

**CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES**

1.	a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE	PAGES
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2. PREAMBLE

- a. This certificate is issued to certify that the package (packaging and contents) described in Item 5 below meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."
- b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

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

- | | | | |
|----|--|----|---|
| a. | ISSUED TO (<i>Name and Address</i>) | b. | TITLE AND IDENTIFICATION OF REPORT OR APPLICATION |
| | Holtec International
1 Holtec Blvd.
Camden, NJ 08104 | | Holtec International Report No. HI-2146261 <i>Safety Analysis Report on the HI-STAR 80 Package</i>
Revision 5, dated November 2023 |

4. CONDITIONS

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

5.

(a) Packaging

- (1) Model No.: HI-STAR 80
- (2) Description

The HI-STAR 80 packaging consists of the following major components: the packaging body, the fuel baskets, the non-fuel waste basket, the impact limiters, and the personal barrier.

The packaging body is comprised of a nickel steel shell welded to a stainless-steel lower forging at the bottom and a stainless steel forging at the top. The closure system consists of two stainless steel closure lids: (i) the inner lid seals against the upper forging flange and a tapered retainer ring connects to the upper forging flange with 36 closure bolts while providing the preload for the inner cask lid, (ii) the outer lid is secured to the upper forging flange with 36 closure bolts. The inner seal of each lid ensures both the containment and moderator exclusion functions of the package.

Radial shielding is provided by lead, steel, copper, and Holtite. Axial shielding is provided by the steel closure lids, and the bottom flange, supplemented by lead and Holtite. The gamma shield consists of lead between the containment shell and an intermediate steel shell supported by four radial ribs welded to both shells. The neutron shield consists of Holtite surrounded by the copper inner and outer shells that are supported by diagonal copper ribs attached to the shells.

The containment system components include: (i) the containment shell, shell cladding, upper and lower forgings; (ii) the inner closure lid including its inner seal, retainer ring, bolts and helical thread inserts, and leak test port plug and seal; (iii) the outer closure lid including its inner seal, bolts, test plug seal and helical thread inserts; (iv) the vent and drain port

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

including its bronze plug, bushing and bushing/plug seal, inner port cover plate, and the port outer containment seal, and (v) the spray cooling port including its cap, cap inner seal, cover plate, and cover plate inner seal, bolts and helical thread inserts.

The HI-STAR 80 is designed for maximum heat loads of 50 kW and 54 kW, respectively, depending upon the fuel basket (F-12P for 12 PWR fuel assemblies or F-32B for 32 BWR fuel assemblies) loaded in the package. Fuel baskets are formed by a honeycomb structure of Metamic-HT plates, surrounded by an array of shaped aluminum spacers (basket shims) in the packaging cavity peripheral spaces. The aluminum basket shims are attached to the basket.

The non-fuel waste basket, designated as NFWB-1 and made from stainless steel, is used for core components such as fuel channels, spacer grids, control rods or control blades, burnable absorbers in solid form. Secondary packagings, which provide no safety function, may be also loaded into the non-fuel waste basket.

Two identical impact limiters, referred to as "AL-STAR," comprised of a rigid steel cylindrical core and a steel cylindrical skirt surrounding the crushable shock absorbing material, are attached to the top and bottom of the packaging with 16 bolts.

The personal barrier, placed over the package lying in a horizontal orientation during transport, is a packaging component when in use, providing a physical barrier to prevent access to hot areas of the package.

The packaging body cavity is approximately 180 ¼ inches long, with an inside diameter of 48 7/8 inches, and an outer diameter of approximately 89 ¼ inches. The packaging is 212 inch long (313 inch with the impact limiters installed) and weighs approximately 157,600 lbs (without the lids). The package as configured for transport, i.e., including impact limiters, weighs from 199,500 lbs (NFWB) to 234,800 lbs (F-32B basket).

(3) Drawings

The packaging shall be constructed and assembled in accordance with the following drawings:

- (a) HI-STAR 80 Cask Drawing No. 9800, Sheets 1-11, Rev. 13
- (b) F-12P Fuel Basket Drawing No. 9796, Sheets 1-4, Rev. 7
- (c) F-32B Fuel Basket Drawing No. 9797, Sheets 1-4, Rev. 7
- (d) NFWB-1 Non-Fuel Waste Basket Drawing No. 9798, Sheets 1-2, Rev. 7
- (e) HI-STAR 80 Impact Limiter Drawing No. 9801, Sheets 1-7, Rev. 7
- (f) HI-STAR 80 Transport Package Drawing No. 9795, Sheets 1-7, Rev. 5

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5(b) Contents

(1) Type and form of material

- (a) Intact, moderate to high burnup, up to 70 GWd/MTU, spent PWR or BWR UO₂ fuel, BWR MOX fuel, quivers, or a mixed load of UO₂ fuel with either MOX fuel assemblies or quivers in the same fuel basket.
- (b) Non-Fuel waste such as fuel channels, transition pieces, spacer grids, core grid and core spray components, control rods or control blades, neutron monitors using fission chambers, and burnable absorbers.

(2) Maximum quantity of material per package:

- (a) 12 PWR UO₂ fuel assemblies (15x15 and 17x17 arrays) in the F-12P basket with characteristics described in Table 7.D.2 of the application. Control rods are authorized for transport within spent PWR fuel assemblies. Fuel assemblies may contain up to 4 irradiated stainless steel replacement rods. The fuel assemblies are restricted to assembly burnup, enrichment, cooling time and minimum number of 1 year cycle requirements, as specified in Table 7.D.4 of the application.
- (b) 10 PWR UO₂ fuel assemblies (15x15 and 17x17 arrays) in the F-12P basket with a maximum of 136 fuel rods in quivers. Control rods are authorized for transport within spent PWR fuel assemblies. Fuel assemblies may contain up to 4 irradiated stainless steel replacement rods. The fuel assemblies are restricted to assembly burnup, enrichment, cooling time and minimum number of 1 year cycle requirements, as specified in Table 7.D.4 of the application.
- (c) 32 BWR fuel assemblies (8x8, 9x9, 10x10 and 11x11 array sizes, and a MOX assembly in a 10x10 array size) in the F-32 B basket with characteristics described in Table 7.D.3 of the application. Non-fuel hardware are not authorized contents with spent BWR fuel assemblies. Fuel assemblies may contain up to 4 irradiated stainless steel replacement rods. The fuel assemblies are restricted to assembly burnup, enrichment, cooling time and minimum number of 1 year irradiation cycle requirements, as specified in Table 7.D.5 of the application. Only four MOX fuel assemblies are authorized to be loaded in the F-32B basket in cells 6, 9, 24, and 27, as identified in Figure 7.D.2 of the application with characteristics described in Table 7.D.6 of the application.
- (d) 28 BWR fuel assemblies (8x8, 9x9, 10x10 and 11x11 array sizes) in the F-32B basket with a maximum of 168 fuel rods in quivers. Non-fuel hardware is not authorized contents with spent BWR fuel assemblies. Fuel assemblies may contain up to 4 irradiated stainless steel replacement rods. The fuel assemblies are restricted to assembly burnup, enrichment, cooling time and minimum number of 1 year cycle requirements, as specified in Table 7.D.5 of the application.

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- (e) Non-Fuel Waste, as described in Condition No. 5(b)(1)(b), in the NFWB-1 basket, meeting the specifications and requirements described in Table 7.D.8 of the application.
6. The Criticality Safety Index (CSI) is 0.0.
7. In addition to the requirements of Subpart G of 10 CFR Part 71:
- (a) The package shall be prepared for shipment and operated in accordance with the Operating Procedures in Chapter 7 of the application; and
- (b) The package must meet the Acceptance Tests and Maintenance Program of Chapter 8.0 of the application.
8. Additional operating requirements of the Model No. HI-STAR 80 package include:
- (a) Damaged fuel assemblies are not authorized for transportation.
- (b) MOX fuel composition must meet the plutonium material vector as defined in Table 7.D.1 of the application. Hybrid MOX fuel assemblies, i.e., BWR fuel assemblies that contain both MOX fuel rods and UO₂ fuel rods, are not authorized contents. For BWR MOX assemblies, the total plutonium mass cannot exceed 14 kg per fuel assembly.
- (c) Maximum allowable times, based on design basis maximum heat load, for the completion of wet transfer operations are defined in Table 3.3.6 of the application.
9. The package shall be transported exclusive use only, with the personnel barrier installed during transport.
10. Transport of fissile material by air is not authorized.
11. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR 71.17.
12. The package may be used in the U.S. for shipment of UO₂ fuel and Non-Fuel Waste meeting the above conditions.
13. Expiration date: December 31, 2028.

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REFERENCES

Holtec International Report No. HI-2146261 *Safety Analysis Report on the HI-STAR 80 Package*, Revision 5, dated November 2023.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

**Yaira K. Diaz-
Sanabria**

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Diaz-Sanabria
Date: 2023.12.20 12:11:58
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Yaira K. Diaz-Sanabria, Chief
Storage and Transportation Licensing Branch
Division of Fuel Management
Office of Nuclear Material Safety
and Safeguards

Date: December 20, 2023





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

**SAFETY EVALUATION REPORT
Docket No. 71-9374
Model No. HI-STAR 80 Package
Certificate of Compliance No. 9374
Revision No. 2**

SUMMARY

By letter dated July 29, 2021 (Agencywide Documents Access and Management System [ADAMS] Package Accession No. ML21210A403), Holtec International (Holtec, the applicant) submitted an amendment request for the Model No. HI-STAR 80 package.

The amendment request included the following:

- (i) addition of quivers to the allowable contents for both the F-12P and F-32B baskets (quivers are containers for storing separated spent fuel rods) with a maximum of 4 quivers to be loaded in the F-12P basket, and 12 quivers to be loaded in the F-32B basket,
- (ii) a maximum heat load of 43.5 kW to allow for spent fuel pools to be offloaded sooner after plant shutdown,
- (iii) a maximum pressurized water reactor (PWR) fuel assembly weight to 800 kg for loading in all basket cell locations,
- (iv) a Metamic-HT weld soundness criteria requiring only visual examination and bend testing,
- (v) a revision of the helium leakage rate acceptance criteria and test sensitivity for the containment enclosure leakage rate test, and
- (vi) the elimination of the requirement for bolting material to perform a volumetric examination of each bolt to ensure absence of voids.

On November 7, 2022, U.S. Nuclear Regulatory Commission (NRC) staff issued a first request for additional information (RAI) (ML22305A588). Some of the applicant's responses (ML22356A253) to the RAIs were deemed inadequate and staff issued a second round of RAIs by letter dated March 26, 2023, for which responses were received on June 27, 2023 (ML23178A233). The applicant removed the proposed change related to the maximum PWR fuel assembly weight to 800 kg for loading in all basket cell locations from further staff's evaluation at the first round of RAI responses.

Also, on June 27, 2023, Holtec requested, in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) Section 71.38(b), a timely renewal of the certificate of compliance (CoC) for the Model No. HI-STAR 80 package which had an expiration date of September 30, 2023.

The applicant submitted Revision 5 of the application by letter dated November 30, 2023 (ML23334A183).

The staff performed a limited technical review of the changes, focusing on the LS-DYNA models for partially loaded casks and the analyses presented in section 2.7 Hypothetical Accident Conditions and section 2.11 Fuel Rods of the HI-STAR 80 safety analysis report (SAR) to confirm that (i) the modeling approach is correct and representative of the HI-STAR 80 package, (ii) the LS-DYNA models and analyses are consistent with the SAR calculations and results, and (iii) the modeling results provide a reasonable assurance of safety for the package.

NRC staff reviewed the application, as supplemented, using the guidance in NUREG-2216 "Standard Review Plan for Spent Fuel Transportation Packages for Spent Fuel and Radioactive Material." The package was evaluated against the regulatory standards in 10 CFR Part 71, including the general standards for all packages and the performance standards specific to fissile material packages under normal conditions of transport and hypothetical accident conditions.

The analyses performed by the applicant demonstrate that the package provides adequate structural and thermal protection to meet containment, shielding, and criticality requirements after being subject to the tests for normal conditions of transport (NCT) and hypothetical accident conditions (HAC).

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

EVALUATION

1.0 GENERAL INFORMATION

The HI-STAR 80 package is a Type B(U)F-96 packaging for transporting radioactive material, including commercial spent nuclear fuel (SNF) and low to high level non-fuel waste (NFW), under exclusive use shipment by rail, road, or seagoing vessel.

The HI-STAR 80 package is a cylindrical steel cask that provides containment and shielding with an approximate length and diameter of 212-in and 90-in, respectively, fitted with AL-STAR 80 impact limiters and is designed to carry (fully or partially) loaded boiling water reactor (BWR) and PWR fuel baskets or non-fuel waste baskets.

The HI-STAR 80 consists of a cryogenic nickel steel shell welded to a stainless-steel forging at the bottom and a welded machined stainless steel forged flange at the top. The stainless-steel forged flange consists of machined surfaces that allow the connection of two independent stainless steel or cryogenic nickel steel closure lids each equipped with two concentric elastomeric seals, and each fastened to the stainless-steel forged flange with a set of closure bolts constructed of either SA-564-630 H1100 or SB-637 N07718. The containment system, including both closure lids, is designed and manufactured to the 2010 Edition of the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel (BPV) Code Section III, Division 1, Subsection NB (ASME 2010a).

The maximum gross weight of the HI-STAR 80 package (with impact limiters, the F-32B fuel basket, and fuel assemblies, spacers, and no personnel barrier) is 106,475 kg per table 7.A.1 of

the application. The weight of the empty Cask (with F-32B Fuel Basket) is 81,250 kg and 77,472 kg without basket or shims.

Quivers are added to the allowable contents for both the F-12P and F-32B baskets. Quivers are containers for storing separated spent fuel rods. Up to 10 PWR fuel assemblies, of which 4 may be quivers, are allowed to be loaded in the F-12P basket, and up to 28 BWR fuel assemblies, of which 12 may be quivers, are allowed to be loaded in the F-32B basket. Quivers are restricted to certain peripheral basket locations where temperatures are lower.

The applicant properly addressed criticality safety of arrays of spent fuel transportation packages and the package has a criticality safety index of 0.0.

The package is constructed and assembled in accordance with the following Drawing numbers:

HI-STAR 80 Cask Drawing No. 9800, Sheets 1-11, Rev. 13

F-12P Fuel Basket Drawing No. 9796, Sheets 1-4, Rev. 7

F-32B Fuel Basket Drawing No. 9797, Sheets 1-4, Rev.7

FWB-1 Non-Fuel Waste Basket Drawing No. 9798, Sheets 1-2, Rev.7

HI-STAR 80 Impact Limiter Drawing No. 9801, Sheets 1-7, Rev. 7

HI-STAR 80 Transport Package Drawing No. 9795, Sheets 1-7, Rev.5

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

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

2.0 STRUCTURAL AND MATERIALS EVALUATION

2.1 STRUCTURAL EVALUATION

The applicant included 13 proposed changes as summarized in Enclosure 1 of the application (Reference 2). The staff reviewed the 13 proposed changes and found that the following 3 proposed changes are most relevant to the structural performance of the package and required structural evaluations. Those proposed changes (PCs) are:

- PC 1 - Separated Spent Fuel Rods in Quiver Containers,
- PC 6 - Increased Cask Design Internal Pressure to 145 psi for the Cavity, and
- PC 7 - Preload/Torque Values for Vent Port Outer Closure Lid Cover Plate Bolts and Drain Port Cover Plate Bolts.

This safety evaluation report (SER) section evaluates the structural analyses of the HI-STAR 80 package performed by the applicant with the proposed changes to verify that the structural performance of the HI-STAR 80 package meets the regulatory requirements of 10 CFR Part 71 under both NCT and HAC.

2.1.1 General Information

The HI-STAR 80 package is comprised of a cylindrical cask consisting of: (i) a cryogenic nickel steel forging or plate containment shell, bottom stainless steel forging with trunnions, stainless steel forged flange with trunnions, double closure lids with two machined concentric groves in each lid for elastomeric O-rings, closure lid bolts, gamma capture space, and a neutron capture space, (ii) PWR or BWR fuel basket or non-fuel waste basket, (iii) two cylindrical impact limiters constructed of a rigid stainless steel enclosure filled with an aluminum honeycomb crushable materials, and (iv) a personnel barrier.

In the Cask Licensing Drawing 9800 Rev. 13, the applicant made the following design changes:

- (i) revised the size of Weld 71 to 9/16 inch and Weld 39 to a 9/16-inch bevel weld with a 3/8 inch cover fillet since the changes in weld size add additional strength to the structural support for the cask bottom trunnions and increase trunnion load capacity,
- (ii) revised Weld 70 as an optional seal weld because this weld is no longer credited as part of the bottom trunnion structural support,
- (iii) included a "Type 2" extended length top trunnion with an option of adding extended length top trunnion to Sheet 10 since this design change improves operational activity to connect the lifting equipment with the trunnion, and
- (iv) allowed an option for redundant leak test ports approximately 180° apart from illustrated test ports, as this option improves the ability to calibrate the leak testing equipment in order to reduce expected worker dose.

In the Impact Limiter Licensing Drawing 9801 Rev. 7, the applicant made a design change, which includes an option for use of threaded studs and nuts as an alternative to the headed bolts used to attach the impact limiter to the cask since threaded studs are structurally equivalent to headed bolts.

In the Basket Licensing Drawings 9796 Rev. 7 and 9797 Rev. 7, the applicant made the following design changes:

- (i) revised the fuel spacer lifting bar as a reference dimension, and included a local note to allow the bar size to vary since this improves operational activities to optimize the ease of use for the handling of the fuel spacers,
- (ii) included optional rectangular lower flow holes in the fuel spacers that have the same width and equivalent area to the original flow hole as this optional design provides flexibility for different type of handling tools,
- (iii) included the option for stainless steel as a fuel spacer retention bar material type, as it provides a material type with an increased durability compared to aluminum,

- (iv) included an option to use mechanical fixing components such as locking clips or cotter pins in place of the welds that secure washers to the end of the fuel spacer retainer bar,
- (v) made an option for the fuel spacer tube to be fabricated from a round tube in place of a square tube, and
- (vi) specified the fuel spacer top plate thickness as a minimum requirement to allow the use of a thicker plate since a thicker top plate allows for larger lead-ins and guiding chamfers to be used for installation operations and setting of the fuel assemblies during loading.

The staff reviewed the drawings of the HI-STAR 80 for completeness and accuracy, and finds that the geometry, dimensions, material, components, notes, and fabrication details are adequately incorporated in the application and are acceptable.

2.1.2 Evaluations of the HI-STAR 80 Package

The applicant used the finite element (FE) method to perform the evaluations of the HI-STAR 80 package under NCT and HAC. The evaluations are presented in sections 2.6 and 2.7 of the SAR, Rev. 4. The structural analyses of the evaluations provided in those sections were performed using either ANSYS or LS-DYNA FE software. The ANSYS and LS-DYNA FE models used for the structural analyses in the SAR, Rev. 4 are identical to those ANSYS and LS-DYNA FE models used for the structural analyses of the previous SAR revision (Reference 3), which were reviewed and accepted by the staff, except that the LS-DYNA FE models in the proposed SAR, Rev. 4 used the appropriate input parameters based on the proposed changes for the structural analyses.

For instance, the applicant used LS-DYNA FE structural analyses to determine the maximum acceleration loads on a partially loaded package, with a surrogate weight that bounds the weight of the quiver (PC 1), and showed these accelerations are less than allowable values to maintain the quiver's structural integrity (Reference 4) as shown in the Calculation Package HI-2167023-R6.

Additionally, the applicant used the proposed design internal pressure of 145 psi of the Proposed Change 6 (PC 6) for structural qualification of the containment boundary (including the inner closure lid and closure bolts) using analytical calculations and ANSYS FE structural analyses as shown in Calculations 3, 5, and 11 in the Calculation Package HI-2156553-R6.

The updated design internal pressure is provided in table 2.1.1 of the SAR, Rev. 4. The SAR, Rev. 4 and the applicant's calculation packages (Enclosures 5 and 6 of the application) include input parameters for structural analyses with all appropriate structural members of the cask, impact limiters and contents using elastic-plastic material models that accurately capture deformation, stress, and strain.

2.1.2.1 Finite Element Models of the HI-STAR 80 Package

The LS-DYNA FE structural drop analyses performed in this application predict the responses (e.g., the deceleration) of the HI-STAR 80 package under various drop conditions as well as the stress and strain results for the structural evaluation of the cask structural members, which are shown in section 11.0 of the Calculation Package HI-2167023-R6 (Enclosure 5 of the application).

The applicant stated that the HI-STAR 80 is designed to transport 12 PWR or 32 BWR fuel assemblies, where the maximum weight of a PWR fuel assembly is 800 kg, which is the increased PWR fuel assembly weight of the Proposed Change 3 (PC 3). The maximum weight of a BWR fuel assembly is 360 kg. Although the weight of a 800 kg PWR fuel assembly is much greater than that of a 360 kg BWR fuel assembly, the total weight of 32 BWR assemblies is greater than 12 PWR assemblies, so the fully loaded BWR content will generate higher inertial loads during impact that may cause greater damage to the basket and containment. Therefore, the previous FE results for a fully loaded BWR package are still applicable and bound a fully loaded PWR package.

For example, the applicant used the BWR fuel assembly for the horizontal orientation structural analyses because the maximum loading applied to the very bottom section of vertical PWR fuel basket panels is about 1,200 kg and 33.3 percent (%) smaller than that of BWR fuel basket panels of 1,800 kg due to:

- (i) the extra load-bearing flux trap panels in the PWR fuel basket, and
- (ii) a relatively small number of loaded PWR fuel assemblies. As a result, all HI-STAR 80 package drop analyses were performed for the governing package configuration loaded with 32 BWR fuel assemblies to obtain bounding fuel basket structural analysis results.

The applicant submitted three updated LS-DYNA models as part of the application. Two of the LS-DYNA models were updated partially loaded package analyses, which simulated the HI-STAR 80 being loaded with only one lower bound 240 kg BWR fuel assembly. The modeling results are presented in appendix H of the Calculation Package HI-2167023-R6. Additionally, NCT load case N2 (Case 10 in table 7.1 of the HI-2167023-R6) was updated, and the LS-DYNA model was submitted for review.

The applicant had originally submitted two 50% partially loaded LS-DYNA models for review. During the RAI process, these models and results were removed from appendix H of the Calculation Package HI-2167023-R6. The applicant stated that these original partially loaded cases, which considered a 50% loaded cask and was first introduced in the Calculation Package HI-2167023-R4, was chosen to match the weight of the partially loaded cases analyzed in the Calculation Package HI-2167211 as part of section 5, "Shielding Analysis," of the SAR, Rev. 4 [and also discussed the details in subsection 5.4.11, "Empty Basket Cells (Partially Loaded Cask)," but it had no other significance. Since the results for the 50% loaded cask were not controlling based on the former results in appendix H of the Calculation Package HI-2167023-R5, nor were they presented in SAR chapter 2 of the SAR, Rev. 4, the 50% partially loaded cases were not updated and instead deleted from appendix H of the Calculation Package HI-2167023-R6.

The information discussed in the following FE parameters paragraphs is based on the review of the LS-DYNA input files (DYN), the LS-DYNA graphical output results files (D3PLOT), and LS-DYNA binary output results files (BINOUT) submitted by the applicant in the application.

Geometry and Weight: A half-symmetry geometry used for the supplemental LS-DYNA models included all structurally relevant components indicated in the design drawings located in section 1.3 of the HI-STAR 80 SAR, Rev. 4. A spot check of the dimensions and weights using the LS-DYNA input and output files indicate that the LS-DYNA models analyzed the correct geometry and weights of the cask, impact limiters and basket. The fuel assembly is modeled as a solid monolith and is appropriate for the free drop structural evaluations of the basket and cask. The

partially loaded cases used the lower bound 240 kg BWR fuel assembly weight and the fully loaded side drop case used the upper bound 360 kg BWR fuel assembly weight.

Material Properties and Material Models: Three different material models were used in the supplemental LS-DYNA models and are appropriate for these analyses. Elastic material properties were used for the BWR fuel assemblies, elastomeric seals, closure bolts, and fastener strain limiter (FSL) lower bushing. These material properties for the closure bolts and FSL were reviewed and found to be consistent with the SAR, Rev. 4.

Aluminum honeycomb crushable foam properties are used for the impact limiters. The material properties for the different crushable materials (Type 1, Type 2, and Type 3) were reviewed and found to be consistent with what is shown in appendix C of the Calculation Package HI-2167023-R6.

A bilinear stress-strain relationship constructed from the material's elastic and tangent moduli is used for the aluminum FSL upper bushing, HOLTITE B neutron shielding, lead shielding, fuel basket aluminum shims, and aluminum enclosure shells. The elastic and tangent moduli for the lead and the elastic modulus for the aluminum components were reviewed and found to be consistent with the SAR, Rev. 4.

Element Formulations and Element Discretization: From a review of the LS-DYNA input files, the LS-DYNA models used selectively reduced thick shell elements (Type 2) with 10 integration points, fully integrated shell elements (Type 16) with 10 integration points, fully integrated solid elements (Type 2), and constant stress solid elements (Type 1) to define HI-STAR 80 package geometry with a total of 1,848,846 elements and 2,259,774 nodes. These element formulations are appropriate for the structural analyses.

The element discretization studies were performed on the aluminum honeycomb impact limiter to determine a suitable mesh density with element aspect ratio less than 10. Additionally, the element discretization of the HI-STAR 80 cask body and contents were developed with finer meshes than what is in the LS-DYNA models for current U.S. NRC licensed HI-STARs (i.e., HI-STAR 60, HI-STAR 180 and HI-STAR 180D). The element discretization is appropriate for these analyses.

Contact Properties and Contact Conditions: The LS-DYNA models use contact elements between the component surfaces with a static and dynamic friction coefficient of 0.50. Additionally, an interior contact element model is used to model the contact between the different impact limiter pieces. The use of contact models is appropriate for these analyses.

Boundary Conditions, Loads and Initial Conditions: A symmetry boundary condition for the half-symmetric HI-STAR 80 geometry is implemented in the LS-DYNA models. Gravitational acceleration is applied during dynamic relaxation (DR) and the drop analyses.

The initial velocity was applied at the beginning of the analysis to the entire LS-DYNA model, excluding the impact surface, in the z-direction. The NCT side drop velocity for the 1-ft (0.3 m) drop was 95.5 in/s and the HAC slapdown drop velocity for the 30-ft (9 m) drop was 527.45 in/s. A maximum normal operating pressure (MNOP) of 80 psi is applied in the LS-DYNA models as a uniform pressure on the inner closure lid plug and gamma shield cover plate (Part IDs 8 and 81) instead of the entire internal cavity space (i.e., bottom forging and containment shell) during DR and the drop analysis. The application of this pressure is sufficient based on the justification added to subsection 2.7.1.1 of the SAR, Rev. 4.

The MNOP specified in table 2.1.1 of the SAR, Rev. 4 is applied only to the inner closure lid plug and the gamma shield cover plate for the following reasons: (i) the closure lid bolts and the closure seals are the most vulnerable components of the containment boundary system (CBS), (ii) for the remaining components of the CBS, the induced stresses due to the MNOP are small in comparison to the mechanical stresses due to the drop event, and (iii) for the containment shell, the tensile hoop stress due to the MNOP counteracts against the effects of the 9-meter side drop.

A uniform pressure of 20 psi is applied to the outer closure lid (Part ID 11) during DR and the drop analysis. The bolting preload of 60 ksi and 20 ksi is applied to the inner closure lid bolts and outer closure lid bolts, respectively, during DR only and remains active during the drop analysis.

2.1.2.2 Results of the Structural FE Analysis of the HI-STAR 80 Package

The applicant performed the three structural analyses using the LS-DYNA FE models with the material properties, boundary conditions and loadings described above, and provided the results of the three updated LS-DYNA model analyses. Two of the LS-DYNA models were the partially loaded package analyses where only one fuel assembly of lower bound weight (240 kg) was analyzed in a half-symmetry model configuration. These cases represented the worst-case NCT (side drop) and HAC (slapdown) drop evaluations.

The third LS-DYNA model analysis was the NCT load case N2 (Case 10 in table 7.1 of the Calculation Package HI-2167023-R) for the fully loaded 0.3 m side drop for NCT.

Results of the Partially Loaded Package: From the new section 2.1.5 of the HI-STAR 80 SAR, Rev. 4, the HI-STAR 80 is allowed to be loaded with only one fuel assembly as a partially loaded package. The limiting NCT (0.3 m side drop) and HAC (9 m slapdown drop) scenarios were analyzed with a single, defeatured 240 kg BWR fuel assembly. A comparison of these partially loaded cases to the fully loaded package companion cases is shown in appendix H of the Calculation Package HI-2167023-R6.

The maximum drop deceleration and the maximum bolting stresses are the metrics used to demonstrate that the structural integrity of the package is maintained. A quiver to contain damaged fuel rods is also permitted in the HI-STAR 80 and discussed in the SAR, Rev. 4. It is noted that the greater weight of the lower bound BWR fuel assembly bounds the influence of the lighter weight quiver on the structural response/damage of the basket and cask.

Table H-2 of the Calculation Package HI-2167023-R6 reports the maximum bolt stress intensity for the partially loaded package for comparison with the fully loaded cases. The true maximum bolt Tresca stress fringe plots are shown in Figures H-4 through H-7 of the Calculation Package HI-2167023-R6.

A comparison of what the applicant reported as maximum bolt stress intensity and the actual maximum bolt stress intensity from the model for the partially loaded package cases is shown in table 1 below.

Table 1. Comparison of Maximum Bolt Stress to Reported Maximum Bolt Stress

Drop Accident	Lid Bolt	Reported Maximum Bolt Stress (ksi)	Actual Maximum Bolt Stress (ksi)	Allowable Bolt Stress (ksi)
9M Slapdown Drop (HAC)	Inner	98.56	109.04	138.05
	Outer	111.68	123.64	
0.3M Side Drop (NCT)	Inner	62.40	77.25	100.05
	Outer	70.90	78.46	

The reported maximum bolt stress in table 1 above was based on an applicant's approach provided in the Calculation Package HI-2167023-R6 to select a 'representative' fringe value from the contour stress plot. The applicant used this approach to mitigate expected stress concentrations in the mesh of the closure bolts. However, this type of approach may not be conservative and can potentially lead to different maximum reported stress values based on the number of divisions used on the fringe scale or what fringe color the analyst visually identifies on the bolts themselves.

The staff was able to obtain different higher peak bolt stresses from the Calculation Package HI-2167023-R6 and provided them in table 1 as "Actual Maximum Bolt Stress." Both reported and actual maximum stresses are acceptable since they are smaller than the allowable stress values, but the applicant's approach did not provide a conservative stress value. Therefore, endorsement of the analytical results in this application should not be construed as an approval of the approach to determine maximum bolt stress for all future applications. Use of such an approach for future demonstrations of package safety may result in similar limitations on its use.

In addition, a good practice to mitigate expected stress concentration in closure bolt meshes is to calculate axial, bending, and shear stresses from extracted forces and moments on each bolt.

Results of the Fully Loaded Package: The maximum drop deceleration and the maximum bolting stresses are reported in appendix H of the Calculation Package HI-2167023-R6 for comparison to the partially loaded side drop case. Table H-2 of the Calculation Package HI-2167023-R6 reports the maximum bolt stress intensity for the fully loaded 0.3 m side drop under NCT.

A comparison of what the applicant reported as maximum bolt stress intensity and the actual maximum bolt stress intensity from the model is shown in table 2 below.

Table 2: Comparison of Maximum Bolt Stress to Reported Maximum Bolt Stress

Drop Accident	Lid Bolt	Reported Maximum Bolt Stress (ksi)	Actual Maximum Bolt Stress (ksi)	Allowable Bolt Stress (ksi)
0.3M Side Drop (NCT)	Inner	66.62	82.51	100.05
	Outer	69.22	76.58	

Again, both reported and actual maximum stresses are acceptable since they are smaller than the allowable stress values, but the applicant's approach did not provide a conservative stress value. Therefore, endorsement of the analytical results in this application should not be construed as an approval of the approach to determine maximum bolt stress for all future applications. Use of such an approach for future demonstrations of package safety may result in similar limitations on its use.

2.1.3 Evaluations of the Proposed Changes

2.1.3.1 Proposed Change 1 - Separated Spent Fuel Rods in Quiver Containers

The applicant proposed to add quivers to the allowable contents for both F-12P and F-32B baskets. The reason for the Proposed Change 1 (PC 1) is that it is necessary for the applicant to transport separated fuel rods with the HI-STAR 80 package and found that the quivers provide a proven means to do so.

The quivers are containers for storing damaged spent fuel rods. The applicant added Figure 1.2.2 to chapter 1 of the SAR, Rev. 4 to provide the typical illustration of a quiver along with general information (i.e., nominal width, maximum length, maximum loaded quiver weight, maximum allowable quiver weight, material of construction, etc.). Section 1.2.2 of the SAR, Rev. 4 provides further description of the quiver.

Table 2.2.1, "Structural Capacity Data on the Quiver," of the SAR, Rev. 4 summarized the structural design data on the quiver, which is extracted from Reference 4. The structural capacity data (including structural criteria) includes total weight, normal handling, NCT drop, HAC drop, and design internal pressure from any scenario leading to heating of the quiver. The applicant stated that:

- (i) the structural performance of the cask must ensure that the loading limits in table 2.2.11, "Structural Capacity Data on the Quiver," are unconditionally met, and
- (ii) the maximum axial/lateral deceleration sustained by the quivers must remain below the design limit.

As a result, the applicant did not perform any LS-DYNA FE structure analyses with the quivers in this application since table 7.D.1, "Fuel Assembly Limits," of the SAR, Rev. 4 limits the weight of the quiver to less than the weight of a fuel assembly with essentially the same identical external dimensions.

Additionally, the structural analysis of the quiver, which is described in subsection 1.2.2 and illustrated in Figure 1.2.2, is summarized in the Westinghouse SKB Quiver specification: the quiver has been analyzed for all applicable load cases, including normal handling, internal pressure, external pressure, and hypothetical drop accident (i.e., 9-meter free drop).

The calculated results for all analyzed load cases satisfy the acceptance criteria and confirm that the quiver assembly, including the sealed tubes containing damaged fuel rods, will maintain its structural integrity under transport loading conditions and, therefore, prevent the escape of any fuel debris. There is no redistribution of damaged fuel rods under transportation loading conditions.

The staff reviewed table 7.D.1 the SAR, Rev. 4 and applicant's statement and found that PC 1 is acceptable because: (i) structurally, the greater weight of the fuel assembly bounds the influence of the lighter weight quiver on the structural response/damage of the basket and cask, (ii) the HI-STAR 80 SAR, Rev. 4 contains analysis results to demonstrate that maximum accelerations of the HI-STAR 80 are within allowable values established for the quiver design located in the Westinghouse documentation (Reference 4), and (iii) table 7.D.1 of the SAR, Rev. 4 limits the weight of the quiver to be less than the weight of a fuel assembly with essentially the same identical external dimensions.

As a result, there is no impact on the structural analysis of the package with the use of the quiver based off the previous fully loaded package analyses in sections 2.6 and 2.7 of the SAR and the partially loaded package analyses presented in appendix H of the Calculation Package HI-2167023-R6.

2.1.3.2 Proposed Change 6 - Increased Cask Design Internal Pressure to 145 psi for the Cavity

The applicant proposed to increase cask design internal pressure to 145 psi for the cavity space. The reason for the Proposed Change 6 (PC 6) is that the increased design internal pressure of 145 psi for the cask cavity space allows an increase in cask pressure when water is being circulated through the cask during loading/unloading operations.

The staff reviewed the applicant's structural analyses and statements, and found PC 6 is acceptable because: (i) table 2.1.1, "Pressures and Temperatures for Normal and Accident Conditions," of the SAR, Rev. 4 reflects the increase cask design internal pressure to 145 psi, and (ii) structural evaluations were performed with the internal pressure of 145 psi in Calculation Package HI-2156553-R8 (Enclosure 6 of the application) and demonstrated that the calculated safety factors for the outer and inner closure lid bolts under the loading conditions are greater than one, as required. Therefore, PC 6 is acceptable.

2.1.3.3 Proposed Change 7 - Preload/Torque Values for Vent Port Outer Closure Lid Cover Plate Bolts and Drain Port Cover Plate Bolts for the Cavity

The applicant proposed to revise: (i) the total preload specified for the inner closure lid cover plate bolts to be consistent with the ASME BPV Code Division I, Subsection NB requirements for design conditions and consistent with revised containment seal seating load requirements, and (ii) the torque specified for the outer closure lid access port plug in table 7.1.1 of the SAR, Rev. 4 as a preload and evaluated consistent with ASME BPV Code Division I, Subsection NB, requirements for design conditions and consistent with revised containment seal seating load requirements. The only reason for the Proposed Change 7 (PC 7) is that the proposed change is necessary for completeness of ASME BPV Code compliance, although the safety case was made in the previous SAR (Reference 3).

The applicant's approach was to perform stress calculations on the various closure bolts in the package as documented in Enclosure 6 (Calculation Package HI-2156553 Rev 8) of the application. The bolt structural integrity was evaluated against Subsection NB stress limits for Level A and Level D service conditions (table 2.1.3 of the SAR, Rev. 4) to determine the recommended torques needed to generate the minimum total preload for the containment seals of the cover plates (table 7.1.1 of the SAR, Rev. 4).

The staff reviewed the applicant's approach and statements and found PC 7 acceptable because: (i) all those specified stress values were previously reviewed and accepted by the

staff, (ii) the proposed changes are only related to a revision to be consistent with the ASME BPV Code Division I, Subsection NB, requirements, and (iii) there is no safety issue involved. Therefore, PC 7 is acceptable.

2.1.4 Evaluation Conclusion

The staff reviewed the applicant's proposed four changes which required structural evaluation and concludes that those proposed four changes to the HI-STAR 80 package are acceptable. The structural performance of the HI-STAR 80 package with these changes are in compliance with the requirements of 10 CFR Part 71. The evaluation of the structural analyses provides reasonable assurance that the HI-STAR 80 package will allow safe transportation of spent nuclear fuels. This finding is reached on the basis of a review that considered the applicable regulations, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

References:

1. U.S. Nuclear Regulatory Commission, Certificate of Compliance No. 9374 for the HI-STAR 80, Revision 1.
2. "Licensing Amendment Request 9374-2 for HI-STAR 80 Transportation Package," Holtec Letter 2370009, July 29, 2021.
3. "The Safety Analysis Report on the HI-STAR 80," Holtec Report HI-2146261, Revision 0.
4. "SKB Quiver – Data for external use", Report NRT 18-403, Latest Revision (Westinghouse Electric Sweden AB Proprietary Report).

2.2 MATERIALS EVALUATION

The staff evaluated the following proposed revisions to the HI-STAR 80 that rely on materials performance characteristics that were not previously evaluated for this transportation package:

- 1) Inclusion of quivers (for leaking fuel rods, broken fuel rods, fuel rod fragments and single rod capsules)
- 2) Test criteria for bolt material
- 3) Fuel cladding alloys

The staff reviewed these proposed changes to ensure that the applicant adequately evaluated materials performance under normal conditions of transport and hypothetical accident conditions. The staff used the guidance in NUREG-2216, chapter 7, to conduct the review.

2.2.1 Drawings

The applicant provided drawings in section 1.3 of the SAR and referenced Quiver details in Westinghouse report (NRT 18-403). The staff reviewed the drawing content 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 material specifications, material properties dimensions, welding specifications, coatings, and post-weld examination requirements. Therefore, the staff finds the drawings to be acceptable.

2.2.2 Codes and Standards

The applicant did not make any changes to the materials codes and standards cited in the drawings and summarized in SAR tables 8.1.6 and 8.1.7. The Quiver codes and standards are listed in NRT 18-403. The staff reviewed the codes and standards for the quivers and determined that the cited codes were acceptable for the materials, fabrication, and examination of this component. Therefore, the staff finds the materials codes and standards to be acceptable.

2.2.3 Welding and Inspection of Quivers

The Quiver welding details are referenced in section 7.1 of NRT 18-403. Welding activities are governed under the SS-EN ISO 3834, and personal performance qualifications are certified according to SS-EN 287-1 or ISO 9606-1:2013. Welding procedures are qualified in accordance with SS-EN ISO 15614-1:2004/A2:2012. The inspection criteria for PWR quivers is in accordance with SS-EN ISO 17637:2011 and BWR quivers with SS-EN ISO 17637:2017. Pressure retaining welds are inspected to ISO 5817:2014 Class B and SS-EN ISO 3834-2.

These standards provide adequate level of requirements that are similar to other accepted welding and inspection standards. Therefore, the staff finds welding and inspection of Quivers acceptable.

2.2.4 Mechanical Properties of Quivers

Mechanical properties of the quivers are referenced in discussed in section 8 of NRT 18-403. The quivers do not have a nuclear safety class; however, it is evaluated in accordance with ASME BPV Code, Section III, NC-3200 Class 2 components in all applicable load cases. The applicant stated elastic analysis was performed in accordance with ASME NC-3217 and ASME Section II, Part D, Appendix 2-110, as shown in table 8-1 of NRT 18-403.

A limit analysis was performed in accordance with ASME NB-3228.1 for Service Level B and Section III, Appendices F-1331(c)(2) for Service Level D as shown in table 8-2 of NRT 18-403.

The applicant also stated that since different parts of the quivers are made from different stainless-steel forms, the most conservative material data and physical properties were used, in accordance with ASME II Part D. A summary of results and acceptance criteria are provided in section 8.2 and section 8.3 of NRT 18-403 for the BWR and PWR quivers, respectively. Based on the applicant's evaluation of the mechanical properties in accordance with the ASME Code, the staff finds the mechanical properties of quivers to be acceptable.

2.2.5 Test Criteria for Bolts

The applicant updated the acceptance criteria for ferritic steel closure bolts in SAR section 2.1.2.2, where the applicant stated that all inner and outer lid bolts are examined to meet or exceed the applicable requirements of ASME Code, Section III, Subarticle NB-2580, which are applicable to use of bolts, studs and nuts. The staff finds that the required examinations and the acceptance standards in the cited ASME Code to be acceptable.

2.2.6 Fuel Cladding Alloys

The staff reviewed the new allowable fuel cladding alloys which expand the types of zirconium cladding alloys. The applicant referenced a publicly available report DMG1273679 from Vattenfall Nuclear Fuel AB that compared cladding characteristics and performance. This report

supports that the newly added fuel cladding types have essentially the same mechanical properties and performance as previously accepted cladding types.

The applicant presented the fatigue performance of the cladding in SAR section 2.6.5 and provided a fatigue endurance limit of 177.5 MPa for zircaloy cladding cited in NUREG/CR-1132 "A Survey of Potential Light Water Reactor Fuel Rod Failure Mechanism and Damage Limits", table 1. The value provided in the SAR aligns well with Zircaloy-2, which has a permissible stress amplitude of 180-185 MPa at 1×10^6 cycles. However, for other cladding types (M5, ZIRLO, Zircaloy-4), the fatigue endurance is less for 1×10^6 cycles at 55MPa (8.0 ksi). Although this is less than Zircaloy-2, it exceeds the maximum bending stress of 34.65 MPa (5.025 ksi) per SAR table 2.6.9.

Induced strains in the cladding due to MPC re-flooding are provided in SAR section 2.6.1.3.5, which are bounding because a conservative yield strength of 382.6 MPa (55,500 psi) is used, which leads to overestimation of the cladding strain. In addition, the applicant states that the safety basis for the cask is moderator exclusion and does not rely on the cladding to withstand damage during any HAC.

The applicant states that the structural evaluation presented in section 2.11 of the SAR is provided and performed as a defense-in-depth analysis. The applicant provided information that the newly added cladding types can be considered as zirconium-based cladding as stated in the SAR and, the fatigue and re-flood analysis provided in the SAR is bounding. Therefore, the staff finds the addition of new fuel cladding alloys acceptable.

2.2.7 Corrosion Resistance and Content Reactions

The staff reviewed the amendment changes and verified that they do not introduce any material-environment combinations that were not previously considered for potential adverse or corrosive reactions in the staff's prior review of the HI-STAR 80. Therefore, the staff finds the materials properties and design of the quivers, new fuel alloys, and transportation package for corrosion resistance and prevention of adverse reactions to be acceptable.

2.2.8 Evaluation Findings

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

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

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

The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.43(d), and 10 CFR 71.87(b) and (g). The applicant has demonstrated that there will be no significant corrosion, chemical reactions, or radiation effects that could impair the effectiveness of the packaging.

The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.55. The applicant provided sufficient details for the design and construction of this transportation package to support the staff's evaluation.

3.0 THERMAL EVALUATION

3.1 Review Objective

The objective of the thermal review of the HI-STAR 80 transportation package was to verify that the thermal performance of the package has been adequately evaluated for the tests specified for NCT and HAC, and that the package design satisfies the thermal requirements of 10 CFR Part 71. The application was also reviewed to determine whether the package is consistent with the acceptance criteria listed in section 3 of NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material."

The applicant sought approval of the following changes that affect thermal performance:

- 1) Add quivers to the allowable contents for both F-12P and F-32B baskets,
- 2) Provide additional heat load patterns for a cask cavity space pressure down to 20.0 kPa (2.9 psia)

3.2 Thermal Evaluation under Normal Conditions of Transport

Section 3.3.1 in the SAR describes the HI-STAR 80 thermal model that the applicant used to perform the thermal evaluation of the package. Except for the addition of quivers (up to 4 quivers in PWR and 12 quivers in BWR), the thermal model (using ANSYS FLUENT CFD code) of the HI-STAR 80 is the same as described in SAR section 3.3.1 which the staff has previously reviewed. A quiver is defined in SAR chapter 1 as precision engineered box to store slightly or severely damaged fuel rods in a helium backfilled environment.

The applicant performed steady state analysis during NCT of the HI-STAR 80, with the addition of quivers. SAR tables 3.3.12 and 3.3.13 for component temperatures for casks with PWR and BWR fuel, respectively shows predicted component temperatures during NCT conditions. Because of the lower decay heat for casks with quivers, all predicted temperatures are significantly lower than the applicable limits.

Results for component temperatures and quiver pressures for casks with PWR and BWR fuel under normal conditions are presented in SAR tables 3.3.12 and 3.3.13 respectively. The results show that quiver pressure meets the design pressure limit presented in SAR table 3.2.14.

3.3 Thermal Evaluation under Hypothetical Accident Conditions

The applicant performed a transient thermal analysis to evaluate the HI-STAR 80 transport package under HAC with the addition of quivers. The initial conditions of the package, prior to the start of the fire accident, are based on the NCT temperature distribution, as described in the SAR section 3.1.3. The applicant's thermal model for fire analysis assumes an emissivity coefficient of 0.9, a flame temperature of 800°C (1475°F). Forced convection heat transfer is used with a convection coefficient of 25.5 W/m²-°C. The forced heat transfer coefficient values

used in the HAC analysis is based on Sandia National Laboratory Report “Thermal Measurements in a Series of Large Pool Fires”, Sandia Report SAND85– 0196 TTC – 0659 UC 71, (August 1971).

The applicant’s predicted temperatures and pressures of the HI-STAR 80 package when quivers are used are based under hypothetical accident conditions presented in SAR section 3.4.1. The results for casks loaded with PWR and BWR fuel are presented in tables 3.4.5 and 3.4.6 respectively. The results show that the temperatures and pressure of all components including the quivers meet their respective allowable limits presented in SAR table 3.2.14 under hypothetical accident conditions.

The staff reviewed the applicant’s analyses of the HI-STAR 80 transportation cask with quivers during NCT and HAC. Based on the information provided in the application regarding these analyses, the staff determines that the application is consistent with guidance provided in section 3.4.5 (Thermal Evaluation under Normal Conditions of Transport) and section 3.4.6 (Thermal Evaluation under Hypothetical Accident Conditions) of NUREG-2216. Therefore, the staff concludes that the analyses are acceptable because the analyses and results satisfy NUREG-2216 and subsequently meet the requirements of 10 CFR Part 71.

3.4 Evaluation Findings

The staff reviewed the application, assumptions, and analysis results to determine consistency with NUREG-2216. The staff agrees with the applicant that the addition of quivers will result in lower temperatures and pressures because of the lower decay heat for cask with quivers. The staff reviewed predicted temperatures and pressures and verify that all predicted values are lower than the allowable limits presented in the application.

Based on its review of the application, the staff concludes that the HI-STAR 80 transport package thermal design has been adequately described and evaluated for the SAR changes as described in section 3.1, and that the thermal performance of the package meets the thermal requirements of 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

4.1 Review Objective

The objective of the containment review of the HI-STAR 80 transportation package was to verify that the containment performance of the package had been adequately evaluated for the tests specified under NCT and HAC, and that the package design satisfies the containment requirements of 10 CFR Part 71. This case was also reviewed to determine whether the package fulfills the acceptance criteria listed in section 4 (“Containment Evaluation”) of NUREG-2216, “Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material.”

The applicant sought approval of the following change that affect containment performance:

1. The proposed change revises the helium leakage rate acceptance criteria and test sensitivity in SAR table 8.1.1 for the HI-STAR 80 containment enclosure leakage rate test.

4.2 Containment Evaluation under Normal Conditions of Transport

Section 4.1 of the SAR provides a description of the HI-STAR 80 containment system. The containment system has been reviewed previously and the SAR revision provided in the application does not include any changes related to the containment system.

The applicant stated that the leakage rate acceptance criteria is a reference leakage rate calculated in SAR section 4.6 and specified in SAR table 8.1.1, during NCT. The staff reviewed the calculations provided in SAR section 4.6 and leakage rates provided in SAR table 8.1.1 to make sure reported values were accurate and consistent throughout the SAR.

4.3 Containment Evaluation under Hypothetical Accident Conditions of Transport

Section 4.1 of the SAR provides a description of the HI-STAR 80 containment system. The containment system has been reviewed previously and the SAR revision provided in the application does not include any changes related to the containment system.

The applicant stated that the leakage rate acceptance criteria is a reference leakage rate calculated in SAR section 4.6 and specified in SAR table 8.1.1, during HAC. The staff reviewed the calculations provided in SAR section 4.6 and leakage rates provided in SAR table 8.1.1 to make sure reported values were accurate and consistent throughout the SAR.

4.4 Evaluation Findings

Based on review of the statements and representations in the application, the staff concludes that the HI-STAR 80 transportation package containment design has been adequately described and evaluated for the SAR changes (as described in section 4.1). The staff finds that the containment evaluation results described in the SAR demonstrate that the HI-STAR 80 transportation package satisfies the containment requirements of 10 CFR Part 71, and that the package meets the containment criteria of American National Standards Institute N14.5-2014.

5.0 SHIELDING EVALUATION

This section of the SER documents the staff's evaluation of changes to the package as it relates to its ability to provide shielding from its radioactive contents and limit dose rate to meet regulatory limits in 10 CFR 71.47 and 10 CFR 71.51(a)(2).

The amendment request consists of 8 proposed changes to the CoC and 12 proposed changes to chapter 7, "Package Operations," referenced by the CoC. Some of these changes have no impact on shielding or dose rates and are therefore not mentioned in this portion of the SER. The staff evaluated the following changes that may have an impact to the package shielding design and/or dose rates:

CoC Changes:

1. Updated cask licensing drawing revision from Rev. 7 to Rev. 13
2. Updated F-12P basket licensing drawing revision from Rev. 4 to Rev. 7
3. Updated F-32B basket licensing drawing revision from Rev. 4 to Rev. 7
4. Updated impact limiter licensing drawing from Rev. 4 to Rev. 7
5. Updated Condition 5.(b)(1)(a) to expanded the condition to allow the loading of quivers containing separated fuel rods.

6. Updated Condition 5.(b)(1)(b) to remove explicit reference to local power range monitorings (LPRMs) and only specify the use neutron monitors using fission chambers.
7. Added two new sections to Condition 5.(b)(2) to provide maximum quantity of material per package for the case of a cask containing both fuel assemblies and quivers.
8. Updated Condition 8.(a) to remove explicit reference to fuel debris, so fuel debris may be allowed for transportation in quivers.

Changes to chapter 7 of the application:

1. (PC-1) Separated Spent Fuel Rods in Quiver Containers
2. (PC-2) Additional Loading Patterns
3. (PC-8) Addition of Zirconium-based Fuel Cladding
4. (PC-9) Expand the Allowable Contents for Non-Fuel Hardware
5. (PC-11) Revised/Expanded Cooling, Average Burnup, and Enrichment for F-12P and F-32B Baskets
6. (PC-12) Unauthorized Empty Cell Locations
7. (PC-13) Removed Minimum Enrichment from Glossary

5.1 Addition of Quivers

The staff evaluated the applicant's addition of quivers to the HI-STORM 80 package design and the effect that it has on the shielding design and calculated dose rates. This evaluation covers changes #5, 7, and 8 to the CoC and changes PC-1 to chapter 7 of the application.

As discussed in the glossary and section 1.2.2.1 of the application, a "quiver" is *"a type of damaged fuel container for individual fuel rods that have been removed from their assembly. The fuel rods may be leaking, broken or fragmented (i.e., fuel debris) and purposely punctured (if needed) to relieve internal pressure."* The quivers in the HI-STAR 80 are hermetically sealed.

The addition of the quivers may have an impact on external dose rate because they carry fuel debris, the source may be relocated to locations where the cask may have less shielding. However, the quivers themselves may provide additional shielding.

The locations of the quivers are shown in figures 7.D.3 and 7.D.4 of the application for the F-12P and figures 7.D.5 through 7.D.8 of the application for the F-32B. The loading tables in the application that define the radiation source term (tables 7.D.4 for the F-12P and table 7.D.5 for the F-32B) are independent of the quivers. Mixed oxide (MOX) fuel is limited to locations where quivers are not allowed, therefore quivers will not be allowed to store MOX fuel. Section I.A.1 and II.A.1 of table 7.D.1 in appendix 7.D of the application show that the allowable fuel assembly weight for the quivers is less than the undamaged fuel assembly.

The applicant performed analyses, documented in section 5.4.12 of the application, stating that they performed dose rate analyses for several different cases including PWR and BWR fuel in under different geometrical conditions including uniform burnup profile, collapse of fuel to half height and relocation of fuel to lower area of the basket near areas where there is reduced cask shielding. The applicant neglects the quiver material, which is conservative as it would provide additional shielding further reducing dose rates.

The applicant assumes that the quiver and individual tubes are structurally sufficient for all transport loads and excluded the possibility that debris moves further down below the lower end of the active region of fuel assemblies within the basket.

The applicant states that all calculated dose rates remain bounded by, or statistically equivalent to, the dose rates with full assemblies.

The staff performed independent dose rate calculations to investigate the change in dose rate at various locations at the surface and 2 meters from the package adding failed fuel to the locations where quivers are allowed. The staff performed two calculations to represent the presence of the failed fuel within the quiver. The dose rate around the package from these two calculations were compared to a case where the locations where quivers were allowed contained intact fuel. Similar to the applicant, the staff did not model the presence of the quiver itself.

The first calculation has assemblies in the locations where quivers are allowed modeled with a uniform burnup profile. Assemblies are burned more in the axial center as this is the area where there is the highest neutron flux. This results in relatively higher burnup than the average near the axial center of the assemblies but lower burnup than the average near the extremities. In the case of the HI-STAR 80, the lead shielding is the thickest in the axial center, which is beneficial for reducing dose rates considering the center peaked axial burnup profile of SNF assemblies, however with failed fuel and fuel debris that do not exhibit a known axial burnup profile, higher burnup fuel may be located at the periphery of the fuel assembly.

The second condition is with fuel in the locations where quivers are allowed is reduced in height by 200 cm (approximately half) and with a uniform axial burnup profile and the density being increased accordingly to maintain the total mass. This results in fuel being concentrated at the lower part of the HI-STAR 80 where the lead shield is not as thick. Although the source term is concentrated in this configuration, the density of the fuel is also increased which has a compensatory effect on dose rates.

Both calculations assume a reduced uranium mass of the fuel within the quivers equivalent to the allowable mass of the fuel assembly within table 7.D.1.

The results of the staff's calculations show that for the case with all full height assemblies and the axial burnup profile is uniform, there is a local increase in dose rate at the top and bottom of the package as well as the upper radial and lower radial locations, but as expected there is a decrease in dose rate at the center of the package on the radial surface. The top and bottom of the package are the areas with the lowest dose rate and although there is an increase in dose rate here, they are all well within the regulatory limit. The 2-meter dose rate in the radial direction, which is limiting for this package, did not show a statistically significant change in dose rate in the radial direction. Dose rate at the top increased a statistically significant amount, but the dose rate at this location is already very low and well within the regulatory limit.

For the case with the half-height assemblies in locations where the quivers are allowed, the staff calculations showed that dose rates at the bottom surface and the lower radial surface increased, as well as 2 meters from the bottom, as expected, but dose rates in these locations had plenty of margin to the regulatory limits. The limiting location, 2-meters in the radial direction at the axial middle section of the cask, was statistically equivalent to the dose with intact assemblies in the quiver locations.

The results of the staff's calculations provide additional assurance that the HI-STAR 80 including damaged and failed fuel in the quivers as specified in tables 7.D.1 and 7.D.4 of the application will continue to meet regulatory dose rate limits.

The staff's calculations are discussed in further detail in section 5.9 of this SER.

5.2 Additional Loading Patterns

The applicant stated that it added new heat load patterns to table 7.1.9 of the application to accommodate a lower cask cavity space pressure down to 20.0 kPa. Although radiation source term and decay heat tend to trend together, a relationship between dose rate and decay heat is difficult to establish. Therefore, fuel specifications for purposes of limiting dose rate must be analyzed separately from those used to meet heat load limits.

Because the same assembly must meet both sets of limits, to simplify this for the user, applicants sometimes base the loading patterns used to justify dose rate off of decay heat loading patterns and try to create allowable loading tables that meet both decay heat and dose rate requirements. Therefore, the staff reviewed the additional loading patterns to see if there was any impact on the dose rate analyses.

Although the applicant stated that it updated burnup, enrichment and cooling time to accommodate the additional loading patterns, the loading patterns analyzed for the dose rate analyses are independent of the heat load values in table 7.1.9 of the application as tables 7.D.4, 7.D.5 and 7.D.6 of the application are based on specific locations from Figures 7.D.1 and 7.D.2 of the application. The updated burnup, enrichment and cooling time values are discussed in section 5.5 of this SER.

5.3 Addition of Zirconium Based Fuel Cladding

The applicant expanded the definition of "Zr" within the glossary to include additional zirconium based alloys as allowable contents. Previously the HI-STAR 80 was authorized to ship fuel with zirconium based cladding limited to Zircaloy 2, Zircaloy 4, ZIRLO and M5 cladding. The applicant proposed to expand this definition to include E110, Optimized Zirlo, HiFi, Ziron, Duplex and Axiom.

The staff looked at reference documents to determine the composition of the proposed new cladding types (References 5.4-1 through 5.4-5). Although there are slightly different compositions in the alloy mixtures and a few different nuclides in some of these new cladding materials, the staff did not find any of the alloying materials in a quantity that would introduce a significant source term, such as Cobalt, that would contribute to external dose. Therefore, the staff found the addition of these additional zirconium based cladding types would have no effect on calculated dose rates and can reasonably be represented by Zircaloy as stated in table 5.2.1 of the application.

References:

- 5.4-1 WCAP-14342-A & CENPD-404-NP-A, Addendum 1-A "Optimized ZIRLO." July 10, 2006, ML062080569
- 5.4-2 WCAP-18126-NP, Rev. 0, "HiFi Cladding for Use in Boiling Water Reactor Fuel." June 30, 2017, ML17180A408
- 5.4-3 NEDO-33353-A, Rev. 1, "Application of GNF-Ziron to GNF Fuel Designs." April 10, 2009, ML19100A263
- 5.4-4 EMF-2403(NP), Revision 0, "Duplex D4 (DXD4) Cladding for PWRs." October 21, 2000, ML003769696

5.4-5 WCAP-18546-P / NP, "Westinghouse AXIOM Cladding for Use in Pressurized Water Reactor Fuel," March 31, 2021, ML21090A111

5.4 Expand the Allowable Contents for Non-Fuel Hardware

The HI-STAR 80 has a basket called the "Non-fuel Waste Basket" or "NFWB-1" for transporting reactor related non-fuel waste. The allowable contents for this basket are listed in table 7.D.8 of the application. As part of this amendment the applicant has proposed to modify these contents to change "LPRM neutron monitors using fission chambers," to "neutron monitors using fission chambers." The applicant made this change to be able to transport other types of neutron monitors and not just LPRM neutron detectors. This also affects Condition 5.(b)(1)(b) of the CoC to remove explicit reference to LPRMs and only specify the use of neutron monitors using fission chambers.

Fission chambers measure the neutron flux within a reactor core by utilizing a very small amount of fissile material that fissions and leads to the creation of ions within an ion chamber that can be used to measure the neutron flux. The amount of fissile material used in these chambers is very small, on the order of micrograms ("U.S. Nuclear Regulatory Commission, General Electric Systems Technology Manual, Chapter 5.3, Local Power Range Monitoring System," ML11258A333).

Considering that all fission chambers operate on the same principles, the staff does not expect that different kinds of fission chambers (other than LPRM fission chambers) would have appreciably more fissile material. Even if multiple fission chambers were shipped in the NFWB-1, there are limits on fissile material in table 7.D.8 of the application to 2 grams, which is a relatively small amount and it's the staff's continued judgment that the neutron source from this content is negligible and has not changed with the proposed changes to the current amendment.

Any gamma emitting nuclides from activation of the materials in the fission chamber would continue to be limited by the non-fuel source strength limits in table 7.D.9 of the application, which has not changed with this application.

Based on the above, the staff did not find that changing the contents of the NFWB-1 "LPRM neutron monitors using fission chambers," to "neutron monitors using fission chambers," would have any effect on the calculated dose rates of the HI-STAR 80 and therefore the staff found this change acceptable.

5.5 Revised/Expanded Cooling, Average Burnup, and Enrichment for F-12P and F-32B Baskets.

Burnup, enrichment, and cooling time are used to characterize the neutron and gamma source terms of the SNF. Limitations on these parameters are used to characterize the source and ensure dose rates are within regulatory limits. Allowable burnup, cooling time and enrichment for the HI-STAR 80 are in tables 7.D.4 (F-12P) and 7.D.5 (F-32B) of the application.

5.5.1 Decrease in Number of Cycles F-12P Basket

The applicant updated table 7.D.4 of the application for the F-12P basket to include additional burnup/enrichment/cooling time combinations for fuel that has been burned with reduced

numbers of irradiation cycles. The number of irradiation cycles has an effect on the source term because if an assembly achieved a certain burnup in a fewer number of cycles versus a greater number of cycles, than it was burned with a higher power and neutron flux, which would change the radionuclides present within the spent fuel by creating more activation products and would change the gamma/neutron as well as energy characteristics of the source term.

As discussed in section 5.F.0 of the application, the applicant uses a nominal number of cycles burned for each burnup range to generate source terms. To load assemblies with a different number of cycles burned, the applicant adjusts the cooling time (higher cooling time for higher power/fewer cycles, lower cooling time for lower power/more cycles).

To justify the change in cooling time, the applicant performed a sensitivity study where it studied the change in dose rates over a range of specific powers as defined in table 5.F.1 of the application and table G.1 of Holtec Proprietary Document HI-2177694, "HI-STAR 80 SOURCE TERMS USING SCALE 6.2.1," March 31, 2021, ML21210A414.

This previous study did not cover the expanded range requested in the CoC revision request. To justify reducing the number of irradiation cycles, the applicant performed additional sensitivity studies where they decreased the number of irradiation cycles by two to show that 4 months of additional cooling time would be enough to compensate for the increase in dose from achieving the same burnup with a decreased number of irradiation cycles. The results are shown in table 5.4.38 of the application.

The staff performed an independent dose rate calculation using depletion parameters consistent with Condition Set 3 from table 7.D.4 for the F-12P basket under NCT and HAC. The results of the staff's calculations show that under both configurations the package is within regulatory limits. This provides the staff additional assurance that the new loading parameters with decreased number of irradiation cycles is acceptable.

5.5.2 Decrease Enrichment F-32B Basket

The applicant also expanded table 7.D.5 of the application for the F-32B loadings to include additional enrichment values. Similar to specific power, enrichment affects the source term. For a lower enriched assembly to achieve the same burnup as a higher enriched assembly it must be exposed for either longer, or at a higher power. In either case, additional activation products will be produced and results in a higher source term and higher dose rate. The applicant has stated in section 5.1.2 of the application that calculations are performed with actual enrichment values.

The staff reviewed the new burnup and enrichment values within the tables and for the same burnup, lower enrichment values exhibit a higher cooling time, and higher enrichment values are allowed a lower cooling time. This behavior is expected.

The staff performed an independent dose rate calculation using depletion parameters consistent with one of the new lower enrichment values from Condition Set 3 for the F-32B basket under NCT and HAC. The results of the staff's calculations show that under NCT, the dose rate 2-meters in the radial direction at the axial middle section of the cask was over the regulatory limit of 10 mrem/hr and that under HAC the dose rate 1 meter in the radial direction at the axial middle section of the cask was also over the regulatory limit of 1 rem/hr.

Although the staff calculations show that they exceed the regulatory limits, it is not by a significant amount. Considering the staff's model is built independently using design information and with the differences in modeling, the staff's independent calculations are close to the applicant, this provides reasonable assurance in the applicant's calculations that do show that the HI-STAR 80 meets regulatory limits with the reduced enrichment values.

The staff's calculations are discussed in further detail in section 5.9 of this SER.

5.6 Unauthorized Empty Cell Locations

The applicant discussed loading patterns with empty cells in section 5.4.11 of the application. Since the HI-STAR 80 has uniform loading (i.e., same fuel burnup, enrichment and cooling time for all cells in the basket) removing fuel would not have a major impact on dose rates. Although this removes some shielding that the assemblies provide, it also reduces source term so overall dose rates are typically not impacted.

However, since there are specified locations in which MOX fuel must be loaded, and the applicant performed an evaluation, as discussed in section 5.4.1.1 of the application that shows that the HI-STAR 80 would exceed regulatory limits if the cells on the periphery of the MOX fuel were empty.

The applicant added a note under table 7.D.6 of the application that states that when MOX fuel is loaded, there must also be fuel assemblies loaded into these locations are next to and peripheral to the MOX assemblies. These assemblies will provide some shielding from the MOX assemblies. Assemblies in these locations would be required to adhere to the loading requirements in table 7.D.5 of the application and therefore the staff found that requiring that there are assemblies in these locations when loading MOX fuel is appropriate and acceptable.

5.7 Removed Minimum Enrichment from Glossary

The applicant removed the definition of minimum enrichment from the glossary. This definition had stated that: "Minimum Enrichment is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment." Table 7.D.1 Note 7 for Basket Model F-12P and Note 6 for Basket Model F-32B include a requirement that the minimum enrichment not include the axial blankets.

Although the staff did not find anywhere in the application that would replace the definition that minimum enrichment be the assembly average enrichment since different fuel pins in a single assembly can have different enrichments, using an actual minimum, versus assembly average, would actually be more conservative as it would represent an assembly as having lower enrichment and could require it to have longer cooling time therefore the staff found that removing the "assembly average" from the definition of minimum enrichment may make the meaning ambiguous, however, would result in only a more conservative interpretation.

Therefore, the staff found removing the definition of "minimum enrichment" from the glossary acceptable.

5.8 Revised Drawings

The applicant made changes to the HI-STAR 80 drawings including the cask licensing drawing, the F-12P basket licensing, the F-32B basket licensing drawing revision, and the impact limiter licensing drawing.

The staff compared the revised drawings to the previously approved drawings and did not find any changes that would appreciably affect the shielding such as changes to shield dimensions or materials.

5.9 Staff Calculations

The staff performed independent dose rate calculations of the HI-STAR 80 with the F-12P and F-32B baskets using the STANDARDS code (available without proprietary information in Radiation Safety Information Computational Center under code package C00873). The model was constructed by Oak Ridge National Laboratory (ORNL) using the application drawings. The STANDARDS code employs the SCALE/MAVRIC to calculate dose rates and ORIGAMI to calculate the neutron and gamma source term from fuel and activated hardware (G. Radulescu, et. al, (2017) "Shielding Analysis Capability of UNF-ST&DARDS," Nuclear Technology, 199:3, 276-288).

The goal of these calculations is to provide an independent check of the applicant's dose rate evaluations to provide additional that the package was modeled appropriately.

All PWR fuel is modeled as Westinghouse 17x17 with a uranium mass of 497.6 kg consistent with table 7.D.1 of the application. BWR fuel is modeled as GE 10x10 with a uranium mass of 226.2 kg consistent with table 7.D.1 of the application. Failed PWR fuel has a uranium mass of 449 kg consistent with table 7.D.1 of the application.

Although this is fuel assembly weight, there is no specific limit on mass of uranium, so this is assumed to be the uranium mass. Cobalt-60 levels for active fuel and fuel hardware regions were consistent with table 5.2.3 of the application, and flux scaling factors were consistent with those from table 5.2.7 of the application.

Depletion parameters are from table 7.D.4 of the application for PWR SNF in the F-12P basket and 7.D.5 for BWR SNF in the F-32B basket with specific parameters chosen shown in table 1 below.

Table 1: Modeling Summary of Staff HI-STAR 80 Dose Rate Evaluations

Case	Basket	Configuration	No. 1-year Irradiation Cycles / Burnup GWd/MTU / Enrichment (wt. % U-235) / Cooling Time (months)
1	F-12P	All intact fuel 2 empty cells, Condition Set 3, NCT	3 / 55 / 4.5 / 22
2	F-12P	All intact fuel 2 empty cells, Condition Set 3, HAC	3 / 55 / 4.5 / 22

3	F-12P	Fuel in 4 quiver locations reduced to 449 kg and uniform burnup profile applied 2 empty cells, Condition Set 3, NCT	3 / 55 / 4.5 / 22
4	F-12P	Fuel in 4 quiver locations reduced to 449 kg, height reduced by 200 cm and uniform burnup profile applied 2 empty cells, Condition Set 3, NCT	3 / 55 / 4.5 / 22
5	F-32B	All intact fuel, no empty cells, Condition Set 3; NCT	4 / 60 / 3.5 / 27
5	F-32B	All intact fuel, no empty cells, Condition Set 3; HAC	4 / 60 / 3.5 / 27

5.10 Conclusion

Based on its review of the information and representations provided in the application and the staff's independent, confirmatory calculations, the staff has reasonable assurance that the proposed package design and contents satisfy the shielding requirements, and the radiation level limits in 10 CFR Part 71. The staff also considered the regulation itself, appropriate regulatory guides, applicable codes, and standards, and accepted engineering practices, in reaching this finding.

6.0 CRITICALITY EVALUATION

The HI-STAR 80 transportation package is designed to transport high burnup PWR or BWR UO₂ fuel rods, BWR MOX fuel, mixed BWR UO₂ and BWR MOX fuel assemblies, or non-fuel radioactive waste and hardware. PWR fuel and non-fuel hardware is transported in the F-12P basket, and BWR fuel and BWR MOX fuel is transported in the F-32B basket. The applicant has proposed the addition of quivers to the allowable contents for both the F-12P and F-32B baskets. Quivers are damaged fuel containers designed to hold separated spent fuel rods.

The objective of this review is to determine whether the HI-STAR 80 package, loaded with spent fuel assemblies as specified in the CoC, continues to meet the regulatory requirements of 10 CFR 71.55, 71.59, and 71.87 to ensure that the HI-STAR 80 remains subcritical under NCT, HAC, and loading and unloading operations with the addition of quivers as allowable contents.

6.2 Criticality Safety Evaluation

NRC staff reviewed the design of the HI-STAR 80 package with quivers added in two different configurations. As described in table 7.D.1, up to 10 PWR fuel assemblies, of which up to 4 may be quivers, are allowed to be loaded in the F-12P basket; and up to 28 BWR fuel assemblies, of which up to 12 may be quivers, are allowed to be loaded in the F-32B basket. Specific cell locations where quivers are allowed are shown in Figures 7.D.3 – 7.D.8 in the SAR. As defined in the glossary and in section 1.2.2.1 of the SAR, a quiver is a type of damaged fuel container for individual fuel rods that have been removed from their assembly. The fuel rods may be leaking, broken, or fragmented (i.e., fuel debris) and purposely punctured (if needed) to relieve internal pressure. Damaged fuel rods, which can include separated spent fuel rods which are

leaking, broken, or fragmented are treated as fuel debris which includes a wide variety of configurations ranging from whole fuel rods to individual fuel pellets.

Staff followed the guidance and acceptance criteria provided in NUREG-2216, "Standard Review Plan for Transportation Packages for Spent Fuel and Radioactive Material" during the review of this amendment.

6.3 Addition of Quivers

The applicant provided criticality evaluations in section 6.2.4 of the SAR. Both the F-12P and F-32B baskets are designed to hold PWR and BWR UO₂ fuel debris enriched up to 5.0 wt.% ²³⁵U loaded in quivers. The specifications, number, and allowed location of quivers are provided in section 1.2.2 and chapter 7 of the SAR. The quivers are covered by the fixed neutron absorbers (Metamic-HT) that is integral to the basket designs and cover any potential axial movement of the quivers within a basket location. As mentioned above, fuel debris can include a wide variety of configurations that range from whole fuel assemblies with severe damage down to individual fuel pellets.

The applicant evaluated the various configurations of fuel debris to determine the configuration that yielded the highest reactivity to determine the bounding configuration, which was found to be bare fuel rods without cladding in arrays.

No changes were made to the F-12P and F-32B basket designs; rather, quivers are designed to occupy specific existing basket locations. The applicant utilized multiple conservatisms in modeling the criticality safety of the quivers, including: replacing the structural materials in the quiver with water, arranging the fuel debris in rectangular arrays of bare fuel rods, replacing the cladding with water, varying the amount of fuel per length of the quiver by changing the number of rods in the array and the rod pitch, assuming the active length of the rods to be equivalent to intact fuel rods; and assuming fresh fuel enriched to 5.0 wt.% ²³⁵U.

The applicant also modeled full cask models that contained the maximum number of fuel quivers for both basket designs. As shown in table 6.2.8 for the F-12P and 6.2.9 for the F-32B, the bounding configurations were identified, and in all instances the resulting k_{eff} s were below 0.95.

Staff requested additional information regarding the structural integrity of quivers containing fuel debris and their ability to maintain their contents under HAC to ensure that preferential flooding of the basket is not possible due to basket flow holes unable to be blocked by fuel debris as specified in section 6.3.4.4 of the SAR. The applicant responded with adequate justification in their responses to structural RAI 2-1 and 2-2 and staff finds this sufficient.

Staff also requested additional information regarding the assumption in section 6.3.5.1 of the SAR of using random locations for larger broken fuel rod segment configurations and whether they would be bounding for all potential damaged fuel configurations. The applicant's response that the potential fuel rod reconfiguration for HBF during HAC is not significant, so that any potential increase is offset by the other multiple conservatisms in the analysis, was found acceptable by staff.

The staff performed independent criticality safety calculations of the HI-STAR 80 transportation package with the F-12P and F-32B baskets using the UNF-STANDARDS code. The models were constructed by ORNL and Pacific Northwest National Laboratory using the drawings located in the SAR. The results obtained by staff agreed closely with those performed by the applicant and staff finds reasonable assurance that the modeling approach is adequate to ensure that the HI-STAR 80 package, as evaluated, continues to meet the requirements of 10 CFR Part 71.

6.4 Conclusions

Staff reviewed the information provided in the application and the applicant's responses to the staff's requests for additional information. Based on its review, the staff finds that the applicant made conservative assumptions in the criticality safety analyses associated with the addition of quivers in the F-12P and F-32B baskets. Based on the review of the information presented by the applicant, the regulation itself, appropriate regulatory guides, and accepted engineering practices, the staff has reasonable assurance that the HI-STAR 80 transportation package with the addition of fuel debris containing quivers continues to meet the regulatory requirement of 10 CFR Part 71 and finds this amendment acceptable.

7.0 OPERATING PROCEDURES

Changes were made to the operating procedures including the following:

Quivers are added to the allowable contents for both the F-12P and F-32B baskets. Quivers are restricted to certain peripheral basket locations where temperatures are lower.

Configuration 2 is described in table 7.D.1 for loading quivers. Up to 10 PWR fuel assemblies, of which 4 may be quivers, are allowed to be loaded in the F-12P basket, and up to 28 BWR fuel assemblies, of which 12 may be quivers, are allowed to be loaded in the F-32B basket.

Figures 7.D.3 through 7.D.8 specify allowable cell locations for fuel assemblies and quivers with the maximum decay heat load specified per cell location. Operational requirements for quivers are provided in SAR table 7.1.8 including the condition of the fuel rods (either broken or fuel debris or punctured fuel rods with a nominal 3 mm or larger opening), their dryness (≤ 0.4 kPa (3 Torr)), backfill gas, backfill pressure, and leaktightness.

The design internal pressure for the cask cavity is increased to 1,000 kPa (145 psi) to allow for an increase in internal cask pressure during loading and unloading operating activities for water circulation within the cask cavity.

The total preload specified for the inner closure lid cover plate bolts has been revised consistent with ASME Code Division I, Subsection NB requirements for design conditions and consistent with revised containment seal seating load requirements. Similarly, the torque specified for the outer closure lid access port plug has been evaluated consistent with ASME Code Division I Subsection NB requirements for design conditions and consistent with revised containment seal seating load requirements. SAR chapter 7 torque table has been revised.

The cooling, average burnup, and enrichment tables within SAR appendix 7.D is expanded to specify additional allowable cooling times to be shipped with the F-12P and F-32B basket configurations to allow greater fuel loading flexibility which allows for spent fuel pools to be offloaded sooner after plant shutdown.

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

8.0 ACCEPTANCE TESTS AND MAINTENANCE

SAR paragraph 8.1.5.5 “Metamic-HT weld soundness criteria” was revised and only requires visual examination and bend testing. Radiography testing of the weld is not mandatory to determine weld soundness, as ASME Section IX specifies bend testing is used to determine the degree of soundness and ductility of weld joints. This change was made to bring the Metamic-HT weld qualification verification in alignment with ASME code compliance.

SAR table 8.1.1 was revised to update the helium’s leakage rate acceptance criterion and test sensitivity with the acceptable limits from the containment analysis.

CONDITIONS

The following conditions were either modified or added in the CoC:

Item No. 3.b was modified to refer to the latest revision of the application.

Condition No. 5(a)(3) was updated with the latest licensing drawing revisions.

Condition No. 5(b)(1)(a) adds quivers as newly authorized contents and allows the loading of quivers containing separated fuel rods/

Condition No. 5(b)(1)b deletes the explicit reference to LPRMs and only specifies the use neutron monitors using fission chambers.

Condition No. 5(b)(2)(b) was added and refers to the 10 PWR UO₂ fuel assemblies (15x15 and 17x17 arrays) in the F-12P basket with a maximum of 136 fuel rods in quivers. It also states that control rods are authorized for transport within spent PWR fuel assemblies and that fuel assemblies may contain up to 4 irradiated stainless steel replacement rods.

Condition No. 5(b)(2)(d) was added and refers to the 28 BWR fuel assemblies (8x8, 9x9, 10x10 and 11x11 array sizes) in the F-32B basket with a maximum of 168 fuel rods in quivers. It also states that non-fuel hardware is not authorized contents with spent BWR fuel assemblies and that fuel assemblies may contain up to 4 irradiated stainless steel replacement rods.

Condition No. 8(a) has removed the explicit reference to fuel debris, so fuel debris may be allowed for transportation in quivers. However, damaged fuel is not authorized for transportation.

Condition No. 11: the CoC has been renewed and the new expiration date is December 31, 2028.

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 80 package has been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

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