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

May 5, 2021

Mr. Luis Hinojosa
Holtec International
1 Holtec Blvd
Camden, NJ 08104

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 9381, REVISION NO. 0, FOR THE MODEL NO. HI-STAR 180L PACKAGE

Dear Mr. Hinojosa:

As requested by your application dated April 10, 2020, as supplemented April 27, 2021, enclosed is Certificate of Compliance No. 9381, Revision No. 0, for the Model No. HI-STAR 180L 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,

Signed by McKirgan, John
on 05/05/21

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

Docket No. 71-9381
EPID No. L-2018-NEW-0007

Enclosures:
1. Certificate of Compliance No. 9381, Rev. No. 0
2. Safety Evaluation Report

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

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SAFETY EVALUATION REPORT
HOLTEC INTERNATIONAL
Docket No. 71-9381
Model No. HI-STAR 180L Package

By letter dated April 10, 2020, Holtec International (the applicant) submitted an application for Certificate of Compliance No. 9381, Revision No. 0, for the Model No. HI-STAR 180L package.

The staff performed an acceptance review of the application and transmitted, by letter dated May 18, 2020, observations from the acceptance review. On July 31, 2020, Holtec responded to staff's observations and provided revised thermal evaluations in Holtec Report HI-2177931R3. On December 21, 2020, Holtec responded to staff's request for additional information letter dated September 17, 2020. Holtec submitted the corresponding revised application, i.e., "HI-STAR 180L Safety Analysis Report (SAR), HI-2177805, Revision 2" by letter dated April 27, 2021.

NRC staff reviewed the application using the guidance in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel". The analyses performed by the applicant demonstrate that the package provides adequate structural, thermal, containment, shielding, and criticality 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 180L package is designed for transportation of undamaged irradiated Uranium Oxide (UO_2) Boiling Water Reactor (BWR) fuel assemblies in a basket, or of individual UO_2 fuel rods in quivers. A quiver is a hermetically sealed container for individual fuel rods which may be leaking, broken or fragmented, i.e., fuel debris. The fuel basket provides criticality control; the packaging body provides containment boundary, moderator exclusion barrier, gamma and neutron radiation shielding, and heat rejection capability. The HI-STAR 180L package uses two independent closure lids, with both closure lids designated as containment boundary components.

The cavity of the HI-STAR 180L package is approximately 4543 mm long. The package is approximately 5390 mm long without impact limiters and 8358 mm long with its impact limiters and impact limiter adapters. The approximate weight of the empty packaging (cask only) is 97 Metric Tons, and approximately 130 Metric Tons when including the basket, the shims, and the impact limiters. The maximum gross weight of the loaded HI-STAR 180L package is 156 Metric Tons.

The F-69L fuel basket is made of Metamic-HT, a metal matrix composite of aluminum and boron carbide, and serves both as structural material and neutron absorber material. Basket shims, between the fuel basket and the inside surface of the containment boundary, provide for heat transfer and lateral structural support to the basket.

The containment vessel is formed by a cylindrical nickel steel shell welded to a nickel steel baseplate at the bottom and a machined nickel steel forging at the top, with machined surfaces to fasten two independent cryogenic steel closure lids, each equipped with a set of concentric metallic seals.

The containment system for the HI-STAR 180L cask consists of the containment shell, the containment base plate, the containment closure flange, the inner closure lid, the outer closure lid, inner and outer closure lid bolts, the inner closure lid port covers, the outer closure lid access port plug, and their respective metallic seals and welds. The outer surface of the cask inner shell is buttressed by the monolithic shield cylinder for gamma and neutron shielding.

The HI-STAR 180L package features two removable top trunnions (inserted into the containment closure flange) which are qualified as lifting points, and two removable bottom trunnions installed in the bottom forging.

The HI-STAR 180L package is fitted with two impact limiters fabricated of aluminum crush material completely enclosed by an all-welded austenitic stainless-steel skin. Both impact limiters interface with the body of the packaging using impact limiter adapters and are attached directly to the body of the packaging with 16 longitudinal bolts.

1.2 Drawings

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

(a) HI-STAR 180L Cask Drawing 10942, Sheets 1-7, Rev. 4

(b) F-69L Fuel Basket Assembly Drawing 10961, Sheets 1-3, Rev. 5

(c) HI-STAR 180L Impact Limiters Drawing 12285, Sheets 1-5, Rev. 0

(d) HI-STAR 180L Impact Limiters Adapters Drawing 10955, Sheets 1-4, Rev. 2

The staff reviewed the drawing with respect to the guidance in NUREG/CR-5502, “Engineering Drawings for 10 CFR Part 71 Package Approvals,” and confirmed that the drawings provide an adequate description of the package specifications, material properties, dimensions, welding specifications, coatings, etc. All licensing drawings now include tolerances for Important to Safety (ITS) components.

Staff had previously noted that the applicant had initially included in the drawings only a few tolerances, quantitative in nature and that any significant deviation from the nominal dimensions in a fabricated package/component could be considered by staff as being noncompliant with the conditions of approval of the package.

1.3 Contents

The packaging can transport either a maximum of 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies or 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies of which up to 4 may be quivers, each containing up to 28 fuel rods or fuel rod pieces (fuel rods in quivers may be leaking, broken, or fragmented).

The minimum initial fuel rod enrichment is 0.7 wt.% 235U, and the maximum initial enrichment of any UO_2 assembly is 5.0 wt.% ^{235}U. The post-irradiation minimum cooling time is 2 years and the maximum average burnup is 66 GWD/MTU. The maximum decay heat is 35 kW.

1.4 Conclusion

The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.33 and 71.31.(c): The applicant described the materials used in the transportation package in sufficient detail to support the staff's evaluation; 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.

2.0 STRUCTURAL AND MATERIALS EVALUATIONS

2.1 Structural Design

2.1.1 Description of Structures

The Model No. HI-STAR 180L package is made of three principal structural components: (i) cask body, (ii) fuel basket, and (iii) impact limiters.

The cask containment shell is constructed of a nickel steel shell welded to a nickel steel baseplate at the bottom and a machined nickel steel flange forged at the top. The top of the cask shell is equipped with a machined flange surface to fasten two independent nickel steel closure lids, with each lid bolted independently to the cask closure flange with seals. Licensing Drawing No. 10942 provides the structural design details for the cask body assembly. The HI-STAR 180L cask containment system parallels the design and construction of the HI-STAR 180 packaging containment system, previously reviewed and approved by staff [Agencywide Documents Access and Management System (ADAMS) Accession No. ML092890310]. The construction materials, welding joint details, non-destructive examination (NDE) requirements, seal joint type, and Code requirements for the design and construction of the HI-STAR 180L packaging are identical to those of the HI-STAR 180 packaging. Furthermore, the double closure lid system of the HI-STAR 180L is identical to the double closure lid system of the HI-STAR 180.

Licensing Drawing No. 10961 provides the structural design details of the fuel basket, named as F-69L fuel basket, which features a honeycomb construction. The F-69L fuel basket is constructed using the same material (Metamic-HT) and construction/assembly methods as used for similar baskets such as the F-32 and F-37 fuel baskets employed in the HI-STAR 180. In addition, Metamic-HT has been qualified and licensed for use for both transport and storage casks, i.e., HI-STAR 190 (Docket No. 71-9373), HI-STAR 180D (Docket No. 71-9367), HI-STORM 100 (Docket No. 72-1014), and HI-STORM FW (Docket 72-1032).

The impact limiter is comprised of a steel skeleton that fits over the top forging and bottom baseplate, and an aluminum honeycomb block interior material for energy absorption during impact. An external thin gauge stainless steel shell encloses the steel skeleton and aluminum honeycomb. Licensing Drawing No. 12285 provides details of the impact limiter while Licensing Drawing No. 10955 provides the structural design details of the impact limiter adapters.

2.1.2 Drawings

The applicant provided the general assembly drawings of the HI-STAR 180L transportation package in Section 1.3 of the application, where the major components of the package were identified.

As indicated in Subsection 2.1.1 of this SER above, the licensing drawings of 10942, 10961, 10955 and 12285 are for the cask body, fuel basket, impact limiter adapter and impact limiter of the HI-STAR 180L transport package, respectively. These drawings do show, at staff's request, tolerances on important-to-safety (ITS) components and not-important-to-safety (NITS) features/components which may affect the function of the ITS components, as applicable, to demonstrate compliance with 10 CFR 71.33(a) and 71.107(a).

The NRC staff reviewed the drawings for completeness and accuracy, and finds that the geometry, dimensions, material, components, notes and fabrication details were adequately incorporated throughout the application.

2.1.3 Design Criteria

The applicant designed the HI-STAR 180L package to meet the normal conditions of transport (NCT) requirements of 10 CFR 71.71 and the hypothetical accident conditions (HAC) requirements of 10 CFR 71.73. In addition, the HI-STAR 180L transportation package design complies with "General Standards for All Packages" as specified in 10 CFR 71.43 and follows the guidance provided in Regulatory Guide (RG) 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels." These criteria were discussed in Subsection 2.1.2 of the application and used to evaluate the structural performance of the HI-STAR 180L package.

The containment boundary was evaluated based on the American Society of Mechanical Engineers (ASME) Code requirements for Levels A and D service, and is consistent with RG 7.6, which provides design criteria based on the ASME B&PV Code, Section III. As a result, the applicant used the allowable stress values for NCT Service Level A Limits and HAC Service Level D Limits.

Tables 2.1.2 through 2.1.8 of the application list the allowable stresses for various stress categories under the NCT and HAC load conditions for materials of the HI-STAR 180L package. The NRC staff performed an independent check of the allowable levels and confirmed that the values are from the ASME B&PV Code, Section III.

The staff also found that the load combinations used by the applicant in performing the structural evaluations for the HI-STAR 180L package are in accordance with RG 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Materials."

Based on the review of the design criteria presented in Subsection 2.1.2 of the application, the staff finds that the structural design criteria for the HI-STAR 180L package provide adequate structural integrity to meet the NCT and HAC requirements of 10 CFR 71.

2.1.4 Weights and Centers of Gravity

The nominal weights and location of the center of gravity (CG) of the HI-STAR 180L package components are provided in Tables 2.1.9 and 2.1.10 of the application, respectively. These weights and CG are used for the structural evaluations to meet the NCT and HAC requirements of 10 CFR 71.

2.1.5 Identification of Codes and Standards for Package Design

Table 2.1.11 of the application lists each major structure, system, and component (SSC) of the HI-STAR 180L packaging, along with its function, and applicable Code or Standard. Table 2.1.13 lists some alternatives to the ASME Code, where appropriate. Additionally, Table 2.1.13 provides applicable Sections of the ASME Code and other documents for material procurement, design, fabrication, and inspection, and testing.

Based on the review of the Codes and Standards presented in Tables 2.1.11 and 2.1.13 of the application, the NRC staff determines that the Codes and Standards identified by the applicant are appropriate to evaluate the structural performance of the HI-STAR 180L package under the NCT and HAC load conditions to meet the regulatory requirements of 10 CFR 71.

2.2 Materials

The HI-STAR 180L is a modified version of the previously approved HI-STAR 180 transportation package, and this SER will briefly discuss the major components in common but focus primarily on specific areas of changes to the design. The changes in the HI-STAR 180L application are primarily focused on the structural components important to safety (ITS) as follows:

Chapter 1, Table 1.2.1, Chapter 2 and licensing drawings of the application described the HI-STAR 180L packaging components and structural design, respectively. In addition, the Chapter 2 table compares major design features between the HI-STAR 180 and HI-STAR 180L casks. The staff notes that no material specifications have changed and the HI-STAR 180L transport package is fabricated from materials, which have been previously evaluated and found suitable by the staff. A brief synopsis of materials of the HI-STAR 180L is provided below.

2.2.1 Cask

The main function of the cask is to provide containment and shielding. An inner most shell is welded to a baseplate forging and a suitably machined top forging, all fabricated to ASME SA-203 Grade E or SA-350 Grade LF3 nickel alloy steel. The top forging is equipped with machined surfaces to fasten two independent steel closure lids, each equipped with machined concentric grooves for metallic seals to meet leak-tight criteria. The cask containment system boundary is defined by the weldment between the top and bottom forging combined with both bolted closure lids. Two trunnions are inserted into both the top forging and the cask bottom ring. The gamma capture space refers to monolithic shield cylinders (carbon-manganese steel) fabricated to ASME SA-352 or ASTM A 352 both Grade LCC, individually heated, slid over the containment shell and cooled to form a slight interference fit. Each monolithic shield cylinder contains an overlapping joint and two offset overlapping concentric circular rows of through thickness pockets for installing Holtite-B, providing structural stability, eliminating potential radiation steaming paths and complete circumferential neutron shielding. The Holtite-B shielding material is capped with the top forging, a steel ASME SA-350 Grade LF2 bottom ring and two (top and bottom) caps fabricated to ASME SA-36 or SA-516 Grade 70 steel. The neutron capture space refers to the sector pockets, which contain pressure relief protection, within the monolithic shield cylinders that are filled with Holtite-B.

Finally, two top lifting trunnions fabricated to ASME SB-637 (UNS-N07718) or SA-564 Type 630 (Condition H1025) or SA-705 Type 630 (Condition H1025) are circumferentially spaced at 180-degrees, and inserted/secured to the top forging with locking hardware fabricated to ASME SA-564 Type 630 (Condition H1025) or SB-637 (UNS-N07718) or SA-540 Grade B23. The trunnions are removable for installing impact limiters during transportation and replaced with steel shielding plugs. In addition, two bottom (optional) trunnions are inserted/secured to the bottom ring and may be used as rotation supports when changing package orientation from vertical to horizontal. The bottom trunnions are fabricated/secured using similar material specifications as the top trunnions.

Table 1.1.1 of the application lists the waste packages qualified for use with the HI-STAR 180L. The F-69L is a bare basket BWR fuel package and is the sole waste package currently qualified for use in the HI-STAR 180L. The F-69L basket is of the same material, construction and assembly method as the F-32 and F-37 waste baskets, employed in the HI-STAR 180 Package, with the main difference in the design as the number of fuel storage cells and cell dimensions. The applicant stated that the F-69L basket principle constituent material is a high temperature metal matrix composite (MMC) of aluminum and boron carbide, manufactured using a powder metallurgy process under the trade name Metamic-HT.

Section 1.2.2 of the application discusses quivers and dummy fuel assemblies. Quivers are to be used to contain damaged fuel in the F-69L basket. The staff notes that Westinghouse - Sweden is providing the long-time storage (LTS) BWR Quiver to be used in conjunction with the HI-STAR 180L package. Westinghouse Report NRT 14-057, Revision 3, provides a technical description of the LTS BWR Quiver. The quiver is a hermetically sealed container, typically fabricated from ASME SA-240 or SA-479 Type 304/316 stainless steels, for damaged fuel rods that have been removed from a fuel assembly. The applicant stated that the fuel rods may be leaking, broken or fragmented (i.e. fuel debris) and purposely punctured (if needed) to relieve internal pressure.

In addition, the external cross section dimensions of the quiver emulate that of a standard BWR fuel assembly. The quiver maintains its contents (fuel rods) in an inert (helium filled) environment, thus precluding the risk of in-service corrosion of its contents. The quivers themselves have been designed for NCT and HAC. The staff notes that Table 7.1.5 discussed quiver operational requirements, specifically leak-tightness, important to moisture control. The dummy fuel assembly refers to a dummy weight ancillary that emulates the weight and exterior dimensions of a fuel assembly and is made of stainless steel. The staff concludes that evacuating the quiver and backfilling with helium will reduce the water content, humidity, and oxidizing potential of the environment as well as reduce the potential for localized corrosion of passive alloys. The staff finds the use of quivers for the HI-STAR 180L acceptable based on the above discussion, material and structural analysis of the quivers and their physical similarity to the BWR fuel assemblies used in the previously accepted HI-STAR 180 package.

The impact limiters consist of a rigid cylindrical core, an ASME SA-516 Grade 70 stainless steel (typical) cylindrical skirt that girdles the cask forging, the aluminum honeycomb energy absorbing material, an outer stainless steel skin, and ASME SA-193 Grade B8S attachment bolts, which imparts high fracture toughness and high ductility suitable for low temperature. The external surface of the impact limiter consists of a stainless-steel skin to provide long-term protection against environmental service conditions. Attachment bolts are also made of stainless steel, which imparts a high fracture toughness and high ductility in the entire temperature range of service. The impact limiters are referred to as AL-STAR 180 since they are the same design used in the previously approved HI-STAR 180 and 180D transport packages.

2.2.2 Drawings:

The staff reviewed application and licensing drawings of the HI-STAR 180L package and verified that the applicant provided an adequate description of the component safety functions, materials of construction, dimensions, tolerances, and fabrication (welding) specifications. The staff notes that the carbon steels used in the fabrication of the HI-STAR 180L are specified in the bill of materials and the associated weld filler materials are procured in accordance with the ASME Code and ASTM specification requirements.

In addition, the Holtite-B neutron shield material and the Metamic-HT neutron absorber material are non-code materials and requirements are per their fabrication specifications. The staff finds the drawings contain sufficient information, including a bill of materials, appropriate consensus code information, such as, American Welding Society (AWS), American Society of Mechanical Engineers (ASME), and American Society for Testing and Materials (ASTM) specification number(s) for the material(s) used in fabrication.

2.2.3 Codes and Standards:

Section 2.1.4, Table 2.1.11, and Table 2.1.13 of the application lists each major structure, system, and component (SSC) of the HI-STAR 180L packaging, along with its function, applicable code or standard and alternatives, respectively. The applicant stated that the design of the HI-STAR 180L package does not invoke ASME Code Section III in its entirety. In addition, specific code paragraphs in ASME Code Section III, Subsection NB-3000 and Appendix F are invoked for design of the containment system of the HI-STAR 180L package.

The applicant stated that all materials and sub-components that do not constitute the containment system in the HI-STAR 180L cask are procured to ASTM or ASME Specifications, except for the F-69L (Metamic-HT) basket and the neutron shield Holtite B, both of which have been previously approved in the HI-STAR 180 and 180D packages. The applicant stated that the lifting trunnions are designed, fabricated, and tested in accordance with the requirements of ANSI N14.6.

The staff finds that the identified codes and standards are acceptable for the material control of the HI-STAR 180L components because they are consistent with NRC guidance in NUREG-2215.

2.2.4 Weld Design and Inspection:

Sections 2.3 and 8.1.2 of the application described that the fabrication and examination techniques of the HI-STAR 180L materials of construction that are specified for the HI-STAR 180L are identified in the licensing drawings and meet the applicable ASME Code sections. The applicant stated that welding of Code materials shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and the applicable ASME Section III Subsections. In addition, welding of welds identified as not important to safety welds may be performed as described above for code welds or using welders and weld procedures that have been qualified in accordance with AWS D1.1 or AWS D1.2 as applicable.

The applicant stated that welds shall be examined in accordance with ASME Code Section V with acceptance criteria per ASME Code Section III. In addition, acceptance criteria for non-destructive examination (NDE) shall be in accordance with the applicable Code for which the item was fabricated. The applicant stated that NDE inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A as specified in Holtec's QA program.

In addition, basket welds connecting Metamic-HT panels shall be examined and repaired in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for welding Metamic-HT with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition).

Further, the basket welds, made by a friction stir welding process, are classified as Category E per NG-3351.3 and belonging to Type III in Table NG-3352-1. The staff verified that that the weld design and inspections are in accordance with the recommendations in NUREG 2215, which includes the use of ASME Code Section III, Subsection NF for other code welds (supports), as appropriate.

The staff notes that welding of the Metamic-HT is by the friction stir weld (FSW) process. The applicant stated that FSW shall meet the applicable requirements of ASME Code Section IX per edition specified in the application Chapter 8. In addition, per ASME Section IX, QG-108, joining procedures, procedure qualifications, and performance qualifications that were made in accordance with Editions and Addenda of Section IX, as far back as the 1962 edition may be used in any construction for which the current edition has been specified.

The applicant stated that FSW has been specified as the mandatory welding process for basket weld joints and, per the licensing drawing, the weld configuration is of Category E, Type III (i.e., corner joint with essentially a thru-thickness "stir zone") per ASME Code Section III Subsection NG. The applicant stated that in the evaluation of the joint's structural strength, the F-69L basket FSW joints are considered to emulate a full penetration weld with its thickness defined by the minimum depth of the friction stir zone per the licensing drawing.

The staff notes that the FSW process was originally approved for use on the HI-STAR 180 Metamic-HT basket welds as a full penetration Category C, Type III weld per ASME Code Section III, Subsection NG. The applicant explained that the weld was initially classified incorrectly as Category C, even though the weld was well described as a "corner joint with essentially a thru-thickness "stir-zone"".

This classification error was later corrected in an amendment request to the HI-STAR 180, Rev. 3. The staff agreed with the applicant and concluded that the correct joint classification is indeed Category E, Type III, and that the HI-STAR 180L Metamic-HT F-69L basket welds are acceptable based on the above discussion, if the welds are restricted to areas where stresses are low, if the welds have been structurally evaluated and meet the requirements of the ASME Code, as applicable.

2.2.5 Material Properties:

Material Mechanical Properties

Sections 2.2.1 and 5.3.2 of the application described the mechanical properties, specifications and compositions of materials used in the fabrication of the HI-STAR 180L package. The following evaluation of material properties considers major structural and containment metallic components. Other packaging materials, for example, criticality, shielding, seals, bolts, etc. will be evaluated throughout the SER materials evaluation.

The staff notes that most of the values in the application and associated tables were obtained from ASME Code, Section II, Part D; however, some of the values were obtained from other acceptable technical references. The staff notes that structural components of the HI-STAR 180L are selected based on their strength, ductility, resistance to corrosion, and brittle fracture characteristics. 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 notes that the Metamic has undergone an extensive testing program, employing a variety of standard ASTM test methods, included the characterization of the yield strength, tensile strength, elongation, reduction in area, Young's Modulus, Charpy impact strength, thermal conductivity, coefficient of thermal expansion, and emissivity.

In addition, isotropy was evaluated, thermal aging effects were examined, welding procedures were developed, weld properties were determined, irradiation effects were evaluated, thermally induced microstructural alteration were assessed, and accelerated creep testing was performed. The staff concludes that the material mechanical properties are acceptable based on the above discussion and that materials used in fabrication of the HI-STAR 180L components are identical to those previously reviewed and approved for the HI-STAR 180 and 180D transport packages.

Material Thermal Properties

Section 3.2 and Tables 3.2.1 through 3.2.12 of the application provides a summary of HI-STAR packaging materials, their respective references and described material thermal properties and specifications of the HI-STAR 180L components. The applicant stated that the HI-STAR 180L Package cold service temperature is conservatively limited to –40°C (-40°F).

The staff reviewed and confirmed that the maximum allowable temperatures specified for components critical to the package containment, radiation shielding, and criticality are acceptable for both NCT and HAC conditions. In addition, except for the impact limiters and Holtite-B neutron shielding, all HI-STAR 180L components remain below their material property limits for a HAC condition of a fire.

The staff notes that the impact limiters and neutron shielding materials are not considered for criticality. The staff concludes that the material thermal properties are acceptable based on the above discussion and that the materials used in fabrication of the HI-STAR 180L components are identical to those previously reviewed and approved for the HI-STAR 180 and 180D transport packages.

Radiation Shielding Material Properties

Section 2.2.1.2.2 and Table 2.2.12 of the application described Holtite-B neutron shielding material as non-structural and provides properties of the neutron shielding material, respectively. The applicant stated that long-term stability of the Holtite-B under normal transport conditions is ensured when material exposure temperatures are maintained below the application Table 3.2.12 limits. Section 8.1.5.4 of the application described manufacturing and testing of Holtite-B neutron shielding material.

The staff notes that Holtite-B is a hydrogen rich, radiation resistant, polymeric material impregnated with boron carbide. The staff concludes that the material mechanical/thermal/radiation absorption properties are acceptable based on the above discussion and that the materials (e.g., Holtite-B) used in the HI-STAR 180L components are identical to those previously reviewed and approved for the HI-STAR 180 and 180D transport packages.

Criticality Control Material Properties

Section 2.2.1.1.3 of the application described the F-69L basket as fabricated from Metamic-HT, a high strength, nanotechnology-based neutron absorber material with primary properties defined as minimum guaranteed values (MGVs) and provided in Table 2.2.8 of the application. The staff notes that Metamic-HT is the applicant's proprietary aluminum-based material used both as a neutron poison for criticality control and as a load-bearing structural material in the HI-STAR 180L package. In addition, the Metamic-HT metal matrix composite is a powder metallurgy material composed of aluminum combined with aluminum oxide and boron carbide.

Further, the aluminum oxide consists of finely dispersed second-phase precipitation strengthened particles, which provides enhanced room temperature and elevated temperature (creep) strength, and allows the use of Metamic-HT as a structural material. The staff notes that neutron attenuation was verified, and corrosion testing was conducted in a simulated borated pool water environment. In addition, Metamic-HT has been previously qualified and licensed for use in the HI-STAR 180 Package.

Fracture Resistance Properties

Section 2.1 of the application described that certain components of the HI-STAR 180L containment system are composed of ferritic steel materials, which may be subject to impact loading in a cold environment and, therefore, must be evaluated and/or subjected to impact testing in accordance with the ASME Code to ensure protection against brittle fracture. Table 8.1.5 of the application provides the fracture toughness test criteria for the HI-STAR 180L containment system components in accordance with the applicable ASME Codes and regulatory guidance (RG 7.11 and 7.12) for prevention of brittle fracture. The staff notes that application Table 8.1.5 provides the criteria for qualification to LST of either -29ºC (-20ºF) or LST of -40ºC (-40ºF).

Section 8.1.5.2 of the application described that the HI-STAR 180L non-containment boundary ferritic steel package dose blocker parts on the exterior of the cask shall meet the impact testing requirements set forth for ASME Code Subsection NF Class 3 support material. The applicant stated that the lowest service temperature (LST) where impactive or impulsive loads are present is -29ºC (-20ºF) per Regulatory Guide 7.8; however, HI-STAR 180L cask will be qualified to an LST of either -29ºC (-20ºF) or -40ºC (-40ºF). The staff concludes that the HI-STAR 180L ferritic structural components and the bolting material are evaluated with the above stated testing, therefore brittle fracture is not a failure mode of concern. The staff has evaluated the HI-STAR

180L materials susceptibility to brittle fracture and finds it to be acceptable based on the above discussion. In addition, the use of similar materials has been previously approved for the HI-STAR 180 and 180D packages.

Creep

Section 2.1.2.2 and associated tables of the application described testing performed to determine the creep characteristics of the Metamic-HT under both unirradiated and irradiated conditions, which provided an equation to provide a bounding estimate of total creep as a function of stress and temperature. The applicant stated that the creep equation is confirmed to provide a conservative prediction of accumulated creep strain by direct comparison to measured creep in unirradiated and irradiated coupons.

The applicant stated that the creep evaluation conservatively demonstrates that the maximum cumulative creep strain will not exceed the 0.4% creep strain limit during the 60-year service life of the cask, therefore, creep is not a concern or a controlling mechanism in the HI-STAR 180L Metamic-HT F-69L basket. The staff notes that the 0.4% criterion is taken from the Japanese standard on aluminum fuel baskets and used as part of acceptance criteria in Holtec Report No. HI-2084122 (proprietary). In addition, both above cited section tables that document the cumulative creep strain after 5 years of transport and predicted creep strain under a hypothetical 60-year duration of transport, respectively, show the 0.4% limit is not exceeded.

Section 2.2.1.2.3 and associated table(s) of the application described the basket supports (aluminum alloy and stainless-steel basket shims), which provide the heat transfer bridge between the basket and the cask inside surface and serve to position the F-69L basket. The applicant stated that the creep behavior of the F-69L basket supports is a function of the level of stress in the component under NCT and that shim creep has no adverse effect on the basket geometry. The applicant stated that the creep in the basket shims is applicable only in the presence of an appreciable load on the basket shims in the horizontal configuration of the HI-STAR 180L transport package for an extended period.

The staff concludes that the creep in the basket shims calculated over a period of 60-years is conservative because the transport package remains in horizontal configuration for relatively short durations. The staff finds that the Metamic-HT F69L basket and supports will maintain geometry during the 60-year service life based on the above discussion, documented cumulative creep strain and predicted creep strain, as maximum basket temperature decreases over time due to fuel decay. Therefore, the staff finds the creep evaluation to be acceptable.

2.2.6 Corrosion, Chemical Reactions, and Radiation Effects

Corrosion Resistance/Content Reactions/Content Integrity

Section 2.2.2 of the application described chemical, galvanic or other reactions and stated that the HI-STAR 180L packaging combines low-alloy and nickel alloy steels, carbon steels, neutron and gamma shielding, and bolting materials. The applicant stated that all of these materials have a long history of non-galvanic behavior within close proximity of each other.

The applicant stated that the external surfaces of the cask are coated to preclude surface oxidation and that the internal surfaces of the cask are lined to preclude any significant surface oxidation. In addition, the coatings and liners do not chemically react significantly with borated water. Chapter 7 of the application discusses how the cask is dried and helium backfilled to eliminate any credible corrosion from moisture and oxidizing gases.

The applicant stated that the Metamic-HT plate has high corrosion resistance and anodizing to meet the required emissivity further enhances its corrosion resistance therefore, chemical, galvanic or other reactions involving the cask materials are unlikely and are not expected. The applicant stated that the interfacing seating surfaces of the closure lid metallic seals are clad with or stainless steel to assure long-term sealing performance and to eliminate the potential for localized corrosion of the seal seating surfaces. In addition, the closure seals do not have separate jackets that can collect moisture or debris; instead closure seals are cladded, coated, or plated with silver for the best possible long-term performance.

The applicant stated that, in accordance with NRC Bulletin 96-04, a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STAR 180L Package, its contents and the operating environment, which may produce adverse reactions, has been performed. The applicant stated that as a result of this review, no operations were identified which could produce adverse reactions. In addition, no closure welding is performed and, thus, hydrogen generation while the cask is in the pool is of minor consequence to cask operations based on previous experience with the same cask materials. The applicant stated that, because no welding activities are involved in the cask closure operations, the potential of a hydrogen ignition event does not exist.

The staff reviewed the design drawings and applicable sections of the application to evaluate the effects, if any, of intimate contact between the various materials used in fabrication of the HI-STAR 180L package. The staff evaluated whether these contacts could initiate a chemical or galvanic reaction that could result in corrosion or combustible gas generation that could adversely affect safety.

The staff finds that the HI-STAR 180L packaging components are fabricated from materials designated by appropriate commercial industry specifications, which are typically not susceptible to chemical or galvanic reactions when coated and in the absence of moisture. In addition, many components are fabricated from corrosion-resistant materials. The staff finds no significant material interactions or galvanic reactions are to be expected, based on the above discussion.

In addition, the HI-STAR 180L package is constructed of similar materials previously approved for the HI-STAR 180 and 180D packages. 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.

Protective Coatings

Sections 2.2.1.2.4 and 2.2.1.2.5 of the application described cask coating/liner of the HI-STAR 180L cask exterior carbon steel surfaces to be coated with a conventional surface preservative such as Carboguard 890 per manufacturer’s data sheet or equivalent with Holtec approval. The applicant stated that a cask liner is required to protect containment boundary carbon steel components against increased corrosion from submersions into the spent fuel pools.

The applicant stated that the HI-STAR 180L cask cavity and inter lid space carbon steel surfaces (except threaded features) may be lined with either a conventional surface preservative, an atomized deposit of a corrosion resistant aluminum oxide layer or other methods in accordance with the licensing drawing. The applicant made no changes to the protective coatings, used to reduce corrosion of the HI-STAR 180L exposed structural steel surfaces to their operating environment, from the previously approved HI-STAR 180 and 180D.

Radiation Shielding/Effects

Sections 2.2.3 and 5.1 of the application described effects of radiation on materials and shielding design, respectively. The applicant stated that the principal design features of the HI-STAR 180L packaging with respect to radiation gamma shielding is provided by the carbon steel cask body, lids, base plate and ASTM B29 lead, while the neutron shielding is provided by Holtite-B neutron absorber embedded in those parts. The applicant stated that the Metamic-HT neutron absorber and Holtite-B have been tested extensively to prove that it will not degrade over the service life of the package.

In addition, the F-69L basket and basket support(s) also provide additional gamma shielding. The applicant stated that gamma radiation damage to metals (e.g., aluminum, stainless steel, and carbon steel) does not occur until the dose level reaches 10^{18} rads or more. In addition, the 50-year gamma dose from the spent nuclear fuel transported in the HI-STAR 180L package is on the order of 1.25×10^9 rads and reduces significantly as it penetrates through cask components.

The applicant stated that significant radiation damage due to neutron exposure does not occur for neutron fluences below approximately 10^{19} n/cm2, which is far greater than the 50-year neutron fluence from spent nuclear fuel transported in the HI-STAR 180L package, which is on the order of 1.25×10^{16} n/cm2.

The staff notes that metallic materials selected for the HI-STAR 180L package components have a long, proven history of use in the nuclear industry and are not affected by the radiation levels produced by the spent nuclear fuel. The staff independently verified the above cited gamma dose and neutron fluence levels and finds that there will be no detrimental radiation effects on the HI-STAR 180L structural steels, containment metallic seals and lead gamma shield. In addition, the applicant made no changes to the materials used in the fabrication of the HI-STAR 180L and the radiation exposure limits discussed above are similar to those of the previously approved HI-STAR 180 and 180D.

Spent Fuel

Section 1.2.1.4 of the application described that the HI-STAR 180L packaging is designed to transport both moderate burnup fuel (MBF) and high burnup fuel (HBF) (66 GWd/MTU maximum average burnup/assembly). In addition, in recognition of the uncertainty surrounding the cladding material properties of HBF, HI-STAR 180L is designed with a double-lid closure system to provide a high level of assurance of water exclusion. The applicant stated that the temperature of the fuel cladding is dependent on the decay heat and the heat dissipation capabilities of the cask. The staff notes that the maximum cask heat load is 35 kW. Table 7.D.1 of the application defines the HI-STAR 180L package allowable contents, for example, Zirconium clad BWR spent nuclear fuel and separated fuel rods meeting the BWR fuel assembly characteristics of Table 7.D.2 of the application for fuel assembly array/class.

The staff notes the criteria in order to assure integrity of the cladding material is to ensure that the calculated maximum (peak) cladding temperature for the spent fuel during NCT and short-term loading operations (i.e. loading, drying, backfilling with inert gas) does not exceed 570°C

(1,058°F) for low burnup fuel, or 400°C (752°F) for HBF. In addition, these temperature limits were defined based on accelerated testing to provide reasonable assurance that thermal creep and hydride reorientation will not compromise the integrity of the cladding.

Section 3.3.10.2 of the application described the forced helium dehydration (FHD) system that ensures that the fuel cladding temperature will remain well below the peak cladding temperatures under normal conditions of transport, which is below the high burnup cladding temperature limit of 400°C (752°F) for all combinations of SNF type, burnup, decay heat, and cooling time authorized for loading in the HI-STAR 180L cask. Table 3.1.3 of the application indicates that the fuel cladding has an NCT and HAC (fire cooldown) temperatures of 364°C and 386°C, respectively. Therefore, the design basis spent fuel cladding temperature of 570ºC (1058°F) for HAC is observed.

The staff verified the potential degradation mechanisms identified for the spent nuclear fuel assemblies including oxidation, corrosion, cladding creep, and hydride redistribution and reorientation within the cladding. The staff notes that the integrity of the HI-STAR 180L containment boundary maintains the inert environment and prevents oxidation of the fuel.

Section 7.1.2 of the application described that an inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding and that the fuel cladding is not to be exposed to air at any time during loading operations. The staff verified that the cladding temperatures within the HI-STAR 180L during NCT and HAC will remain below the maximum (peak) cladding temperature limits that would preclude cladding damage possibly leading to gross rupture.

2.2.7 Component-Specific Reviews

Bolting

Section 2.1.2.2 of the application described that the candidate ASME SB-637 (UNS NO7718) bolt material for both the outer and inner lid joints provides immunity from brittle fracture concerns at cask LST of either -29ºC (-20ºF) or LST of -40ºC (-40ºF) per ASME Code Section III and NUREG/CR-1815. The applicant stated that ASME SA-564, SA-705, SA-193 Grade B7 and SA-320 Grade L7 are also candidate bolt materials for closure lid joints. Table 8.1.5 of the application lists containment bolt materials subject to fracture toughness testing criteria as required per ASME Code Section III, Subsection NB.

The staff has evaluated the HI-STAR 180L bolt materials susceptibility to brittle fracture and concludes ASME SB-637 material is austenitic and does not undergo a ductile-to-brittle transition, but a progressive reduction in Charpy impact value in the temperature range of interest (i.e., down to -40ºF) and therefore, does not require brittle fracture evaluation. In addition, the non-austenitic alloy steel bolt materials discussed above are to be Charpy impact tested in accordance with ASTM A 370 and evaluated to -40ºF. Therefore, the staff finds the bolt materials to be acceptable and brittle fracture is not a failure mode of concern. In addition, the use of similar materials has been previously approved for the HI-STAR 180 and 180D packages.

Seals

Section 2.2.1.1.6 and licensing drawing of the application described that the containment integrity of the HI-STAR 180L package relies on a double closure lid system with stainless steel or overlaid with stainless steel metallic seals. The applicant stated the minimum useful spring-back of the seal to maintain the leak-tight acceptance criterion, and the seal seating load for the inner and outer lid closure seals as critical seal parameters to provide leak-tight containment. provided by the two self-energizing seals located in each of the two annular grooves per lid.

Table 2.2.13 and Appendix 8.A of the application described critical characteristics and critical sealing dimensions consistent with seal manufacturers' data, respectively. Tables 8.A-1 through 8.A-4 of the application provides manufacturer, seal part/drawing number and described critical seal design parameters including seal and groove dimensions with tolerances, seal seating load with tolerances, surface finishes for sealing surfaces, and specific seal spring and material combinations for the inner closure lid seals, the outer closure lid seals, the inner port cover seals, and the outer lid access port plug seal.

Table 8.1.1 of the application describes the seal acceptance criterion as leak-tight, which is defined as a leakage rate of no greater than 1x10-7 reference cubic centimeter per second (ref-cm^3/s) of air, in accordance with American National Standards Institute (ANSI) N14.5, "American National Standard for Radioactive Materials – Leakage Tests on Packages for Shipment."

The staff reviewed the seal and groove dimensions presented in Appendix 8.A to verify the seals described would properly fit within the seal grooves as designed. The applicant made no changes to the seal materials used to provide leak-tight containment of the HI-STAR 180L from previously approved HI-STAR 180 and 180D. Therefore, the staff finds these materials are capable of withstanding all design and accident conditions and operating environments without loss of function.

2.2.8 Evaluation findings

The application described the materials that are used for structures, systems, and components (SSCs) important to safety and the suitability of those materials for their intended functions in sufficient detail to facilitate evaluation of their effectiveness. 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 design of the HI-STAR 180L and the selection of materials adequately protect the spent fuel cladding against degradation that might otherwise lead to gross rupture. This finding in the materials review area is contingent on the thermal analyses demonstrating that material temperature limits will not be exceeded. 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 HI-STAR 180L employs only noncombustible materials that will help maintain safety control functions. The applicant has met the requirements of 10 CFR 71.43(f) and 71.51(a); the applicant demonstrated effective materials performance of packaging components under normal conditions of transport and hypothetical accident conditions.

Materials that comprise the HI-STAR 180L will maintain their mechanical properties during all conditions of operation. The applicant has met the requirements of 10 CFR 71.85(a); the applicant has determined that there are no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce the effectiveness of the packaging.

The HI-STAR 180L employs materials that are compatible with canister loading operations and facilities. These materials are not expected to degrade over time, or react with one another, during conditions of transportation. The applicant has met the requirements of 10 CFR 71.43(d), 71.85(a), and 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 prior to each shipment to verify its condition.

The applicant has met the requirements of 10 CFR 71.43(f), 71.51(a) (for Type B packages), and 71.55(d)(2) (for fissile 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.

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

2.3 Fabrication and Examination

2.3.1 Fabrication

The applicant identified six key parameters necessary to ensure that the HI-STAR 180L package design can be readily constructed using current and available manufacturing techniques. The main parameters include the following:

(i) tolerances are achievable,

(ii) weldability of dissimilar materials,

(iii) specification of post heat treatment or other residual stress relief,

(iv) manufacturing sequence must allow for unimpeded NDE as well as remedial repairs,

(v) manufacturing sequence must allow for unimpeded access to relevant post weld machining of critical surfaces, and

(vi) manufacturing sequence does not engender unnecessary risk to worker safety.

The NRC staff reviewed a typical fabrication sequence, as provided in Subsection 2.3.1 of the application, and determined that it provides sufficient information to adequately describe the fabrication process and is acceptable.

2.3.2 Examination

The applicant identified eleven key fabrication control parameters and required inspections, as follows:

(i) materials of construction must be specified on the licensing drawings. ITS materials will be obtained with appropriate certification and documentation required by Sections II and III of ASME Code, where applicable,

(ii) welders and weld procedures will be qualified in accordance with Section IX and applicable subsections of Section III of ASME Code,

(iii) welds will be examined utilizing Section V of ASME Code with acceptance criteria in accordance with Section III of ASME Code,

(iv) the containment boundary will be examined and tested via a helium leak test, pressure test, ultrasonic testing, magnetic particle testing, and/or liquid penetrant testing as applicable,

(v) grinding and machining operations will be examined by ultrasonic testing to ensure that the metal wall thicknesses are not reduced beyond design limits,

(vi) dimensional inspections will occur to confirm compliance with design drawings and verify the fitting tolerances of individual components,

(vii) trunnions are designed, inspected, and tested in accordance to ANSI N14.6, “Special Lifting Devices for Shipping Containers Weighing 10,000 pounds (4500 kg) or More,”

(viii) upon completion of hydrostatic or pneumatic pressure tests, the internal surfaces of the package will be inspected for cracking or deformation,

(ix) each plate or forging used for the containment boundary will be drop weight tested per Regulatory Guides 7.11, “Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 inches (0.1 m)” and 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)” where applicable, and ASME Charpy V-notch testing will be performed on these materials. Test results will be recorded in the final QA document,

(x) leak tests will be performed upon completion of the fabrication of the containment boundary, and

(xi) all required tests, inspections, and examinations will be documented and be included in the final quality documentation report(s).

The NRC staff determined that the applicant provided adequate information to describe the examination requirements and that those are acceptable.

2.4 General Requirements for All Packages

2.4.1 Minimum Packaging Size

The applicant stated that the smallest dimension of the HI-STAR 180L package is larger than the minimum requirement of 4.0 inches, as shown in Section 1.3 of the application. The NRC staff determines that the application meets the regulatory requirement of 10 CFR 71.43(a).

2.4.2 Tamper-Indicating Features

The HI-STAR 180L package incorporates a wire tamper-indicating seal with a stamped identifier attached to the upper impact limiter at a location where the upper impact limiter must be removed to gain access to the closure lid bolting and the radioactive contents. This seal, when breached, will indicate that the package has been tampered with. The NRC staff determines that the application meets the regulatory requirements of 10 CFR 71.43(b).

2.4.3 Positive Closures

The HI-STAR 180L package is sealed using two bolted closure lids. These bolts are tightened during the loading process to a torque value that cannot be inadvertently loosened. Opening of the cask requires specialized tools and a power source, thereby inadvertent opening of the cask cannot occur. The staff determines that the application meets the regulatory requirements of 10 CFR 71.43(c).

2.5 Lifting and Tie-Down Standards for All Packages

2.5.1 Lifting Devices

The applicant evaluated devices and components related to: (i) a lifting operation including the trunnions, (ii) the closure lid lifting holes, and (iii) the containment baseplate. The trunnions and lid lifting holes were evaluated using the guidance in NUREG-0612, “Control of Heavy Loads at Nuclear Power Plants,” which requires a factor of safety on yield strength of 3.0 and a factor of safety on ultimate strength of 10.0.

Tables 2.5.1 to 2.5.3 of the application provide results of the stress evaluations based on the value of 3.0 against material yield strength mandated by 10 CFR 71.45(a) and 10.0 against material ultimate strength per NUREG-0612.

The results show that the calculated safety factors for all components are larger than the required minimum safety factors, indicating that the lifting devices have sufficient margin against the material yield strength.

Based on a review of the calculations, the staff finds that the results of the analyses for the lifting devices are acceptable.

The NRC staff determines that the application meets the regulatory requirements of 10 CFR 71.45(a).

2.5.2 Tie-Down Devices

The HI-STAR 180L package does not incorporate any structural feature that is used as a tie-down device. The NRC staff determines that the requirements of 10 CFR 71.45(b) are not applicable.

2.6 Normal Conditions of Transport

The applicant analyzed the HI-STAR 180L package using the ANSYS and LS-DYNA finite element (FE) analysis computer programs to demonstrate compliance with 10 CFR 71.71 regulatory requirements for NCT. The ANSYS FE program was used for static stress analysis and the LS-DYNA FE program was used for dynamic (impact and crush) analysis.

The applicant stated in Section 2.6 and Appendices 2.A and 2.B of the application that the LS-DYNA solutions were benchmarked with the results of the quarter-scale model tests during the licensing of HI-STAR 100, and the test data and the analytical correlation model provided the basis of NRC's certification of the HI-STAR 100 package (Docket No. 71-9261). In addition, as a result of the successful benchmarking of LS-DYNA, the Model Nos. HI-STAR 180, 60 and 180D were qualified using LS-DYNA, and certified by the NRC staff in Docket Nos. 71-9325, 71-9336 and 71-9367, respectively. The same model and approach have been used for the structural analyses of HI-STAR 180L.

The NRC staff reviewed the statements and concluded that the use of the ANSYS and LS-DYNA FE analysis computer programs to evaluate the HI-STAR 180L package under NCT is acceptable because: (i) the applicant previously demonstrated the capability of the ANSYS and LS-DYNA FE programs to validate the structural performance of the transportation package by comparison studies between the FE analytical solutions and the results of the model tests, (ii) those FE programs were previously used to analyze other transport package models (i.e., HI-STAR models 60, 100, 180 and 180D), which the NRC staff reviewed and accepted, and (iii) the staff found that the results of those FE analytical solutions met the requirements of 10 CFR 71.71, as described in the sections of this SER below.

2.6.1 Heat

The applicant performed thermal evaluations of the HI-STAR 180L package to demonstrate structural adequacy of the package design for the temperatures specified in 10 CFR 71.71(c)(1). The applicant provided detailed thermal evaluations and their results in Chapter 3 of the application. A brief summary of the thermal analysis was also provided in Subsection 2.6.1, as follows:

The applicant considered pressure and temperature to evaluate structural performance of the HI-STAR 180L package under NCT. Chapter 3 of the application presents the maximum normal operating pressure evaluation as well as the maximum component temperature evaluation for NCT. Tables 2.1.1 and 2.6.2 summarized values for pressures and temperatures (based on the thermal analysis in Chapter 3) that are used as inputs for the structural analyses of the HI-STAR 180L under NCT.

The applicant considered thermal dependent material properties of the package components to calculate the radial and longitudinal expansions of the cask and basket. Table 3.3.12 in Section 3.3 (Thermal Evaluation under NCT) provided the results of calculations for the radial and axial expansions prior to and after heat-up.
Using the ANSYS and LS-DYNA FE analysis computer programs, the applicant calculated stresses of the structural components of the HI-STAR 180L package under combined pressure and thermal loading conditions, as guided in RG 7.8. The applicant provided the results of the stress calculations in Subsection 2.6.1.3 of the application.

The applicant provided a comparison study between the calculated stress intensities and the material allowable limits for the NCT conditions in Tables 2.6.3 to 2.6.6. The comparison study shows that the calculated stress intensities are larger than the ASME Code allowable limits, indicating that HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.71(c)(1).

Based on the reviews and verifications on the results of the analyses, the staff determines that the application meets the regulatory requirements of 10 CFR 71.71(c)(1).

2.6.2 Cold

10 CFR Part 71.71(c)(2) requires that the package is subjected to a temperature of -40°F in still air and shade. The applicant performed a thermal evaluation for the HI-STAR 180L package under the cold NCT condition (-40ºF). With respect to internal pressure and allowable stresses, the applicant concluded that the internal pressure will decline with decreasing ambient temperature while the material allowable stresses will increase under the same condition.

The applicant stated that decreasing the load and increasing the available material strength would result in larger margins of safety in a cold condition than what would be expected in a hot condition. The applicant concluded that no further analysis is required with respect to the thermal expansion due to the cold NCT condition because (i) the restraint of free thermal expansion is less under cold condition, and (ii) material strength properties tend to be greater at lower temperatures, resulting in higher allowable stress limits.

The staff reviewed the thermal evaluation and subsequent conclusions made by the applicant and determines that the HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.71(c)(2).

2.6.3 Reduced External Pressure

10 CFR Part 71.71(c)(3) requires that the package is subjected to a reduced external pressure of 3.5 psia. The applicant stated that the effects of a reduced external pressure equal to 3.5 psia are bounded by results from the design internal pressure analysis for the cask. Therefore, no further analysis is required. The staff agrees with the statement because the package was designed with the internal pressure of 80 psig, and actual pressures during use are much less than this design pressure. Therefore, the effects of a reduced external pressure of 3.5 psia, which is a drop in pressure from the atmospheric pressure of 14.7 psia, is negligible. The NRC staff determines that the application meets the regulatory requirements of 10 CFR 71.71(c)(3).

2.6.4 Increased External Pressure

10 CFR Part 71.71(c)(4) requires that the package is subjected to an external pressure of 20 psia. The applicant stated that the effect of an external pressure of 20 psia is considered negligible for the HI-STAR 180L package. This conclusion was based on the NCT structural analyses presented in Section 2.6.7 of the SAR, where it demonstrated the structural integrity of the HI-STAR 180L transportation package under many different loading cases, which exceed the external pressure requirement (i.e., external pressure of 290 psia due to a head of water for a period of one hour). The staff agrees with the statement and determines that the application meets the regulatory requirements of 10 CFR 71.71(c)(4).

2.6.5 Vibration

The applicant stated that the effects of vibration are considered negligible for the HI-STAR 180L package. The applicant calculated the natural frequencies of the fuel basket and cask, and found that those frequencies exceeded the vibration frequencies expected during NCT by a significant margin. Thereby, the possibility of resonance and subsequent elevated stress conditions are not credible.

The staff reviewed the frequency and stress calculations, and found them both acceptable. The staff determines that the regulatory requirements of 10 CFR 71.71(c)(5) for normal vibration incidents during transportation are met.

2.6.6 Water Spray

10 CFR Part 71.71(c)(6) requires that the package must be subjected to a water spray test that simulates exposure to rainfall of approximately 2 in/h for at least 1 hour. The water spray test is primarily intended for packaging relying on material that absorbs water and/or are softened by water. The HI-STAR 180L packaging outer layer is designed to be fabricated entirely with steel materials. Thus, the water spray test is not applicable.

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

2.6.7 NCT Free Drop

The applicant evaluated the HI-STAR 180L package to meet the free drop requirements of 10 CFR 71.71 using the LS-DYNA FE analysis program. Two drop orientations (end and side drops) were considered in the analyses. The specified drop height was a 1-foot drop onto a flat, essentially unyielding horizontal surface.

2.6.7.1 Cask Stress Analysis

The applicant discussed its evaluations of the free drop of the cask under NCT in Subsection 2.6.1.3 of the application and presented the results of the FE analysis in Table 2.6.6. As shown in the table, the margin of safety is positive when compared with the allowable stresses. The staff reviewed the analysis and verified the analysis results.

2.6.7.2 Fuel Basket Stress Analysis

The applicant discussed evaluations of the free drop of the fuel basket under NCT in Subsection 2.6.1.3, and presented the results of the FE analysis in Table 2.6.7 of the application. As shown in the table, the calculated stresses are less than the ultimate strength of the material and the calculated deformation of the fuel basket is less than the allowable deformation. The NRC staff reviewed the analysis and verified the analysis results. Based on the reviews and verifications, the staff determined that the HI-STAR 180L package meets the regulatory requirements of 10 CFR 71.71(c)(7).

2.6.8 Corner Drop

The applicant stated that this condition is not applicable to the HI-STAR 180L package per 10 CFR 71.71(c)(8). The NRC staff agrees with the statement because 10 CFR 71.71(c)(8) requires this test for a fiberboard, wood, or fissile material rectangular packages not exceeding 110 lbs and a fiberboard, wood, or fissile material cylindrical packages not exceeding 220 lbs. Since the weight of the HI-STAR 180L package exceeds 220 lbs, a corner drop test is not required.

The staff determined that the corner drop analysis is not applicable to the HI-STAR 180L package, and the HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.71(c)(8).

2.6.9 Compression

The applicant stated that this condition is not applicable to the HI-STAR 180L package per 10 CFR 71.71(c)(9). The NRC staff agrees with the statement because 10 CFR 71.71(c)(9) only requires this test for a package weighing up to 11,000 lbs. Since the weight of the HI-STAR 180L package exceeds 11,000 lbs, a compression test is not required.

The staff determines that the compression test is not applicable to the HI-STAR 180L transportation package, and the HI-STAR 180L transportation package satisfies the regulatory requirements of 10 CFR 71.71(c)(9).

2.6.10 Penetration

The applicant stated that this condition is not applicable to the HI-STAR 180L package per RG 7.8.

The staff agrees with the statement because 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. Since the HI-STAR 180L cask is a large shipping cask and has no unprotected valves or rupture disks that could be affected by NCT, the penetration test is not required.

The staff finds that the applicant's statement is acceptable and determines that the HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.71(c)(10).

2.7 Hypothetical Accident Conditions

The applicant evaluated the HI-STAR 180L package for HAC of free drop, crush, puncture, thermal, and water immersion as required by 10 CFR 71.73. The applicant analyzed the HI-STAR 180L package using the ANSYS and LS-DYNA FE analysis computer programs to demonstrate the compliance of the 10 CFR 71.73 regulatory requirements for HAC. The applicant used the same FE model as was used for the NCT analyses. This analytical methodology is the same methodology that was previously used for the evaluation of the HI-STAR 180 package, which was reviewed and accepted by the staff (ADAMS Accession No. ML092890310).

2.7.1 Free Drop

10 CFR 71.73(c)(1) requires that a cask needs to be demonstrated for structural adequacy by a free drop through a distance of 30 feet onto a flat, unyielding, horizontal surface in a position for which maximum damage is expected. In order to determine the orientation that produces the maximum damage, the applicant evaluated the HI-STAR 180L for impact orientations in which the cask strikes the impact surface on its bottom end and side.

The applicant considered four drop configurations: (i) side drop ($\theta = 0°$), (ii) end drop ($\theta = 90°$), (iii) center of gravity over corner (CGOC) ($\theta = \theta_c$), and (iv) oblique drop (slapdown) ($90° > \theta > \theta_c$ and $0° < \theta < \theta_c$), where θ is defined as a drop event orientation angle of the HI-STAR 180L longitudinal axis with the impact surface and θ_c is an angle at the demarcation line between single and dual impact events.

Figures 2.7.1 to 2.7.4 of the application show four drop configurations used for the LS-DYNA drop analyses.

Tables 2.7.3 to 2.7.6 of the application provided the results of the stress analyses using the LS-DYNA FE program. Based on the results, the applicant made the following conclusions.

(i) for the dual impact scenarios (i.e. slapdown drop accident), the secondary impact is always more severe than the primary impact,

(ii) the primary stress intensities for the containment components are below the ASME NB limits for all drop configurations,

(iii) the closure lid bolts show no gross yielding and the gaskets remain under a compressed state at the conclusion of the event; therefore, continued bolted joint effectiveness in the wake of the 30-feet free drop event is assured,

(iv) the fuel basket does not undergo gross plastic deformation in the active fuel region, and the global average permanent deformation remains below the limit value established by the acceptance criteria in Section 2.1 of the application,

(v) there is no buckling of the containment components during any of the postulated HAC, and

(vi) impact limiters remain attached to the cask subsequent to the drop event.

The staff reviewed the modeling methodologies, results of the LS-DYNA dynamic analyses, and comparisons with allowable stresses, and determined that the HI-STAR 180L transportation package meets the regulatory requirements of 10 CFR 71.73(c)(1).

2.7.2 Crush

10 CFR Part 71.73(c)(2) requires a dynamic crush test by positioning the specimen on a flat, essentially unyielding horizontal surface, so as to suffer maximum damage by the drop of a 1,100 lb mass from 30 feet onto the specimen. However, the crush test is required only when the specimen has a mass not greater than 1,100 lbs and an overall density not greater than 62.4 lb/ft^3. The applicant stated that the crush test specified in 71.73(c)(2) is not required for the HI-STAR 180L since the weight of the HI-STAR 180L package exceeds 1,100 lbs. The staff verified that the HI-STAR 180L package weighs more than 1,100 lbs and overall density is greater than 62.4 lb/ft^3, and determined that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(2).

2.7.3 Puncture

10 CFR Part 71.73(c)(3) requires that a free drop of the specimen through a distance of 40 inches in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface. The bar must be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than 0.25 inch, and of a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar must be vertical.

The applicant evaluated the puncture performance of the HI-STAR 180L using the LS-DYNA FE analysis computer program. The same FE model that was used for the top-end drop was used for this puncture analysis. A mild steel bar, having the required dimensions, placed in the vertical orientation, and fixed to the ground, was added to the model.

Table 2.7.5 of the application provided a summary of the results from the LS-DYNA puncture analysis. Based on the results, the applicant made the following conclusions.

(i) the bolted joint maintains its integrity,

(ii) no thru-wall penetration of the containment boundary or dose blocker parts (shield cylinder) is indicated,

(iii) the stress levels in the closure lid, containment shell, and baseplate remain below their respective Level D condition limits,

(iv) the shield cylinder continues to maintain its shielding effectiveness (i.e., no thru-wall cracks), and

(v) the above results confirm the structural adequacy of the package under the “puncture” event of 10 CFR 71.73.

The staff reviewed the modeling methodologies and results of the LS-DYNA puncture analysis, and determined that the HI-STAR 180L package meets the regulatory requirements of 10 CFR 71.73(c)(3).

2.7.4 Thermal

10 CFR Part 71.73(c)(4) requires exposure of the package with an average flame temperature of at least 1,475°F for a period of 30 minutes.

The applicant performed thermal evaluations of the cask body under HAC and presented the evaluation findings in Chapter 3 of the application. The staff’s detailed safety evaluations on the applicant’s thermal evaluations are provided in this SER. The following evaluation is based on a brief summary of the applicant’s thermal evaluations provided in Subsection 2.7.4 of the application:

(i) differential thermal expansions under the limiting conditions of the fire event are evaluated in Subsection 3.4.4, and the analyses show that, under the fire condition, there is no restraint of free thermal expansion of the fuel basket,

(ii) the primary stress intensities in the containment boundary remain well below the ASME Level D (Faulted Condition) limits, and

(iii) the bolt stresses in the containment boundary joint, due to differential thermal expansion, rise but remain within the ASME Level D limits.

The staff reviewed the evaluations presented by the applicant and found the reasoning and conclusions credible. Additional detailed reviews and safety evaluations by the staff on the applicant’s thermal evaluations are provided in this SER. The staff determined that the HI-STAR 180L package meets the regulatory requirements of 10 CFR 71.73(c)(4).

2.7.5 Immersion – Fissile Material

10 CFR Part 71.73(c)(5) requires that for fissile material subject to 10 CFR Part 71.55, in those cases where water in-leakage has not been assumed for criticality analysis, it must be evaluated for immersion under a head of water of at least 3 feet in the attitude for which maximum leakage is expected.

The applicant stated that the HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.73(c)(5) because: (i) a head of water at a depth of 3 feet is equal to 1.3 psi, (ii) this head of water (1.3 psi) is bounded by the NAC and HAC external pressure for the cask (10 CFR 71.61), and (iii) the analyses demonstrated that the containment components meet the applicable stress allowables for NCT and HAC (both conditions impose pressures larger than 1.3 psi on the components). Therefore, the applicant concluded that there is no in-leakage of water into the cask under a head of water at a depth of 3 feet.

The staff reviewed the statement and found that there is a reasonable assurance that no water leaks into the cask under a head of water at a depth of 3 feet for the reasons delineated above. The staff determines that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(5).

2.7.6 Immersion – All Packages

10 CFR Part 71.73(c)(6) requires that a separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 50 feet (equivalent pressure of 21.7 psi) for a period of 8 hours. The applicant stated that the HI-STAR 180L package satisfies the regulatory requirements of 10 CFR 71.73(c)(6) because this external pressure condition is bounded by the analysis in Subsection 2.7.7 of the application. The staff finds the statement acceptable and provides an evaluation in Section 2.7.7 of this SER below. The NRC staff determines that the application satisfies the regulatory requirements of 10 CFR 71.73(c)(6).

2.7.7 Deep Water Immersion Test (for Type B package containing more than 10^5 A_2)

10 CFR 71.61 requires that a Type B package containing more than 10^5 A_2 must be designed so that its undamaged containment system can withstand an external water pressure of 290 psi for a period of not less than 1 hour without collapse, buckling, or in-leakage of water. The applicant used ASME Code Case N-284 to evaluate the buckling response due to deep immersion in water. The NRC staff agrees that this evaluation is adequate and that the requirements of 10 CFR 71.61 are satisfied with respect to stress limits and stability requirements.

As stated in Ch.1, “General Information,” Ch. 2, “Structural Evaluation,” Ch. 5, “Shielding Evaluation,” and Ch.6, “Criticality Evaluation” of the application, the design of the HI-STAR 180L package has been evaluated to ensure Moderator Exclusion by complying with ISG-19, “Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e).” The package design includes two closure lids with each lid being individually designated as a containment boundary. Both the inner and outer lid feature two concentric annular metallic seals each, thus providing a total of four independent barriers against leakage.

Each lid is independently bolted to the containment closure flange to provide added assurance in preventing water intrusion. The bolted joint in each lid has adequate structural strength to prevent unloading of any of the four seals in the most penalizing free drop orientation. Therefore, each of the four seals, which remains essentially intact during a free drop accident, individually provides containment isolation without the aid of the other three seals. In addition, each gasket-seating surface complies with the finish requirement of ANSI N14.5, "Radioactive Materials - Leakage Tests on Packages for Shipment," for leak-tightness level when the seal is properly loaded over it.

The NRC staff finds that the package containment space will remain inaccessible to the moderator under the immersion event of 10 CFR 71.73, which follows the free drop, puncture and fire events. The NRC staff considers that the package design ensures that in-leakage of water through the containment system boundary seals is a non-credible event. The staff finds that the double lid closure system with each bolted lid joint being engineered to meet the leak-tight criterion of ANSI N14.5 under all NCT and HAC conditions of transport, ensures moderator exclusion by complying with ISG-19. The staff has reasonable assurance that the package meets all acceptance criteria given in Section 2.1 of this SER above under the immersion condition.

The staff determines that the application satisfies the regulatory requirements of 10 CFR 71.61.

2.7.8 Summary of Damage

The applicant stated in Subsection 2.7.8 of the application that the results of the analyses reported in Subsections 2.7.1 through 2.7.7 of the SAR demonstrated that there were no structural damages to diminish the cask abilities for maintaining the containment boundary of the HI-STAR 180L package during HAC. Specifically, the applicant made the following assessments.

(i) the HI-STAR 180L containment space will safely withstand the HAC free drop, puncture and fire test performed in sequence and remain inaccessible to the moderator under the immersion event of 10 CFR 71.73, which follows free drop, puncture and fire, and

(ii) both lids will continue to maintain a positive contact load at their interfaces with the flange subsequent to the hypothetical accident event indicating that both primary and secondary lid gaskets will remain functional to contain the radioactive materials and as effective leakage barriers to moderator intrusion into the containment cavity.

The staff reviewed the evaluations and their results presented in Section 2.7.1 through 2.7.7 of the application and finds that the damage assessments by the applicant are acceptable. The staff determines that the application meets the regulatory requirements of 10 CFR 71.73.

2.8 Accident Conditions for Air Transport of Plutonium

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for air transport of plutonium and, therefore, does not address the accidents defined in 10 CFR 71.74.

2.9 Accident Conditions for Fissile Materials for Air Transport

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for air transport of fissile materials and, therefore, does not address the accidents defined in 10 CFR 71.55(f).

2.10 Special Form

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for transport of special form radioactive materials and, therefore, the requirements of 10 CFR 71.75 are not applied.

2.11 Fuel Rods

The applicant evaluated a fuel rod of the HI-STAR 180L package under the HAC free vertical drop. The methodology of this evaluation was based on: (i) the study conducted by Pacific Northwest National Laboratory (PNNL) and NRC (PNNL/NRC), "Spent Nuclear Fuel Structural Response When Subject to an End Impact Accident," and (ii) NUREG/CR-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage."

The applicant used the LS-DYNA FE analysis computer program for the structural analysis of the HI-STAR 180L with the following five steps:

(i) replicate the LS-DYNA model of a single fuel rod based on the detailed description provided in the PNNL/NRC study,

(ii) verify the accuracy of the LS-DYNA fuel rod model by simulating a vertical drop of a transport cask from a height of 30 feet above the target surface and compare the results with those from the PNNL/NRC study,

(iii) modify the mass and the dimensional properties of the fuel rod model to reflect the HI-STAR 180L design basis fuel,

(iv) simulate 30 feet vertical end drop of the HI-STAR 180L Package in LS-DYNA using the model developed from step (iii) above, and

(v) obtain the results and evaluate the strain ductility demand on the fuel cladding.

The staff reviewed the results in Figure 2.11.1 of the application and found that the applicant's model study from step (i) above was effective at reproducing results obtained from the PNNL/NRC study. This gives reasonable assurance that the principle structural behavior is being correctly modeled. The staff also reviewed the results in Figures 2.11.5 and 2.11.6 of the application and found that the applicant's model study illustrated that the strain ductility demand is below the acceptance criteria limit of 1.7 percent strain with a minimum factor of safety greater than 1.0 indicating that the HI-STAR 180L design basis fuel cladding is not vulnerable to failure (rupture or breach) under a 30 feet drop accident event.

2.12 Evaluation Findings

Based on a review of the statements and representations in the application, SAR, the staff concludes that the structural design has been adequately described and evaluated and that the HI-STAR 180L transportation package has adequate structural integrity to meet the structural requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

The objective of the review is to verify that the thermal performance of the Model No. HI-STAR 180L package has been adequately evaluated for the tests specified under both NCT and HAC, and that the package design satisfies the thermal requirements of 10 CFR Part 71.

3.1 Description of the Thermal Design

3.1.1 Packaging Design Features

The applicant described in Section 3.1.1 of the application the following thermal design features in order to provide adequate heat removal for the Model No. HI-STAR 180L package by passive mechanisms only:

- The Model No. HI-STAR 180L cavity is backfilled with helium for heat conduction which also provides an inert atmosphere to prevent spent fuel cladding oxidation and degradation.

- The F-69L basket for the transport of 69 BWR fuel assemblies is formed from the honeycomb structure of thick, conductive Metamic-HT plates. Heat is transferred in the peripheral spaces of the basket by contact heat transfer, helium conduction, thermal radiation across narrow gaps, and conduction through aluminum basket shims. The basket is also designed to minimize gaps which can introduce thermal resistance to heat transfer.

- The top and bottom plenums have interconnected downcomer paths to facilitate heat dissipation by internal helium circulation which occurs when the package is tilted a few degrees from horizontal orientation.

- On the outside surface of the package, heat is transferred to the environment by natural convection and thermal radiation. Inside the Model No. HI-STAR 180L cavity, heat transfer is conservatively limited to conduction and thermal radiation. While buoyance induced convection occurs within the open spaces of the Model No. HI-STAR 180L cavity, it is conservatively neglected.

3.1.2 Codes and Standards

The staff verified that established codes and standards for material properties and components (e.g. ASTM, ASME B&PV Code) are referenced by the applicant throughout the application.

3.1.3 Content Heat Load Specification

The staff verified the package decay heat and burnup limit for the fuel assemblies and quivers are specified in Table 7.D.1 of the application. Table 7.D.1 of the application specifies that the total heat load is limited to 35 kilowatts (kW), 8.75 kW per quadrant, and 0.5 kW per quiver for the F-69L basket. The maximum per assembly heat loads are shown in the basket heat loads (patterns A and B) in Figures 7.D.1 and 7.D.2 of the application.

Table 7.D.1 of the application also specifies equations for the per quadrant heat load to ensure that the heat load limit is not exceeded; the staff finds that these equations were consistent with Figures 7.D.1 and 7.D.2 of the application. Table 7.D.1 and Figures 7.D.1 and 7.D.2 of the application are included in Chapter 7 of the application, and Chapter 7 of the application is referenced in a condition of the Certificate of Compliance.

The applicant determined the bounding scenario for the decay heat distribution by considering the local and global heat load distribution and the orientation of panel gaps with respect to the heat load distribution. Based on the staff's review of the heat load scenario descriptions and the applicant provided temperature results in Table 3.3.4 of the application, the staff finds the bounding scenario for the decay heat distribution to be acceptable.

3.1.4 Summary Tables of Temperatures

The applicant provided the Model No. HI-STAR 180L NCT maximum temperatures in Table 3.1.1 of the application. The components include: fuel cladding, fuel basket, basket shim, containment shell, monolithic shield cylinder, neutron shield, lead, package surface, containment baseplate, containment top flange, bottom ring, inner closure lid, outer closure lid, inner closure lid seals, outer closure lid seals, and impact limiter type 1 and 2 crush material.

The staff confirmed that all of the components, excluding the package surface, in Table 3.1.1 of the application remain below the maximum allowable NCT temperature limits provided in Tables 3.2.10 through 3.2.12 of the application. The package surface temperature with the personnel barrier is evaluated in Section 3.4 of this SER.

The applicant provided the Model No. HI-STAR 180L HAC initial conditions maximum temperatures that the staff confirmed were consistent with the values provided in Table 3.1.1 of the application, the end of fire temperatures, and the maximum post-fire cooldown temperatures in Table 3.1.3 of the application. The components include: fuel cladding, fuel basket, basket shim, containment shell, monolithic shield cylinder, lead, containment baseplate, inner closure lid, outer closure lid, inner closure lid seals, and outer closure lid seals. The neutron shield and impact limiter crush material were not included in Table 3.1.3 of the application. This is because the neutron shield is assumed to be lost during the post-fire cooldown which the staff finds to be consistent with Section 5.1.4 of the application, and the structural integrity of the impact limiter crush material is not relied upon during or after the fire which the staff finds to be consistent with the order indicated of the tests specified in 10 CFR 71.73; therefore, the staff finds this to be acceptable. The staff confirmed that all components in Table 3.1.3 of the application remain below the maximum allowable HAC temperature limits provided in Tables 3.2.10 through 3.2.12 of the application.

The applicant described in Section 3.3.15 of the application and based on the staff's review of Section 3.3.15 of the application the staff accepts that the effect of gadolinium fuel rods on temperature is negligible.

The applicant described in Section 3.3.13 of the application that quivers are used to store damaged fuel rods in a helium backfill environment. The applicant concluded, based on the results provided in Table 3.3.11 of the application, that the peak cladding temperature with quivers loaded in the peripheral basket locations is bounded by the licensing basis evaluations in Tables 3.1.1 and 3.1.2 of the application.

The applicant concluded and the staff accepts that, based on the quiver thermal requirements provided in Table 3.3.13 of the application, there is reasonable assurance that the leaktight acceptance criteria that is required in Table 7.1.5 of the application is maintained.

3.1.5 Summary Tables of Pressures in the Containment System

The applicant provided the Model No. HI-STAR 180L maximum normal operating pressure (MNOP) for the package cavity and the inter-lid space in Table 3.1.2 of the application. The staff confirmed the pressures in Table 3.1.2 of the application were below the respective pressure limits in Table 2.1.1 of the application.

The applicant provided the Model No. HI-STAR 180L maximum hypothetical fire accident pressures for the package cavity and quivers internal pressure in Table 3.1.4 of the application. The staff confirmed the pressures in Table 3.1.4 of the application were below the respective pressure limits in Table 2.1.1 of the application for the package cavity and Table 2.2.14 of the application for the quivers.

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The applicant provided material thermal properties such as thermal conductivity, density, specific heat, and surface emissivity for the thermally modeled components of the package. The staff reviewed these properties and finds the properties to be acceptable.

3.2.2 Technical Specifications of Components

The applicant described in Table 3.2.12 of the application that the containment boundary metallic seals have a maximum temperature limit of 200°C (392°F) during NCT and that the seals will remain leak-tight for at least 50 years at temperatures less than 200°C (392 °F), which bounds the HAC maximum calculated seal temperatures in Table 3.1.3 of the application. The applicant also described that the package cold service temperature is -40°C (-40°F). The staff reviewed, and therefore, finds these component specifications to be acceptable.

3.2.3 Thermal Design Limits of Package Materials and Components

The Model No. HI-STAR 180L package materials and components are summarized in Chapter 2 and Chapter 3 of the application and these materials are required to be maintained below the maximum pressure and temperature limits. The staff verified that the maximum pressure and temperature limits of package materials and components, as provided by the applicant in Tables 2.1.1, and 3.2.10 through 3.2.12 of the application, are used consistently in the application. The staff reviewed and confirmed that the maximum allowable temperatures limits for components critical to the package containment, radiation shielding, and criticality are specified in Tables 3.2.10 through 3.2.12 of the application.

The staff verified that the spent fuel cladding temperature limits in Table 3.2.11 of the application are in compliance with the recommended limits specified in NUREG-1617 for moderate and high burnup spent fuel, as supplemented by Interim Staff Guidance (ISG) 11, Revision 3. Table 3.2.10 of the application describes the temperature limits that are evaluated in Chapter 2 of this SER; the staff finds these temperature limits to be acceptable.

3.3 General Considerations for Thermal Evaluations

3.3.1 Evaluation by Analyses

The applicant described the quarter-symmetric three-dimensional (3-D) thermal model of the Model No. HI-STAR 180L transportation package that was developed using the FLUENT computational fluid dynamics (CFD) code in Section 3.3.4 of the application. The transfer of heat from the spent fuel assemblies to the environment is through heat conduction from the spent fuel through the spent fuel basket, the helium gap, the aluminum shims, the containment shell, and the neutron shield.

The applicant also described in Section 3.3.2 of the application that heat rejection from the package surface to the ambient is modeled by external natural convection and thermal radiation heat transfer. The applicant described in Section 3.3.1 of the application that the spent fuel assembly is modeled using the effective thermal conductivity approach.

The applicant described in Section S.2 of the Holtec Report No. HI-2177931, "Thermal Evaluations of HI-STAR 180L in Transport," and in Table 3.3.12 of the application the engineered gaps in the thermal model.

The staff finds the overall analysis approach and assumptions acceptable because the description satisfies NUREG-1617.

3.3.2 Evaluation by Tests

The first fabricated Model No. HI-STAR 180L unit shall be thermally tested to confirm its heat transfer capability. However, a thermal test for a similar package design (i.e. Model No. HI-STAR 180 Docket No. 71-9325) may be used in lieu of thermal testing of the Model No. HI-STAR 180L along with an engineering evaluation of the Model No. HI-STAR 180L and the Model No. HI-STAR 180 that shall be documented and become part of the equipment documentation.

Section 8.1.7 of the application provides a basic description of the testing sequence and the condition for its acceptability. Based on the staff's review of Section 8.1.7 of the application, the staff finds this to be acceptable.

For each package, a periodic thermal performance test is also performed at least once within the 5 years prior to each shipment to demonstrate that the thermal capabilities of the package remain within its design basis. Section 8.2.4 of the application provides a basic description of the testing sequence and the condition for its acceptability. Based on the staff's review of Section 8.2.4 of the application, the staff finds this to be acceptable.

3.4 Evaluation of Accessible Surface Temperature

The applicant described in Section 3.1.5 of the application that, in still air and in the shade, the package surface is above the 85°C (185°F) limit specified in 10 CFR 71.43(g). Therefore, the applicant described the use of a personnel barrier, shown in Figure 1.3.2 of the application, that the applicant evaluated in Section 3.3.7.3 of the application.

The applicant demonstrated in Table 3.3.9 of the application that the package accessible surface temperature remains below the 85°C (185°F) limit specified in 10 CFR 71.43(g); therefore, the staff finds that 71.43(g) is met.

Section 7.1.3 of the application describes that surface temperatures of the accessible surfaces are measured to confirm that temperatures are within the 10 CFR 71.43 requirements if the personnel barrier is not used. Section 7.1.3 of the application also describes that a personnel barrier is optional if the package surface temperature and the dose rates without the personnel barrier are within 10 CFR 71.43 and 10 CFR 71.47 requirements, respectively.

3.5 Thermal Evaluation under NCT

The applicant performed the thermal evaluation using the FLUENT CFD code. Three-dimensional models were developed to analyze the F-69L spent fuel basket and various regionalized heat loading patterns, were experimented to establish a bounding configuration. Inside a spent fuel cell, the applicant replaced the detailed BWR spent fuel assembly with an equivalent square section characterized by an effective thermal conductivity in the planar and axial directions. The temperature dependent thermal conductivities are obtained using a two-dimensional conduction-radiation FLUENT thermal model.

The applicant described in Section 3.3.3 of the application, that the solar heat input is averaged over 24 hours rather than as is specified in 10 CFR 71.71(c)(1) for a 12-hour period. While this is not the same as the regulations in 10 CFR 71.71, the staff finds this to be acceptable for the Model No. HI-STAR 180L package because of its large size and thermal mass, and also because the applicant described a sensitivity study in the Model No. HI-STAR 180D application, (ADAMS Accession No. ML20108F186), a similar transportation package, and concluded the cyclic effect of insolation is small compared to 24-hour steady state insolation. The applicant used a solar absorption coefficient of 1.0 that is applied to the package exterior surface.

The Model No. HI-STAR 180L package 3-D thermal model includes several features to conservatively predict the maximum temperatures: e.g., a quarter-symmetric array of fuel storage cells, a uniform gap between the fuel rods in the basket cells, detailed 3-D components (i.e., neutron shield pockets, lids, base plates, impact limiters, etc.), no internal convection in the package cavity, and FLUENT discrete ordinate radiation model.

The applicant performed a grid convergence study to obtain the discretization error for the transport configuration. The discretization error is determined using the procedure specified in American Society of Mechanical Engineers, “Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer,” (ASME V&V 20-2009, November 30, 2009).

The staff finds the approach to perform the NCT evaluation acceptable because the developed thermal model is adequate to capture the heat transfer characteristics expected for this design.

3.5.1 Heat

Under a 38ºC (100°F) ambient temperature, still air, solar heat, maximum decay heat, and bounding heat load distribution, the applicant predicted the maximum temperatures of the fuel cladding, fuel basket, containment boundary and lid seals, aluminum basket shims, neutron shielding, and lead. These temperatures are listed in Table 3.1.1 of the application.

The staff confirmed that these maximum temperatures are below the material temperature limits with sufficient margin and finds the temperatures to be acceptable.

3.5.2 Cold

With no decay heat, no solar heat load, and an ambient temperature of -40°C (-40°F), the entire package uniformly approaches the steady-state ambient temperature. Package components, including the seals, are not adversely affected by exposure to cold temperatures.

The staff finds these arguments acceptable because the materials of construction are designed to operate at this low temperature.

3.5.3 Temperatures

See Section 3.1.4 of this safety evaluation report (SER).

3.5.4 Maximum Normal Operating Pressure

The MNOP is determined by different sources of gases, including initial backfill helium, water vapor, release of fission products, and spent fuel rod failures. Generation of flammable gas is not considered. Based on the heat condition, 38ºC (100°F), still air, and insolation specified in 10 CFR 71.71(c)(1) and the design heat load, the MNOP is 365.4 kPa (53 psia) for normal conditions and 379.2 kPa (55 psia) with 3% rod rupture.

The staff determined that MNOP is well below the containment design pressure of 552 kPa (94.7 psia), as reported in Table 2.1.1 of the application, and therefore is acceptable.

3.5.5 Thermal Stresses

The applicant evaluated the maximum thermal stresses in Section 3.3.12 of the application. The Model No. HI-STAR 180L uses high conductivity materials to minimize temperature gradients and large fit-up gaps to allow unrestrained thermal expansion of the package internals during NCT. The differential thermal expansion is evaluated in Section S.6.7 of the Holtec Report No. HI-2177931.

Basket-to-cavity radial and axial differential thermal expansions, quiver-to-basket radial expansion, and quiver-to-cavity axial expansion are evaluated based on the thermal expansion coefficients at the worst conditions. The evaluation results are presented in Table 3.3.12 of the application and include the quiver-to-basket radial expansion and quiver-to-cavity axial expansion. The methods presented are standard methods described in textbooks on the subject and the evaluation is done under the worst operating conditions.

The results show adequate margin to exclude any safety concern. The staff finds the evaluation methods acceptable because the description and analysis satisfy NUREG-1617.

3.6 Thermal Evaluation for Short Term Operations

3.6.1 Time-to-Boil Limits

The applicant determined time limits for completion of wet operations upon removal of a loaded Model No. HI-STAR 180L package from the pool to prevent water boiling inside the Model No. HI-STAR 180L cavity. The applicant described in Section 3.3.9 of the application an adiabatic heat up using the combined thermal inertia of the package; alternatively, a CFD method also described in Section 3.3.9 of the application could be used.

Table 3.3.6 of the application provides a summary of the maximum allowable time limits at several representative pool initial temperatures. Based on the staff’s review of Section 3.3.9 and Table 3.3.6 of the application, the staff finds the applicant’s approach for obtaining the time-to-boil limits acceptable for this package application.

3.6.2 Package Cavity Drying

The application describes two methods for drying the package cavity: a conventional vacuum drying approach for packages containing moderate burnup assemblies only, and forced helium dehydration (FHD) for packages with high burnup fuel. For the vacuum drying approach, drying is performed based on multiple vacuum drying cycles. The applicant provided the vacuum drying time limits in Table 3.3.15 of the application.

For cycle 1, the applicant obtained a maximum fuel cladding temperature of 370ºC (698ºF), under vacuum drying operations, which is below the ISG-11 limit with an adequate margin. The enhanced heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain well below the peak cladding temperature under NCT, which is itself below the high burnup cladding temperature limit of 400ºC (752ºF) for all loading combinations authorized in the package. Thus, the fuel cladding temperature will remain below the ISG-11 limits for high burnup fuel.

The staff reviewed the applicant's approach to perform the thermal evaluation of the Model No. HI-STAR 180L package short-term operations and finds it acceptable because it satisfies NUREG-1617.

3.6.3 Fuel Reconfiguration

As a defense-in-depth, the applicant performed a thermal analysis considering fuel reconfiguration during NCT based on the following assumptions:

(i) All heat producing fuel pellets from the ruptured rods (3% of total fuel rods) are uniformly deposited on the bottom surface of the inner closure lid.

(ii) The fuel region is modeled the same as the intact fuel under normal condition of transport with 97% of total heat load.

(iii) A steady-state thermal analysis is performed for the bounding scenario.

The results reported in Table 3.3.7 of the application show that all component temperatures are below their respective temperature limits. The cavity temperature and hence the cavity pressure during NCT remains unaffected due to fuel reconfiguration.

The staff reviewed the applicant's approach to perform the thermal evaluation of the Model No. HI-STAR 180L package short-term operations and finds it acceptable because it satisfies NUREG-1617.

3.7 Thermal Evaluation under HAC

The applicant performed the regulatory fire analysis using a 3-D FLUENT model of the limiting F-69L basket thermal loading in two stages: a 30-minute engulfing fire and a post-fire cooldown. The accident scenario considers the cumulative damage from the drop test and penetration test. Localized crushing of the impact limiter and rupture of neutron shield pockets are considered by maximizing the heat input during the fire and minimizing the heat rejection in the post-fire analysis.

To maximize the fire heat input, the neutron shield conductivity is overstated, and the impact limiter conductivity is assumed to be undegraded aluminum honeycomb material. To minimize the heat rejection during the post fire cooldown, the neutron shield is replaced by air and surface emissivity of bare carbon steel is assumed.

The staff finds the thermal evaluation under HAC to be acceptable because the description and analysis satisfy NUREG-1617.

3.7.1 Initial Conditions

The initial conditions of the package, prior to the start of the fire accident are 38ºC (100°F) ambient temperature, in still air, with insolation, that the staff confirmed is prescribed in 10 CFR 71.71(c)(1). The applicant used the Model No. HI-STAR 180L steady-state temperature distribution evaluated in Section 3.1.3 of the application as the initial conditions for the fire accident evaluation. The staff finds the initial conditions acceptable because the description satisfies NUREG-1617.

3.7.2 Fire Test

The applicant performed a transient thermal analysis to evaluate the package under hypothetical accident conditions. During the fire, the applicant evaluated the package at 802ºC (1475ºF) for 30 minutes using the limiting decay heat scenario described in Section 3.3.5 of the application.

The applicant described that during the fire, the surface emissivity of the package is assumed to be 0.9, the staff confirmed that value is prescribed in 10 CFR 71.73(c)(4) and the surface absorptivity of the package is assumed to be 1, which the staff confirmed bounds the value that is prescribed in 10 CFR 71.73(c)(4).

The analysis simulates the engulfing fire by prescribing a combination of radiation and convection heat transfer on the package surface. The Sandia National Laboratory fire experiment convection heat transfer coefficient is adopted for the calculation from the Sandia Report SAND85 – 0196 TTC – 0659 UC 71, August 1971, “Thermal Measurements in a Series of Large Pool Fires,” which the staff finds to be consistent with the guidance in NUREG-1617.

After the 30-minute fire, the 38ºC (100°F) ambient temperature is restored and the damaged package is allowed to proceed through a post-fire cooldown phase. In the post-fire cooldown phase, no credit is taken for conduction through the Holtite neutron shield and a solid air zone is substituted instead.

The applicant used the ending condition of the 30-minute fire analysis as initial condition for the post-fire cooldown that is of sufficient duration to allow the package and its contents to reach maximum temperatures. The staff finds the fire test conditions to be acceptable because the description satisfies NUREG-1617.

3.7.3 Maximum Temperatures and Pressure

The maximum temperatures calculated by the applicant are listed in Table 3.1.3 of the application. The accident temperatures in the table reflect the peak temperature of a specified component from the time the fire was extinguished to the time the package reached steady-state conditions. For both normal and accident conditions, the inner cavity was assumed to be filled with helium.

Under normal conditions, all of the materials remain below their respective melting temperatures. The staff confirmed that all components in Table 3.1.3 of the application remain below the maximum allowable HAC temperature limits provided in Tables 3.2.10 through 3.2.12 of the application. Based on the applicant's analysis and staff's review, the staff concludes that the cladding integrity will not be compromised during the fire or post-fire cooldown.

The applicant calculated the maximum containment pressure during HAC assuming that 100% of the fuel rods fail, and all rod fill gas along with 30% of the gaseous fission products are available for release. The lower bound cavity free volume and the maximum initial fill pressure were also used. The maximum containment pressure under HAC is 859.8 kPa (124.7 psia), based on the average cavity gas temperature of 291ºC (556 °F). The maximum containment pressure is lower than the pressure limit listed in Table 2.1.1 of the application and therefore, the staff finds this to be acceptable.

3.7.4 Maximum Thermal Stresses

The Model No. HI-STAR 180L package is designed to ensure a low state of thermal stress with high conductivity materials to minimize temperature gradient and large fit-up gaps to allow unrestrained thermal expansion of package internals.

The differential thermal expansion analysis of the basket during NCT bounds the HAC fire condition because the thermal effect on the basket is isolated by the outer package and more expansion is expected in the outer package. Therefore, the gap is expected to be larger in the fire analysis. The staff reviewed and accepted this argument because more expansion is expected on the outer package which is in direct contact with the fire.

3.7.5 Fuel Reconfiguration

The applicant provided the package component temperatures for the postulated fuel reconfiguration post hypothetical accident drop and during fire in Table 3.4.4 of the application. The results show that the containment boundary components including seals are well below their temperature limit. Since the bulk cavity temperature remains unchanged, the containment pressure is also below the allowable limit. The staff finds the applicant's defense-in-depth analysis of HAC to be acceptable because it satisfies NUREG-1617.

3.8 Evaluation Findings

The staff reviewed the package description and evaluation and concludes that they satisfy the thermal requirements of 10 CFR Part 71.

The staff has reviewed the material properties and component specifications used in the thermal evaluation and concludes that they are described in sufficient detail to permit an independent review of the package thermal design.

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

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

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

4.0 CONTAINMENT EVALUATION

The focus of this review is to ensure that the containment system for the Model No. HI-STAR 180L meets the regulatory requirements for containment performance in 10 CFR Part 71 and complies with the standards in ANSI N14.5, 2014 [Radioactive Materials - Leakage Tests on Packages for Shipment] as far as the applicant has committed to implement those standards.

The system materials of construction, welding joint details, NDE requirements, seal joint type, and Code of construction for the HI-STAR 180L packaging, are identical or similar to those of the HI-STAR 180 packaging. In addition, the double closure lid system of the HI-STAR 180L is identical to the double closure lid system of HI-STAR 180.

4.1 Description of the Containment System

The HI-STAR 180L containment system is comprised of the containment shell, base plate, and closure flange, the inner closure lid, the outer closure lid, inner and outer closure lid bolts, the inner closure lid port covers, the outer closure lid access port plug and their respective metallic seals and welds. The containment boundary and the containment system components are depicted in the drawings in Figure 4.1.1 of the application.

The discussion in Section 4.1 of the application states that the system was fabricated in accordance with the requirements of the ASME Code, Section III, Subsection NB. The applicant states that the containment system boundary, including both closure lids, is designed and manufactured to ASME Section III Division 1, Subsection NB. In addition, the HI-STAR 180L package is engineered to meet the leak-tight criterion of ANSI N14.5-2014 (where the leakage rate is no greater than $1x10^{-7}$ ref-cm^3/s of air with a test sensitivity of $5x10^{-8}$ ref-cm^3/s of air) for both normal conditions of transport and accident conditions of transport.

Section 2.1 of the application provides applicable code requirements and exceptions to specific code requirements with the necessary justifications presented in Table 8.1.8. Based on staff's review of the design of the containment vessel, the design of the containment vessel, containment boundary and code requirements meet the requirements of 10 CFR Part 71.33 and 10 CFR 71.31(c).

4.1.1 Containment Vessel

The containment vessel forms the inner containment space and an expanded containment inter-lid space. The applicant stated that the containment vessel is represented by the containment shell, containment base plate, containment closure flange, and inner and outer closure lids. The materials of construction for the containment vessel are specified in the drawing package provided in Section 1.3 of the application (specifically Drawing No. 10942). Based on staff's review of the design of the components of the containment vessel, the design of the containment vessel meets the requirements of 10 CFR Part 71.33.

4.1.2 Containment Penetrations

The containment penetrations include the inner closure lid vent and drain ports, and the outer lid access port. The applicant states that each penetration has redundant metallic seals designed and tested to ensure that radionuclide release rate limits specified in 10 CFR 71.51 are not exceeded.

Based on the staff's review of the design of the containment penetrations, the description of the containment penetrations meets the requirements of 10 CFR Part 71.33.

4.1.3 Seals and Welds

The package uses a combination of seals and welds that were designed and tested to provide containment during normal conditions and hypothetical accident conditions of transport. These penetrations include the inner closure lid vent and drain ports and the outer lid access port. The applicant stated, in Section 4.1.2 of the application, that each penetration has redundant metallic seals and are designed and tested to ensure that the radionuclide release rates specified in 10 CFR 71.51 are not exceeded.

The applicant provided a discussion of the containment system seals. These seals were designed and fabricated to meet the design requirements highlighted in Section 2.1.2 of the application. The seal and lid closure details are within the drawings in Section 1.3, Drawing No. 10942 and Appendix 8.A of the application.

The application states that the inner closure lid uses two concentric metallic seals to form the closure with the containment closure flange surface. For the inner closure lid, the inner seal is the containment seal. A stainless-steel weld overlay is provided during manufacturing on both the inner closure lid and the mating containment closure flange to protect the sealing surfaces against corrosion.

The application states that the cask outer closure lid uses two concentric metallic seals to form the closure with the containment closure flange surface. In the outer closure lid, the inner seal is the containment seal. To protect the sealing surfaces against corrosion, a stainless-steel weld overlay is provided during manufacturing on both the outer closure lid and mating containment closure flange. In the outer closure lid, the containment boundary seal is tested for leakage through an inter-seal test port.

In Section 4.1.3.2, the applicant provides a description of the containment welds. The applicant states that the cask containment system welds consist of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment closure flange, and the full penetration weld connecting the containment base plate to the containment shell. All containment system boundary welds are fabricated and inspected in accordance with ASME Code Section III, Subsection NB. The weld details and examinations are shown in the drawing package in Section 1.3 of the application.

All containment boundary welds are full penetration bevel or groove welds to ensure structural and containment integrity. The full penetration welds are designed per ASME, Section III, Subsection NB and are fully examined by radiography (RT) or ultrasonic (UT) methods in accordance with Subsection NB. A liquid penetration (PT) examination is also performed on the containment welds.

Based on staff review of the design of the containment penetrations in the application, the design of the seals and welds meet the requirements of 10 CFR Part 71.43(c).

4.1.4 Closure Lids

In Section 4.1.4 of the application, the applicant provided a discussion of the closure lids for the 180L package. The package inner and outer closure lids are secured using multiple closure bolts around the perimeters of the lids. The individual closure lid seals (inner and outer) are formed through the torqueing of the closure lid bolts that compresses the concentric metallic seals between the closure lids and the containment closure flanges. The applicant continued by discussing the closure of the inner closure lid vent and drain port cover plates.

The application stated that both the inner closure lid vent and drain port cover plates are closed by using multiple port cover plate closure bolts around the perimeter. Torqueing of cover plate closure bolts compresses the concentric metallic seals between the port covers (for the vent and drain ports) and the respective port flanges in the closure lid to ensure an adequate seal.

Closure of the outer closure lid access port is provided by a single threaded plug and seal installed in the penetration. Torqueing of outer closure lid access port plug compresses the metallic seal between the outer closure lid access port plug and the outer closure lid to form the port seal. The access port cover plate, containing a single metallic seal, is installed with multiple perimeter port cover closure bolts.

Bolt torqueing patterns, lubrication requirements, and torque values are provided in Table 7.1.1. The torque values are established to maintain leak-tight containment during normal and accident conditions of transport. Torque values for the inner and outer closure lid bolts preclude separation of the closure lids from the containment closure flange as clarified in Chapter 2 (Section 2.6.1.3.2). The closure lid bolts cannot be opened unintentionally or by a pressure that may arise within the package, as demonstrated by the evaluations provided by the applicant in Section 2.7 of the application.

Based on the staff's review of the design of the closure lids in the application and that the double closure lid system of the HI-STAR 180L is identical to the double closure lid system of HI-STAR 180, Revision 3 (see ML20122A228), the design of the seals and welds meet the requirements of 10 CFR Part 71.33.

4.1.5 Moderator Exclusion Features for High Burnup Fuel

The HI-STAR 180L packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF). To address concerns with the structural integrity of HBF under accident conditions and its potential impact on criticality safety, the HI-STAR 180L is designed to provide water exclusion under a postulated 71.73 accident scenario.

The approach for moderator exclusion in the HI-STAR 180L is through package design (double closure lid and containment boundary integrity analysis). Details of the design measures and technical confirmation to meet the intent and performance objectives of ISG-19 [Moderator Exclusion Under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent

Fuel Under the Requirements of 10 CFR 71.55(e)] are described in Appendix 1.A of the application, where additional defense-in-depth measures to ensure sub-criticality compliance are also discussed. The overall licensing approach on HBF is summarized in Section 1.2 of the application.

Based on the review of the design for the moderator exclusion features for high burnup fuel in the application and the fact that it uses the features from the HI-STAR 180 (see ML20122A228), the requirements of 10 CFR 71.55 and 10 CFR 71.59 for moderator exclusion are met for the 180L package.

4.2 Containment under Normal Conditions of Transport

The HI-STAR 180L has been designed to meet the criteria of containment given in 10 CFR 71.71 for NCT, specifically to meet the criteria specified in 71.51(a)(1) for release of radionuclides. Section 2.6 shows that all containment system components are maintained within their code-allowable stress limits and the metallic seals remain sufficiently compressed during all normal conditions of transport to preclude any release of radionuclides in excess of what is allowed by 71.51(a)(1).

Section 3.1 of the application demonstrates that all containment system components are maintained within the allowable temperature and pressure limits for all normal conditions of transport. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (see Table 8.1.1 of the application) will not be exceeded during normal conditions of transport.

The seal temperature limit for NCT is revised from 371ºC to 200 ºC. The applicant provided, and staff reviewed, additional information from the seal manufacturer that demonstrated the physical characteristics of the seal were appropriate for the intended application during transportation.

The applicant stated that the MNOP is 89.6 kPa with a 3% rod rupture. This is lower than the design internal pressure for the cavity space of 552 kPa.

In Table 3.1.2 of the application, the applicant demonstrated that the pressure in the inter-lid space is 163.4 kPa absolute, which is equal to the cask inter-lid space maximum operating pressure of 62 kPa gauge.

The applicant reported, in Table 3.1.4 of the application, that the maximum cavity accident pressure, with assumed 100 percent fuel rod rupture, is 883.7 kPa absolute, which bounds the inter-lid pressure and is lower than the accident condition internal pressure (design pressure limit) of 963.3 kPa absolute.

The applicant determined the MNOP of 16.9 psig for NCT based on the maximum head load of 3 kW and the maximum burnup of 70 GWD/MTU. The staff reviewed Sections 2.6.1 and 3.1.4 of the application and verified that the MNOP of 16.9 psig is below the test pressure of 30 psig considered for the structural evaluation under NCT.

Regarding the containment criteria, the allowable leakage rate criteria and types of tests specified are provided in Tables 8.1.1 and 8.1.2 of the application, based on the analysis given by the applicant, thus the radionuclide release rates in 10 CFR 71.51(a)(1) will not be exceeded during NCT. The HI-STAR 180L cask is engineered to be leak-tight in accordance with ANSI N14.5-2014.

The applicant also proposed to revise the conversion factor from air reference conditions to helium reference conditions from a factor of 2 to a factor of 1.85 to be consistent with ANSI N14.5-2014. The staff verified that multiplying the leakage rate acceptance criterion and leakage rate test sensitivity when using air as a tracer gas by a factor of 1.85 when using helium as a tracer gas is acceptable.

The sensitivity for the leakage test instrument shall be equal to ½ of the allowable leakage rate in accordance with ANSI N14.5 (8.1.6), which is provided in Table 8.1.1 of the application.

Based on review of the description for containment under normal conditions of transport in the application, the design for the containment system of the 180L meets the containment requirements in 10 CFR 71.71 for normal conditions of transport.

4.3 Containment under Hypothetical Accident Conditions of Transport

The HI-STAR 180L has been designed to meet the criteria of containment given in 10 CFR 71.73 for HAC, which states that the radionuclide release rates in 10 CFR 71.51(a)(2) would not be exceeded. The analysis presented in Section 2.7 of the application demonstrates that all inner containment system components are maintained within their code-allowable stress limits during HAC tests. Section 3.1 demonstrates that all inner containment system components are maintained within their peak temperature and pressure limits during HAC thermal tests.

The applicant determined the maximum pressure of 90.9 psig for HAC based on the maximum head load of 3 kW and the maximum burnup of 70 GWD/MTU. The staff reviewed Sections 2.7.4 and 3.1.4 of the application and verified that the maximum pressure of 90.9 psig is bounded by the test pressure of 120 psig considered for the structural evaluation under HAC.

In Section 4.3. of the application, the applicant states that this package is leak-tight per the definition provided in ANSI N 14.5. Regarding the containment criteria, the allowable leakage rate criteria (as defined by ANSI N14.5) and types of tests specified are provided in Tables 8.1.1 and 8.1.2. The applicant stated, in Section 4.3.1 of the application, that no containment analyses were performed for HAC as the radionuclide release rates in 10 CFR 71.51(a)(2) will not be exceeded during HAC due to the structural and thermal performance of the containment boundary components.

Based on the review of the description for containment under hypothetical accident conditions of transport in the SAR, the design of the containment system of the 180L meets the containment requirements in 10 CFR 71.73 for hypothetical accident conditions of transport.

4.4 Leakage Rate Tests for Type B Packages

In Section 4.4 of the SAR, the applicant stated that all leakage rate testing of the cask containment system shall be performed in accordance with the guidance in ANSI N14.5. Table 8.1.2 of the SAR provides the containment system components to be tested and prescribes the types of leakage tests to be performed for post-fabrication, pre-shipment, periodic, and maintenance of the package.

In Section 4.4.1, the applicant discusses the fabrication leakage rate test. This portion of the SAR stated that the containment system, as fabricated, provides the required level of containment. The fabrication leakage test, performed on the HI-STAR 180L package at the fabrication facility, will ensure that the welded enclosure vessel, as fabricated, will perform its containment function.

The requirements for the pre-shipment leakage rate test are specified in Section 4.4.2 of the application. The application stated that this test demonstrates that the containment system closure has been properly performed. The initial pre-shipment leakage rate test is performed by the user before shipment, after the contents are loaded and the containment system is assembled. The pre-shipment leakage rate test remains valid for 1 year.

The requirements for the periodic leakage rate test are specified in Section 4.4.3 of the application. The application stated that the periodic leakage rate test demonstrates that the containment system closure capabilities have not deteriorated over time. This test is only required if the most current leakage rate test occurred more than twelve months prior to package transport. Periodic leakage rate testing is performed by the user before each shipment if the previous leakage rate test has expired. The periodic leakage rate test remains valid for 1 year.

The requirements for the maintenance leakage rate test are specified in Section 4.4.4. The application stated that the maintenance leakage rate test demonstrates that the containment system provides the required level of containment after undergoing maintenance, repair, and or containment component replacement and shall be performed prior to returning a package to service.

Based on reviewing the description for the leakage rate tests for Type B packages in the application, the proposed leakage tests for the 180L transportation system meet the test standards found in ANSI N14.5, which the applicant has committed to follow.

4.5 Evaluation Findings

The staff has reviewed the applicant’s evaluation of the containment system of the 180L under normal conditions of transport and concludes that the package is designed, constructed, and prepared for shipment such that under the tests specified in 10 CFR 71.71, “Normal Conditions of Transport,” the package satisfies the containment requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a)(1) for normal conditions of transport with no dependence on filters or a mechanical cooling system.

The staff has reviewed the applicant’s description and evaluated the containment system based on the necessary codes and standards. Staff finds that the description satisfies the containment requirements for codes and standards found in 10 CFR 71.31(c).

The staff has reviewed the applicant’s description and evaluated the description regarding the containment system being securely closed. Staff finds that the description satisfies the requirements for a containment being securely closed found in 10 CFR 71.43(c).

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

Based on the review of the statements and representations in the application, the staff concludes that the containment design for the HI-STAR 180L 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 objective of the shielding review is to ensure that there is adequate protection to the public and occupational workers against direct radiation from the contents of the HI-STAR 180L transportation package, and to verify that the package design meets the external radiation requirements of 10 CFR 71.47 and 10 CFR 71.51 under NCT and HAC.

5.1 Description of the shielding design

5.1.1 Shielding Design Features

The principal design features of the HI-STAR 180L packaging with respect to radiation shielding are the fuel basket and basket support structures, the cask lids, the cask body, and the central steel structures of the impact limiters. The fuel basket and the basket support maintain the fuel assemblies in a fixed position within the package, and provide additional gamma shielding. Any shielding effect of the crushable impact limiter material and its surrounding steel skin is neglected for both normal and accident conditions. Neutron shielding is provided by the Holtite neutron absorber. The dimensions of the shielding components are shown in the drawing package in Section 1.3 of the application. The shielding material densities are listed in Table 5.3.2 of the application.

5.1.2 Summary of Maximum Radiation Levels

Different loading patterns were analyzed: the applicant specified how it determined the bounding loading pattern in Appendix 7.D of the application. The applicant independently analyzed each pattern to verify that the calculated dose rates were less than the regulatory limits. The applicant presented the bounding loading patterns that result in the highest dose rates at the surface and 2 m under NCT, and at 1 m under HAC in subsection 5.3.3. Dose rates for additional configurations are presented in Section 5.4 of the application.

5.2.2 Summary of Maximum Radiation Levels

The applicant provided a summary of the maximum dose rates in Tables 5.1.1 to 5.1.4 of the application for the package under NCT and HAC. The applicant's maximum calculated dose rate on the surface of the package loaded with the F-69L fuel basket is 107.87 mrem/hr under NCT. This dose rate shows the package shielding design meets the regulatory requirements of 10 CFR 71.47(b) and 71.51(a)(1) which is 200 mrem/hr under NCT.

The applicant's maximum calculated dose rate at 2 meters from the package with the F-69L fuel basket is 8.8 mrem/hr under NCT. This dose rate shows the package shielding design meets the regulatory requirements of 10 CFR 71.47(b)(3) which is 10 mrem/hr under NCT.

The applicant's maximum calculated dose rate with uncertainty in the vehicle cab for the package with the F-69L fuel basket is 1.52 mrem/hr under NCT. This dose rate shows the package shielding design meets the regulatory requirements of 10 CFR 71.47(b)(4) which is 2 mrem/hr under NCT.

For the package under HAC, the applicant's maximum calculated dose rate at 1 meter from the surface of the damaged package loaded with the F-69L fuel basket is 888.77 mrem/hr. This dose rate shows demonstrated that the package shielding design meets the regulatory requirements of 10 CFR 71.51(a)(2) which is 1000 mrem/hr under HAC.

The staff reviewed the dose rates presented in these tables and finds that the applicant has correctly identified the location of the maximum dose rates for the package under NCT and HAC pursuant to the regulatory requirements of 10 CFR 71.47 and 71.51.

5.2 Source specification

The applicant used TRITON and ORIGAMI modules of SCALE 6.2.1 to calculate neutron and gamma source terms. In performing the TRITON and ORIGAMI calculations, the applicant used a single full power cycle to achieve the desired burnup. Staff finds this acceptable because when using a single power cycle, no discharges between cycles are assumed resulting in the final burnup values being conservative. The assemblies to be qualified for transportation in the HI-STAR 180L contains BWR UO_2 assemblies.

The applicant provided a description of the design basis fuel assemblies for the source term calculations in Table 5.2.1 of the application. The steel and Inconel hardware masses for the design basis BWR assembly are listed in Table 5.2.2 of the SAR. The applicant determined the 8x8L2 fuel assembly to be the bounding fuel assembly based on a comparison of total fuel mass and/or fuel mass per unit length of the active region.

The applicant calculated the source terms in a two-step process.

> The first step is the TRITON calculation, which established appropriate cross section libraries for the subsequent ORIGAMI depletion calculations. SCALE 6.2.1 contains many predetermined TRITON libraries for different fuel types and conditions. In order to make sure that the libraries match the specifications of the fuel qualified here, including the specific operating conditions, the applicant generated all relevant cases in TRITON, and none of the predetermined libraries were used. Staff finds the applicant's use of these libraries acceptable because using the predetermined library may not reflect the actual operating conditions for the fuel types qualified for transport.
>
> The second step is a series of depletion calculations the applicant performed with ORIGAMI. In the applicant's source terms analysis, the active region of the fuel assemblies is divided into 25 axial sections in order to allow an appropriate modeling of the axial burnup distribution and an axial void distribution during depletion. ORIGAMI allows the specification of the axial burnup profile and the axial void profile, and together with the input of the specific fuel and depletion parameters, and the applicable TRITON library, it then generates source terms and material properties separately for each axial section, in a single ORIGAMI run.

Staff finds the applicant's depletion calculation acceptable because ORIGAMI produces files containing SCALE and MCNP composition input for material in the burnup distribution, and energy-dependent radioactive source for use in shielding calculations.

Appendix 7.D of the application specifies the burnup, cooling time and enrichment configurations for spent nuclear fuel that were analyzed for transport in the HI-STAR 180L.

Staff reviewed these and finds them acceptable based on the information provided by the applicant and by staff's confirmatory calculations.

5.2.1 Gamma Source

As mentioned above, the applicant used TRITON and ORIGAMI modules of SCALE 6.2.1 to calculate neutron and gamma source terms. The applicant provided gamma sources in MeV/s and photons/s for a subset of burnup and cooling time configurations from Appendix 7.D in Table 5.2.3 of the application.

The applicant included photons with energies in the range of 0.45 to 3.0 MeV in the shielding calculations. The applicant stated that photons with energies below 0.45 MeV are too weak to penetrate the steel of the cask, and photons with energies above 3.0 MeV are too few to contribute significantly to the external dose. According to NUREG/CR-1716, "In general, only gammas from approximately 0.8 MeV-2.5 MeV will contribute significantly to the external radiation levels."

However, the applicant included photons with energy below 0.8 MeV based on a previous application (HI-STAR 180), which is like this package. Based on the previous application, the applicant found that photons with energies below 0.45 MeV are too weak to penetrate the steel of the cask, and photons with energies above 3.0 MeV are too few to contribute significantly to the external dose.

For Co-60, the primary source of Co-59 in a fuel assembly is the impurities in the steel structural material above and below the fuel. The applicant provided the steel and inconel masses of the design basis fuel assembly outside the active fuel zone in Table 5.2.2 of the application. The applicant used ORIGAMI to calculate a Co-60 activity level for the desired burnup and decay time.

The applicant used the in-core fuel region flux at full power in the calculation because it is a conservative approach since the flux can vary its power resulting in less burnup. Then, the applicant modified the calculated activity by the appropriate scaling factors listed in Table 5.2.4 of the Application. Table 5.2.5 of the application provides the Co-60 activity the applicant utilized in its shielding calculations.

5.2.2 Neutron Source

For the neutron source terms, the applicant used minimum enrichment. Staff finds this approach acceptable since the neutron source strength for a UO_2 assembly increases as enrichment decreases at a constant burnup and decay time.

The applicant selected the minimum enrichment for each fuel burnup listed in appendix 7.D of the application and this was used to develop the source terms.

The applicant provided its calculated neutron source in neutrons/s for selected burnup, enrichment, and cooling time configurations in Table 5.2.6 of the application.

5.3 Model specification

5.3.1 Configuration of Source and Shielding

The applicant performed its shielding analysis of the HI-STAR 180L with MCNP5, Version 1.51. The applicant included the neutron shield and parts of the impact limiter in place in its MCNP model of the HI-STAR 180L Package under NCT. Credit was taken for the outer dimensions of the impact limiters under NCT. For (n,γ) reactions in the material of the HI-STAR 180L cask, the applicant stated that this source of photons is properly accounted for in MCNP when a neutron calculation was performed in a coupled neutron-gamma mode.

Staff finds this acceptable because Monte Carlo transport code offers a full three-dimensional combinatorial geometry modeling capability including complex surfaces, such as cones and tori. This means that no gross approximations were required to represent the HI-STAR 180L in the shielding analysis. The applicant replaces the neutron shield with a void and removes the impact limiters from its MCNP model under HAC.

Staff finds this acceptable because replacing the neutron shield with a void and removing the impact limiters from its MCNP model under HAC makes the model conservative since it is expected that those parts remain in place under HAC.

The applicant used a mesh tally on dose locations to ensure that the maximum dose rate was identified. Staff reviewed the applicant's grid and finds it was a sufficiently fine grid mesh to determine the area of highest dose. The applicant identified the areas of highest combined dose calculated for each pattern in Figures 5.1.1 and 5.1.2 of the application.

5.3.1.1 Shielding Configuration

The applicant used the drawings presented in Section 1.3 of the application to create the MCNP models used in the radiation transport calculations. The package drawings also illustrate the HI-STAR 180L on a typical transport vehicle with a personnel barrier installed. However, the applicant did not consider the vehicle and barrier in the MCNP model. Instead, the applicant assumed that the outer dimensions of the vehicle were to be identical to the outer dimensions of the package as modeled for normal conditions.

Staff finds this acceptable because the calculated dose rates on the surface of the cask are below 200 mrem/hr. Therefore, dose rates at any point on the outer surface of the vehicle will also be below 2 mSv/h. The HI-STAR 180L therefore complies with 10 CFR 71.47(b)(2).

The applicant included tolerances for selected dimensions in the drawings in Section 1.3 of the application. The applicant reduced dimensions where the effect of the tolerances would have a significant effect of dose rates to a minimum value, with a special focus on those dose rates with smaller margins to the regulatory limits. The staff found this approach acceptable since minimum dimensions will result in conservative calculated dose rates.

Under the NCT tests prescribed in 10 CFR 71.71, the applicant showed the package does not experience any damages that significantly affect the shielding of the package, and therefore the applicant did not make any additional considerations to the shielding model under NCT to account for these tests. Any deformities to the impact limiter due to the tests in 10 CFR 71.71 are inconsequential.

Under HAC, as discussed in Section 5.1.4 of the application, the applicant assumed the neutron shield is destroyed and replaced by a void in its shielding analysis under HAC. Also, the applicant omitted the impact limiters in its HAC model. Staff finds these assumptions acceptable because some portion of the neutron shield would be expected to remain after the fire, and the impact limiters were shown through the calculations in Chapter 2 to remain attached following impact.

To model the lead slump of the lead in the base plate (Bottom Gamma Shield), the applicant replaced part of the lead with a void. The staff found this conservative and acceptable since the analysis presented by the applicant concluded that radiation steaming through the lead slump circular segment does not result in an increase of the maximum design basis dose rate. The results of this analysis are provided in Appendix H in Report HI-2178014.

For the F-69L Fuel Basket Modeling, the applicant made some simplifications that omit small details from the model, such as the rounded corners of the shims. The staff found this approach acceptable since it neglects a small amount of material in the analyses. The applicant modeled the annular monolithic cylinders as one casting rather than multiple castings stacked on top of one another. The staff found this approach acceptable since the gap between the castings is small, and the castings overlap to prevent any significant streaming.

The applicant did not explicitly model the trunnions because the trunnions are removed during transportation. The resulting void is modeled as a solid material due to the insertion of trunnion plugs. The applicant did not model the bolts utilized for closure of the inner and outer lid, but rather the bolt hole locations are modeled as a solid material.

Staff finds this acceptable because they are recessed in the body of the package and help to minimize the dose rates in the local area. The applicant represented all empty spaces in and around the cask by voids in the model. The staff found this approach acceptable, since any absorption and scattering in air would have a very small effect in comparison to the dose rates at the close distances analyzed in the application.

Lastly, in the MCNP model, the applicant modeled fuel as fresh UO_2 fuel with an enrichment of 2.0 wt% U-235. The staff found this approach acceptable since the actual spent fuel has fewer amounts of fissile isotopes as compared to using a U-235 enrichment of 2.0 wt%.

5.3.1.2 Fuel and Source Configuration

The staff examined some of the applicant's representative shielding input files. The staff verified that the dimensions were consistent with the package drawings presented in Section 1.3 of the application. The applicant used minimum dimensions for all the package components expected to have a significant effect on external dose rates. Table 5.3.3 of the application shows the description of manufacturing tolerances with minimum values in the drawings and the values used in the shielding model.

The applicant modeled fuel as a homogenized region. The staff found this approach acceptable based on NUREG/CR-6802, "Recommendations for Shielding Evaluations for Transport and Storage Packages", which states that "an assumption that drastically simplifies the model is the smearing of the source and/or materials in the packaging cavity.

Under this approximation the active fuel materials are smeared over the cavity radius and the hardware/end fitting materials are also smeared over the cavity radius, but in a separate region." The applicant modeled the end fittings and the plenum regions as homogenous regions of steel.

The axial description of the design basis fuel assembly is provided in Table 5.3.1 of the application.

5.3.1.3 Streaming Through Radial Steel Regions

The HI-STAR 180L package utilizes Holtite as a neutron absorber in radial and axial directions. Radially, the Holtite is in two layers of pockets of monolithic shield cylinders. The two layers of pockets are staggered so steel regions of the inner and outer layer are not aligned with each other. This will reduce the potential of localized dose rate peaks.

To assure that the dose rates on the radial steel region is accounted for, the applicant included a fine azimuthal grid of dose locations, with individual dose locations aligned with each of the steel regions in the inner and outer layer of the Holtite, and dose locations in the areas in between to determine the maximum dose rate at the surface and 2 meter distance. The applicant's results showed that the dose rates are in compliance with 10 CFR 71.47 and 71.51.

The maximum dose rates on the surface was identified in location 3A with 107.87 mrem/hr compared to a limit of 200 mrem/hr.

5.3.2 Material Properties

The applicant lists the material properties used for the dose rates evaluations in Table 5.3.2 of the application. The staff reviewed the properties and geometries of the materials the applicant used for its shielding MCNP model and finds that they are consistent with the applicant's specifications. The applicant modeled all steel components as carbon steel. The applicant's use of a reduced lead density to account for the gap between the lead shield and the steel is based on a calculation of the actual volume of the lead shield space and the actual thickness of the lead layer.

The staff reviewed the material composition of the Holtite-B neutron shield materials described in the Section 3.3 of the application and found them acceptable, since the improved Holtite-B composition was approved in a previous application (e.g. HI-STAR 180D). In Appendix B of the Report: HI-2178014, "Shielding analysis for the HI-STAR 180L for transport", the applicant examined the potential thermal expansion of Holtite-B to experience changes in material densities at operating temperatures.

The applicant described assumptions considered for Holtite-B density and composition calculations in Section 5.3.2 of the application. Two of the considerations are as follows: 1) Holtite items are modeled with no gaps, but with reduced densities, and 2) to minimize Holtite-B density, the Holtite-B composition with 10% Cu and 2% B_4C is used, which are the minimum amount of Cu and B_4C in Holtite-B.

Staff finds the applicant's consideration of Holtite-B acceptable because modeling with no gaps minimize the neutron streaming through the steel regions that could result in a localized dose peaks and by minimizing the density of the Holtite, this will account for the minor long-term loss of Holtite from exposure to the temperatures.

5.3.3 Tally Specifications

To demonstrate that the package design meets the external dose rates at locations prescribed for under NCT and HAC, the performed dose rate evaluations around the entire surface of the package used sufficiently small tally bins such that a maximum is not reduced to an average. The applicant's tally specifications are discussed in Section 5.3.3 of the application. Staff reviewed the applicant's tallies and finds these tallies will capture the maximum dose rates around the package.

The applicant used the MCNP computer code to calculate the dose rate values that are listed in Tables 5.1.1 through 5.1.4 of the application. The dose point locations are illustrated in Figures 5.1.1 and 5.1.2 of the application.

To calculate dose rates from streaming through the radial ribs where there is no neutron shielding, the applicant computed dose rates in the radial direction where the dose locations were represented by cylindrical rings with a thickness of 1 cm or 2 cm each at the surface, at 1 m and at 2 m from the package. This dose location captures the maximum dose rate around the radial shield cylinder.

The radial surfaces were divided azimuthally into 2° and 5.5° wide tally cells spanning the entire 360° around the cask. Figure 5.3.3 of the application shows those tally volumes on the cask surface. In the axial direction, the tally volumes are circular disks that are divided into radial sections, each about 20 cm wide assembly.

The staff found that the applicant's tally specification for calculating the external dose rate acceptable because these tallies will generate the average flux along the surface and the number of particle tracks crossing the selected surface.

5.4 Shielding Evaluation

5.4.1 Methods

The applicant calculated the gamma and neutron source terms from radioactive fission products using the TRITON and ORIGAMI/ORIGEN modules of the SCALE 6.2.1 system using the 252-group library.

The applicant uses the MCNP-5 code to calculate external dose rates. The applicant used cross section libraries from ENDF/B-V and ENDF/B-VI data, except for Sn isotopes where it used the ENDL92 data, and uranium isotopes where it used LANL/T16 data. The applicant states that these are the default libraries for the MCNP code. The staff finds these libraries acceptable because the evaluated data coming from these libraries are added to the file based on the best microscopic measurements and theoretical models available and validated against well tested benchmark experiments using the most advance calculational models.

The applicant modeled the energy distribution of the source term explicitly in MCNP. A different MCNP calculation was performed for each of the three source terms, neutron, decay gamma, and Co-60. The axial distribution of the fuel source term is based on the axial burnup distributions listed in Appendix 5.B of the application. The applicant determines loading limits assuming a bounding source term, as well as treatment of uncertainties as a bias (all uncertainties exist simultaneously).

With these considerations, the staff has reasonable assurance that the uncertainties related to benchmarking are bounded mainly because all those effects that are applied as a bias, which will be presented as the worst-case combination of all applicable effects.

The staff noted that the applicant used an explicit approach in their analyses representing the axial burnup profiles, where source terms were determined individually for each axial section, based on the local burnup calculated from the assembly average burnup and the axial profile. The staff found this approach acceptable since it is more accurate than that used in Holtec's previous applications like for the HI-STAR 190, where the source terms were determined only for the assembly average burnup, and a correction factor was applied for each axial section.

A comparison of the resulting dose rates with dose rates calculated for the range of other available and applicable profiles is presented in Appendix 5.B of the application. The staff examined the applicant's comparisons and noted that there were no significant differences in dose rates between the different profiles. Therefore, the staff concludes that the profiles used for the design basis calculations are acceptable.

The applicant evaluated the external dose rates using what it calls a "two-step" process. This is described in Section 5.4.1 of the application.

> In the first step of the process, the applicant calculates the dose rate for each dose location per starting particle for each neutron and gamma group in each axial section for each axial and azimuthal dose location.
>
> The second step is to multiply the dose rate per starting particle for each energy group and axial section (i.e., tally output/quantity) by the source strength (i.e., particles/sec) in that group and axial section.

Then the applicant sums the resulting dose rates for all groups and axial sections for each dose location. The applicant performs normalization of these results and calculation of the total dose rate from neutrons, fuel gammas or Co-60 gammas using equation 5.4.1 of the application.

The staff reviewed the applicant's two-step evaluation method described by Equation 5.4.1 in the application and found it acceptable for this application because this method is capable of considering the neutron and gamma contributions to external dose rates and allows the applicant some flexibility in being able to evaluate external dose rates from multiple loading patterns and assemblies.

Since MCNP is a statistical code, the calculated values have an uncertainty associated with them. This uncertainty needs to be considered in the dose rate evaluation. The applicant shows how it did this in Section 5.4.1 of the application. The staff reviewed this information and found it acceptable.

5.4.2 Input and Output Data

The principal input data used in the shielding model is the dimensions shown in the drawings in Chapter 1 of the application, the fuel specifications, and the material compositions listed in Section 5.3 of the application. The applicant provides a sample input file for MCNP in Appendix 5.A of the application. Staff reviewed the applicant's input and finds that the data was captured in the input.

5.4.3 Flux-to-Dose-Rate Conversion

The applicant used the ANSI/ANS 6.1.1-1977 flux-to-dose rate conversion factors in all the shielding evaluations. The staff finds this acceptable per Section 5.5.4.3 of NUREG-1617.

5.4.4 Fuel Reconfiguration

Based on structural analysis, the applicant demonstrated that fuel rod breakage under vibratory loads associated with the normal transport condition is not viable, and therefore no noticeable impact on the dose rates is expected under normal condition. In Section 2.11 of the application, the applicant shows that the fuel is expected to remain essentially undamaged during the hypothetical accident conditions. However, the applicant conducted additional calculations with some fuel reconfigurations under normal and accident conditions and evaluates if any consideration of those need to be taken for the design basis calculations.

Under NCT, the applicant presented a scenario where the fuel collapses 10% axially, resulting in a corresponding increase in density. The applicant assumed that all fuel assemblies are collapsed, regardless of their burnup. The applicant based the MCNP model for this scenario directly on the MCNP model of the normal condition without any fuel collapse (Section 5.3 of the application). The applicant made the following modifications: reduced the length of the active fuel region by 10%; increased the active region density by 10%; and increased source term intensity by 10% per unit length. The applicant did not modify upper and lower end fittings in the collapsed model.

Under HAC, the applicant analyzed three hypothetical accident scenarios. The scenarios are detailed in Section 5.4.5 of the application. For all three scenarios, only the neutron and (n,γ) and gamma MCNP calculations were performed for simplification, since the dose rates from end fittings are not expected to be changed. The results from the three scenarios described above along with a nominal reference case for accident conditions are shown in Table 5.4.2 of the application.

The scenarios presented by the applicant are:

1. The active regions of all fuel assemblies are modeled as collapsed to their half height, with a corresponding increase in density. The collapsed fuel is located close to the bottom of the cask, which has less shielding in the axial direction than the top of the cask. The collapse could lead to a situation where axial sections of higher and lower burnups are collapsed into each other. Therefore, in this scenario, a flat axial burnup profile was utilized for the fuel. This would maximize dose rates in axial direction at the bottom of the cask (Dose Location 5).

2. The second scenario uses the same physical model as in Scenario 1, but a compressed axial profile is used instead of a flat profile. This maintains the source term peak at the center of the fuel height, and therefore maximizes the dose rate in the radial direction.

3. To evaluate the potential effect of large areas with a reduced fuel amount, the third scenario retains the full fuel height, but reduces the fuel density and source strength.

The staff reviewed this approach and finds that the applicant has adequately analyzed the hypothetical fuel reconfigurations under HAC. The staff considers fuel reconfigurations scenarios 1 and 2 more reasonable, if there was fuel reconfiguration.

However, the staff does not believe that scenario 3 is reasonable because it is physically impossible to have a reconfiguration that would cause the fuel to reduce its density and strength by 50%. This assumption is not conservative because it assumes a reduced source terms by 50% with no physical basis.

Nevertheless, the first two scenarios would bound most of the plausible fuel reconfigurations. On this basis, the staff determined the applicant's fuel reconfiguration analyses to be acceptable and the results demonstrate that the dose rate meets the regulatory limit as prescribed in 10 CFR 71.51(b)(2).

5.4.5 Lead Slump

The applicant considered the loss of Holtite and lead slump as a result of fire and a 9-meter (30 foot) drop in its design basis calculations of hypothetical accident conditions. The lead slump geometry was based on the applicant's structural analysis. The applicant performed the analysis for the package for loading pattern 7 under HAC. Loading pattern 7 was selected for this calculation since the applicant showed it produces the maximum dose rate at 1 m from the bottom of the cask. The assumptions used by the applicant in the MCNP model are as follows:

- A 12.8 cm-high cylindrical segment of the lead in the base plate (Bottom Lead Gamma Shield) is replaced with a void.
- Holtite is replaced with void.

The applicant's analysis showed that radiation steaming through the lead slump circular segment does not result in an increase of the maximum design basis dose rate. The staff examined the lead slump analysis and found it acceptable because assuming void in this affected area is conservative.

5.5 Evaluation Findings

The staff reviewed the package shielding design, calculated dose rates, material specification, and models for dose rate calculations. The staff found the applicant used the dimensions and material compositions consistent with the package drawings and bill of materials. The applicant's dose rate calculations, including source term and shielding model assumptions are conservative.

The staff has reviewed the external radiation levels of the package and vehicle as it will be prepared for shipment and concludes that they satisfy 10 CFR 71.47(b) for packages transported by exclusive-use vehicle and 10 CFR 71.51 for a package under HAC respectively. The staff reviewed the shielding analysis provided by the applicant, which provided the sensitivity study of the source terms, MCNP modeling parameters, and dose rates.

The staff found them acceptable since the dose rates were calculated from all basket regions to obtain the fuel loading that result in the highest dose rate at that tally point location. The staff also performed confirmatory analysis for source terms using ORIGEN-ARP from SCALE 6.1 depletion code. The confirmatory analysis showed that there is a close (5%) agreement with the applicant's calculations.

The staff followed the guidance provided in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," March 2000, in its review. Based on its review of the information and representations provided in the application, the staff has reasonable assurance that the proposed package design and contents satisfy the shielding requirements and external dose rate limits in 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

This section presents the analysis and findings of the criticality safety review for the application to allow shipment of the Model No. HI-STAR 180L transportation package. The BWR fuel assembly classes that the applicant requested for transportation in the HI-STAR 180L with the F-69L basket include: 8x8L1, 8x8L2, 8x8L3, 8x8L4, 8x8L5, 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4, 10x10L5, 10x10L6, 10x10L7, 10x10L8, 10x10L9, and 11x11L1.

Staff evaluated the package for its ability to meet the fissile material requirements of 10 CFR Part 71, including the general requirements for fissile material packages in 10 CFR 71.55, as well as the standards for arrays of fissile material packages in 10 CFR 71.59.

Staff reviewed the criticality safety analysis of the HI-STAR 180L presented in the application and performed independent criticality safety calculations to confirm the results presented by the applicant. This review considers the criticality safety requirements of 10 CFR Part 71 as well as the review guidance presented in NUREG-1617.

6.1 Description of the Criticality Design

6.1.1 Packaging Design Features

The HI-STAR 180L package consists of a cylindrical, steel shell containment system, with a flat bottom and bolted closure lid at the top, with a basket system used to maintain the location of fuel assemblies. The basket is fabricated with 69 cells designed to hold undamaged BWR UO2 fuel assemblies and fuel debris. UO_2 assemblies are specified with a maximum planar-average enrichment.

Three different configurations are used within the basket:

> Configuration 1 contains undamaged fresh BWR fuel assemblies in all positions in the basket.
>
> Configuration 2 has quivers (i.e., damaged fuel containers or DFCs) containing fresh fuel debris in up to four of the cells, with fresh undamaged fuel in the remaining positions.
>
> Configuration 3 can contain fresh fuel assemblies with up to four missing fuel rods that have not been replaced with dummy rods in 9 of the cells in the center of the basket, with fresh undamaged fuel assemblies in the remaining positions.

General details of the basket configurations are found in Section 1.3 of with SAR, with basket details pertinent to criticality safety are in Section 6.3.1 of the SAR.

Criticality safety of the HI-STAR 180L is maintained by controlling the geometry of the fuel basket design within the cask, the use of fixed neutron-absorbing material (i.e., Metamic-HT) in the fuel basket structure, an administratively controlled maximum planar-average enrichment of the fuel, and preventing fresh water in-leakage into the cask during accident conditions. Metamic-HT is an aluminum and boron carbide (B_4C) composite material with at least 10% B_4C by weight that is used for criticality control as well as structurally, and completely surrounds each basket cell.

6.1.2 Codes and Standards

The applicant identified the established codes and standards used in their review of the HI-STAR 180L, which included 10 CFR Part 71, NUREG-1617, 10 CFR Part 50, NUREG-0800, and ISG-19, “Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)”.

6.1.3 Summary Table of Criticality Evaluations

The applicant provided a summary of the criticality evaluations in Table 6.1.1 of the application, which is summarized below for the F-69L basket. The summary results contain the highest reported k_{eff} for the most reactive fuel assembly type, with the most reactive configuration (i.e., either moderately burned fuel (MBF), high burnup fuel (HBF) or HBF in a quiver).

The reported results include the calculated keff including the bias, uncertainties, and calculational statistics.

F-69L Basket, 10x10L7, 4.33 wt% ^{235}U, Configuration 3	
Configuration	**Maximum k_{eff}**
Single Package, unreflected	0.9479
Single Package, fully reflected	0.9488
Containment, fully reflected	0.9490
Single Package, Damaged	0.4183
Infinite Array of Undamaged Packages	0.4267
Infinite Array of Damaged Packages	0.4206

6.1.4 Criticality Safety Index

The applicant provided an analysis to demonstrate that infinite arrays of HI-STAR 180L packages are subcriticality under NCT and HAC. Therefore, the applicant stated that the criticality safety index (CSI), as determined under the guidelines of 10 CFR 71.59(b), is 0.0.

6.2 Spent Nuclear Fuel Contents

As described above, the HI-STAR 180L is designed to transport up to 69 fuel assemblies in a F-69L basket with the characteristics delineated in Table 7.D.1 of the application in the three configurations outlined in Section 6.1.1 above. The BWR assembly configurations include the number and locations of fuel rods and water rods, maximum active fuel length, partial length rods, maximum pellet outer diameter (OD), maximum fuel rod pitch, maximum cladding inner diameter (ID), minimum cladding OD, minimum water rod thickness, and maximum channel thickness.

The applicant used bounding fuel dimensions for each BWR fuel assembly class in their analysis to define the authorized fuel contents, discussed in Section 6.3.4 of this SER. Each BWR assembly class is specified in Table 7.D.1 of the application with a maximum planar-average enrichment.

The F-69L basket is also designed to contain BWR fuel debris loaded into quivers, which are a type of damaged fuel container for individual fuel rods that have been removed from an assembly. These fuel rods may be leaking, broken, or fragmented (i.e., fuel debris), and are hermetically sealed.

A quiver may contain up to 28 damaged fuel rods or fuel rod pieces. The number of quivers and allowable locations are provided in Section 1.2.2 of the application. Since fuel debris includes a wide range of configurations, the applicant used a bounding approach based on the analysis of regular arrays of bare fuel rods without cladding. The quiver OD is used as the debris boundary, with the fresh fuel debris arranged in rectangular arrays of bare fuel rods varying between 16 and 225 rods to cover the range of materials that may be present in each quiver.

Except for the 10x10L4 BWR fuel class, the applicant conservatively neglects gadolinium (Gd_2O_3) normally present in BWR fuel for all other BWR fuel classes. The 10x10L4 fuel assembly class has a higher enrichment than the maximum allowable fuel enrichment as defined in Table 6.1.2 (up to 5 wt% ^{235}U). The applicant relies on a partial gadolinium credit as detailed in table 6.1.3 and Section 6.3.10 of the SAR and discussed in Section 6.3.4.1 of this SER.

The applicant ensured that the calculated reactivity would be less than the real world reactivity with the following conservative assumptions: assuming that the most reactive fuel would be loaded into any specific basket; taking no credit for the fuel burnup; only using 90% of the minimum ^{10}B content for the neutron absorber; using the maximum fuel pellet density (10.77 g/cm^3) for all assembly classes; using the most restrictive combination of tolerances; and assuming the largest outer diameter and smallest cladding thickness for fuels of differing radial size.

For undamaged fuel assemblies, all positions in an assembly are assumed to contain a fuel rod, with any missing fuel rods replaced by dummy rods that displace an equal volume of water. Fuel assemblies may contain up to four missing rods that are not replaced; however, those assemblies are limited to no more than nine cells in the F-69L basket as specified in Configuration 3, with fresh undamaged assemblies in the remaining 60 cells.

6.3 General Considerations for Criticality Evaluations

With the exception of the partial gadolinium credit discussed in Section 6.3.4.1 of this SER, the applicant applied the same considerations to the criticality safety evaluations of a single package, arrays of packages under normal conditions of transport, and arrays under hypothetical accident conditions in accordance with NUREG/CR-5661, “Recommendations for Preparing the Criticality Safety Evaluation of Transportations Packages.

6.3.1 Model Configuration

The applicant evaluated the HI-STAR 180L using three dimensional models of both a single package as well as arrays of packages under both NCT and HAC. The applicant explicitly modeled the fuel rods and cladding, guide tubes, water rods, water gaps, and neutron absorber material in the F-69L basket. The applicant conservatively neglected any neutron absorber materials inherent to the spent fuel (e.g., gadolinium) in all but one configuration (i.e., partial gadolinium credit for the 10x10L4 BWR fuel assemblies). In cases where the containment of the HI-STAR 180L is flooded, the applicant conservatively assumed the fuel-to-clad gap is flooded with fresh water.

The applicant also evaluated the effect of material tolerances and potential deflections of basket walls due to accident conditions to determine the most reactive dimensional configurations possible as listed in Table 6.3.2 of the SAR and used these for all criticality calculations. The results shown in Table 6.3.4 demonstrate that the maximum fuel density and water density are bounding for all calculations.

The applicant models the most conservative parameters and treats both NCT and HAC models the same. Staff finds this acceptable since the baskets remain intact with slight deflections, including the integral neutron poison material during accident conditions, for both normal and accident conditions. The models also neglect the external neutron absorber.

The HI-STAR 180L is designed to prevent water in leakage during HAC, and flooding is considered not credible; however, these effects were evaluated in Section 6.3.4 of the application. Fuel reconfiguration resulting from HAC were also evaluated in Section 6.3.5. Staff evaluation is discussed in Section 6.3.4 of this SER.

6.3.2 Material Properties

Compositions of the materials making up the HI-STAR 180L package are listed in Table 6.3.5 of the application and include the UO_2 fuel, aluminum and steel structural components, as well as the Metamic neutron absorbers.

The applicant models UO_2 fuel up to 5.0 wt% ^{235}U at a density of 10.77 g/cm^3 and ignores gadolinium for all but one of the evaluated fuels. The exception is the 10x10L4 fuel that takes partial gadolinium credit in the analysis, which has the same fuel and density as the others with the addition of 3.0 wt% Gd_2O_3 added, instead of the 5.0-8.0 wt% that BWR fuel typically uses for gadolinium loading.

The applicant conservatively assumes 90% of the neutron absorber minimum specified B_4C content in the Metamic neutron absorber that is integrated into the basket structure of the HI-STAR 180L, as discussed in Section 8.1.1.5 of the SAR.

This assumption was validated based on calculations for the HI-STORM FW application previously reviewed and approved by the NRC.

6.3.3 Analysis Methods and Nuclear Data

The applicant used the thee-dimensional Monte Carlo code MCNP-5 version 1.51 with continuous energy ENDF/B-VII cross-section libraries for all criticality calculations for the HI-STAR 180L package. The applicant also used the two-dimensional, multi-group transport theory depletion code, CASMO5 Version 2.00.00, with the ENDF/B-VII cross-section library to determine the burned fuel compositions that are to be shipped in the package.

6.3.4 Demonstration of Maximum Reactivity

The HI-STAR 180L baskets are designed to allow shipment of fuel with the enrichments indicated in Appendix 7.D of the application. The applicant assumes that the HI-STAR 180L package is fully flooded with water. The applicant divided the BWR fuel assembly types into classes based on the array size of each assembly (i.e., 8x8, 9x9, 10x10, and 11x11) and performed bounding calculations for each assembly class to apply to all assemblies within that class (e.g., 10x10L1, 10x10L2, etc.).

This approach has been used by the applicant in previous applications which prior staff reviews found acceptable. The applicant performed sensitivity studies to demonstrate every most reactive assembly dimensions, including maximum active fuel length, maximum fuel pellet diameter, maximum fuel rod pitch, minimum fuel rod diameter, maximum cladding inside diameter, minimum guide tube thickness, minimum water rod thickness, and maximum BWR channel thickness.

BWR fuel assemblies may have non-uniform radial and axial enrichments, including a top or bottom low-enriched UO_2 blanket. The applicant demonstrated in Section 6.2.2 that it is conservative to assume that the maximum planar-average enrichment is uniform throughout each assembly. Some BWR fuel assemblies may also have partial length rods (i.e., 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4, 10x10L7, 10x10L8, 10x10L9, and 11x11L1).

The applicant determined it would be conservative to remove the partial length rods in assemblies 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4, and 11x11L1. The applicant determined it would be conservative to replace the partial length rods with full length rods in assemblies 10x10L7, 10x10L8, and 10x10L9, since these partial length rods were on the periphery or facing the water gap. These results are consistent with other analyses performed by the applicant for other NRC-approved transportation systems.

The applicant performed sensitivity studies for a single HI-STAR 180L package as well as array configurations to determine the most reactive conditions for each. Parameters studied included variation of internal and external moderation, partial flooding, clad gap flooding, preferential flooding of DFCs (i.e., quivers), eccentric positioning of assemblies, fuel reconfiguration, partial loading, fuel assemblies with missing rods, damaged and undamaged fuel, sealed rods replacing water rods, and neutron sources in fuel assemblies.

By using the most reactive materials and fuel tolerances for the HI-STAR 180L, the applicant determined the most reactive conditions to comply with 10 CFR 71.55 and 10 CFR 71.59.

6.3.4.1 Partial Gadolinium Credit

The applicant also evaluated BWR fuel with a partial gadolinium credit for the 10x10L4 fuel assembly in the F-69L basket since the enrichment limit may exceed the limits referenced in Table 6.1.2 of the application. The 10x10L4 assembly may have an enrichment up to 5.0 wt% ^{235}U. The applicant's methodology to determine the partial gadolinium credit consisted of replacing no more than two fuel rods in each assembly with 97% UO_2 and 3% Gd_2O_3. Normally a BWR contains 10-20 gadolinium rods at 5-8 wt% of gadolinium at an enrichment of 5.0 wt% ^{235}U. All other rods in the assembly are 100% UO_2.

The applicant's modeling of the10x10L4 assemblies with partial gadolinium credit is identical to the other evaluated assemblies with the exception of the composition of the fuel material as mentioned above and can be found in Table 6.3.5 of the application. The applicant placed the limited number of rods in specific locations to limit their effect on the reactivity of the assembly as a whole, but not on the periphery since the gadolinium rods, had an insufficient effect. As such, the applicant will adhere to the following administrative requirements for 10x10L4 fuel assemblies:

- Gadolinium rod loading may not be less than 3.0 wt% Gd_2O_3
- Gadolinium rods located in the peripheral row of the fuel lattice cannot be credited
- A minimum of two gadolinium rods must be present in each credited assembly
- Gadolinium rods are not needed for fuel debris held in quivers

The applicant evaluated several layouts of gadolinium rods in the fuel assembly using both one or two rods, in order to minimize the effect of the gadolinium and maximize the reactivity of the assembly when the rods are credited. In addition, the applicant continued to use the fresh fuel assumption for the fuel in the 10x10L4 assemblies and did not take any burnup credit for the fuel.

The gadolinium assumed present in the fuel rods is much less than would be present in fresh fuel. NUREG/CR-7194, "Technical Basis for Peak Reactivity Burnup Credit for BWR Spent Nuclear Fuel in Storage and Transportation Systems," allows for burnup credit and residual burnable absorbers in BWR fuel. Typically, if credit is taken for the residual burnable absorber, then the peak reactivity that occurs from the rapid depletion of the burnable absorber must be accounted for. This is known as a peak reactivity method, or "gadolinium credit", and applies a credit for the burnup.

However, the method used by the applicant does not require any credit for the actual burnup of the fuel (i.e., fresh fuel is used). This is due to the minimal amount of burnable absorber that is credited in the analysis. This yielded a simpler method than that described in NUREG/CR-7194 and provides an additional reactivity margin.

The applicant demonstrated that these partial credit rods reduce reactivity of the assemblies in the HI-STAR 180L package by performing an analysis where the 10x10L4 fuel assemblies were placed in different layouts within the assembly and determining that a negative Δk_{eff} (as shown in Figure 6.3.7 of the application) applied to all evaluated cases.

In addition, the applicant determined that the use of partial gadolinium credit in the 10x10L4 assemblies result in lower peak reactivities than the design basis fuel in all cases, with a margin greater than 0.05 Δk_{eff} when compared to an assembly without gadolinium rods.

To account for possibly misloading of BWR fuel assemblies without gadolinium rods, the applicant considered the worst case misloading for the F-69L basket in a HI-STAR 180L package (i.e., where all fuel assemblies with gadolinium rods in the basket were replaced by fuel assemblies without any gadolinium rods).

As shown in Table 6.3.19 of the application, these misload configurations remain subcritical using a reduced safety margin (i.e., 0.02 Δk, or 0.98 k_{eff}) as recommended in NUREG-1617. Staff finds that the applicant provided adequate justification and conservatism in their methodology of the misload evaluation.

6.3.5 Confirmatory Analyses

Staff used the SCALE 6.3 computer code system, with the KENO VI three-dimensional Monte Carlo code and the continuous-energy ENDF/B-VII cross section library to perform independent criticality calculations.

Staff performed independent evaluations of the HI-STAR 180L transportation package for the bounding fuel assembly classes in the F-69L basket using assumptions similar to those used by the applicant. Staff confirmed that the package meets the criticality safety requirements of 10 CFR Part 71.

6.4 Single Package Evaluation

6.4.1 Configuration

The applicant modeled a single HI-STAR 180L package with the F-69L basket configured in the most reactive condition as described in Section 6.3.4 above. There is full water moderation within the basket with the containment shell fully reflected by water, and the fuel is in the as-loaded condition to comply with 10 CFR 71.55(b). The applicant modeled three configurations with the assemblies centered in the basket, which yielded the bounding k_{eff} for each assembly.

> Configuration 1 for Moderate Burnup Fuel (MBF) has all basket cells containing fresh undamaged fuel assemblies at the fuel-specific maximum planar-average initial enrichment, and the applicant arranged High Burnup Fuel (HBF) similarly considering the fuel reconfiguration cases outlined in Section 6.3.5.1 and 6.3.5.2 of the SAR.

Configuration 2 included fuel debris in specific F-69L basket locations at an enrichment of 5.0 wt% ^{235}U for MBF where the rest of the basket is filled with fresh undamaged fuel, and for HBF the basket is filled with bounding reconfigured fuel.

The applicant modeled Configuration 3 with fuel assemblies missing fuel rods in no more than 9 cells, and the rest of the basket filled with undamaged fresh fuel.

The applicant demonstrated subcriticality under NCT per the requirements of 10 CFR 71.55(d) by modeling a single package with full internal moderation and external water reflection for all three configurations.

To demonstrate subcriticality under HAC, per the requirements of 10 CFR 71.55(e), the applicant modeled a single package as internally dry based on the leak-tight analysis of Chapter 2 of the SAR, with full external water moderation.

6.4.2 Results

The maximum k_{eff} calculated by the applicant for each single package configuration is shown in Table 6.4.1 of the application. In all instances, the resulting calculated k_{eff}s are less than 0.95 for each single package configuration. The damaged single package with dry containment and major reconfiguration had a k_{eff} less than 0.5.

Staff reviewed the applicant's evaluation of the HI-STAR 180L single package configurations and finds the evaluations are consistent with the recommendations of NUREG-1617. Staff finds reasonable assurance that a single HI-STAR 180L package remains subcritical under NCT and HAC and meets the requirements of 10 CFR 71.55.

6.5 Evaluation of Package Arrays

6.5.1 Package Arrays Under NCT

6.5.1.1 Configuration

The applicant modeled an infinite array of hexagonally pitched packages, using the single package model for NCT referred to in Section 6.4.1 of this SER that was both internally and externally dry. Since Chapter 2 of the application indicated that the HI-STAR 180L package does not leak under NCT, staff finds this is an acceptable approach.

6.5.1.2 Results

As shown in Table 6.5.1 of the application, the maximum k_{eff} is well below the administrative limit since the system is dry. Staff reviewed the applicant's evaluation of NCT single package arrays and found them to be consistent with the recommendations of NUREG-1617, and staff finds reasonable assurance that arrays of packages remain subcritical under NCT and meet the requirements of 10 CFR 71.59.

Since the applicant demonstrated an infinite number of HI-STAR 180L packages is subcritical, the CSI is zero.

6.5.2 Package Arrays under HAC

6.5.2.1 Configuration

The applicant modeled an infinite array of hexagonally pitched packages, as was done for the NCT case above, that was internally dry with full external water reflection. Based on the Chapter 2 analysis demonstrating the under HAC there is no water in-leakage into the HI-STAR 180L package, staff finds this acceptable.

6.5.2.2 Results

As shown in Table 6.6.1 of the application, the maximum k_{eff} is below the administrative limit of 0.95 recommended by NUREG-1617. Additionally, the applicant performed studies for the major fuel reconfiguration cases under accident conditions with a fully flooded containment boundary and water in-leakage into the package to demonstrate defense in depth.

As shown in Table 6.6.2 of the application, this extremely conservative model remains subcritical. Although the results of these studies indicate a k_{eff} higher than 0.95, the results are below 0.98, which staff has accepted in similar cases due to the unlikeliness of such a condition occurring (i.e., flooded package since water intrusion was shown not to occur under HAC).

Since the HI-STAR 180L package design has been demonstrated to be leak tight, based on the structural and material components, and is also designed with a double lid closure system, this provides additional assurance that water would be precluded from entering into the containment system during accident conditions.

Staff reviewed the applicant's evaluation of HAC single package arrays and found them to be consistent with the recommendations of NUREG-1617, and staff finds reasonable assurance that arrays of packages remain subcritical under HAC and meets the requirements of 10 CFR 71.59(a)(2). Since an unlimited number of HI-STAR 180L packages is subcritical, the resultant CSI is zero.

6.6 Benchmark Evaluations

The applicant selected critical experiments to bound a range of parameters covered by the criticality design and contents of the HI-STAR 180L package. The applicant analyzed the k_{eff} results for trends and determined the maximum bias and bias uncertainty for the HI-STAR 180L criticality safety analyses consistent with recommendations of NUREG-1617. These results are presented in Appendix 6.A of the application.

The applicant considered 562 critical experiments, which were grouped according to neutron absorber, reflectors, neutron absorber geometry, fuel burnup, moderation, and temperature. 178 fresh UO_2 critical experiments were used to determine the bias and bias uncertainty to be applied to the fresh fuel evaluations of the F-69L basket in the HI-STORM 180L package.

The applicant also evaluated 156 Haut Taux de Combustion (HTC) critical experiments that were selected to be similar to the compositions of the fuel assembly types for evaluating the minimum amount of gadolinium that would be present in burned fuel rods as part of their partial gadolinium evaluation.

Since the applicant is using the conservative assumption of the fuel being unburned, the use of the partial gadolinium credit results in a reactivity greater than the peak reactivity as outlined in Section 6.3.4.1 of this SER.

The applicant ensured that cases with gadolinium were present in the benchmarking analysis to support the use of partial credit of gadolinium within the 10x10L4 assembly type. These include critical experiments that include various configurations with soluble gadolinium in water, Gd_2O_3 rods, and UO_2-Gd_2O_3 rods, as well as other neutron absorber and neutron reflector materials.

Staff finds that the benchmark evaluations and bias determination are for the types of fuel to be transported in the HI-STAR 180L package are representative and appropriate and demonstrate a conservative bias for their calculations.

6.7 Evaluation Findings

The applicant has demonstrated that the HI-STAR 180L transportation package, when loaded with the fuel assemblies that meet the characteristics specified in Appendix 7.D.1 of the SAR, are adequately subcritical under all NCT and HAC.

Staff finds the applicant has provided reasonable assurance that the package is in compliance with 10 CFR 71.31(a)(1), 71.33(a), and 71.33(b), and staff finds the applicant provided an appropriate and bounding evaluation of the package criticality safety performance in compliance with 10 CFR 71.31(a)(2), 71.31(b), 71.35(a) and 71.41(a).

7.0 PACKAGE OPERATING PROCEDURES

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.

7.1 Package loading

Package loading operations include package preparation, fuel assembly loading, and package closure activities as well as preparation for transport. Package preparation activities include (i) visual inspections to verify that there are no indications of impaired physical conditions, before and after removal of the impact limiters, on either the cask surface itself, the containment closure flange inner and outer seal surfaces, the inner and outer closure lid bolts, the cask neutron absorber panel sheathing, etc., (ii) the performance of a radiological survey, (iii) the removal of the impact limiters, if previously attached, and of any road dirt or debris or any foreign material, (iv) the upending of the cask, and (v) the removal of the cask lids and used seals.

The CoC limits loading to 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies, of which a maximum of 9 may be fuel assemblies, including up to 4 missing fuel rods not replaced with dummy rods. Also, the package's maximum contents are 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies of which a maximum of 4 may be quivers, each quiver containing up to 28 fuel rods.

The staff notes that Table 7.1.5 discusses quiver operational requirements, specifically leak-tightness, important to moisture control. The staff concludes that evacuating the quiver and backfilling with helium will reduce the water content, humidity, and oxidizing potential of the environment as well as reduce the potential for localized corrosion of passive alloys.

After being raised out of the spent fuel pool, the cask is decontaminated and placed in a preparation area. The lid vent line is opened to prevent cask pressurization and the inner closure lid bolts are installed and torqued, per specifications. The cask drying operation is critical to the spent fuel cladding integrity:

> For drying with forced helium, the Forced Helium Dehydration (FHD) System is connected to the package and used to remove moisture from the cask cavity. There is no time limit on FHD drying. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. After the bulk water has been removed, the helium exiting the FHD demoisturizer is cooled to the temperature or dew point given in Table 7.1.2 and circulated through the duration given in Table 7.1.2 to ensure that the cask cavity is dry.

For drying with vacuum, a vacuum drying system is connected to the cask and used to remove moisture from the cask cavity. The user performs a site-specific evaluation to determine whether cyclic vacuum drying with time limits is necessary to ensure the vacuum drying criteria is met. Users shall refer to Table 7.1.2 and Table 7.1.3 for vacuum drying criteria. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. The cask cavity is vacuum dried.

Regarding cask closure, the inter-seal test port plugs of the inner closure lid are installed with new seals and torqued. The containment closure flange outer sealing surface protective cover is removed and the sealing surfaces for the outer closure lid are inspected for signs of damage. New seals are installed in the outer closure lid and the lid is then installed on the cask.

Bolt torque requirements and recommended tightening procedure for containment boundary components are provided in Table 7.1.1 and Figure 7.1.1, respectively. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4. The outer closure lid access port plug, fitted with a new seal, is torqued to the requirements in Table 7.1.1

If more than twelve months have elapsed since the performance of the leakage tests described in Subsection 7.1.2.1, a periodic leakage test shall be performed. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

The personnel barrier is optional, in accordance with regulations, if the package surface temperature and the dose rates without the personnel barrier are within 10CFR71.43 and 10CFR71.47 requirements, respectively. However, the CoC conditions shipment of the HI-STAR 180L package as an exclusive use shipment and with the personnel barrier installed.

7.2 Package Unloading

Package unloading operations include the receipt of the package from the carrier, the cooling of the fuel assemblies, the flooding of the cask internal cavity, the removal of the lids and bolts, the unloading of the fuel assemblies and the quivers followed by the release of the package for future transport operations.

Most notably, for packages containing HBF, surface temperature measurements shall include the surface temperature measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of the application. Package surfaces shall be dry at the time of temperature measurements. Gas sampling is performed to assess the condition of the fuel cladding.

An inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during unloading operations.

If the cask is not immediately moved to the spent fuel pool, water is circulated through the cask to cool the contents and allow for establishment of a Time-To-Boil time limit. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to placement of the cask in the spent fuel pool.

Inner closure lid bolts may be removed at any time from after the internal cavity pressure is equalized until the time the inner closure lid is to be removed. In addition, the inner closure lid bolts are removed either before the cask is placed in the spent fuel pool or other fuel unloading area or after placement of the cask in one of these areas.

7.3 Preparation of Empty Package for Shipment

The minimum requirements for preparing an empty package (previously used) for transport are similar to those required for transporting the loaded package with some differences such as a survey for removable contamination on the internal and external surfaces of the packaging to verify that the limits of 49 CFR 173.428 and 10 CFR 71.87(i) are met.

7.4 Evaluation Findings

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.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The examination of the HI-STAR 180L packaging welds are performed in accordance with the applicable codes, or code alternatives, and standards, with approved procedures, by personnel qualified in accordance with SNT-TC-1A. All required inspections, examinations, and tests are part of the documentation package for the HI-STAR 180L.

Some of the specific weld requirements are as follows:

1. Containment boundary welds, including any attachment welds, are examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. 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.

2. NF welds on the packaging (other than containment boundary welds) and primary load bearing members in the impact limiter and fuel spacers, are examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5300. 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.

3. Basket welds, connecting Metamic-HT panels, are examined and repaired in accordance with NDE specified in the drawing package, and with written and approved procedures developed specifically for welding Metamic-HT, with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition).

4. The basket welds, made by the Friction Stir Weld process, are classified as Category E per NG-3351.3 and belong to Type III in Table NG-3352-1. Qualification of the Friction Stir Welding (FSW) process shall meet the following

> requirements from ASME Section IX, 2013 Edition: the Procedure Qualification Record (PQR) shall meet the essential variable requirements of QW-267; the Weld Procedure Specification (WPS) shall meet the essential variable requirements of QW-267, QW-361.1(e) and QW-361.2; the welder operator performance qualifications shall meet the essential variable requirements of QW-361.2; the welder operator may be qualified by volumetric NDE of a test coupon; or a coupon; the procedure qualification of the Friction Stir Welding process may be accomplished by tensile testing the appropriate number of coupons per ASME Section IX.

Pressure testing of the HI-STAR 180L containment boundary and expanded containment boundary (inter-lid space) is required. The cask cavity space shall be hydrostatically or pneumatically pressure tested at 125% or 110%, respectively, of the applicable cask cavity space design internal pressure in accordance with ASME Code Section III, Subsection NB, Article NB-6000. The pressure test may be performed at any time during fabrication, after the fabrication of the containment boundary is completed.

A shielding effectiveness test of each packaging must be performed after loading with approved contents, but prior to the first shipment. The test may be performed with the loaded package in the vertical or horizontal configurations (no impact limiters) or in the horizontal orientation with impact limiters.

The first fabricated HI-STAR packaging shall be tested to confirm its heat dissipation capability. A thermal test performed for a similar cask design (e.g. HI-STAR 180 USNRC Docket 71-9325) may be used as proof of heat transfer capability in lieu of thermal testing of the HI-STAR 180L. Section 8.1.7 of the application provides a basic description of the testing sequence and the condition for its acceptability. Based on the staff's review of Section 8.1.7 of the application, the staff finds this to be acceptable.

Periodic thermal performance tests are performed in accordance with written and approved procedures at the frequency indicated in Table 8.2.1 to demonstrate that the thermal capabilities of the package remain within its design basis. This test, performed immediately after a package is loaded with spent fuel to verify a continued adequate rate of heat dissipation from the package to the environment, ensures that design basis fuel cladding temperature limits, to which the HI-STAR 180L package is qualified under design basis heat loads, will not be exceeded during transport.

For packages containing HBF, package surface temperatures and surface dose rates shall be measured as a practical means of monitoring the condition of the fuel assemblies although fuel reconfiguration and fuel cladding damage is not expected after the transportation period of each shipment.

Leakage rate tests on the containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5, 2014. Tables 8.1.1 and 8.1.2 specify the allowable leakage rates and test sensitivity as well as components to be tested for maintenance and periodic leakage rate tests.

A pre-shipment leakage rate test of cask containment seals is performed following loading of authorized contents into the cask. This pre-shipment leakage rate test is valid for 1 year or until the tested component(s) is opened or respective containment fasteners are untorqued. In case of an unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied. If the pre-shipment leakage rate test expires, a periodic leakage rate test of the containment seals must be performed prior to transport. This periodic leakage rate test shall be performed at the frequency indicated in Table 8.2.1. A leak-tight criterion is applicable to fabrication, maintenance, pre-shipment and periodic leakage tests.

Maintenance leakage rate testing shall be performed prior to returning a package to service following maintenance, repair (such as a weld repair), or replacement of containment system components (such as containment seal replacement and/or removal of closure bolts/plugs). Only that portion of the containment system that is affected by the maintenance, repair or component replacement needs to be leak tested.

Leakage rate testing procedures shall be approved by an American Society for Nondestructive Testing (ASNT) Level III Specialist in leak testing for the nondestructive method(s) of leak testing for which the procedures are written. Leakage rate testing shall be performed by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A.

The HI-STAR 180L packaging is equipped with metallic closure seals on the inner and outer closure lids and other penetration closure joints as specified in the drawings. Once installed and compressed, the seals should not be disturbed by removal of closure fasteners. Removal of closure fasteners requires replacement of closure seals and performance of a maintenance leakage rate test for closure seals classified as containment boundary seals. Closure seals are specified for long-term use and do not require additional maintenance.

The applicant determined that requirements, previously specified in the HI-STAR 180 and HI-STAR 60 applications, for volumetric examination of closure lid bolts were unnecessary and could be eliminated for bolts that do not fall under the diameter requirements of Subsection NB of the ASME Code (according to Subsection NB, Article NB-2581, bolts that are 2 inches (50mm) or less do not require volumetric examination). The staff noted that the package containment closure lid bolts are 42mm and that Holtec already fully commits to the ASME Code, except for some code alternatives duly stated in the application.

Therefore, staff agreed that a volumetric examination of closure lid bolts with a diameter that is outside ASME Code diameter requirements for volumetric examination could not indeed be required. As a consequence, the previous requirement of “a volumetric examination of each bolt to ensure absence of voids…” was deleted from the application. Staff also noted that Holtec does list Charpy V-notch testing for containment boundary components including bolts, even though for the bolts ASME Code criteria, using -29°C or -40°C, are followed as applicable (see Table 8.1.5 of the application)

The maintenance inspections and tests program schedule are presented in Table 8.2.1 of the application. Table 8.2.1 also lists the materials for the inner closure lid port cover bolts and shows the bolting cycle values corresponding to each material, in accordance with the calculations presented in Chapter 2 of the application, e.g., 227 bolting cycles for SB-637 or 225 bolting cycles for SA 564-630 for the inner closure lid port cover bolts.

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:

Broken, leaking, or fragmented fuel rods, or otherwise purposely punctured (to relieve internal pressure) fuel rods with a nominal 3 mm, or larger, opening, are loaded into quivers. Quivers are placed in one region (4 cells) at the periphery of the basket, as specified in Figures 7.D.1 and 7.D.2 of the application.

The minimum initial fuel rod enrichment is 0.7 wt.% ^{235}U, and the maximum initial enrichment of any UO_2 assembly is 5.0 wt.% ^{235}U.

The post-irradiation minimum cooling time is 2 years and the maximum average assembly burnup is 66 GWD/MTU.

Allowable loading patterns are specified in Table 7.D.3 with fuel specifications for burnup, enrichment and cooling time in Table 7.D.4 of the application; Basket regions are defined in Table 7.D.5 and Figures 7.D.1 and 7.D.2 of the application. In each loading pattern, the fuel specification, the package heat load limits and the locations of the quivers must be satisfied.

The maximum decay heat is 35 kW. Requirements for fuel assemblies and dummy fuel assemblies for a partial loading of a package are specified in Table 7.D.1 of the application.

A maximum of 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies, of which a maximum of 9 may be fuel assemblies, including up to 4 missing fuel rods not replaced with dummy rods.

A maximum of 69 undamaged BWR fuel assemblies and/or dummy fuel assemblies of which a maximum of 4 may be quivers, each quiver containing up to 28 fuel rods.

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.

Transport of the HI-STAR 180L package must be performed under exclusive use shipment and with the personnel barrier installed.

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

Transport by air of fissile material is not authorized.

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 180L 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. 9381, Revision No. 0.

CERTIFICATE OF COMPLIANCE NO. 9381, REVISION NO. 0, FOR THE MODEL NO. HI-STAR 180L PACKAGE DATE May 5, 2021

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