawings provided in [SAR] appendix 1.4.1. All NDE is performed in accordance with written and approved procedures. The inspection personnel are qualified in accordance with SNT-TC-1A¹.”

The staff reviewed the description of the welds provided in the application and found that the welds as described were acceptable. The acceptability of the welds in providing a leaktight containment boundary during transportation of the TN-32B is discussed below, in section 4.5 of this SER.

4.3 Closure

The applicant described the closure of the TN-32B in section 4.1.4 of the SAR. Part of the applicant’s description provided in the SAR is as follows: “The containment vessel contains an integrally welded bottom closure, and a bolted and flanged top closure lid, and the TLA closures that are secured to the welded penetration sleeves. The outer lid plate is attached to the shell flange with 48 bolts and hardened washers. The bolt tightening torque required to seal the metallic seals located in the closure lid and maintain containment under normal and accident conditions are provided in Drawings 19885-71-2 and 19885-71-3 in Appendix 1.4.1. The closure lid bolt analysis is presented in Appendix 2.12.3”.

For the lid penetrations mentioned previously, the applicant described the closure for these penetrations as follows: “the two vent and drain penetrations “are sealed by flanged cover plates” and “secured to the lid by eight bolts each, and” the “seven thermocouple lance assemblies...are each secured by eight socket head jacking screws via a jacking plate and compression plate”, as illustrated in Drawing 19885-71-2, provided in SAR appendix 1.4.1, which also provides the torque specification for these components (on Sheet 1 of 4).

Drawing 19885-71-3 (Sheet 1 of 4), also provided in SAR appendix 1.4.1, provides the appropriate torque specification for seating the metallic seals and maintaining containment under normal and accident conditions when installing the vent and drain port covers.

For closure of the containment vessel, both the bolt torque and the bolt torquing procedure remained unchanged for the TN-32B transportation application when compared with what was previously reviewed and approved for the storage application of the TN-32 (See section 8.1.4 of ML17234A539).

The staff reviewed the closure section of the applicant's SAR and found the description of the TN-32B cask closure provided to be acceptable.

4.5 Containment under NCT

The applicant provides a discussion in SAR section 4.2 of how the TN-32B meets the requirements found in 10 CFR 71.51, "no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A₂ per hour" regarding a release occurring under the tests specified in 10 CFR 71.71 for NCT.

Containment of Radioactive Material

The applicant discussed the containment of the radioactive contents in section 4.2.1 of the SAR. The applicant indicated that the results of the structural and thermal evaluations for NCT, presented in SAR sections 2.6 and 3.3, respectively, provided evidence that, for the NCT tests described in 10 CFR 71.71, release of radioactive material is not expected as the TN-32B containment will have been demonstrated to meet the "leaktight" standard as defined in ANSI N14.5 (2014).

The applicant further claims, also in SAR section 4.2.1, that all containment boundary seals for the TN-32B were demonstrated to be "leaktight" at the time of loading. In SAR section 8.1.4, the applicant provides a discussion of a "best effort" test of the containment boundary represented by the metallic cask body conducted during the closure lid modification to accept the TLAs, in order to verify "leak tightness." A discussion of the NRC staff's review of the "best effort" test, conducted by the applicant, is provided below in this SER.

As mentioned above, during storage of the TN-32 cask, seals are monitored by the OP system to ensure that a leaktight condition is maintained in the lid sealing system of the cask during storage. The applicant notes that the guidance provided in section 4.2.1 of NUREG-2224, "Dry Storage and Transportation of High Burnup Spent Nuclear Fuel", indicates that there are no release calculations required in order to demonstrate compliance with the regulatory release limits found in 10 CFR 71.51, for a "leaktight" system.

The staff reviewed the containment section of the applicant's SAR and found the description provided to be acceptable.

Pressurization of Containment Vessel

The applicant discussed the pressurization of the containment vessel under NCT in section 4.2.2 of the SAR. For the TN-32B demonstration cask, the applicant calculated the maximum normal operating pressure (MNOP) to be 30.5 psig (from SAR section 3.3.2).

The applicant stated that the containment boundary design pressure is 100 psig. In addition, the applicant stated that the structural evaluation in chapter 2 of the SAR demonstrated that, for pressure increases up to 100 psig, containment integrity (described in SAR section 4.2.1) of the TN-32B demonstration cask will be maintained.

Containment Criterion (NCT)

As presented by the applicant in SAR section 4.2.1 and indicated in the discussion in this SER (above), the TN-32B containment remains leaktight for NCT and, as a result, the staff finds reasonable assurance that there will be no release, loss, or dispersal of the contents of the package under NCT.

4.6 Containment under Hypothetical Accident Conditions (HAC)

Fission Gas Products

Because the applicant maintains, as described in section 4.3.1 of the SAR, that the containment boundary of the TN-32B cask has been demonstrated to be leaktight per ANSI N14.5, the applicant would, therefore, not need to explicitly determine a source term available for release from the contents of the TN-32B cask. Further, the applicant indicates that the structural and thermal evaluations, presented in chapters 2 and 3 of the SAR, respectively, provide verification that the containment boundary sealing surfaces remain elastic and that no containment boundary components exceed allowable material temperature limits.

The staff has reviewed the applicant's claims as presented above and finds them acceptable.

Containment of Radioactive Material

As indicated by the applicant in section 4.3.2 of the SAR and indicated in the discussion in this SER (above), leakage that would lead to a release in excess of the criteria defined in 10 CFR 71.51 for HAC is not expected from the TN-32B package under HAC.

Containment Criterion (HAC)

As stated by the applicant in Section 4.3.2 of the SAR and indicated in the discussion in this SER (above), the TN-32B remains leaktight for hypothetical accident conditions of transport and, as a result, there will be no release, loss, or dispersal of the contents of the package during transport under the HAC tests described in 10 CFR 71.73.

Leakage Rate Tests for Type B Packages

The TN-32B demonstration cask that is the subject of the application was fabricated in 2002-2004 timeframe, under CoC No. 1021. The cask was never loaded with spent fuel; however, the closure lid and associated seals were put in place and the unit was backfilled with helium and the closure was leak tested, as described above in section 4.1.3.1 of this SER. The entire containment boundary, including all welds and the base metal, was not leak tested at the time of fabrication or closure.

The unit remained in the applicant's fabrication facility until 2017 and the containment boundary, pressurized to 25 psig with helium at the time of sealing (for over 13 years of storage), did not indicate any loss of pressure (according to an OP monitoring system). As described in section 4.1.3.2 of the SAR, all weld joints in the containment boundary shell are full penetration with multi-layered welds for each joint, both magnetically and radiographically inspected. As described in section 1.2.1.2 of the SAR, the containment boundary shell is surrounded by an 8" thick gamma shield shell forging.

The TN-32B cask was loaded with fuel and placed in storage in November 2017. As described previously, after closure and sealing of the cask, fuel assembly temperatures were monitored by thermocouple lances inserted through the closure lid.

The applicant, in SAR section 4.4, describes the leakage tests performed on the TN-32B demonstration cask, stating that those tests are based on the tests found in chapter 7 of ANSI N14.5. The applicant provides a comprehensive discussion of the testing that was conducted in section 8.1.4 of the SAR. A summary of the testing discussed by the applicant is provided in the table below:

Type of Test	Date of Test	Components Tested	Acceptance Criteria/Test Results	Test Performed
Fabrication Leakage Rate	2003	Cask lid and seals ¹	1×10^{-5} ref cm ³ /s	Mass spectrometer leak detector (MSLD) performed during the original fabrication of the cask (2003)
Fabrication Leakage Rate	2017	<i>All containment O-ring seals; containment boundary forgings; and thermocouple lance assembly welds</i>	1×10^{-7} ref cm ³ /s	MSLD performed during the closure lid modification
<i>“Best-Effort” helium leakage rate test (Described in Section 8.1.4 of the SAR)</i>	August 2017	Entire metallic containment boundary	<i>helium leakage rate of less than 1×10^{-8} atm cm³/s (recorded after 2 hours on three separate tests)</i>	<i>Following the closure lid modification</i>
Fabrication Leakage Rate	September 2017	<i>All containment O-ring seals; containment boundary forgings; and thermocouple lance assembly welds</i>	1×10^{-7} ref cm ³ /s	
Pre-Shipments/Maintenance Leakage Rate Test ²	November 2017	<i>All containment O-ring seals; containment boundary forgings; and thermocouple lance assembly welds</i>	1×10^{-4} ref cm ³ /s and a sensitivity of 5×10^{-5} ref cm ³ /s or less	<i>helium mass spectrometer test</i>

Notes:

¹Leak testing did not include entire containment boundary (i.e., welds or base material)

²As metallic seals may only be utilized for one transport, pre-shipment leakage testing also fulfills the requirements for the maintenance and periodic leakage rate tests for the package.

The NRC staff's assessment of the leakage tests listed in the table above is provided below.

Fabrication Leakage Rate Testing

In SAR section 8.1.4, the applicant described two leakage tests performed on all of the metallic containment boundary seals. The first was during cask fabrication (in 2003), which had an acceptance criteria of 1×10^{-5} ref cm³/sec. The applicant further stated that: "Prior to opening the cask in July 2015 for the closure lid modification, the helium gas concentration and pressure in the cavity were measured, and determined to be 80.5% and 25 psig, respectively."

The second leakage test was done following the closure lid modification (which occurred between July 2015 and August 2017) and included containment O-ring seals, the containment boundary forgings, and the welds for the thermocouple lance assemblies. These tests, performed to an acceptance criterion of 1×10^{-7} ref cm³/s, demonstrated that the welds associated with the lid modifications and the seals installed at the time of the test were "leaktight". It should be noted, however, that this test did not constitute a test of the entire containment boundary of the TN-32B cask (Bryan, Charles R., Jarek Russell L, Flores, Christopher J, & Leonard Elliott J, Analysis of Gas Samples Taken from the High Burnup Demonstration Cask, United States <https://doi.org/10.2172/1498450>).

Review of "Best-Effort" helium leakage rate test

The applicant completed a "best effort" test on the metallic containment boundary of the TN-32B HBU cask at the time of the closure lid modification (in 2017). Leak Testing Specialists (LTS) of Orlando, Florida, prepared a procedure for this leakage test which was reviewed and approved by an individual with a Non-Destructive Testing (NDT) Level III certification, as recommended by ANSI N14.5.

The test report that documented the results of the testing was also reviewed and approved by a leak testing NDT Level III certified individual. The LTS technicians that performed the test were also NDT Level II and Level III certified. NDT Levels of Qualification are as described in Recommended Practice SNT-TC-1A (2016), "Personnel Qualification and Certification in Nondestructive Testing." The test is described in some detail in section 8.1.4 (pages 8-4 thru 8-6) of the SAR. A summary of how this test was conducted follows.

Figure 1, below, is a schematic provided in the applicant's SAR of the test setup that was used to conduct this "best effort" leakage test. To prepare for the test, the applicant drilled two holes through the ½ in. groove weld joint in the cask body flange/gamma shield, circumferentially located 180 degrees apart, in order to access the gap (annulus) that exists between the containment boundary shell (1½-in. thick) and the gamma shield shell (8-in. thick).

In order to facilitate leakage detection, one access hole was connected to a helium MSLD and a roughing vacuum pump while the other hole was connected to a calibrated standard leak and another roughing vacuum pump, as indicated, by the letters "A" and "B", respectively, in Figure 1 below.

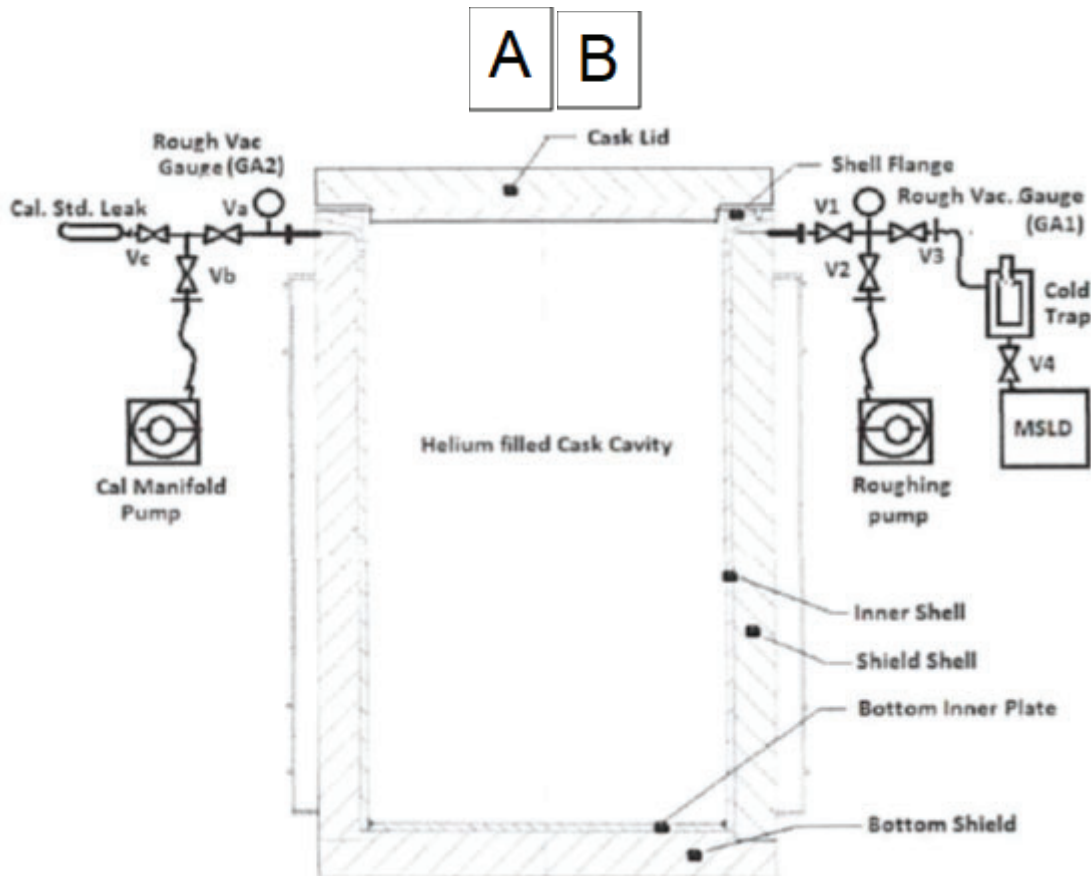


Figure 1: “Best Effort” TN-32B HBU Helium Leakage Test Setup

The applicant described, in Section 8.1.4 of the SAR, two “accumulation” tests which placed the annulus between inner shell and the shield shell under vacuum and were performed with the cask cavity under vacuum. The applicant reports that, within 30 minutes, the annulus pressure was decreased to 3.4 mTorr (6.57×10^{-5} psi) during these two tests.

The applicant reported that the MSLD employed in the test measured a peak helium leakage rate for each of the accumulation tests of 1.0×10^{-6} atm cm^3/s and 8.1×10^{-6} atm cm^3/s , respectively, approximately one hour into each of those tests. The applicant provided the following conclusion related to the leakage measured in the first two tests that were conducted: “These background helium leakage rates were attributed to lack of cleanliness between the shield and inner shell surfaces of the annulus, and not an indication of a leak in the containment boundary”.

During a third accumulation test, helium gas was introduced into the cask cavity, creating a reported pressure difference between the cavity and the annulus of 740 Torr (14.3 psig). For this test, a peak helium leakage rate of 1.1×10^{-5} atm cm^3/s was reportedly measured approximately one hour from the start of the third accumulation test.

The test report provided by the applicant indicates that, for all three accumulation tests, the measured helium leakage rate decreased to less than 1.0×10^{-8} atm cm^3/s after 2 hours. The applicant’s concluded the following: “that there was no leak path in those areas of the annulus that had conductance to the sensing port at the top of the cask.”

The applicant further concluded: "That leakage rate is convincing objective evidence that the metallic containment boundary is leaktight." The applicant further states that their conclusion on the determination that the containment was "leaktight" is supported by the fact that "the cask cavity maintained a pressurized helium atmosphere for over 13 years during the cask storage."

In response to an RAI related to the "best effort" leakage rate test discussed above, the applicant provided additional discussion of the test itself and the results obtained, the main points of that which are summarized below.

"The test of the metallic containment boundary was performed in accordance with ANSI N14.5, to the maximum extent possible. The measured leakage rate of the three separate "accumulation" tests was lower than leaktight criteria found in ANSI N14.5, i.e., 1×10^{-7} ref-cm³/sec; however, due to the fabrication and assembly process of the TN 32B cask, i.e., the "shrink fit" of a forged gamma shield around the cylindrical metallic containment boundary (the inner shell in Figure 1, above), a complete evacuation of the total volume of the annulus between the gamma shield and the inner shell may not be possible. As such, this would mean that the test, as it was conducted, could not ensure that the helium mass spectrometer leak detector (HMSLD) would be able to detect a helium leak over every square in. of the inner shell."

The applicant further noted that this condition is true for all TN metallic storage casks (e.g., TN-40/40HT, and TN-68), and, therefore, for this reason, the applicant concludes that the "best effort" leakage rate test cannot fully satisfy the requirements of the ANSI standard.

Pre-shipment Leakage Rate Test

As described in SAR section 7.1.3, the vent port seal will undergo a leak test upon replacement prior to shipment of the packaging. The applicant has indicated that this test will utilize a helium mass spectrometer with a sensitivity of 5×10^{-5} ref cm³/s, or less, and an acceptance criterion of 1×10^{-4} ref cm³/s for leakage rate test to verify proper assembly of the package for shipment.

The applicant has also indicated that since metallic seals may only be utilized for one transport, pre-shipment leakage testing also fulfills the requirements for the maintenance and periodic leakage rate tests for the package.

"Leaktight" Performance of the TN-32B Demonstration Cask

The unique nature of the TN-32B Demonstration dry storage cask, which includes additional penetrations in the cask lid for installed thermocouple lances and that has been primarily used for experimental purposes under an NRC CoC, means that this package, should it be moved from its current location, would likely be moved only once as part of a single transport operation.

The applicant, in section 4.1.1 of the SAR, stated that: "The containment vessel was designed to the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel (B&PV) Code, Section III, Subsection NB, Article NB-3200 to the maximum practicable extent. The containment vessel was fabricated and examined in accordance with Subsections NB-2500, NB-4000, and NB-5000."

As described in section 4.1.3.2 of the SAR, all weld joints in the containment boundary shell are full penetration with multi-layered welds for each joint, that were examined using surface (MT testing) and volumetric (radiographic testing) NDE methods. As described in section 1.2.1.2 of the SAR, the containment boundary shell is surrounded by an 8" thick gamma shield shell forging.

Following the fabrication of the TN-32B in 2000: "the assembled containment vessel was hydrostatically pressure tested in accordance with the requirements of the ASME B&PV Code, Section III, Subsection NB, Article NB-6200" and the empty cask was sealed and pressurized with helium. Although the initial backfill pressure of the TN-32B was not recorded, the cask was attached to a pressure monitoring system, and it remained sealed for over 13 years. During this time, there was no indication of any kind of leak from the pressure monitoring system attached to the helium-filled cask. When the TN-32B was opened in preparation for the closure lid modification, the applicant reported the cask cavity pressure and helium gas concentration were 25 psig and 80.5%, respectively.

As described above, the applicant had a "best effort" containment boundary leakage test performed on the TN-32B when the closure lid was modified in 2017. The test report, provided by the applicant, indicates that for three consecutive accumulation tests, the measured helium leakage rate decreased to less than 1.0×10^{-8} atm cm³/s after 2 hours. The applicant concluded "that there was no leak path in those areas of the annulus that had conductance to the sensing port at the top of the cask."

The applicant further concluded: "That leakage rate is convincing objective evidence that the metallic containment boundary is leaktight." The applicant further states that their conclusion on the determination that the containment was "leaktight" is supported by the fact that "the cask cavity maintained a pressurized helium atmosphere for over 13 years during the cask storage."

Staff Findings

The NRC staff, while reviewing the containment performance of the proposed TN-32B design transportation certificate request, considered the unique nature of the TN-32 storage cask, a single storage cask deployed with a lid modified to accommodate a temperature monitoring system in order to gather data on high burn-up SNF assemblies that are the current contents of this cask.

The cask in question, as mentioned above, has a documented performance history that includes pressure and leakage tests of the confinement boundary following initial fabrication, an evacuation and helium backfill, followed by a 13-year storage history, with pressure monitoring, that indicates that there was no leakage from the cask during that time. When the TN-32B receive the lid modifications, described above, there was another round of pressure and leakage testing, specifically of the installed lid penetrations and associated seals that made up the newly established confinement boundary for the TN-32B cask.

Further the "best effort" leakage test of the cask, which sought to capture as much of the confinement boundary as physically possible, was also conducted. The applicant has argued that these factors have demonstrated, to the greatest extent possible, "leaktight" behavior of the TN-32B demonstration cask.

This cask will likely undergo only one shipment under a transportation CoC. Given the known history of this cask system, taking the factors above into account, which provides defense in

depth, and given the information provided in the application and the applicant's responses to NRC staff RAIs, the staff has reasonable assurance that there would be no credible leakage from the TN-32B demonstration cask, if prepared and transported in accordance with the NRC issued CoC and, therefore, the TN-32B demonstration package would meet the applicable containment requirements for transportation found in 10 CFR Part 71.

4.6 Summary Conclusion

Based on review of the statements and representations in the application, the NRC staff concludes that the TN-32B package has been adequately described and evaluated to demonstrate that it satisfies the containment requirements of 10 CFR Part 71.

4.7 Evaluation Findings

From NUREG 2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material":

The staff has reviewed the applicant's 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, a package valve or similar device, if present, is protected against unauthorized operation and, except for a pressure-relief valve, is provided with an enclosure to retain any leakage.

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 NCT with no dependence on filters or a mechanical cooling system.

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

5.0 SHIELDING EVALUATION

The purpose of this evaluation is to verify that the shielding design of TN-32B cask to transport 32 intact pressurized water reactor (PWR) spent fuel assemblies with six PRAs meets the dose rate limits set forth in 10 CFR 71.47(b) and 71.51(a)(2) under NCT and HAC under exclusive use.

The staff evaluated the capability of the TN-32B shielding features to provide adequate protection against direct radiation from its contents during transport. This review includes the staff's evaluation of the descriptions of the proposed contents, the package shielding features and the calculation of the dose rates from both gamma and neutron radiation at locations near the package and at distances away from the package during transportation for both NCT and HAC. This SER documents the staff's review of the shielding analysis for the TN-32B package.

5.1 Shielding Design Description

The applicant designed the TN-32B to store three types of high burnup 17x17 PWR spent fuel assemblies (AMBW, LOPAR, and NAIF) with nominal enrichments of 4.55 wt.%, 3.59 wt.%, and 4.45 wt.% ^{235}U , respectively. The applicant indicated that irradiated non-fuel hardware, e.g., thimble plugging devices, would not be stored in the TN-32B cask. Tables 1.1-1 and 1.2-1 of the Design and Licensing Basis Document (DLBD), Rev. 8 (ML17109A457) identified the TN-32B cask design characteristics and fuel data respectively. Chapter 4.0 of the DLBD, Rev. 8 (ML17109A457) described the bounding radiation source terms for the fuel assemblies to be stored in the TN-32B package.

The shielding for the TN-32B is provided by the steel cask body, the containment vessel, and the closure lead (gamma shielding) borated polyester resin in aluminum boxes located radially around the containment vessel, the outer shell surrounding the resin, the aluminum rails inside the cavity, and the borated aluminum in the fuel basket provide additional shielding. The fuel assemblies for TN-32B are listed in section 1.2.2 of the SAR.

5.2 Summary Table of Maximum Radiation Levels

Table 5.2 of the application represents the maximum dose rates for NCT and HAC for fuel that is transported by the TN-32B. Only one cask will be transferred therefore the exclusive dose limits used.

Because the geometry of the source, basket design, and source strength vary widely between the fuel types, no one fuel type may be considered bounding for all dose rate locations therefore the applicant evaluated dose rates of the package for all fuel types. The 2-m dose rate is calculated at 2 meters from the vehicle side, while the occupied location (i.e., the driver) is calculated from the centerline of the package. This is acceptable because the package will be transported in a horizontal position in an open vehicle with an enclosure.

The NCT dose rate limits per 10 CFR 71.47 are 1000 mrem/hr for the enclosed package surface, 200 mrem/hr for the vehicle surface, 10 mrem/hr at 2 meters from the vehicle surface, and 2 mrem/hr for occupied locations. The HAC dose rate limit per 10 CFR 71.51(a)(2) is 1000 mrem/hr at 1 meter from the cask surface. The vehicle is 10 ft. and 8 in. wide and 40 ft. long.

Under NCT, the maximum enclosed package surface dose rate is 211.8 mrem/hr, the maximum vehicle surface dose rate is 35.2 mrem/hr, the maximum dose rate 2 meters from the vehicle surface dose rate is 7.6 mrem/hr, and the dose rate in the occupied location for a 40-ft. railcar is 0.7 mrem/hr, and under HAC, the maximum dose rate at 1 m from the cask is 505 mrem/hr. Since the reported dose rates are all below regulatory limits, the staff finds this acceptable.

5.3 Source Terms

To determine the bounding radiation source terms for the fuel assemblies to be loaded in the TN-32B cask, the applicant modeled spent fuel assemblies using a uranium loading of 0.460 MTU and 0.466 MTU, nominal enrichments ranging from 3.59 wt% U-235 to 4.55 wt% U-235, and burn-up ranging from 50.047 to 55.496 GWd/MTU per assembly. The applicant used the actual number of irradiation cycles for each assembly and a specific power of 21.015 MW per

fuel assembly in the model. Except for fuel assembly OA4, which has two irradiation cycles, the applicant used three irradiation cycles in the models for all assemblies. The applicant used the assembly which produced the largest total source term as the bounding assembly and conservatively assumed all assemblies had this source term for the dose rate calculations.

The applicant used the ORIGEN-ARP/ORIGEN-S modules of the SCALE code to generate radiation source terms. The applicant identified that fuel assembly 54B produced the largest neutron and gamma source terms. The applicant used the neutron and gamma source terms for each assembly to calculate the dose rates for the TN-32B cask. The applicant also determined gamma sources from activated hardware in the plenum, top and bottom end fitting regions for fuel assembly using ORIGEN-ARP/ORIGEN-S.

The applicant presented the primary gamma source terms from the bottom nozzle, the active fuel region, the plenum, and the top nozzle, as well as the neutron source term, in Table 5.8 of the SAR for each fuel assembly. The applicant increased the enrichment of the fuel source by 0.05 for each fuel assembly, and increased burnup by 2.5% to accommodate for any uncertainty in the enrichment and burnup. The applicant also used an axial peaking factor a subcritical multiplication factor, and homogenized materials in their modeling of each axial region.

Staff reviewed the applicant's source term calculation methodology and the calculation results Using Scale 6.1 code. The staff's determination is based upon that the code is cited as a well-established code commonly used for spent fuel dry transportation packages source term and shielding evaluations that the staff has found to be acceptable in section 5.4.2.1 of NUREG-2216.

Staff also performed confirmatory source term analyses using the same fuel depletion parameters provided in the in the SAR with the 238-group ENDF/VII cross section library of the ORIGEN-ARP isotopic depletion and decay sequence in the SCALE 6.1 computer code. Staff's confirmatory calculations generated results which were similar to the applicant's results; therefore, staff found the applicant's results acceptable.

Gamma Source

The applicant calculated the gamma source terms as function of energy for each fuel types using the ORIGEN-ARP sequence of SCALE 6.1 computer code for in-core region and activated hardware. The source term used the design MTU loading and radiation history for each fuel assembly. The 18-group gamma source spectra is consistent with SCALE 27n-18g structure. Scaling factors in Table 5-7 of the SAR applied in calculating of the inputs from ORIGEN-ARP code in estimating plenum, top nozzle, and bottom nozzle gamma contributions. Table 5-9 through Table 5-40 of the SAR represent the gamma source for each fuel assemblies.

Neutron Source

Neutron source as function of energy presented in the Tables 5-41 through 5-72 of the SAR. The neutron source is evaluated from all contributing nuclides, and all reactions include spontaneous fission and alpha, n reactions. The total source for all 32 assemblies is 1.778×10^{10} n/sec from ORIGEN-ARP. The neutron subcritical multiplication due to fission is accounted for by a separate calculation.

5.4 Shielding Model

The applicant developed a 3-D MCNP model of an intact TN-32B cask and used this model to evaluate dose rates for both NCT and HAC. For each model, contribution from neutron, secondary gamma from neutron interactions, and primary gamma contributions were evaluated. A four axial zone model was used for bottom end fitting, in-core, plenum, and top end fitting.

The applicant homogenized the fuel over the cross section of the fuel in basket and used the appropriate length and axial peaking factors for in the core region. Three separate models for NCT and HAC were used to find contributions from gamma, neutron, and secondary gamma. The source was modeled uniformly in radial position and varied axially to apply peaking factors.

The results of the three evaluations for each NCT and HAC were added to find the total dose rates of the package. The MCNP model was based on the drawing in appendix 1.4.1. The basket was modeled as stainless-steel boxes encircled by aluminum plates. The rails and neutron resin boxes were modeled individually. The borated polyester resin, the steel surrounding the resin outer shell, and the impact limiters were not credited for HAC in the MCNP model.

Thermocouple Penetrations.

Seven penetrations were made to the lid confinement boundary and shield plate in the original design. Thermocouple lance assemblies were mounted and secured in each of the seven penetrations, and each lance mounting assembly was designed with its own double-metallic, silver-jacketed O-ring seals to comprise part of the confinement boundary. During transportation, a steel lance cover with a thickness 2.13 in. was placed over each penetration, and 1.75 in. thick resistant steel plate installed over the closure lid. Figure 5.4 of the SAR shows the MCNP model of the lid with these seven holes.

Material Properties

The applicant used material properties based on the fuel specifications presented in Table 5.73 of the SAR and material mass density of fuel assembly in Table 5.74 of the SAR. The applicant used material properties for the remaining structures and components from the standard material composition library of SCALE computer code package which has been adequately verified and validated for this type of application. Therefore, staff finds the material properties of the cask structure and components used in the criticality safety analysis models appropriate and acceptable.

5.5 Shielding Evaluation.

5.5.1 Methods

The applicant used the MCNP-5 code with ENDF/B-VII. nuclear data library to calculate dose rates for each individual energy group at the desired locations. Per the guidance in NUREG-2216 section 5.4.4.1, the staff found that the MCNP code, with the latest nuclear data, is acceptable for the shielding evaluations of the TN-32B HBU package.

5.5.2 Fluence-Rate-to-Radiation-Level Conversion Factors

The MCNP code calculates a fluence per emitted particle. This fluence is then converted into a dose rate by using fluence-to-dose rate conversion factors to arrive at the dose rate per emitted particle. The applicant used the fluence-to-dose-rate conversion factors recommended by NUREG-2216 (i.e., the 1977 ANS/ANSI-6.1.1 standard) and are therefore acceptable to the staff. The applicant added an additional two sigma to the fluence calculated by MCNP to account for the statistical uncertainty of the Monte Carlo code. The staff found it to be a conservative and acceptable way to account for this uncertainty.

5.5.3 Dose Rate Results

External Radiation Levels

The MCNP code uses “tallies” when determining particle flux at a location of interest. The tally cell represents the volume in space that the particles are collected. Tally cells need to be small enough to reasonably represent a maximum dose (versus an average). The mesh tallies F4 employed by the applicant in calculating dose rates around the surface of the TN-32B.

The staff used its judgment and consideration for the conservatism within the source term modeling and found that the size of the tally for the dose rate calculations is acceptable with these considerations. The locations of the tally cells are based on the locations specified in 10 CFR Part 71 (e.g., surface, 2 meters, and 1 meter under HAC).

To determine dose rates on the radial, top and bottom surfaces of the TN-32B HBU cask, as well as 1 and 2 meters from the cask radial and top surfaces, the applicant used MCNP5 mesh tallies. These MCNP5 tallies determined the number of particles per unit area (i.e., the particle flux).

The applicant placed the mesh tally (F4) at the surface of the TN-32B HBU. For the 2-meter tally, it is placed 2 meters from the vehicle surface assuming a 100-in.-wide trailer. This is acceptable since the regulation in 10 CFR 71.47(b) has dose rate limits defined from the vertical planes projected by the outer edges of the vehicle for a flat-bed trailer. The applicant assumed a vehicle width of 128 in.

The staff found that the size of the trailer assumed by the applicant is a reasonable width based on the standard width of a trailer and standard width of U.S. roads. For HAC, the applicant located the tallies at 1 meter from the package surface. This is appropriate and acceptable to the staff as dose rate limits under HAC in 10 CFR 71.51(a)(2) are defined at 1 meter from the package.

The results of the applicant's calculations for dose rate at the various regulatory locations are summarized in Table 52 of the application for gammas, neutrons for the surface of the package and total, for top, side of the package, vehicle surface, and 2 meters from vehicle surface, 1 meter from package in HAC and occupied location of the vehicle.

The results of the applicant's evaluations of the dose rate are in Table 5.83 through Table 5-85 of the application. Figure 5-9 through 5-18 graphically show dose rates on the surfaces of the package and vehicle surface.

5.6 Evaluation Findings

The staff concludes that the shielding design of the TN-32B package, when used as described in the application, is in compliance with 10 CFR Part 71 and that the applicable design and acceptance criteria have been satisfied.

The staff has reasonable assurance that the TN-32B design will provide safe transportation high burnup fuel. This finding is based on the appropriate regulatory guides, applicable codes, and standards, the applicant's analysis, responses to requests for additional information, and acceptable engineering practices.

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. Therefore, the staff finds that the package design and contents satisfy the dose rate limits in 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

The purpose of this evaluation is to verify that the TN-32B package meets the criticality safety requirements of 10 CFR 71 under the conditions described in 10 CFR 71.71 and 71.73. The contents of this proposed one-time shipment consist of a fixed, spent fuel inventory with known burnup, enrichment, and cooling times. The package is designed to be transported under exclusive use. Staff's evaluation follows the guidance of NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material" (SRP).

6.1 Description of Criticality Design

6.1.1 Packaging Design Features

The components of the TN-32B important to criticality safety include the following: basket assembly; containment vessel; forged steel shell and neutron shield; and outer shell. The applicant relies on the basket assembly to support the contents and maintain fissile material geometry. The basket also contains a fixed neutron absorber, and the applicant relies on a minimum absorber concentration to maintain criticality safety.

The applicant also installed unirradiated PRAs, for which the applicant also assumed a minimum absorber concentration to maintain criticality safety. Criticality safety for the TN-32B package does not rely upon the containment vessel for moderator exclusion. The forged shell assembly maintains credible spacing in the applicant's analysis of arrays of packages.

6.1.2 Summary Table of Criticality Evaluations

The upper subcritical limit (USL) for ensuring the TN-32B package remains subcritical is 0.95. The applicant presented the most limiting results of its criticality analyses in Table 6-3. The staff reviewed the results and noted all are less than the USL with all biases and uncertainties applied. As a result, the staff finds reasonable assurance the applicant's calculations are at a 95 % confidence level or better.

6.1.3 Criticality Safety Index

The applicant demonstrated that an infinite array of flooded casks, both undamaged and damaged, remains subcritical. As a result, the TN-32B has a Criticality Safety Index (CSI) of 0 for the most limiting configuration according to 10 CFR 71.59(b).

6.2 Nuclear Contents

The TN-32B package contains 32 undamaged 17x17 PWR fuel assemblies. These consist of Westinghouse 17x17 LOPAR, NAIF, and AREVA 17x17 AMBW assemblies. The assemblies were irradiated between roughly 50 and 55.5 GWd/MTU, and are considered high burnup (i.e., irradiated to more than 45 GWd/MTU). The assemblies have initial ^{235}U enrichments ranging from 3.59 to 4.55 wt.%. The earliest shipping date requested by the applicant will result in a minimum cooling time of 11.56 years, with a maximum of 36.45 years. The burnup, enrichment, and cooling time (BECT) parameters for the fuel assemblies are listed in Table 6-4 of the application. Two of the assemblies have had fuel rods removed and replaced with stainless steel rods with equivalent water displacement. Six, unirradiated PRAs are inserted into fuel assemblies for criticality control. The specifications of the PRAs are shown in Table 6-2 of the application. No irradiated non-fuel hardware will be transported in the TN-32B package. Two assemblies have had fuel rods removed and replaced with stainless steel rods with equal moderator displacement. There will be no damaged fuel assemblies transported in the TN-32B package.

6.3 General Considerations for Criticality Evaluations

6.3.1 Model Configurations

6.3.1.1 Depletion Model

Using TRITON, the applicant modeled a Westinghouse-type 17x17 fuel array with an initial enrichment ranging from 3-5 % ^{235}U and a Zircaloy 4 cladding. The applicant evaluated enrichment over that range in 0.5 % increments. The applicant included burnable poison rod assemblies (BPRAs) in its TRITON model, which it modeled as $\text{Al}_2\text{O}_3\text{-B}_4\text{C}$ (3% B_4C) with a Zircaloy 4 cladding. The applicant assumed the gap between the burnable poison rods (BPR) and guide tubes are flooded with the same borated water as the coolant during irradiation. The applicant also assumed the BPRAs are present throughout the irradiation cycle. The staff finds this acceptable because prior evaluation has shown the presence of BPRs to be conservative since the depletion code will over-predict plutonium generation and thus calculate a higher reactivity. The applicant did not consider the presence of control rods, and the staff finds that acceptable since the presence of BPRAs is bounding for depletion analysis.

One BPRA was of a different design, $\text{B}_2\text{O}_3\text{-SiO}_2$ with 12.5% B_2O_3 . Since the absorber still consists of boron, there will likely be no significant effect on the calculated neutron spectrum during the depletion analysis. In addition, the maximum $\Delta k/k$ that can be expected from the presence of BPRAs during three burn cycles is about 2-3%, and the impact of a single different BPRA on depletion would be a fraction of that since it would only affect one out of 32 assemblies. As a result, staff finds the presence of this one BPRA will have no significant effect on the applicant's depletion analysis.

The applicant used a simplified STARBUCS model to calculate the isotopic depletion for each region using assembly irradiation history and an assumed cooling time of 5 years at enrichments of 3.0, 4.0, and 5.0 wt.% ^{235}U . These enrichments span the range the applicant

used in its analysis to determine the most reactive configuration and the staff finds them acceptable.

The maximum burnup the applicant calculated in its depletion analysis is 77.5 GWd/MTU. The spent fuel assemblies authorized for the TN-32B all have less than 60 GWd/MTU of burnup. Prior Oak Ridge National Laboratory (ORNL) studies have evaluated the nuclear data and methodology up to 60 GWd/MTU, which encompasses the selected inventory of spent fuel contents. As a result, the staff finds the applicant's burnup calculations up to 60 GWd/MTU acceptable. The applicant evaluated a minimum of 5 years cooling. The staff finds the burnup range and minimum cooling time acceptable since they encompass the burnup and cooling time range of the TN-32B contents.

The applicant used a constant, bounding specific power and zero down time between cycles. Prior studies have shown these assumptions increase calculated discharge reactivity, and the staff finds these acceptable. The applicant did not evaluate the effects of axial blankets. Since axial blankets are not present in the fuel at NAPS, the staff finds their omission from the burnup consideration of these 32 fuel assemblies acceptable.

The applicant selected an axial profile that prior ORNL studies have shown to sufficiently capture burnup distribution effects; therefore, the staff finds it acceptable. The applicant did not evaluate a horizontal burnup profile. Except for fuel assemblies on the periphery of the core, typical PWR operation results in a uniform horizontal burnup. The probability of those peripheral assemblies being loaded in a single package with orientations to cause a significant difference in reactivity is unlikely.

In addition, the 32 assemblies for the TN-32B package are all high burnup, and any effect on reactivity decreases as burnup increases. For these reasons, the staff finds the applicant's assumption of uniform horizontal burnup acceptable. The applicant selected the fuel temperature from a nominal range from the operating history at NAPS. The applicant presented its fuel temperature sensitivity results in Table 6-11 of the application, and the staff noted the applicant's bounding value is the same that studies have shown to be conservative with respect to criticality.

The applicant selected a high, bounding soluble boron concentration. Higher levels of boron in the moderator during depletion will result in a harder neutron spectrum and increase the calculated production of ^{239}Pu . Since this increases the calculated reactivity of the contents, the staff finds the applicant's bounding soluble boron concentration acceptable. The applicant selected the minimum moderator density of the nominal range at NAPS. This value is lower than the reference value used in Reference 5. A lower density yields a harder spectrum which will increase the amount of calculated actinide production which increases predicted reactivity. As a result, the staff finds the applicant's minimum moderator density value acceptable.

It should be noted that the applicant's determination of most reactive depletion parameters ignores the actual irradiation history of any assembly in the spent fuel inventory. In effect, the applicant selected the most limiting parameter of any specific assembly and applied it uniformly to the entire inventory, which results in an inherently conservative calculation.

For the reasons discussed above, the staff finds reasonable assurance the applicant's selection of burnup conditions will yield a bounding, calculated, post-irradiation composition of the 32 North Anna fuel assemblies.

6.3.1.2 Criticality Model

The applicant used STARBUCS to calculate isotopic inventory at given BECTs. The applicant used STARBUCS to determine which perturbations to the KENO.Va geometry that result in the most reactive configuration (e.g., shifting of fuel assemblies within basket locations). Each configuration is evaluated across a set of conditions that span the range of burnup, enrichment, and cooling times for the fuel assemblies. STARBUCS is used to calculate the isotopic inventory for each axial node for each of the cooling time groups for each of the fuel types. The applicant differentiated the fuel into 18 axial zones. This follows prior studies that show this number of zones sufficiently captures effects that are important to criticality safety (4), and the staff finds this acceptable.

For its criticality analyses, the applicant again used the STARBUCS module of SCALE 6.1 to calculate the isotopic inventories present for a given BECT. The STARBUCS module will automatically call the CSAS5 module to calculate k_{eff} using the TN-32B KENO-V.a model with the isotopic inventory for the contents it just calculated. The SCALE modules used by the applicant and relevant staff findings regarding the criticality safety analyses are discussed in section 6.3.3 below.

Generally, the TN-32B package relies on fixed neutron absorbers in the basket, PRAs, and favorable basket geometry to ensure criticality safety. The applicant assumed the basket structure does not experience significant deformation as a result of HAC. The staff found the applicant's analysis in appendix 2.12.8 of the application supports this assumption. The applicant modeled 30 cm of water reflection outside of a single package under both NCT and HAC. The difference between the NCT and HAC models is the nature of the interior flooding and exterior reflection. Under NCT, the applicant assumed full-density, unborated water. For HAC, the applicant varied the density of the unborated water to determine maximum reactivity. These assumptions follow the guidance of the SRP, and the staff finds them acceptable. For arrays, the applicant made no changes to the geometry except for the radial reflective boundary conditions to effectively model an infinite array of packages under NCT and HAC.

The applicant presented package component dimensions important to criticality safety in Table 6-1 of the application. The staff reviewed these numbers and compared them to those used in a previous criticality safety analysis for a dry storage system using identical packaging. The staff noted the dimensions are the same as those that the staff previously found acceptable. The applicant presented the design-basis assembly characteristics important to criticality safety in Table 6-5 of the application. The staff noted the type, dimensions, and characteristics are the same as those previously found acceptable by the NRC staff.

The applicant did not model the peripheral aluminum rails explicitly and homogenized the aluminum content of those rails as a single mixture of aluminum and water. The NRC staff has evaluated this assumption in TN-32 storage applications and found it acceptable.

The applicant modeled all the fuel assemblies in the basket compartments shifted toward the center of the package. This has been shown to be the most reactive assembly configuration and the staff finds this acceptable.

6.3.2 Material Properties

The applicant relies on the basket geometry as described in chapter 2, appendix 2.12.8. The applicant included BPRAs in its TRITON analysis with compositions taken from Reference 3. The staff has previously reviewed this reference and used it to develop guidance for the application of burnup credit, and the staff finds its use here appropriate.

The applicant assumed 90% of the fixed boron loading for its criticality analyses. The applicant detailed its testing program in section 8.1.6.2 of the application. The staff previously reviewed the applicant's testing (9) and found it acceptable, therefore the staff finds the use of 90% of the boron density in the TN-32B basket absorber acceptable. This follows SRP guidance in NUREG-2216 and the staff finds it acceptable. The applicant only credited a portion of the B_4C content for the PRAs. The applicant did not present a testing program to verify the boron content of the PRAs. The staff reviewed the PRA boron fraction the applicant relies on for criticality safety and noted it is less than the maximum allowed per section 6.3 of the SRP. Since this will result in a higher calculated k_{eff} , the staff finds the applicant's PRA boron fraction acceptable.

The applicant presented the material composition used in its depletion and criticality analyses in Tables 6-9 and 6-10 of the application, respectively. The staff reviewed the properties of the homogenized regions and finds the applicant appropriately scaled the composition in its analyses. With other materials, the applicant used the material properties that are distributed with the SCALE composition library. These have a long history of use with criticality analyses and the staff has previously found them acceptable.

The applicant calculated the initial uranium isotopic composition using data from Reference 11. These uranium isotope ratios, given as a function of initial enrichment, have a long history of use in nuclear analysis and the staff finds their use acceptable. The applicant modeled initial enrichments at 3.5 and 4.6 wt.%. This bounds the enrichments of the selected fuel assemblies as shown in Table 6-4 of the application, and the staff finds this acceptable. The applicant grouped the fuel assemblies evaluated into six groups with equal or greater cooling time within a group, as seen in Table 6-4 of the application. Since minimum cooling time is conservative for loading, the staff finds the applicant's cooling time modeling acceptable.

6.3.3 Methods and Nuclear Data

The applicant performed its criticality analyses with the SCALE 6.1 code suite. The applicant used several different modules, including STARBUCS, ORIGEN-ARP, and CSAS5/KENO-V.a for depletion and package criticality models. STARBUCS is an analysis sequence in SCALE designed to automate burnup credit criticality safety analyses. It does this by coupling other SCALE modules which determine spent fuel composition, self-shielded cross-sections, and the k_{eff} of a given spent fuel configuration. The ORIGEN-ARP module develops problem-specific cross-section libraries by interpolating from pre-calculated ORIGEN libraries. ORIGEN-ARP has been validated for LWR spent fuel and the staff finds its use appropriate. KENO-V.a/CSAS5 is a three-dimensional Monte Carlo transport program designed for criticality analysis. These software applications were specifically designed by ORNL to evaluate nuclear safety and are well vetted with a long history of use in spent fuel analysis. Therefore, the staff finds the applicant's use of this software acceptable.

The applicant used the 238-group cross-section library distributed with SCALE 6.1 that is based on ENDF/B-VII nuclear data. This data has a long history of use with nuclear evaluations and has been extensively validated. As a result, the staff finds the applicant's use of these cross-sections appropriate.

6.3.4 Demonstration of Maximum Reactivity

The applicant determined the most limiting assembly type, from a criticality safety standpoint, is the AREVA 17x17 AMBW. The AMBW type assemblies have both a higher initial heavy metal load and higher enrichment than the LOPAR and NAIF type. A higher heavy metal loading means more uranium is present, and higher enrichment yields a more reactive assembly. For

these reasons, the staff finds the applicant's limiting its criticality evaluation to the AMBW type assembly acceptable.

As discussed in section 6.3.1.1 above, the applicant's bounding inventory also utilizes the most reactive perturbation of each of the depletion parameters. The staff finds this acceptable since it maximizes the calculated reactivity. The applicant modeled the TN-32B with the cavity flooded with full-density, unborated water which meets the requirements of 10 CFR 71.55(b).

The applicant evaluated fuel assemblies with an assumed initial enrichment of 4.6 wt.% and a burnup of 50 GWd/MTU. These values are bounding of the fuel inventory in the TN-32B HBU demonstration cask since all the assemblies are enriched less than 4.6 wt.% and burned to greater than 50 GWd/MTU. The applicant selected the most bounding ORIGEN-ARP library with the most bounding depletion parameters from its depletion analysis for subsequent criticality analyses.

The applicant created additional STARBUCS models to calculate isotopic inventory at a series of discrete cooling times from the ORIGEN-ARP libraries generated for the bounding burnup and enrichment values. The STARBUCS code uses CSAS5 to perform a criticality calculation with the same KENO-V.a geometry.

The configuration changes the applicant analyzed in its evaluation are axial offset, basket tolerance, neutron poison plate thickness, fuel-cladding gap and thickness, missing fuel rods, uniform and non-uniform pitch expansion, moderator density, pitch contraction, and axial repositioning.

In the axial offset analysis, the applicant shifted the entire active fuel region of the fuel assembly to offset from the borated aluminum poison plates. The design length of the poison plates the same as that of the active fuel region. As a result, axial shifting will place part of the active fuel region above the poison plates which may allow more neutron interaction among the assemblies. The staff reviewed the range of the applicant's axial shift and the results in Table 6-16 of the application and finds the magnitude of the shift covers the possible motion of the fuel assemblies.

The applicant modeled the basket thickness at its minimum manufacturing tolerance for its baseline case. This has the effect of increasing the fuel compartment size. Any further evaluation of the fuel compartment tolerance could require a change to the modeled overall inner cask dimension. As a result, the applicant evaluated the largest possible fuel compartment size while maintaining the inner cask diameter. The staff reviewed the applicant's results in Table 6-17 of the application and can confirm that the smallest compartment size of the baseline case is more reactive. As a result, the staff finds the applicant's use of the manufacturing tolerance as a baseline limit to the compartment size acceptable.

The applicant evaluated the effect of reducing the poison plate thickness. The applicant presented the results of its analysis in Table 6-18 of the application. The staff reviewed the results and noted that the effect was small, however the largest calculated Δk_{eff} was positive. The applicant adjusted its model to incorporate the change which maximizes the calculated system k_{eff} . As a result, the staff finds this acceptable.

The applicant modeled the fuel-cladding gap as filled with unborated water in all fuel rods. This has been shown to be conservative in past evaluations, however the applicant still evaluated a case with the fuel-cladding gap filled with void. The staff reviewed the applicant's results in Table 6-19 of the application and can confirm that the flooded gap is more reactive.

For its evaluation of clad thinning, the applicant considered two scenarios; expanding gap, which is when the clad deteriorates from the inside, and contracting exterior, which is when the clad deteriorates from the outside. The staff reviewed the magnitude of the thinning considered by the applicant and finds it covers the range of any likely thinning to occur. The applicant presented the results of its expanding gap and contracting exterior evaluations in Tables 6-20 and 6-21 of the application, respectively.

A number of fuel rods were removed from some assemblies in the TN-32B and replaced with stainless steel “dummy” rods of equal volume. The applicant ignored this specific change and modeled all rods as normal fuel pins. Typically, increasing the fissile material in the package will correspond to an increase the calculated k_{eff} . The applicant presented this comparison in Tables 6-22 and 6-23 of the application. The staff noted the applicant’s results confirm that modeling the stainless-steel rods as irradiated uranium is more conservative, and the staff finds this modeling assumption acceptable.

The applicant evaluated the effect of both uniform and non-uniform pitch expansion on calculated reactivity. For uniform pitch expansion, the applicant varied the pitch until the outermost fuel pins contacted the inside of the fuel compartments. The applicant’s results in Table 6-24 of the application show that the expanded pitch is most reactive. Since the pitch cannot expand beyond the size of the fuel compartment, the staff finds this limit to the uniform pitch expansion acceptable.

For the non-uniform pitch expansion, the applicant modeled a “birdcage” effect where the pitch expands in one region and contracts in another. The applicant again expanded the “birdcage” effect until the pins contacted the fuel compartment interior. The applicant presented the results in Table 6-25 of the application which showed the non-uniform expansion to be more conservative than uniform expansion. As a result, the staff finds the applicant’s use of the non-uniform expansion model acceptable.

For moderator density, the applicant modeled both the interior and exterior moderator density independently from 0% to 100%. The applicant presented its results in Table 6-27 of the application. The staff noted that the most reactive case is with 100% density in the package cavity and 30% moderator density external to the packaging. The staff finds the applicant’s use of this moderator configuration acceptable since it maximizes the calculated k_{eff} .

For these reasons, the staff finds reasonable assurance that the applicant has determined the most reactive credible configuration within the TN-32B package.

6.4 Single Package Evaluation

The applicant uses its most reactive fuel model discussed in section 6.3.4. For a single package, the model is surrounded by 30 cm of full-density water and vacuum boundary conditions. Both the NCT and HAC models are identical, except the exterior moderator is reduced to 30% density under HAC. The applicant presented results in Table 6-27 of the application that show this to be the most reactive configuration and the staff finds the reduced external moderator acceptable.

6.5 Evaluations of Package Arrays

To evaluate package arrays under NCT, the applicant swapped the vacuum boundary condition in the single package evaluation for a reflective one, effectively modeling an infinite array of packages.

To evaluate package arrays under HAC, the applicant used reflective boundary conditions, effectively modeling an infinite array of packages. The applicant left the basket and cask geometry unchanged. The staff material review found that significant reconfiguration due to HAC is unlikely, and the staff finds the assumption that the applicant's basket and cask geometry acceptable.

The applicant independently evaluated internal and external moderator densities to determine the most reactive configuration. The staff reviewed the applicant's results in Table 6-27 of the application and finds reasonable assurance that the applicant evaluated the most reactive configuration of package arrays under HAC.

6.5.1 Package Array Results and CSI

The applicant demonstrated that an infinite array of flooded packages will remain subcritical. Per 10 CFR 71.59, the TN-32B package has a CSI of zero.

6.6 Benchmark Evaluations

The applicant selected a series of critical experiments to validate its computational method. The applicant obtained its burnup credit critical data from the International Handbook of Evaluated Criticality Safety Benchmark Experiments (IHECSBE) and Haut Taux de Combustion (HTC) program. The staff finds this acceptable since this data has been shown to be applicable to spent fuel systems.

The applicant selected the critical experiments for its benchmark analysis based on experimental similarity to the TN-32B package (e.g., material composition, moderation, and geometry). The staff finds this acceptable since it follows the recommendations of Reference 7. The applicant presented its selected critical experiments in Table 6-28 of the application.

6.6.1 Experiments and Applicability

The applicant selected experimental data from thermal critical systems with similar fuel, clad and absorber material as the TN-32B contents. The applicant limited its selection to solid, fissile material experiments of arrays of rods and excluded soluble fissile experiments. The staff reviewed the remaining experiments in Table 6-29 of the application and determined they are thermal uranium and/or plutonium systems in a lattice geometry, which is appropriate composition for spent fuel analysis. The HTC experiments were specifically designed to mimic spent fuel composition and the staff finds the applicant's selection of that data appropriate.

6.6.2 Bias Determination

The applicant evaluated the critical experiment results for trends to determine bias and bias uncertainty. The parameters the applicant reviewed are ^{235}U enrichment, fuel pitch, energy of average neutron lethargy causing fission (EALF), average energy group of neutrons causing fission (AEG), fuel rod radius, moderator-to-fuel volume ratio ($V_{\text{mod}}/V_{\text{fuel}}$), hydrogen-to-fuel (H/X) ratio, and plutonium content. The applicant performed a trending analysis on each parameter using SCALE 6.1 to re-create the IHECSBE and HTC experiments and determine a correlation coefficient between k_{eff} and each of the experimental parameters.

The applicant determined a weighted one-sided lower tolerance limit that incorporates the uncertainty from both measured and calculated results. The overall uncertainty was already determined for the measured critical parameters. Since the critical experiments are not exactly critical, an additional adjustment needs to be made to the calculated k_{eff} , which the applicant did by normalizing the calculated k_{eff} to the experimental value.

The applicant applied a factor, $1/\sigma^2$, which reduces the weight of each value by the square of the combined calculational and experimental uncertainty. From these weighted values and associated uncertainty, the applicant calculated the weighted mean value of k_{eff} , the variance about that mean, and the average total uncertainty. Since the applicant's determination of the one-sided lower tolerance limit follows that described in Reference 7, the staff finds it acceptable.

ORNL has conducted studies that estimate k_{eff} bias and bias uncertainty for PWR SNF to be 0.01 and 0.03, respectively, for fuel with assembly-average burnup of 40-60 GWd/MTU (5). ORNL results showed that SCALE 6.1 with the ENDF/B-VII nuclear cross-section data produces a small positive k_{eff} bias (i.e., the code calculates a higher reactivity) with significantly larger associated uncertainty. The bias uncertainty is primarily due to bias uncertainties associated with the actinide nuclide concentrations (90-95%). Fission products account for less than 3 % of bias uncertainty due to bias uncertainty of nuclide concentrations.

The applicant used the depletion bias factors directly from the SRP. As discussed in Section 6.7.3.1 below, the applicant met the conditions stated in section 6.4.7.3 of the SRP, and the staff finds this acceptable.

The applicant based its USL equation from equation 3.1 of Reference 6:

$$K_p + \Delta k_p + \beta_i + \Delta k_i + \beta + \Delta k_\beta + \Delta k_x + \Delta k_m \leq k_{\text{limit}}$$

The applicant combined the calculated value ($k_p + \Delta k_p$), the depletion bias, bias, and bounding code bias due to nuclide cross-section data that might not be adequately accounted for in the benchmark experiments (i.e., β_i , β , and Δk_x , respectively) into a single value taken from the highest calculated k_{eff} from the applicant's analysis.

The applicant statistically combined the bias uncertainties, Δk_i and Δk_β , into a single value. The applicant also applied a 0.05 Δk_m administrative margin (i.e., initial unbiased maximum k_{eff} is 0.95). The staff reviewed the USL with the bias and bias uncertainty applied and noted that it is higher than the most reactive configuration identified by the applicant. Since the applicant's calculations follow the recommendations of Reference 6, the staff finds them acceptable.

Except for the reduced fuel rod radius, the applicant's selection of experiments and bias evaluation falls within the area of applicability shown in Table 6-31 of the application. The staff noted that the reduced fuel radius is still within the range covered by the critical experiments; also, the baseline configuration falls within the area of applicability.

The applicant selected a reduced fuel radius which yields the most reactive configuration used in the bias evaluation. Since any extrapolation may only be necessary due to conservative modifications to the baseline model, the staff finds the applicant's experiments and bias evaluation adequately cover the package evaluations for the parameters important to criticality safety.

6.7 Burnup Credit Evaluation

The applicant included the reduction of reactivity as a result of irradiation (i.e., burnup credit) in its analyses. The applicant did not credit burnups greater than 60 GWd/MTU, which covers the range of the highest burned fuel in this package. The applicant imposed minimum and maximum cooling times that cover the range of cooling times allowed.

6.7.1 Limits for Certification Basis

The applicant limited its burnup credit based the guidance of interim staff guidance-8 Rev. 3, which is now part of the SRP. The applicant used experimental data that covered a range of enrichment up to 5%, irradiated in a PWR with a maximum assembly-average burnup of 60 GWd/MTU, and cooled for a period of 1-40 years. Since the inventory of the TN-32B package falls within these limits, and the applicant is seeking to credit the nuclides given in Table 6-2 of the SRP, the staff finds the applicant's burnup evaluation is supported by available data.

6.7.2 Model Assumptions

The applicant's depletion model is discussed in section 6.3.1.1 above.

6.7.3 Isotopic Code Validation

The applicant used TRITON in the SCALE 6.1 code for its depletion analyses to generate problem-specific cross-section libraries. The staff finds the use of TRITON acceptable per the guidance in Attachment 6 A to the SRP. The applicant used multi-group cross-section libraries based on the ENDF/B-VII nuclear data, which the staff also finds acceptable per the guidance in Attachment 6 A to the SRP. These TRITON-generated libraries cover a range of operating conditions (e.g., enrichment, moderator temperature and density, boron concentration) that have an impact on the isotopic inventory of the fuel during irradiation.

The staff reviewed the applicant's selection of parameters in section 6.3.1.1 of the application and finds they follow guidance in section 6.4.7.2 of the SRP. The staff reviewed the applicant's TRITON geometry and finds that it is representative of the Westinghouse 17x17 type fuel lattice. The applicant used its TRITON-generated libraries with the STARBUCS model to generate a series of predicted isotopic inventories based on the irradiation condition experienced by the spent fuel assemblies.

STARBUCS is a module within SCALE 6.1 that uses ORIGEN-ARP, another SCALE 6.1 module, to interpolate among the data points generated from TRITON libraries. Since the ORIGEN-ARP code interpolates from the problem-specific libraries, the generated libraries must cover the range of chosen parameters. The staff reviewed the parameter ranges over which the applicant developed its libraries and found they acceptably cover the irradiation histories of the spent fuel inventory.

6.7.3.1 Depletion Bias and Bias Uncertainty

Per the SRP, an applicant may use the bias and bias uncertainty values from Tables 6A-3 and 6 A-4 in the SRP in lieu of an explicit depletion validation analysis. In order to do this, the applicant must meet three conditions, which are split up and discussed in the following three subsections.

6.7.3.1.1 Depletion Code and Cross-Section Library

The first condition is the applicant must use the same depletion code and cross-section library that was used in Reference 5 (i.e., SCALE/TRITON and ENDF/B-V or ENDF/B-VII cross-section libraries). As discussed above, the applicant used SCALE/TRITON with ENDF/B-VII libraries, which meets this condition.

6.7.3.1.2 Similarity of the TN-32B HBU to the GBC-32

The second condition is the applicant must show the package design is similar to the GBC-32 model used by ORNL for isotopic depletion validation. The GBC-32 is a hypothetical spent fuel

storage and transportation system designed by ORNL as a reference configuration that contains neither unnecessary details nor any proprietary information. It is designed for general use to normalize analyses and estimations of additional reactivity margin available from fission products and minor actinides. The GBC-32 model was loaded with Westinghouse 17x17 OFA fuel assemblies.

The applicant performed a qualitative comparison of the material properties of the TN-32B to the GBC-32. One potential significant difference is the basket poison; the TN-32B uses borated aluminum (e.g., Metamic), and the GBC-32 used Boral with aluminum cladding. Both Boral and borated aluminum rely on ^{10}B for criticality control and will behave similarly from a neutronic standpoint. While borated aluminum may be credited for up to 90% of available boron, Boral is limited to 75%. However, the boron density assumed in the GBC-32 Boral is higher than the design boron density of borated aluminum in the TN-32B package. After accounting for these differences in design boron content and allowable credit, the areal boron densities of the GBC-32 Boral and the borated aluminum used in the TN-32B package are $10 \text{ mg } ^{10}\text{B}/\text{cm}^2$ and $9 \text{ mg } ^{10}\text{B}/\text{cm}^2$, respectively. Some other configuration differences include the cask wall thickness and the position of the fuel assemblies in each basket compartment. Components external to the basket have little to no significant effect on the neutronic characteristics of the package.

While shifting the contents will impact reactivity, it does not change the material properties in the basket and has no significant effect on the neutronic characteristics. The contents of both the TN-32B and the GBC-32 are UO_2 fuel in square-pitch lattice geometry with similar material construction and irradiated under typical PWR conditions. Both systems are assumed to be filled with unborated water with full water reflection externally. There is a minor difference in the boundary condition set in the models. The GBC-32 set a water boundary condition, and the applicant modeled water explicitly in its TN-32B model and set a vacuum boundary condition, which effectively mimics the water boundary condition. For these reasons, the staff finds the applicant's qualitative determination of material and configuration similarity acceptable.

The applicant also included a comparison of global nuclear parameters in its assessment of similarity. The applicant performed a series of KENO/CSAS5 comparisons between corresponding models at a burnup 50 and 57 GWd/MTU for each model. The applicant obtained the burnup-dependent isotopic concentrations from the STARBUCS calculations discussed in Section 6.7.3 above. The global parameters the applicant compared are the H/X ratio, AEG, EALF, and $V_{\text{mod}}/V_{\text{fuel}}$ ratio. KENO/CSAS5 output contains the information to determine H/X and the code automatically calculates AEG and EALF.

The applicant used the axially averaged ratio of hydrogen to the sum of uranium and plutonium number densities to determine H/X. Since the staff already determined these codes to be appropriate for this evaluation, the staff finds the applicants determination of H/X, AEG, and EALF acceptable.

In order to calculate $V_{\text{mod}}/V_{\text{fuel}}$, the applicant simply compared the two-dimensional area of the moderator and fuel within a unit pin cell in the fuel assembly model. Since the PWR fuel geometry in the TN-32B cask does not vary axially, the staff finds this approach acceptable. The applicant noted that the only significant difference between the applicant's modeled system and the GBC-32 is the fuel pellet diameter. The applicant presented the comparison of these global parameters in Tables 6.34 - 6.39 of the application. The staff noted that most of the global

parameters do not differ significantly, as a result the staff finds the applicant's qualitative assessment of similarity acceptable.

The applicant also performed a quantitative comparison of the TN-32B to the GBC-32 with the TSUNAMI-3D module in SCALE 6.1. The TSUNAMI-3D code calculates the sensitivity of computed responses (e.g., k_{eff} and ratios of reaction rates) on changes in nuclide densities for a given system. Using these calculated sensitivities and the cross-section covariance data, another code within SCALE 6.1, TSUNAMI-IP, compares these sensitivities among two systems (12). Two systems that exhibit the same sensitivities to the same perturbation can be considered to have a high degree of similarity, which the code quantifies in a single correlation coefficient, c_k . A c_k value higher than 0.8 indicates marginal similarity, and a value greater than 0.9 indicates similarity.

The applicant's comparison of the TN-32B to the GBC-32 yielded c_k values greater than 0.99 at the burnups evaluated. This c_k value indicates a high degree of similarity, and the staff finds it acceptably verifies the similarity of the TN-32B HBU to the GBC-32.

6.7.3.1.3 Nuclides Credited for Reactivity Reduction

The third condition is the applicant must limit credit to the specific nuclides listed in Tables 6A-1 and 6 A-2 of SRP Attachment 6 A. The staff reviewed the isotopes the applicant has included for burnup credit in Table 6-8 of the application and confirmed they match those in SRP Attachment 6 A.

Since the applicant met all three of the criteria set forth in appendix 6A of the SRP, the staff finds the applicant's use of the depletion bias and bias uncertainty values in Tables 6-A3 and 6-A4 of the SRP in lieu of its own calculations acceptable.

6.7.4 Loading Curve and Burnup Verification

The applicant used STARBUCS to calculate a loading curve. STARBUCS will perform loading curve analysis automatically, however the code is limited to a single UO_2 fuel type. Since there is more than one assembly type in the TN-32B HBU cask, the applicant modeled each fuel type for a unique STARBUCS calculation.

The staff reviewed the applicant's STARBUCS enrichment and burnup values and finds they bound those of the assemblies in the TN-32B HBU demonstration package. The staff reviewed the applicant's cooling times and finds they sufficiently cover the spent fuel inventory.

6.7.5 Misload Analysis

The spent fuel inventory is fixed for the TN-32B. Given that there has been no fuel moving in or out of the demonstration cask, the staff finds reasonable assurance the spent fuel assemblies have been accurately identified. As a result, the staff finds the applicant does not need to perform a misload analysis for the transportation of these 32 spent fuel assemblies.

6.8 Confirmatory Analyses

The staff conducted its own confirmatory analyses using the SCALE 6.3 code suite. Specifically, the staff used TRITON to independently calculate burned fuel compositions for use in subsequent criticality calculations. The staff used KENO-VI to conduct its criticality analyses. For both depletion and criticality evaluations, the staff used continuous energy libraries based on ENDF/B-VII nuclear data.

Since the applicant's assumptions into its depletion calculations had been shown to be conservative in prior studies, the staff used the same assumptions (e.g., zero down time between cycles, BPRAs present). Rather than re-create an entire suite of problem-specific libraries to allow evaluation across the range of BECT combinations, the staff chose to limit the scope of its evaluation.

The staff opted to calculate its own spent fuel isotopic composition at seven burnups related to the minimum assembly-average burnup and maximum initial enrichment of any assembly in the TN-32B cask. The staff selected these burnup values to correspond to certain nodes in applicant's axial burnup profile.

The staff calculated a unique isotopic composition for the top two and bottom two nodes due to the significant burnup gradient. The middle nodes were split into three groups based on effective nodal burnup. Most of the nodes fell into two burnup groups that differed by less than 1% from that group average. The last two nodes at the top of this range (nodes 15 and 16) comprised the last group since they differed more significantly from the rest.

The staff's baseline criticality model consisted of the basket with poison plates containing fuel assemblies centered in the fuel compartments, a homogenized region of water and aluminum surrounding the basket, an inner shell, and the cask wall, which was all surrounded by more water. The staff modeled eight effective axial fuel zones, however there were only seven unique isotopic compositions. Since the staff categorized the middle zones according to burnup, axial nodes with identically modeled composition were not necessarily adjacent.

The staff's resulting calculated k_{eff} for this baseline configuration aligned relatively closely with the applicant's result for the same configuration.

The staff also evaluated some of the conditions of maximum reactivity the applicant determined. Those were axial alignment, uniform pitch expansion, and external moderator density for package arrays. The relative percent change in the staff's calculated k_{eff} results aligns with the relative change observed by the applicant.

Even with conservative and bounding assumptions, and accounting for two standard deviations, the most reactive array configuration calculated by the applicant remains below the package USL. The staff results provide additional assurance that the applicant has accurately demonstrated the TN-32B package will remain subcritical under NCT and HAC.

6.9 Evaluation Findings

Based on the staff's evaluation discussed in the preceding sections, the staff made the following findings:

The staff has reviewed the TN-32B package and concludes that the application adequately describes the contents and package design features that affect nuclear criticality safety in compliance with 10 CFR 71.31(a)(1), 71.33(a), and 71.33(b) and provides an appropriate and bounding evaluation of the package's criticality safety performance in compliance with 10 CFR 71.31(a)(2), 71.31(b), 71.35(a), and 71.41(a).

The staff has reviewed the TN-32B package and concludes that the application specifies the number of packages that may be transported in the same vehicle through provision of an appropriate CSI in compliance with 10 CFR 71.35(b).

The staff has reviewed the TN-32 package and concludes that the applicant used package contents configurations and materials properties in the criticality safety analyses that are consistent with and bounding for the package's design basis, including the effects of the NCT

and the relevant accident conditions in 10 CFR 71.73. The applicant has adequately identified the package configurations and material properties that result in the maximum reactivity for the single package and package array analyses.

The staff has reviewed the TN-32B package and concludes that the criticality evaluations in the application of a single package demonstrate that it is subcritical under the most reactive credible conditions, in compliance with 10 CFR 71.55(b), 71.55(d), and 71.55(e). The evaluations in the application also demonstrate that the effects of the NCT tests do not result in a significant reduction in the packaging's effectiveness in terms of criticality safety, in compliance with 10 CFR 71.43(f) and 10 CFR 71.55(d)(4) and, for Type B fissile packages, 10 CFR 71.51(a)(1). The evaluations in the application also demonstrate that the geometric form of the contents is not substantially altered under the NCT tests, in compliance with 10 CFR 71.55(d)(2).

The staff has reviewed the TN-32B package and concludes that the criticality evaluation in the application of the most reactive array of 5 N undamaged packages demonstrates that the array of 5 N packages is subcritical under NCT to meet the requirements in 10 CFR 71.59(a)(1).

The staff has reviewed the TN-32B package and concludes that the criticality evaluation in the application of the most reactive array of 2 N packages subjected to the tests in 10 CFR 71.73 demonstrates that the array of 2 N packages is subcritical under hypothetical accident conditions in 10 CFR 71.73 to meet the requirements in 10 CFR 71.59(a)(2).

The staff has reviewed the TN-32B package and concludes that the applicant's evaluations include an adequate benchmark evaluation of the calculations. The applicant identified and evaluated experiments that are relevant and appropriate for the package analyses and performed appropriate trending analyses of the benchmark calculation results. The applicant has determined an appropriate bias and bias uncertainties for the criticality evaluation of the package.

The staff has reviewed the TN-32B package and concludes that the application identifies the necessary special controls and precautions for transport, loading, unloading, and handling and, in case of accidents, compliance with 10 CFR 71.35(c). These controls include a limited contents inventory that precludes the possibility of a package misload.

The staff has reviewed the TNB-32B package and concludes that the evaluations in the application assume unknown properties of the fissile contents are at credible values that maximize neutron multiplication consistent with 10 CFR 71.83. This includes following the recommendations in section 6.4.7 and Attachment 6 A to the SRP for crediting the burnup of the SNF contents.

Based on review of the statements and representations in the application, the staff has reasonable assurance that the proposed TN-32B package design and contents satisfy the nuclear criticality safety requirements in 10 CFR Part 71. In making this determination, the staff considered the regulation itself, appropriate regulatory guides, applicable codes and standards, accepted engineering practices, prior staff review, and the staff's own independent confirmatory calculations.

6.10 References

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5. U.S. Nuclear Regulatory Commission, "An Approach for Validating Actinide and Fission Product Burnup Credit Criticality Safety Analyses – Isotopic Composition Predictions," NUREG/CR-7108, April 2012.
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8. U.S. Nuclear Regulatory Commission, "Evaluation of the French Haut Taux de Combustion (HTC) Critical Experiment Data," NUREG/CR-6979, September 2008.
9. U.S. Nuclear Regulatory Commission, "Transnuclear, Inc. TN-32 Dry Storage Cask System Safety Evaluation Report," ML003696918, March 2000.
10. TN Americas, LLC, TN-32 Updated Final Safety Analysis Report, Revision 6 (CoC 1021, Docket No. 1021), April 2014.
11. Oak Ridge National Laboratory ORNL/CSD/TM-244 "Reactivity and Isotopic Composition of Spent PWR Fuel as a Function of Initial Enrichment, Burnup, and Cooling Time," October 1987.
12. Oak Ridge National Laboratory, RSICC Computer Code Collection, "SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design," June 2011.

7.0 OPERATING PROCEDURES

The staff reviewed the applicant's description of package operations to ensure that it is operated, transported, received, and unloaded in a manner consistent with its design.

The package operations descriptions contain the essential elements of operations for using the package. The staff reviewed the operating procedures for the TN-32B to ensure that the procedures reflect acceptable operating sequences, guidance, and generic procedures for key operations. The staff finds that, based on its review, the operations descriptions in the application are consistent with these considerations.

Alternates to sequences or operating instructions, as currently described in the SAR, will need to be reviewed by staff in an amendment request.

8.0 ACCEPTANCE TESTS AND MAINTENANCE

The fabrication and acceptance testing of the TN-32B cask were completed under TN Americas' QAP, which has been found to conform to the criteria in found in 10 CFR Part 71, Subpart H (ML18270A116). Similarly, the applicant performed the design, fabrication, and testing of TLAs under the QAP of AREVA, Inc., which was in effect at the time, and which conformed to the criteria in Subpart B of 10 CFR Part 50.

Further, the applicant followed the requirements of the ASME B&PV Code, to the maximum extent practicable, for the fabrication, examination, and testing of the containment vessel of the TN-32B cask. Section III, Subsection NB, Article NB-3200 was used for design, while fabrication and examination of the containment vessel was completed in accordance with Subsections NB-2500, NB-4000, and NB-5000 of the ASME B&PV code. Materials of construction meet the requirements of section III, Subsection NB-2000 and Section II, Material Specifications of the ASME B&PV code, or the corresponding ASTM Specifications, with any exceptions noted as ASME code alternatives discussed in appendix 2.12.13 of the SAR.

Hydrostatic pressure testing of the assembled containment vessel was done in accordance with the requirements of the ASME B&PV Code, section III, Subsection NB, Article NB-6200, during original fabrication of the cask in 2000, while the TLAs were hydrostatically tested during the lid modification completed in 2017.

Staff reviewed the information provided by the applicant and finds the description of the containment vessel to be acceptable.

In order to ensure adequate surface control of all seating surfaces for the seals, a stainless-steel overlay is applied to all seating surfaces for metallic seals; this is also true of the TLAs. The applicant maintains that surface control of the sealing surfaces contributed to the ability of the seals to successfully pass both fabrication (during cask fabrication) and pre-shipment (during loading of the HBU fuel payload) leakage tests, meeting the leaktight acceptance criteria per ANSI N14.5 (2014).

The applicant further states that at the time of loading the TN-32B, in November of 2017, the cask cavity was backfilled with helium gas and pressurized to above atmospheric pressure to preclude air in-leakage and the seals for the closure lid, port covers and TC lances were tested for leakage. The applicant reported that the seals were tested to leaktight criteria, i.e., they collectively had a leakage rate of $\leq 1 \times 10^{-7}$ ref cm³/s, in accordance with ANSI N14.5 (2014).

The applicant further states that monitoring of the performance of the O-ring seals via the OP system during the storage period, indicated that there has not been any leakage from the containment boundary for the duration of the storage period.

The seals described above were reviewed and found acceptable during the review of the storage configuration for the TN-32 design under 10 CFR Part 72. The seal configuration has not changed between the time the TN-32 storage cask was loaded and the submission of the current application for a 10 CFR Part 71 certificate, and while the requirements for containment found in 10 CFR Part 71 for transportation are similar to the confinement requirements found in 10 CFR Part 72 for storage, they are not the same; therefore, the system of seals found

acceptable for storage requirements was re-evaluated by the staff based on the containment requirements for transportation found in 10 CFR Part 71 and found acceptable, as documented in this SER.

Welds

The containment boundary welds for the of the TN-32B (with the exception of the TLA penetration sleeve welds) are full-penetration welds that include both circumferential welds (such as those that attach the shell flange and bottom inner plate to the inner shell) and longitudinal welds (such as those used on the rolled plate, or shells, that form the cylindrical inner shell). Circumferential welds were used to attach the rolled shells together forming the completed inner shell.

Thermocouple Lance Assembly (TLA) Welds

Each TLA consists of a welded Inconel oversheath that contains nine K-type thermocouples, a reinforcing Inconel oversheath, and a Type 304/304L stainless steel insert that is welded to a Type 304/304L stainless steel body. Except for the square weld that joins the sheath tip plug to the oversheath, the lance containment boundary welds are fillet and partial penetration welds.

The sleeves that penetrate the TN-32B package closure lid and shield plate in order to receive the TLAs are secured to the lid with partial penetration groove welds, which makes them integral to the lid. The upper groove weld of the TLA sleeve that attaches the forging “to the closure lid is part of the containment boundary. The integrity of the upper groove weld, which, under section NB of the ASME B&PV Code, is classified as a Category C weld, was verified at the time of welding through visual and NDE, in accordance with Section V and the acceptance standards of section NB-5000 of the ASME B&PV Code, utilizing multi-level liquid penetrant (PT) examination in the root, and on each subsequent weld pass.

The welds for the TLA assemblies were performed utilizing the GTAW process, and are classified as a Category D under section III, Subsection NB-3352.4 of the ASME B&PV Code, which specifically permits fillet and partial penetration welds. TLA weld examinations were done by a liquid PT process using acceptance standards that exceeded the acceptance standards of Section III, Subsection NB-5352, as confirmed from a response to an RAI from the staff.

The TN-32 containment vessel was fabricated in 2000 and hydrostatically pressure tested (at a pressure of 45 psig) in accordance with the requirements of the ASME B&PV Code, section III, Subsection NB, Article NB-6200. Weld joints of the containment boundary that were accessible were examined using MT examination for any defects. The applicant further conducted a bubble leakage rate test on the neutron shield enclosure (at 4.4 psig) which included the outer shell, outer shell top and bottom rings, in order to identify potential leak paths through the enclosure welds. Later, during fabrication of the TLAs (in 2017), the containment boundaries of the TLAs successfully passed a hydrostatic pressure test (to an external pressure of 3,125 psig) and a helium leakage rate test.

In SAR section 8.1.2, the applicant stated that containment welds for the TN-32B are “designed, fabricated, tested and inspected in accordance with ASME B&PV Code, section III, Subsection NB.” The applicant reviews ASME code alternatives (regarding the containment vessel) in SAR appendix 2.12.13. Welding of the TN 32B containment was performed, to the maximum extent practical, using processes and personnel qualified in accordance with the ASME B&PV Code.

The staff reviewed the description of the welds provided in the application and found that the welds as described were acceptable. The acceptability of the welds in providing a leaktight containment boundary during transportation of the TN-32B was discussed above, in section 4.5 of this SER. Finally, all NDE is performed in accordance with written and approved procedures. The inspection personnel are qualified in accordance with SNT-TC-1A1.

The applicant did not identify any maintenance tests that will need to be performed on the TN-32B HBU in relation to the shielding performance. The staff has not identified any degradation mechanisms that would affect the shielding performance during the service lifetime of the package and found this acceptable.

The staff has reviewed the identification of the codes, standards, and provisions of the Quality Assurance 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). The staff has reviewed the identification of the codes, standards, and provisions of the QAP 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).

CONDITIONS

The following are Conditions of the CoC:

In addition to the requirements of Subpart G of 10 CFR Part 71:

- (a) The package must be prepared for shipment and operated in accordance with the "Operating Procedures" in chapter 7 of the application, as supplemented.
- (b) Each packaging must be acceptance tested and maintained in accordance with the "Acceptance Tests and Maintenance Program" in chapter 8 of the application, as supplemented.

Transport by air is not authorized.

The personnel barrier shall be installed at all times during transport to meet package surface temperature and/or package dose rates requirements.

The package shall be transported under exclusive-use.

CONCLUSION

Based on the statements and representations contained in the application, and the conditions listed above, the staff concludes that the Model No. TN-32B package has been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

Issued with CoC No. 9377, Revision No. 0.