CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE		PAGES
9378	1	71-9378	USA/9378/B(U)F-96	1	OF	4

2. PREAMBLE

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

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

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

a. ISSUED TO *(Name and Address)*

Holtec International
1 Holtec Blvd.
Camden, NJ 08104

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

Holtec International Report No. HI-2188080 *Safety Analysis Report on the HI-STAR 100MB Package* Revision 5, dated April 29, 2021.

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 100MB

(2) Description

The HI-STAR 100MB packaging consists of the following major components: the packaging body, the multi-purpose canister (MPC) or the fuel basket, the impact limiters with either a "standard set" design or a "LW" design, and the personal barrier. The packaging has two cavity lengths, designated as XL and SL.

The packaging body, comprised of a nickel steel shell welded to nickel steel bottom and top flanges, provides the containment boundary, the helium retention boundary, gamma and neutron shielding and heat rejection capability of the package. The containment system consists of the inner shell, bottom and top flanges, top closure lid(s), closure lid inner O-ring seal, vent and drain port cover and inner seals, and bolts for the closure lids and port covers. The outer surface of the inner shell is buttressed with a layered combination of lead, steel and Holtite B neutron shielding material. The top flange has bolted closure lid(s) with machined concentric grooves for elastomeric seals. The packaging body also features collapsible trunnions.

The MPC, a welded cylindrical structure with flat ends, consists of a honeycombed fuel basket made from panels of Metamic-HT, a baseplate, canister shell, lid and closure ring. Fuel spacers may be used to minimize the assembly to MPC lid gap. There is only one MPC model, the MPC-32M, designated for use with this packaging. With the MPC configuration, applicable only to the Type XL package, the HI-STAR 100MB utilizes a single bolted lid.

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

The fuel basket, made of Metamic-HT both as a structural and neutron absorber material, exists in two configurations, the F-24 M and F-32 M. The F-24 M basket has flux traps. With the fuel basket configuration, only applicable to the Type SL package, the HI-STAR 100 MB has two bolted lids, with each lid equipped with two concentric seals.

The “standard” impact limiter set is fabricated of aluminum honeycomb crush material completely enclosed by an all-welded stainless-steel skin and may be used with both types of packaging, designated as Types XL and SL. The “LW” impact limiter set is fabricated of aluminum rings and unidirectional crush material completely enclosed by an all-welded stainless-steel skin and may only be used with the Type SL F-24 M configuration. Both versions of impact limiters are attached to the top and bottom of the packaging with 16 bolts each.

The personal barrier 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 165 3/8 inches long (SL configuration) or 191 1/8 inches long (XL configuration) with respective total lengths of the packaging body of 197 inches or 212 inches, respectively. Both versions have an inside diameter of 68 3/4 inches, and an outer diameter of approximately 99 ¼ inches without impact limiters, and 124 inches with the impact limiters installed.

The maximum packaging weights of the SL and XL versions are approximately 258,000 pounds and 246, 000 pounds respectively. The package, as configured for transport, i.e., including impact limiters, weighs from 288,000 lbs (SL version) to 300,000 lbs (XL version).

(3) Drawings

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

(a) HI-STAR 100MB Cask Drawing No. 11070, Sheets 1-7, Rev. 7

(b) F-24M Fuel Basket Drawing No. 11083, Sheet 1, Rev. 2

(c) F-32M Fuel Basket Drawing No. 11082, Sheet 1, Rev. 2

(d) MPC-32M Basket Drawing No. 11084, Sheet 1, Rev. 2

(e) MPC Enclosure Vessel Drawing No. 3923, Sheets 1-9, Rev. 38

(f) HI-STAR 100MB Impact Limiter Drawing No. 11101, Sheets 1-4, Rev. 4

(g) Impact Limiter Version LW Drawing No. 11758, Sheets 1-4, Rev. 2

5(b) Contents

(1) Type and form of material

Moderate to high burnup, up to 55 GWd/MTU, undamaged spent PWR UO_2 Zr cladding, fuel with a maximum initial enrichment of 5 wt.% U-235 and a minimum cooling time of 3.5 years. Fuel assembly arrays are 14x14, 15x15, 16x16, and 17x17. The maximum weight of a fuel assembly, including assemblies containing non-fuel hardware, must not exceed 1680 lbs. Fuel assembly characteristics are listed in Table 7.7.1 of the application.

(2) Maximum quantity of material per package:

(a) 24 or 32 PWR UO_2 fuel assemblies in the F-24M or F-32M basket, respectively.

(b) 32 PWR UO_2 fuel assemblies in the MPC-32M.

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 100MB package include:

(a) Damaged fuel assemblies, fuel debris, and irradiated non-fuel hardware are not authorized for transportation.

(b) Maximum allowable time for the completion of wet transfer operations, based on design basis maximum heat load and initial pool water temperature of 48.9°C, is 17.5 hours. The maximum allowable time maybe recalculated, with other cask heat loads and pool water measured temperatures, prior to loading operations, as specified in Section 7.1.7.3 of the application.

(c) The vacuum drying operations do not prescribe time limits for (i) the F-24M and F-32 M baskets respectively, for high burnup fuel, provided the cask heat load is equal to or below 24 kW and 26 kW respectively, and (ii) the MPC-32M for both high burnup fuel and all configurations with moderate burnup fuel.

(d) The minimum specific power, the maximum moderator temperature, the maximum fuel temperature of each fuel design shall not exceed the values listed in Table 7.7.4 of the application.

(e) The fuel burnup credit loading curve is applicable only to spent fuel assembly classes, loaded in the MPC-32M/F-32M, identified in Table 7.7.3(a) of the application.

(f) The maximum heat load is either 32 kW for the package with the F-32M or F-24M basket, or 29 kW for the package loaded with the MPC-32M.

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. "LW" Impact limiter's purchased material requirements, including tolerances for minimum yield strength, are specified in Section 8.1.5.3 of the application.

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

13. Expiration date: August 31, 2024.

REFERENCES

Holtec International Report No. HI-2188080 *Safety Analysis Report on the HI-STAR 100MB Package*, Revision 5, dated April 29, 2021.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

John B. McKirgan

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Date: 2021.05.20 09:39:33 -04'00'

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

Date: May 20, 2021.

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

SAFETY EVALUATION REPORT
HOLTEC INTERNATIONAL
Docket No. 71-9378
Model No. HI-STAR 100MB Package

By letter dated October 25, 2019, Holtec International submitted an amendment request to Certificate of Compliance No. 9378 for the Model No. HI-STAR 100MB package (ADAMS No. ML19311C314)

The application was accepted for review on January 23, 2020; staff issued a first request for additional information on April 14, 2020, for which Holtec provided responses by letter dated September 11, 2020 (ADAMS No. ML20258A052). On April 30, 2021, Holtec provided responses (ADAMS No. ML21120A133) to the staff second request for additional information, dated December 10, 2020, and a revised application, Revision No. 5, dated April 29, 2021 (ADAMS No. ML21120A132)

Several changes were included as part of this amendment request, including:

- The addition of the AL-STAR impact limiter design, Version LW, for the HI-STAR 100MB Version SL with the fuel basket F-24M. The Impact Limiter Version LW allows a reduced package weight for transportation routes with restrictive weight limits.

- The analysis of the top and bottom trunnion designs as tie-down supports for normal conditions of transport (NCT) and hypothetical accident conditions (HAC). The transportation frame is modified to secure the package by the top and bottom trunnions.

- The addition of a new 17x17F fuel assembly class to the allowable contents, including an increase to the initial enrichment up to 5% and an increase in the Cobalt-59 content of fuel assembly hardware to 1.2 g/kg. The initial enrichment and burnup are expanded to specify additional allowable cooling times to be shipped, with the F-24M basket configuration, in a HI-STAR 100MB Version SL.

- The revision of the helium leakage rate criteria to 1×10^{-5} ref-cm^3/s for the containment enclosure leakage rate test, based on the containment analysis demonstrating compliance with 10 CFR 71.51(a)(1) and 10 CFR 71.51(a)(2).

- The visual examination and bend testing requirements for the Metamic-HT weld soundness criteria in lieu of radiography testing of the weld, which is not mandatory as ASME Section IX specifies bend testing is used to determine the degree of soundness and ductility of weld joints.

- The addition of two threaded containment connections in the center of the optional port cover plate for the cask lid. The central threaded connections are used to purge the port cover space with helium during the installation of the port cover plate.

Enclosure

- The addition of a metallic seal to the port cover seals for maintaining containment when the port cover is sealed, for fabrication flexibility due to seal design availability.

- The reduction of the intermediate shell thickness from 3” to 2.49” to allow for fabrication flexibility but the total thickness of the containment shell, intermediate shell, and outer shell remains at least 5”.

- The addition of a thermal insulation, as an optional material, between the intermediate shell and neutron shield, in order to provide additional margin to the thermal temperature limit of the neutron shield material.

- The reduction of the dimensions of the solid shim design for the F-24M Version SL to conform to the geometry of the F-24M basket, due to tolerances of components. The hollow shim dimensions for the F-24M Version SL are modified to improve the hollow shims extrusion during fabrication, while maintaining the shim liner overall length along the fuel basket face.

- The revision of the containment analysis to include permeation effects through the elastomeric seal material and to also correct an error with the source term used.

NRC staff reviewed the application using the guidance in NUREG-1617 " Standard Review Plan for Transportation Packages for Spent Nuclear Fuel".

The analyses performed by the applicant demonstrate that the package provides adequate structural, thermal, containment, shielding, and criticality protection under normal and accident conditions.

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

1.0 GENERAL INFORMATION

1.1 Design Characteristics

The package design was not drastically modified as part of this amendment request. The most noticeable changes include:

(i) a bolted lid joint engineered to meet the new leakage rate criterion in Table 8.1.1 under NCT and HAC,

(ii) the AL-STAR MB impact limiters either in a standard version or the new “Version LW”, designed only for use with the HI-STAR Version SL with the F-24M fuel basket, and

(iii) the HI-STAR 100MB four cask trunnions which are now used to tie down the package to the transportation frame and are qualified as tie down devices in accordance with 10 CFR 71.45(b)(1).

1.2 Drawings

All licensing drawings were updated and revised to include tolerances for Important to Safety (ITS) components. Staff had noted that the applicant had initially included in the drawings only a few tolerances, quantitative in nature, and that most technical analyses only used nominal dimensions, without any tolerances; thus, any significant deviation from the nominal dimensions in a fabricated package/component could be considered by staff as being noncompliant with the conditions of approval of the package.

Code requirements (fabrication and examination) for the weld connections and for all NITS and ITS components are now identified in the licensing drawings. The licensing drawings were also updated to include the material information for the impact limiter enclosure skin and show how the skin and the access tubes are connected.

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.

1.3 Contents

The additional new authorized content requested in this application, the 17x17F class fuel, is specified in Table 7.7.2 of the application. There is no change in the fuel basket design. No damaged fuel is authorized.

With the addition of the 17x17F fuel design in this amendment, the authorized spent fuel contents include:

- Westinghouse (WE) 15x15: 15x15B and 15x15C
- Babcock & Wilcox (B&W) 15x15: 15x15D, 15x15E, 15x15F and 15x15H
- Combustion Engineering (CE) 15x15: 15x15I
- CE 16x16: 16x16A and 16x16B
- WE 16x16: 16x16C
- WE 17x17: 17x17A, 17x17B, 17x17C, and 17x17F.

The revised Table 7.7.3 (a) of the application provides the minimum burnup for fuel to be loaded in the MPC-32M and F-32M baskets. No minimum burnup is required for fuel to be transported in the F-24M basket.

Table 7.7.3(b) of the application provides the maximum allowable initial enrichment for each of the fuel classes.

The non-fuel waste and some non-fuel hardware may be transported in the non-fuel waste basket. However, the total weight of the fissile materials in the waste is limited to the exempted quantity of fissile materials, as defined in 10 CFR 71.15.

2.0 STRUCTURAL AND MATERIALS EVALUATION

The purpose of the review is to verify that the structural and materials performances of the Model No. HI-STAR 100MB package has been adequately evaluated for the requested changes or design modifications to meet the requirements of 10 CFR Part 71.

2.1 Addition of the Version LW Design for the Impact Limiter

Section 1.2.1 of the application notes that an additional impact limiter design, the HI-STAR 100MB Impact Limiter Version LW, is added as an optional impact limiter for the HI-STAR 100MB Version SL Cask with the fuel basket F-24M.

The new impact limiter design includes a perforated aluminum ring, in lieu of the common honeycomb crushable construction, and is attached to the package in the same manner as for the previously approved standard impact limiters, except that two bushings are used with each impact limiter bolt. The impact limiter enclosure skin is made of a very ductile Type 304 stainless steel, with a true failure stress greater than 100,000 psi, for material temperatures below roughly 800°F. The impact limiter stainless steel enclosure skin is 16 gauge thick at the end surface of the package and 11 gauge thick at other locations.

Staff asked the applicant to clarify the behavior, dimensions, and material properties of the bushings to verify that the impact limiter bolts adequately retain the impact limiters in the post-drop test scenarios. Staff had noted that the maximum tensile stress experienced by the bushings was not compared to the yield strength of the material of construction in order to appropriately size the bushings. Staff also asked the applicant to better describe the structural integrity of the impact limiter bolts with appropriately dimensioned access tubes and bushings with a more realistic failure model used for the bushings.

The applicant used a combination of material testing and LS-DYNA simulation, to demonstrate the performance of perforated aluminum ring. Specifically, six aluminum specimens were used for quasi-static tensile testing. Results from two of these specimens were used to calibrate the LS-DYNA simulation of the perforated aluminum ring using the material model.

The applicant addressed staff's concerns that the larger diameter lower bushing, following the failure of its internal lip, could slide towards the attachment bolt head and be trapped by the deformed access tube, thus resulting in a greater interaction than that between the upper bushing and the access tube.

The applicant also showed that a maximized tube-to-bushing interaction only slightly increases the peak deceleration at the cask baseplate by 3.9%. In addition, the applicant performed a new LS-DYNA sensitivity run for the governing slap-down drop scenario, which accounts for the triaxiality effect on the failure strain of the enclosure skin material (SA-240 304). The triaxiality effect is incorporated per the general statement in ASME BPVC.III.A, Appendix EE. Both the original LS-DYNA simulation and the sensitivity run indicated that the impact limiter enclosure skin only experiences local plastic deformation without gross failure.

Finally, the access tubes were reclassified as ITS-C components on licensing drawing No. 11758 to ensure that their material strength properties conform with the analysis.

The application includes a calculation package that, under various cask free drop scenarios, determines that all the calculated peak deceleration, deformation, and stress results are below the allowable limits that were previously established in the application.

The staff reviewed the Holtec calculation package and determined that applicant has adequately assessed the structural performance of the LW impact limiter. On this basis, the staff concludes that the LW impact limiter is an acceptable option for spent fuel transport with fuel basket F-24M.

2.2 Qualification of Cask Trunnions as Tie- Downs

The application now states that the upper and lower trunnions on the HI-STAR 100MB package also serve as tie-down devices during transport.

To demonstrate their structural capability, the set of four trunnions is evaluated to also meet the tie-down requirements of 10 CFR 71.45(b). The applicant noted that, based on the saddle configuration as well as the location and orientation of the trunnions, the trunnions are required to resist the vertical and horizontal components concurrently for a resultant load equal to 10.2 times the total weight of the loaded package.

Staff noted that the calculated stresses in the trunnions, and in the surrounding cask structure, remain below the material yield strength when the set of four trunnions are subjected to a load equal to 10.2 times the maximum package weight. The ultimate load capacity of the trunnion is governed by the cross section of the trunnion outboard of the cask; therefore, the loss of the external shank of the trunnion, under excessive load, will not cause the loss of any other structural or shielding function of the HI-STAR 100MB package.

2.3 Addition of Optional Port Cover Design for the Cask Lids

The optional port cover design, similar to the MPC port cover plate design, includes two additional threaded containment connections in the center of the port cover plate. The central threaded connections are used to purge the port cover space with helium during installation of the port cover plate.

The optional port cover design is analyzed in Calculation Package HI-2188083 and the required torque value equation for bounding seal parameters is listed in Table 2.2.11.a and 2.2.11.b. As noted in Section 2.2 of the application, Table 2.2.10, Chapter 7, and Table 7.1.1 are updated to reflect the torque values needed to maintain containment with this design.

Since the port cover structural integrity and corresponding torque value equation are previously approved by the staff for both NCT and HAC conditions, the staff concludes that the optional port cover design is structurally adequate to perform its safety functions.

2.4 Reduction of the Intermediate Shell Thickness

The applicant reduced the intermediate shell thickness for the package and performed a new puncture evaluation for the 1-meter horizontal drop event. The analysis was performed with the Nelm’s equation and results in a safety factor of 1.171, which is greater than unity, and is therefore acceptable.

On this basis, the staff concludes that the reduced intermediate plate thickness to 2.49 inches is structurally capable of preventing the plate perforation during the 1-meter drop event.

2.5 Materials Codes and Standards

The applicant did not make any changes to the materials codes and standards cited in the drawings and summarized in Tables 2.1.14 and 2.1.16. The new Impact Limiter Version LW uses the same American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (BPV) Code Section III, Division 1, and Section IX construction codes and the same ASME BPV Code, Section II, and ASTM materials specifications as those previously approved for the standard version of the impact limiter. Therefore, the staff finds the materials codes and standards to be acceptable.

2.6 Welding

In Section 8.1.5.5 of the application, the discussion on the weld procedure qualification for the Metamic-HT fuel basket was revised to remove a requirement to perform radiography of the weld coupons used to qualify the friction stir welding procedure. The requirements to perform tensile testing, bend testing, and visual examinations of the weld coupons remain in effect. The applicant stated that the change was made to be consistent with ASME BPV Code, Section IX, "Welding, Brazing, and Fusing Qualifications." The staff reviewed the applicant's revision to the qualification of the friction stir welding procedure and verified that it is in accordance with the applicable code criteria because ASME BPV Code Section IX does not require radiography of the weld coupons. In addition, the staff confirmed that the remaining coupon tests (e.g., tensile, bend) are consistent with ASME BPV Code, Section IX, Article II, "Weld Procedure Qualifications." Therefore, the staff finds the revised weld procedure qualification to be acceptable.

The staff also notes that the welding criteria for the new Impact Limiter Version LW are consistent with those used for the original version of the impact limiter previously approved for the HI-STAR 100MB transportation package. The structural welds of the impact limiter are fabricated in accordance with ASME Code, Section IX, and examined in accordance with Section V using Section III, Division 1, Subsection NF, acceptance criteria.

Based on the staff's verification that the impact limiter welding criteria are unchanged in the amendment, and that those criteria have been previously confirmed to be consistent with the guidance in NUREG-2216, the staff finds the welding of the new impact limiter to be acceptable.

2.7 Materials Mechanical Properties

2.7.1 Lower Crush Material: Impact Limiter Version LW

To model the mechanical behavior of the lower crush material (perforated aluminum rings) of the Impact Limiter Version LW, the applicant defined the plastic deformation behavior of the type 6061-T6 aluminum alloy using a combination of published data and laboratory benchmark testing. The applicant's approach, summarized in its response to staff's request for additional information, references a proprietary report on the finite element analysis of the package in drop accidents.

The true stress-true strain curve, needed to model the aluminum, was based, first, on engineering stress-strain curves available in the technical literature and data on the strain rate sensitivity and temperature sensitivity of aluminum. The staff notes that, during uniform deformation, the measured engineering stress-strain behavior can be readily converted to true stress-strain behavior. In order to refine the material model during uniform elongation and to validate the modeling of material behavior beyond uniform elongation (i.e., during necking and final fracture of a tensile specimen), the applicant used laboratory testing to benchmark the model.

This benchmark testing included several tensile tests and a single crush test of a reduce-scale section of the perforated aluminum ring. Through this testing and refinement of the predicted material behavior, the applicant demonstrated that the mechanical behavior of the aluminum could be accurately modeled to high levels of strain.

In addition, Table 8.1.8 of the application includes acceptance criteria to ensure that the strength of the procured aluminum material is consistent with the material model. Therefore, based on the staff's review of the applicant's development of the aluminum deformation behavior, including the validation provided by the benchmark testing, the staff finds the lower crush material properties to be acceptable.

2.7.2 Upper Crush Material: Impact Limiter Version LW

The mechanical properties of the upper crush material (aluminum honeycomb) in the Impact Limiter Version LW are defined in the drawings, which establish the allowable range of crush strength and density. The applicant provided a proprietary test report on honeycomb materials from two suppliers, and the staff verified that those materials conform to the drawing requirements.

In addition, as stated in Section 8.1.5.3 of the application, verification of crush strength is performed by testing sample blocks of each batch of honeycomb material that will be used to construct the impact limiters. Therefore, the staff finds that the mechanical properties of the upper crush material used in the structural analyses are acceptable.

The staff also reviewed the applicant's thermal analysis in Chapter 3 of the application to ensure that the mechanical properties of all SSCs remain valid under the temperatures associated with the new impact limiter and other changes to the system. The staff verified that the component temperatures are bounded by those associated with the previously approved casks and contents, as well as below each of the material's allowable service temperatures. Therefore, the staff finds the mechanical properties used in the applicant's structural analysis to be acceptable.

2.8 Materials Thermal Properties

In SAR Section 3.2, the applicant added thermal property data for the Impact Limiter Version LW lower crush material (perforated aluminum rings) and upper crush material (aluminum honeycomb). The staff evaluated the new data in Tables 3.2.2 and 3.2.7 on the thermal conductivity, specific heat capacity, and material density to ensure that the thermal analyses of the impact limiters are based on appropriate materials properties.

For the lower crush material, the staff verified that the aluminum thermal property data is largely consistent with the values specified in the ASME BPV Code, Section II, Part D, "Properties, Materials." The staff noted some minor deviations from the ASME BPV Code thermal conductivity values. However, the staff found that the thermal modeling used adequate conservatisms, and small variations in the thermal properties of the impact limiter do not affect the conclusion that maximum allowable component temperatures will not be exceeded in the HAC fire accident. Therefore, the staff finds the thermal properties of the lower crush material to be acceptable.

For the upper crush material, the staff verified that bounding minimum and maximum thermal conductivity values used in the thermal analyses are consistent with test data provided by the applicant in a proprietary material test report. The staff also verified that the material density is consistent with the values required in the impact limiter drawing and that the calculations for specific heat capacity (which is based on a volume-weighted average of aluminum and air) use appropriate aluminum properties. Therefore, the staff finds that the thermal properties of the upper crush material are acceptable.

The applicant also revised the cask drawings to include an option for an insulation layer between the intermediate shell and the neutron shield. However, the applicant conservatively did not take credit for the insulation in its thermal analysis of hypothetical accident conditions. Therefore, the staff did not evaluate the thermal properties of this material.

2.9 Radiation Shielding Materials

In SAR Table 5.3.2, the applicant added the aluminum density data that is used in the shielding analysis of the fuel basket shims and the honeycomb upper crush material in the Impact Limiter Version LW. The staff reviewed the density used in the shielding analysis of the aluminum basket shims and verified that it conservatively bounds the values specified in the ASME Code Section II, Part D, “Properties, Materials.”

The staff also verified that the density data for the honeycomb upper crush material conservative bounds the density required in the drawings for the Impact Limiter Version LW. Therefore, the staff finds the material density data used in the radiation shielding analysis to be acceptable.

2.10 Corrosion

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 100MB application. Therefore, the staff finds the transportation package’s design for corrosion resistance and prevention of adverse reactions to be acceptable.

2.11 Spent Fuel Assembly

The applicant added a new fuel assembly type 17x17F to the previously approved Westinghouse 17x17 PWR fuel assemblies (including types 17x17A, B, and C).

The new assembly type introduces a unique combination of enrichment, rod pitch, cladding dimensions, fuel pellet diameter, and Co-59 impurity levels. The fuel assembly materials, zirconium fuel cladding materials, burnup, and enrichment limits are consistent with those previously analyzed and approved for the HI-STAR 100MB CoC. The addition of the 17x17F assembly type did not change any the material property inputs into the structural analysis.

In addition, as discussed in SAR Section 3.1 and 3.3.9, the existing thermal design basis calculations remain bounding for the amendment to introduce the new fuel assembly type, the new LW impact limiter design, and other changes. The peak cladding temperatures in normal conditions of transport and hypothetical accident conditions are unchanged.

The staff verified that the fuel cladding temperatures remain below those associated with the previously approved casks and contents, as well as below the allowable cladding temperatures recommended in NUREG-1917. Therefore, the staff finds the new assembly type to be acceptable.

2.12 Seals

2.12.1 Elastomer Seals

In SAR Table 2.2.11a, the applicant revised the short-term upper temperature limit and the lower temperature limit “critical characteristic” for the elastomeric containment boundary seals. The SAR requires the use of seals that can operate at sustained and short-term temperatures and under radiation exposure. The two commercially available seals that the SAR states as meeting the seal requirements remain the same as those in the previously approved CoC.

The staff reviewed the elastomeric seal requirements in the SAR to verify that the closure seals will be capable of performing their containment function.

> For the revised upper temperature limit, the staff reviewed the manufacturer’s data sheets for the elastomer seal materials referenced in the SAR and verified that, when exposed to the new limit, the materials’ hardness and elongation remain within the allowable range of these critical seal characteristics previously defined in the SAR.
>
> For the lower temperature limit, the applicant no longer defines this characteristic in terms of a specific “TR-10” elasticity test, but rather requires that the seals be documented by the manufacturer to operate at the lower temperature limit.

The applicant stated that it relies on its procurement controls to ensure that seal manufacturer documentation demonstrates adequate performance at low temperatures. The staff verified that the manufacturer’s data sheets for the elastomer seal materials referenced in the SAR state that the seals can be used at temperatures consistent with the SAR criteria.

The staff finds the changes in elastomer seal temperature limits to be acceptable because the combination of (1) procuring seals that are documented by the manufacturer to operate in the required temperature range and (2) imposing additional critical characteristics (e.g., hardness, elongation) is considered to be capable of ensuring that the seals provide containment performance during temperature extremes.

2.12.2 Metallic Seals

In addition, in SAR Section 4.1.2 and the cask drawings, the applicant added an option to use metallic seals for the port covers in the cask lid. SAR Table 2.2.11b provides the required characteristics of the metallic port cover plate seals, which includes upper and lower operating temperature limits.

The applicant also provided manufacturer data on aluminum and silver-covered helical spring seals to demonstrate that those seals remain leak tight during short-term temperature exposures.

The staff reviewed the manufacturer seal data and the critical seal characteristics defined in the SAR and confirmed that seals procured to meet the defined critical characteristics will be capable of fulfilling the containment performance requirements.

Therefore, the staff finds the added option to use metallic seals for the port covers to be acceptable.

2.13 Findings and Conclusion

The staff has reviewed the package description and concludes that the applicant has met the requirements of 10 CFR 71.33. The applicant has described the structural design and also described the materials used in the package in sufficient detail to support the staff's evaluation. The staff has reviewed the package design 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), 10 CFR 71.85(a), and 10 CFR 71.87(b) and (g). The applicant has demonstrated that there will be no significant corrosion, chemical reactions, or radiation effects that could impair the effectiveness of the packaging. In addition, the package will be inspected before each shipment to verify its condition.

The staff has reviewed the package and concludes that the applicant has met the requirements of 10 CFR 71.43(f) and 10 CFR 71.51(a) for Type B packages and 10 CFR 71.55(d)(2) for fissile packages. The applicant has demonstrated that the package will be designed and constructed such that the analyzed geometric form of its contents will not be substantially altered and there will be no loss or dispersal of the contents under the NCT tests.

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

Based on review of the statements and representations in the application, the staff concludes that the structural design changes and the materials used in the Model No. HI-STAR 100MB package have been adequately described and evaluated and that the package has adequate structural integrity to meet the requirements of 10 CFR Part 71.

3.0 THERMAL EVALUATION

The purpose of this evaluation is to verify that the Model No. HI-STAR 100MB package provides adequate protection against the thermal tests specified in 10 CFR Part 71 and meets the thermal performance requirements of 10 CFR Part 71 under NCT and HAC. The thermal review is to ensure that the peak cladding temperatures (PCTs) and package component temperatures are below the required limits and that the temperature gradients within the fuel basket are minimized to reduce thermal stresses.

3.1 Description of Thermal Design

The applicant described in Section 3.1.1 of the application, *Design Features*, that the HI-STAR 100MB package is designed for both bare baskets (F-32M and F-24M) with a heat load limit of

32 kW and a multi-purpose canister MPC-32M with a heat load limit of 29 kW. The heat generation in each fuel assembly is non-uniformly distributed over the active fuel length to account for design basis fuel burnup distribution, as discussed in the shielding section. The HI-STAR 100MB Package is designed to safely dissipate heat under passive conditions.

The applicant described that the fuel basket in HI-STAR 100MB package is engineered with a honeycomb structure of Metamic-HT plates which provides for the transmission of heat from the interior of the basket to its periphery. The space in and around the basket is filled with helium to ensure an inert environment enveloping the fuel cladding. Heat is transferred from the package to the environment by passive heat transport mechanisms only. In the MPC, the MPC's enclosure vessel serves as the pressure boundary with pressurized helium serving as the conductive and convective medium for heat rejection. The space between the package cavity and the MPC also contains slightly pressurized high purity helium. In the bare basket package configuration, the entire cavity is at the same helium pressure. The fuel basket is surrounded by basket shims installed to minimize the resistance to lateral transmission of heat. Heat dissipation from the fuel basket to the cask occurs by a combination of contact heat transfer, convection, conduction and radiation.

The applicant described, in Section 3.1.4, *Governing Regionalization Configuration*, that fuel loading is permitted (i) under an uniform loading configuration wherein all storage cells are generating heat at the maximum permissible rate or (ii) under regionalized loading which allows hot fuel placement in certain regions of the fuel basket without challenging fuel cladding temperatures. The applicant described that the uniform heat load case bounds all regionalized storage arrangements and, therefore, the thermal calculations are performed assuming the design heat load being uniformly distributed among the fuel assemblies. The applicant provides the calculated maximum temperatures in SAR Tables 3.1.1 for NCT and Table 3.1.3 for HAC. The applicant also summarizes the calculated maximum pressures in SAR Table 3.1.2 for NCT and Table 3.1.4 for HAC.

The staff reviewed the HI-STAR 100MB package thermal design described in Section 3.1, and assessed whether (a) the package is designed to safely dissipate heat under passive conditions and (b) the package and contents' temperatures will remain within their allowable values or criteria for NCT and HAC, as required in 10 CFR Part 71. The staff reviewed the thermal design and determined that the description of the thermal design is appropriate for a thermal evaluation.

3.2 Material Properties and Component Specifications

The applicant presented the material properties and specifications of the HI-STAR 100MB package in Section 3.2, *Material Properties and Component Specifications*. The applicant provided the packaging materials thermal properties in Tables 3.2.1 ~ 3.2.9 and listed the temperature limits of materials, fuel cladding, and packaging components in Tables 3.2.10, 3.2.11, and 3.2.12, respectively. The applicant noted in Table 3.2.12 that the short-term and fire accident limits for the gamma shield, made of lead, are set below the melting point of lead to preclude melting.

The applicant stated in Section 3.2.2, *Component Specifications*, that the cladding temperature limits, specified in ISG-11 Rev. 3, are adopted for moderate burnup fuel (MBF) and high burnup fuel (HBF). Neutron absorber material (Metamic-HT) used for criticality control, is stable in excess of 538˚C (1000˚F).

The staff reviewed SAR Tables 3.2.1 ~ 3.2.9 for the material properties of contents and packaging components, and SAR Tables 3.2.10 ~ 3.2.12 for materials and component temperature limits and agrees with the material properties, the component specifications and the temperature limits used in the thermal analysis.

3.3 General Considerations for Thermal Evaluations

3.3.1 Thermal Model

The applicant evaluated the thermal performance of the HI-STAR 100MB package using the 3-D FLUENT CFD code, as described in SAR Section 3.3.1, *Overview of the Thermal Model*. The thermal evaluations were performed on the HI-STAR 100MB package for bare basket cask (F-32M, 32 kW) and MPC (MPC-32M, 29 kW).

Based on the methodology used in the thermal model, the staff confirmed that the methodology, which was reviewed and accepted by the NRC, is acceptable for the HI-STAR 100MB package thermal analysis.

3.3.2 Screening Evaluations to Determine Limiting Heat Load Pattern

The applicant stated in Section S.6.1 of Report HI-2188066 that the steady-state thermal evaluations were performed, as part of screening calculations, for the basket designs of F-32M, F-24M, and MPC-32M to define the thermally most limiting transport scenario. Based on the calculated results listed in Table S.6.1 for F-32M and F-24M and Table S.6.2 for MPC-32M, the applicant concluded that the F-32M results in the maximum PCT and cavity average temperature and is thus adopted as the bounding scenario for further evaluations.

Based on the analysis described in the Report HI-2188066, the applicant further evaluated the two regionalized heat loading scenarios for the F-32M fuel basket, as shown in Figures S.4.1 and S.4.2, in compliance with the requirements in Section 3.1.4 of the application.

The applicant summarized the PCTs in Table S.6.14 for two regionalized heat loading scenarios at the design basis heat load of 32 kW, and concluded that the regionalized heat load scenarios are bounded by the F-32M at the design basis uniform heat load (32 kW).

The staff reviewed the analysis in Section S.6.1 and compared the peak cladding temperatures in Tables S.6.1, S.6.2, and S.6.14. The staff finds the applicant's screening evaluations to be acceptable and that the regionalized heat load scenarios are bounded by the F-32M at the design basis uniform heat load (32 kW).

3.3.3 Grid Sensitivity Studies

The applicant stated in Section 3.3.2, *Description of HI-STAR 100MB 3D Thermal Model*, that the HI-STAR 100MB mesh defined for the thermal analysis is guided by grid sensitivity studies carried out for the Model No. HI-STAR 190. In this manner, a grid independent calculation of the peak cladding temperature is reasonably ensured.

The staff compared the HI-STAR 100MB with the HI-STAR 190 (Holtec's Report HI2146214) package configurations and thermal design features and agrees with the applicant's conclusions on the grid sensitivity analysis performed for the HI-STAR 190.

3.4 Thermal Evaluations of Loading Operations

3.4.1 Time-to-Boil Limits

The applicant stated in SAR Section 3.3.6.1, *Time-to-Boil Limits*, that water inside the package cavity is not permitted to boil during fuel loading or unloading operations, in accordance with NUREG-1536. As described in Section 3.3.6.1, the applicant performed an adiabatic heat up calculation to determine a bounding heat-up rate based on the package heat load and thermal inertia of the loaded package, and then obtained the maximum permissible time duration for fuel to be submerged in water.

The applicant performed calculations to determine the maximum allowable time for completion of wet transfer operations for the bounding F-32M basket under a design maximum heat load of 32 kW. The applicant tabulated the maximum allowable time limits for completion of wet transfer operations under flooded HI-STAR 100MB conditions for several cask decay heat loads, as shown in SAR Table 3.3.5.

The staff reviewed SAR Section 3.3.6.1 and Table 3.3.5 and confirmed that:

(a) the assumptions and the methodology used to derive the time-to-boil limits were reviewed by the staff, and are appropriate for derivation of the maximum allowable time for completion of wet transfer operations (the time-to-boil limit) for the HI-STAR 100MB package, based on staff's engineering justification on physical phenomena and thermal characteristics, and

(b) the allowable time limits for completion of wet transfer operations of the F-32M, as shown in SAR Table 3.3.5, bound those for the F-24M and the MPC-32M, respectively, because of the bounding heat loads of 32 kW and fuel basket configuration.

3.4.2 Moisture Removal Operations

Vacuum Drying (VD)

The applicant stated in SAR Section 3.3.6.2, *Fuel Temperatures during Moisture Removal Operations*, that a transient thermal evaluation is performed under the loading specific heat loads in vacuum conditions. The time required in cycle 1 for the fuel to heat up from an initial temperature of 100°C (212°F) to 370°C (698°F) under high burnup fuel loading, or 540°C (1004°F) under all moderate burnup fuel loading, is computed. If the drying completion criteria are not met, then the cask cavity or MPC must be backfilled with helium to facilitate cooling and ensure that the steady state maximum fuel temperatures remain below the limits of 400°C for HBF and 570°C for MBF, in accordance with ISG-11 Rev. 3.

Up to 9 additional cycles of heat-up and cooldown may be performed for fuel temperature variations less than 65°C in each cycle. If a total of 10 drying cycles fails to meet drying criteria, then other competent means to dry fuel (such as forced helium dehydration) must be used or the cask -or MPC - must be defueled.

The staff reviewed the operations and criteria of vacuum drying described in SAR Section 3.3.6.2, and determined that the PCTs of 370°C (698°F) for HBF loaded in the MPC-32M and

540°C (1004°F) for MBF loaded in F-32M, used for determining the cycle time of drying, are bounding and acceptable, based on the temperature margins allowed for VD operation.

Forced Helium Dehydration (FHD)

The applicant stated in SAR Section 3.3.6.2 that the FHD ensures the PCT below the high burnup fuel temperature limit of 400°C (752°F) for all combinations of SNF type, burnup, decay heat and cooling time authorized for loading in the HI-STAR 100MB package because the FHD operation induces the forced convection heat transfer and has the PCT lower than the PCT in the quiescent mode of cooling under NCT.

The staff reviewed Section 3.3.6.2 and accepts that FHD can be conducted to maintain the PCT below the 400°C for all SNF fuel types, because of its heat removal capability enhanced by forced convection.

3.5 Thermal Evaluation under Normal Conditions of Transport

3.5.1 Heat and Cold

The applicant analyzed the thermal performance of the HI-STAR 100MB package with a bare basket F-32M, as the bounding scenarios under NCT, and provided the PCT and maximum component temperatures in SAR Table 3.1.1.

The applicant analyzed the thermal performance of the HI-STAR 100MB package with the MPC-32M under NCT, and provided the PCT and maximum component temperatures in SAR Table 3.1.6.

The staff reviewed SAR Table 3.1.1 for the NCT maximum temperatures of the F-32M and Table 3.1.6 for the NCT maximum temperatures of the MPC-32M. The staff confirmed that:

(a) the heat load pattern of the F-32M, as the bounding case for the HI-STAR 100MB package, due to its bounding decay heat,

(b) the PCTs of both the F-32M and the MPC-32M are below the limit of 400°C per ISG-11, Rev. 3,

(c) the maximum temperatures of the containment seals and lid seals for both the F-32M and the MPC-32M are below the design limits shown in SAR Table 3.2.10 and 3.2.12, respectively, and

(d) the maximum component temperatures for both the F-32M and MPC-32M are below their design limits indicated in SAR Table 3.2.10, 3.2.11, and 3.2.12, respectively.

Cold Conditions (-40°C or -40°F)

The applicant assumed zero decay heat and no insolation as the bounding conditions for cold evaluation, and stated in SAR Section 3.3.4, *Heat and Cold*, that the temperature distribution in the HI-STAR 100MB package uniformly approaches the cold ambient temperature of -40°C (-40°F) and all package materials of construction perform their intended function under this cold condition.

The staff reviewed SAR Section 2.6.2, *Cold*, and Section 3.3.4, plus the fracture toughness test criteria shown in SAR Table 8.1.5 and confirmed that the materials used for the HI-STAR 100MB package are qualified to a lowest service temperature of -40°C (-40°F).

3.5.2 Maximum Normal Operating Pressure (MNOP)

The applicant stated in SAR Section 3.3.5, *Maximum Normal Operating Pressure*, that the MNOP evaluation is based on the initial maximum backfill pressure, 3% fuel rod failure, in accordance with NUREG 1617, and helium form radioactive decay, and generation of flammable gases. The applicant calculated MNOPs using the Ideal Gas Law under heat condition of 38°C ambient, still air & insolation, design heat load, and a 30% release of the fission gases and a 100% release of the rod fill gas from 3% fuel rod failure. The applicant tabulated the fuel cavity MNOPs and maximum gas pressures in the annulus & inter-lid spaces in SAR Table 3.1.2 for the F-32M and the MPC-32M.

The staff reviewed the heat conditions used for the pressure calculations, and the NCT maximum operating pressures (MNOPs) shown in SAR Tables 3.1.2 and accepts that (a) the calculated MNOPs for the F-32M and the MPC-32M under 3% fuel rod failures are bounded by the design basis pressure as shown in SAR Table 2.1.1 and (b) the calculated maximum pressures in the MPC-32M annulus and F-32M inter-lid space are also below the design basis pressures presented in SAR Table 2.1.1. The NCT design basis pressures in Table 2.1.1 were reviewed and accepted by the NRC in the previous application.

3.5.3 Personnel Barrier Evaluation

The applicant stated in SAR Section 3.1.7, *Cask Surface Temperature Evaluation*, that a maximum surface temperature of 145°C (293°F) was computed for the HI-STAR 100MB package under NCT in still air at 38°C and in shade, as shown in Table 3.1.5, and therefore a personnel barrier is required to provide personnel protection and meet the accessible surface temperature limit specified in 10 CFR 71.43(g) for an exclusive use shipment.

The staff reviewed Table 3.1.5 and confirmed the use of the personal barrier is required with the accessible package surface temperature above the limit of 85°C, as defined by 10 CFR 71.43(g) for an exclusive use shipment.

Based on the review of SAR Section 3.5, *Thermal Evaluation under Normal Conditions of Transport*, the staff accepted that the NCT thermal evaluations are in compliance with 10 CFR 71.71.

3.5.4 Fuel Reconfiguration under NCT

The applicant stated in SAR Section 3.3.8, *Fuel Reconfiguration under Normal Transport*, that (a) the fuel assemblies remain intact prior to and during NCT based on the structural evaluations provided in SAR Section 2.11, *Fuel Rods*, and (b) the defense-in-depth hypothetical fuel reconfigurations, considered in the HI-STAR 190 and HI-STAR 180D applications, show no significant impact to containment boundary and fuel assembly due to the margins in cavity pressures and fuel temperatures.

The staff reviewed SAR Section 3.3.8 and finds the applicant's statements to be acceptable because (a) the bounding F-32M PCT and maximum component temperatures are below the design limits shown in SAR Table 3.1.1 and (b) the maximum NCT pressures in the fuel cavity (MPC-32M and F-32M), annulus (MPC-32M) and inter-lid space (F-32M), are below the corresponding design limits shown in SAR Table 2.1.1.

3.5.5 Thermal Expansions under NCT

The applicant computed thermal expansions for the components of the HI-STAR 100MB package in the radial and axial directions: (a) basket-to-cavity/MPC radial growth, (b) basket-to-cavity/MPC axial growth, (c) fuel-to-cavity/MPC axial growth, (d) MPC-to-package cavity radial growth, and (e) MPC-to-package cavity axial growth, as shown in Section S.6.6 of Report HI-2188066. The applicant provides the NCT thermal expansions of the F-32M and MPC-32M baskets in SAR Table 3.3.6 and Table S.6.9 of Report HI-21888066.

The staff reviewed SAR Table 3.3.6 and Table S.6.9 of Report HI-2188066 and confirmed that the calculated NCT thermal expansions of both the F-32M and MPC-32M are less than the minimum cold gaps because the high conductivity materials (Metamic-HT and low alloy steels) are used to minimize temperature gradients and the package has adequate clearances to allow unrestrained thermal expansions of the package internals under NCT.

3.6 Thermal Evaluation under Hypothetical Accident Conditions

3.6.1 Maximum Temperatures under HAC

The applicant described the design basis fire event in SAR Section 3.4.1, *Design Basis Fire Event*, and the fire conditions in SAR Section 3.4.2. During the 30-minute HAC fire with insolation, transfer of heat from the fire source to the package is by a combination of radiation and forced convection heat transfer with (a) a minimum fire emissivity of 0.9 and a lower-bound package absorptivity (0.8), and (b) the forced convection with heat transfer coefficients from the reported Sandia pool fire test data. During the post-fire cooldown, transfer of heat from the package to the ambient combines radiation with the package surface emissivity of 0.66, natural convection between package surface and ambient air, and air conductivity used for conductivity of neutron shielding materials.

The applicant selected the F-32M as the bounding pattern for the HAC thermal analysis because of its bounding heat load, higher NCT fuel cladding and packaging component temperatures. The applicant presented the PCTs and maximum packaging component temperatures in SAR Table 3.1.3 for F-32M fuel basket and SAR 3.1.7 for the MPC-32M under the HAC.

The staff reviewed SAR Sections 3.4.1 and 3.4.2, and Tables 3.1.3 and 3.1.7 and confirmed that:

> (a) the HAC initial conditions, fire conditions and thermal model, described in SAR Section 3.4, are consistent with those in the previous application which was reviewed and accepted by the NRC and therefore are acceptable,
>
> (b) the PCTs are below the fuel cladding temperature limits as shown in SAR Table 3.2.11, and in accordance with ISG-11 Rev. 3,
>
> (c) the package maximum component temperatures are below the materials temperature limits as shown in SAR Table 3.2.11, and

(d) there is no melting of the lead during the HAC fire.

3.6.2 Maximum Pressures under HAC

The applicant tabulated the maximum HAC pressures for the F-32M and the MPC-32M in SAR Table 3.1.4 which shows (a) the maximum HAC pressures of fuel cavity of F-32M and MPC-32M under the conditions with no rods rupture and with assumed 100% rods rupture, respectively, and (b) the maximum HAC pressures of the inter-lid space for F-32M and of the annulus for MPC-32M.

The staff reviewed the assumptions, boundary conditions, and parameters used in the HAC thermal evaluations and the calculated pressures presented in SAR Table 3.1.4, and confirmed that the maximum package fire accident pressures in the fuel cavity, the inter-lid space (F-32M), and the annulus (MPC-32M) are below the HAC design basis pressures defined in Table 2.1.1. The HAC design basis pressures in Table 2.1.1 were reviewed and accepted by the NRC in the previous application.

3.6.3 Thermal Expansions under HAC

The applicant provides the HAC thermal expansions of the F-32M basket and the MPC-32M, respectively, in Table S.6.10 and Table S.6.20 if of Report HI-21888066.

The staff reviewed Tables S.6.10 and S.6.20 and confirmed that the calculated HAC thermal expansions of the F-32M and the MPC-32M are less than the minimum cold gaps because the high conductivity materials (Metamic-HT and low alloy steels) are used to minimize temperature gradients and the package has adequate clearances to allow unrestrained thermal expansions of the package internals under HAC.

3.7 Evaluation Findings

In its RAI response (ADAMS No. ML20258A052), the applicant provided a manufacturer data sheet for the VM125-75 seal material (one of the prequalified seals) to justify its use at a revised lower temperature operating limit for the elastomeric containment seals from -30°C to -40°C. This limit is defined as a required critical characteristic in Table 2.2.11a of the application. The applicant clarified that the change was not made to modify the temperature limit from -30°C to -40°C, but to modify which temperature limit is a critical characteristic, while both seals can meet the low temperature operating limit specified in Table 2.2.11a.

According to the statements and representations in the HI-STAR 100MB application, the staff concludes that the thermal design has been adequately described and evaluated, and that the thermal performance of the HI-STAR 100MB package meets the thermal requirements of 10 CFR Part 71.

4.0 CONTAINMENT EVALUATION

The HI-STAR 100MB package uses a single cask design with two possibilities for a single lid when used with an MPC (specifically, the MPC-32M) and a double lid when used with a bare basket configuration. Both possibilities are qualified to transport high burnup fuel (HBF). When used to transport HBF, both configurations consist of an independent redundant double containment to prevent the release of radioactive materials to the environment.

Within this amendment to the HI-STAR 100MB, three major changes were made within this section of the application. Those changes were:

1) Modification of the helium leakage rate criteria to 1 x 10^{-5} cm^3/s,

2) Addition of the optional port cover design for the HI-STAR 100MB cask lids, and

3) Addition of the metallic seal option for the port covers of the HI-STAR 100MB cask lids.

4.1 Description of the Containment System

The applicant revised Section 4.1 of the SAR (for the outer containment system), Section 4.1.2, “Containment Penetrations,” Section 4.1.4, “Single Closure Lid – MPC,” and Section 4.1.5, “Dual Closure Lid – Basket.” In the revision of Section 4.1.2, the applicant addressed the optional metallic seals and port cover plate design for both the single lid cask and for the dual cask lid. In the revision of Section 4.1.4, the applicant revised this section to account for the updating of the leakage rate acceptance criteria for the single closure lid in the MPC.

Within Section 4.1.5 of the SAR, the applicant revised the SAR to address the changes made regarding the optional metallic seals and port cover plate design for both the inner closure lid and the outer closure lid of the bare basket. Section 4.2 of the SAR (for the inner containment system) provided revisions made by the applicant regarding the updated leakage rate acceptance criteria.

With the optional port cover design or the optional metallic seal option being implemented in this amendment, after review of the SAR, staff has concluded that since the seals being used are approved seals and that the seals are being leak tested after implementation, staff has reasonable assurance that the safety conclusions would not change from the previous amendment, thus meeting the containment requirements of Part 71.

4.2 Review of the Applicant’s Containment Analysis

The applicant performed the containment analysis using ANSI N 14.5 2014, NUREG/CR-6487, Regulatory Guide 7.4, and NUREG-1617 to ensure that appropriate values are used for the calculations.

The applicant performed calculations to determine the composition of a bounding release during normal or accident conditions using the radionuclide inventory for isotopes other than Co-60 that was calculated using modules from SCALE 6.2.1.

The applicant asserted, and staff confirmed, that the radiological inventories were developed using realistic parameters for the fuel assemblies identified to be the contents of the HI-STAR 100MB.

The fuel inventory for normal and accident releases was all calculated with release fractions consistent with the values found NUREG/CR-6487. The applicant illustrated the released radionuclide concentration for each operating condition. Staff reviewed the radionuclide inventories provided in the analysis and found these values to be acceptable.

The applicant calculated the HI-STAR 100MB leakage rates under normal conditions of transport and hypothetical accident conditions using the methodology given in NUREG/CR-6487.

To determine the leakage rates for a set of contents type, the following values were calculated:

1) the source term concentration for the releasable material,
2) the effective A_2 of each individual contributor,
3) the releasable activity,
4) the effective A_2 for the total source term,
5) the allowable radionuclide release rates, and
6) the allowable leakage rates at transport (operating) conditions.

The corresponding leakage hole diameters were calculated using the equations for continuum and molecular flow. Once the leak hole diameters were calculated, the values for the corresponding leakage rates at test conditions were calculated. Staff reviewed the analysis and the values for the leakage rates and determined that the values did not exceed the limits stipulated in ANSI N. 14.5. Therefore, staff finds these values acceptable.

4.3 Evaluation Findings

Based on review of the statements and representations in the application along with the analysis provided by the applicant, the staff concludes that the containment design for the HI STAR 100MB has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR Part 71.

5.0 SHIELDING EVALUATION

The objective of this review is to verify that the HI-STAR 100MB package design satisfies the external radiation requirements of 10 CFR Part 71 under NCT and HAC. The staff followed the guidance provided in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel."

The applicant has requested a revision to CoC No. 9378 to allow the loading of Westinghouse 17x17 F class fuel assemblies in the F-24M basket. This class of fuel assembly may have an increased hardware activation source, as a result of higher allowable Co^{59} impurity levels. Staff's review focused on the changes to the application required to justify the inclusion of the new contents.

5.1 Description of the Shielding Design

5.1.1 Packaging Design Features

The HI-STAR 100MB package generally consists of a fuel basket or MPC, the overpack and impact limiters. In the radial direction from the center, the cask body consists of a stainless-steel lined cavity surrounded by lead gamma shielding, a layer of stainless-steel, neutron shielding material (i.e., Holtite A), and an external stainless-steel shell.

Axially, the bottom consists of stainless-steel with a layer of Holtite A sandwiched within, and both inner and outer closure lids consist entirely of stainless-steel. The inner closure lid is only used in conjunction with a bare fuel basket. The contents are held either in a MPC or bare fuel basket installed in the cask cavity.

The packaging, basket, and MPC design and materials remain unchanged from the previous revision.

5.1.2 Summary of Maximum Radiation Levels

The HI-STAR 100MB is designed and analyzed for exclusive use shipment on an open conveyance with an enclosure; thus, the dose rate limits for 10 CFR 71.47(b) apply. For the HI-STAR 100MB, the enclosure consists of a personnel barrier that spans between the two impact limiters. The personnel barrier does not encompass the impact limiters. Thus, a limit of 200 mrem/hr applies to the external surface of the impact limiters, the personnel barrier, and the bottom surface of the rail car.

The applicant calculated dose rates for both a bare basket and a MPC and presented them in SAR Tables 5.1.1-5.1.8. The applicant assumed design-basis fuel loadings as determined in Section 7.7 of the SAR and accounted for configurations under NCT and HAC.

The applicant's calculation used a relatively fine grid to determine the highest total dose rate for any location for these results. Staff review of Revision 0 of this package previously found the applicant's shielding model conservatively neglected the separation provided by the personnel barrier and much of the shielding provided by the impact limiters. Thus, staff finds reasonable assurance that the dose rates presented by the applicant demonstrate compliance with 10 CFR 71.47.

5.2 Source Specification

The applicant selected the Westinghouse 17x17 (WE 17x17) as the design-basis assembly for bare fuel baskets. The WE 17x17 has the largest fuel mass of the assemblies that may be loaded into a bare basket, and the WE 17x17 F is restricted to the F-24M basket due to the level of cobalt impurity. Staff finds the applicant's selection of design-basis assemblies acceptable because a larger mass correlates with a larger source term for a given set of burnup, enrichment, and irradiation parameters.

The applicant determined both neutron and gamma source terms with TRITON and ORIGAMI modules within the SCALE 6.2.1 code system using the 252-group library from the ENDF/B-VII cross-section library. The applicant assumed a single, full-power cycle to the desired burnup. For ORIGAMI source term calculations, the applicant uses predetermined TRITON libraries distributed with SCALE 6.2.1.

Since the proposed fuel assembly type falls in a previously evaluated fuel class and the applicant's methodology has not changed from the prior revision, staff finds its continued use acceptable.

5.2.1 Gamma Source

Gamma radiation in spent fuel originates from decay of actinides and fission products, secondary photons from neutron capture, and activation of fuel hardware and non-fuel hardware. The applicant's gamma radiation analysis is largely unchanged except for the increased Co^{59} impurity levels permitted with the new WE 17x17 F contents.

For the WE 17x17 F class of assembly, the applicant has proposed to allow an impurity level up to 1.2 g/kg. The staff finds this level of Co^{59} impurity acceptable because it is consistent with the value justified in the technical bases for Regulatory Guide 3.54, "Spent Fuel Heat Generation in an Independent Spent Fuel Storage Installation."

The applicant adjusted the minimum required cooling time in Section 7.7 of the application for the WE 17x17 F class of assembly. The applicant also updated the gamma and neutron dose rates in Tables 5.1.1, 5.1.3, 5.1.5, and 5.1.7.

5.2.2 Neutron Source

Neutron radiation in spent fuel originates from spontaneous fission, alpha-n reactions, neutrons produced through subcritical multiplication, and gamma-n reactions. The applicant minimized the assumed enrichment in determining the neutron source. Spontaneous fission of Cm^{244} accounts for approximately 95% of the total neutron source.

Minimizing the enrichment in the model increase the contents Cm^{244} quantities. The staff finds this to be acceptable because it produces a conservative neutron source. Other sources include alpha-n reactions in Cm^{244}, and neutrons generated from subcritical multiplication reactions. The applicant presented the results of its neutron source calculations in Table 5.2.6 of the application.

5.3 Model Specification

Section 5.3 of the application includes most of the model description as it pertains to the applicant's shielding analysis. The applicant included additional details in the discussion of the shielding methodology in Section 5.4 of the application. The staff reviewed the shielding model, which included comparison of the details in Section 5.3 with the drawings in Chapter 1 of the application, and the applicant's sample input files. The applicant's shielding geometry, material properties, and modeling simplifications largely remain unchanged from the previous revision.

In its model, the applicant homogenized the fuel regions within the basket cells and homogenized the end fitting and plenum regions as reduced density steel. This simplification is still appropriate for the proposed WE 17x17 F fuel assemblies, which do not differ much in design from other WE 17x17 assemblies. In Section 5.3.1.1 of the application, the applicant lists some potentially non-conservative modeling simplifications.

Staff reviewed the packaging simplification where the applicant did not model the bottom flange air gap and cover plates at the minimum dimensions and confirmed the overall thickness of shielding material is still modeled as minimum even though those components are modeled with non-conservative dimensions.

Staff performed a confirmatory sensitivity study to evaluate the applicant's modeling simplification 16. Considering the calculational uncertainty, staff results showed insignificant effect on external dose rates (i.e., any effects were within the calculational uncertainty, which is only a few percent), which confirmed the applicant's determination.

Prior studies have shown the properties of aluminum alloy basket and internal components have small effects on external dose rates. The applicant performed a sensitivity study for packaging simplification 17 which confirmed this expectation. As a result, staff finds the applicant's modeling simplifications acceptable.

The configuration of the source remains unchanged from the prior revision. The source term will differ due to the activation of the higher Co^{59} impurity levels.

The applicant calculated the activation source with ORIGAMI using the in-core fuel region flux at full power. The applicant scaled the activation source for assembly regions using factors from "Spent Fuel Assembly Hardware: Characterization and 10 CFR 61 Classification for Waste Disposal," PNL-6906 vol 1. These factors have been used in other NRC-approved applications and staff finds their use here appropriate.

5.4 Shielding Evaluation

The applicant performed its shielding analyses with MCNP-5 Version 1.51. MCNP is a standard Monte Carlo transport code widely used in shielding applications. The applicant determined source terms with the TRITON and ORIGAMI codes from the SCALE 6.2.1 code suite.

These codes have been evaluated and proved to be robust methods to determine the radiation sources of spent fuel and activated fuel and non-fuel hardware. The methodology remains unchanged from the prior CoC revision.

The applicant used dose response functions taken from ANSI/ANS 6.1.1-1977. The staff finds this is consistent with the acceptance criterion provided in NUREG-1617 and therefore to be acceptable.

5.5 Confirmatory Analysis

Staff modeled the HI-STORM 100 MB package with the F-24M basket with the MAVRIC module in the SCALE 6.2.3 code suite. The staff used a 46-group cross-section library based on ENDF/B-VII nuclear data. Staff did not homogenize the fuel region and modeled the fuel as an array of pins in the configuration of the assembly being evaluated. Staff modeled the steel, lead, and Holtite shielding components at the same minimum density as the applicant's evaluation.

Staff evaluated detector locations that the applicant chose and examined a mesh tally to determine if there were any other points of interest. Given the applicant proposed no significant changes to the packaging, no additional locations of interest were expected, and staff evaluation confirmed this.

Staff modeled the Westinghouse 17x17 F fuel assembly and the design-basis assembly from a prior revision of this CoC in the F-24M basket.

The results of the staff's evaluation confirmed the applicant's assumptions and modeling methods are either conservative or do not significantly impact calculated dose rates.

5.6 Conclusion

Based on its review of the information and representations the applicant provided, and the staff's own independent, confirmatory calculations, the staff has reasonable assurance that the proposed HI-STAR 100MB package design and contents satisfy the shielding requirements and dose rate limits in 10 CFR Part 71.

6.0 CRITICALITY EVALUATION

6.1 Review Objective

The objective of this review is to verify that the amended HI-STAR 100MB transportation package, loaded with the spent fuel assemblies as specified in the Certificate of Compliance (CoC) Revision No. 1, meets the regulatory requirements of 10 CFR 71.55 and 71.59, i.e., a single package and an array of the packages remains subcritical under NCT and HAC.

6.2 Criticality Safety Evaluation

The HI-STAR 100 Version MB (HI-STAR 100MB thereafter) is designed to transport high burnup PWR UO_2 fuel in intact conditions. This amendment requests an addition of a new PWR spent fuel assembly design, 17x17F with an initial enrichment of 5.0% U-235, to the authorized contents.

The 17x17F PWR spent fuel assembly design is similar to the previously approved 17x17 PWR fuel assembly designs, i.e., 17x17A, 17x17B, 17x17C, except that this fuel assembly is shorter in active fuel length and has some variations in parameter such as pellet diameter, rod pitch, and guide tubes. The most significant change in this amendment request is to increase the fuel enrichment from 4.7% to 5.0% U-235.

The NRC staff reviewed the criticality safety design of the HI-STAR 100MB package containing the new 17x17F spent fuel. The staff's criticality safety review results are documented in the following subsections of this chapter of the SER.

In its review, the staff followed the guidance and the acceptance criteria provided in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (NUREG-1617 thereafter) and the Staff Interim Guidance 8, Revision 3 (ISG-8, Rev. 3, thereafter).

6.2.1 Package Criticality Safety Design Features

The HI-STAR 100MB packaging system consists of an overpack and a weld-sealed canister (the M mode) or an open bare fuel basket (the B mode). The M mode is designed to transport fuel that is already loaded in a weld-sealed canister (canister based) and the B mode is designed to transport spent fuel that is directly loaded into the fuel basket that is installed in inner cavity of the overpack.

The overpack is made of a multi-layered cylindrical shell with a flat bottom plate and one (two in the B mode) flat top lid that is bolted onto the cylindrical shell. In the M mode, the weld-sealed and leak-tight pressure vessel MPC is loaded into the cask cavity. In the B mode, the bare fuel basket is attached to the overpack and has its own closure lid.

The canister and basket designs that can be transported by the HI-STAR 100MB overpack include the MPC-32M, F-32M (bare basket configuration), and F-24M (bare basket configuration). In both M and B modes, the fuel baskets are constructed with Metamic material, which is an NRC-approved boron-doped structural material for fuel basket. The advantage of using the Metamic fuel basket design is that the fuel is ensured to be covered by poison plates under both NCT and HAC conditions to ensure criticality safety.

The HI-STAR 100MB is designed to transport 32 (MPC-32M and F32-M) or 24 (F-24M) intact PWR fuel assemblies. No damaged fuel is authorized. Table 1.1.2 lists the authorized new MPCs and bare baskets. Chapter 7, “Operating Procedures” of the application provides specific fuel qualification criteria for the authorized PWR fuel contents, including the new 17x17F class fuel.

Fuel assemblies are held in the cells of the fuel basket to maintain their geometric locations in the package under NCT and HAC. There is no structural change in packaging design for this amendment. A fuel spacer will be used to hold the fuel in axial position because the 17x17F fuel is 144-inch-long which is shorter than the length of the fuel basket 155 inches. Based on the structural design, all assemblies in the basket are always surrounded by neutron absorbing material to ensure criticality safety of the package under NCT and HAC because the entire fuel basket structural material is made of Metamic which also serves as neutron absorber even without the axial spacers. On this basis, the staff finds that there is no concern for the fuel to slide out of the envelope of the neutron poison plates under both NCT and HAC.

The applicant took burnup credit in the criticality safety analyses for the package containing the MPC-32M canister or the F-32M fuel basket. In the application, the applicant states that it used the same burnup credit analysis method as it used in the previously approved applications for the HI-STAR 190 loaded with the MPC-37 canister and the HI-STAR 100 package, as approved in amendment 10 for transport of the MPC-32 canister.

The criticality safety design of the package containing the F-24M basket design includes flux traps but does not take burnup credit. This special design feature reduces the neutronic coupling between the adjacent fuel assemblies in the fuel basket to reduce the potential of nuclear chain reactions so that this basket design does not rely on burnup credit. This is another criticality safety feature that reduces the reactivity, k_{eff}, of the package.

The applicant includes the licensing drawings in the application. Licensing drawing No. 11070 shows the layout and dimensions of the HI-STAR 100MB overpack assembly and components. Licensing drawing 3923 shows the MPC enclosure vessel. Licensing drawing No. 11084 shows the structure and dimensions of the MPC-32M fuel basket. Licensing drawings No. 11082 and 11083 show the structure and dimensions of the F-32M and F-24M fuel basket, respectively.

The staff reviewed these drawings and finds that these drawings provide sufficient details for the staff to compare with the dimensions and tolerances used in the criticality safety analysis models. On this basis, the staff finds that the drawings are acceptable.

The HI-STAR 100MB packaging system is designed to transport high burnup fuel (HBF), i.e., fuel burnup exceeding 45 GWd/MTU. To support the transport of HBF, the packaging design employs a double containment barrier system design. When the package is loaded in the B mode for transporting HBF, both the fuel basket lid and the overpack lid are credited for moderator exclusion because both lids are qualified to serve as a stand-alone leak-tight containment boundary.

When the package is loaded in the M mode for transport of HBF, the welded fuel basket and the overpack lid closure form two independent containment boundaries for moderator exclusion because both closures are qualified to serve as a stand-alone containment boundary.

The structural designs of the basket and overpack ensure that both closures meet the leak-tight standard of ANSI N14.5 under NCT and HAC as prescribed in 10 CFR 71.71 and 71.73, respectively. Based on the results of structural review, each containment boundary closure meets the water exclusion criterion with significant safety margin because moderator exclusion requires no ingress of water into the cavity of the package; which is a much less restrictive requirement in comparison with a leak-tight design. On this basis, the staff determined that the package design meets the criterion for moderator exclusion in accordance with the acceptance criteria specified in Interim Staff Guidance No. 19 (ISG-19).

In summary, the HI-STAR 100MB package uses neutron poison plates and burnup credit (MPC-32M and F-32M) or a combination of neutron poison plates and flux trap (F-24M basket only) to ensure criticality safety of the package under NCT. It also employs double closure lids to meet the criterion of moderator exclusion, in accordance with the guidance provided in ISG-19 to ensure that the package meets the requirement of 10 CFR 71.55(e), i.e., the package remains subcritical under HAC.

6.2.2 Spent Nuclear Fuel Contents

The additional new authorized content requested in this application, the 17x17F class fuel, is specified in Table 7.7.2 of the application. There is no change in the fuel basket design. No damaged fuel is authorized.

With the addition of the 17x17F fuel design in this amendment, the authorized spent fuel contents include:

- Westinghouse (WE) 15x15: 15x15B and 15x15C
- Babcock & Wilcox (B&W) 15x15: 15x15D, 15x15E, 15x15F and 15x15H
- Combustion Engineering (CE) 15x15: 15x15I
- CE 16x16: 16x16A and 16x16B
- WE 16x16: 16x16C
- WE 17x17: 17x17A, 17x17B, 17x17C, and 17x17F.

The revised Table 7.7.3 (a) of the application provides the minimum burnup for fuel to be loaded in the MPC-32M and F-32M. No minimum burnup is required for fuel to be transported in the F-24M basket. Table 7.7.3(b) of the application provides the maximum allowable initial enrichment for each of the fuel classes. Table 7.7.4 provides the bounding fuel depletion parameters.

The non-fuel waste and some non-fuel hardware may be transported in the non-fuel waste basket. However, the total weight of the fissile materials in the waste is limited to the exempted quantity of fissile materials as defined in 10 CFR 71.15. Therefore, non-fuel hardware in the non-fuel waste basket is not subject to a criticality safety review. For this reason, the staff did not perform a criticality safety review for the package having non-fuel wastes.

Plutonium fuel, in any form other than in the spent UO_2 fuel, is not authorized for transport.

6.2.3 Summary of Criticality Evaluations

The applicant performed criticality safety analyses for the packages containing MPC-32M, F-32M, and F-24M PWR fuel baskets that are loaded with the 17x17F fuel. The applicant evaluated a single package assuming a flooded internal and reflected with 30 cm of water to demonstrate that the package complies with the regulatory requirements of 71.55(b) and

71.55(d). To demonstrate that the packages containing the MPC-32M or F-32M basket complies with the regulatory requirement of 71.55(e), i.e., the package under HAC, the applicant took credit of the double closure design feature of the package and evaluated the criticality safety without moderator because the package meets moderator exclusion design criterion as provided in ISG-19.

The applicant provided a summary of the calculated k_{eff} values in Tables 6.1.1 of the application, for packages containing either the MPC-32M or F-32M basket that is loaded with the 17x17F fuel. The data presented in Table SAS.2 show that the maximum k_{eff} value for the package containing the fully loaded F-24M basket with the maximum U-235 enrichment of 5.0 wt% is 0.9474.

The calculated k_{eff} values show that the package under NCT remains subcritical with all uncertainties in the calculation and an adequate administrative safety margin of 0.05Δk. The staff finds that results demonstrate that the packages containing the MPC-32M, F-32M or F-24M basket loaded with the 17x17F fuel meets the acceptance criterion for criticality safety as specified in NUREG-1617. On this basis, the staff finds that the applicant has demonstrated that the package meets the requirements of 10 CFR 71.55(b) and 71.55(d).

The applicant calculated the k_{eff} value for a single package containing the 17x17F class fuel in one of the loading configurations, i.e., MPC-32M, F-32M, and F-24M, as well as an infinite array of packages and provides the results in Table SAS.3 of the application. These data demonstrate that the k_{eff} values for the package loaded with different fuel types in the MPC-32M and F-32M are all below 0.95. The staff finds that results meet the acceptance criterion for criticality safety as specified in NUREG-1617.

As discussed earlier in this section of the SER, based on the evaluation results of the package's structural performance under the tests prescribed in 10 CFR 71.73, the staff finds that the applicant's criticality safety analysis for the package under HAC is consistent with the damaged condition, i.e., there is no water ingress into the package internal cavity, and the assumptions used in the modeling of the package are conservative and meets the acceptance criterion provided in NUREG-1617. On this basis, the staff finds that the applicant has demonstrated that the package meets the requirements of 10 CFR 71.55(e).

In addition, the applicant's criticality safety evaluations show that an infinite array of undamaged or damaged packages remains subcritical. The applicant calculated the criticality safety index (CSI) of this package following the procedures as prescribed in 10 CFR 71.59. The CSI for this package is determined to be 0.

The staff reviewed the applicant's calculation of the CSI and modeling of arrays of packages under NCT and HAC. The staff finds that the applicant's criticality safety analyses for arrays of packages under NCT and HAC are consistent with the package performance under the respective conditions. The staff also finds that the applicant's calculation of the CSI value followed the method prescribed in 10 CFR 71.59 and is therefore acceptable.

6.3 General Considerations for Criticality Evaluations

The applicant performed criticality safety analyses for the HI-STAR 100MB package containing either the MPC-32M canister, the F-32M, or a package containing the F-24M fuel bare basket loaded with the requested fuel designs. The applicant used the MCNP5.1 computer code and the ENDF/B-VII cross section library in its criticality safety analyses. For the package taking burnup credit, the applicant used the CASMO5 computer code with ENDF/B-VII cross section library to perform depletion analyses to determine the material concentrations of the spent fuel. The staff's evaluations of the computer codes and cross section libraries are documented in Section 6.3.3 of this SER.

The CASMO code is one of widely used computer codes for reactor design. The applicant performed code benchmarking analyses for the CASMO5 code using radiochemistry assay (RCA) data from samples of spent fuel from various reactors. Detailed discussion on the use of the CASMO code for burnup credit analysis is discussed in Section 6.6 of this SER.

The applicant applied burnup profile in its burnup credit analysis. The applicant used the axial burnup profiles with 18 burnup axial zones. The staff finds that this detailed modeling of the axial burnup distribution is sufficient to capture the effect of under burned fuel regions at the ends of the fuel assemblies and is consistent with the recommendation of ISG-8, Revision 3. On this basis, the staff finds this approach to be appropriate and acceptable.

6.3.1 Model Configuration

The applicant explicitly modeled the fuel assembly, Metamic-HT fuel basket fuel cell structure which is a neutron poison material, and other structural and overpack components of the package that are important to criticality safety. The impact limiters are not included in the model.

The package is assumed to contain the most reactive spent fuel authorized to be loaded into each of the specific basket designs, MPC-32M, F-32M or F-24M. The criticality analyses assume 90% of the minimum ^{10}B content in the neutron poison plates manufactured with acceptance criteria as specified in Chapter 8 of the application, "Acceptance Tests and Maintenance Programs." The staff finds that this assumption is consistent with the acceptance criterion specified in NUREG-1617 and therefore acceptable.

The fuel stack density is assumed to be 10.686 g/cm^3. This is a conservative value because this is 97.5% of the theoretical density of UO_2, and it corresponds to a pellet density of 99% or more of the theoretical density. This difference between stack and pellet density is a result of the necessary dishing and chamfering of the pellets. The staff finds that this assumption is conservative and to be acceptable because it is almost the theoretic density, which is the highest possible amount of UO_2 fuel per unit volume.

In addition, the applicant used the following assumptions:

(1) full flooded package internal with full density of fresh water, i.e., 1.0 g/cc,

(2) flooded fuel rod pellet-to-clad gap regions with fresh water under NCT and routine operations (including loading and unloading operations),

(3) the worst-case combination of manufacturing and fabrication tolerances, and

(4) reflected with 30 centimeters of water outside of the package. These tolerances are consistent with the package's allowable tolerances as shown in the drawings of the package.

The applicant performed a sensitivity study on the moderator density variation and finds that the system is most reactive and therefore there is no concern on that preferential flooding may create a more reactive condition. The staff's evaluation of these studies and the conclusion is documented in Section 6.3.4 "Demonstration of Maximum Reactivity" of this SER.

In the criticality safety analyses for the package, the applicant took credit for 90% of the boron in the Metamic-HT neutron poison plates. The staff finds that this is consistent with the guidance provided in Interim Staff Guidance-23, "Application of ASTM Standard Practice C1671-07 when performing technical reviews of spent fuel storage and transportation packaging licensing actions," and therefore to be acceptable.

The applicant used fresh fuel composition for the spent fuel assemblies contained in the F-24M basket. This assumption does not take credit for the loss of fissile materials and accumulation of fission products and non-fissile transuranic materials that are physically present in the spent fuel assemblies. The staff finds that this is a significant conservative assumption in the criticality safety analysis for the package and therefore to be acceptable.

The applicant performed sensitivity studies on parameters, such as fuel density and water temperature in the cask, that affect reactivity using the CASMO5 code. The results are presented in Table 6.3.4 of the application and show that using the maximum fuel density and the minimum water temperature (corresponding to the maximum water density) provides a bounding condition for criticality safety analyses.

The applicant used these conditions in all the criticality safety analysis models. However, the applicant stated that the fuel temperature sensitivity analyses it performed are not used to demonstrate compliance with the regulation; rather they are used to determine sensitivity of the system to changes in temperatures of the moderator, fuel, and structure material and find the bounding conditions.

The staff reviewed these analyses and finds it to be acceptable to use the approach for performing comparative analyses because the purpose of this study is to compare the impact of different parameters on the system's reactivity. However, as indicated by the applicant in the application that these analyses are used to identify the bounding parameters to inform the design basis criticality safety analyses. The computer codes that are used for demonstration of compliance with the regulations need vigorous code benchmarking analyses to identify any potential bias of the code for this specific application.

The applicant took burnup up credit for the packages containing the MPC-32M canister or the F32-M fuel basket that is loaded with the design basis fuel assemblies. The staff's detailed evaluation of the applicant's burnup credit analyses is documented in Section 6.3.5 of this SER.

6.3.2 Material Properties

The applicant provides material compositions for the various components of the HI-STAR 100MB packaging system in Table 6.3.5 of the application. The data in the table include the nuclide identification number (ZAID) for each nuclide, the atomic number, mass number, and the cross-section evaluation identifier, which are consistent with the ZAIDs in the MCNP manual.

The HI-STAR 100MB package uses Metamic-HT fixed neutron poison plate, which is aluminum alloy containing B_4C as neutron absorber. The applicant states that the HI-STAR 100MB is designed to ensure that the fixed neutron absorber will remain effective for a period greater than 50 years and there are no credible degradation mechanisms to cause significant loss of B-10 in the poison plates during this design basis package life-time.

The continued effectiveness of the fixed neutron absorber is assured by acceptance testing, documented in Paragraph 8.1.5.5 of the application, to validate the B-10 concentration in the fixed neutron absorber. In addition, based on its own calculations for a similar cask model, the staff finds that loss of B-10 atoms in the fixed neutron absorber by neutron absorption during the service life time because of irradiation by the neutrons from the content is negligible (less than 10^{-8} percent of the original loading). Therefore, it is not necessary to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

The applicant provides a detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of the fixed neutron absorber to demonstrate that the minimum requirement B-10 concentration is assured. This determination is confirmed by the material reviewer and documented in the material review chapter of this SER. The material compositions and properties of the other packaging materials are consistent with the specifications commonly used criticality safety analyses. However, the Metamic components are still subject to the maintenance requirement for compliance with the regulatory requirements of 10 CFR 71.31(c) and specific maintenance requirements of Chapter 8 of the application.

In the criticality safety analysis models, the applicant did not include the Holtite neutron shield on the outside of the package, nor the impact limiters. The staff finds this modeling simplification to be conservative and acceptable, because these assumptions omit the absorption of neutrons in the neutron shield layer and creates closer reflectors in the radial and axial directions of the package. The combinations of these two factors produces more conservative results in criticality safety analyses. Therefore, the staff did not review the material properties of these components because there are not included in the criticality safety analyses.

The staff reviewed the material properties and the assumptions used in the criticality safety analysis. The staff finds that the material properties the applicant used in the criticality safety analyses are consistent with the commonly available material data and the material properties, such as density, composition, and amount of Boron-10. On these bases, the staff determined that the material properties of the packaging materials and the contents are appropriate and acceptable.

6.3.3 Computer Codes and Cross Section Libraries

The applicant used the three-dimensional transport theory-based Monte Carlo solution method code MCNP5, Version 5.1 and ENDF/B-VII cross section library in the package criticality safety analyses. In the MCNP criticality safety analysis models, the applicant used 10,000 simulated histories per cycle, a minimum of 400 cycles were skipped before averaging, a minimum of 400 cycles were accumulated, and the initial source was specified as uniform over the fueled regions (assemblies).

The applicant explicitly examined the Shannon entropy index, which is part of the MCNP5 model output, to ensure convergence of the calculations by confirming that both the k_{eff} value and fission source distribution have properly converged at the end of the calculations. The staff reviewed the Shannon Entropy index provided by the applicant in the sample output file and finds that calculations have adequately converged and therefore finds the resultant k_{eff} values acceptable.

The staff reviewed the applicant's criticality safety evaluation method, including the computer code and cross section library as well as the assumptions used in the models. The staff finds that the MCNP code version is one of codes recommended by NUREG-1617 for criticality safety evaluation and the cross-section library represents the up-to-date measurement data.

The examination of the Shannon Entropy assured the adequate conversion of the calculations and therefore the accuracy and reliability of the resultant k_{eff} values. On this basis, the staff finds that the computer code and cross section library are adequate for this application.

6.3.4 Demonstration of Maximum Reactivity

The applicant calculated the neutron multiplication factor, k_{eff}, for the HI-STAR 100MB package with each of allowable fuel type as specified in Tables 7.7.1 and 7.7.2 and Chapter 1 of the application. The applicant searched the maximum reactivity with considerations of moderator density and rod pitch changes, which are the two most important parameters that may cause the system k_{eff} to change for the package under NCT for some selected enrichment (Holtec Report No: H-2188084). The results are summarized in Table 6.1.3 of the application for a single package as well as array of packages under NCT and HAC conditions for each basket type.

Concerning the potential for preferential flooding (also known as partial flooding), the applicant cited research results, published by Cano, et al, that show that the phenomenon of a peak in reactivity at a hypothetical low moderator density (also called "optimum" moderation) does not occur to any significant extent in a system with heavy neutron poison loading. Based on this publication, the applicant did not evaluate the reactivity of a partially flooded package. Instead, it studied the reactivity effect of variation of the water level in the package.

The applicant studied the reactivity changes during the flooding process were evaluated in both the vertical and horizontal positions and provides the results of these calculations are shown in Table 6.3.12. In general, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is fully flooded. The fully flooded case therefore represents the bounding condition for all basket types.

Based on the applicant's analyses, as shown in Table 6.3.12 of the application, for package containing either the MPC-32M canister or the F-32M basket, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is at a fully flooded condition. In these calculations, the cask is partially filled (at various levels) with full density (1.0 g/cm^3) water and the remainder of the cask is filled with steam consisting of ordinary water at partial density (0.0002 g/cm^3).

The staff reviewed the publication cited by the applicant and the staff finds the applicant's justification for not performing criticality analyses for preferential flooding of the package to be acceptable because the analyses for the fully flooded package bounds the "preferential flooding" condition.

The staff reviewed the cited publication and finds that the study is applicable to the HI-STAR 100MB package design because the system is loaded with heavy neutron absorbing materials, namely B-10, in the Metamic plate and is similar to the systems analyzed in the study. On this basis, the staff finds that there is no need to perform further study on internal preferential flooding of the package.

The applicant studied the reactivity effect of annular fuel pellets (some fuel pellets at the ends of the fuel rods are made with holes in the center of the pellets to save fuel) at the top and the bottom of the fuel rods. Since the annular pellets are loaded at the regions with the high neutron leakage, the applicant determined that the effect on reactivity is minimal. The staff reviewed this conclusion and finds it to be acceptable because: (1) these are the regions with the very low neutron importance and (2) the contribution of neutrons in these regions to reactivity is very low based on the fundamental of neutron transport and multiplication theory [Ref. 9].

The applicant also studied the reactivity effect of eccentric positioning of assemblies in the fuel cells, i.e., fuel assemblies moving inward toward the center of the fuel basket and presents the results in Table 6.3.13 of the application. The result shows that in most of the cases, moving the assemblies in the regular and specific cells to the periphery of the basket results in a reduction in reactivity, compared to the cell centered position, while moving the assemblies towards the center results in an increase in reactivity, compared to the cell centered position.

All calculations are therefore performed with the assumption that all fuel assemblies moved towards the center of the basket. This result is consistent with the basic nuclear criticality theory that the reactivity increases when the fuel assemblies move toward the center because the neutronic coupling between fuel assemblies gets enhanced. On this basis, the staff finds the results acceptable.

Based on the analyses discussed above, the applicant demonstrated that the package under HAC is much less reactive than a fully flooded package even with consideration of highly unlikely fuel reconfiguration. The staff finds the applicant’s analysis for the package under HAC and the results are consistent with the well understood nuclear physics (much lower reactivity without moderator for low enrichment system). On this basis, the staff determined that the applicant has identified the most reactive configuration of the package and the package meets the regulatory requirements of 10 CFR 71.55(b) and 71.55(d).

The staff reviewed the method and results of these analyses and finds that the method is acceptable, and the results are reasonable. The staff determined that the applicant has considered all credible NCT and HAC scenarios as prescribed in 10 CFR 71.71 and 71.73 and the method of evaluations and conclusions meet the acceptance criteria of NUREG-1617. On these bases, the staff finds that the package design meets the criticality safety requirements of 10 CFR 71.55(d) and 71.55(e).

6.3.5 Burnup credit analyses for MPC-32M and F-32M packages

The applicant took burnup credit for the HI-STAR 100MB package containing either the MPC-32M canister or the F-32M bare fuel basket. The applicant takes credit for all isotopes as listed in ISG-8, Rev. 3 except Eu^{151}. The reason is that the COSMO code used to calculate the material composition of spent fuel does not have the capability of tracking this isotope.

The applicant used a direct difference method to determine the bias and bias uncertainty of the major actinides, as listed in ISG-8, Revision 3. The applicant calculated the bias and bias uncertainty of the major actinides using the direct different method as laid out in NUREG/CR-

6811. The applicant used the HTC and MOX critical experiments, as recommended by NURG/CR-7109 in code benchmarking analysis for the major actinides.

The staff reviewed the burnup credit analysis method used by the applicant for major actinides and finds that it is consistent with the recommendation of ISG-8, Revision 3, and the results have been accepted in the previously approved HI-STAR 100 packages. On this basis, the staff finds that the method the applicant used for determining the basis and bias uncertainty for major actinides as listed in ISG-8, Revision 3 to be acceptable.

For the minor actinides and fission products (MAFPs) as listed in ISG-8, Revision 3, the applicant used the recommendation of the ISG and NUREG/CR-7205. In its burnup credit analysis, the applicant used the CASMO-5 code to determine the material composition of the spent fuel with 3 years of cooling time. The applicant then used the MCNP 5.1 computer code to determine the reactivity of the packages.

In the application, the applicant states that the results of benchmark evaluations for the MPC-37 of HI-STAR 190 are applied to all HI-STAR 100MB fuel packages. The results of the burnup credit analysis and the verification of the assembly burnup evaluated for MPC-37 of HI-STAR 190 are directly applied to the MPC-32M and F-32M fuel packages; however, additional MAFP validation is performed in accordance with ISG-8 Rev. 3 for the MPC-32M and F-32M fuel packages in Appendix 6.C of the application.

The applicant also states that for studies that have historically shown a certain aspect or variation is statistically equivalent to the corresponding design basis calculations, or is clearly bounded by those, are not repeated in this chapter. The results of these studies done for MPC-37 of the HI-STAR 190 application are inserted directly in this chapter and their conclusions are applied to the MPC-32M and F-32M baskets.

The applicant provides a comparison of the fuel and package design parameters in Table 6.0.2 of the application. The application states that the differences between the HI-STAR 190 and the HI-STAR 100MB packages are insignificant; therefore, qualitative studies or studies that show insignificant variations are not repeated in this application.

The staff reviewed the application and SER for the HI-STAR 190 and finds the results of the burnup analyses for that package are not directly applicable to the HI-STAR 100MB because the differences in the capacity, dimensions, and fuel depletion parameters used in the analyses between these two packages are significantly different. However, the staff did not perform any detailed review on the applicability of the burnup credit analyses for the HI-STAR 190 package because the applicant provided new analyses for the HI-STAR 100MB package.

The applicant developed the fuel loading curves in form of equations as shown in Table 7.7.3(a) of the application, which show the minimum required burnup for a given initial enrichment of each PWR fuel class. The loading curves are developed based on a targeted k_{eff} value of 0.95. The k_{eff} includes all biases and uncertainties at a 95-percent confidence level and should not exceed 0.95. In the actual calculations, the applicant used a target value of 0.945 as the maximum allowable k_{eff} when determining the loading curve for the minimum required burnup as a function of enrichment for the MPC-32M canister and the F-32M basket. This added another small conservatism in the calculation and, therefore, an additional small safety margin for criticality safety.

The staff reviewed the applicant's burnup credit analyses and finds that the method used for the major actinides is consistent with the guidance and acceptance criteria of ISG-8, Revision 3 and therefore is acceptable.

The staff finds that the applicant's use of the recommendation of ISG-8, Rev. 3 for MAFPs appropriate. However, the depletion analysis computer code used in this application, CASMO, is not capable of tracking all isotopes listed in the ISG-8, Revision 3. Therefore, the analyses do not meet the condition of using the ISG-8, Rev. 3 recommendation. Also, the staff finds that the lack of the capability of tracking all isotopes may significantly skew the calculated isotope concentrations of the other isotopes that are included in the burnup analyses because missing one or more major neutron absorber isotopes will arbitrarily overestimate some of the isotopes that are tracked and credited.

To assess the overall criticality safety of the package, the staff conducted an independent confirmatory analysis of the reactivity impact of Eu^{151} using SCALE 6.1 computer code package.

> The staff first calculated the Eu^{151} concentration based on the design and irradiation parameters of the design basis fuel, including the power density, soluble boron concentration, moderator density, burnup, and cooling time.
>
> Then the staff built two models, one includes Eu^{151} and the other model did not. Based on its own analyses, the staff finds that the estimated Eu^{151} concentration is about 0.455 grams per MTU.
>
> Comparing the reactivity of the package with and without this isotope, the staff estimated that reactivity is largely comparable with the 1.5% reactivity worth of the MAFPs.

On this basis, the staff finds that the burnup credit calculation in this application to be acceptable.

For the above-discussed reason, the staff's acceptability decision is made based on the staff's independent analysis for this specific package design. This does not establish the basis for the approval of future applications. Section 6.6 of this SER provides a detailed discussion on the reasons why the recommendation of ISG-8, Revision 3 for the MAFPs is not appropriate when using the CASMO code to calculate the material composition for burnup credit analyses.

6.3.6 Estimated Additional Safety Margin

One significant conservative assumption of the burnup credit methodology described in the application is crediting only the recommended set of actinides and fission products, i.e. excluding Eu^{151} and other fission products and actinides that are not endorsed by ISG-8. To estimate the safety margin that corresponds to just this single assumption, additional calculations were performed crediting all isotopes from the CASMO5 depletion calculations.

These calculations were performed for Configuration 1, i.e. a uniform loading pattern, and the comparison with the design basis calculations are listed in Table 6.B.6 of the application. The results show that neglecting additional actinides and fission products results in an estimated safety margin of 0.01 delta-k.

The staff reviewed the applicant's analysis and finds that the result is comparable with similar previously approved packages with similar design features. On this basis, the staff determined that the applicant's estimation of additional criticality safety margin to be acceptable.

The applicant states that for a package with the F-24M basket configuration, there is no need to estimate the additional reactivity margin. The staff finds this assertion to be acceptable because this package does not take burnup credit and the guidance of ISG-8 for estimation of additional reactivity is not applicable.

6.4 Single Package Evaluation

The applicant performed criticality safety analyses for packages containing the MPC-32M, F-32M, and the F-24M basket under NCT. The results are summarized in Table 6.1.3 for all fuel packages and for the most reactive configurations and fuel condition in each basket. The analysis results include the worst combination of manufacturing tolerances, and the computational bias, uncertainties, and computational statistics. The applicant explicitly modeled the fuel basket structure, which also serves as neutron poison plates, and the overpack in the models.

The applicant modeled the fuel assembly assuming flooded fuel cladding gap and the inter-cavity of the package. The applicant ignored the impact limiters. Table 6.1.1 of the application provides the results of the criticality evaluation. The results of the analyses show that the package meets the criticality safety requirements of 10 CFR 71.55(b) and 71.55(d).

The applicant also evaluated the criticality safety of a single package under HAC with the assumptions that the package internal remains dry, i.e., there is no moderator intrusion. The applicant surrounded the package with 30 cm of water reflector. The applicant ignored the impact limiters in the model. Table 6.1.1 of the application provides the results of the criticality calculations. The results show that the package remains subcritical when subjected to the tests prescribed in 10 CFR 71.73.

The staff reviewed the applicant's criticality safety analyses for a single package under HAC. Based on the result of structural review as documented in Chapter 2 of this SER, the staff determined that the package meets the acceptance criteria of moderator exclusion design as defined in NUREG-1617 and ISG-19. Therefore, the criticality safety analyses based on moderator exclusion is acceptable.

The applicant presents in Table 6.1.1 of the application the maximum k_{eff} values for the packages under HAC. The result demonstrates that the package meets the regulatory requirements of 10 CFR 71.55(e). On this basis, the staff determined that the applicant has demonstrated that the package meets the regulatory requirements of 10 CFR 71.55(b), 71.55(d), and 71.55(e).

6.5 Evaluation of Array of Packages under Normal Conditions of Transport and Hypothetical Accident Conditions

The applicant performed criticality safety analyses for an array of packages under NCT and HAC separately. The applicant used the same assumptions as it used in the evaluation for a single package. Based on its calculations, an array of an infinite number of packages under NCT or HAC remain subcritical with considerations of all potential uncertainty and an administrative safety margin of Δk_{eff} = 0.05.

Based on the results of the criticality safety analyses for the infinite array of packages under NCT and HAC, the applicant calculated the Criticality Safety Index of the array of packages in accordance to the method prescribed in 10 CFR 71.59 and determined that the CSI for this package is zero (0).

The staff reviewed the applicant's analyses of the criticality safety of arrays of packages under NCT and HAC and the calculation of the CSI value. The staff finds that the assumptions used in the models for an array of packages under NCT as well as an array of packages under HAC are conservative and are acceptable based on the acceptance criteria provided in NUREG-1617 and Supplement 1 to NUREG-1617.

Based on its review, the staff finds that the package design with the authorized PWR fuel assemblies meets the acceptance criteria as provided in NUREG-1617. The staff also finds that the applicant's calculation of the CSI followed the procedures prescribed in 10 CFR 71.59(a) and therefore the calculated CSI value is acceptable. On these bases, the staff determined that the applicant has demonstrated that the package design meets the regulatory requirement of 71.59.

6.6 Computer Code Benchmarking

As discussed earlier in this SER, the applicant used two computer codes CASMO5 and MCNP5.1 in its criticality safety analyses. For the package containing the F-24M bare basket, the applicant assumed that fuel is unirradiated, i.e., fresh fuel assumption. The criticality safety analysis for this package used the MCNP code only because the fuel composition is already known and there is no need for determining the spent fuel composition.

The applicant provides code benchmarking using criticality experiments selected from the International Handbooks of Evaluated Criticality Safety Benchmark Experiments [Ref. 18]. The staff reviewed the list of the critical experiments selected by the applicant and finds these selected critical experiments are appropriate for the enrichment range and fuel assemblies to be transported. On this basis, the staff determined that the applicant's code benchmarking analyses for the package containing spent fuel in the F-24M bare fuel basket is adequate and acceptable.

As discussed earlier in the SER, the package design takes burnup credit for the spent fuel contents loaded in the MPC-32M canister or the F-32M fuel basket. In the criticality safety analysis for these packages, the applicant used the CASMO5 code to determine the material concentrations of spent fuel and the MCNP code to determine the neutron multiplication factor, k_{eff}, of the package.

The applicant performed code benchmarking analyses for the CASMO5 code using the radiochemistry assay (RCA) data from a collection of experiments as presented in Holtec report HI-2032982, "Isotopic Benchmarks for Bunrup Credit, Supplement 4, Revision 4." The applicant states that the NRC has accepted this code for burnup credit analyses in the previous applications. The staff verified that this statement is true and therefore did not perform any more detailed review of the suitability of the CASMO code for burnup credit analyses.

As discussed in Section 6.3.5 of this SER, the applicant used the direct difference method to determine the bias and bias uncertainty of the MCNP code for the major actinides as listed in Table 1 of ISG-8, Revision 3. This is one of the approaches recommended in NUREG/CR-6811. The applicant used HTC and MOX fuel with fresh water in its code benchmarking analysis for these isotopes. All trends are checked and the trend with the maximum bias (Pu concentration trend) is selected because it bounds all other trends. For this reason, this trend is considered in the bias determination and used for the K_{eff} calculations for packages containing MPC-32M or F-32M.

The staff reviewed the applicant's code benchmarking analyses for the actinides as listed in Table 1 of ISG-8, Revision 3. The staff finds that the direct difference method is appropriate for this benchmarking analyses because it is one of the recommended methods developed in NUREG/CR-6811.

For minor actinides and fission products (MAFPs), ISG-8, Rev.3 allows the applicant to use the bias (β_i) and bias uncertainty (Δk_i) values estimated in NUREG/CR-7109 and NUREG/CR-7205 in lieu of explicit code benchmarking. However, the burnup credit analyses must meet the conditions. Specifically, ISG-8, Rev. 3 states:

> "In lieu of an explicit benchmarking analysis, the applicant may use the bias (β_i) and bias uncertainty (Δk_i) values estimated in NUREG/CR-7108 using the Monte Carlo uncertainty sampling method, as shown in Tables 3 and 4 below. These values may be used directly, provided that:
>
> - the applicant uses the same depletion code and cross section library as was used in NUREG/CR-7108 (SCALE/TRITON and the ENDF/B-V or -VII cross section library),
> - the applicant can justify that its design is similar to the hypothetical GBC-32 system design used as the basis for the NUREG/CR-7108 isotopic depletion validation, and credit is limited to the specific nuclides listed in Tables 1 and 2,
> - demonstrates that the credited minor actinide and fission product worth is no greater than 0.1 in k_{eff}."

From these conditions, it is clear that the burnup credit analysis performed by the applicant for the HI-STAR 100MB does not meet the conditions for using the recommendation of ISG-8, Revision 3 because the CASMO code does not track the isotope concentration of Eu^{151} in depletion analyses.

Followed the same logic as elaborated in the SER for Revision 0 of HI-STAR 100MB package design, the staff evaluated the reactivity worth of the Eu^{151} in the HI-STAR 100MB package containing the 17x17F PWR fuel loaded in the MPC-32M and F-32B and finds that the reactivity worth is comparable with that of the 1.5% reactivity of the bias and bias uncertainty of the MCNP code.

On this basis, the staff finds that there is a reasonable assurance that omitting the credit of Eu^{151} is likely to compensate the bias introduced in the CASMO code for not being able to track all key fission product like Eu^{151}.

However, the staff did find that the concentration of Eu^{151} isotope in the 17x17F fuel is slightly lower than what is in the 17x17A fuel assembly. This difference does not upend the conclusion because the difference in Eu^{151} concentration has an insignificant effect on the reactivity worth as demonstrated in the staff's independent analysis. Therefore, excluding Eu^{151} in the MAFP credit still bounds the 1.5% reactivity worth of the MAFP estimated in NUREG/CR-7205.

It is important to point out that these depletion parameter values are directly taken from the input file of the CASMO depletion models provided by the applicant in its calculation package [Ref.

15]. But the code's lack of the ability to track all key fission products will skew the neutron flux and the absorption calculations of the isotopes; including fissile materials and absorbers that are being tracked. For these reasons, the staff's approval of this application is on a case by case basis.

For the abovementioned reasons, the approval of this application (HI-STAR 100MB Revision 1 does not establish the basis for a generic evaluation of the method. Future applications must use the recommendation of ISG-8, Rev. 3 in its entirety, or be evaluated on a case by case basis.

Because there is no change in the applicant's code benchmarking analyses for burnup credit, the above conclusions for the HI-STAR 100MB are all applicable to the HI-STAR 100MB amendment.

6.9 Burnup verification method

One of the requirements for applying burnup credit is to provide a means to verify that the burnup of the selected fuel meets the required minimum burnup assumed in burnup credit analyses. In the proposed application, the applicant implemented the recommendation of ISG-8, Rev. 3, and performed a misloading analysis to demonstrate that even with an accident misload, the cask remains subcritical.

The applicant performed misload analyses for several scenarios and demonstrated the under these highly unlikely scenarios, the package remains subcritical. In the misloading analyses, the applicant used $k_{eff} \leq 0.98$ as acceptance criterion.

The staff evaluated the method and results of the applicant's misload analysis and finds it is consistent with the recommendation of ISG-8, Rev. 3, and therefore to be acceptable. Specifically, ISG-8, Rev. 3 states: "Misload analyses may be performed in lieu of a burnup measurement. A misload analysis should address potential events involving the placement of assemblies into a SNF storage or transportation system that do not meet the proposed loading criteria. The applicant should demonstrate that the system remains subcritical for misload conditions, including calculation biases, uncertainties, and an appropriate administrative margin that is not less than 0.02 Δk."

The staff finds that the applicant's analyses meet the acceptance criteria recommended by ISG-8, Rev. 3. On this basis, the staff finds the applicant's burnup verification method to be acceptable.

6.10 Confirmatory Analysis

The staff performed an independent confirmatory analysis for the most reactive configuration, i.e., water flooded and reflected single package containing the F-24M basket loaded with bounding 17x17F PWR assemblies. The staff use the SCALE 6.1 computer code with continuous energy cross sections derived from the ENDF/B-VII cross section library. The results confirm the applicant's calculated k_{eff} value for the bounding package design.

6.11 Conclusions

The 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, including maximum allowable quantity of fissile materials (assuming fresh fuel), conservative tolerance of cask geometry, reduced credit of B-10 in poison plates in the cask and the calculated maximum neutron multiplication factor, k_{eff}, with appropriate code benchmarking analyses.

Based on the review of the information presented by the applicant and the independent confirmatory analyses, the staff determined that the HI-STAR 100MB package meets the regulatory requirement of 10 CFR 71.55 and the acceptance criteria specified in NUREG-1617 on criticality safety with the condition that no damaged fuel is authorized for transportation in this package.

7.0 PACKAGE OPERATING PROCEDURES

The operations covered in this Chapter of the application include (i) the preparation for loading a packaging, (ii) the loading of the contents, (3) the preparation for shipment of a package, (4) the package unloading, and (5) the preparation for shipment of an empty packaging.

Chapter 7 was revised to reflect securing the trunnions to the transport frame prior to shipment, now that the top and bottom trunnion designs have been analyzed as tie down supports.

The optional port cover design for the cask lid includes two additional threaded containment connections in the center of the port cover plate that are used to purge the port cover space with helium during installation of the port cover plate. The central threaded connections are used to purge the port cover space with helium during installation of the port cover plate.

The optional port cover design is analyzed in Calculation Package HI-2188083 and the required torque value equation for bounding seal parameters is listed in Table 2.2.11.a and 2.2.11.b. As noted in Section 2.2 of the application, Table 2.2.10, Chapter 7, and Table 7.1.1 are updated to reflect the torque values needed to maintain containment with this design. This change was made to provide flexibility for purging the port cover space with helium.

As described in SAR Section 7.7 and Table 7.7.2, the applicant added a new fuel assembly type 17x17F to the previously approved Westinghouse 17x17 PWR fuel assemblies (including types 17x17A, B, and C). The new assembly type introduces a unique combination of enrichment, rod pitch, cladding dimensions, fuel pellet diameter, and Co^{59} impurity levels. The fuel assembly materials, zirconium fuel cladding materials, burnup, and enrichment limits are consistent with those previously analyzed and approved for the HI-STAR 100MB CoC. The addition of the 17x17F assembly type did not change any the material property inputs into the structural analysis.

In addition, as discussed in SAR Section 3.1 and 3.3.9, the existing thermal design basis calculations remain bounding for the amendment to introduce the new fuel assembly type, the new LW impact limiter design, and other changes. The peak cladding temperatures in normal conditions of transport and hypothetical accident conditions are unchanged. The staff verified that the fuel cladding temperatures remain below those associated with the previously approved casks and contents, as well as below the allowable cladding temperatures recommended in NUREG-1917. Therefore, the staff finds the new assembly type to be acceptable as content.

The design heat loads are limited to 32 kW for bare basket casks F-32M and F-24M and 29 kW for MPC-32M. The maximum cell heat load complies with Table 7.7.5 regionalized limits.

Chapter 7, "Operating Procedures" provides specific fuel qualification criteria for the authorized PWR fuel contents, including the new 17x17F class fuel.

The leak test of the overpack closure devices, performed regardless of MPC contents, is as follows:

(i) drying and backfilling the cask annulus,
(ii) closing the closure lid access port plug,
(iii) installation of the closure lid access port cover is installed,
(iv) torque the port cover bolts, and
(v) leak test the closure lid inner-seal and closure lid port cover plate seal(s).

For packages containing high burnup fuel, surface temperatures are measured as required by the post-shipment fuel integrity acceptance test specified in Chapter 8. The MPC Enclosure Vessel is credited as an inner containment boundary for high burnup fuel. The acceptance criteria and supplemental requirements for crediting the MPC Enclosure Vessel are contained in Chapter 8. These requirements include the performance of the pre-shipment MPC leakage test included in Subsection 7.1.4 of the application.

The staff reviewed the applicant's description of package operations to ensure that they result in the package being used in accordance with the shielding design specified in the technical drawings and appropriate regulatory radiation limits. Adequate package operations descriptions are those that contain the essential elements of operations for using the package. Also, where alternate sequences or operations are acceptable, such operations descriptions include these alternates. Staff reviewed the changes to the applicant's descriptions of the package operations which include the new fuel assembly type. Staff finds they are consistent with these considerations.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

In SAR Section 8.1.5.5, the applicant revised the discussion on the weld procedure qualification for the Metamic-HT fuel basket. In this revision, the applicant removed a requirement to perform a radiography of the weld coupons used to qualify the friction stir welding procedure. The requirements to perform tensile testing, bend testing, and visual examinations of the weld coupons remain in effect. The applicant stated that the change was made to be consistent with ASME BPV Code, Section IX, "Welding, Brazing, and Fusing Qualifications." The staff reviewed the applicant's revision to the qualification of the friction stir welding procedure and verified that it is in accordance with the applicable code criteria because ASME BPV Code Section IX does not require radiography of the weld coupons. In addition, the staff confirmed that the remaining coupon tests (e.g., tensile, bend) are consistent with ASME BPV Code, Section IX, Article II, "Weld Procedure Qualifications." Therefore, the staff finds the revised weld procedure qualification to be acceptable.

The weld soundness criteria of Metamic-HT require only 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.

The staff also notes that the welding criteria for the new Impact Limiter Version LW are consistent with those used for the original version of the impact limiter previously approved for the HI-STAR 100MB package. The structural welds of the impact limiter are fabricated in accordance with ASME Code, Section IX, and examined in accordance with Section V using Section III, Division 1, Subsection NF acceptance criteria. Based on the staff's verification that the impact limiter welding criteria are unchanged in the amendment, and that those criteria have been previously confirmed to be consistent with the guidance in NUREG-2216, the staff finds the welding of the new impact limiter to be acceptable.

Basket welds shall be examined and repaired in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for welding Metamic-HT with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition). The basket welds, made by the Friction Stir Weld process, are classified as Category C per NG-3351.3 and belonging to Type III (by virtue of being corner joint with an essentially thru-thickness “stir zone”) in Table NG-3352-1. These weld requirements are not applicable to welds identified as NITS on the drawings.

The top trunnions, provided for vertical lifting and handling of the loaded or empty cask, are required to be designed, tested and inspected in accordance with ANSI N14.6. Two bottom trunnions are provided for rotation of the loaded or empty cask for downending/upending operations. All four trunnions are used as a tie-down device during transport.

The user of MPCs containing HBF, and stored beyond the duration of the initial 20-year license period under the provisions of 10 CFR 72, shall confirm that the general licensee implementing the approved HBF Aging Management Program has not concluded that the analyzed configuration of the HBF has been compromised during the period of extended storage. MPCs containing high burn-up fuel and stored under the provisions of 10 CFR 72 shall undergo an MPC enclosure vessel shell surface defect inspection prior to shipment as specified in Subsection 8.1.6 of the application.

The helium leakage rate criteria in Table 8.1.1 was revised to $1x10^{-5}$ ref-cm^3/s for the system containment enclosures leakage rate test. The leakage rate criteria are based on a containment analysis which demonstrated compliance with 10 CFR 71.51(a)(1) and (a)(2). ANSI N14.5, 2014 Edition, has been adopted in the application for leak testing.

The HI-STAR 100MB Cask is equipped with elastomeric seals on the closure lid and elastomeric and/or metallic seals on the port cover. The seals are to be visually inspected to ensure they remain free of debris, they are not damaged, and they do not exhibit excessive compression set. If elastomeric seals are deemed acceptable, they may be re-used. Metallic seals shall be replaced after the bolted joint is opened. Closure seals are specified for long-term use and do not require in-service maintenance if not disturbed. Reused elastomeric seals are subject to replacement based on seal design life as recommended by the seal manufacturer.

The applicant provided a manufacturer data sheet for the VM125-75 seal material (one of the prequalified seals) to justify its use at a revised lower temperature operating limit for the elastomeric containment seals from -30°C to -40°C. This limit is defined as a required critical characteristic in Table 2.2.11a of the application. The applicant clarified that Revision 2 of the SAR listed the TR-10 temperature as a critical characteristic where Revision 3 lists the minimum operating temperature as a critical characteristic. The change was not to modify the temperature limit from -30°C to -40°C, the change was to modify which temperature limit is a critical characteristic, and both seals can meet the low temperature operating limit specified in Table 2.2.11a. The new minimum operating temperature critical characteristic is captured in a

Holtec purchase specification that is imposed on the qualified vendor. The vendor will provide documentation to confirm that all requirements in the purchase specification are met.

At staff's request, the applicant provided mechanical properties validated by test data for materials whose post-yield behavior was described in Holtec Report HI-2188068. The structural evaluation/finite element analyses of HI-STAR 100MB package for drop accidents used a strain-based methodology to determine the structural integrity of ITS components (such as aluminum, stainless steel, and Metamic for impact limiter components, the basket, etc.) subject to NCT and HAC drop conditions, but was not relying on material properties based on test data.

Therefore, the fidelity of the true-stress-true strain curves had to be demonstrated by performing LS-DYNA simulations of actual material tensile tests. This benchmark testing included several tensile tests and a single crush test of a reduce-scale section of the perforated aluminum ring. Through this testing and refinement of the predicted material behavior, the applicant demonstrated that the mechanical behavior of the aluminum could be accurately modeled to high levels of strain.

Table 8.1.8 of the application includes acceptance criteria to ensure that the strength of the procured aluminum material is consistent with the material model. Therefore, based on the staff's review of the applicant's development of the aluminum deformation behavior, including the validation provided by the benchmark testing, the staff finds the lower crush material properties to be acceptable.

Table 8.1.8: Impact Limiter LW Crush Material

Item Number	Crush Strength (PSI)	Density (PCF)
3	390 ~ 600	4.5 ~ 7.5
Item Number / Material	Yield Strength (KSI)	Ultimate Strength (KSI)
4 – SB 209 6061 T651	40	47
NOTE: THE IMPACT LIMITER PERFORATED ALUMINUM RING (ITEM 4) VOLUMETRIC STRENGTHS AT ROOM TEMPERATURE SHALL NOT DEVIATE FROM THE VALUES LISTED IN THIS TABLE BY MORE THAN 10%		

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

CONDITIONS

The following changes were made to the Certificate of Compliance:

Condition No. 5(a)(2) was revised to include a description of the "LW" impact limiter, update the maximum packaging weights for both cask versions, and include the personal barrier as a packaging component when in use.

Condition No. 5(a)(3) was updated with the revised licensing drawings.

Condition No. 5(b)(1) includes the 17x17 fuel assembly as a new authorized content.

Condtion No. 5(b)(2)(c) was deleted. This was identified as an error because the permissible contents from Section 7.7 of the application do not currently allow irradiated non-fuel hardware to be loaded and shipped.

Condition No. 8(f) specifies the maximum heat load for the package with the F-32M or F-24M basket or the MPC-32M.

Condition No. 11 has been entirely rewritten to state that the “LW” impact limiter’s purchased material requirements, including tolerances for minimum yield strength, are specified in Section 8.1.5.3 of the application

As a result of the new Condition No. 11, the previous Condition Nos.11 and 12 were renumbered 12 and 13, respectively.

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 100MB package has been adequately described and evaluated and that the package meets the requirements of 10 CFR Part 71.

Issued with Certificate of Compliance No. 9378, Revision No. 1.