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

June 24, 2021

Mr. Christopher O'Mullane
Holtec International
1 Holtec Blvd
Camden, NJ 08104

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 9375, REVISION NO. 0, FOR THE MODEL NO. HI-STAR ATB 1T PACKAGE

Dear Mr. O'Mullane:

As requested by your application dated June 7, 2019, as supplemented June 22, 2020, and May 4, 2021, enclosed is Certificate of Compliance No. 9375, Revision No. 0, for the Model No. HI-STAR ATB 1T package. The staff's Safety Evaluation Report is also enclosed.

Holtec International has been registered as a user of the package under the general license provisions of Title 10 of the *Code of Federal Regulations* 10 CFR 71.17. The approval constitutes authority to use the package for shipment of radioactive material and for the package to be shipped in accordance with the provisions of 49 CFR 173.471.

If you have any questions regarding this certificate, please contact Pierre Saverot of my staff.

Sincerely,

John B. McKirgan Digitally signed by John B. McKirgan
Date: 2021.06.24 15:50:06 -04'00'

John B. McKirgan, Chief
Storage and Transportation Licensing Branch
Division of Fuel Management
Office of Nuclear Material Safety
and Safeguards

Docket No. 71-9375
EPID No. L-2019-LRM-0006

Enclosures:
1. Certificate of Compliance No. 9375, Rev. No. 0
2. Safety Evaluation Report

cc w/encls: R. Boyle, Department of Transportation
J. Shuler, Department of Energy

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 9375, REVISION NO. 0, THE MODEL NO. HI-STAR ATB 1T PACKAGE

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SAFETY EVALUATION REPORT
HOLTEC INTERNATIONAL
Docket No. 71-9375
Model No. HI-STAR ATB1T Package

By letter dated June 7, 2019, Holtec International, submitted an application for Certificate of Compliance No. 9375, Revision No. 0, for the Model No. HI-STAR ATB 1T package (Agencywide Documents Access and Management System (ADAMS) Accession No. ML19158A515).

The U.S. Nuclear Regulatory Commission staff (the staff) performed an acceptance review of the application and issued a request for supplemental information (RSI) letter dated July 15, 2019 (ADAMS No. ML19198A027). Holtec responded to the RSI letter on August 9, 2019 (ADAMS No. ML19221B423). Staff issued a first request for additional information on November 8, 2019 (ADAMS No. ML19316A159) for which Holtec provided responses by letter dated June 22, 2020 (ADAMS No. ML20174A484).

Staff issued a second request for additional information on October 27, 2020 (ADAMS Accession No.: ML20301A804) for which Holtec provided responses by letter dated April 20, 2021. The revised application incorporating the RAI responses, Revision No. 3, was submitted on May 4, 2021 (ADAMS No. ML21124A204).

NRC staff reviewed the application using the guidance in NUREG-1609, “Standard Review Plan for Transportation Packages for Radioactive Material”. The analyses performed by the applicant demonstrate that the package provides adequate structural, thermal, containment, and shielding protection under normal and accident conditions.

Based on the statements and representations in the application, and the conditions listed in the Certificate of Compliance, the staff concludes that the package meets the requirements of 10 CFR Part 71.

1.0 GENERAL INFORMATION

1.1 Design Characteristics

The HI-STAR ATB 1T, designed for transportation of radioactive non-fuel waste including segmented reactor internals and related waste and hardware, consists of three major components: the packaging body, the secondary containers, and the waste baskets.

The HI-STAR ATB 1T is a rectangular-parallelepiped multi-layer steel-weldment with a closure lid secured by a custom designed locking system. Closure verification is provided by the installation of the locking wedge lock bars after closure of the lid and prior to transport. The outer surface of the packaging body inner structure is buttressed with steel for gamma shielding. The interfacing surfaces of the lid and the flange at the top of the packaging body are machined

to seat two concentric elastomeric gaskets. An insulation board is used in the closure region of the packaging to ensure sealing gasket performance is not compromised. The containment system consists of the Closure Lid, Containment Wall Plates, Containment Baseplate and Closure Lid Locking Wedges.

The HI-STAR ATB 1T has both internal and external impact absorbers. The internal impact absorbers are the lid spacer, aluminum spacers inserted in the bottom of the lid, and internal austenitic stainless-steel adjustable inserts recessed in the side walls of the HI-STAR ATB 1T. The external impact absorbers are made of either aluminum, austenitic stainless steel, or a combination of aluminum and austenitic stainless steel, and such impact absorbers are located on the top, bottom, side, end, and corner exterior surfaces of the package.

The secondary containers, called BFA-Tanks (BTs), have four design variants (T-50, T-100, T-150, T-200) each with a different wall thickness, thus each qualified for a certain total maximum activity and specific activity level. BFA-Tanks are painted carbon steel rectangular parallelepiped weldments with bolted lids. The lids of the BFA-Tanks are equipped with metallic seals. BFA-Tanks have external dimensions of approximately 130” long, 51” wide and 90” high.

There are four BFA-Tank Cassette (BTCs) design variants, each matched to a specific BFA Tank variant, as described above. Each type of BTC is designed to accommodate contents of a given mass and activity. BTCs are rectangular steel weldments that include a baseplate and a removable upper cover plate or lid. The package’s main gamma shielding are the following steel components: base plate, top flange, containment wall plates, dose blocker plates, and closure lid. The steel BFA-Tank and BTC plates also provide additional gamma shielding.

A Weather Protection Cover (WPC) is secured to the top of the HI-STAR ATB 1T package to prevent dirt and water from accumulating on its external surfaces. The WPC is not a structural component of the package but is designated as a packaging component when used.

The outer dimensions of the HI-STAR ATB 1T package, with impact limiters installed, are approximately 168” long, 94” wide and 115” high. The empty packaging weighs approximately 136,686 lbs., while the maximum gross weight of the loaded HI-STAR ATB 1T package is 249,122 lbs.

1.2 Drawings

The packaging is constructed and assembled in accordance with the following Holtec International Drawing Numbers:

(a) HI-STAR ATB 1T Cask Drawing 9786, Sheets 1-7, Rev. 7

(b) BFA-Tanks and Cassettes Drawing 9876, Sheets 1-3, Rev. 9

The drawings also identify the containment component regions deemed to be sacrificial zones because they are integral parts of the cask lid and cask body, respectively, and are not distinct components. The materials are the same as the cask parts from which these regions are designated, i.e., ASME SA-514 or ASTM A514 material, which are the material options specified for the containment side walls, end walls and closure lid.

The drawings also show tolerances for ITS components as well as for both the relative spacing and positions relative to the cask centerline for parts such as the impact absorbers and lifting trunnions: all impact absorbers are centered within ¼” relative to the cask centerline.

Staff noted the perimeters of the inner O-ring groove and outer O-ring groove (approximately 379 inch), their respective groove widths (approximately 0.225 inch), the surface finish of the O-ring groove of 125 micro-inch Ra or better and the surface finish of the seal seating surface of 63 micro-inch Ra or better, corresponding to approximately 3 micron and 1.5 micron, respectively, are critical dimensions that affect the containment evaluation.

1.3 Contents

Authorized contents include:

(a) Segmented and non-segmented activated stainless steel or Inconel reactor internals, e.g., Top Guides/Core Grids, Core Shrouds, Steam Separator Units, Core Spray Sparger Assemblies, Steam Dryers, etc.,

(b) Surface-contaminated reactor related hardware,

(c) Secondary waste (i.e. debris/chips) generated by the mechanical cutting process, chip drums (stainless steel) with surface contamination or induced activity and metallic waste filters (stainless steel or ceramic mesh screens) pre-packed in separate drums.

2.0 STRUCTURAL AND MATERIALS EVALUATIONS

2.1 Structural Design

2.1.1 Description

The HI-STAR ATB 1T packaging is a rectangular cross-section structure with a double wall construction joining a multi-layered baseplate at the bottom. A lid is secured to the containment walls via a boltless Closure Lid Locking System (CLLS). The package is a prismatic structure except for the lifting trunnions and the crushable attachments that protrude from the cask side walls and the closure lid. The crushable attachments are connected, in various locations, to the exterior of the package and are designed to deform under severe impact events (i.e., 9-meter free drop).

The HI-STAR ATB 1T packaging includes a self-energizing gasket joint functioning as a seal between the steel rectangular lid and the cask’s top flange. The CLLS secures the lid to the top flange to prevent the lifting of the lid and subsequent unloading of the gasket during Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) conditions. For structural purposes, the materials used in the construction of the package are predominately stainless steel for the cask, carbon steel for the inner tanks and Inconel in certain parts that make up the containment boundary. Aluminum is used in portions of the impact limiters and Inconel is used at the closure.

The containment system consists of the containment baseplate, the containment side walls, the containment end walls, the closure lid, and the CLLS. The following criteria are applicable to the primary containment seal to ensure that closure seal worthiness is maintained:

(i) there is no inelastic strain in the primary seal seating groove and the corresponding seal seating surface,

(ii) the residual gap (at the end of the drop event) between the seal seating surfaces is less than the useful seal springback, so that there is no physical opening in the containment boundary,

(iii) any partial momentary unloading of the containment seal, during a hypothetical drop event, is quantified and the potential radioactive release shall be within the applicable HAC limits. The NRC staff insisted that the applicant ensure the plastic strain at the closure region remains localized (e.g., two FE cells) and very small (approximately 10^{-4} inch/inch): this strain corresponds to less than the surface finish mentioned in Section 1.2 of the SER above.

For structural purposes, the containment boundary of the package is evaluated with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Section III, Division 1, Subsection NB, consistent with Regulatory Guide 7.6, “Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels.”

The HI-STAR ATB 1T utilizes a secondary container fitted inside the cask, the BFA-Tank, which is a rectangular steel vessel that provides radiation shielding for the package. The HI-STAR ATB 1T design also includes an optional steel waste basket, the BFA-Tank Cassette (BTC), which is loaded into the BFA-Tank. Only the BTC top and bottom plates provide a shielding function under NCT.

The staff noted in RAI 2-1 of the October 27,2020 RAI letter (ADAMS Accession No. ML20301A804) that, unless the wall plates or other lateral support components are designated as Important to Safety (ITS), the full length of the corner tubes must be considered for the buckling calculation. The applicant then revised Drawing 9876 to note that the BTC T-200 differs from the other cassettes (T-50, T-100 and T-150) in that the BTC T-200 requires lateral bracings to demonstrate acceptable buckling capacity.

The BTC T-200 is now provided with lateral bracings (wall support beams) to limit the maximum unsupported length of the corner tubes to 1200 mm. Where credited as lateral bracing, these wall support beams are designated as ITS for the BTC T-200 cassette. Where not credited for lateral bracing, and for all other cassettes, these lateral bracings remain as optional and are classified as not Important to Safety (NITS) components. Correspondingly, the T-200 BTC is evaluated to credit the lateral supports or bracings, as described and detailed in Drawing 9876. Other BTCs are evaluated distinctly from T-200. The limiting cassette among T-50, T-100 and T-150 was determined based on the buckling capacity. The applicant updated the drawings and calculations for the BTC to reflect all changes noted above.

The calculations demonstrate positive safety factors for the BFA-Tank Cassettes against critical buckling, with a minimum safety factor of 1.5 for the T-200 BFA-Tank Cassette, which occurred at the corner tubes, and 1.05 for the other BFA-Tank Cassettes (i.e. T-50, T-100 and T-150).

The applicant justified and clarified the number of bolts, their size and material properties, and their placement on the BFA-Tank top cover for all four BFA-Tank versions. For each BFA-Tank version (T-50, T-100, T-150, and T-200), there are two acceptable configurations for the top cover bolts, which are detailed on Sheet 4 of Drawing No. 9876. Regarding the bolt material

and its strength properties, the bolts are made of high strength steel with minimum yield and tensile strengths of 83 ksi and 118 ksi, respectively. The bolt stress limits from ASME B&PV Code Section III, Division 1, Subsection NF have been used to demonstrate that the top cover plate bolts will not fail under NCT. The bolts, however, are not NF components, and therefore they need not satisfy the material requirements of ASME Section III, Subsection NF. The top cover bolts may be fabricated from any steel material specification that meets the minimum strength requirements above.

During transport, the top cover bolts are not vulnerable to significant corrosion loss, since the BFA-Tank is sealed inside the HI-STAR ATB 1T containment cavity, which protects the top cover bolts from the ambient environment. Also, carbon steel and low alloy steel have very similar electrode potentials, and therefore galvanic corrosion involving the top cover bolts would be unlikely. Also, the top cover bolts on the BFA-Tank must not fail under NCT, as stated in Safety Analysis Report (SAR) paragraph 2.1.2.2. As described in this paragraph, the shielding function of the BFA-Tank walls is not compromised by local yielding of the BFA-Tank components and the failure of the BFA-Tank weld is permissible since the shielding evaluation conservatively assumes that all BFA-Tank welds fail under HAC. As such, failure of the top cover bolts under HAC is permissible.

With respect to their material specification, all lock washers and threaded inserts (if either is used) shall be made from stainless steel when they interface with package components made from stainless steel base material. Similarly, they shall be made from carbon steel when they interface with package components made from carbon or alloy steel base material. The pairing of like materials is done for managing corrosion risk and mitigating galvanic reactions. These additional requirements are captured in the Notes of Drawing No. 9786. Finally, it is noted that the aluminum impact absorbers on the HI-STAR ATB 1T package are coated to inhibit galvanic reactions.

Collapsible lifting trunnions are located on the side of the package and collapsible lifting attachment in the lid. The package utilizes non-integral supports and restraints for the tie-down system and are designed in accordance with NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants.” A weather protective cover is attached to the top of the package and is not a structural component of the packaging.

The applicant provided licensing drawings with tolerances as requested by staff, welding symbology and definitions, material designation, and associated standards. The licensing drawings include component description and arrangement of components relative to each other has been detailed by the applicant.

The staff has reviewed the package structural design description and concludes 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).

2.1.2 Identification of Codes and Standards for Package Design

The material standards used for the package comply with American Society of Testing and Materials (ASTM) and ASME B&PV Code standards. The containment boundary was evaluated using ASME B&PV Code Section III, Division 1, Subsection NB for both NCT and HAC conditions following the guidelines detailed in Regulatory Guide 7.6. The applicant evaluated the trunnions with ASME B&PV Code Section III, Division 1, Subsection NF and the provisions of NUREG-0612.

Specific paragraphs in NB-3000 of ASME B&PV Code Section III, Division 1, Subsection NB are used for the design of the containment system of the HI-STAR ATB 1T packaging. Table 2.1.7

of the SAR lists each major structure, system, and component of the packaging along with the applicable code or standard: as an example, in a 9 m free drop, the containment system must meet Level D stress intensity limits per Subsection NB.

SAR Table 8.1.3 lists some alternatives to the ASME B&PV Code where appropriate. SAR Table 8.1.2 of the application provides applicable sections of the ASME B&PV Code as well as documents for material procurement, fabrication, and inspection pursuant to the guidance in NUREG-1609.

2.1.3 Design Criteria

The applicant designed the HI-STAR ATB 1T package following ASME B&PV Code Section III, Division 1, Subsection NB, in accordance with Regulatory Guide 7.6, for structural qualification of the package under NCT and HAC. The applicant followed a variety of other ASME B&PV Code Sections for different aspects of the design, as described in the application and throughout this Safety Evaluation Report (SER), when applicable. The structural qualification of the trunnions for normal handling follows the provisions in NUREG-0612 and the stress limits of Subsection NF of the ASME B&PV Code Section III, Division 1.

The loading conditions and load combinations for transport are consistent with Regulatory Guide 7.8, “Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material.” In particular, the lifting trunnions are designed with a factor of safety of five against ultimate strength per NUREG-0612, when considering redundant load path.

The primary membrane plus bending stress intensity of the containment system shall be less than 1.5 times the ASME Code stress intensity, per Subsection NB. The containment system must meet Level A stress intensity limits per ASME B&PV Code Section III, Division 1, Subsection NB for NCT and Level D stress intensity limits per Subsection NB for HAC. Also, the primary bending stress intensity of the CLLS shall be less than 1.5 times the ASME Code stress intensity for NCT and less than 3.6 times the ASME Code stress intensity for HAC. In addition, the primary shear stress must meet Level D limits per ASME B&PV Code Section III, Division 1, Subsection NB.

2.1.4 Weights

The applicant lists the maximum weight of the loaded package as 249,122 lb ((113,000 kg) and the nominal weight of the empty HI-STAR ATB 1T packaging as 136,686 lb (62,000 kg) in SAR Table 7.1.1.

2.2 Materials Evaluation

The following discussion focuses principally on the primary important-to-safety (ITS) containment and structural components; however, a comprehensive review was conducted of all packaging materials. The packaging consists of the major components as follows:

2.2.1 Package Description:

The HI-STAR ATB 1T package is a rectangular parallelepiped configuration with an inset heavy lid, which provides access for the contents. The interfacing surfaces of the lid and the top flange of the cask body are machined to seat 2 concentric elastomeric gaskets forming a compression joint. Apart from the elastomeric closure lid inner gasket and nickel alloy locking wedges, the containment boundary of the HI-STAR ATB 1T consists of American Society for Testing and Materials (ASTM) A514 or American Society of Mechanical Engineers (ASME) SA-

517 high-yield (HY) alloy steel components that include a baseplate, containment walls, closure lid containment plate, and associated containment boundary welds.

The top flange or machined region of the containment walls, interfaces with the closure lid sealing surface, which is equipped with a retractable Closure Lid Locking System (CLLS) consisting of 8 closure lid locking wedges constructed of ASME SB-637, nickel alloy (N07718), an actuating device/system (e.g., hydraulic, pneumatic or other as necessary) and a locking wedge lock bar constructed of ASME SA-240, Type 304 stainless-steel.

An aluminum (6061-T6 or T651) spacer may be used to close the gap between the top of the BFA-Tank and the underside of the cask lid or between the cask base plate and bottom of the BFA-Tank.

The baseplate and side walls weldment of the containment boundary, along with the closure lid, are buttressed by a thick ASME SA-240, Type 304 stainless-steel enveloping plate structure, called the "Dose Blocker Structure" (DBS). The DBS provides additional shielding under NCT and protects the containment boundary from damage during the postulated HAC.

The HI-STAR ATB 1T package has internal and external impact absorbers. The impact absorbers are located on the top, bottom, side, end, and corner exterior surfaces of the cask and are made of either Type 6061-T6/T651 aluminum or ASME SA-240, Type 304 austenitic stainless-steel. Internal impact absorbers include the aluminum lid spacer and impact absorber spacers and the stainless-steel internal side shim assemblies used to mitigate secondary HAC impact effects. External impact absorbers include stainless-steel and aluminum external crushable attachments.

The lifting trunnions, constructed of ASME SA-182, stainless-steel Grade FXM-19 (hollow shaft) and SB-637 nickel alloy N07718 (solid shaft), are located on the side walls and are designed to lift the package with structural safety margins consistent with NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants." Foldable loading guides that are not important-to-safety (NITS) may be attached to the side walls of the cask. Additional ASME SA-240 or SA-479, Type 304 stainless-steel lifting attachments, lift lug, lift lug tube, and lift lug base plate, are welded, and only used for lifting of the closure lid containment plate.

The BFA-Tanks are carbon steel (e.g., ASTM A36 and EN 10250-2 Grade S235JRG2) rectangular vessels that conform to the internal dimensions of the HI-STAR ATB 1T cask and provide a sealed enclosure for holding radioactive wastes during transportation. The distinguishing feature of each type of BFA-Tank is the wall thickness designed as gamma shielding. Additional BFA-Tank shielding is provided by a top cover and bottom plate, and thicknesses are increased when used without a BTC to provide equivalent shielding. The top covers of the BFA-Tanks are equipped with metallic seals and serve a "cleanliness" function only and are NITS. The applicant stated that the BFA-Tank top, bottom, and side plates may be fabricated from multiple layers to achieve required minimum thicknesses.

The BTC's or optional waste baskets are designed to accommodate loading, and transfer of radioactive waste from the storage pool to the BFA-Tank and are of the same carbon steel design as described above, consisting of a base plate, and a lid, separated by tie rods in the corners. Each type of BTC is designed to accommodate contents of a given mass and activity and by design assigned to a specific type of BFA-Tank. The applicant stated that only the BTC lid and base plate are credited for shielding.

The staff reviewed the licensing drawings 9786 and 9876 and verified that the drawings contain a bill of materials, including appropriate consensus code information such as the American Welding Society (AWS), ASME, and ASTM specification number(s) for the material(s) used in fabrication. Weld requirements are well-characterized on the license drawings, and standard welding symbols, and notations are in accordance with AWS Standard A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination. Therefore, based on the above discussion, the staff finds the description of materials, and fabrication in the drawing to be acceptable.

2.2.2 Design Criteria

2.2.2.1 Codes and Standards:

Sections 2.1.2 and 2.1.4 of the application describes the HI-STAR ATB 1T design criteria and codes and standards for the package, respectively. Specific code paragraphs in ASME B&PV Code, Subsection NB (NB-3000), of Section III are used for the design of the containment system of the HI-STAR ATB 1T package; however, the design does not invoke ASME B&PV Code (ASME Code) Section III in its entirety. Table 8.1.3 of the application listed alternatives to the ASME Code where appropriate.

Table 2.1.7 of the application listed each major structure, system and component (SSC) of the HI-STAR ATB 1T packaging, including function, and applicable code or standard. Section 1.3 identifies whether items are ITS or NITS using the guidance of NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety." Table 8.1.2 of the application provided applicable sections of the ASME Code and other documents for material procurement, design, fabrication, and inspection, and testing. The staff notes that containment SSCs should be designed to ASME Code material requirements. In addition, non-containment SSC should be designed to ASME, ASTM or AISI material requirements. The staff finds that the identified codes and standards are consistent with the NRC guidance in NUREG-1609. Therefore, they are acceptable for the material control of the HI-STAR ATB 1T components.

2..2.2.2 Weld Design and Inspection:

Section 2.3, Tables 8.1.2 and 8.1.3 of the application discusses fabrication and examination of the HI-STAR ATB 1T package. The welds of the containment boundary are fabricated and qualified in accordance with ASME B&PV Code Section III, Subsection NB-4000, while the welds associated with the DBS and impact limiters are fabricated in accordance with ASME B&PV Code Section IX.

The applicant stated that containment boundary welds, including any attachment welds (and temporary welds to the containment boundary), shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. In addition, these welds shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450, and examined after repair in the same manner as the original weld. The applicant stated that weld overlays (if used) for cask sealing surfaces shall be examined using visual (VT) and liquid penetration (PT). The applicant stated that all inspections of structural code welds shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification, and Certification in Nondestructive Testing."

The applicant stated that ITS welds for the cask DBS and top and bottom cask impact absorbers shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5300. In addition, these welds shall be repaired in accordance with ASME Code Section III, Article NF-4450, and examined after repair in the same manner as the original weld. The NITS welds shall be examined and repaired in accordance with written and approved procedures.

The staff verified that that the weld design, fabrication, and inspections are consistent with NRC guidance in NUREG-1609, which includes the use of ASME Code Section III, Subsection NB, for containment boundary welds, and Subsections NF for other code welds, as appropriate. In addition, non-code welds are examined in accordance with ASME Code Section V, with acceptance criteria per Subsection NF.

The staff notes that, although ASME Code Section III, Subsection NB, does not require visual examination of welds, the applicant stated welds will be visually examined to ensure conformance with the fabrication drawings (e.g., proper geometry, workmanship etc.). The staff finds, based on the above discussion, that the weld design, and inspections of the HI-STAR ATB 1T packaging, meets the requirements of the ASME and AWS Codes, as applicable.

2.2.3 Material Properties

2.2.3.1 Mechanical/Thermal Properties:

Mechanical Properties:

Section 2.2.1, Tables 2.2.1 through 2.2.6, and Table 5.3.1 of the of the application discussed both strength and materials properties used in the HI-STAR ATB 1T packaging structural analyses. The staff notes that most of the values in the SAR tables were obtained from ASME Code, Section II, Part D; however, some of the values were obtained from other acceptable technical references. The staff independently verified the temperature-dependent values for the allowable stress, modulus of elasticity, Poisson's ratio, weight density, thermal conductivity, and coefficient of thermal expansion. The staff finds, based on the above discussion, that the mechanical properties of materials used by the applicant for the design of HI-STAR ATB 1T packaging components are acceptable.

In reaching the above conclusion of adequate mechanical properties, the staff evaluated the applicant's approach to analyze the performance of materials that may experience significant plastic deformation under HAC. Sections 2.1 and 2.2.1.6 of the application discussed structural design of the cask crushable attachments, which are fabricated from ASME SA-240, Type 304 stainless-steel, and ASTM B228-08, alloy 6061 aluminum bars/plates.

To model the mechanical behavior of the exterior impact absorber crushable material, the applicant defined the plastic deformation behavior of the Type 304 stainless-steel and 6061 aluminum alloy using laboratory benchmark testing. The applicant's approach is summarized in Holtec Report HI-2210251, "Benchmarking of Material Stress-Strain Curves in LS-DYNA (proprietary)." The staff notes that the purpose of the report was to develop a method to establish the true-stress-true-strain curve of the analyzed material expected by the finite-element code for elastoplastic analyses based on the standard material strength data.

The true stress-true strain curves needed to model the stainless-steel and aluminum were based, first, on engineering stress-strain curves readily available in the technical literature, and

data on the strain rate sensitivity, and temperature sensitivity of aluminum. The staff noted that, during uniform deformation, engineering stress-strain curves can be readily converted to true stress-strain curves. To refine the material model during uniform elongation and to validate the modeling of material behavior beyond uniform elongation (i.e., during necking and final fracture of a tensile specimen), the applicant used laboratory testing to benchmark the model.

This benchmark testing included tensile tests for each of the material types discussed above. Through this testing, validation, and refinement of the model's predicted material behavior, the applicant demonstrated that the mechanical behavior of the aluminum, and stainless-steel could be accurately modeled to high levels of strain. Based on the staff's review of the applicant's modeling of the behavior of aluminum and stainless-steel in deformation, including the validation provided by the benchmark testing, the staff finds the material properties of the crushable attachments to be acceptable.

Thermal Properties:

Section 3.2 of the application discussed material thermal properties and component specifications. Table 3.2.1 and Section 3.4 of the application provided a summary of references used to obtain package material properties for performing all thermal analyses. The staff evaluated the applicant's thermal properties of the materials credited in the thermal analysis and determined that the thermal properties (e.g., thermal conductivity, thermal expansion, etc.) are consistent with those in the technical literature. Therefore, the staff finds the HI-STAR ATB 1T material thermal properties to be acceptable.

2.2.3.2 Brittle Fracture:

Section 8.1.5.2 of the application discussed impact testing of the HI-STAR ATB 1T packaging materials to ensure that the packaging components have adequate resistance to brittle fracture. The applicant stated that containment boundary ferritic steel components are tested per the fracture toughness test criteria in Table 8.1.4 of the application. The staff verified that the fracture toughness testing of the ferritic steel containment boundary components is consistent with the guidance in Regulatory Guide 7.12, Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) but not Exceeding 12 Inches (0.3 m)," which provides guidance for protecting transportation packages against brittle fracture.

Section 8.1 of the application also stated that non-containment boundary metallic components and associated welds (other than the secondary containers discussed below) are either austenitic stainless-steel, nickel alloy or aluminum, and therefore are exempt from brittle fracture testing in accordance with ASME Code Section III, Subsections NF-2311 (components), and NF-2430 (associated welds). The staff notes that these non-containment boundary components include the DBS, impact absorbers, the cask lid locking system, and trunnions. The staff verified that the materials of construction of the non-containment components (other than the secondary containers) are constructed of materials that the ASME Code exempts from fracture testing due to their lack of a ductile-to-brittle transition at low service temperatures.

Section 2.2.5 of the application discussed the absence of required fracture toughness testing of the secondary containers (BFA-Tanks and BTCs). The applicant stated that BFA-Tank and BTC shall be made from structural carbon steel material with minimum strength properties as noted in the licensing drawings. In addition, based on geometry, and dose rate evaluations performed in Section 5.3.1.1.2 of the application, fracture toughness testing of the BFA-Tank,

and BTC structural carbon steel materials is not required because cracking of these components will not impact safety. The applicant stated that the BFA-Tanks and BTC's are not relied upon as containment barriers or pressure retaining vessels.

In addition, under normal drop events, the maximum tensile stress in any component is less than 1 ksi. The applicant stated that, under HAC, even if through-thickness cracks were to develop in portions of the BFA-Tanks or BTCs that experience significant tensile stresses, it would not result in sufficient component dislocation to cause a loss in the shielding function.

In summary, based on the staff's verification that appropriate fracture testing will be performed on ferritic steels, and that the non-ferritic materials have adequate fracture toughness, the staff finds the applicant's design against brittle fracture to be acceptable.

2.2.3.3 Shielding Materials

Sections 1.2.1.4 and 5.1 of the application discuss gamma shielding features. The shielding analysis credits the attenuation of gamma radiation through three sequential metal masses in the body of the HI-STAR ATB 1T package. The staff notes that the first or initial gamma attenuation is provided by carbon steel BFA-Tank/BTCs and through self-shielding of non-fuel metallic waste. The second gamma attenuation is provided by the HY alloy steel containment boundary weldment designed to withstand all design basis HAC. The third or last stage of gamma attenuation is provided by the stainless-steel DBS weldment, which envelopes the containment boundary.

The staff reviewed the material properties (e.g., density) used in the applicant's shielding analyses and verified that the proprieties are consistent with the technical literature and with those used in previously approved transport packages. Therefore, the staff finds the shielding materials to be acceptable.

2.2.4 Corrosion, Chemical Reactions and Radiation Effects

2.2.4.1 Corrosion Resistance:

The applicant stated that all materials and construction ensure that there will be no significant chemical, galvanic or other reaction as required by 10 CFR 71.43(d).

The staff reviewed the licensing drawings and applicable sections of the application to evaluate the effects, if any, of degradation of cask components due to exposure to the service environment and due to contact between various materials in the HI-STAR ATB 1T package materials of construction during all phases of operation. The staff evaluated whether chemical or galvanic reactions could result in corrosion or combustible gas generation that could adversely affect safety.

The staff notes that, due to the vacuum drying operations, and containment seals that prevent moisture ingress, the HI-STAR ATB 1T internals will not be subject to sufficient moisture to promote corrosion or other adverse reactions. Further, visual inspections are to be performed of the payload cavity prior to loading and following off-loading, which provide reasonable assurance against any considerable corrosion occurring unnoticed.

The HI-STAR ATB 1T package is constructed of materials (e.g., HY alloy steel, aluminum, stainless-steel, and coated carbon steel) that have been previously approved and successfully

transported. Therefore, the staff finds, based on the above discussion, that no credible corrosion, or other adverse reactions of the non-fuel waste package will exist during transport.

2.2.4.2 Protective Coatings:

Sections 1.2 and 2.2.4 of the application discussed packaging coatings. The applicant stated that the coatings identified are commercially available products with years of proven performance. In addition, chemically identical products (i.e., different product names), including products that have had proven performance in similar applications, environments, and/or operating conditions, may be determined equivalent with consideration of manufacturer's recommendations. The applicant stated that protective coatings shall be applied in accordance with the manufacturer's recommendation or as approved by the applicant.

The applicant stated that cask surfaces may be coated for surface preservation purposes, including corrosion prevention. In addition, the interior and exterior surfaces of the BFA-Tanks (steel weldment and lid) and the surfaces of the BTC's are coated for surface preservation purposes. The applicant stated that coating materials are chosen based on expected service conditions and are appropriate for exposure to the pool water and radiation as well as environmental exposure.

The staff reviewed the applicant's use of protective coatings (epoxy primer/paint) and finds them to be acceptable based on the above discussion, independent review of various technical literature (e.g., data sheets, handbooks, etc.), their ability to prevent oxidation, and withstand the maximum service temperatures without undergoing adverse reactions that could impact package performance of the HI-STAR ATB 1T during NCT and HAC.

2.2.4.3 Content Reactions:

The applicant stated that the cask and its contents are dried to remove water, thus preventing a significant increase in cask cavity pressure due to vaporization and/or gas generation from radiolysis of water. In addition, the BFA-Tank is vacuum dried; therefore, chemical, or radiolytic reactions that would produce significant combustible gas, or significantly affect the internal pressure of the containment vessel is not expected. Table 7.1.1 of the application, Package Control Parameters & Their Basis, states that a maximum vacuum drying pressure of 8 millibar will be applied for a minimum of 2 hours and is sufficient for removal of all bulk water from cask.

Section 1.2.2 of the application states that the chip drums design allows water to drain by gravity, prevents pooling of residual water, and facilitates moisture removal during the vacuum drying process. In addition, the bottom and lower sides of chip drums are constructed from a perforated metal (stainless-steel). The applicant stated that this design of chip drums is to prevent pooling of residual water by gravity when the cassette loaded with the drums is lifted out of water.

In addition, the remaining moisture on the wet surfaces of the chips is dried during the vacuum drying process of the BFA-Tank through the perforated walls of chip drums. The applicant stated that to prevent flammable conditions and maintain hydrogen concentrations less than 5% by volume, the vacuum drying process is continued until the required vacuum is reached and maintained as per the drying procedure.

The staff reviewed the potential for gas generation due to the thermal decomposition of materials (e.g., lubricating grease, graphite paste, Loctite adhesive, etc.) which may be present

within the containment of the HI-STAR ATB 1T during or following the HAC fire event. Based on verification of the applicant's statements by independent review of various technical literature (e.g., data sheets, handbooks, etc.), the staff finds that it is not of concern.

2.2.4.4 Radiation Effects:

Sections 2.2.3 and 5.2 of the application discuss the effects of radiation on the HI-STAR ATB 1T packaging materials. The applicant stated that the HI-STAR ATB 1T package is composed primarily of HY alloy steel and stainless-steel, which have a proven history of use in the nuclear industry. In addition, the contents of HI-STAR ATB 1T are classified as fissile-exempt, and therefore the cask's materials will not be subject to appreciable neutron fluence.

The applicant stated that gamma radiation damage to stainless-steel does not occur until the fluence level reaches 10^{18} rads or greater. The applicant also stated that the 50-year gamma fluence (i.e., 50-year design basis without radioactive decay) from the waste transported in the HI-STAR ATB 1T package reduces significantly as it penetrates through cask components. The applicant stated, as a result, that there is no risk of degradation of the containment system due to gamma fluence from the waste being transported.

The applicant stated that the neutron source (n/s/kg) in Table 7.1.2 of the application is an input to the neutron dose calculations presented in Table 5.4.5 of the application and demonstrates that dose rates from neutron emitting radionuclides will have a negligible contribution to the total dose rates. In addition, the primary source of activity in the waste content that contributes to external dose rates arises from Co-60.

The staff notes that the gamma radiation associated with the decay of non-fuel activated waste (Co-60) is expected to have no detrimental effect on the HY alloy steel, stainless-steel, carbon steel, and aluminum comprising the primary structural components of the HI-STAR ATB 1T package during transportation.

In addition, since the payload of the HI-STAR ATB 1T package is heavily shielded, the radiation exposure of the materials is negligible, and the containment seal, which is also located outside of the gamma shielding, likewise receives a negligible exposure. The staff finds, based on the above discussion, there will be no deleterious radiation effects on the packaging materials, and therefore, the requirements of 10 CFR 71.43(d) are met.

2.2.5 Component Specific Reviews

Bolting

Section 8.2.4 and licensing drawing 9786 (flag note 8) of the application discuss component/material tests and cask bolting material, respectively. The applicant states that the HI-STAR ATB 1T packaging fasteners for the cask impact absorbers are to be austenitic stainless-steel with minimum 50ksi (345MPa) tensile strength.

The applicant states that the cask impact absorbers shall be visually inspected for indications of damaged or loose fasteners. In addition, loose fasteners shall be visually inspected for wear on the threaded surfaces prior to reinstallation or replaced. The applicant states that threaded fasteners shall be visually examined in accordance with ASME Section III, Subsection NF-2582. In addition, impact absorbers shall remain attached to the cask during loading, unloading, and transport operations.

Therefore, a fatigue analysis for bolts, and internal threads, is not required.

Section 5.3.1 and licensing drawing 9876 (flag note 1) of the application discussed configuration of shielding and bolt material, respectively. The applicant states that, under the HAC drop, the BFA-Tank and BTC experience significant decelerations which may result in a failure of the welds and ASTM A36 (typical) carbon steel lid bolts, and therefore all welds, and lid bolts are conservatively assumed to fail.

The applicant states that, due to the geometry arrangement of the individual carbon steel plates used to fabricate the BFA-Tank and BTC, relocation is not possible. In addition, configuration of shielding provided by the top cover of BFA-Tanks is maintained without the presence of bolts, as the top cover is restrained in position by side and end walls, and therefore BFA-Tank bolts are defined as NITS.

Table 3.1.1 of the application discusses component maximum temperatures of the HI-STAR ATB 1T during NCT. The staff notes that all bolts have low thermal expansion based on the low package heat load and the thermal expansion properties of the bolts and bolted packaging materials. The staff concludes that, based on the above discussion, failure is not a concern during transportation.

Seals

Table 2.2.6 and associated notes of the application discussed critical characteristics for the cask containment seals. The applicant states that the interfacing surfaces of the lid and the top flange of the cask body are machined to seat two concentric elastomeric gaskets forming a compression joint. A fluorocarbon is identified as the inner (O-ring) seal and is designated as ITS. In addition, an ethylene propylene is identified as the outer (O-rings) seal and is designated as NITS. The applicant stated that the lids of the BFA-Tanks are equipped with unidentified metallic seals, as indicated in the application licensing drawings, but only serve a cleanliness function, and are NITS.

Section 8.2.4 of the application discussed component and material tests of the HI-STAR ATB 1T packaging. The applicant stated that the seals are considered to be reusable until pre-shipment leakage testing indicates that they can no longer meet the leakage criterion or unless they fail a visual inspection. The applicant stated that seals which have been in-service for more than 1 year shall be replaced the next time that the CLLS is disengaged.

The applicant identified the dimensions, tolerances, and material characteristics for the elastomeric containment boundary seals in Section 2.2.6 and licensing drawings of the application. The applicant specified seal performance requirements in the application, including

(1) ensuring testing of the containment boundary is performed to ANSI N14.5-2014, “American National Standard for Radioactive Materials—Leakage Tests on Packages for Shipment,” leak-tight criteria,

(2) adequate performance of the inner seal in the temperature range of -40°F to 608°F (which bounds the maximum temperature during the tests for NCT and HAC in 10 CFR 71.71 and 10 CFR 71.73, respectively),

(3) pressure rating of 1350 psi maximum tensile strength (which bounds the maximum internal pressure of the package and maximum external pressure due to package immersion), and

(4) 60 lbf/inch combined maximum compression force (seal materials are tested to confirm the load required to achieve metal-to-metal contact at the seal interface is less than this value).

The staff reviewed the seal specifications and licensing drawings. Based on the discussion above and by verification of the applicant's statements by an independent review of various technical literature (e.g., ASTM standards, data sheets, handbooks, etc.), the staff concludes that the seals are capable of adequately meeting these performance requirements.

The staff notes that the ITS O-Ring is a synthetic rubber containing higher amounts of fluorine than the NITS O-Ring, which provides increased high temperature, and chemical resistance. The staff notes that a review of literature concerning radiation resistance of the ITS seal shows the material can withstand 10^6 rad with little effect on physical properties, which bounds the seal irradiation conditions as described in Chapter 5 of the application.

The staff notes that the HI-STAR ATB 1T seals are visually inspected, and leak tested, prior to shipment, and are replaced if transport period exceeds 1 year of in-service operation. The staff concludes that, based on the discussion above, the containment seal material can perform in the thermal, and radiation environments under NCT and HAC.

Insulation

Sections 1.2, 3.1 and the licensing drawing 9786 (flag note 6) of the application discuss the HI-STAR ATB 1T cask insulation board. The applicant stated that a Kaowool 1401 Millboard is used as insulation in the cask body (between HY alloy steel containment wall and stainless-steel dose blocker plate) and the closure lid to ensure that sealing gasket performance is not compromised during HAC fire. The applicant stated that the insulation material is suitable to resist temperatures in excess of bounding temperatures for both NCT and HAC.

The staff notes that the maximum temperatures reached during the fire and post-fire cooldown are shown in Table 3.1.2 of the application. The staff notes that Kaowool Millboard 1401 grade is fabricated from ceramic fibers, clay, inert fillers, and a small amount of binders for increased strength. The staff reviewed the vendor's 1401 grade technical specification for various material/physical/thermal properties as follows: chemical composition of silicon dioxide, aluminum oxide, and zirconium dioxide, density of (560-641) kg/m^3, modulus of rupture (4.48-5.17) MPa, thermal conductivity to ASTM C 201, continuous use temperature of 2000°F, and a melting temperature of 3200°F.

The staff verified the insulation material would adequately perform at temperatures expected during HAC, based on the staff's review of the service conditions, and the vendor's technical data. Therefore, the staff finds, based on the discussion above, the insulation material is acceptable for use in the HI-STAR ATB 1T package.

2.2.6 Evaluation Findings

The staff has reviewed the package and concludes that 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 staff has reviewed the package and concludes that 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 staff has reviewed the package and concludes that 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 normal conditions of transport and hypothetical accident conditions. The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.85(a). The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.43(d), 10 CFR 71.85(a), and 10 CFR 71.87(b) and (g). The applicant has demonstrated that there will be no significant corrosion, chemical reactions or radiation effects that could impair the effectiveness of the packaging. In addition, the package will be inspected before each shipment to verify its condition.

The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a) for Type B packages. 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 and there will be no loss or dispersal of the contents under the tests for normal conditions of transport.

2.3 Fabrication and Examination

The HI-STAR ATB 1T packaging is a stainless steel and alloy steel weldment of rectangular cross-section. The inner walls and baseplate of the cask are fabricated of alloy steel (SA-517/A514) qualified to ASME B&PV Code Section III, Division 1, Subsection NB. The closure lid is a monolithic plate made of the same material, and also procured to ASME B&PV Section III, Division 1, Subsection NB specifications. The inner walls, inner baseplate, and closure lid constitute the containment boundary of the cask.

The cask outer walls and bottom plates, as well as the closure lid outer plate, are made from austenitic stainless steel (Type 304), procured to ASME Section II specifications.

All weld procedures are qualified to Section IX of the ASME code. The in-process inspection of finished welds is provided in Chapter 8 of the application.

2.4 General Considerations for the Structural Evaluation of the Packaging

The applicant evaluated the package with a combination of analytical tools and physical drop testing to determine its structural integrity in both NCT and HAC conditions. The applicant first did a pre-analysis using finite element (FE) modeling tools to simulate drop testing of a prototype, followed by physical testing of the prototype, and then a refinement of the pre-analyses FE model. Throughout this process, the applicant modified the package as needed. Finally, the applicant created a full-scale simulation to evaluate the package.

The LS-DYNA structural methodology was validated by ¼ scale drop tests, as described in SAR Appendix 2B. An example LS-DYNA output is shown in Figure 8.2.6 of the referenced calculation package HI-2177539, "Drop Analysis of the HI-STAR ATB 1T Transport Package," Rev. 4 that showed strain contours at a section of the HI-STAR ATB 1T transportation package after a 30-ft drop. The numerical values of the strain are provided in the legend of Figure 8.2.6 as ten gradations of true plastic strain.

Results showed that there was no plastic strain in the lid and flange areas at the containment boundary's inner seal. Other strain contour plots only indicated that approximately two of the FE analysis cells toward the edge of the lid near the outer test O-ring showed slight inelastic strain on the order of 10^{-4} inch/inch, corresponding to approximately one-micron strain displacement (see SER Section 1.2 relative to the surface finish).

The applicant described the numerical LS-DYNA analyses that modeled the package during normal conditions of transport and hypothetical accident conditions. The LS-DYNA drop models of the transportation package included the flange, lid, and the lid's inner containment boundary O-ring groove and the outer O-ring groove. The LS-DYNA drop model was composed of approximately 1,390,000 elements with nearly 5,000 elements for each seal groove, with other modeling details described in Table 2.6.4 and Figures 2.6.1 through 2.6.6 of the application. The full-scale model utilizes beam, shell, and solid elements. A finer mesh is used for parts at or near the seating surface such as the CLLS closure lid, flange, cladding, and sealing surface. A coefficient of friction is used for all contact surfaces. Welds between the containment wall plates and base plate have been explicitly modeled.

Regarding the modeling of the package contents, the BFA-Tank and BTC are secondary containers made of carbon steel. The contents are represented by the BTC, and its density is adjusted accordingly. The applicant explicitly modeled the BTC and the mass of the waste material in the BTC is accounted for by adjusting the density of the BTC, so that the total mass of BTC and waste is accurately represented in the model. The BTC side wall plates, which are classified as optional NITS components are represented in the numerical simulations to reflect the maximum full weight of the BTC. The BTC decelerations (g-loads) obtained from the NCT drop simulations are used to substantiate its structural adequacy.

The BFA-Tanks provide secondary packaging for the contents and are fitted into the HI-STAR ATB 1T cask. Their top and bottom plates provide a shielding function, and the following structural criteria are imposed on the BFA-Tanks:

a. The BFA-Tank walls and top and bottom plates must not be subject to gross failure under NCT and HAC and must not collapse due to buckling or excessive primary stresses beyond yield.

b. The connections between the BFA-Tank walls and the top and base plates must not fail under NCT. During the HAC drops, a BFA-Tank weld failure is permissible since geometric constraints preclude a significant reconfiguration of BFA-Tank walls or top and base plates, which thus ensures a continued shielding effectiveness.

The BTC are loaded into the BFA-Tanks. Only the BTC top and bottom plates provide a shielding function under NCT. Accordingly, the following structural criteria are imposed on the BTC:

a. The BTC corner tie rods must not buckle or suffer gross yielding under the postulated normal drop events.

b. The BTC top and bottom plates must not separate from the corner tie rods. The top and bottom plates of the BTC are also credited for shielding under HAC. However, a relocation of those plates is considered in the shielding analyses (i.e., no credit is taken for the corner tie rods). Therefore, no structural acceptance criterion applies to the BTC under HAC.

Regarding hourglassing of the finite element models, the ratio of hourglass energy to internal energy should be kept to a ratio of 10% or less. The reason for this is that hourglass energy

indicates that a nonphysical part of internal energy is present in the model, which, in turn, implies that deformations and the overall physical behavior of the part may not be realistically simulated.

The staff noted (ADAMS Accession No. ML19316A159) that, for some drop simulations such as the 9-m top end drop, the top lid of the BTC or the intermediate dose blocker plate initially exhibited ratios well above 10%. Thus, the applicant revised the analysis to demonstrate that the total hourglass energy is indeed less than 10% of the peak internal energy of the cask and that the identical measure (ratio of total hourglass energy to the peak internal energy) for individual parts is also minimized to the extent practicable.

To protect the package from damage by the trunnions and the lid lifting attachments during a free drop event, the trunnions and the lid lifting attachments have been designed to be axially collapsible under a moderate axial load.

At the staff's request, (ADAMS Accession No. ML19198A025), the applicant performed a sensitivity analysis of the concrete strength to demonstrate that the concrete portion of the target plays a small role in imparting g-loads to the package. The staff noted that this was necessary to demonstrate that the modeling approach was consistent with the physical drop testing of the package. In the study, the applicant modified the concrete material model and concrete compressive strength used in the finite element analysis. The applicant reported the results of this sensitivity analysis in the August 9, 2019 RSI Response (ADAMS Accession No. ML19221B423), which showed consistent deformations of the cask and target following the impact. Based on these results, the applicant concluded that the dynamic response of the cask was not sensitive to the different concrete material model or changes in the concrete compressive strength within the tested range of 6000 psi to 7500 psi.

2.4.1 Minimum Package Size

Given that the minimum package dimension is greater than 10 cm, the package satisfies the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper-Indicating Features

The package contains a security seal which indicates access to the contents. The seal is a NITS feature which is attached to the locking wedge lock bar. The cask lid cannot be removed without movement of the locking wedge lock bar, which would foul the tamper-indicating device. As a result, the package satisfies the requirements of 10 CFR 71.43(b) for a tamper-indicating feature.

2.4.3 Positive Closure

Positive closure of the package is achieved by the CLLS which is made up of the closure lid locking wedges, actuating device/system and locking wedge lock bar. The wedges are installed at the interface between the flange and the lid, providing a compressing force on the seals. The staff reviewed the package closure description and finds that the package satisfies the requirements of 10 CFR 71.43(c) for positive closure.

2.4.4 Package Valves

The package does not contain any valves. The lid and flange of the package protect the sealing surface. Since the package does not contain any valves or other device whose failure would allow a radioactive release, the staff agrees that the package closure description satisfies 10 CFR 71.43(e).

2.5 Lifting and Tie-Down Devices

The applicant followed NUREG-0612 in the evaluation of the lifting devices for the package. The applicant assumed a dynamic amplifier in the design of lifting devices.

The package has a total of eight retractable trunnions on the package, with four on each long side of the package. Of the eight trunnions, only four are assumed to participate in the analyzed lift. Safety factors for the trunnions are based on three times the lifted load compared against the material yield strength.

The applicant evaluated the trunnions with a classical analysis following ASME B&PV Code Section III, Division 1, Subsection NG. The bearing safety factor of 1.3 controlled the design. The applicant reported safety factors for the trunnions in Table 2.5.1 of the SAR, while the closure lid lifting attachments associated safety factors are located in Table 2.5.2.

2.5.1 Failure of Lifting Devices

10 CFR 71.45 requires that the lifting attachments permanently attached to the cask be designed in a manner such that a structural failure during lifting will not impair the ability of the package to meet other regulatory requirements. The applicant noted that the ultimate load carrying capacity of the lifting trunnions is governed by the cross-section of the trunnion external to the package and that the loss of the external shank of the lifting trunnion will not cause the loss of any other structural or shielding function of the HI-STAR ATB 1T package; therefore, the staff agrees that the package is in compliance with 10 CFR 71.45(a).

The staff noted that the HI-STAR ATB 1T shielding models have been conservatively updated to consider a loss of the trunnion external to the cask main body surface, under NCT, as shown in Figure 5.3.2 of the HI-STAR ATB 1T application. The applicant provided dose rates at the surface and 2 meters from the “failed” trunnion under NCT for each waste package type in Tables 5.4.6 and 5.4.7, respectively. The applicant performed a static lifting analysis with the ANSYS analysis software using the dynamic amplifier. The applicant reported the critical safety factors from this ANSYS lifting analysis in Table 2.5.3 of the application.

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

2.5.2 Tie-Down Devices

The package is tied down via cleats which fit into three recesses on each side of the package. These cleats are part of a transportation frame which was not examined by the NRC staff. The applicant analyzed the forces generated on the package as a result of the use of these cleats. The cleats themselves are not meant to affix permanently to the package and thus, are not considered to be part of the package itself. The failure of these cleats will not impair the ability of the package to meet other 10 CFR 71 requirements.

The staff finds this description of the tie-down devices to be consistent with the requirements of 10 CFR 71.45(b) for tie downs.

2.6 Normal Conditions of Transport

The applicant’s model included the following refinements:

- The finite element mesh, used for the free drop simulations, is sufficiently discretized to predict reasonably well the primary membrane and bending stresses as well as the secondary stresses and strains at locations of gross/local structural discontinuities. Table 2.6.4 provides input data for the model.

- The HI-STAR ATB 1T, the BFA-Tank, and the BTC are modeled as separate parts and have no connectivity with the interfacing adjacent components except for the contact interfaces. Interfacing cask components expected to undergo element erosion/failure use an “eroding_surface_to_surface” contact.
- The HI-STAR ATB 1T cask containment, the dose blocker structure and the crushable attachments have a finer mesh. The sealing surfaces on the closure lid and the cask body have been modeled with a fine mesh and the closure lid locking wedge is also modeled explicitly using a finer mesh to simulate the joint behavior accurately during the drop event.
- The coefficient of friction is the same for all contact surfaces.
- The material stress-strain relationship used in the LS-DYNA drop simulations was correlated by a material benchmark study that validated the material true stress-strain behavior. The benchmark study involved physical testing of multiple tensile test specimens for the separate materials used in the HI-STAR ATB 1T package followed by numerical simulations in LS-DYNA using the identical input conditions, including specimen geometry, boundary conditions, and material inputs. The same method is used to develop the nonlinear true-stress-true-strain curves for all deformable materials used in the HI-STAR ATB 1T drop simulations. For the baseline drop simulations, all cask component materials are represented by their true-stress-true-strain relationships developed using the minimum properties specified in the ASME B&PV Code.
- The BFA-Tank is modeled as a rectangular box of equivalent internal density while the BTC is explicitly modeled and the mass of the waste material in the BTC is accounted for by adjusting the density of the BTC so that the total mass of BTC and waste is accurately represented in the FE model.
- The welds between the containment wall plates and the base plate are explicitly represented in the model. The crushable bars/components attached externally to the cask are also explicitly represented in the model because they undergo severe plastic deformation and failure.

The NCT events discussed in this section and the HAC events discussed in Section 2.7 of this SER occur under the maximum ambient temperature at 38ºC or minimum ambient temperature at -40ºC; thus, all the drop events are conservatively evaluated at component bounding temperatures.

Figures 2.6.1 through 2.6.7 in the SAR show the finite element models and layout of the package and of the BFA-Tank and the BTC, respectively.

2.6.1 Heat

The applicant considered package temperatures corresponding to an ambient temperature of 38°C with solar insolation. Material properties used in their simulation model corresponded to this upper end. This matches the 38°C ambient temperature dictated by Part 71. Thus, the staff concludes that the heat requirements for the package satisfy the standards of 10 CFR 71.71(c)(1).

2.6.2 Cold

The applicant evaluated material properties at a minimum temperature of -40°C when performing drop testing and used material properties at this temperature. Since the materials used in the package such as austenitic stainless steels are not susceptible to brittle fracture at

this temperature, the package, as a whole, is not prone to brittle fracture. The staff also noted that the fracture toughness test requirements for the containment boundary components are given in Table 8.1.4 of the SAR for the lowest service temperature of -40ºC (-40ºF). The closure lid locking wedges securing the lid are made of a material that is not susceptible to brittle fracture. Thus, the staff concludes that the package complies with 10 CFR 71.71(c)(2).

2.6.3 Reduced External Pressure

Based on the construction of the package, the staff agrees that the reduced external pressure of 3.5 psia will not significantly challenge the package. The staff concludes that the package satisfies the standards of 10 CFR 71.71(c)(3).

2.6.4 Increased External Pressure

The applicant evaluated the HI-STAR ATB-1T package for an external pressure of 20 psia, corresponding to a 50-foot immersion into water. This evaluation considered ASME B&PV Code service Level A stress intensity limits to determine safety for the containment. The results of this evaluation are presented in Table 2.6.1 of the application, which shows safety factors of 8.46 for the closure lid, 7.95 for the containment wall plate, and 12.35 for the base plate are shown.

As such, the package containment boundary components have substantial safety factors under the external pressure loading and the staff concludes that the package satisfies the standards of 10 CFR 71.71(c)(4).

2.6.5 Vibration and Fatigue

The applicant states that vibrations within the cask will be small relative to accident loads and that vibrational effects during NCT will not cause the top cover bolts to become loose and separate from the BFA-Tank for the following reasons:

(i) The dimensions of the thinnest BFA-Tank lid (i.e., T-50 Version) are such that the lowest natural frequency of the lid is above 33 Hz. Therefore, the BFA-Tank lid behaves like a rigid body and low frequency vibrations are not transmitted to the top cover bolts during NCT.

(ii) Because of the transport in a vertical upright orientation, the BFA-Tank lid is always in a seated position, and this prevents the top cover bolts from backing out.

(iii) Physical limitations inside the HI-STAR ATB 1T containment cavity also prevent the top cover bolts from separating from the BFA-Tank. The maximum gap between the bottom of the HI-STAR ATB 1T closure lid and the top of the BFA-Tank is lower than the minimum engagement thread for the top cover bolts. Therefore, the top cover bolts cannot completely separate from the BFA-Tank, once the HI-STAR ATB 1T closure lid is installed.

The staff reviewed the applicant's evaluation of vibrations for the package and concludes that vibrational effects will be small, relative to other NCT conditions, due to the construction of the package. The staff concludes that the calculations provided by the applicant show that the package is rigid and has high frequency characteristics, which are not susceptible to resonance at lower frequencies.

As described in SAR Section 2.6.5, the applicant considered the effects of fatigue on the package by comparing the induced stresses from the dead weight loading conditions to the allowable stress amplitude of SA-517 steel at a million cycles with a strength reduction factor.

The applicant concluded that the dead load induced stresses were an order of magnitude less than the allowable stress amplitude with a large strength reduction factor, and this indicates that vibrations will not cause fatigue of the package.

The staff noted that the most flexible mode of frequency for the package calculated by the applicant as being far from 33 Hz, the frequency which the applicant assumes will cause resonance. The staff reviewed the fatigue evaluation and finds it to be acceptable.

The staff has reviewed vibration and fatigue requirements for the package and concludes that they satisfy the requirements of 10 CFR 71.71(c)(5).

2.6.6 Water Spray

10 CFR Part 71.71(c)(6) requires that the package be subjected to a water spray test that simulates exposure to rainfall of approximately 2 inches/hour for at least 1 hour. The water spray test is primarily intended for packaging relying on material that absorbs water and/or are softened by water.

In SAR Section 2.1.2.1, the applicant concluded that the water spray test was not structurally significant for the HI-STAR ATB 1T. Based on a review of the package and the materials of the package's construction, the staff concludes the water spray test will not impair the package structurally, and thus the staff finds the package satisfies the standards of 10 CFR 71.71(c)(6).

2.6.7 NCT Free Drop

Based on the weight of the package, the applicant evaluated a 0.3 m free drop for the NCT free drop test. The applicant defined the evaluation criteria for the NCT free drop in Load Case 5 listed in SAR Table 2.1.1.

In analyzing the NCT free drop, the applicant evaluated the containment system to the Level A stress intensity limits following ASME B&PV Code Section III, Division 1, Subsection NB. The applicant determined the containment system of the package remained leak resistant during the NCT free drop. The cask lid locking system remained in the elastic range; the gaskets remained compressed following the event; and the dose blocker structure components did not undergo gross yielding.

The applicant presented the results of the NCT free drop test in SAR Table 2.6.2, showing the containment boundary met the Level A stress intensity limits. The applicant determined the BFA-Tank walls, the top and bottom plates, and their connections did not suffer gross yielding, buckle, or exceed the Level A stress intensity limits. For the BTC, the applicant determined the top and bottom plates did not separate from the corner tie rods and the tie rods did not buckle or suffer gross yielding.

As discussed in SAR Section 2.6.3, the applicant concluded that the performance during the NCT drops of the seal between the closure lid and top containment walls and the thermal insulation board's support bars were bounded by the HAC drop analyses discussed in Section 2.7 of this SER.

The staff reviewed the applicant's evaluation of the NCT free drop test LS-DYNA results which indicated there was no plastic deformation at the closure and that there would be no loss of content and no loss of containment boundary integrity during normal conditions of transport; therefore, there would be no release of radioactive contents, thus demonstrating compliance with 10 CFR 71.43 and 71.51(a). The staff concludes that the package meets the regulatory requirements of 10 CFR 71.71(c)(7).

2.6.8 Compression

The applicant subjected the package to a load corresponding to the compression test and performed a finite element analysis to determine the corresponding stresses in the cask containment components. The applicant summarized the results of this evaluation in Table 2.6.3 of the application, which showed large safety factors for the containment boundary components under the compression loading. Based on the safety factors from the compression analysis, the staff finds that the package satisfies the standards of 10 CFR 71.71(c)(9).

2.6.9 Penetration

The outer portion of the ATB-1T package is made of stainless steel and does not have any valves or opening that would be susceptible to 6-kg bar impacting it. RG 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," states that the penetration test is not required for a large shipping cask, except for unprotected valves and rupture disks. Following RG 7.8, the penetration test was not required. The staff finds the package satisfies the regulatory requirements of 10 CFR 71.71(c)(10).

2.7 Hypothetical Accident Conditions

The structural evaluation of the HI-STAR ATB 1T package for HAC conditions considered ASME B&PV Code provisions and stress limits to determine the structural integrity of ITS components. The applicant allowed non-containment boundary components of the outer portion of the cask (e.g., impact limiter plates and crush blocks) to go beyond yield during HAC.

The applicant initially utilized material models in LS-DYNA to simulate drop tests which incorporated post-yield behavior, such as element erosion and strain rate dependency. However, it was observed from the first HI-STAR ATB 1T package HAC drop simulations that the package crushable attachments (intended to absorb significant energy from impact) underwent extensive inelastic deformations, and the model relied heavily on the post-yield behavior.

Therefore, it became essential that the material inputs to the LS-DYNA drop simulations accurately captured the full range of material true stress-strain behavior, particularly in the plastic and post-necking region through failure. As such, the applicant was requested to perform physical material testing to determine the full range of material behavior and benchmark the material models used in the LS-DYNA drop simulations.

The applicant followed ASTM Standard E8, “Standard Test Methods for Tension Testing of Metallic Materials,” for the physical material testing of the materials that were subject to extensive plastic deformation during the HAC drops. The three materials tested were:

(i) stainless steel SA 240, Grade 304, which undergoes significant area reduction before fracture and is used for a crushable component attached outside of the HI-STAR ATB 1T package,

(ii) aluminum alloy 6061 – ASTM B221-08, which is used for a crushable component attached externally to the HI-STAR ATB 1T package,

(iii) Inconel - SB 637 N07718, which is used for the closure locking bars in the HI-STAR ATB 1T package.

Five specimens for each material were prepared and subjected to uniaxial tensile testing, per ASTM Standard E8. Subsequently, the applicant simulated the physical material tests in LS-DYNA to benchmark the LS-DYNA material models with the physical testing. The applicant

then used these benchmarked, true-stress-true strain material models to represent the full range of material behavior in the LS-DYNA drop simulations for HAC.

Based on the results from the drop simulations, which used the ASME minimum material strength properties to develop material models, the governing drop orientation was then reanalyzed in a sensitivity study. The sensitivity study considered the upper bound material strength properties for the external crushable attachments to the package and the lid impact absorber spacers. The sensitivity study demonstrated that using the upper bound material strength properties had a negligible effect on the structural performance of the package in the HAC drops.

2.7.1 Free Drop

As described in Section 2.7.1 of the SAR, the applicant analyzed top, bottom, side, top and bottom corner, and oblique drop orientations for the maximum damage in a 9-meter drop. The applicant evaluated the structural integrity of the containment boundary components under the HAC drops by comparing the component stress intensity results from LS-DYNA simulations to the design basis requirements of ASME Code Section III, Division 1, Subsection NB and the Level D stress intensity limits.

Also, the applicant assessed whether the containment system remained leak resistant during the HAC free drop, which the applicant considered as the cask lid locking system remaining in the elastic range and the gaskets remaining compressed. SAR Table 2.7.1 summarized the critical results for the HAC drop conditions.

In the LS-DYNA drop simulations, the applicant used the material models described in Section 2.7 of this SER for the stainless steel and aluminum crushable attachments, which undergo significant deformation culminating in material failure. The applicant used LS-DYNA standard piecewise linear plasticity material formulation for the behavior of the other components, which are protected against excessive deformation by the crushable attachments.

The results of the LS-DYNA drop simulations showed that, other than the crushable attachments, the deformation of the cask was minimal. The simulation results also demonstrated that:

- There was no gross failure or separation of the dose blocker components from the cask body,
- The closure joint was demonstrated to be leak-tight,
- The closure lid support bars limited the deformation of the dose blocker plate relative to the closure lid and maintained the performance of the thermal insulation board,
- The BFA-Tank walls were not subject to gross failure; and
- The BFA-Tank top lid and baseplate remained connected to the tank walls.

As described in SAR Section 2.7.1, the applicant did not take credit for the corner tie rods in the shielding analysis due to the relocation of the BTC top and bottom plates, which are credited for shielding under HAC. Because of this, the applicant concluded that there was no structural acceptance criterion required for the BTC under HAC.

The shims between the BFA-Tank and the HI-STAR ATB 1T package mitigate the effect of secondary impact on package deformations, including the seal area, and are classified as ITS. It also is noted that the BFA-Tank lid bolts have a minimum of 1 inch (25.4 mm) thread engagement, such that the 10 mm gap restriction between the BFA-Tank and HI-STAR ATB 1T

lid and baseplate is less than the BFA-Tank lid bolt thread length: this means that the lid remains attached to the BFA-Tank.

The applicant demonstrated (Calculation package HI-2177540) that the BFA-Tank walls are not subject to gross failure under NCT or HAC conditions and that the welds connecting the BFA-Tank bottom plate to the side walls are not subject to direct shear loading during a side drop. In addition, LS-DYNA plots did not indicate any separation between the BFA-Tank walls during HAC.

The permissible upper bound material strengths for the crushable components are specified in Table 8.1.5 of the application and are required to be verified by testing during the HI-STAR ATB 1T package fabrication.

Based on a review of the applicant's analyses, modeling, and testing, the staff finds that the applicant satisfied the requirements of 10 CFR 71.73(c)(1) for the HI-STAR ATB 1T package.

2.7.2 Crush

The ATB 1T package weighs more than 500 kg and is exempt from the HAC crush test, per 10 CFR 71.73(c)(2).

2.7.3 Puncture

The applicant examined a total of four puncture drop scenarios: a top end puncture, a side puncture drop onto the trunnion, a top center of gravity over corner puncture, and a bottom center of gravity over corner puncture.

From the four drop analyses, the staff noted that:

1. The top end puncture scenario did not cause inelastic deformation in the sealing surface.
2. For the side puncture drop onto trunnion scenario, the applicant assumed that the package strikes the trunnion head on and assumes that the puncture bar fits completely within the trunnion recess (without the trunnion), leaving only 2 ½" of containment boundary material (6" thick otherwise). The applicant's simulation model demonstrated that inelastic strains did not occur in the containment boundary. Since the puncture bar's diameter cannot fit within the opening, the staff concludes this scenario was conservative.
3. The top center of gravity over corner puncture scenario resulted in a very minimal inelastic deformation in the cladding away from the inner seal toward the outer edge of the package, where the puncture bar contacts a top corner of the package that had already observed damage from the 9 m drop.
4. The bottom center of gravity over corner puncture scenario resulted in no inelastic deformation beyond that suffered in the preceding HAC free drop.

Overall, results showed that there was no plastic strain in the lid and flange areas at the containment boundary's inner seal. As mentioned earlier in the SER, other strain contour plots only indicated that approximately two of the FEA cells toward the edge of the lid near the outer test O-ring showed slight inelastic strain on the order of 10^{-4} inch/inch, corresponding to approximately one-micron strain displacement.

The applicant also demonstrated that there is no thru-wall penetration of the containment boundary; that the primary stresses in the closure lid, the containment shell, and the baseplate remain below their respective limits; and that the opening between the closure lid and top flange was small enough that the closure seal remains compressed. The staff noted that the analysis results, in particular the lack of any no thru-wall cracks, demonstrated that shielding effectiveness of the package is maintained.

Based on a review of the applicant's puncture drop analyses, the staff finds that the applicant satisfied the requirements of 10 CFR 71.73(c)(3) for the HI-STAR ATB 1T package.

2.7.4 Thermal

The applicant described the package as having little thermal stresses due to low temperatures in the cask for NCT conditions and near uniform temperatures throughout the package. The applicant evaluated the differential thermal expansion of the seals relative to the growth of the metallic CLLS during the fire event for the package. The applicant found that the useful rebound of the seals greatly exceeds the expansion of the CLLS and thus the seals will continue to function as intended.

The applicant also demonstrated that the increase in internal pressure during the HAC fire scenario will not cause the containment boundary components of the package to yield, as the pressure built up during the fire scenario did not cause any of the components in the containment boundary to yield. The staff reviewed the structural evaluation of the thermal effects and concludes that the standards of 10 CFR 71.73(c)(4) are satisfied.

2.7.5 Immersion

The applicant used the ANSYS analysis software to analyze the package assuming 40 psi of pressure, which exceeds the 50-foot pressure head of the HAC immersion test. The applicant used ASME B&PV Code Section III, Division 1, Subsection NB to evaluate this scenario and demonstrating a safety margin of 4.62 The staff reviewed the structural evaluation of the immersion test and concludes that it satisfies the standards of 10 CFR 71.73(c)(6).

2.8 Evaluation Findings

The staff has reviewed the package structural design description and concludes that the contents of the application satisfies the requirements of 10 CFR 71.31(a)(1) and (a)(2) as well as 10 CFR 71.33(a) and (b). The staff has reviewed the structural codes and standards used in package design and finds that they are acceptable and satisfy the requirements of 10 CFR 71.31(c).

The staff has reviewed the lifting and tie-down systems for the package and concludes that they satisfy the standards of 10 CFR 71.45(a) for lifting and 10 CFR 71.45(b) for tie-down. The staff has reviewed the package description and finds that the package satisfies the requirements of 10 CFR 71.43(a) for minimum size. The staff reviewed the package closure description and finds that the package satisfies the requirements of 10 CFR 71.43(b) for a tamper-indicating feature.

The staff reviewed the package closure system and the applicant's analysis for normal and accident pressure conditions and concludes that the containment system is securely closed by a positive fastening device and cannot be opened unintentionally or by a pressure that may arise within the package and therefore satisfies the requirements of 10 CFR 71.43(c) for positive closure. The staff reviewed the package description and finds that the package does not

contain a valve, the failure of which would allow radioactive contents to escape and therefore satisfies the requirements of 10 CFR 71.43(e).

The staff reviewed the application and finds that the package was evaluated by subjecting a specimen to test in a method acceptable to the Commission, and therefore satisfies the requirements of 10 CFR 71.41(a). The staff reviewed the structural performance of the packaging under the Normal Conditions of Transport required by 10 CFR 71.71 and concludes that there will be no substantial reduction in the effectiveness of the packaging that would prevent it from satisfying the requirements of 10 CFR 71.51(a)(1) for a Type B package.

The staff reviewed the structural performance of the packaging under the hypothetical accident conditions required by 10 CFR 71.73 and concludes that the packaging has adequate structural integrity to satisfy the containment and shielding requirements of 10 CFR 71.51(a)(2) for a Type B package.

Based on review of the statements and representations in the application, the NRC staff concludes that the package has been adequately described and evaluated to demonstrate that it has the structural integrity to meet the requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

The objective of the review was to verify that the thermal design and performance of the HI-STAR ATB 1T transportation package was adequately described and evaluated under normal conditions of transport (NCT) and hypothetical accident conditions (HAC) and that the package design satisfies the thermal requirements of 10 CFR Part 71. Regulations applicable to the thermal review include 10 CFR 71.31, 71.33, 71.35, 71.41, 71.43, 71.51, 71.71, and 71.73.

3.1 Description of the Thermal Design

3.1.1 Packaging Design Features

The HI-STAR ATB 1T is a Type B package that consists of the cask and a waste package; the waste package is comprised of a secondary container (BFA-Tank) and waste basket (BFA-Tank Cassette; “BTC”). Contents include radioactive wastes of solid radiation-activated and surface-contaminated reactor internals, secondary waste generated by mechanical cutting processes (chips, debris) placed in chip drums, and metallic waste filters (stainless steel or ceramic mesh screens) placed within the chip drums. Acceptance review Observation 3-4 (Enclosure 1 to Transmittal Letter 2404004-NRC) stated that the size and material associated with the metal chips indicate that they are not pyrophoric.

SAR Section 4.2.1 stated that the content is dried prior to shipment and organic materials that can undergo radiolysis and result in reactions that would impact package operations, including plastics and water, are not included in the radioactive waste contents. SAR Table 7.1.2 indicated package contents could include up to 2 grams of special nuclear material (SNM). In addition, SAR Section 1.2.3 stated that the package may contain plutonium. A CoC condition states that air transport is not allowed; therefore, 10 CFR 71.64 does not apply, and a 60-minute fire thermal analysis is not required.

The maximum permissible weight of the cask contents is 112,436 lbs. The transport cask packaging is composed of the following major components:

- A transport cask consisting of a high strength alloy steel containment boundary,

- An insulation board material in the closure seal region and cask body,

- A BFA-Tank Cassette (BTC) placed within a BFA-Tank secondary container; the BFA-Tank is listed as important-to-safety (ITS) and is credited in the safety analysis,

- A Closure Lid Locking System (CLLS) is used to secure the closure lid; the CLLS components are non-flammable according to SAR Section 1.2.4. Likewise, according to SAR Section 2.2.4, the coatings, lubricants, and adhesives used in the packaging are non-flammable.

According to SAR Section 1.2.1.6, the package's decay heat is passively dissipated without mechanical or forced cooling. The passive dissipation of heat is via conduction, convection, and thermal radiation. SAR Section 1.2.1.6 indicated that clearance gaps between the BFA-Tank and transport cask are minimized to reduce thermal resistance. According to SAR Sections 1.1, 1.2, 3.1.1, Appendix 1.A, and 3.1.1, insulation board material (described in Flag Note 6, drawing 9786, sheet 1 of 9, and SAR Appendix 1.A) in the cask body and closure seal region helps to ensure O-ring seal performance during the thermal-related hypothetical accident condition.

A Weather Protection Cover (WPC) prevents dirt and water accumulation on the external surfaces of the transportation package, which can be shipped by land or sea transport. As noted in the application, the WPC, which is not important-to-safety, "… shall be configured to mitigate heat input to the cask by insolation and the presence of the WPC shall not significantly reduce the rate of heat rejection from the cask which occurs to the ambient by convection and radiation." Staff notes that SAR Table 3.1.1 and Table 3.1.2 showed package component temperatures well below allowable values such that a WPC that does not reduce the rate of heat rejection should not result in temperatures approaching allowable values.

3.1.2 Codes and Standards

SAR Section 2.1.1 indicated that American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code Section III, Division I, Subsection NB is used for the design and construction of the HI-STAR ATB 1T containment system. Likewise, SAR Table 8.1.2 indicated that the design and stress/deformation analysis criteria, material procurement, welding (fabrication and qualification), inspection, and testing of the HI-STAR ATB 1T containment boundary is per the ASME B&PV Code, Section III, Subsection NB.

SAR Section 2.1.2 provided the references that describe the ASME Code Sections associated with the material properties. Likewise, SAR Table 3.2.1 listed the references for the thermal properties.

3.1.3 Content Heat Load Specification

As described in SAR Section 1.2.2 and SAR Table 7.1.2, the package's maximum permissible heat load is 1.75 kW; this value was analyzed in the SAR thermal chapter. SAR Table 1.2.1 provided the maximum calculated waste heat load for Waste Package Types A through E. It is noted that Waste Package Type A had the largest maximum calculated waste package heat load of 1.65 kW.

3.1.4 Summary Tables of Temperatures

Package component temperature summary tables were presented in SAR Table 3.1.1 for NCT; likewise; SAR Section 2.6.1 also referred to these temperatures. The components presented in the tables included closure lid seals, wall plates, base plate, closure lid, dose blocker plates, waste, and external surfaces. These temperatures were below the normal condition temperature limits listed in SAR Table 3.2.7 and SAR Table 2.2.6.

A summary table of component temperatures was provided in SAR Table 3.1.2 for HAC. In addition, SAR Figure 3.4.1 showed the transient temperature plots for the containment, closure lid, and inner seal during the hypothetical accident fire condition. The component temperatures listed in SAR Tables 3.1.1 and 3.1.2 were below the respective temperature limits reported in Table 3.2.7; it is noted that SAR Table 3.1.2 indicated that the inner seal temperature during the thermal-related HAC was below the short-term operation allowable temperature reported in Table 2.2.6 and was only a few degrees greater than the continuous operating allowable temperature. SAR Figure 3.4.1 showed decreasing package component temperatures, including the inner seal, after the hypothetical accident condition.

SAR Section 3.3.8.2 stated that the minimum temperature of the package at a -40°F ambient temperature, assuming no decay heat and no insolation, would be -40°F and that the stainless steel used in the construction and shielding of the package would perform satisfactorily. SAR Table 2.2.6 indicated that the inner seal and outer seal, which is used as a redundant barrier according to SAR Section 1.1, have a minimum continuous operating temperature of -40°F.

3.1.5 Summary Tables of Pressures in the Containment System

The analyses for determining the maximum internal pressure within the package during normal conditions of transport and hypothetical accident conditions were presented in SAR Sections 3.3.9 and 3.4.3.2, respectively. SAR Table 3.1.3 indicated that the pressure within the cask body was calculated to be less than 17 psia.

According to SAR Section 3.3.9, this is based on assuming an initial ambient temperature during the lid closure and using the Ideal Gas Law to calculate the pressure at the cavity pressure during normal conditions of transport. The MNOP pressure is less than the 5 psig normal design pressure listed in Table 1.2.1. The SAR noted that the calculated MNOP is conservative because the actual temperature of the cavity during lid closure is greater than ambient due to the heating that occurs prior to cask sealing.

The calculated cask cavity temperature (SAR Section 3.4.3.2) increased by 160°C, as a result of the fire. As noted in the RAI responses (ADAMS No. ML20174A484, June 2020), this calculation considered the weighted average rise in bulk average temperature of the closure lid and containment walls that are more directly exposed to the fire boundary condition. The applicant calculated the pressure within the cavity and reported it in Table 3.1.3 of the SAR. SAR Section 2.7.3 stated there is no contribution to inelastic strain of the containment boundary due to this pressure.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The thermal properties of the materials used in the HI-STAR ATB 1T transport package were presented in SAR Section 3.2. SAR Table 3.2.1 listed the references from which the emissivity,

conductivity, density, and heat capacity of the internal packages carbon steel components and stainless-steel forgings and plates were obtained; SAR Tables 3.2.2, 3.2.3, 3.2.4, 3.2.5 included the property values. Insulation board properties were provided in SAR Table 3.2.8.

3.2.2 Technical Specifications of Components

Table 2.2.6 of the SAR listed the inner and outer O-ring seal characteristics and specifications, including Shore-A durometer value, maximum compression set, maximum and minimum continuous operating temperature, minimum tensile strength, etc. Kaowool insulation board design considerations and specifications were provided and described in Flag Note 6, drawing 9786, and SAR Appendix 1A.

3.2.3 Thermal Design Limits of Package Materials and Components

Temperature limits for package components, including closure lid seals, wall plates, base plate, top flange, closure lid, dose blocker plates, waste, and external surfaces, were below the normal condition and hypothetical accident temperature limits listed in SAR Table 3.2.7 and SAR Table 2.2.6.

3.3 Thermal Evaluation Methods

3.3.1 Evaluation by Analyses

The applicant used the FLUENT CFD code (Version 14.5.7, according to Attachment 1 to Holtec letter 2404007-NRC) to perform thermal analyses that modeled the HI-STAR ATB 1T transportation package during normal conditions of transport and hypothetical accident conditions.

According to SAR Section 3.3.5, the analyses are based on a three-dimensional (3D) half-symmetric model of the package and, according to Figure 3.3.1, consists of the insulation board, closure lid, containment base plate, dose blocker plates, and content waste. SAR Section 3.3.5 indicated that BFA-Tank T-200 was modeled because it had the maximum calculated heat load and maximum waste volumetric heat generation rate.

Two additional analyses were performed to model the limiting heat load distributions. One model consisted of a concentrated heat load whereby the radioactive source was assumed to be concentrated within a block of metal (with mass equal to the content) in the center of the cassette. The other model assumed a uniform heat load distribution within the BTC. As described in SAR Section 3.3.6 and calculation package Document HI-2156585 Rev. 0, the licensing basis “uniform heat distribution” model yielded the same maximum temperature as the concentrated heat load model by choosing an effective thermal conductivity of the cassette box.

Boundary conditions applied to the 3D, half-symmetric model included insolation, natural convection, and thermal radiation. According to SAR Table 3.3.2, averaged insolation values were greater than those provided in 10 CFR 71.71; it is noted that the maximum gross weight of the package is 249,122 lbs and the margins between component temperatures and allowable temperatures were approximately 400°F and higher.

The emissivity values applied to the exterior and interior components were defined in SAR Table 3.2.5 with references for those values reported in SAR Table 3.2.1. SAR Section 3.3 indicated that the steady-state analyses for maximum temperature were based on the maximum

allowable decay heat using the uniform heat load distribution assumption and assumed ambient conditions of 100°F with insolation. In addition, the applicant applied uniform natural convection heat transfer coefficients to the exterior 3D model based on the correlations presented in SAR Section 3.3.4.

The vacuum drying operation to ensure the removal of all liquid water from the BFA-Tank and HI-STAR ATB 1T cask was discussed in SAR Section 3.3.11. According to the SAR, this can be achieved by performing the vacuum drying using the parameters in SAR Table 7.1.1 (maximum of 8 millibar for a minimum of 2 hours) such that the vacuum pressure is less than the saturated water vapor pressure of air at 45°F. The SAR and Calculation package Document HI-2156585 Rev. 0 noted that temperatures during vacuum drying are similar to those at normal conditions.

The response to Acceptance review Observation 3-4 (Enclosure 1 to Transmittal Letter 2404004-NRC) stated that all bulk water is removed during the vacuum drying process, which prevents appreciable gas generation from radiolysis (i.e., below flammable limits). Staff notes that a CoC condition states that flammable gas concentration inside the package is to be less than 5%.

According to SAR Section 3.3.10, sensitivity analyses of the gap between dose blocker plates and the containment boundary showed a change in content temperature by a few degrees.

SAR Section 3.3.7 and SAR Table 3.3.4 presented the results of a grid sensitivity study that showed the effect of waste temperature for different mesh sizes. Referencing the ASME CFD Verification and Validation report (SAR Reference 3.3.3), the applicant performed three analyses with different mesh sizes; each mesh had approximately twice the number of grid cells as the previous mesh analysis. The difference in waste temperature among the three mesh analyses was less than 1°F.

According to SAR Section 3.4.1, the initial conditions for the fire hypothetical accident condition thermal analysis used the steady-state normal conditions of transport with 100°F ambient temperature, still air, and insolation. According to the FLUENT model, a mixed thermal boundary condition was applied to the package's external surface. This mixed thermal boundary condition included the convection heat transfer due to the fire, radiative heat transfer input due to the fire with an emissivity of 0.9 and a fire temperature of 1475°F, and heat transfer from the package surface. SAR Table 3.4.2 stated the fire's convection heat transfer coefficient of 4.5 Btu/ft^2 -hr-F was based on the data from Sandia National Laboratory large pool fire tests ("Thermal Measurements in a Series of Large Pool Fires", Sandia Report SAND85-0196 TTC-0659 UC 71, August 1971). It is noted that SAR Table 3.4.2 and SAR Section 3.4.2 indicated that the fire (1475°F for 30 minutes) had an emissivity of 0.9 and the cask emissivity was 0.9. SAR Figure 3.4.1 provided the transient temperature profiles (temperature rise and cooldown) based on the transient thermal analysis. Staff finds that the model conditions are consistent with the information presented in NUREG-1609.

3.3.2 Evaluation of Accessible Surface Temperature

The package is to be transported as an exclusive use shipment (SAR Section 1.1) because the maximum temperature of accessible surfaces in still air at 100°F without insolation is greater than 122°F and less than 185°F. SAR Section 3.1.5 stated that the maximum cask accessible surface temperature was less than 150°F for the condition of 100°F ambient temperature with

insolation. It is noted that 10 CFR 71.43(g) states that surface temperatures for exclusive use shipments should be below 185°F assuming no insolation.

3.4 Thermal Evaluation under Normal Conditions of Transport

3.4.1 Heat and Cold

Package component temperature summary tables were presented in SAR Table 3.1.1 for normal conditions of transport; SAR Section 2.6.1 also referred to these temperatures. The components presented in the tables included closure lid seals, wall plates, base plate, closure lid, dose blocker plates, waste, and external surfaces. These temperatures were below the normal condition temperature limits listed in SAR Table 3.2.7 and SAR Table 2.2.6.

SAR Section 3.3.8.2 stated that the minimum temperature of the package at a -40°F ambient temperature, assuming no decay heat and no insolation, would be -40°F and that the stainless steel used in the construction and shielding of the package would perform satisfactorily. SAR Table 2.2.6 indicated that the elastomeric inner seal and outer seal, used as a redundant barrier according to SAR Section 1.1, have a minimum continuous operating temperature of -40°F.

3.4.2 Maximum Normal Operating Pressure (MNOP)

The analyses for determining the maximum internal pressure within the package during normal conditions of transport were discussed in SAR Section 3.3.9. SAR Table 3.1.3 indicated that the pressure within the cask body was calculated to be less than 17 psia during hot normal conditions. According to SAR Section 3.3.9, this is based on assuming an initial ambient temperature during the lid closure and using the Ideal Gas Law to calculate the pressure at the cavity pressure during normal conditions of transport.

The MNOP is less than the 5 psig normal design pressure listed in Table 1.2.1. The SAR noted that the MNOP is conservative because the actual temperature of the cavity during lid closure is greater than ambient due to the heating that occurs prior to cask sealing. Based on the above, staff finds that the MNOP is less than the design pressure and that the use of a higher pressure for calculation purposes is conservative.

3.4.3 Maximum Thermal Stresses

The stated clearances between the BFA-Tank and the cask cavity and between the BFA-Tank Cassette and BFA-Tank, respectively, are such that there is no interference due to thermal expansion (SAR Section 1.2.1.1.b and Section 1.2.1.1.c).

Likewise, SAR Section 2.7.3 discussed that thermal stresses would not impact the CLLS during normal conditions of transport because of the low decay heat, similar temperatures of the top flange, closure lid and locking wedges, and similar coefficients of thermal expansion.

3.5 Thermal Evaluation under Hypothetical Accident Conditions

3.5.1 Initial Conditions

The applicant performed a transient thermal analysis to evaluate the package with maximum decay heat under the hypothetical accident condition consisting of a 30 minute all engulfing fire (i.e., heat input on all cask sides). The thermal model assumed the package cavity as a solid

volume with uniform heat generation and effective density, specific heat, and thermal conductivity properties.

According to SAR Section 3.4.1, the pre-fire condition, based on normal conditions (described above), included a 100°F ambient temperature, still air, and insolation, with radiation heat transfer and convection heat transfer at the package surface. According to SAR Section 3.4.1, the analyzed scenario included the effects of a 30-ft drop and puncture, including a reduced insulation board thickness and loss of insulation board in the local puncture region near the seals.

3.5.2 Fire Test Simulation

The hypothetical accident condition thermal analysis assumed bounding gaps between the containment boundary plates and the dose blocker plates to maximize the heat input into the cask. As illustrated in the FLUENT model, a mixed thermal boundary condition was applied to the package's external surface.

This mixed thermal boundary condition included the convection heat transfer due to the fire (from SAR Table 3.4.2, the fire's convection heat transfer coefficient of 4.5 Btu/ft^2-hr-F was based on the data from the previously mentioned large pool fire tests), radiative heat transfer input due to the fire with an emissivity of 0.9 and an engulfing fire temperature of 1475°F, and heat transfer from the package surface.

SAR Section 3.4.2 indicated that the package absorptivity value was 0.8. The transient thermal analysis results were provided in SAR Figure 3.4.1, which indicated package temperatures reached a maximum and started to decrease during the 100-minute calculated cooldown period.

3.5.3 Maximum Temperatures and Pressure

A summary table of temperatures for hypothetical accident conditions was provided in SAR Table 3.1.2. The components analyzed included the containment wall, base plates, closure lid, inner seal, and insulation boards. The component temperatures listed in SAR Table 3.1.2 were below the respective temperature limits reported in Table 3.2.7 and SAR Table 2.2.6.

In particular, Table 3.1.2 indicates that the inner seal temperature during the thermal-related HAC was below the short-term operation allowable temperature reported in Table 2.2.6 and was only a few degrees greater than the continuous operating allowable temperature.

Section 3.4.3.2 of the application calculated that the cask cavity temperature increased by 160°C as a result of the fire; this calculation considered the weighted average rise in bulk average temperature of the closure lid and containment walls that are more directly exposed to the fire boundary condition. Using the Ideal Gas Law, the pressure within the cavity was reported in SAR Table 3.1.3 to be less than 25 psia. SAR Section 2.7.3 indicated there was no contribution to inelastic strain of the containment boundary due to this pressure.

3.5.4 Maximum Thermal Stresses

SAR Section 3.4.4 indicated that the package included sufficient gaps such that there is no internal interference and no constraint of free expansion. SAR Section 2.7.3 indicated there is potential differential thermal growth between the closure lid and the CLLS interlocking wedges.

However, the applicant referred to Holtec Calculation Document HI-2177540, Revision 1, "Structural Calculation Package for HI-STAR ATB 1T Transport Package" to show that the calculated differential thermal growth is much less than the lid seal's springback such that the seals would remain functional and the containment boundary's integrity would be maintained.

3.6 Computer Program Description

FLUENT is a benchmarked code that has been validated within Holtec's quality assurance program. In addition, SAR Section 1 stated that the HI-STAR ATB 1T would be designed in accordance with the U.S. NRC approved quality assurance program.

3.7 Evaluation Findings

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

4.0 CONTAINMENT EVALUATION

The objective of the review was to verify that containment of the HI-STAR ATB 1T transportation package was adequately described and evaluated under normal conditions of transport (NCT) and hypothetical accident conditions (HAC), as required per 10 CFR Part 71. Regulations applicable to the containment review include 10 CFR 71.31, 71.33, 71.35, 71.43, and 71.51.

4.1 Description of Containment System and Package Contents

Description of Containment System

The containment boundary (SAR Figure 4.1.1) consists of a base plate, containment end wall, containment side wall (which includes the top flange landing on which the closure lid rests, per SAR Section 4.1.3.1), closure lid and lid inner seal. In addition, SAR Section 4.1.3.2 stated that the containment boundary welds include the full penetration welds connecting the containment side wall plates to the containment end wall plates and the full penetration welds connecting the containment side and end wall plates to the containment baseplate.

Sealing of the lid and lid inner seal gasket is performed by the Closure Lid Locking System (CLLS). Drawing 9786 listed the containment components and assigned an Important to Safety category to them, and specifically, SAR Section 2.2.4 and Section 4.1.3.1 stated that the O-ring seals are procured as an Important-to-Safety component. The containment boundary components have a direct impact on maintaining containment and, therefore, as noted in NUREG/CR-6407, would be characterized by Classification Category A.

SAR Table 2.2.6 listed seal characteristics for the inner and outer elastomeric O-rings, including Shore-A Durometer value, maximum expected compression set, minimum useful springback, maximum load on seals to compress seals and achieve metal-to-metal contact of lid/flange, minimum tensile strength, operating temperatures, compatibility with radiation and compatibility with boric acid.

SAR Section 2.2.4 and SAR Table 2.2.2 noted the seal is to be engineered for the packaging's seal and groove/gland dimensions; the seal groove/gland dimensions and surface roughness were provided in drawing 9786. As noted in RAI response 4-3 (Attachment 1 to Holtec Letter

2404007-NRC), the inner seal and outer seal (the outer seal is a redundant barrier against leakage, per SAR Section 1.1) are designed to seal against internal and external pressures (such as water intrusion). SAR Table 3.1.1 and Table 3.1.2 indicated that the inner and outer seals are within the maximum and minimum allowable temperatures reported in SAR Table 2.2.6.

According to SAR Section 4.1, the containment boundary is designed and fabricated in accordance with Section III, Subsection NB of the ASME Boiler and Pressure Vessel Code. In addition, SAR Table 8.1.2 indicated that the design, material procurement, welding (fabrication and qualification), inspection, and testing of the HI-STAR ATB 1T containment boundary is per the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB (e.g., full penetration welds as noted in SAR Section 1.2.1.1.a).

SAR Section 7.1.2 indicated there are two loading scenarios. One loading scenario is that waste in a storage pool is placed within a cassette (BTC), which is then subsequently placed within a BFA-Tank; the BFA-Tank is then placed within the HI-STAR ATB 1T transportation package. The other loading scenario was described as placing an already filled BFA-Tank within the HI-STAR ATB 1T transportation package. Although the BFA-Tank is not considered the containment boundary, SAR Section 1.1 noted that it provides “enhanced protection against release of radionuclides”; in addition, SAR Section 1.2.1.1.b stated that the BFA-Tanks are equipped with metallic seals.

According to SAR Section 1.1, there is no pressure relief device or feature that allows continuous venting. In addition, SAR Section 1.2.1.8 stated that “the closure lid covers the only penetration on the cask with access to its contents”; this cask lid is locked via the cask locking wedges of the CLLS. According to SAR Section 1.2.1.1.a and SAR Section 7.1.3, closure of the CLLS is verified by installing the system’s locking wedge locking pins after lid closure. SAR Section 4.1.3 stated that the welds and seal gaskets (closed by the CLLS closure) result in a closed system that cannot be opened unintentionally or by an internal pressure within the package, thereby satisfying 10 CFR 71.43(c).

Description of Package Contents

The HI-STAR ATB 1T transportation package is to be used to transport content that is characterized as non-dispersible solids with radioactive surface contamination (as defined in NUREG/CR-6487). According to SAR Section 1.2.2, content consists of Non-Fuel Waste (NFW), which includes radioactive wastes of solid radiation-activated and surface-contaminated reactor internals, secondary waste generated by mechanical cutting processes (chips, debris) placed in chip drums, and metallic waste filters (stainless steel or ceramic mesh screens) placed within the chip drums. The size and material associated with the metal chips indicate that they are not pyrophoric.

SAR Section 4.2.1 stated that the content is dried prior to shipment and Observation 3-4 stated that organic materials that can undergo radiolysis and result in reactions that would impact package operations, including plastics and water, are not included in the radioactive waste contents.

SAR Section 4.4.1 stated that the content’s activity used in the release calculations is conservative because the analysis applies the surface activity density to a larger surface area than that which is to be transported and the assumed surface area of the contaminated solids is larger than the upper bound actual surface area to be transported in the HI-STAR ATB 1T. As

stated in Note 2 of SAR Table 7.1.2, the activity that is to be transported is verified to be less than those reported in Table 7.1.2.

This includes a maximum permissible Co-60 activity of non-fixed surface contamination of 2.211×10^{13} Bq and the crud surface activity density (from Table 4.4.4), which served as the basis for the release calculations and determination of acceptable leakage rate acceptance criterion. The 2.211×10^{13} Bq value was the basis for the surface activity crud source term (on a per area basis) and accident condition source term (on a per volume basis) reported in SAR Table 4.4.4 and Table 4.4.5, respectively.

4.2 Combustible Gas Generation

SAR Section 4.2.1 stated that the BFA-Tank is drained and dried prior to its closure such that the metallic waste (i.e., primarily stainless steel, per SAR Section 3.3.2) within the BFA-Tank would not produce gas or vapor to significantly affect internal pressures. Likewise, SAR Section 7.1.2.1, Section 7.1.2.3, and SAR Table 7.1.1 indicate that the vacuum drying process would remove water from the package/contents during the loading of the BTC and BFA-Tank. Removal of water from the package's contents is necessary to mitigate generation of flammable gas concentrations. Staff notes that a CoC condition states that flammable gas concentration inside the package is to be less than 5%.

4.3 Containment Evaluation under NCT

4.3.1 Demonstration of Containment Design Criteria

The HI-STAR ATB 1T maximum normal operating pressure (MNOP) was identified as 16.9 psia (SAR Table 3.1.3), which is less than the 5 psig (19.7 psia) design pressure reported in SAR Table 1.2.1. SAR Section 3.3.9 indicated that the MNOP calculation is conservative because it is based on the pressure rise from ambient temperature, when in fact, the cavity pressure is heated by the decay heat contents prior to lid closure. SAR Table 4.4.2 indicated the package's normal conditions were based on an upstream pressure of 1.48 atm (21.76 psia), which is higher than the 16.9 psia value listed as the MNOP; according to SAR Section 4.4.1, the 1.48 atm was used in calculating the leakage rate because a higher pressure is a conservative assumption.

SAR Section 4.4 and Report HI-2156697 Rev. 2 presented the methodology and Holtec performed calculations based on NUREG/CR-6487 "Containment Analysis for Type B Packages Used to Transport Various Contents" to show the leakage rate acceptance criterion to satisfy 10 CFR 71.51 for both NCT and HAC.

This methodology included calculating the activity concentration of a powder aerosol, which was a function of the activity fraction of the surface contamination that spalls off the surface for both normal and accident conditions, the surface activity (product of total surface area of contaminated solid and the activity surface density shown in SAR Table 4.4.4 and SAR Table 7.1.2), and the free volume associated with the containment boundary.

The SAR noted that all surface activity was assumed to be Co-60, which has an A_2 of 10.8 Ci. The releasable activity was a function of the activity concentration of the powder aerosol and the free volume associated with the containment boundary. The permissible NCT and HAC releases (i.e., allowable leakage that meets regulatory releases described in 10 CFR 71.51(a)) were functions of the total source term activity (for NCT and HAC) and the allowable release

rate for NCT and HAC as described in NUREG/CR-6487 and “American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment”, ANSI N14.5.

The leakage rate acceptance criteria for the test conditions was determined from the unchoked flow correlation found in NUREG/CR-6487. SAR Table 4.4.8 indicated that the results of these calculations showed an NCT allowable leak rate of 2.1×10^{-4} atm cm^3/sec (air) at reference conditions and a HAC allowable leak rate of 1.12×10^{-1} atm cm^3/sec (air) at reference conditions.

4.3.2 Compliance with Containment Criteria

The applicant demonstrated by analysis using an LS-DYNA model that there was no plastic deformation at the closure, no loss of content, and no loss of containment boundary integrity during normal conditions of transport, thus meeting 10 CFR 71.43(f).

Likewise, SAR Table 3.1.1 showed that seal temperatures were below allowable values. In addition, SAR Table 8.1.1 indicated that containment-related leakage rate tests (fabrication, periodic, maintenance, and pre-shipment) would have an acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions and a sensitivity of 5×10^{-5} atm-cm^3/sec (air) at reference conditions.

As mentioned in Section 4.3.1 above, these criteria are less than the 2.1×10^{-4} atm-cm^3/sec (air, at reference conditions) allowable leakage rate that was reported in SAR Table 4.4.8 for NCT.

4.4 Containment under Hypothetical Accident Conditions

4.4.1 Containment Design Criteria

SAR Table 3.1.3 specified that the HI-STAR ATB 1T cask cavity pressure would be 24.9 psia, as a result of the design basis fire accident. Section 2.7.3 stated that the induced stress caused by this pressure is less than the yield stress, thus resulting in no permanent deformation of the containment boundary of the package. Likewise, SAR Table 3.1.3 indicated that the inner seal temperature during the thermal-related HAC was below the short-term operation allowable temperature reported in SAR Table 2.2.6 and was only a few degrees greater than the continuous operating allowable temperature.

SER Section 4.3 provided the evaluation of the SAR’s determination of the allowable leakage rate of the content for both NCT and HAC. Based on the analyses presented in Section 4.4, it was stated that a 1.12×10^{-1} atm cm^3/sec (air, reference conditions) allowable leakage rate would result in meeting 10 CFR 71.51(b) for HAC.

4.4.2 Demonstration of Compliance of Containment Design Criteria

The demonstration of satisfying 10 CFR 71.51(b) for hypothetical accident conditions relied on the structural analysis results of LS-DYNA simulations (see, for example, the above discussion in SER Section 4.3.2 about the model and the SAR Structural chapter for additional model details) of the HI-STAR ATB 1T package (e.g., HI-STAR ATB-1T, BFA-Tank, BTC) as well as the leakage rate test criteria described earlier and below.

As discussed in the SER Structural Evaluation section, the structural analyses of the hypothetical accident conditions were based on the LS-DYNA finite element analysis code, which showed there was no plastic deformation at the containment closure. The structural

aspects of the containment and closure areas were presented in the SER Structural Evaluation, including Section 1.2 (surface finish, O-ring groove width), Section 2.1.1, Section 2.4 (LS-DYNA model details and results), and Section 2.7 (drop and puncture effects of the closure area and BFA-Tank performance).

As noted earlier, although the BFA-Tank (which is equipped with metallic seals) is not considered the containment boundary. SAR Section 1.1 noted that the BFA-Tank acts as an additional barrier that provides “enhanced protection against release of radionuclides”. The SAR provided details of the BFA-Tank design and the structural analyses indicated the condition of the BFA-Tank at HAC. As mentioned in the Structural SER, these analyses demonstrated that the BFA-Tank retained positive lid attachment, maintained structural integrity of the tank sidewalls, and maintained structural weld integrity for the analyzed cases. Staff finds that these aspects of BFA-Tank design and performance would indicate that the BFA-Tank provides an additional barrier against release of radionuclides.

According to SAR Section 4.4.2.7, the LS-DYNA analyses indicated the possibility of the lid briefly separating from the flange beyond the useful springback of the lid’s O-rings during the top end drop and slap down drop HAC scenarios. As described in SAR Section 4.4.2.7 and calculation package HI-2156697, Rev. 2, Attachment C, there was the potential opening of 2.286 mm for 1.5 millisecond for the top end drop and a potential opening of both 3.81 mm and 2.286 mm for 20 millisecond and 1.5 millisecond, respectively, for the slap down drop.

An analysis was performed in HI-2156697 Rev. 2, Attachment C to demonstrate that potential leakage through the briefly opened areas was below the 10.8 Ci radioactivity release limit specified in SAR Table 4.4.6. As stated in the SAR Section 4.4.2.7 and the calculation package, the potential flow through the openings did not meet molecular flow criteria and choked flow criteria and would be in the turbulent flow regime; these conditions are different from the molecular and continuum flow regimes that form the bases for the leakage rate calculations described in NUREG/CR-6487 and ANSI N14.5 - 2014.

The calculation package used correlations to account for pressure drop losses (SAR Chapter 4 reference [4.4.4] Crane Technical Paper 410, 1976) associated with frictional losses, turns, expansions, and contractions for the flow path from inside the package through the changing areas between the two seals and the turn through the lid. The calculation derived the leakage flow rate through the paths of the openings by balancing the driving pressure differential with the calculated pressure drop losses.

A potential radioactivity release was computed based on the volume of gas leakage through the lid gap flow area during the brief opening period (i.e., milliseconds) and the amount of radioactivity concentration (Ci/cm^3) provided in SAR Table 4.4.5. It is noted that staff applied inputs from the above mentioned calculation package to the molecular and continuum correlations provided in ANSI N14.5 (and NUREG/CR-6487) and found that the predicted releases for the specific conditions were less than those reported when using the turbulent friction factor and flow loss correlations described above.

The calculation package results indicated that the computed radioactivity release after a 30-ft top end drop or a slap down drop was between seven to seventy times less than the radioactivity release limit specified in SAR Table 4.4.6. This relatively large margin coupled with the fact that the content is placed within both the HI-STAR ATB 1T transportation package and the additional BFA-Tank barrier would indicate that release from a potential 3.81 mm opening

and 2.286 mm opening for a 1.5 or 20 millisecond period would be less than the radioactivity release limit.

SAR Table 8.1.1 indicated that containment-related leakage rate tests would have an acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions and a sensitivity of $5x10^{-5}$ atm-cm^3/sec (air) at reference conditions. These criteria are less than the $1.12x10^{-1}$ atm-cm^3 /sec (air, at reference conditions) allowable leakage rate that was reported in SAR Table 4.4.8 for HAC.

4.5 Leakage Rate Tests for Type B Packages

SAR Table 8.1.1 provided the types of leakage rate tests and the leakage test rate acceptance criteria based on the analysis presented in SAR Section 4.3. Using the test designations denoted in ANSI N14.5-2014, the tests include A.5.3 (gas filled envelope) for fabrication leakage test, and A.5.1 (gas pressure drop), A.5.2 (gas pressure rise), A.5.3, and A.5.4 (evacuated envelope) for the pre-shipment, maintenance, and periodic leakage rate tests.

The fabrication leakage rate test and maintenance leakage rate test include testing the entire containment boundary (e.g., base plate, containment wall plates, top flange, closure lid, closure lid inner seal, and the containment boundary welds) to a leak rate acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions.

Likewise, the pre-shipment and periodic leakage rate tests of the closure lid inner seal have a leakage rate acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions. According to SAR Section 8.1.4, leakage rate tests on the containment boundary are to be performed in accordance with the requirements of ANSI N14.5 - 2014; the leakage rate testing procedures are to be approved by an American Society for Nondestructive Testing (ASNT) Level III Specialist in the Leak Testing examination method, and the leakage rate testing is to be performed by personnel qualified and certified in accordance with the requirements of SNT-TC-1A. Likewise, SAR Section 8.1.4 stated that leakage rate testing is to be performed in accordance with a written quality assurance program.

4.6 Evaluation Findings

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

5.0 SHIELDING EVALUATION

The staff has reviewed the application to ensure that the package design meets the external dose rate requirements of 10 CFR Part 71 for NCT and HAC. As stated in Section 1.1 of the application, the Model No. HI-STAR ATB 1T package must be transported by exclusive use. The allowable contents are radioactive non-fuel waste and hardware and are shipped within secondary containers. There are 4 available configurations which use secondary containers referred to as “waste packages” that can be shipped within the ATB 1T package and they consist of a waste basket, called the BFA-Tank Cassette (BTC), within a sealed secondary container, itself called the BFA-Tank. The BFA-Tanks all have identical external dimensions but have varying wall thicknesses for increased shielding capacity. The four BFA-Tank Cassettes match a specific BFA-Tank variant.

5.1 Description of Shielding Design

5.1.1 Design Features

The HI-STAR ATB 1T is a rectangular-parallelepiped multi-layer steel-weldment with a removable closure lid. The outer dimensions of the ATB 1T are approximately 3733 mm long, 1802 mm wide and 2882 mm high. The package features of the ATB 1T that provide the main gamma shielding are the following steel components: base plate, top flange, containment wall plates, dose blocker plates, and closure lid. The steel BFA-Tank and BTC plates also provide additional gamma shielding.

5.1.2 Summary Table of Maximum Radiation Levels

The applicant included a summary table of the maximum radiation levels for each of the 4 waste basket configurations. The applicant provided the calculated surface dose rates under NCT in Table 5.1.1 of application, the calculated dose rates at 2 meters from the package in Table 5.1.2 of the application, the calculated dose rates at 1 meter under HAC in Table 5.1.3 of the application, and distances for meeting dose rates in a normally occupied space in Table 5.1.4 of the application.

Even though the applicant states in Section 1.1 of the application that the HI-STAR ATB 1T must be transported via exclusive use, the applicant also provided calculated dose rates at 1 meter in Table 5.1.5 of the application to demonstrate that the maximum transport index (TI) would not exceed regulatory limits for a non-exclusive use package. The staff reviewed these tables and found that all reported dose rates show that the package meets the regulatory dose rate limits within 10 CFR 71.47 and 10 CFR 71.51(a)(1) and (2).

5.2 Radiation Source

5.2.1 Gamma Source

Section 1.2.2 of the application describes the contents as non-fuel waste from a nuclear power plant over the plant's entire life cycle. It further describes the waste as segmented and non-segmented reactor internals and gives examples of potential contents.

The applicant models the radiation source as Co-60, which is always the dominant radioisotope that contributes to external gamma dose rates from decommissioned reactor internals. Since it is not the only radioisotope present, the applicant performed an analysis, discussed in Appendix 5.A of the application, using ORIGEN-S to calculate the activation nuclides of stainless steel and Inconel 718 using the neutron flux, adjusted for a location on the periphery of the reactor.

The results of the applicant's activation evaluation showed that, for the 360,000 MWd/MTU case, the contribution from other non-Co-60 radionuclides to the external dose rate is less than 10% after 1 year of decay. As a consequence, there is a restriction within Table 7.1.2 of the application, which is referenced by the CoC, that states that the contents to be shipped in the HI-STAR ATB 1T must have decayed at least 1 year.

The applicant stated it added an additional 10% Co-60 specific activity, beyond the CoC limits specified in Table 7.1.2 of the application, to the external dose rate evaluations to account for the non-Co-60 nuclides. The staff found reasonable that this 10% additional margin should compensate for any additional nuclides present, based on the applicant's calculations and

evaluations performed in Appendix E, “Radionuclide Inventories,” of NUREG/CR-0602, Vol. 2, “Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station,” and “Appendix C, “Estimates of Residual Radioactivity,” of NUREG/CR-0130, Vol. 2, “Technology, Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station.”

Table 1 of the “HI-STAR ATB 1T Shielding Calculation Package” (HI-2156583 Rev. 5) shows the source activity and self-shielding medium used within the shielding evaluations. The staff verified the specific activity the applicant used in its evaluation using the activities from Table 1 of HI-2156583 Rev. 5 and dimensions of the BFA Tank and BTC top and bottom plates from Drawing No. 9876,“BFA Tanks and Cassettes T-50, T-100, T-150 & T-200,” and verified that the modeled specific activity is 10% higher than the maximum specific activity allowed in Table 7.1.2 of the application.

The staff found that exposure equivalent to 360,000 MWd/MTU would not necessarily bound components that have been within a reactor for its entire life cycle (e.g. reactor internals from a decommissioned reactor), and the applicant’s analysis shows that with longer burnup, non-Co-60 nuclides compose a larger contribution to the external dose rate. However, this difference is a little over 1% between the 180,000 MWd/MTU and the 360,000 MWd/MTU.

The nuclides found by the applicant to be significant contributors to the dose rate are listed in Tables 5.A.3 through 5.A.6 of the application. The staff verified that these nuclides would be bounded by Co-60 in terms of MeV/disintegration and, therefore, representing these nuclides as Co-60 is conservative and is acceptable to the staff.

In evaluating the contribution to external dose rate from non-Co-60 nuclides, the applicant states it neglected gammas below 0.45 MeV. The staff performed a calculation using MICROSHIELD 11.20, modeling a point source at 0.45 MeV neglecting the BFA tank and BTC at 10% of the allowable activity and found that there was indeed an insignificant contribution to dose rate. Considering the highly conservative nature of the staff’s model, the staff found that the contribution to dose rate from these photons would likely be bounded by the applicant’s conservative assumptions, such as assuming all non-Co-60 nuclides are Co-60, and the margin to regulatory dose rate limits calculated by the applicant. Therefore, in the staff’s judgment, it is acceptable to neglect gammas at or below 0.45 MeV but only for this application.

The CoC is restricted to activated reactor components made primarily of stainless steel and Inconel. Section 1.2.2 of the application states that any contents that are not made from stainless steel or Inconel only contain CRUD and surface contamination. The applicant represented the CRUD as additional Co-60. The applicant states that the dominant contributor to dose from surface contamination or CRUD is Co-60 (NUREG/CR-6487, “Containment Analysis for Type B Packages Used to Transport Various Contents,” November 1996 and Section 2.6 of NUREG/CR-0130, Vol. 1).

Based on this and Section 10 of ORNL/SPR-2020/1586, “Best Practices for Shielding Analyses of Activated Metals and Spent Resins from Reactor Operation,” September 2020, the staff found that representing CRUD and surface contamination as Co-60 is acceptable for this application.

5.2.2 Neutron Source

Although the HI-STAR ATB 1T package is not designed or authorized for significant neutron sources, it is not practical to restrict the contents to have zero neutron emitting sources. Due to

the nature of the contents, there may be trace materials with neutron emissions. Therefore, to cover this possibility, the applicant has an allowance for a small neutron source within Table 7.1.2 of the application. The applicant states in HI-2156583 Rev. 5 that it used the energy spectrum from a high burnup PWR spent fuel. The staff found this acceptable as any neutron radiation emitted would likely be from SNF contaminants.

5.3 Shielding Model

The staff reviewed the structural and thermal sections of the application and found that conditions consistent with NCT and HAC were appropriately represented in the shielding model and are discussed in the following subsections. The staff examined the drawings in Section 1.3 of the application and found that it is sufficiently detailed to perform a detailed review of the package. The staff found that the minimum dimensions of the components credited for the shielding were appropriately specified.

5.3.1 Source Geometry and Self-Shielding

Since the contents of the HI-STAR ATB 1T will vary by shipment, it is impossible to model the exact configuration of each loaded package. Therefore, the applicant must perform an analysis that is bounding for all possible contents and configurations. The applicant states that it modeled full density stainless steel. The allowable contents are specified in terms of a specific activity, (activity/mass) so although increasing the waste density increases self-shielding (a non-conservative assumption), increasing the waste density also increases the source term (a conservative assumption).

To justify the assumption of full density steel, the applicant performed a sensitivity study varying the waste density within the Type A, BFA-200 tank, package configuration. The applicant showed the results of these evaluations in Tables 5.4.2 (NCT) and 5.4.3 (HAC) of the application. The applicant found that there is no statistical difference between the calculated dose rates for the densities assumed; therefore, the staff found that modeling the contents at full density is acceptable.

The applicant modeled a uniform source distribution. Components may not be activated uniformly in that reactor internals are subject to the core flux profile or higher activity components may be loaded with lower activity components and surface contamination would be present on the surface of components where they experience no self-shielding. Based on a study documented in Section 10 of ORNL/SPR-2020/1586, “Best Practices for Shielding Analyses of Activated Metals and Spent Resins from Reactor Operation,” September 2020, ORNL found that homogenization of the neutron-activated corrosion products within the waste material is not recommended because this modeling approach would result in an underestimation of cask external dose rate caused by self-shielding effects.

However, the staff found the homogenization acceptable for this package, based on the following conservative assumptions that would compensate for this non-conservative assumption:

- Contents are specified in terms of activity/mass and apply to the most activated portion of the waste.

- The applicant modeled the source as filling the entire cavity of the BTC (BFA Tank Cassette). This modeling approach results in more total Co-60 than what is allowed by Table 7.1.2 of the application, which is conservative.

- Attachment 2 to the June 7, 2019 letter (ADAMS Accession No. ML19158A519) states that more than 99% of total activity comes from reactor internals with CRUD and surface activity contributing less than 1%; therefore, neglecting this surface source is acceptable to the staff.

- The applicant's calculations show that there is margin to the regulatory dose rate limits.

5.3.2 Shielding Configuration

5.3.2.1 Normal Conditions of Transport (NCT)

The results of the NCT tests specified in 10 CFR Part 71.71 indicate there is no significant damage to the cask and BFA tank. Therefore, the staff found it acceptable to model all cask dimensions as specified in the drawings under NCT. The applicant made some modeling simplifications as outlined in Section 5.3.1.1.1 of the application; the staff reviewed these simplifications and found that they would have a conservative or negligible effect on dose and found them acceptable.

5.3.2.2 Hypothetical Accident Conditions (HAC)

Based on the results described in Section 2.7 of the application, the package experiences two bounding consequences from HAC that affect the shielding capability of the package. These are the damage (possible weld and bolt failure) and deformation to the walls of the BFA tanks, and damage (reduction in shielding thickness) to the impacted surface of the HI-STAR ATB 1T package as a result of the 9-meter (30 foot) drop.

As discussed in Section 2.2.5 of the application, the BFA-Tanks and BTCs are assumed to fail under HAC. Based on the geometry and the location of the welds of the BFA-Tanks, the staff found it reasonable to assume that the walls would not significantly re-locate even if the welds failed.

For the BTC, the applicant assumed full relocation of the bottom plate. The staff found this conservative and acceptable because, based on the geometry of the BTC, it could fail in such a way that a plate could rotate or relocate, and contents may relocate to the other side of the plate.

Under HAC, the bottom location becomes the most limiting dose rate location due to the failure of the secondary containers that were credited during NCT.

The applicant states that there could be localized damage of the package outer surface during the pin puncture and drop accidents, but that these localized deformations were not included in the HAC model because they would have negligible impact at 1 meter from the surface. The staff found it acceptable to neglect these effects for the HAC evaluation based on the following:

- The staff generally agrees that localized effects are less significant at 1 meter, as long as the effect is small enough.

- The staff performed a sensitivity study discussed in Section 5.5 of this SER, where it modeled a more bounding streaming path under HAC.

- The applicant's calculated dose rates under HAC has margin within its calculations. The localized effects would need to increase HAC dose rates by 16% to reach the regulatory dose rate limit and based on the staff's sensitivity study, it is very unlikely that this will happen from localized damage.

- The applicant used conservative assumptions within the HAC analysis.

Based on the above reasons, the staff has reasonable assurance that the package will meet regulatory dose rate limits under HAC, even though the applicant did not include some localized damage within its model.

5.3.2.3 Streaming

The applicant took into account possible streaming paths in its modeling of the HI-STAR ATB 1T package under NCT. As these are localized areas of reduced shielding, these are considered under NCT. Under HAC, the applicant considered the streaming path that results from failed welds as the limiting accident condition considered together with the failure and relocation of the BTC.

The applicant calculated the localized dose increase, under NCT, due to the following effects: trunnions, closure lift lug holes, chamfered edges, and self-adjusting shims, as shown in Table 5.4.6 of the SAR.

The trunnions slide out of the package wall during lifting and collapse back into the package. 10 CFR 71.45(a) has requirements that such failure of any lifting device, under excessive load, would not impair the ability of the package to meet other requirements of this Subpart. This requires the applicant to consider failure of the trunnions when demonstrating compliance with external dose rate regulations in 10 CFR 71.47 as well as 10 CFR 71.51(a)(2).

The applicant assumed that the part of the trunnion that would be external to the package (when in use) was sheared off, leaving a gap behind the trunnion, thus reducing shielding material and creating a streaming path in this area. The staff found that this was a reasonable failure assumption of the trunnion and found that incorporating this failure mechanism addresses the regulatory requirement in 10 CFR 71.45(a).

Under HAC, the applicant did assume the trunnions were missing, but this effect is not as significant as the dose rate on the bottom of the package due to the relocation of the BTC, which is the limiting location under HAC.

The applicant found that the highest calculated surface dose rate due to these localized areas of reduced shielding is due to the self-adjusting shims. These shims are components added to the interior of the package that are used to mitigate the effects of secondary impact of the BFA tank by holding the BFA-Tank in place and absorbing energy during an accident.

The shims are made of steel; therefore, their presence would provide the same amount of shielding that they are displacing; however, there is a streaming path in between and around the area where the springs are located, as can be shown from sheet 3 in Drawing 9786. Staff notes

that, since it is at an angle, this would help mitigate the streaming slightly and the springs themselves would also provide some shielding.

5.3.3 Material Properties

Section 1.2.2 of the application states that the radioactive contents are activated stainless steel or Inconel. The applicant states in Sections 5.3.1.2.1 and 5.3.1.3 of the application that it modeled the contents as full density stainless steel. The applicant performed a sensitivity study to justify the density, this is discussed in Section 5.3.1 of this SER and the staff found full density acceptable. The applicant performed additional calculations using Inconel instead of stainless steel for the waste material and found no difference in calculated dose rates.

For the package components including the BFA Tanks and BTC, the applicant states in Section 5.3.1.3 of the application that it modeled all packaging components as carbon steel. The applicant specified the composition and density of the stainless and carbon steel in Table 5.3.1 of the application. The applicant specified the composition of the Inconel in Table 5.A.1 with the density in Tables 5.4.2 and 5.4.3 of the application.

The staff reviewed the composition and density of these materials and found that they are consistent with published values for these materials (PNNL-15870 Rev. 1, “Compendium of Material Composition Data for Radiation Transport Modeling,” March 4, 2011). The staff also found the modeling of all packaging components as carbon steel to be acceptable. The material compositions are conservative because the density of carbon steel is slightly lower.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant performed shielding calculations with MCNP5 using cross sections based on ENDF/B-VII data. MCNP is a three-dimensional Monte Carlo transport code developed and maintained by Los Alamos National Laboratory. This code is used extensively for shielding calculations. Section 5.4.4.1 of NUREG-2216 states that the MCNP code is commonly used and with the complex geometry associated with streaming paths in this package, the staff found the 3D Monte Carlo code appropriate for use in this application.

5.4.2 Input and Output Data

The applicant provided input and output files for the MCNP calculations. The staff examined these files and determined that uncertainties were relatively low and that all calculations had passed enough of the statistical checks for the staff to determine that the result had reached proper convergence.

The staff performed calculations as an independent check to verifying that doses are within regulatory limits to give itself reasonable assurance that the post processing of the results is adequate. This is discussed in Section 5.5 of this SER.

5.4.3 Flux-to-Dose-Rate Conversion

The applicant used conversion factors that were derived from the ANSI/ANS 6.1.1-1977 standard for both gammas and neutrons. These are shown in Table 5.4.1 of the application. Per the guidance in NUREG-1609, these are acceptable to the staff for use in this application.

5.4.4 External Radiation Levels

The staff verified that the external radiation levels meet the limits in 10 CFR 71.47 for NCT and 10 CFR 71.51(a)(2) for HAC.

Although all package configurations have similar dose rates under NCT, the maximum calculated surface dose rate is for the Type C (BFA-100)]] configuration at 1.2 mSv/hr (120 mrem/hr). This meets the regulatory limit in 10 CFR 71.47(a) of 2 mSv/hr (200 mrem/hr).

At 2 meters the maximum dose rate is the same for all package variants and is 0.05 mSv/hr (5 mrem/hr). This meets the regulatory limit in 10 CFR 71.47(a) of 0.1 mSv/hr (10 mrem/hr).

The regulatory requirement is for 2 meters from the outer lateral surface of the vehicle and the applicant calculates it at 2 meters from the package surface. The maximum calculated accident condition dose rate is for the Type A (BFA-200) and is 8.6 mSv/hr (860 mrem/hr). This meets the regulatory limit in 10 CFR 71.51(a)(2) of 10 mSv/hr (1 Rem/hr).

5.4.4.1 Tally Locations

The applicant discusses the tallies it used for calculating radiation levels in Section 5.1.3 of the application. Details on the specific size and location of the tallies are in Table 3 of HI-2156583 Rev. 5.

The tallies are specified for locations around the package including all sides and the top and bottom. The applicant also included tallies for streaming paths and some package features where shielding may be reduced. This includes tallies adjacent to the trunnions, the closure lid lift lug holes, self-adjusting shims and the chamfered cask edges. Tallies for the closure lid lift lug holes, self-adjusting shims and the chamfered cask edges are only specified as surface tallies under NCT. Under HAC the applicant included tallies 1 meter from the trunnions and the self-adjusting shims.

The staff reviewed the tally specifications for these locations and found that they are of sufficient size to be able to discern a maximum dose. The staff reviewed the tally locations and found that they are appropriate for calculating the dose rates at the distances specified within 10 CFR 71.47(a) and 71.51(a)(2).

5.5 Staff Calculations

5.5.1 Normal Conditions of Transport

The staff performed independent calculations of the HI-STAR ATB 1T under NCT using the MAVRIC code from the SCALE 6.2.3 code package using ENDF/B-VII cross sections. The staff modeled the Type A (T-200) configuration for convenience as this was the configuration modeled under HAC (see Section 5.5.2 of this SER).

The staff included a conservative representation of the streaming path from the shims assuming it is at maximum size, as discussed in Section 5.3.2.3 of this SER, with the spring extended, neglected the material in the springs and assumed the streaming path was not at an angle and went straight through the shielding. For this version, the staff also increased the amount of source material inside of the package to maintain maximum specific activity. This is conservative because the amount of source material exceeds the total activity limit.

The staff chose this assumption to ensure the maximum dose rate around the streaming path regardless of source geometry. The staff's calculation confirmed the applicant's result that the package meets regulatory requirements on the surface of the package with significant margin.

The staff also calculated the dose at 2 meters and confirmed applicant's result that the package meets regulatory requirements at this distance with significant margin. The staff found that its calculations provide additional assurance that the applicant had modeled the package correctly and conservatively and that the package meets regulatory requirements under NCT.

5.5.2 Hypothetical Accident Conditions

The staff performed independent calculations of the HI-STAR ATB 1T under HAC where the BTC bottom plate was not credited as this is the configuration that is the closest to the regulatory dose rate limit. In the staff's calculation, the staff assumed BTC bottom plate was re-located to the top of the package such that all contents were relocated to the other side of the shielding plate.

The bottom face of the HI-STAR ATB 1T without the BTC plate has the least amount of shielding of any of the package faces and has the highest dose rates under HAC. The staff modeled the Type A configuration (T-200), as this has the highest total source and source concentration limits from Table 7.1.2 of the SAR. This is because the Type A configuration also has the thickest BFA-Tank plates and BTC plates so relocation of the BTC plate has the most significant effect on this configuration.

The staff calculated the source volume so that it would have maximum activity and maximum specific activity from Table 7.1.2 of the application and assumed uniform distribution of Co-60 throughout the steel. The staff's model includes the streaming path from the BFA-tank plates where the welds are assumed to have failed to reveal a 1 cm gap between the plates. This gap is included at the longest side of the package.

The staff was able to confirm the applicant's dose rate result and found that this provides further assurance that the applicant's model is appropriate and that the package meets regulatory requirements under HAC.

The staff performed a sensitivity study with the same HAC configuration as described above, but with a 4cm gap in the BFA-tank plates, which was consistent with a previous design. Although this gap is no longer achievable with the addition of the shims, the staff found that it provided additional information on the effect streaming paths have on dose rate at 1 meter under HAC.

The staff's model with the larger streaming path results in about a 25% increase in dose rate at 1 meter. This resulted in a dose rate slightly above regulatory limits, however this is only a sensitivity study. This size gap in shielding would bound any localized streaming due to local damage to the package.

Therefore, the staff found it useful knowing the severity of a streaming path that would cause the calculated dose rate to increase above the regulatory limit. Such a large gap in the shielding, that traverses the length of the BFA-Tank, is not bound to happen as a result of the tests performed under 10 CFR 71.73. But this provides the staff with additional assurance that neglecting the other smaller local effects under HAC, such as the pin puncture, is acceptable.

5.6 Evaluation Findings

Based on its review of the statements and representations in the application and independent confirmatory calculations, the staff found reasonable assurance that the shielding design has been adequately described and evaluated and that the package meets the external radiation requirements of 10 CFR Part 71.

CHAPTER 7 OPERATING PROCEDURES

This chapter of the application provides a summary description of the essential elements and requirements necessary to prepare the HI-STAR ATB 1T package for shipment to ensure that it operates in a safe and reliable manner under normal and accident conditions of transport pursuant to the provisions of 10 CFR Part 71. The operations covered in this Chapter of the application include (i) the preparation for loading a packaging, (ii) the loading of the contents, (3) the preparation for shipment of a package, (4) the package unloading, and (5) the preparation for shipment of an empty packaging.

The HI-STAR ATB 1T packaging has been designed to facilitate loading and unloading of radioactive wastes with a self-energizing gasket joint functioning as a seal between the steel rectangular lid and the cask's top flange. The CLLS secures the lid to the top flange to prevent the lifting of the lid and subsequent unloading of the gasket.

Section 7.1.2 of the application presents two loading scenarios. One loading scenario is that waste in a storage pool is placed within a cassette (BTC), which is then subsequently placed within a BFA-Tank; the BFA-Tank is then placed within the HI-STAR ATB 1T transportation package. The other loading scenario was described as placing an already filled BFA-Tank within the HI-STAR ATB 1T transportation package.

Table 7.1.2 of the application contains specific activity limits for each of the 4 potential configurations. The staff reviewed this table and determined that the specific activity limits for each of the Tank configurations are consistent with the modeling in the shielding evaluation in Chapter 5 of the application. The staff verified that it includes an appropriate minimum cooling time to account for the decay of the non-Co-60 nuclides that may be present within the contents and an appropriate neutron source limit that was appropriately justified within Chapter 5 of the application.

To prevent hot spots within the waste, Note 4 of Table 7.1.2 of the application contains a requirement that the maximum specific activity limits have to be met by the most activated portion of any single waste item. The glossary of the application contains a specific definition of "single waste item" to clarify that this item cannot be divisible under accident conditions. The staff found that this should help prevent relocation of higher activity material under HAC.

The lift points of the package are rendered inoperable during transport by the installation of the weather protection cover (WPC); this is accomplished by:

(i) securing the WPC to the waste package by direct attachment to the cask lifting trunnions, so that they are not capable of being engaged by a lifting device;

(ii) the presence of the WPC itself, which, by virtue of its coverage of the entire top surface of the cask, prevents overhead access to the lifting trunnions required for engagement of a lifting device. Step 5 of Subsection 7.1.4 (Preparation for Transport)

and of Subsection 7.2.1 (Receipt of Package from Carrier) provide confirmation that this is the case.

The description of package loading (Section 7.1) also clarifies that the WPC must be installed prior to shipment, and is not optional.

The inspection and removal of the security seal is included in Step 4 of Subsection 7.2.1, as follows: The security seal is verified to be intact, to ensure that the package has not been opened by unauthorized persons. Following verification, the security seal is removed.

As stated in Step 8 of Subsection 7.1.2.1 and Step 1 of Subsection 7.1.2.2, the bolts are installed "wrench-tight". Step 3 of Subsection 7.1.2.2 adds the additional provision that BFA-Tank lid bolts shall be installed as recommended by the BFA-Tank supplier, as the supplier may suggest additional torque requirements related to BFA-Tank assembly for operational reasons that are not applicable to the safety-related function of the BFA-Tank. The bolts are classified as ITS components.

The staff reviewed the Operating Procedures in Chapter 7 of the application to verify that the package will be operated in a manner that is consistent with its design evaluation. On the basis of its evaluation, the staff concludes that the combination of the engineered safety features and the operating procedures provide adequate measures and reasonable assurance for safe operation of the package in accordance with 10 CFR Part 71.

CHAPTER 8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAMS

In Section 8.1.1 the applicant states that, before use of the package, controls shall be implemented to ensure that the packaging conforms to the dimensions and tolerances specified on the licensing drawings. The applicant also states that non-containment boundary metallic components and associated welds are either austenitic stainless-steel, nickel alloy or aluminum, and therefore are exempt from brittle fracture testing in accordance with ASME Code Section III, Subsections NF-2311 (components), and NF-2430 (associated welds). The staff notes that these non-containment boundary components include the DBS, impact absorbers, the cask lid locking system, and trunnions. The staff verified that the materials of construction of the non-containment components (other than the secondary containers) are constructed of materials that the ASME Code exempts from fracture testing due to their lack of a ductile-to-brittle transition at low service temperatures.

Since the entire HI-STAR ATB 1T body and secondary containers are made from stainless steel, the staff accepts inspections of the dimensions as a sufficient acceptance test for ensuring shielding performance as these are manufactured to industry standard specifications and are not subject to the material irregularities faced from non-standard materials or a poured lead shield.

Table 8.1.2 of the application provided applicable sections of the ASME Code and other documents for material procurement, design, fabrication, and inspection, and testing. The staff notes that containment SSCs are designed to ASME Code material requirements, while non-containment SSC could be designed to ASME, ASTM or AISI material requirements. The staff finds that the identified codes and standards are consistent with NRC guidance. Therefore, they are acceptable for the material control of the HI-STAR ATB 1T components. Table 8.1.3 of the application lists alternatives to the ASME Code where appropriate.

Tables 8.1.2 and 8.1.3 of the application discusses fabrication and examination of the HI-STAR ATB 1T package. The welds of the containment boundary are fabricated and qualified in accordance with ASME B&PV Code Section III, Subsection NB-4000, while the welds associated with the DBS and impact limiters are fabricated in accordance with ASME B&PV Code Section IX. The applicant states that containment boundary welds, including any attachment welds (and temporary welds to the containment boundary), are examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. In addition, these welds are repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450, and examined after repair in the same manner as the original weld.

The applicant stated that weld overlays (if used) for cask sealing surfaces shall be examined using visual (VT) and liquid penetration (PT). The applicant stated that all inspections of structural code welds shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification, and Certification in Nondestructive Testing."

Table 8.1.1 provided the types of leakage rate tests and the leakage test rate acceptance criteria based on the analysis presented in SAR Section 4.3. Using the test designations denoted in ANSI N14.5-2014, the tests include A.5.3 for fabrication leakage test, and A.5.1, A.5.2, A.5.3, and A.5.4 for the pre-shipment, maintenance, and periodic leakage rate tests.

The fabrication leakage rate test and maintenance leakage rate test include testing the entire containment boundary (e.g., base plate, containment wall plates, top flange, closure lid, closure lid inner seal, and the containment boundary welds) to a leak rate acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions.

Likewise, the pre-shipment and periodic leakage rate tests of the closure lid inner seal have a leakage rate acceptance criterion of 10^{-4} atm-cm^3/sec (air) at reference conditions. Leakage rate tests on the containment boundary are to be performed in accordance with the requirements of ANSI N14.5 - 2014; the leakage rate testing procedures are to be approved by an American Society for Nondestructive Testing (ASNT) Level III Specialist in the Leak Testing examination method and the leakage rate testing is to be performed by personnel qualified and certified in accordance with the requirements of SNT-TC-1A. Likewise, leakage rate testing is to be performed in accordance with a written quality assurance program.

In Section 8.1.6 of the application the applicant provides information on the pre-shipment acceptance tests performed by the user to ensure that the package shielding is functional and consistent with the assumptions within the shielding evaluation in Chapter 5 of the application. The acceptance criteria for measurements will be verified against calculations performed for as-loaded contents. The staff found that this acceptance criteria is appropriate to determine that the shielding is functional.

Section 8.2.4 of the application discussed component and material tests of the HI-STAR ATB 1T packaging. The applicant stated that the seals are considered to be reusable until pre-shipment leakage testing indicates that they can no longer meet the leakage-criteria or unless they fail a visual inspection. The applicant stated that seals which have been in-service for more than 1 year shall be replaced the next time that the CLLS is disengaged.

The permissible upper bound material strengths for the crushable components are specified in SAR Table 8.1.5. The upper bound material strength properties are further discussed in the application and must be verified by testing during the HI-STAR ATB 1T package fabrication.

The permissible upper bound material strengths for the crushable components are specified in SAR Table 8.1.5. The upper bound material strength properties must be verified by testing during the HI-STAR ATB 1T package fabrication.

Based on the review of the statements and representations in the application, the staff concludes that the acceptance tests for the packaging meet the requirements of 10 CFR Part 71, and that the maintenance program is adequate to assure packaging performance during its service life.

CONDITIONS

The following Conditions are included in the Certificate of Compliance:

> The package shall be prepared for shipment and operated in accordance with Chapter 7 of the application.
>
> The package shall meet the acceptance tests and be maintained in accordance with Chapter 8 of the application.
>
> The package shall be transported exclusive use only.
>
> No air shipment is authorized. Flammable gas concentrations shall be less than 5% by volume.
>
> The package may be used in the U.S. if the BFA-Tanks and BFA-Tank Cassettes are manufactured under a US NRC approved QA Program.
>
> Certified mill test reports (CMTRs) for (i) the crushable components attached externally to the cask and (ii) the closure lid impact absorbers must comply with the material properties specified in Table 8.1.5 of the application.
>
> The expiration date of the certificate is June 30, 2026.

CONCLUSION

Based on the statements and representations contained in the application, and the conditions listed above, the staff concludes that the Model No. HI-STAR ATB1T package has been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9375, Revision No. 0.