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

October 1, 2009

Dr. K. P. Singh
President and CEO
Holtec International
555 Lincoln Drive West
Marlton, NJ 08053

SUBJECT: CERTIFICATE OF COMPLIANCE NO. 9325, REVISION NO. 0, FOR THE MODEL NO. HI-STAR 180 PACKAGE

Dear Dr. Singh:

As requested by your application dated January 17, 2009, as supplemented February 19, July 13, and September 25, 2009, enclosed is Certificate of Compliance No. 9325, Revision No. 0, for the Model No. HI-STAR 180 package. The staff's Safety Evaluation Report is also enclosed.

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

If you have any questions regarding this certificate, please contact me or Pierre Saverot of my staff at (301) 492-3408.

Sincerely,

Steven Baggett, Acting Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Docket No. 71-9325
TAC No. L24304

Enclosures:
1. Certificate of Compliance No. 9325, Rev. No. 0
2. Proprietary Safety Evaluation Report
3. Non-Proprietary Safety Evaluation Report

cc w/encls 1 & 3: R. Boyle, Department of Transportation
J. Shuler, Department of Energy

Enclosure 2 transmitted herewith contains proprietary information. When separated from enclosure(s), this transmittal document is decontrolled.

Official Use Only – Proprietary Information

CERTIFICATE OF COMPLIANCE
FOR RADIOACTIVE MATERIAL PACKAGES

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. DOCKET NUMBER	d. PACKAGE IDENTIFICATION NUMBER	PAGE		PAGES
9325	0	71-9325	USA/9325/B(U)F-96	1	OF	6

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
Holtec Center
555 Lincoln Drive West
Marlton, NJ 08053

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

Holtec International Report No. HI-2073681, *Safety Analysis Report on the HI-STAR 180 Transport Package,* Revision 3, dated September 25, 2009.

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 180

(2) Description

The HI-STAR 180 package is designed for transportation of undamaged irradiated Uranium Oxide (UO_2) and Mixed Oxide (MOX) fuel assemblies. The fuel basket provides criticality control and the packaging body provides the containment boundary, helium retention boundary, moderator exclusion barrier, gamma and neutron radiation shielding, and heat rejection capability. The outer diameter of the HI-STAR 180 packaging is approximately 2700 mm without impact limiters and approximately 3250 mm with impact limiters. The maximum gross weight of the loaded HI-STAR 180 package is 140 Metric Tons.

Fuel Basket

Metamic-HT, a metal matrix composite of aluminum and boron carbide, is the principal constituent material of the fuel basket, both as structural material and neutron absorber material. Two interchangeable fuel basket models, designated F-32 and F-37, contain either 32 or 37 Pressurized Water Reactor (PWR) fuel assemblies respectively, in regionalized and uniform loading patterns. The fuel basket features a honeycomb structure and flux traps between some but not all cells.

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

Packaging Body

The cylindrical steel shell containment system is welded to a bottom steel baseplate and a top steel forging machined to receive two independent steel closure lids, with each lid being individually designated as a containment boundary component. The outer surface of the the cask inner shell is buttressed with a monolithic shield cylinder for gamma and neutron shielding. Each closure lid features a dual metallic self-energizing seal system designed to ensure its containment and moderator exclusion functions. For this package, the inner closure lid inner seal and the inner closure lid vent/drain port cover inner seals are the containment boundary components on the inner lid; the outer closure lid inner seal and the outer closure lid access port plug seal are the containment boundary components on the outer lid.

Impact Limiters

The HI-STAR 180 package is fitted with two impact limiters fabricated of aluminum honeycomb crush material completely enclosed by an all-welded austenitic stainless steel skin. Both impact limiters are attached to the cask with 16 bolts.

(3) Drawings

The packaging shall be constructed and assembled in accordance with the following Holtec International Drawings Numbers:

(a) HI-STAR 180 Cask	Drawing No. 4845, Sheets 1-6, Rev. 7
(b) F-37 Fuel Basket	Drawing No. 4847, Sheets 1-4, Rev. 5
(c) F-32 Fuel Basket	Drawing No. 4848, Sheets 1-4, Rev. 5
(d) HI-STAR 180 Impact Limiter	Drawing No. 5062, Sheets 1-5, Rev. 5

5.(b) Contents

(1) Type, Form, and Quantity of Material

(a) Only undamaged UO_2 and MOX PWR fuel assemblies, with a Zr cladding type, meeting the specifications and requirements provided in Conditions 5.b(1)(b) through 5.b(1)(j), and with the characteristics listed in Table 1 below, are authorized for transportation.

5.(b)(1)(a) continued

Table 1- PWR Fuel Assembly Characteristics

Fuel Assembly Type	14x14
Design Initial Heavy Metal Mass (kg/assembly)	≤341
Maximum Fuel Assembly Mass (kg)	500
No. of Fuel Rod Locations	179
Fuel Rod Clad O.D. (mm)	≥10.72
Fuel Rod Clad I.D. (mm)	≤9.58
Fuel Pellet Diameter (mm)	≤9.31
Fuel Rod Pitch (mm)	≤14.224
Active Fuel Length (mm)	≤3070
Maximum Fuel Assembly Length (mm)	3524
Fuel Assembly Width (mm)	≤199.3
No. of Guide and/or Instrument Tubes	17
Guide/Instrument Tube Thickness (mm)	≥0.325
Minimum Cooling Time for Assemblies with Zr Guide/Instrument Tubes (years)	3
Minimum Cooling Time for Assemblies with Stainless Steel Guide/Instrument Tubes (years)	15
Minimum Cooling Time for Assemblies with NFH insertion more than 38 cm into the active region during full power operation (years)	20

(b) Damaged fuel assemblies, i.e., assemblies with known or suspected cladding defects greater than pinhole leaks or hairline cracks and which cannot be handled by normal means, as well as fuel debris, non-fuel hardware and neutron sources are not authorized contents.

(c) The maximum initial enrichment of any UO_2 assembly is 5.0 percent by weight of uranium-235.

(d) Each loaded MOX fuel assembly must meet one of the criteria sets (1-4) from Table 2 and one of the criteria sets (1-3) from Table 3. MOX fuel isotopic compositions in Table 2 are bounding for dose and decay heat and used to establish the loading patterns. MOX fuel isotopic characteristics in Table 3 are bounding for criticality purposes.

Table 2

Isotopic Characteristics of MOX Fuel

	Isotopic Composition (gram/assembly)			
Criteria / Isotope	1	2	3	4
Pu238	≤700	≤202	≤202	≤202
Pu239	≥13000	≥11000	≥7524	≥8000
Pu240	≥5800	≥3800	≥1700	≥1700
Pu241	≤2300	≤1600	≤1250	≤1600
Pu242	≤1900	≤751	≤700	≤751
U235	≥730	≥720	≥2100	≥720
U238	≤297000	≤320200	≤326000	≤326000

Table 3

Isotopic Characteristics of MOX Fuel

Criteria / Composition	1	2	3
Pu-239 (g/kg-HM)	≤39.5	≤49	≤26
Pu-238/Pu-239 (g/g)	≥0.0	≥0.015	≥0.0
Pu-240/Pu-239 (g/g)	≥0.27	≥0.38	≥0.21
Pu-241/Pu-239 (g/g)	≤0.15	≤0.20	≤0.16
Pu-242/Pu-239 (g/g)	≥0.012	≥0.06	≥0.012
Am-241(g/kg-HM)	≥0.0	≥0.0	≥0.0
U-235 (g/kg-HM)	≤7.1	≤7.1	≤7.1

5(b)(1) Continued

(e) The post-irradiation minimum cooling time, maximum burnup, maximum decay heat load, and minimum initial enrichment per assembly are listed in Tables 1.2.8 and 1.2.9 of the application. The F-32 and F-37 fuel basket cell numbering and quadrant identification are depicted in Figures 1.2.3 and 1.2.4 respectively.

(f) Regions, cells and quadrants for regionalized loading of the F-32 and F-37 baskets are identified in Tables 1.2.6.a and 1.2.6.b of the application. Table 1.2.7 of the application provides the minimum burnup requirements for the F-37 basket, based on initial enrichment.

(g) In-core operating limits for those assemblies that need to meet the burnup requirements in Table 1.2.7 of the application are as follows:

Parameter	Requirement
Assembly Average Specific Power	≤39.4 MW/MTU
Assembly Average Moderator Temperature	≤597° K
Maximum Assembly Average Fuel Temperature	1127°K
Core Average Soluble Boron Concentration	≤700 ppmb

(h) For those spent fuel assemblies that need to meet the burnup requirements specified in Table 1.2.7 of the application, a burnup verification shall be performed either in accordance with Section 6.F.3.1 or 6.F.3.2 of the application.

(i) Allowable loading patterns and fuel specifications for each basket region are referenced in Tables 1.2.8 and 1.2.9 of the application. Alternative fuel specifications for each regional loading pattern are presented in Table 1.2.10 of the application.

(j) The maximum decay heat for either the F-32 or F-37 basket model is 32 kW per basket, with 8 kW maximum decay heat per basket quadrant.

5.b.(2) Maximum Quantity of Material Per Package

32 or 37 PWR fuel assemblies, as described in 5(b)(1), in the F-32 or F-37 basket respectively.

5.(c) Criticality Safety Index (CSI)= 0.0

6. 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 Chapter 7 of the application.

   (b) The package shall meet the acceptance tests and be maintained in accordance with Chapter 8 of the application.

7. The personnel barrier shall be installed and remain installed while transporting the package if necessary to meet package surface temperature and/or package dose rates requirements.

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

9. Transport by air of fissile material is not authorized.

10. The package may be used in the U.S. for shipment of UO_2 fuel meeting the above specifications.

11. Expiration Date: October 31, 2014

REFERENCES:

Holtec International application dated September 25, 2009.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Steven Baggett, Acting Chief
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety
and Safeguards

Date: 1 October, 2009

NUCLEAR REGULATORY COMMISSION
WASHINGTON 20555-0001

NON-PROPRIETARY

SAFETY EVALUATION REPORT
Docket No. 71-9325
Model No. HI-STAR 180 Package
Certificate of Compliance No. 9325
Revision No. 0

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SAFETY EVALUATION REPORT
Model No. HI-STAR 180 Package
Certificate of Compliance No. 9325
Revision No. 0

SUMMARY

By application dated January 17, 2009, as supplemented February 19, 2009, and July 13, 2009, Holtec International requested approval of the Model No. HI-STAR 180 as a Type B(U)F-96 package. Revision No. 3 of the package application, dated September 25, 2009, supersedes the submittals dated January 17, February 19 and July 13, 2009.

The Model No. HI-STAR 180 package consists of a metal cask designed to hold undamaged low and high burnup Uranium Oxide (UO_2) and Mixed Oxide (MOX) irradiated fuel assemblies in a thermally conductive fuel basket. Metamic-HT, a metal matrix composite of aluminum and boron carbide, is the principal constituent material of the fuel basket. The package has two closure lids, with each lid individually designated as a containment boundary component. The inner and outer lids each feature two concentric annular metallic seals. The outer diameter of the package is approximately 2.7 m without the impact limiters. The length of the package is approximately 4.43 m without the impact limiters and 7.24 m with the impact limiters. The maximum gross weight of the loaded package is 140 Metric Tons.

This specific package design ensures that in-leakage of water through the containment boundary seals is a non-credible event under hypothetical accident conditions. Based on this design and analyses that were performed, the staff approved moderator exclusion in compliance with 10 CFR 71.55(e).

The package was evaluated against the regulatory standards in 10 CFR Part 71, including the general standards for all packages and the performance standards specific to fissile material packages under normal conditions of transport and hypothetical accident conditions. The analyses performed by the applicant demonstrate that the package provides adequate thermal protection, containment, shielding, and criticality control under normal and accident conditions.

NRC staff reviewed the application using the guidance in "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," NUREG-1617 and other relevant Interim Staff Guidance documents. 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.

References

Holtec International application "Safety Analysis Report on the HI-STAR 180 Transport Package," Holtec Report No. HI-2073681," Revision No. 3, dated September 25, 2009.

1.0 GENERAL INFORMATION

The Model No. HI-STAR 180 package is a Type B(U)F-96 package designed for the transport of undamaged commercial UO_2 and MOX fuel assemblies over a plant's entire life cycle.

1.1 Packaging

The Model No. HI-STAR 180 package is a metal cask consisting of a monolithic cylinder configured from several short annular shield cylinders, holding the Holtite-B neutron shielding material, which are stacked on top of each other to provide full-length gamma and neutron shielding. The containment boundary is formed by a cryogenic steel inner shell welded at the bottom to a nickel steel baseplate (containment baseplate) and at the top to a machined nickel steel forging (containment closure flange). The cask closure system includes two independent closure lids, each equipped with two concentric annular metallic seals. Each lid is bolted independently to the containment closure flange.

Two fuel baskets, the F-32 and F-37 models, made entirely of Metamic-HT, are available for this package. In both models, flux traps exist between some but not all cells. The Minimum Guaranteed Values (MGVs) of the critical characteristics of Metamic-HT having a role in the fuel basket safety function are determined and compiled in the Metamic-HT Sourcebook. The high conductivity of the basket material (Metamic-HT) and the honeycomb design of the basket facilitate cell to cell connectivity and provide for an uninterrupted heat transmission path along the basket's walls. The F-37 basket relies on burnup credit to meet the subcriticality requirements under optimal moderation conditions, while the F-32 basket is designed for all fresh fuel. Basket shims, made of aluminum alloy, occupy the space between the basket and the inside surface of the containment boundary to prevent significant movement of the basket during all transport conditions. Axial restraints to the movement of the fuel in the basket are provided in the form of Fuel Impact Attenuators (FIA.)

Two removable top and bottom trunnions are threaded into the top and bottom forgings respectively. Impact limiters, installed at each extremity of the package to protect it under all angular drop orientations, are made of aluminum honeycomb crush material and are completely enclosed by an all-welded stainless steel skin. The installation of the impact limiters requires the replacement of top and bottom trunnions with steel shielding plugs flush with the cask for proper fit-up.

The Model No. HI-STAR 180 package is designed for transport by either rail or road using appropriate packaging supports and restraints. The transport cradle, the longitudinal stops, the support saddles, the tie-down systems and wedge shims are non-integral to the package and, as such, are not designated as packaging components.

The approximate dimensions and weights of the Model No. HI-STAR 180 package are:

Inside Diameter of the Cask Cavity:	1,850 mm
Length of the Cask without Impact Limiters:	4,429 mm
Length of the Cask with Impact Limiters:	7,240 mm
Nominal Empty Packaging Weight (F-37 basket):	119,000 kg
Maximum Gross Weight of the Package:	140,000 kg

1.2 Contents

The package is designed to transport low, medium and high burnup fuel over the reactor's entire life cycle. Burnup and cooling times are specified in Tables 1.2.8, 1.2.9 and 1.2.10 of the application.

The fuel basket holds either thirty two (32) or thirty seven (37) PWR undamaged irradiated fuel assemblies with each basket cell holding one fuel assembly. Regionalized and uniform loading patterns are used. Damaged fuel, fuel debris, non-fuel hardware and neutron sources are not permitted for transportation.

Table 1.2.3 of the package application lists the physical characteristics of the 14x14 PWR fuel assemblies to be transported. UO_2 fuel assemblies are limited to an enrichment of less than or equal to 5 weight per cent of uranium 235. MOX fuel assemblies must meet the isotopic characteristic limits of one of the sets in Tables 1.2.4 and 1.2.5 of the application to be accepted for transport. Loading patterns for the F-32 and F-37 baskets are presented in Tables 1.2.8 and 1.2.9 of the application respectively.

The maximum weight of the authorized contents is 18,500 kg, assuming that the F-37 basket is completely filled with fuel assemblies at the maximum allowable fuel mass. The maximum mass of fissile material permitted for transport is 696 kg, assuming that the F-37 basket is filled with 25 bounding UO_2 fuel assemblies and 12 bounding MOX fuel assemblies, i.e., maximum number of MOX fuel assemblies allowed by the loading patterns. There are no moderating materials or neutron absorbers in the contents, nor any other material that would create a chemical, galvanic, or other reaction leading to the release of combustible gases.

1.3 Materials

The monolithic shield cylinders that provide full length shielding around the containment shell and active fuel region are equipped with "sector pockets" that hold the Holtite®-B neutron shielding material. Holtite-B is a hydrogen rich, radiation resistant, polymeric material impregnated with boron carbide, which was initially developed as Holtite®-A by the applicant as part of the Model No. HI-STAR 100 package design development program.

Metamic-HT is a composite of nano-particles of aluminum oxide and boron carbide particles dispersed in the metal matrix of pure aluminum. Metamic-HT is the constituent material of the fuel baskets. The Minimum Guaranteed Values (MGVs) of the critical mechanical, thermal and neutronic properties of Metamic-HT have been determined. Metamic-HT material procured for the Model No. HI-STAR 180 packaging is qualified as Important to Safety.

Material and manufacturing control processes are carried out using written procedures to ensure that all critical characteristics are met. In particular, a sampling plan is an integral part of the Metamic-HT manufacturing manual and provides a reasonable assurance that the MGVs are met in the production lots.

Staff reviewed the materials selected for use in the fabrication of components of the Model No. HI-STAR 180 package, as well as the Metamic-HT Qualification Sourcebook, and found that they meet the service requirements of such components.

1.4 Approval of Moderator Exclusion

A package for fissile material must be designed to be subcritical after Hypothetical Accident Conditions (HAC) as specified in 10 CFR 71.55(e). The Model No. HI-STAR 180 package is designed to transport both moderate and high burnup fuel, as explained in Section 1.2 of this report. It is known that the cladding of high burnup fuel may become brittle and could fracture under impact loads associated with HAC free drop test conditions. As a consequence, severe cladding damage could lead to reconfiguration of the fuel potentially leading to an increased reactivity exceeding the applicant's upper subcritical limit on k_{eff} if inleakage of water occurs after HAC. Therefore, it is necessary to demonstrate the criticality safety of the reconfigured fuel with the assumed inleakage of fresh water, <u>or alternatively</u> demonstrate that inleakage is not credible after HAC.

Interim Staff Guidance (ISG-19) "Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)" provides guidance to staff on two basic approaches and criteria acceptable to show subcriticality under 10 CFR 71.55(e) and approval of high burnup fuel in a transport package:

- Approval based on reconfigured fuel by showing that the reconfigured fuel is subcritical, assuming water inleakage and performing a criticality evaluation of bounding reconfigured fuel geometries.

- Approval based on moderator exclusion by showing that there is no water inleakage under HAC and demonstrating through physical testing the water exclusion boundary so that damage to the fuel would be inconsequential from a reactivity control perspective.

For approval based on moderator exclusion, ISG-19 proposes to (i) include the bolt closure system in the package scale model in the 9 m drop tests of the impact limiters, (ii) perform relative leak rate testing by testing before and after each drop, (iii) demonstrate an acceptable leakage rate to prevent water inleakage. ISG-19 states that the objective of the physical test of the scaled bolt closure system is to provide an added assurance of moderator exclusion under HAC.

The applicant requested package approval based on moderator exclusion under HAC, but, as an alternative to the criteria in ISG-19, without performing a physical drop test. The applicant asserted that the double lid design meets the intent of ISG-19, and that the integrity of both the inner and outer lids after a free-drop event is demonstrated through an analysis that confirms that bolted joints in each lid have adequate structural strength to prevent the unloading of any of the four seals in the most vulnerable free drop orientation, either during normal conditions of transport (NCT) and HAC.

Staff reviewed the criteria in ISG-19, the proposed alternatives by the applicant, and the associated design and found: ISG-19 and concurred that:

(i) ISG-19 prescribes the physical drop test because an analytical model does not always represent a proper interaction between the impact limiter bolts and the containment boundary. However, the double closure lid system, with each lid maintaining its prescribed ANSI N14.5 leak-tightness criterion, eliminates the

need for physical testing and is consistent with the intent of the second condition of Table 1 for moderator exclusion in ISG-19

(ii) ISG-19 prescribes that the basket remains geometrically intact even though the fuel may be reconfigured in the basket fuel cell. The structural integrity of the basket, e.g., potential deformation, validation of material properties of Metamic-HT, related tolerances and welding issues, has been adequately demonstrated by the applicant.

(iii) ISG-19 prescribes that, in lieu of demonstrating moderator exclusion through physical tests and analyses, a structural analysis can determine the geometry of reconfigured fuel and the criticality analysis may demonstrate that the bounding reconfiguration is subcritical under full moderation The applicant did not attempt to demonstrate that all possible reconfigurations were subcritical. However, criticality analyses for a limited number of fuel reconfigurations were performed by the applicant for a fully flooded package as defense in depth. The applicant demonstrated that even under damaged fuel condition (and resulting fuel reconfiguration), no significant increase in reactivity occurred compared to intact fuel. The staff determined that the package design also included sufficient margins for additional credible reconfigurations due to random rod movements.

As detailed in Chapters 2, 4, and 6 of this report, the detailed technical review and evaluation of the structural, thermal, containment, and criticality chapters of the application concludes that the Model No. HI-STAR 180 package complies with 10 CFR Part 71 requirements. In particular, key technical items that were evaluated and verified by staff include the following:

- Only the inner lid is subject to the inertial load of the contents and the outer lid experiences no impact loading, other than its own inertia force that may act to unload its bolted joint.

- The outer lid joint is protected from the seal unloading forces during a drop event, providing a level of assurance against loss of containment integrity that is not realized in a single-lid cask.

- The integrity of both the inner and outer lids after a free drop event is satisfactorily demonstrated by a conservative analysis.

- The two containment lids with the two bolted joints together are structurally competent to ensure moderator exclusion. Leak testing of both lids to a leaktight standard is appropriately specified, in accordance with ANSI N14.5, at time of loading of the contents and prior to shipment.

- Analysis of the package as fully flooded under NCT, with a conservative modeling of high burnup fuel as fresh fuel or low burnup fuel, shows that the reactivity, without taking credit for its diminution by high burnup, remains below the applicant's calculated upper subcritical limit even after a credible reconfiguration of the rods due to damage to the fuel assembly.

Fuel reconfiguration has no adverse effect on the temperature field of the package containment structure. The integrity of the containment boundaries, lid seals, and shielding materials is unaffected.

Therefore, the staff finds that the package design (double lid closure system, with each lid being independent and capable of maintaining the containment boundary under NCT and HAC conditions) and alternative analyses provided by the applicant, ensures moderator exclusion consistent with the intent and level of safety provided in the guidance of ISG-19.

The staff has reasonable assurance that this specific package design ensures that inleakage of water through the containment system boundary seals is a non-credible event under HAC in 10 CFR 71.73.

1.5 Criticality Safety Index

The Criticality Safety Index (CSI) for the HI-STAR 180 package is zero, as an unlimited number of packages will remain subcritical under the procedures specified in 10 CFR 71.59(a).

1.6 Drawings

The packaging is constructed and assembled in accordance with the following Drawing Nos.:

HI-STAR 180 Cask:	Drawing 4845, Sheets 1-6, Rev. 7
HI-STAR 180 F-37 Fuel Basket:	Drawing 4847, Sheets 1-4, Rev. 5
HI-STAR 180 F-32 Fuel Basket	Drawing 4848, Sheets 1-4, Rev. 5
HI-STAR 180 Impact Limiters:	Drawing 5062, Sheets 1-5, Rev. 5

1.7 Evaluation Findings

A general description of the Model No. HI-STAR 180 package is presented in Chapter 1 of the package application, with special attention to design and operating characteristics and principal safety considerations. Drawings for structures, systems, and components important to safety are included in Section 1.3 of the application.

Based on the structural design, materials specifications, and leak testing procedures, the staff finds that this specific package design (double lid closure system, with each lid being independent and capable of maintaining the containment boundary under both NCT and HAC because the containment seals of each closure lid system and each penetration meet the leak-tight criterion of ANSI N14.5) ensures moderator exclusion consistent with the intent of ISG-19. The staff has reasonable assurance that this specific package design ensures that inleakage of water through the containment system boundary seals is a non-credible event under HAC in 10 CFR 71.73.

The package application identifies the Holtec International's Quality Assurance Program for the Model No. HI-STAR 180 package and the applicable codes and standards for the design, fabrication, assembly, testing, operation, and maintenance of the package. NRC staff evaluated the Model No. HI-STAR 180 package and documented the security assessment separately, as it contains sensitive information that cannot be made publicly available. The security assessment should be reviewed prior to approval of any amendment to this application.

The staff concludes that the information presented in this section of the application provides an adequate basis for the evaluation of the Model No. HI-STAR 180 package against 10 CFR Part 71 requirements for each technical discipline.

2.0 STRUCTURAL REVIEW

The objective of the structural review is to verify that the structural performance of the package meets the requirements of 10 CFR Part 71, including performance under the tests and conditions for both NCT and HAC.

2.1 Structural Design

The Model No. HI-STAR 180 package is comprised of a steel containment system with a Metamic-HT basket, cast monolithic external shield cylinders and steel and aluminum impact limiters. The cylindrical steel shell containment system is welded to a bottom steel baseplate and a top steel forging machined to receive two independent steel lids with a total of four independent metallic seals. This dual lid arrangement, where each lid is bolted independently to the containment closure flange and each closure lid employs two seals, forms the basis for allowing moderator exclusion when evaluating the safety of this package.

The Metamic - HT fuel basket has a honeycomb design to achieve high structural rigidity. Adjacent to the fuel basket are aluminum shims which are manufactured to fit securely within the remaining space between the external basket walls and the internal surface of the steel shell. Cast shield cylinders are affixed externally to the containment shell to provide radial shielding. The impact limiters are comprised of a steel skeleton, that fits snugly over the top forging and bottom baseplate, and aluminum honeycomb block material to provide energy absorption during impact. An external thin gauge stainless steel shell encloses the steel skeleton and aluminum honeycomb.

2.1.1 Analytical Modeling

The licensing basis for the Model No. HI-STAR 180 package structural performance is predicated on successful analytical modeling rather than experimental testing. Analytical modeling has distinct advantages over testing because an analyst can extract far more information from a structural simulation than can be obtained from a test. However, it is always necessary to ensure that the modeling results are reliable and consistent with both the data and the overall structural behavior obtained from either a full scale or scale model testing.

The staff made the applicant aware of several options for that purpose and the chosen methodology consisted of a limited analytical benchmark model to demonstrate that the applicant's methodology is sufficient to capture the rigid body dynamics and gross structural performance of a quarter scale version of the previously licensed Model No. HI-STAR 100 package (Docket No. 71-9261).

The applicant found that this analytical model compared well with both the test data and the Classical Dynamics Method (CDM) previously approved as part of the Model No. HI-STAR 100 package licensing basis. Subsequently the applicant proceeded with the evaluation of the Model No. HI-STAR 180 package by utilizing a two-step approach which included both classical and numerical dynamic modeling to determine a peak deceleration which is then amplified and incorporated in a quasi-static numerical stress and deformation evaluation, similarly to the methodology used for the Model No. HI-STAR 100 package.

2.1.2 Design Criteria

The structural design criteria are developed to assure that the Model No. HI-STAR-180 package has adequate structural strength to meet NCT and HAC requirements. These criteria are designated as those that affect the containment boundary and those that affect other package structures which contribute to the overall structural performance of the package.

The containment boundary is evaluated based on the American Society of Mechanical Engineers (ASME) code requirements for Level A and D service and is consistent with Regulatory Guide 7.6 "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels."

The remaining design requirements address the shield cylinders, the fuel basket, the fuel basket supports, the impact limiter deformation and attachment.

2.1.2.1 Loading and Load Combinations

Loads and load combinations are evaluated using ASME code for internal and external pressure, NUREG-0612 "Control of Heavy Loads at Nuclear Power Plants. Resolution of Generic Technical Activity A-36" for handling loads, and 10 CFR Part 71 for NCT and HAC loads.

NCT Load combinations include combination N1 (Bolt pre-load plus design internal pressure and normal operating temperature plus loading from FIAs subject to Level A condition stress limits) and N2 (Free drop from 0.3 meter plus bolt pre-load). HAC load combinations include 9 meter free drops, end and side puncture, deep submergence (2 MPa), and gasket relaxation due to fire.

2.1.2.2 Acceptance Criteria

The structural acceptance criteria of the Model No. HISTAR-180 package are established for (i) the containment boundary, (ii) the fuel basket, (iii) the shielding components and, (iv) the impact limiters.

(i) Containment Boundary

1. The containment boundary must meet the stress intensity limits of Subsection NB of the ASME Code for design pressure and temperature under Level A conditions.

2. The containment boundary must remain leaktight under the Free Drop event as well as satisfy the ASME Code limits for Section III, Level A and D stress intensity limits for the respective drop heights.

3. Under a penetration event, the containment boundary must not be breached, remain leaktight, and Level D stress intensity limits must be satisfied away from the point of impact.

4 The closure lid seals must remain functional under all events

5 The containment boundary materials must not be susceptible to brittle fracture

(ii) Fuel Basket

1 The fuel basket acceptance criterion for permanent deformation is limited to 1 mm relative to adjacent plates.

2 Creep deformation must remain negligible.

3. Brittle fracture must not occur.

4 Basket tearing must not occur

5. B-10 areal density to meet criticality requirements must be assured

6. Mechanical strength and physical properties under NCT must be maintained.

7. Physical properties of the basket material under neutron and gamma fluence must be maintained.

(iii) Shielding Components

1. The shielding should not separate from the cask or suffer extensive damage.

2. Brittle fracture damage resulting in through thickness cracks, thereby causing a loss in shielding function, is not allowed.

(iv) Impact Limiters

1. Must perform impact limiting functions over range of temperatures.

2. Must remain permanently attached to the package.

3. Must have adequate crush characteristics to prevent bottoming out of the cask body.

4. Must provide adequate protection against damage which would cause the containment to leak, cause the stress limits to be exceeded, or cause the fuel basket to fracture or suffer catastrophic local and global deformation.

2.1.3 Weights and Centers of Gravity

Table 2.1.11 of the application summarizes several content configurations with varying weights. The center of gravity of the Model No. HI-STAR 180 package is shown in Table 2.1.12.

2.1.4 Codes and Standards

The Codes and Standards utilized for the package design are identified in Section 2.1.4 of the application. Specifically, the containment boundary is designed to Section III of the ASME Code, including subsection NB and Appendix F. The application also lists and classifies structures, systems, and components as Important To Safety (ITS) or Not Important To Safety (NITS), based on guidance presented in NUREG/CR 6407 "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety." Where applicable, the applicant has also listed alternatives to the ASME Code.

Other materials and components that do not comprise the containment boundary are designated as meeting the American Society for Testing Materials (ASTM) specifications with the exception of Holtite-B and Metamic-HT, which are proprietary specialty materials not covered by ASTM specifications.

2.2 Mechanical Properties of Materials

2.2.1 Introduction

Metamic-HT is the applicant's proprietary aluminum-based material used both as a neutron poison for criticality control and as a load-bearing structural material in the Model No. HI-STAR 180 package. Although the applicant often uses the terminology "metal matrix composite" to generically describe Metamic-HT, Metamic-HT is a powder metallurgy material composed of aluminum combined with aluminum oxide and boron carbide; the aluminum oxide is a finely dispersed second-phase which provides enhanced room temperature and elevated temperature (creep) strength. This strengthening mechanism allows the use of Metamic-HT as a structural material. The neutronic properties of Metamic-HT, from the boron carbide acting as neutron poison for criticality control, evolve from a previous, non-structural, grade of "classic" Metamic (approved for the Model No. HI-STAR 60 package, CoC No. 9336): these properties are already well characterized and are not discussed in this report.

Since Metamic-HT is a new structural material, a comprehensive test program was required to fully determine its physical properties and characteristics. The applicant (who is also the Metamic-HT manufacturer) provided extensive testing data, based on a typical program for the qualification of an ASME Code structural material, which is documented in the report "Metamic-HT Qualification Sourcebook." Since this data is proprietary, the staff summarizes the testing program and findings on the Metamic-HT structural characteristics in lieu of excerpting detailed technical discussions from the applicant's documents.

The testing program, employing a variety of standard ASTM test methods, included the characterization of the yield strength, tensile strength, elongation, reduction in area, Young's Modulus, Charpy impact strength, thermal conductivity, coefficient of thermal expansion, and emissivity.

Additionally, isotropy was evaluated, thermal aging effects were examined, welding procedures developed, weld properties determined, irradiation effects evaluated, thermally induced microstructural alteration assessed, and accelerated creep testing was performed. Neutron attenuation was verified (as in the case of the "classic" Metamic material) and corrosion testing was conducted in a simulated borated pool water environment.

For each material property and evaluation, up to 30 samples were tested. Samples were taken from multiple lots of material to determine lot to lot variability, which was found to be minimal.

Overall, the staff found that the applicant's test program was comprehensive in scope and supported the wide variety of property data needs for characterizing Metamic-HT.

2.2.2 Thermal Aging Effects on Mechanical Properties

All metals undergo changes in their mechanical properties when exposed to elevated temperatures. Aluminum-based materials typically exhibit a decline in properties at temperatures above about 93°C. These property changes are generally reversible after exposure to short-duration moderate temperature excursions; however, long-duration elevated temperature exposure generally results in permanent decrease of mechanical properties such as yield and tensile strength. Since the transportation package is designed for a 5-year, renewable, license interval, the Metamic-HT long-term performance is of primary interest, particularly because it is designed to operate in the temperature regime above the typical ASME Code limit of about 204°C for aluminum alloys.

To determine the long-term, elevated temperature performance of Metamic-HT, the applicant exposed approximately 30 samples to temperatures above the design temperature limit of 300°C in order to "age" the material in an accelerated fashion. The accelerated aging technique is intended to duplicate on a faster time scale the metallurgical and physical property changes that would occur in the material under design conditions. This accelerated testing is done by exposing the material to a higher temperature (for a shorter time period) and using a mathematical model to equate this accelerated "aging" process to a lower temperature, longer duration exposure as it would occur in normal service. After thermal aging, the samples are tested and compared to "as-produced" (un-aged) material samples to determine if any permanent changes have occurred to the material properties.

The applicant asserts that Metamic-HT should not exhibit any aging effects since it is not a heat-treatable material, unlike typical high strength aluminum alloys. The applicant's test data supports this contention: aged samples do exhibit some small changes in properties when compared to un-aged (room temperature) samples but the staff judges these changes to be minor. Tensile and yield strength values drop about 2 percent to 4 percent whereas elongation slightly increases and reduction in area slightly decreases. The Charpy impact strength is virtually unchanged. This is a unique response for this Metamic-HT material, as all other high-strength aluminum-base Code materials exhibit some form of aging effect, often severe.

The staff finds that the applicant's data supports the contention that thermal aging is not a significant factor at the design temperature. Thus, no long-term, thermally induced, degradation would be expected in service.

2.2.3 Thermal Aging Plus Irradiation Effects on Mechanical Properties

Samples of Metamic-HT were exposed to elevated temperatures plus radiation fluence levels beyond those to be found in service. Test results do not reveal any unexpected or significant adverse synergistic effects. Some increase in both tensile and yield strength is noted along with a corresponding slight reduction in ductility and toughness. This result is consistent with the performance of other metals in similar service.

The staff finds that the results of the thermal plus irradiation exposure show some small effect which is consistent with the experience for other metals. Thus no unanticipated response to service conditions (heat plus radiation) would result.

The staff further notes that the fluence levels for a transportation package are orders of magnitude lower than the accumulated dose in reactor operation

This provides an additional margin of safety against adverse effects (such as brittle fracture) in Metamic-HT components in service.

2.2.4 Thermal Aging Effects On Microstructure

Microstructural alteration is an important indicator of material property changes. To support the mechanical property data provided, the applicant microscopically examined "as-extruded" material and compared its microstructure to thermally aged samples.

The thermally aged samples show little or no microstructural alteration compared to the as-extruded (e.g., new material) samples. This demonstrates a thermal stability of Metamic-HT which is not observed in other aluminum-base systems. especially at the temperature of interest i.e., 300°C

The staff examined the photomicrographs of the "as-extruded" (new) and thermally aged materials and found no significant changes to the microstructure. Based upon this examination, the staff finds that Metamic-HT is highly stable at the design temperature.

This provides reasonable assurance that microstructural changes under service conditions will not occur, and thus the material properties of Metamic-HT will remain unaffected during service.

2.2.5 Low Temperature Effects

Since Metamic-HT is an aluminum-base material, it is expected that it would not be susceptible to ductile-brittle transformation or brittle fracture issues at low temperatures. To verify this assumption, coupons were tested at minus 40°C and the samples show no degradation in tensile or elongation properties, compared to room temperature properties. Thus, it is demonstrated that no low temperature issues affect Metamic-HT.

The staff finds that Metamic-HT is suitable for the lowest design temperatures of minus 28°C and minus 40°C, as specified by 10 CFR Part 71.

2.2.6 Anisotropy

Anisotropy of mechanical properties is often an issue with many high performance aluminum materials. Potential anisotropy in Metamic-HT was explored, as part of its characterization, and a series of samples, including as-manufactured, artificially aged and aged and irradiated samples, were tested in accordance with the ASTM E9-89 compressive test technique. Test results show minimal variation and the applicant concludes that anisotropy in Metamic-HT is negligible.

Upon review of the provided data, the staff finds that the anisotropy in Metamic-HT is small and may be neglected for the intended application.

2.2.7 Weld Properties

High performance aluminum alloys are generally unweldable. This is due to the fact that the heat of welding adversely alters the microstructure, obtained by heat-treatment, which most high

strength aluminum alloys undergo to attain their enhanced strength. Consequently, high-strength aluminum alloy structures (such as those used in an aircraft) are always riveted, bolted or bonded instead of welded.

Metamic-HT utilizes a strengthening mechanism ("oxide dispersion strengthening"), different from that employed in most aluminum-base materials, which does not depend upon a heat treatment to achieve its strength levels. However, the Metamic-HT strengthening mechanism is adversely affected by weld-zone, temperature-induced, microstructural alteration. Therefore any Metamic-HT weld is expected to have less than base material strength.

The applicant undertook a weld development program to optimize the strength of Metamic-HT welds and was able to achieve a weld strength of approximately 60 percent of the base material strength. This weld performance obviously affects weld design and restricts weld utilization. To compensate for this loss of strength, the Metamic-HT basket welds are restricted to areas where stresses are low.

Welds with strengths lower than the base material would not be permitted in an ASME Code-based design. However, the Metamic-HT basket is not designed in compliance with the ASME Code. Instead, a strain-controlled design method and the placement of the welds in a low stress (hence strain) location of the Metamic-HT basket remove, in this case, the issue of reduced weld strength. The structural evaluation of the welds is detailed in this Chapter.

The staff finds that, although Metamic-HT is "deficient" with respect to normally accepted, e.g., ASME Code, weld strength requirements, the strain-limited design approach and the placement of the welds in a low stress (and strain) region of the basket ensures adequate performance in service.

2.2.8 Creep Properties

Since the fuel basket operates above the ASME Code temperature limit of about 204°C for aluminum-base materials, creep strength/performance was identified early as a key issue in the Metamic-HT characterization program. Consequently, a creep test program was established to determine the creep strength of Metamic-HT at the design operating temperature.

Seven long-term creep samples were tested. Samples were tested at 300, 350, and 400°C. Stress levels used in the tests ranged from 200 to 1000 psi. The test conditions were designed to provide data which can be extrapolated to a creep life at design conditions. Although employing a limited number of creep test samples, the applicant attempted to bound design conditions sufficiently to ensure a large margin of safety.

The design conditions for the Metamic HT basket are 300°C at 150 psi. The samples are thus all clearly tested at temperature and/or stress levels significantly above the design maximums.

The creep samples accumulated varying test times, between about 13,500 hours and 20,000 hours at various temperature and load conditions. When testing was discontinued, no specimens had failed. Cumulative creep strains were reported to vary between about 0.07 percent and 0.24 percent, depending upon test conditions such as time, stress, and temperature.

The staff observes that the creep testing was extremely severe compared to design conditions. Normally, a wide difference (such as the applicant employed) between the accelerated test

conditions and the design conditions is avoided because of metallurgical considerations. Typical creep tests are generally conducted at a slightly elevated temperature but at the same stress as the maximum design stress. The reason is to avoid metallurgical phenomena which could distort results and lead to a significantly understated (but conservative) creep life prediction. While this would be safely conservative, it could be unnecessarily so by leading to much shortened creep life predictions.

The applicant uses the accumulated creep data in conjunction with an established creep strain equation to produce a cumulative creep strain versus operating time relation. The applicant then compares the creep equation predictions with the data from the creep test samples. In every case, it is shown that the creep equation over-predicted the actual measured creep strain by a comfortable margin. The applicant asserts that this demonstrates that their equation is conservative due to over-predicting the cumulative creep strain

In conjunction with the creep equation, a limiting creep strain of 0.4 percent is adopted by the applicant as the maximum allowable creep strain in service This limit is based on a foreign construction Code creep strain limit for aluminum components. Employing the applicant's creep strain equation along with the 0.4 percent allowable creep strain limit yields a service life well beyond the normal 5 year license period.

Although this method is logical, the limiting creep strain is not adequately supported by the available data, because none of the creep test specimens were tested to failure. This means the creep strain at failure is undetermined. Thus, any creep strain limit based on failure strain is not supported. The applicant has demonstrated what the creep strain rate is for the several specimens. But absent failure data, there is no way to predict either creep strain at failure or maximum creep life, meaning time to failure. Adoption of the 0.4 percent creep strain limit may be conservative, based upon general creep failure strain knowledge, but it remains speculative absent failure strain data.

Another issue with the creep testing program involves the choice of test parameters (temperatures and stresses). It is recognized that a limitation of accelerated creep testing is the susceptibility to overstate the creep strain at failure, at design conditions. Higher temperature, or, especially, higher stress, accelerated creep testing is susceptible to yielding creep failure strains which are slightly larger than those which would be achieved under service conditions. The reasons are related to the activation of additional creep mechanisms due to the necessarily more severe conditions employed during testing. In the applicant's case, the test temperatures were significantly higher than what would be typically employed for accelerated creep testing. Thus, the staff must view the achieved creep strains as being possibly overstated. However, the test outcome, when the time (not strain) element is considered, is highly conservative with respect to predicting the useful creep life under design conditions. Thus, although the staff finds the measured creep strains as possibly being overstated, the creep life (time) performance of the material when in operation is very conservatively assured.

With respect to predicted creep life, as measured in hours instead of accumulated creep strain, the applicant applied a mathematical formula called the Larson-Miller (L-M) equation. The L-M equation is frequently employed to relate the time at accelerated test conditions to time at operating conditions. Again, as for the creep strain equation, the L-M equation cannot predict total creep life unless the creep data includes samples tested to failure. However, given that the test samples never failed, it is assured that a predicted service life based upon the test sample times will be conservative.

The applicant provides a L-M calculation based on the least conservative data from one of the lower temperature and stress test samples, which shows that a 40-year continuous operating life is achievable. The staff, through an independent L-M calculation, verified that a 40-year operating life is amply supported by the applicant's creep test data.

Despite some shortcomings of the test program, the staff finds that the creep testing has bounded the design conditions by a wide margin. The severity of the creep tests will tend to understate the predicted service life (as measured in hours), which is very comfortably conservative at a predicted continuous service life of greater than 40 years. With respect to creep strain, the staff finds that due to the very elevated test conditions (temperature, stress), and the lack of failure strain data, the validity of the proposed 0.4 percent creep strain limit is unknown. However, the shortcoming of strain results and predictions becomes immaterial when the service life is employed instead.

In conclusion, the staff finds that the creep tests have conclusively demonstrated the ability of Metamic-HT to adequately perform continuously at design conditions for the 5-year license interval. An added level of conservatism exists when it is recognized that no package is ever likely to be loaded with a design basis heat load for the entire license period.

2.2.9 Corrosion Resistance

Metamic-HT was tested for compatibility with borated water, as it would be typical for cask loading and unloading conditions. Aluminum alloys are very slightly corroded by borated water and Metamic-HT performed similar to other aluminum-based materials in immersion tests. The applicant concludes that Metamic-HT has more than an adequate corrosion resistance for the intended service.

The staff finds that Metamic HT is not susceptible to significant chemical or galvanic reactions and will perform in accordance with 10 CFR 71.43(d).

2..2.10 Other Materials of Construction

The balance of the Model No. HI-STAR 180 transport package is fabricated from materials which have all been previously evaluated by the NRC staff for their suitability. The bill of materials in the Licensing Drawings and Chapter 2 of the application provide details of each material type and specification. Since all such materials have been previously reviewed and employed for transportation packages (in particular for the Model Nos. HI-STAR 100 and HI-STAR 60 packages – CoC Nos. 9261 and 9336 respectively), only a brief synopsis of materials related findings are summarized below:

Impact Limiters: The impact limiters are fabricated from aluminum honeycomb, with a stainless steel sheet metal cover, alloy steel or precipitation hardened stainless steel fasteners, and carbon or alloy steel stiffeners. The impact properties of the aluminum, stainless, and alloy or precipitation hardened stainless components are suitable for low temperature and/or impact service without adverse effects. The carbon and alloy steel components are tested to demonstrate adequate properties for their intended service.

Containment Boundary: The containment boundary of the transport canister is fabricated from various ASME/ASTM grades of nickel-bearing steel with excellent low temperature properties, making these components immune to low temperature brittle fracture problems.

Gamma and Neutron Shield: The radiation shield is composed of carbon and low alloy steel, lead, and a Holtec proprietary filled polymer neutron shield material. For the design service conditions, there are no conditions which will result in a degradation of the materials performance for the duration of the license period (5 years) Calculations have previously shown that the materials should easily achieve 40 years of service with no loss of performance. Under design basis accident conditions for fire, there is no effect on the steel or lead shielding material. It is conservatively assumed that the bulk of the neutron shield material is lost, due to fire effects. Despite this assumed loss of neutron shielding, the dose rates remain within regulatory limits.

Seals: The containment lid seals are all metallic, employing stainless steel and/or inconel, with a silver coating on sealing surfaces These materials are capable of withstanding all design and accident conditions and environments without loss of function (see Chapter 4 of this report)

Weld Material: All weld filler materials utilized in the welding of the Code components comply with the provisions of the appropriate ASME Code Subsection. All "non-Code welds" (e.g., not important to safety) will be made using weld procedures that meet ASME Section IX, AWS D1.1, D.1.2, or equivalent. All non-destructive examinations will comply with Section V of the ASME Code.

Chemical, Galvanic, or Other Reactions: There is no credible mechanism for significant chemical or galvanic reactions in the package during loading operations or in the package during transport. Similar to other transportation packages, the Model No. HI-STAR 180 package combines low-alloy and nickel alloy steels, carbon steels, neutron and gamma shielding, and alloy steel bolting materials. All of these materials have a long history of non-galvanic behavior within close proximity of each other when exposed to the normally encountered environments both during fuel loading and transportation. Additionally, the external surfaces of the cask are coated to preclude oxidation. The internal surfaces of the cask are lined to preclude any significant corrosion. The coatings and liners do not chemically react significantly with borated water. The cask is dried and helium backfilled to eliminate any credible corrosion from moisture and oxidizing gasses. Therefore, chemical, galvanic, or other reactions involving the cask materials are either minimal or unlikely.

2.3 Fabrication and Examination

2.3.1 Fabrication

The applicant identified seven key criteria necessary to ensure that the Model No. HI-STAR 180 package design can be readily constructed utilizing current and available manufacturing techniques. These criteria include the following:

1) Tolerances are achievable
2) Design is not overly reliant on stringent tolerances
3) Weldability of dissimilar materials
4) Specification of post heat treatment or other residual stress relief
5) Manufacturing sequence must allow for unimpeded Non-Destructive Evaluation as well as remedial repairs

6) Manufacturing sequence must allow for unimpeded access to relevant post weld machining of critical surfaces
7) Manufacturing sequence does not engender unnecessary risk to worker safety

The applicant subsequently provided an overview of a typical fabrication sequence for this package. Staff reviewed this sequence and determined that it is of reasonable detail to fully describe the fabrication sequence.

2.3.2 Examination

The applicant identified eleven key fabrication control and required inspections, which are necessary to ensure that conditions of the Certificate of Compliance (CoC) can be met. These criteria include the following:

1) Materials of construction must be specified on the licensing drawings. ITS materials will be obtained with appropriate certification and documentation required by Sections II and III of the ASME code, where applicable. All materials and components will be inspected for visual and dimensional defects, adherence to specification requirements, and traceability markings where applicable.

2) Welders and weld procedures will be qualified in accordance to Section IX and applicable subsections of Section III of the ASME Code.

3) Welds will be examined utilizing Section V of the ASME Code with acceptance criteria in accordance with Section III of the ASME Code. The acceptance criteria for non-destructive examination will be consistent with the Code requirements for the component that was fabricated. Post weld inspections will be identified in a weld inspection plan, which details the weld, examination requirements, the examination sequence and the acceptance criteria and is subject to a mandatory review and approval in accordance to the applicant's Quality Assurance (QA) program prior to its implementation. Non-destructive examination inspections will be performed in accordance to written and approved procedures by qualified personnel.

4) The containment boundary will be examined and tested via a helium leak test, pressure test, ultrasonic testing, magnetic particle testing, and/or liquid penetrant testing as applicable. Category A and B welds are subject to volumetric examinations based on Subsection NB of the ASME Code.

5) Grinding and machining operations will be examined by ultrasonic testing to ensure that the metal wall thicknesses are not reduced beyond design limits.

6) Dimensional inspections will occur to confirm compliance with design drawings and verify the fitting tolerances of individual components.

7) Trunnions are designed, inspected, and tested in accordance to ANSI N14.6 "Special Lifting Devices for Shipping Containers Weighing 10,000 pounds (4500 kg) or More." A visual examination following a test at a maximum of 300% maximum design service loading applied for a minimum of 10 minutes will be performed to verify that no gross deformation or cracking has occurred.

8) Upon completion of hydrostatic or pneumatic pressure tests the internal surfaces of the package will be inspected for cracking or deformation. Subsequent discovery and repair for deformation or cracking will require retesting of the package and the test results will be documented and incorporated in to the final quality documentation.

9) Each plate or forging used for the containment boundary will be drop weight tested per Regulatory Guides 7.11 "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 inches (0.1 m)" and 7.12 "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 inches (0.1 m) But Not Exceeding 12 inches (0.3 m)" where applicable, and ASME Charpy V-notch testing will be performed on these materials. Test results will be recorded in the final QA document.

10) Leak tests will be performed upon completion of the fabrication of the containment boundary.

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

2.4 General Standards for All Packages (10 CFR 71.43)

2.4.1 Minimum Package Size

The smallest overall dimension exceeds the specified requirement of 10 cm; therefore, the package meets the requirements of 10 CFR 71.43(a) for minimum size.

2.4.2 Tamper-Proof Feature

The impact limiter attachment studs/nuts are fitted with a wire tamper seal. Removal of the impact limiter is required to access radioactive contents which would require removal of the attachment studs/nuts, thereby damaging the tamper seal. Thus, the requirements of 10 CFR 71.43(b) are satisfied.

2.4.3 Positive Closure

Positive closure is demonstrated by the use of two bolted closure lids each weighing several metric tons each (6.34 Metric Tons for the inner closure lid, and 3.33 Metric Tons for the outer closure lid) as well as sealed and bolted port covers/caps. Opening of the cask requires specialized tools and a power source; therefore, inadvertent opening is not credible. The package was adequately analyzed for maximum internal and external differential pressures as well as expected external and internal pressures during NCT and HAC. Thus, the requirements of 10 CFR 71.43(c) are satisfied.

2.4.4 Chemical and Galvanic Reactions

Section 2.2 of this report describes issues related to the package materials.

2.5 Lifting and Tie-Down Standards for All Packages (10 CFR 71.45)

2.5.1 Lifting Devices

The applicant evaluates all devices or components related to a lifting operation including the trunnions, the closure lid lifting holes and the containment baseplate The trunnions and lid lifting holes are evaluated by using the guidance of NUREG-0612 for storage which requires a factor of safety on yield strength of 6 and a factor of safety on ultimate strength of 10. These acceptance criteria exceed those imposed by NUREG-1617 "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel," and 10 CFR 71.45(a) which only requires a factor of safety against yielding of 3. Both the trunnions and lid lifting holes have adequate margin for lifting operations

The baseplate is evaluated for static lifting including a 15 percent inertial load multiplier and found acceptable based on ASME Level A allowable stresses.

The applicant also evaluates the effects of the failure of the lifting devices permanently attached to the cask and determines that such a failure would occur away from the containment boundary such that the containment and shielding functions would not be compromised.

The requirements of 10 CFR 71 45(a)(1) for lifting devices are met

2.5.2 Tie-Down Devices

The package does not incorporate any structural feature that is used as a tie-down device. Thus, the requirements of 10 CFR 71.45(b)(1) are not applicable.

2.6 Normal Conditions of Transport (10 CFR 71.71)

2.6.1 Heat

2.6.1.1 Differential Thermal Expansion

The applicant identifies axial fuel growth of the fuel assemblies as a potential mechanism for applying load to the internal surfaces of the package during a cold condition. The applicant concludes that the restraint of thermal expansion is lower in the cold condition and the allowable stresses are larger, therefore the stresses on the fuel assembly and inner package surface are greater in the hot condition.

The hot condition evaluation illustrates that the Fuel Impact Attenuators (FIA) is compressed 8 mm, which imparts a minimal load on the interior of the containment cavity. A buckling evaluation of the fuel assembly is performed and it is demonstrated that the load imparted by the compressed FIA does not cause a global or local buckling event to occur.

2.6.1.2 Gaps

To consider the mitigation of secondary impact due to inherent gaps between the contents, including the fuel assemblies and the basket, the applicant employs FIAs to provide a deformable energy absorbing spacer to consume most of the existing gaps as well as absorb a significant portion of the energy imparted to the fuel assembly. Staff agrees with both this approach and the analysis provided by the applicant, i.e., maximum gaps are considered.

Staff however disagrees with much of the following text from page 2.6-5 of the application: *"As heuristic reasoning would suggest, increased internal gaps would produce increased impact loads during impact events due to the rebound of the unfixed masses (fuel assemblies and/or*

basket) from their support surfaces during the package's free fall. For example, an elastic surface such as the baseplate or lid of the cask supports the weight of the fuel by flexural action when the cask is in a vertical orientation prior to the initiation of the drop event. As soon as the free fall begins, the "flexural spring" would begin to relieve its strain energy, resulting in the presence of a possible gap between the fuel assembly and the baseplate or lid surface at the moment of impact. The extent of separation depends on the flexibility of the support surface and weight of the supported mass. Scoping calculations show that the extent of separation between the fuel assembly and the cask and basket surfaces are rather minute at the instant of impact in any impact event. However, for conservatism, the initial gap is assumed to be at its maximum geometrically feasible value in any drop orientation. This is an evidently counterfactual assumption made to maximize the computed severity of the impact events."

While staff does not disagree with the physics presented with respect to a vertical freefall event from rest, i.e., an elastic springback effect, staff specifically disagrees with the conclusion drawn by the applicant that the assumption of a maximum gap is a counterfactual assumption. With respect to longitudinal gaps, the staff's position is that, when transported, the package is oriented in a horizontal position such that an accident event will tend to load the package in an axial direction without the benefit of having a completely closed geometric gap near the bolted lid due to the manner in which the package is loaded onto the conveyance. If the package is vertical, there exists a maximum geometric gap between the closure lid and the contents. As the package is upended in preparation for transport, this gap will still exist as the direction of gravity does not change to allow for the contents to translate relative to the lid and close the gap. Staff concludes that reliance on only a typical test configuration wherein the package has an initial condition of base-down or bottom-down, which allows gravity to act on the contents and close the existing geometric gap, is un-conservative and ignores the "as-shipped" conditions of the package.

The same logical exercise can be performed for the C.G. Over Corner or Slapdown orientations to show that consideration of maximum gaps is conservative and appropriate.

2.6.1.3 Structural Evaluation (Design Condition, Normal Operating Condition, and 0.3 Meter Free Drop)

The applicant considers two load cases for the normal heat NCT condition. The load case N1 considers bolt preload plus design internal pressure stresses, normal operating pressure, and the loads imparted by the FIAs. The load case N2 consists of the 0.3 meter free drop plus bolt reload.

Results illustrate similar factors of safety and that both load cases N1 and N2 are indicators of the level of safety provided under NCT.

2.6.1.4 Lid Bolts and Seals

The applicant performed two independent evaluations to determine the state of stress in the lid bolts as well as the degree of compression in the seals due to NCT loadings. The applicant concluded that no bolt overstresses occurred nor did the closure plate seals unload.

2.6.1.5 Basket Stability

Large deformation nonlinear finite element analyses performed by the applicant showed no evidence of incipient buckling of the fuel basket plates.

The staff reviewed the statements and conclusions made by the applicant, reviewed calculations presented in supporting documents, reviewed and replicated outputs from submitted finite element calculations and determined that the structural performance of this package under the normal heat NCT satisfies the requirements of 10 CFR 71.71(c)(1).

2.6.2 Cold

The applicant evaluates the cold NCT condition (-40°C) with respect to internal pressure, allowable stresses, bolt stress, and differential thermal expansion. With respect to internal pressure and allowable stresses, the applicant concludes that the internal pressure will decline with decreasing ambient temperature while the material allowable stresses will increase under the same condition. The applicant concludes that decreasing the load and increasing the available material strength would result in larger margins of safety than what would be expected for a hot condition.

Based on calculations performed to determine the relative change in stress in the closure bolts the applicant finds that there is an insignificant change and no effect on the effectiveness of the closure lid seals. In addition, the increase of allowable stresses also increases for bolts under the cold condition leaving the margin of safety relatively unchanged. The applicant identifies axial fuel growth of the fuel assemblies as a potential mechanism for applying the load to the internal surfaces of the package during a cold condition. The applicant concludes that the restraint of thermal expansion is lower in the cold condition and the allowable stresses are larger, therefore the stresses on the fuel assembly and inner package surface are greater in the hot condition.

Staff reviewed the calculations and subsequent conclusions made by the applicant and determined that the structural behavior of this package under the cold NCT condition will satisfy the allowable stresses for the materials and components of construction.

The requirements of 10 CFR 71.71(c)(2) are satisfied.

2.6.3 Reduced External Pressure

Under a reduced external pressure of 25 kPa, the structural behavior is bound by the design internal pressure; therefore, the staff agrees that the requirements of 10 CFR 71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

Under an increased external pressure of 140 kPa, the structural behavior is bounded by the requirements of 10 CFR 71.61, i.e., this type of package must be capable of withstanding an external pressure of 2 MPa due to a head of water for a period of one hour.

The staff agrees that the requirements of 10 CFR 71.71(c)(4) are satisfied.

2.6.5 Vibration and Fatigue

2.6.5.1 Vibration

The applicant calculates the natural frequencies of the fuel basket and cask and determines that those frequencies exceed the vibrations frequencies expected during NCT by a significant margin. Since the possibility of resonance and subsequent elevated stress conditions are not credible, the conditions of 10 CFR 71.71(c)(5) are satisfied for vibration.

2.6.5.2 Fatigue

The applicant evaluates the package for fatigue and determined based on the ASME Code (NB-3222.4 (d) of section III) that a detailed fatigue analysis was not required. Five conditions including Atmospheric to Service Pressure Cycles, Normal Pressure Service Fluctuation, Temperature difference at startup and shutdown, Temperature difference during normal service, and Mechanical Loads were evaluated to demonstrate that the package was exempt from such detailed fatigue calculations. The staff agrees that the exemption criteria of the ASME code are satisfied.

The applicant then performs a fatigue analysis on the closure bolts and determined that the main outer closure bolts should not be torqued and untorqued more than 588 times and the inner closure bolts should not be torqued and untorqued more than 225 times if they are high strength material. A calculation is also performed for the top forging closure bolt threads and found that the maximum service life was 1500 cycles.

Based on the analyses presented, the staff agrees that the requirements of 10 CFR 71.71(c)(5) are satisfied for fatigue due to vibration.

2.6.6 Water Spray

Based on Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material," the staff determines that water spray is not significant to the structural design of large casks and agrees that the requirements of 10 CFR 71.71(c)(6) are satisfied.

2.6.7 Free Drop

The structural evaluation of a 0.3 m drop was reviewed and evaluated in Section 2.6.1.3 of this report. Based on the staff's review of the information presented in the application, the staff agrees that the requirements of 10 CFR 71.71(c)(7) are satisfied.

2.6.8 Corner Drop

The corner drop test does not apply since the gross weight of the package exceeds 50 kg, in accordance with 10 CFR 71.71(c)(8).

2.6.9 Compression

The compression drop test does not apply since the gross weight of the package exceeds 5000 kg, in accordance with 10 CFR 71.71(c)(9).

2.6.10 Penetration

Based on Regulatory Guide 7.8, the NRC staff determines that penetration is not significant to the structural design of large casks.

The staff agrees that the intent of the requirements of 10 CFR 71 71(c)(10) is satisfied

2.7 Hypothetical Accident Conditions (10 CFR 71 73)

As indicated above, the licensing basis for the Model No. HI-STAR 180 package is predicated on analysis only and relied on test data solely to verify the analytical modeling capabilities with respect to rigid body dynamics. This preliminary analysis was designated as a benchmark study and consisted of the simulation of the quarter scale drop tests conducted for the Model No. HI-STAR 100 package (Docket No. 71-9261). The benchmarking of the Model No. HI-STAR 100 package drop test conducted by the applicant provides additional assurance that the deceleration and gross deformation results obtained from the evaluation of the Model No. HI-STAR 180 package are reasonably accurate and conservative. However, the Model No. HI-STAR 100 package quarter scale tests were not designed as a benchmark test and thus lacked the requisite instrumentation that would have allowed a more robust benchmarking effort to be completed

As a result, the applicant decided to initiate a dual path, i.e., an independent dynamic analysis that would allow the use of a similar previously approved methodology for the Model No. HI-STAR 100 and the state-of-the-art explicit dynamics code, LS-DYNA. This dual path approach has two distinct phases: (1) the determination of the rigid body decelerations, and (2) the determination of the stresses and sealing integrity. In Phase 1, the previously approved Classical Dynamics Method (CDM) and LS-DYNA would be utilized independently to produce a peak deceleration for each respective drop orientation that would be used as an input for Phase 2. Each approach produces results (α_{max}) which are then compared, followed by the selection of the higher value of peak deceleration for each drop orientation, and subsequently amplified to the final design value (β_{max}) used to determine the stresses in the package components in Phase 2.

Phase 2 consists of utilizing the values for β_{max}, generating equivalent loads on various surfaces within a quasi static model in the finite element software, ANSYS, and running the quasi-static analysis to obtain relevant stress and deformation results. These results are then compared with the results from LS-DYNA to provide cross validation and ultimately provide additional reasonable assurance that the results obtained are consistent and conservative.

2.7.1 9 Meter Free Drop

The staff requested the applicant to utilize the same methodology than the one used for previously approved packages, i.e., the Classical Dynamics Method and the LS-DYNA non-linear Finite Element Analysis (FEA) approach. Results from such independent analyses are meant to provide additional reasonable assurance that the methodologies are sufficient to demonstrate the safety margin of the package under the 9 meter HAC drop conditions for this class of problems.

The peak deceleration results produced by these two independent methodologies globally demonstrate that each method is a reliable predictor of the average peak deceleration for the narrow class of problems for which they are applied; however, LS-DYNA has superior capabilities in capturing, with overall more details, the deceleration time history characteristics.

In previous analyses, the staff observed that discrepancies still existed between the Classical Dynamics Method and the LS-DYNA approach, e.g., an initial high amplitude deceleration spike

occurring early in the simulation and corresponding to the rotation of the Impact Limiter (IL), and the failure of the Fastener Strain Limiter (FSL). Further to staff's question as to why the analyses performed for the Model No. HI-STAR 180 package show no such spike, the applicant responded that the IL steel skirt for the Model No. HI-STAR 180 package is both longer and tighter fitting than in other designs submitted by the applicant, thereby engaging a larger portion of the package geometry axially. Such differences in the design mitigate the IL rotation, thereby eliminating the deceleration spike early in the deceleration time history.

Staff reviewed the modeling methodologies, calculation packages, results from the dynamic and quasi-static evaluations, and comparisons with allowable stresses. Staff also verified values obtained from the analytical models by reproducing reported data and associated plots showing deceleration time histories, stress contours, and deformed and un-deformed configurations of the package Finally, the staff verified that the energy balances for each of the drop scenarios are consistent with good practice in explicit dynamics finite element analysis.

The analytical modeling in aggregate satisfies the requirements of 10 CFR 71 73(c)(1)

2.7.2 Crush

This evaluation is not applicable due to the package mass exceeding 500 kg (1100 lbs) per 10 CFR 71.73(c)(2).

2.7.3 Puncture

The applicant performs two independent analyses of the puncture event at two locations on the Model No. HI-STAR 180 package, i.e., (i) an analytical approach using the FEA approach with the LS-DYNA code, (ii) a method utilizing a strength of materials approach in which the strain energy required to shear a plug of material from a rigid plate is calculated and compared with the analytical result.

The applicant concludes that (i) the bolted joints maintain their integrity, (ii) no through wall penetration occurs in the shielding components or containment boundary, (iii) all stress levels remain below ASME Level D allowable stress limits, and (iv) the monolithic shield cylinder does not exhibit through wall cracks. The applicant reports a factor of safety greater than one for the lid puncture event and a factor of safety greater than eleven for the side puncture event.

When evaluating the initial submission of the side drop puncture event, the staff requested an explanation of the nonphysical deformation of the impact bar, which was shown to fracture and subsequently pass through the remaining fixed cylinder. The applicant responded that the deficiency was the result of an incorrectly defined "contact condition" and resubmitted a new analysis, which employed an eroding self-contact algorithm to prevent the nonphysical deformation from occurring. The erosion detected in the impact pin in the previous simulation is initially observed at the top and bottom edges of the contact interface (edges first contacting with the monolithic cylinder) where the elements are overstressed due to edge effect. The erosion further extends to other periphery surface elements of the impact pin until the conformal contact between the monolithic cylinder and the impact pin is established. Once the conformal contact is established, the center elements beneath the impact pin contact surface fail due to excessive shear stress. Unlike the LS-DYNA simulation result, erosion of material might not happen in a real puncture test even though the effective stress exceeds the failure limit (leading to surface cracks and even cracks below contact surface). The applicant performed an additional simulation in which no failure strain is specified in the puncture bar material model,

and results from the new simulation indicate no erosion on the impact pin, which is consistent with the new material definition. The new simulation also indicates that the predicted damage on the impacted monolithic cylinder surface is significantly reduced if the impact pin elements are not allowed to erode. Only a few elements on the monolithic cylinder erode along the edge of the contact interface due to contact edge effect (i.e., stress concentration). Significant failure, on the other hand, was observed on the monolithic cylinder in the previous simulation, since the impact pin elements erosion effectively reduced the overall contact area.

Staff evaluated the analyses presented by the applicant for both the transient dynamic finite element approach and the strength of materials approach and found that overall, the results presented support the safety basis made by the applicant relative to the puncture drop event. The requirements of 10 CFR 71.73(c)(3) are met.

2.7.4 Thermal

The applicant utilizes temperature information from the evaluated fire event to determine the effects on the structural integrity of the package and concludes that:

(i) the metal temperature averaged across any section of the containment boundary remains below the maximum allowable temperature for Level A conditions for ASME NB components,

(ii) the outer surface of the package directly exposed to the fire does not slump,

(iii) internal part interferences do not occur due to differential thermal expansion both during and after the fire event, and

(iv) the cask closure lid bolts do not unload leading to a reduction of compression load on the gasketed surfaces.

The staff reviewed the evaluation presented by the applicant and found the reasoning and conclusions credible; therefore, the requirements of 10 CFR 71.73 (c)(4) are met.

2.7.5 Immersion - Fissile

This requirement is bounded by the deep water immersion requirement; therefore, the requirements of 10 CFR 71.73(c)(5) are met.

2.7.6 Immersion - All Packages

This requirement is bounded by the deep water immersion requirement; therefore, the requirements of 10 CFR 71.73(c)(6) are met.

2.7.7 Deep Immersion

The applicant utilizes ASME Code Case N-284 to evaluate the buckling response due to deep immersion in water. The staff agrees that this evaluation is adequate and that the requirements of 10 CFR 71.61 are satisfied with respect to stress limits and stability requirements.

As stated in the "General Information," "Structural Evaluation," "Shielding Evaluation," and "Criticality Evaluation" sections of this report, the package design has been evaluated by staff as

ensuring Moderator Exclusion by complying with the "intent of ISG-19. The package design includes two closure lids with each lid being individually designated as a containment boundary. Both the inner and outer lid feature two concentric annular metallic seals each, thus providing a total of four independent barriers against leakage.

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

The staff finds that the package containment space will remain inaccessible to the moderator under the immersion event of 10 CFR 71.73, which follows the free drop, puncture and fire events. The staff considers that the package design ensures that in-leakage of water through the containment system boundary seals is a non-credible event. The staff finds that the double lid closure system with each bolted lid joint being engineered to meet the leaktight criterion of ANSI N14.5 under all NCT and HAC conditions of transport, ensures moderator exclusion by complying with the "intent" of ISG-19.

The staff has reasonable assurance that the package meets all acceptance criteria given in Section 2.1 above under the immersion condition.

2.8 Fuel Rods

The applicant adopted a single pin analytical model, developed by Pacific Northwest National Laboratory (PNNL) and used in NUREG-1864, "A Pilot Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant," to determine the strain ductility demand that a typical fuel pin may be subject to during a 9 m HAC drop. The model was constructed with shell elements for the fuel cladding, internal springs to prevent ovalization of the cladding, springs to represent spacer grids, a cask-fuel pin spring, a cask-ground spring representing the behavior of the impact limiter. In two cases, the applicant evaluated a no gap condition to represent a typical design basis case and a 20 mm gap to simulate the maximum available gap. The applicant also included internal pressure to ensure that all realistic loadings were considered.

The applicant utilized a lower bound strain ductility acceptance criteria of 1.7 percent which is below the range of values that have been published for high burnup fuel. The applicant developed several distinct models, as follows:

Model 1: Benchmark model to simulate PNNL model and verify that the analytical methodology is acceptable.

Model 2: Modified Model 1 with parameter changes to reflect the design basis fuel in the Model No. HI-STAR 180 package. The model incorporates zero gap between the end of the fuel rod and the cask spring and no internal pressure.

Model 3: Upper bound model identical to Model 2, but a 20 mm gap is incorporated between the end of the fuel rod and the cask-rod spring and an upper bound FIA.

Model 4 Lower bound model identical to Model 3, but a 200 mm gap is incorporated between the end of the fuel rod and the cask-rod spring and a lower bound FIA.

Model 5: Impact only model identical to Model 3, but a 200 mm gap is incorporated between the end of the fuel rod and the cask-rod spring. No FIA and no pressure are included.

A review of the results illustrates that Model 1 is effective at reproducing results obtained by the NRC and PNNL. This gives reasonable assurance that the principle structural behavior is being correctly modeled. Results for the remaining models illustrate that the strain ductility demand for all cases are below the acceptance criteria limit of 1 7 percent strain with a minimum factor of safety greater than one.

2.9 Evaluation Findings

Due to the fact that no direct physical testing was performed for the Model No. HI-STAR 180 package, the staff indicated to the applicant that utilizing the "Classical Dynamics Method" previously approved for the Model No. HI-STAR 100 package in conjunction with the use of LS-DYNA computational modeling would provide a reasonable assurance that the Model No. HI-STAR 180 package would function as intended. The applicant performed Classical Dynamics simulations using the upper bound strength values for the impact limiter crush material because the use of such values maximizes the peak cask decelerations. The results were similar to what was previously observed for the Model No. HI-STAR 60 package, i.e., the peak decelerations predicted by LS-DYNA for the end, side, and CGOC drop orientations bound the results from the Classical Dynamics Method by a significant margin. This confirms the conclusion reached in the Model No. HI-STAR 60 application that LS-DYNA is a valid method for predicting rigid body cask decelerations.

The staff requested the applicant clarify the maximum distance that a center fuel pin can deform assuming that all pins deform identically in the in-plane direction. The applicant had initially defined a design limit for maximum fuel basket panel deformation of 0.5 mm, in addition to material and manufacturing tolerances that were also considered in the criticality analysis, to decouple the criticality from the structural analyses; further to staff's clarification request, the applicant revised the expression of the basket panel deformation criterion and the maximum total deflection at any point along the panel width (relative to the panel supports) must not now exceed 1 mm. Such a limit is more restrictive than the previous one because the allowable limit is now defined in terms of the total (plastic and elastic) deflection and the limit is now placed on the maximum deflection at any point along the width of the panel basket as opposed to the average deflection over the width of the panel. Also, the deflection-based criterion is more conservative than the ASME Code stress intensity limits.

The applicant clarified that the fuel basket panel deformations due to an end drop are bounded by the results for the 9-meter side drop. The staff requested that the applicant provides a sensitivity study showing that thick shell elements perform similarly to solid elements when predicting the structural performance of Metamic-HT under axial and lateral dynamic or quasi-static loads. Further to staff's request, the applicant provided comparison tables, for clarity and information purposes, showing the relative component stresses, strains, and deformations obtained from ANSYS static and LS-DYNA dynamic simulations.

The applicant explained why the 9 meter side drop deceleration time history was not influenced by FSL failure, as was the case for the Model No. HI-STAR 60 package evaluation. The applicant revised the LS-DYNA benchmark model to incorporate staff's observations made during the review of the Model No. HI-STAR 60 package application (Docket No. 71-9336). In particular, the spring rates for all contact springs were reduced by a factor of 2 in accordance with the half-symmetric fuel rod model and the lateral clearance between the fuel rod outside diameter and the compartment wall was increased from 0.998 inch to 1.17 inch to match the PNNL model.

The applicant provided an analysis for the vent and drain port cover bolts to confirm that the seals do not unload during NCT and HAC. The staff found that the double lid closure system, with each lid being independent and maintaining its prescribed leak-tightness under HAC conditions, ensures moderator exclusion by complying with the "intent of" ISG-19. The staff considers that the package design ensures that in-leakage of water through the containment system boundary seals is a non-credible event and the staff has reasonable assurance that the package meets all acceptance criteria given in Section 2.1 above under the immersion condition.

The applicant provided data to quantify the performance and characteristics of Metamic-HT in a manner somewhat emulating that of an ASTM/ASME material, but with several deviations from normal ASME Code practice (which the staff uses as a benchmark). One deviation is the establishment of the "minimum guaranteed value" (MGV) for various properties. The MGV values adopted by the applicant differ from the "stress allowable" used by the ASME Code. The Code "stress allowable" is directly used for stress-based design calculations. The applicant's MGV data is primarily used as the Metamic-HT material production QA/QC acceptance criteria. Consequently, a direct comparison of "stress allowable" with MGV's is not valid. A second major deviation in Metamic-HT performance from normal ASME Code requirements is the reduced weld strength. The Code does not permit welds of a lower strength than the base material. The applicant recognized this characteristic and specified weld use only in low stress areas. However, since the basket is a strain-based design, the "stress allowable" method becomes immaterial and the adequacy of the welds must be evaluated by means of the structural strain analysis. As determined from the structural analysis (and discussed in this chapter), the welds were found to provide an adequate margin of safety for their specific application. The third deviation from Code practice involves the creep test data. Code practice is to creep test materials to failure. The Metamic-HT creep testing program never took a sample to failure. Thus, the data is "incomplete" in the sense that failure creep strain and ultimate time to failure is not determined. However, the applicant has adequately demonstrated that the Metamic HT will easily perform without failure for well beyond the license period (5 years) for a transportation package. No safety significant issue results from the "incomplete" creep test data, even when license re-validation is considered for a total service life of as much as 40 years. Thus, the staff finds that (i) the creep test data easily bounds the normal 5 year license period of the package, (ii) Metamic-HT has adequate creep properties for the intended application and well beyond, as demonstrated by the creep life calculation, and (iii) it has reasonable assurance that Metamic-HT will not experience significant creep rates in transport applications.

The applicant provided Revision No. 2 to the Qualification Sourcebook incorporating major changes largely prompted by the staff's review. In particular, additional coupons tested were added to the respective data tables to broaden the data base for all properties; the coupons data includes separate data sets of up to 30 coupons each for as-extruded as well as thermally aged and irradiated coupons at different temperatures; the use of the statistical approach (mean

minus two sigma has been discontinued in favor of a more conservative approach. Now the MGV is required to be less than the "Minimum Measured Value" of the property from the entire batch of data in the database to eliminate concerns of data scatter and lot-to-lot variability design criteria for structural reliance of Metamic-HT in fuel basket applications have been added to the Sourcebook and a justification provided for the dimensionless maximum lateral deflection in fuel baskets utilizing Metamic-HT panels in lieu of ASME based code stress limits; the production sampling plan has been expanded to establish the link between in-production testing and the required level of reliability of the material's property; the data on thermal diffusivity, which is a derived property, has been replaced by specific heat, which is a fundamental material property; and creep data on the coupons has been updated. The cumulative creep after 40 years of transport in the Model No. HI-STAR 180 package (in an horizontal configuration so that the basket is loaded by the fuel's dead weight) is only about 0.109 percent, thus providing reasonable assurance that Metamic-HT will not experience significant creep rates in transport applications. Results of the structural analysis of the basket show that the Metamic-HT welds have a safety factor of 3.65 against failure under HAC conditions.

On the basis of the review of the Metamic-HT Sourcebook, Revision No. 2, the applicant s responses and the statements and representations in the application, the staff concludes that the package is adequately described and evaluated to demonstrate that its structural capabilities meet the requirements of 10 CFR Part 71. The data contained in the Metamic-HT Sourcebook is accepted by the NRC staff only for the HI-STAR 180 package application to the extent that it has been used to make a safety determination. Because of deficiencies in the contents of the Sourcebook with respect to materials characterization, the Sourcebook is not sufficient by itself to make a safety determination for Metamic-HT.

3.0 THERMAL REVIEW

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

3.1 Description of the Thermal Design

3.1.1 Packaging Design Features

The design criteria for the Model No. HI-STAR 180 package cover both NCT and HAC conditions (fire). To provide adequate heat removal capability, the Model No. HI-STAR 180 package is designed with the following design features:

1. Helium backfill gas for heat conduction which also provides an inert atmosphere to prevent spent fuel cladding oxidation and degradation.

2. Minimum heat transfer resistance through the basket by fashioning the basket like a honeycomb structure that is welded completely from the basket base to the top.

3. Top and bottom plenums for transverse flow of helium gas aiding in convective heat transfer. Buoyancy-induced convective heat transfer is enhanced by low pressure drop flow passage within the open space of cask cavity.

4. Continuous axial metal heat conduction provided by the basket structure

5. Flexible aluminum heat conduction elements for heat transfer from the basket periphery to the primary containment shell

The staff verified that all methods of heat transfer internal and external to the spent fuel basket and outer cask are appropriate. Drawings in Section 1.3 of the application with the material properties in Tables 3.2.1 through 3.2.9 of the application provide sufficient detail for the staff to perform an in-depth evaluation of the thermal performance of the entire package

3.1.2 Codes and Standards

Appropriate codes and standards are referenced by the applicant throughout the application

3.1.3 Content Heat Load Specification

The Model No. HI-STAR 180 package design includes two baskets i.e., F-32 and F-37, for the transport of 32 and 37 PWR spent fuel assemblies, respectively. The package decay heat limits are understated to limit radiation dose from hot (short cooled) spent fuel. This is accomplished by specifying fuel loading patterns in compliance with both the decay heat and burnup limits of Tables 1.2.8 and 1.2.9 of the application for the F-32 and F-37 baskets, respectively. Fuel loading can be done under uniform and regionalized loadings. The total heat load under all transport configurations is limited to 32 kW.

The thermal loads are different for NCT and HAC: the surface thermal load (combustion heat) is external during a fire accident, while the surface thermal load (insolation) is applied continuously during normal conditions of transport.

The staff reviewed all the external heat loads into the package. These heat loads are expected and acceptable.

3.1.4 Summary Tables of Temperatures

The summary tables of the package component temperatures, i.e., Tables 3.1.1 and 3.1.3 of the application, were verified. The components include spent fuel cladding, spent fuel basket, containment shell, neutron shield, cask surface, impact limiters, primary closure lid, secondary closure lid, containment base plate, primary and secondary lid seals, and aluminum basket shims. The temperatures are consistently presented throughout the application for both NCT and HAC conditions. For HAC, the applicant presented the pre-fire, during-fire, and post-fire component temperatures. With the exception of the impact limiters and neutron shield, all components remain below their material property limits listed in Table 3.2.10 to 3.2.12 of the application. The temperatures and design temperature limits for the package components were reviewed and found to be consistent throughout the application.

3.1.5 Summary Tables of Pressures in the Containment System

The summary tables of the containment pressure under NCT and HAC, i.e., Tables 3.1.2 and 3.1.4 of the application, were reviewed and found consistent with the pressures presented in the General Information, Structural Evaluation, and Containment Evaluation chapters of the application. These tables report the Maximum Normal Operating Pressure (MNOP) for NCT and HAC (fire).

3.2 Material Properties and Component Specifications

3.2.1 Material Properties

The application provides material thermal properties such as thermal conductivity, density, and specific heat for all modeled components of the package. The staff finds these properties acceptable. The applicant specifies the natural convection heat transfer coefficient as a function of the product of Grashof and Prandtl numbers This product is a function of length scale, surface-to-ambient temperature difference, and air properties. Regarding the thermal stability and radiation resistance of the neutron shield material, Holtite®-B, the applicant states that a qualification testing was conducted to confirm that Holtite®-B would not degrade at elevated temperature and would not be affected by high neutron fluence and megarad gamma doses. The staff accepted the qualification testing based on the test conditions and the computed weight loss of 2.6 percent after 40 years of simulation. The thermal properties used for the analysis of the package are appropriate for the materials specified and for the package conditions required by 10 CFR Part 71 during NCT and HAC

3.2.2 Technical Specifications of Components

The package materials and components are summarized in Chapter 2 and Chapter 3 of the application. These materials are required to be maintained below maximum pressure and temperature limits for safe operation. The staff reviewed and accepts these specifications.

3.2.3 Thermal Design Limits of Package Materials and Components

Maximum pressure and temperature limits of package materials and components are provided by the applicant. The staff verified that they are used consistently in the application. The applicant states that components and materials would not degrade under an extreme low temperature of -40°C. The application also describes the long-term stability of Holtite®-B under NCT and the leak tightness of the closure lids through the use of metallic seals. Neutron absorber stability for temperatures exceeding 538°C is discussed. Peak cladding temperature compliance for moderate and high burnup spent fuel is demonstrated.

The staff reviewed and confirmed that the maximum allowable temperatures for components critical to the package containment, radiation shielding, and criticality are specified. The staff verified that the design basis spent fuel cladding temperature of 570°C for accident conditions is observed. This temperature limit is based on the Pacific Northwest National Laboratory report, PNL-4835, which is a methodology accepted by the staff.

3.3 Thermal Evaluation Methods

3.3.1 Evaluation by Analyses

A detailed three dimensional (3-D) thermal model of the Model No. HI-STAR 180 package system was developed by the applicant using Fluent finite volume and ANSYS finite element codes. Transfer of heat from the spent fuel assemblies to the environment is through heat conduction from spent fuel through the spent fuel basket, the helium gap, the aluminum shim, the primary containment shell, and the enclosure neutron shield. The spent fuel assembly is modeled through the effective thermal conductivity (K_{eff}) approach (i.e. modeling the detailed spent fuel assembly geometry and gaps between spent fuel rods as a uniform medium with

equivalent thermal conductivity under different temperature conditions. Heat rejection from the cask surface to the ambient is modeled by including natural convection and thermal radiation heat transfer from the vertical and top cover surfaces. Solar heat is included by adding a volumetric heat source in the thin layer of the outer shell to comply with the regulations. The staff finds the overall analysis approach and assumptions acceptable.

For NCT, the maximum bounding cladding temperature is obtained for the F-32 basket under the pattern A/B heat load. The steady-state analysis produces a maximum cladding temperature of 314°C which is below the allowable limit of 400°C. For HAC, the analysis shows a maximum cladding temperature of 352°C occurring during the post-fire cool down. This is below the allowable limit of 570°C for accident conditions.

The staff also reviewed all component temperature limits and maximum temperatures. All the maximum temperatures comply with the temperature limits for both normal conditions of transport and accident scenario.

3.3.2 Evaluation by Tests

The first fabricated HI-STAR 180 unit shall be thermally tested to confirm its heat transfer capability. Section 8.1.7 of the application provides a basic description of the testing sequence and the condition for its acceptability.

For each package, a periodic thermal performance test is also performed at least once within the 5 years prior to each shipment to demonstrate that the thermal capabilities of the package remain within its design basis.

3.3.3 Temperatures

See Section 3.1.4

3.3.4 Pressures

See Section 3.1.5

3.3.5 Thermal Stresses

Thermal stresses are evaluated in Section 3.4.4 of the application. The applicant uses high conductivity materials to minimize temperature gradients and large fit-up gaps to allow unrestrained thermal expansion of the cask internals during NCT. The differential thermal expansion is evaluated in Section 7.4 of the Holtec Report No. HI-2073649 "Thermal Analysis for HI-STAR 180." Basket-to-cavity radial and axial growths are evaluated based on the thermal expansion coefficients at the worst conditions. The evaluation results are presented in Table 3.4.2 of the application. For HAC fire conditions, the gap growth in the radial and axial directions is bounded by the NCT.

The methods presented are standard and the evaluation is done under the worst operating conditions. The results show adequate margin to exclude safety concern. The staff finds the evaluation methods acceptable.

3.3.6 Confirmatory Analyses

The staff reviewed the applicant's thermal models used in the analyses. The staff checked the code input in the calculation packages and confirmed that the proper material properties and boundary conditions are used. The engineering drawings were also consulted to verify that proper geometry dimensions were translated to the analysis model. The material properties presented in the application were reviewed to verify that they are appropriately referenced and used.

The staff performed Fluent sensitivity calculations for the peak cladding temperature based on the thermal model provided by the applicant. Seventeen test cases were conducted to cover the following areas:

1. The bounding configuration (F-32 loading pattern A and B) peak cladding temperature for NCT.

2. Selective F-32 and F-37 loading configurations to confirm the temperature trends.

3. Radiation model used Discrete Ordinates (DO) Method vs. Discrete Transfer Radiation model (DTRM).

4. Confirmation of DTRM using different model options.

5. Increase of heat load by 10 percent.

6. Increase gap between basket and aluminum shim to 8 mm.

7. Decrease spent fuel Keff by 25 percent.

8. Confirm F-32 basket fire and post-fire cool down analysis.

9. Increase heat transfer coefficient in HAC condition by 25 percent.

10. Establish worst scenario of added heat load (10 percent additional), increased gap distance (8 mm), and 25 percent reduced spent fuel K_{eff}.

The following table shows the comparison of predicted peak cladding temperature (PCT) between the applicant's and the staff's sensitivity analyses:

Table 3-1

PCT Comparison

Test Number	Description	Holtec PCT (°C)	NRC PCT (°C)
1	NCT F-32, A/B load, DTRM NOK32-3D-7f.cas	314	315.9
2	NCT F-32, 2KW on periphery NOK32-3D-2KW-periphery.cas	286	288.4
3	NCT F-32, uniform heat load NOK32-3D-Unif.cas	290	293.6
4	NCT F-32, DTRM NOK32-3D-7f.cas	314	318.3 (no Radiation)
5	NCT F-32, A/B load, DTRM NOK32-3D-7f.cas	314	315.5 (DTRM modified Ntheta=4, Nphi=4)
6	NCT F-37, A/B load, DTRM NOK37-3D-9f.cas	305	308.0
7	NCT F-37, uniform heat load NOK37-3D-Unif.cas	287	289.4
8	NCT F-37, C load NOK37-3D-10f.cas	302	304.6
9	NCT F-32, 110% heat load NOK32-3D-7f.cas	N/A	338.6
10	NCT F-32, 75% Keff NOK32-3D-7f.cas	N/A	322.5
11	NCT F-32, 8 mm shims-to-basket gap NOK32-3D-7f.cas	N/A	336.5
12	NCT F-32, DORM NOK32-3D-7f-DO.cas	314 ±1	315.0
13	NCT F-32, 110% heat load , 75% Keff , 8 mm shims-to-basket gap NOK32-3D-7f-integral.cas	N/A	367.8
14	HAC F-32, 30 min fire NOK32-3D-7f-fire.cas	687 for cask surface 314 for PCT	657.5 for cask surface 315 for PCT
15	HAC F-32, post-fire cooldown NOK32-3D-7f-postfire.cas	687 for cask surface 352 for PCT	657.5 for cask surface 347 for PCT
16	HAC F-32, 125% heat transfer , 30 min fire NOK32-3D-7f-fire.cas	N/A	665.2 for cask surface 315 for PCT
17	HAC F-32, 125% heat transfer , post-fire cooldown NOK32-3D-7f-postfire.cas	N/A	665.2 for cask surface 347.7 for PCT

For NCT, the staff confirmed that the F-32 basket with the A/B heat load pattern proposed by the applicant is the bounding configuration based on the trends and maximum cladding

temperature values. The staff also confirmed that the use of the DO radiation model resulted in approximate values as compared to the DTRM radiation model. A combined analysis with a 10 percent additional heat load, a 25 percent reduction of K_{eff} and a 8 mm shim-to-basket gap size showed that the maximum cladding temperature (368°C) is still below the allowable limit (400°C). Based on the applicant's predicted results and own sensitivity study, the staff has reasonable assurance that, even with a conservative combination of input parameters aimed to predict higher temperatures, the calculated peak cladding temperature will still remain below allowable limits.

For fire analysis and post-fire cooldown, the staff confirmed both calculations (Tests 14 and 15 of Table 3-1 of this SER). Due to time constraints, the staff used a larger time step in the transient calculation and ensured that the larger time step does not result in significant differences. The results showed that Holtec's PCTs are more conservative than the staff's calculated values. The difference is mainly due to different radiation models, i.e., DO vs. DTRM. With a 25 percent higher convective heat transfer coefficient (Test 16 and 17), the maximum cladding temperature increases 1°C (Test 16, during the 30-minute fire) and 34°C (Test 17, for the post-fire cool down process) and is well below the allowable limit. The staff has reasonable assurance that the temperatures are lower than the regulatory and material limits.

3.4 Evaluation of Accessible Surface Temperature

Under NCT, the package is designed and constructed such that the surface temperature is 105°C, with the design basis heat load and no solar insolation. This temperature is above 85°C specified in 10 CFR 71.43(g) requirements. According to section 7.1.3 of the application, a personnel barrier is installed if the package surface temperature and the dose rates are within 10 CFR 71.43 and 10 CFR 71.47 requirements.

3.5 Thermal Evaluation under Normal Conditions of Transport

The applicant performs the thermal evaluation using the Fluent Computational Fluid Dynamics (CFD) code. The 3-D models were developed to analyze the F-32 and F-37 spent fuel baskets and various heat loading patterns, i.e., uniform and regionalized, were experimented to establish a bounding configuration. The bounding configuration conservatively assumes high heat high gamma dose UO_2 fuel in the interior cells and high heat low gamma dose MOX in the Region 1 peripheral fuel locations. Inside a spent fuel cell, the detailed PWR spent fuel assembly is replaced with an equivalent square section characterized by an effective thermal conductivity in the planar and axial directions.

The temperature dependent thermal conductivities are obtained using a two dimensional conduction-radiation ANSYS model. The turbulent condition is satisfied based on the product of Grashof and Prandtl numbers and a temperature difference of about 10°F between the package surface and the ambient. Therefore, applicable turbulent heat transfer coefficient correlations are chosen to model the cask convective heat transfer to the ambient. For solar heating, the applicant used the 12-hour daytime insolation, as specified in 10 CFR Part 71, averaged over a 24-hour period to account for the dynamic time lag. A solar absorption coefficient of 1.0 is applied to the cask exterior surface.

The HI-STAR 180 package 3D thermal model includes several features to conservatively predict the maximum temperature, e.g., a half-symmetric array of fuel storage cells, a uniform gap between the fuel rods in the basket cells, 4 mm helium gaps for shims-to-basket and shims-to-cavity, detailed 3-D components (i.e., neutron shield pockets, lids, base plates, impact limiters,

etc., no internal convection in cask cavity, and both DO and DTRM radiation models. The applicant also used an adequate number of cells to model the cask, particularly in the areas of high thermal resistance, i.e., spent fuel region and basket shims. The staff finds the approach acceptable.

3.5.1 Heat

Under a 38°C ambient temperature, still air, and solar heat, the applicant predicted the maximum temperatures of the fuel cladding, fuel basket, containment boundary and lid seals, and aluminum basket shim and neutron shielding. These temperatures are listed in Table 3.1.1 of the application. The staff confirms that these maximum temperatures are below the material temperature limits with sufficient margin and find them acceptable.

3.5.2 Cold

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

3.5.3 Maximum Normal Operating Pressure (MNOP)

The MNOP is determined by different sources of gases – initial backfill helium, water vapor, release of fission products, and spent fuel rod failures. Generation of flammable gas is not considered. Based on the heat condition, 38°C, still air, and insolation specified in 10 CFR 71.71(c)(1) and the design heat load, the MNOP is 67.6 kPa for normal conditions and 89.6 kPa for 3 percent rod rupture. The MNOP is well below the containment design pressure of 552 kPa, as reported in Table 2.1.1 of the application.

3.6 Thermal Evaluation for Short Term Operations

3.6.1 Time-to-Boil Limits

The applicant determined time limits for completion of wet operations upon removal of a loaded Model No. HI-STAR 180 package from the pool to prevent water boiling inside the cavity. The applicant performed an adiabatic heat up using the combined thermal inertia of the package. Table 3.3.5 of the application provides a summary of the maximum allowable time limits at several representative pool initial temperatures. To verify the time limits based on the adiabatic heat up approach, the applicant performed a CFD analysis using the design basis decay heat and the bounding heat load pattern. The applicant's CFD results confirmed that the approach outlined in the application is conservative. The applicant made the following assumptions in the time-to-boil confirmatory analysis: design basis heat load is used, internal convection is neglected, bulk temperature of water is computed based on the fuel storage cells relative to the downcomer spaces, and radiation heat transfer through water is disabled.

The staff questioned the applicant's assumptions of neglecting internal convection and disabling radiation heat transfer in the cask cavity since it would appear that such assumptions would result in non-conservative water temperatures. The staff performed additional analyses to confirm the applicant's assumptions. From the staff's confirmatory analyses, it appears that an increase in the bulk temperature of water would be negligible when radiation heat transfer is used. The staff also confirmed that allowing internal convection in the package would aid in decreasing the bulk temperature of water. The staff also verified that calculating the bulk

temperature of water based on the fuel cells and the empty spaces of the cask would result in higher temperatures. Based on the application and the applicant's response to staff's Request for Additional Information, the staff finds the applicant's approach for obtaining the time-to-boil limits acceptable for this package application.

3.6.2 Cask Drying

The application provides two methods for drying the cask cavity: a conventional vacuum drying approach for packages containing moderate burnup assemblies only, and forced helium dehydration (FHD) for packages with high burnup fuel.

Table 3.3.6 of the application presents the maximum fuel cladding temperature of 485°C, under vacuum drying operations, which is below the ISG-11 limit with adequate margin.

The enhanced heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain well below the peak cladding temperature under NCT, which is itself below the high burnup cladding temperature limit of 400°C for all loading combinations authorized in the package. Thus, the fuel cladding temperature will remain below the ISG-11 limits for high burnup fuel.

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

3.7 Thermal Evaluation under Hypothetical Accident Conditions

The applicant performed the regulatory fire analysis using a 3-D Fluent model of the limiting F-32 basket thermal loading in two stages: a 30-minute engulfing fire and a post-fire cool down.

The accident scenario considers the cumulative damage from the drop test and penetration test. Localized crushing of the impact limiter and rupture of neutron shield pockets are considered by maximizing the heat input during the fire and minimizing the heat rejection in the post-fire analysis. To maximize the fire heat input, the neutron shield conductivity is overstated and impact limiters are assumed to be solid aluminum. To minimize the heat rejection during the post fire cooldown, the neutron shield and impact limiters are replaced by air and surface emissivity of bare carbon steel is assumed. The analysis simulates the engulfing fire by prescribing a combination of radiation and convection heat transfer on the cask surface. The Sandia National Laboratory fire experiment convection heat transfer coefficient is adopted for the calculation ("Thermal Measurements in a Series of Large Pool Fires," Sandia Report SAND85 –0196 TTC – 0659 UC 71, August 1971). The ambient temperature during the fire is set at 802°C.

3.7.1 Initial Conditions

The applicant performed a transient thermal analysis to evaluate the package under hypothetical accident conditions. The initial conditions of the package, prior to the start of the fire accident, are based on the bounding NCT temperature distribution, i.e., a 38°C ambient temperature and the insolation prescribed in 10 CFR 71.71(c)(1).

During the fire, the surface emissivity of the package is assumed to be 0.9. After the 30-minute fire, the 38°C ambient temperature is restored and the damaged cask is allowed to proceed through a post-fire cooldown phase. In the post-fire cool down phase, no credit is taken for

conduction through the Holtite's neutron shield and a solid air zone is substituted instead. The ending condition of the 30 minute fire analysis is used as initial condition for the post-fire cooldown.

3.7.2 Maximum Temperatures and Pressure

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

Under normal conditions, all of the materials remain below their respective melting temperatures. For accident conditions, all of the materials, with the exception of the aluminum impact limiter and the neutron shield, remain below their respective materials temperature limits. Although the impact limiter was shown to exceed its limit, the applicant assumed the material did not melt during the fire thus maximizing the amount of heat to have entered the package. Even though the neutron shield fails during the fire accident, the dose rates are shown to remain below the regulatory limit of a total dose of 10 mSv/hr at one meter, which is accepted by the staff. Based on these analyses and review, the staff has reasonable assurance that the cladding integrity will not be compromised during the fire or post-fire cool down.

The applicant calculated the MNOP assuming that 100 percent of the fuel rods fail, all rod fill gas and 30 percent of the gaseous fission products are available for release. The lower bound cavity free volume is used. The MNOP under HAC is 883.7 kPa, based on the average cavity gas temperature of 270°C. The MNOP is lower than the pressure limit listed in Table 2.1.1 of the application and therefore is acceptable.

3.7.3 Maximum Thermal Stresses

The Model No. HI-STAR 180 package is designed to ensure a low state of thermal stress with high conductivity materials to minimize temperature gradient and large fit-up gaps to allow unrestrained thermal expansion of cask internals. The differential thermal expansion analysis of the basket during NCT transport bounds the fire condition because the thermal effect on the basket is isolated by the outer cask and more expansion is expected in the outer cask. Therefore, the gap is expected to be larger in the fire analysis. The staff reviewed and accepted this argument.

The staff finds the applicant's analysis of HAC acceptable.

3.7 Evaluation Findings

The staff requested that (i) all material properties used for the package thermal evaluation be listed in the application, (ii) thermal properties used to perform the thermal evaluation be consistent with the properties provided in the application, and (iii) a confirmatory CFD Time To Boil analysis be performed in addition to the adiabatic heat-up analysis method.

The confirmatory CFD analysis computed that the boiling temperature would be reached in 19 hours versus 13.4 hours calculated by the adiabatic heat-up analysis methods, thus providing additional assurance that the adiabatic heat-up method used in the application is conservative.

The applicant clarified that the 0.8 mm thermal total gap is modeled in the radial direction and that the gap is evenly split with 0.4 mm contact resistance on each side of the intersection basket panel. The applicant also clarified that the fuel basket design and manufacturing process ensures a panel-to-panel connectivity and that there is contact between any two stacked Metamic-HT panels. The applicant performed a sensitivity study using the Fluent Code to determine the effect of an axial gap of 0.5 mm at every panel to panel interface. The applicant demonstrated that the fuel cask component temperatures are insensitive to axial gaps.

The staff requested the applicant to revise the fire and post-fire analysis of the package using an emissivity of 0.8 or greater for all surfaces exposed to the fire. The applicant revised the fire analysis using a cask emissivity of 0.85 (before fire), a flame emissivity of 0.9 (during fire) and a cask emissivity of 0.66 (after fire). In addition, to comply with staff's request, the revision of the fire analysis included changes to the surface characteristics of the polished impact limiter as follows: emissivity of 0.11 and absorptivity of 0.42, in alignment with the approved Model No. HI-STAR 60 package application (Docket No. 71-9336).

The staff also requested the applicant to calculate the MNOP for the package inter-lid space and to revise the seals defined as part of the containment boundary, i.e., the containment boundary seals are the inner closure lid inner seal, the vent/drain port cover plate inner seal, the outer closure lid inner seal, and the access port plug seal. Tables 3.1.1 and 3.1.3 of the application were also revised to include the temperature of the containment boundary seals.

The staff reviewed the package description, the material properties, component specifications and the methods used in the thermal evaluation, and found reasonable assurance that they are sufficient to provide a basis for evaluation of the package against the thermal requirements of 10 CFR Part 71. The staff reviewed the accessible surface temperatures of the package as it will be prepared for shipment and found reasonable assurance that the temperatures satisfy 10 CFR 71.43(g) for packages transported by exclusive-use vehicle. The staff reviewed the package preparations for shipment and found reasonable assurance that the package material and component temperatures will not extend beyond the specified allowable limits during normal conditions of transport, consistent with the tests specified in 10 CFR 71.71. The staff also found reasonable assurance that the package material and component temperatures will not exceed the specified allowable short-time limits during hypothetical accident conditions, consistent with the tests specified in 10 CFR Part 71.

4.0 CONTAINMENT REVIEW

The objective of the review is to verify that the Model No. HI-STAR 180 package containment design is adequately described and evaluated under NCT and HAC, as required per 10 CFR Part 71.

4.1 Description of the Containment System

The containment system components are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NB, to the maximum extent practicable. Section 2.1 of the application provides applicable Code requirements and alternatives to specific Code requirements are presented in Table 2.1.14 of the application.

The containment system boundary consists of the SA203-E or SA350-LF3 containment shell and containment baseplate, the SA350-LF3 containment closure flange, the SA203-E or SA350-LF3 inner closure lid (and subcomponents), and the SA203-E or SA350-LF3 outer closure lid

and subcomponents. The inner closure lid subcomponents include sixty-eight SA564-630 (H1025) or SA705-630 lid bolts which are used to fasten the inner closure lid to the containment closure flange. SA240-S/S inner closure lid vent and drain port covers, and a total of twelve SA193-B7 port cover bolts. The inner closure lid containment boundary seals include the inner closure lid inner seal, and the inner closure lid port covers inner seal. The outer closure lid subcomponents include sixty-eight SA193-B7, or SA564-630 (H1025), or SA705-630 (H1025) lid bolts and the SA193-B8 outer closure lid access port plug. The outer closure lid containment boundary seals include the outer closure lid inner seal and the outer closure lid access port plug seal.

Bolt torque patterns, lubrication requirements, and torque values are provided in Table 7.1.1 of the application. The applicant states that the containment system cannot be opened unintentionally or by an internal pressure within the package. The containment seals are spring energized "C" seals having material options that include stainless steel 321, 304L, or 316L, with inconel 718, or X750 for springs and silver plating on the seal jacket. Critical characteristics of the seals are provided in Table 2.2.12 of the application. All of the containment system components, as identified above are shown in the drawings. Information regarding components of the containment system is consistent with that presented in the Structural and Thermal Evaluation sections of the application.

The containment boundary penetrations are the inner closure lid vent and drain ports, and the outer closure lid access port. The containment penetrations are designed and tested to ensure that the radionuclide release rates specified in 10 CFR 71.51 will not be exceeded.

The cask inner and outer closure lids each use two concentric metallic seals to form the closure with the containment closure flange surface. Inter-seal test ports provide access to the volume between the two metallic lid seals. The inner seal is the containment seal for both the inner and outer closure lids. Following leakage rate testing of the inner closure lid inner seal, a threaded plug with a metallic seal is installed in the inter-seal test port hole. To protect the sealing surfaces against corrosion, a stainless steel or nickel alloy weld overlay is provided during manufacturing on both closure lids and mating containment closure flange. The inner closure lid vent and drain ports are closed by bolted port covers with two concentric metallic seals. An inter-seal test port provides access to the volume between the two metallic port cover seals. The inner seal is the containment seal for both port covers. The outer closure lid access port is closed by a threaded access port plug with a single metallic seal, the containment seal. The outer closure lid inner seal and access port plug seal are leakage tested. A bolted access port cover, with a metallic seal, is installed over the access port plug providing redundant closure of the outer closure lid access port penetration. On the outer closure lid, the outer metallic seal provides redundant closure.

The applicant states that the inner closure lid containment boundary and redundant boundary sealing surfaces are not subject to corrosion due to the presence of the outer lid and inter-lid cavity helium backfill. The outer closure lid containment sealing surfaces are not subject to corrosion due to the presence of redundant closure features. The applicant also states that the materials of construction are highly corrosion resistant. No galvanic, chemical, or other reactions will occur between the seal and the packaging or its contents during transportation. According to the Licensing Drawings, the seals are the proper size to fit within the seal grooves. Tolerances for the containment boundary seal and groove dimensions have been provided on the Licensing Drawings. The seal description, materials, and critical characteristics are incorporated by reference.

The cask containment system boundary welds consist of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment closure flange, and the full penetration weld connecting the containment baseplate to the containment shell. All containment system boundary welds are fabricated and inspected in accordance with ASME Code Section III, Subsection NB.

4.2 Containment Under Normal Conditions of Transport (NCT)

Under NCT, the containment system of the package is designed to be leaktight as defined in ANSI N14.5-1997, i.e., there is no seal leakage greater than $2x10^{-7}$ ref-cm^3/s of helium with a test sensitivity of $1x10^{-7}$ ref-cm^3/s of helium as is described in Table 8.1.1 of the application.

Based on Section 4.5.2.2 of NUREG 1617, Supplement 1. "Standard Review Plan for Transportation Packages for MOX Spent Nuclear Fuel," the staff believes that designing the containment system to be leaktight is appropriate for this package. Thermal and structural evaluation demonstrate no release of radioactive material under NCT The maximum normal operating pressure of the HI-STAR 180 is 89.6 kPa with 3 percent rods rupture (see Section 3.3.2 and Table 3.1.2 of the application), which is lower than the design internal pressure of 552 kPa. The pressure in the inter-lid space is 163.4 kPa, which is also lower than the design internal pressure.

The NCT maximum temperatures of the containment shell, inner closure lid, outer closure lid, containment baseplate, and inner and outer lid seals as shown in Table 3.1.1 of the application do not exceed the temperature limits presented in Tables 3.2.10 and 3.2.12 of the application. Section 2.6.1.4.2 states that the LS-DYNA finite element analysis results indicate that all closure lid seal elements remain closed (i.e., the loading in the elements representing the seal remains compressive) and the bolts remain elastic. The applicant also performed analysis on the inner closure lid port cover bolts to demonstrate that the torque requirement is sufficient to maintain closure.

4.3 Containment Under Hypothetical Accident Conditions of Transport (HAC)

Under HAC, the containment system of the package is designed to be leaktight as defined in ANSI N14.5-1997, i.e., there is no seal leakage greater than $2x10^{-7}$ ref-cm^3/s of helium with a test sensitivity of $1x10^{-7}$ ref-cm^3/s of helium as is described in Table 8.1.1 of the application.

Thermal and structural evaluations demonstrate no release of radioactive material under HAC. The accident condition internal pressure (assuming fire and 100 percent rod rupture) of 862 kPa is used in the structural evaluation for stress analysis purposes. The maximum internal pressure with assumed 100 percent fuel rods rupture is 883.7 kPa as stated in Section 3.4.3.2 and Table 3.1.4 of the application. The cask cavity accident pressure bounds the inter-lid pressure.

The HAC maximum temperatures of the containment shell, inner closure lid, outer closure lid, containment baseplate, and inner and outer lid seals shown in Table 3.1.3 of the application do not exceed the temperature limits presented in Tables 3.2.10 and 3.2.12 of the application. Section 2.7 of the application shows that all containment system boundary components are maintained within their code-allowable stress limits and the metallic lid seals will remain compressed during all hypothetical accident conditions of transport. The applicant also performed an analysis on the inner closure lid port cover bolts to demonstrate that the torque requirement is sufficient to maintain closure.

4.4 Leakage Rate Tests for Type B Packages

Fabrication leakage rate tests demonstrate that the containment system, as fabricated, provides the required level of leaktight containment. Fabrication leakage rate tests are performed on the containment shell, baseplate, closure flange, inner closure lid, outer closure lid, vent and drain port covers, containment welds, and containment seals as is stated in Table 8.1.2 of the application. The containment shell, baseplate, closure flange, inner closure lid, outer closure lid, vent and drain port covers, and containment welds undergo a gas filled envelope (test A.5.3 from ANSI N14.5-1997) leakage rate test and the containment seals undergo an evacuated envelope leakage rate test (test A.5.4 from ANSI N14.5-1997). The allowable leakage rates and test sensitivities are shown in Table 8.1.1 of the application and containment components are tested to the helium leaktight criterion

Pre-shipment leakage rate tests are performed before each shipment after the contents are loaded and the containment system is assembled. Pre-shipment leakage rate tests are performed on all containment seals as is stated in Table 8.1.2 of the application The containment seals undergo an evacuated envelope leakage rate test (test A.5.4 from ANSI N14.5-1997). The allowable leakage rates and test sensitivities are shown in Table 8.1.1 of the application and all seals are tested to the helium leaktight criterion because all seals are replaced prior to each shipment.

Periodic leakage rate tests demonstrate that the containment capabilities of the packagings built to an approved design have not deteriorated over an extended period of use. Periodic leakage rate tests are performed on all containment seals as is stated in Table 8.1.2 of the application. The containment seals undergo an evacuated envelope leakage rate test (test A.5.4 from ANSI N14.5-1997). The allowable leakage rates and test sensitivities are shown in Table 8.1.1 of the application and all seals are tested to the helium leaktight criterion. The periodic leakage rate tests are valid for one year.

Maintenance leakage rate tests confirm that any maintenance, repair, or replacement of components has not degraded the containment system and are performed prior to returning the package to service. Maintenance leakage rate tests are performed on the containment shell, baseplate, closure flange, inner closure lid, outer closure lid, vent and drain port covers, containment welds, and containment seals as is stated in Table 8.1.2 of the application.

The containment shell, baseplate, closure flange, inner closure lid, outer closure lid, vent and drain port covers, and containment welds undergo a gas filled envelope (test A.5.3 from ANSI N14.5-1997) leakage rate test and the containment seals undergo an evacuated envelope leakage rate test (test A.5.4 from ANSI N14.5-1997). The allowable leakage rates and test sensitivities are shown in Table 8.1.1 of the application and all containment components are tested to the helium leaktight criterion.

The fabrication, pre-shipment, periodic, and maintenance tests verify the integrity of the containment boundary, and that the containment components will maintain their leaktight containment function. The tests are consistent with the guidelines of ANSI N14.5-1997.

4.5 Evaluation Findings

To address the staff's requests for further description of the leakage testing of the inner closure lid and vent/drain port cover respective outer seals using the inter-seal test ports, the applicant

changed the package seals that are classified as the containment boundary seals. For this package, the inner closure lid inner seal and the inner closure lid vent/drain port cover inner seals are the containment boundary seals on the inner lid, the outer closure lid inner seal and the outer closure lid access port plug seal are the containment boundary seals on the outer lid. The staff requested the applicant to clarify that all containment sealing surfaces are stainless steel, stainless steel overlay, or nickel alloy overlay. The staff also requested the applicant to clarify all leakage rate tests for the containment system and Table 8.1.2 of the application was extensively revised. The applicant agreed with staff that unacceptable leakage rate will require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting the seals.

The staff requested the applicant to (i) describe in detail the maintenance and periodic leakage rate tests according to ANSI N14.5-1997, (ii) define the periodic leakage test as the leakage rate test performed on containment seals (after the expiration of the last leakage rate test) prior to transport, and (iii) perform leakage testing of the inner lid and vent/drain port inner seals through their respective inter-seal test ports during the initial loading. The staff requested the applicant to justify that the material selection and sizing of the seals and grooves were adequate to ensure containment performance during NCT and HAC. The applicant provided additional information from the seal manufacturer that demonstrated the physical characteristics of the seal was appropriate for the intended application during transportation.

The staff requested the applicant to include on the Licensing Drawings tolerances to the containment boundary seal and groove dimensions in order to adequately incorporate compression, springback and plasticity characteristics that are required to assure sufficient sealing within the seal gland. The staff also requested that Table 2.2.12 of the application, the description of the seals as "Spring energized "C" seals," and the silver coating on the seal jacket be also included in the Licensing Drawings to ensure adequate recovery and a leaktight seal.

Based on the review of the statements and representations in the application, the staff concludes that the HI-STAR 180 containment design has been adequately described and evaluated and that the package design meets the containment requirements of 10 CFR Part 71.

5.0 SHIELDING REVIEW

The objective of the review is to verify that the shielding of the Model No. HI-STAR 180 package provides adequate protection against direct radiation from its contents and that the package design meets the external radiation requirements of 10 CFR Part 71 under NCT and HAC.

5.1 Shielding Design Features

The Model No. HI-STAR 180 package is designed as a Type B(U)F-96 package for transport of UO_2 and MOX fuel assemblies. The containment of the contents is provided by a steel shell welded to a steel base plate at the bottom and a suitably machined steel forging at the top, which is equipped with machined surfaces to fasten two independent cryogenic steel closure lids, each equipped with two concentric gaskets. The main design features of the shielding consist of the fuel basket and basket support structures, the package including its two lids, and part of the impact limiters. Gamma shielding is provided by the steel of the containment shell, base plate, closure flange; the closure lids, the steel monolithic shield cylinder; the bottom steel and lead gamma shields; and the primary closure lid lead gamma shield. The fuel basket and the basket supports also provide additional gamma shielding. The central steel structures in the impact limiters are credited in the analysis as additional gamma shielding in the axial direction.

The initial attenuation of gamma and neutron radiation emitted by the spent fuel is provided by the fuel basket and the fuel basket shims

Neutron shielding is provided in two overlapping radial layers within the monolithic shield cylinder to maximize neutron capture. Additional neutron shielding is provided at the bottom of the package by the bottom neutron shield and at the top of the package by the primary closure lid neutron shield. The shielding against neutron irradiation is provided by Holtite®-B which is a hydrogen rich, radiation resistant, polymer material impregnated with boron carbide with 2 percent by weight concentration B_4C in finely dispersed powder form. In the radial direction, the neutron absorber is located in two overlapping rows of pockets near the outer surface of the cask. In the axial direction, the neutron absorber is present in the bottom section of the package, and in the primary lid.

5.2 Radiation Source Specification

The neutron and gamma source terms are calculated with the SAS2H and ORIGEN-S modules of the SCALE 4.4 system using a 44-group library. SAS2H has been validated for PWR fuel with a burnup up to 46.46 GWd/MTU. Since the burnup for the UO_2 fuel assemblies allowed in the Model No. HI-STAR 180 package may be as high as 66 GWd/MTU (61.5 GWd/MTU for MOX fuel assemblies), comparisons of the measured-to-computed percentage differences were made as a function of the increasing burnup.

The evaluation demonstrated that the differences indicated no significant trends and were therefore applicable for the higher burnup fuel. For the source term calculations, the applicant used a single power cycle with no down time between cycles. In addition, the power level and core conditions were kept constant over the duration of the burnup.

5.2.1 Selection of Design Basis Assembly

The methodology used by the applicant to determine the design basis for the UO_2 and MOX fuel assemblies consists of examining the fuel and core operating parameters from the Beznau plant and establish which parameters important to source term calculations are conservatively bounding. Separate calculations were performed to determine bounding UO_2 and MOX fuel assemblies for the source term calculations.

To calculate the UO_2 source term, the dimensions corresponding to the assembly with the highest fuel weight (i.e., 340kg) were used. For the MOX source term, the fuel weight was calculated based on the heavy metal isotopic composition of the MOX assemblies, as shown in Table 5.2.3 of the application. To derive the values listed in Table 5.2.3, the applicant selected several bounding pairs of ^{242}Pu and ^{239}Pu, the two predominant isotopes affecting the source strength for MOX fuel, each of which bounding a range of assemblies.

The source term calculations are performed using an infinite array of assemblies during irradiation. This is conservative for MOX fuel because MOX fuel assemblies are not placed directly adjacent to each other in the reactor core in order to improve the reactivity control. The applicant analyzes an infinite array of MOX assemblies, resulting in a harder neutron spectrum that a normal configuration with both UO2 and MOX assemblies, as an additional layer of conservatism, and does not take any credit for this condition.

5.2.2 Gamma Source

The applicant performed gamma source calculations with SAS2H and ORIGEN-S for bounding burnup and cooling time combinations for UO_2 and MOX fuel and for the burnup and cooling time combinations for uniform loading cases. Gammas with energies in the range of 0.45 to 3.0 MeV are included in the shielding analysis.

The primary source of activity in the non-fuel regions of an assembly comes from the activation of ^{59}Co to ^{60}Co primarily due to the impurities in the steel structural material contained both above and below the fuel. The ^{59}Co limits are based on design limits from the manufacturer. In all instances, the higher impurity tolerance limits are conservatively used, e.g., 2 g/kg for steel and 1 g/kg for inconel. Since some assemblies, used in earlier reactor cycles, contain stainless steel guide tube and/or inconel grid spacers instead of zirconium based components, all assemblies with a cooling time of greater than 15 years are assumed to contain stainless steel and inconel parts in order to bound such assemblies.

The activity of the ^{60}Co from ^{59}Co in steel and Inconel was calculated using ORIGEN-S using the in-core fuel region flux at full power. The activity thus calculated was modified by the appropriate scaling factors. The third source of gammas from (n,γ) reactions is properly accounted for in MCNP calculations performed in a coupled neutron-gamma mode.

5.2.3 Neutron Source

Since the neutron source strength for a UO_2 assembly increases as enrichment deceases for a constant burnup and decay time, the applicant performed source calculations using enrichments of 3.15 wt%, 3.95 wt%, and 4.5 wt% to develop conservative source terms for UO_2 fuel. For MOX fuel assemblies, four different MOX vectors are specified and analyzed, as indicated in Section 5.2.1 above.

For both fuel types, the spontaneous fission of ^{242}Cm isotopes accounts for approximately 95 percent of the total number of neutrons produced. Any neutrons generated from subcritical multiplication, (n, 2n) or similar reactions, are properly accounted for in the MCNP shielding calculations.

5.2.4 Uncertainties in the Depletion Calculation

The various uncertainties associated with SAS2H and ORIGEN-S calculations, including those inherent to the code, the source term input reactor operating parameters, the decay heat calculations, and the source term values, are evaluated by the applicant and incorporated into the shielding calculations.

5.3 Shielding Model

The shielding analysis of the package was performed with MCNP4A using the continuous energy ENDF/B-VI neutron and photon cross section libraries. For NCT, the package model includes both the neutron shield and impact limiters while, for HAC, the neutron shield is replaced with void and the impact limiters are completely removed. The shielding effect of the aluminum honeycomb in the impact limiters is conservatively neglected in the MCNP models but credit is taken for the outer dimensions of the impact limiters in the axial direction under NCT. To ensure that the maximum dose rate is identified, a fine grid of dose locations is used and the highest combined dose for each pattern is calculated. The applicant also conservatively ignores the vehicle and the barrier and uses the outer dimensions of the package for dose calculations.

The Holtite®-B, used as neutron absorber in the radial and axial directions, is located in two layers of pockets of the annular monolithic cylinders. The monolithic cylinders are modeled as one casting rather than multiple castings stacked one on top of another because the gap between the castings is small and the castings overlap prevents any streaming. Other MCNP modeling simplifications include the fact that the bolts for closure of the inner and outer lid are not modeled, the penetrations in the two lids are not modeled, the trunnions are not modeled and the holes in the basket shims are modeled with squared rather than rounded corners.

The B_4C content of both the Holtite® and Metamic-HT used for the construction of the basket is approximately 2.25 percent, i.e., slightly larger than the minimum value of 2.0 percent, but this has a negligible effect on dose rates. All steel in the package is modeled as carbon steel Since the materials all remain at or below their design temperatures, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

Design basis fuel assemblies are modeled in each of the basket locations with the active fuel region being modeled as a homogeneous zone. The bottom nozzle, plenum and top nozzle regions are also modeled as homogeneous regions of steel. Each of the source terms, fuel neutron, fuel photon and hardware ^{60}Co are calculated individually. The Cobalt source in the hardware is assumed to be uniformly distributed. In the model for the F-32 basket, the fuel is modeled as fresh UO_2 fuel with an enrichment of 5.0 wt% ^{235}U. In the model for the F-37 basket, the fuel is modeled as fresh UO_2 fuel with an enrichment of 3.5 wt%, as equivalent to the various loading combinations of fresh and burned fuel as shown in Chapter 6 of the application.

Numerous dose tallies are calculated at dose point locations in both radial and axial directions

5.4 Shielding Evaluation

The applicant utilizes several conservative assumptions, throughout the shielding calculations, to provide assurance that the actual dose rates will always be below the regulatory limits and the calculated dose rates: minimum dimensions are used where applicable; the fuel is assumed to only go through a single cycle to provide conservative source terms; a bounding value of 2 g ^{59}Co per kg of stainless steel is used for the steel activation; an infinite array of MOX assemblies is assumed, in lieu of the actual configuration where they are surrounded by UO_2 assemblies, resulting in higher source terms; and the axial profile of the neutron sources for both UO_2 and MOX assemblies is based on the UO_2 behavior, which is conservative for MOX assemblies.

The MCNP-4A code, a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code, is used for all of the shielding analyses. The calculated energy distribution of the source term is used explicitly in the MCNP model but separate calculations are performed for each of the three source terms (i.e., decay gamma, neutron, and ^{60}Co). The axial burnup distributions listed in Table 1.2.11 of the application are representative of the fuel type to be loaded. The cobalt source present in the steel hardware is assumed to be uniformly distributed over the appropriate regions.

In order to account for the non-linear relationship between the neutron source strength and the assembly axial fuel burnup, the neutron source strength in each of the 32 axial nodes listed in Table 1.2.11 of the application was determined by multiplying the average source strength by the relative burnup level raised to the power of 4.2 (for UO_2 fuel) or 1.7 (for MOX fuel). This calculation results in a 28 percent increase in neutron source strength for UO_2 fuel assemblies, while the increase at the peak node is approximately 7 percent for MOX fuel. For all NCT calculations, the higher increase from the UO_2 fuel is conservatively used for all assemblies in the basket, including the MOX assemblies. For HAC, the dose rates are dominated by the neutron source from the MOX assemblies and therefore the increase from the MOX assemblies is used, but is conservatively raised to the power of 2.0 instead of the 1.7 that was determined above.

Dose rates are calculated using a two-step process: the dose rate is calculated for each location, then the resulting dose rate is multiplied by the source strength in each group and the sum is taken for all groups and basket locations in each dose location. These results are normalized and the standard deviations of the various results are statistically combined to determine the standard deviation of the total dose in each dose location. This 2-step process

allows for the consideration of the neutron and gamma source spectrum as well as the location of the individual assemblies

The axial burnup profile is modeled by assigning a source probability to each of the 32 axial sections of the active region based on a representative axial burnup profile For the gammas present in the fuel, the probability is proportional to the burnup while, for neutrons, the probability is proportional to the burnup raised to the power of 4.2, as indicated above. The applicant performed a comparison of the probability distribution with that derived from a burnup distribution and found the total source difference to be negligible

MCNP uncertainties, as a statistical code, are expressed as the standard deviation of the mean divided by the mean. Parameters, such as variance reduction and the number of starting particles for each run, were chosen by the applicant so that the relative error for the dose rates were typically less than 4 percent.

For each loading pattern, a reference loading is specified in Section 1.2.2 of the application with a maximum burnup, a minimum cooling time, and an initial enrichment (for UO_2 fuel assemblies) specified for each of the eight regions in the basket For MOX fuel assemblies, four limiting isotope vectors are evaluated and the dose rates are compared to identify the bounding MOX vector. In addition to this bounding MOX vector, alternative burnup, cooling time, and enrichment combinations are specified for each basket region to result in the same dose rate at the reference loading in each location. This dose rate is determined by varying separately the conditions in each region and determining those conditions essentially equal to or below the reference loading condition at 2 meters from the radial surface of the package. Two bounding cases are analyzed to maximize either the neutron source terms or the gamma source term in the basket.

External dose rates on the surface of the package are presented in Tables 5.1.1 and 5.1.2 of the application for the F-32 and F-37 basket respectively. Table 5.1.3 for the F-32 basket and Table 5.1.4 for the F-37 basket show the external dose rates at 2 meters from the package during NCT. All dose rates comply with 10 CFR 71.47(b)(2) and 71.47(b)(3). For HAC, the maximum dose rates at 1 meter from the surface of the cask are also calculated.

Even though structural analyses, performed in Chapter 2 of the application, show that the fuel is expected to remain essentially undamaged during HAC, the applicant looked at feasible fuel reconfigurations and determined that the expected dose rates would still be below regulatory limits.

5.5 Evaluation findings

The staff requested the applicant to justify the use of SAS2H/ORIGEN-S point depletion codes and account for uncertainties in the calculations due to a maximum burnup of 66 GWD/MTU for UO_2 fuel and 61.5 GWD/MTU for MOX fuel. The applicant performed a quantitative comparison of the uncertainties of the depletion calculation to conservatisms in the dose calculations and concluded that there are sufficient embedded conservatisms in the dose calculations to offset the uncertainties in the depletion calculations.

The staff reviewed the description of the package design features related to shielding and the source terms for the design basis fuel and found them acceptable. The methods used are consistent with accepted industry practices and standards.

The staff reviewed the maximum dose rates for normal conditions of transport and hypothetical accident conditions and determined that the reported values were below the regulatory limit in 10 CFR 71.47 and 71.51.

Based on its review of the statements and representations provided in the application, the staff has reasonable assurance that the shielding evaluation is consistent with the appropriate codes and standards for shielding analyses and NRC guidance, and that the package design and contents satisfy the shielding and dose limits in 10 CFR Part 71.

6.0 CRITICALITY REVIEW

This section presents the findings of the criticality safety review for an application to authorize shipment of the Model No. HI-STAR 180 transportation package under a criticality analysis using credit for fuel burnup.

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

The staff reviewed the criticality safety analysis presented in the package application, and also performed independent calculations to confirm the applicant's results. The staff's review considered the criticality safety requirements of the radioactive material transportation regulations in 10 CFR Part 71, as well as the review guidance presented in NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel."

6.1 Description of the Criticality Design

6.1.1 Packaging Design Features

The Model No. HI-STAR 180 package design consists of a cylindrical, steel shell containment system, with a flat bottom and two bolted closure lids at the top, and with two different available internal basket structures to transport up to 32 PWR assemblies in the F-32 basket or up to 37 PWR assemblies in the F-37 basket. The package design relies on fixed neutron absorber plates, configuration control, and a minimum burnup to provide criticality control in the F-37 configurations that account for burnup of the fuel.

The basket material consists of Metamic-HT, an aluminum and boron carbide (B_4C) composite material used for both the structure of the basket and for criticality control. The F-32 basket has three sets of flux traps in each direction, as shown in Figure 1.2.1 of the application. These flux traps provide a very effective means of criticality control, resulting in the package being adequately subcritical without considering burnup of the fuel. The F-37 has two sets of slightly narrower flux traps in each direction, as shown in Figure 1.2.2 of the application. The fewer and narrower flux traps in the F-37 basket are less effective at neutron absorption, resulting in the minimum burnup requirement for some of the fuel in the basket.

A single HI-STAR 180 package, as loaded with intact PWR fuel, is demonstrated to be subcritical assuming fresh water in-leakage, per the requirements of 10 CFR 71.55(b). Additionally, single packages and arrays of packages are shown to subcritical under NCT and HAC. The package is also designed to exclude moderator under HAC, per the recommendations of ISG-19, as discussed in Chapter 1 of this report and Appendix 1.B of the package application. HAC k_{eff} results are therefore reported for the package in its damaged state, without fresh water inside the containment system. Additionally, as defense-in-depth, the applicant performed several analyses assuming credible reconfiguration of the spent fuel contents under HAC, with fresh water in the containment system. These analyses also

demonstrate that the package remains adequately subcritical under several credible reconfiguration scenarios, with fresh water inleakage

6 1 2 Codes and Standards

The applicable regulations considered in the review of the criticality chapter of this application include the fissile material requirements in 10 CFR Part 71, specifically the general requirements for fissile material packages in 10 CFR 71.55, and the standards for arrays of fissile material packages in 10 CFR 71.59. The staff also used the review guidance contained in NUREG-1617, as well as in Interim Staff Guidance 8 (ISG-8), Revision 2, "Burnup Credit in the Criticality Safety Analysis of PWR Spent Fuel in Transport and Storage Casks," and in ISG-19, "Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent fuel under the Requirements of 10 CFR 71.55(e)."

6 1 3 Summary Table of Criticality Evaluations

The applicant provided a summary of criticality evaluations in Table 6.1 1 of the application which is summarized below for both the F-32 and F-37 baskets. All results include the calculated k_{eff} plus two standard deviations, the code bias, and the bias uncertainty.

F-32		F-37	
Configuration	Maximum k_{eff}	Configuration	Maximum k_{eff}
Single package, reflected	0.9429	Single package, reflected	0.9487
Single package, HAC	0.3800	Single package, HAC	0.3716
Infinite array, NCT	0.4025	Infinite array, NCT	0.3891
Infinite array, HAC	0.4080	Infinite array, HAC	0.3961

6.1.4 Criticality Safety Index

The applicant demonstrated that infinite arrays of the Model No. HI-STAR 180 packages are adequately subcritical under NCT and HAC. Therefore, the criticality safety index (CSI), determined in accordance with 10 CFR 71.59(b), is 0.0.

6.2 Spent Nuclear Fuel Contents

The Model No. HI-STAR 180 package is designed to transport 14x14 PWR assemblies with the fuel characteristics listed in Table 6.2.1 of the application. The limiting fuel assembly dimensions, based on previous studies of reactivity effects, are the maximum active length, maximum pellet diameter, maximum clad inner diameter, minimum clad outer diameter and thickness, and minimum guide tube thickness.

The F-32 basket is evaluated assuming that the fuel is unburned (i.e., fresh), and may transport undamaged UO_2 or MOX fuel assemblies without a minimum burnup requirement. Spent UO_2 fuel enriched up to 5.0 wt% ^{235}U may be loaded in any position in the basket. Spent MOX fuel meeting one of the three limiting fuel compositions given in Table 6.2.3 of the application may also be loaded in any basket location. This table also shows the reactivity difference of modeling the three limiting MOX fuel compositions in the F-32 and F-37 baskets compared to UO_2 fuel, demonstrating that 5.0 wt% enriched UO_2 fuel is bounding.

The F-37 basket is evaluated assuming actinide-only credit for the burnup of the undamaged UO_2 fuel, per the recommendations of ISG-8, Rev 2, in specific locations in the basket The remaining locations in the basket are evaluated assuming undamaged fresh 5.0 wt% enriched UO_2 fuel, and may also contain undamaged MOX fuel There are nine different burnup credit loading configurations for the F-37 basket, each with a different loading curve for the burned fuel locations in the basket. These loading configurations are described in Table 6.1.2 of the application, along with the loading curves associated with each configuration.

6.3 General Considerations for Criticality Evaluations

6.3.1 Model Configuration

The applicant evaluates three-dimensional models of a single package and arrays of packages under both NCT and HAC. The applicant explicitly models the fuel rods and cladding, guide tubes, water gaps, and neutron absorber in the basket For all cases where the containment is flooded, the fuel-to-clad gap is also conservatively assumed to be flooded with fresh water The applicant models the cask body conservatively neglecting the neutron shielding material, allowing more neutron communication between packages in an array, as well as better neutron reflection from the cask wall in the single package. Preferential flooding is not considered, due to the holes present at the top and bottom of the basket cell walls to prevent preferential flooding.

Although the HI-STAR 180 package containment is designed to exclude moderator under HAC, the applicant also evaluates the reactivity effects of potential fuel reconfiguration under these conditions as defense-in-depth. This model configuration considers random rod repositioning within the F-32 basket cell, as well as rod segment relocation between grid straps.

6.3.2 Material Properties

Fresh fuel compositions are modeled as UO_2 with 96 percent of theoretical density. The ^{234}U and ^{236}U which are present in fresh fuel, are conservatively ignored. For burned fuel compositions, the applicant models the fuel with 10 major actinides (^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{241}Am) incorporated into the fuel matrix. Section 6.B.2 of the application discusses the calculations to determine burned fuel compositions.

Table 6.3.4 of the application provides the composition of the major components of the Model No. HI-STAR 180 package, including the UO_2 and MOX fuel, steel and aluminum structural components, and Metamic-HT neutron absorber panels. The criticality analyses conservatively assume 90 percent of the neutron absorber manufacturer's minimum specified ^{10}B content. The requirements regarding verification of the minimum specified ^{10}B content in the Metamic-HT neutron absorber panels are discussed in Section 8.1.5.4 of the application.

6.3.3 Computer Codes and Cross Section Libraries

The CASMO-4 two-dimensional multigroup transport theory depletion code is used to determine burned fuel compositions. The MCNP4a three-dimensional Monte Carlo code, along with the continuous-energy ENDF/B-V cross-section library, is used for all criticality calculations.

The staff used the ORIGEN-ARP point-depletion code to confirm the burned fuel compositions used in the applicants burnup credit analysis. The staff used the CSAS26 criticality sequence of the SCALE 6 computer code system, with the 238-group ENDF/B-V cross-section library, for confirmatory criticality calculations.

6.3.4 Demonstration of Maximum Reactivity

[PROPRIETARY TEXT REMOVED]

6.3.5 Confirmatory Analyses

The staff performed confirmatory evaluations of the Model No. HI-STAR 180 package, for both fresh and burned fuel configurations. Using assumptions similar to the applicant's, the staff confirmed that the package will meet the criticality safety requirements of 10 CFR Part 71.

[PROPRIETARY TEXT REMOVED]

6.4 Single Package Evaluation

6.4.1 Configuration

The applicant evaluates the package using the bounding configuration determined in earlier sensitivity studies, including a flooded pellet to clad gap and assemblies centered in each basket location. For the F-32 basket, all assemblies are modeled as UO_2 fuel enriched to 5.0 weight-percent, which bounds all MOX assemblies. The F-37 basket is modeled with each of the nine loading configurations given in Table 6.1.2 of the application. Fresh fuel assemblies in each configuration are modeled as UO_2 fuel enriched to 5.0 wt% which bounds all MOX assemblies. Spent fuel assemblies are modeled with compositions determined from an initial enrichment of 5.0 wt% and with their minimum permissible burnup given in Table 6.1.2.

Under NCT, the package is modeled with full internal and external moderation, per the requirements of §71.55(b). Under HAC, the structural and thermal analyses in Chapters 2 and 3 of the application demonstrate that the damage to the package is limited to of a loss of neutron shield material due to the impact and fire conditions of 10 CFR 71.73. The structural analysis demonstrates that the cask remains leaktight under all accident conditions, with the second bolted lid closure as additional defense against water in-leakage. Therefore, a single package under HAC is modeled with intact fuel, with no moderator inside the containment boundary, and fully reflected by water externally. Additional analyses are provided which demonstrate that, with credible fuel damage scenarios and a flooded containment, the package would still remain subcritical.

6.4.2 Results

The results of the single package evaluations are given in Table 6.4.1 of the application The single package under NCT has a maximum k_{eff}, including biases and uncertainties, of 0.9487 A single damaged package has a maximum k_{eff}, including biases and uncertainties, of 0.3800. The results of the calculations for potential fuel reconfiguration under HAC, including flooding of the containment system of the package, are given in Tables 6.3.13 and 6.3.14 of the application. These results show that credible reconfigurations typically decrease the maximum k_{eff}, and in the worst case increase k_{eff} negligibly.

6.5 Evaluation of Package Arrays

6.5.1 Configuration

Studies of infinite package arrays in Section 6.3.4 of the application demonstrate that the pitch of packages in the array and the interstitial moderator density have little effect on array reactivity, for both NCT and HAC. Since the containment of the package is considered to be dry under NCT and HAC (based on ISG-19), there is a significant margin on subcriticality for these array configurations.

6.5.2 Results

The results of the single package evaluations are given in Tables 6.5.1 and 6.6.1 of the application. The infinite array of packages under NCT has a maximum k_{eff}, including biases and uncertainties, of 0.4080. An infinite array of damaged packages has a maximum k_{eff}, including biases and uncertainties, of 0.4025.

6.6 Benchmark Evaluations

6.6.1 Experiments and Applicability

Benchmark evaluations related to burnup credit in the F-37 basket are discussed in Section 6 7 below. For the fresh fuel calculations in the F-32 basket, the applicant benchmarks the MCNP4a code against 56 UO_2 critical experiments chosen to bound the range of parameters in the criticality design of the Model No. HI-STAR 180 package. Table 6.A.1 of the application gives the reference, fuel enrichment, energy of the average lethargy causing fission (EALF), and calculated k_{eff} for each of the experiments used in the benchmarking analysis. The applicant analyzes the k_{eff} results for trends with respect to EALF, enrichment, ^{10}B loading in the neutron absorbers, reflector material and spacing, and fuel pellet diameter and lattice pitch There are no observable trends on any of these parameters.

6.6.2 Bias Determination

The applicant determines the bias and the standard error of the bias for the fresh fuel calculations based on the k_{eff} results of the selected benchmark critical experiments. The applicant reports bias and standard error of the bias based directly on the calculated k_{eff} values in Table 6.A.1, as well as those based on truncating to 1.0 any k_{eff} value that exceeds 1.0. The larger value of the bias plus the standard error of the bias, 0.0027, based on the truncated k_{eff} analysis, is used to evaluate maximum k_{eff}s in the fresh fuel criticality analysis of the Model No. HI-STAR 180 package.

6.7 Burnup Credit

6.7.1 Limits for the Licensing Basis

[PROPRIETARY TEXT REMOVED]

6.7.2 Code Validation

[PROPRIETARY TEXT REMOVED]

[PROPRIETARY TEXT REMOVED]

6.7.3 Licensing-Basis Model Assumptions

[PROPRIETARY TEXT REMOVED]

6 7 4 Loading Curve

[PROPRIETARY TEXT REMOVED]

6 7 5 Assigned Burnup Loading Value

[PROPRIETARY TEXT REMOVED]

6.7.6 Estimate of Additional Reactivity Margin

[PROPRIETARY TEXT REMOVED]

6.8 Findings

[PROPRIETARY TEXT REMOVED]

[PROPRIETARY TEXT REMOVED]

[PROPRIETARY TEXT REMOVED]

The staff requested the applicant to discuss how uncertainties in the recorded burnup value for assemblies to be loaded are accounted for in the proposed alternative burnup confirmation method. The applicant revised this part of the application in conformance with Interim Staff Guidance 8, Revision No. 2, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks," to state that, for burnup verification through both an administrative procedure and qualitative measurements, the assembly burnup value to be compared with the minimum required burnup should be the reactor record burnup value as adjusted by reducing the value by the uncertainties in the reactor record value.

The applicant has demonstrated that the Model No. HI-STAR 180 package, when loaded with fuel assemblies meeting the characteristics of Table 1.2.3 of the application, and meeting the enrichment limit of 5.0 wt% ^{235}U for the F-32 basket and the loading curve requirements of Table 1.2.7 of the application for the F-37 basket, will be adequately subcritical under all conditions.

Therefore, the applicant has shown and the staff agrees that the Model No. HI-STAR 180 package meets the fissile material requirements of 10 CFR 71.55 for single packages, and 10 CFR 71.59 for arrays of packages with a CSI of 0.0.

7.0 PACKAGE OPERATIONS

Chapter 7.0 of the application provides a summary description of package operations, including package loading and unloading operations, to ensure that the package is operated in a safe and reliable manner under NCT and HAC conditions of transport. The preparation of an empty package for shipment is also described.

7.1 Package Loading

Package loading operations include package preparation, fuel assembly loading, and package closure activities as well as preparation for transport.

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

Prior to fuel loading, the user (i) verifies that the proper Fuel Impact Attenuator (FIA) is positioned in the bottom of each fuel basket cell location, and (ii) identifies the fuel assembly to be loaded through a visual verification of its Identification Number and verifies that the fuel assembly meets the conditions of the Certificate of Compliance. For those spent fuel assemblies that need to meet the burnup requirements in Table 1.2.7 of the application, a burnup verification shall be performed either in accordance with Section 6.F.3.1 or 6.F.3.2 of the application.

New seals are installed on the inner closure lid before the lid is lowered into the water and installed onto the cask. The lid is visually inspected to confirm that it is properly seated. The user performs a site-specific Time-To-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to the beginning of the draining operations. The maximum allowable time for completion of fuel loading operations is indicated in Table 3.3.5 of the application, e.g., 17.8 hours assuming a pool water temperature of 32.2°C. If operational malfunctions occur and if it appears that the Time-To-Boil limit will be exceeded prior to draining operations, the user implements specific procedures to either replace the water in the cask cavity with an inert gas or circulate the water through the cask cavity to reset the Time-To-Boil clock.

After being raised out of the spent fuel pool, the cask is decontaminated and placed in a preparation area. The lid vent line is opened to prevent cask pressurization and the inner closure lid bolts are installed and torqued, per specifications provided in Table 7.1.1 of the application, after the vent line is opened and before the cask cavity is drained. A Forced Helium Dehydration drying system is connected to the cask and used to remove moisture from the internal cavity. As the water is drained from the cask, helium is introduced into the cask to prevent oxidation of the fuel cladding. The cask drying operation is critical to the spent fuel cladding integrity. The dryness criteria are specified in Section 7.1.2.1 of the application while requirements for the cask cavity backfill with a 99.99 percent purity helium are specified in Table 1.2.1 of the application.

The space beneath the port covers are also filled with 99.99 percent purity helium; the port cover bolts are torqued in accordance with specifications of Table 7.1.1 of the application, and the vent and drain port cover plate inner seals are leaktested through their respective inter-seal test port to ANSI N 14.5 criteria. Unacceptable leakage rates require cleaning or repair of the seal surfaces and/or replacement of the seals prior to retesting the seals.

For cask closure, the outer closure lid is installed using new seals and with the outer closure lid access port positioned directly above one of the inner closure lid inter-seal test ports; the outer closure lid bolts are torqued in accordance with specifications of Table 7.1.1 of the application, the inter-lid space is backfilled, with 99.99 percent purity helium, to the requirements of Table 1.2.2 of the application, the outer closure lid inner-seal and outer closure lid access port plug seal are helium leak tested and the lid access port cover and inter-seal test port plug are installed with new seals and torqued in accordance with specifications of Table 7.1.1 of the application.

Periodic leakage tests shall be performed, as described in Section 7.1.3.1 of the application, if more than 12 months have elapsed before the package is placed on the transport vehicle. After downending the package on the transport vehicle, the cask trunnions are removed, the trunnion hole plugs and the impact limiters are installed, contamination surveys are performed, and an optional personnel barrier may be installed before the assembled package may be released for transport.

7.2 Package Unloading

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

Upon receipt from the carrier, the package is visually inspected to verify there are no indications of impaired physical conditions; a radiological survey is performed and the impact limiters are removed; the cask trunnions are installed to upend the package and move it to a designated preparation and unloading area. The outer lid access port cover is then removed to draw a gas sample from the inter-lid space, the inner closure lid port covers are removed to access the vent and drain ports, and a gas sample from inside the cask cavity is collected to assess the condition of the fuel assembly cladding. If the cask is unloaded under water, the cask is cooled if necessary to reduce the internal temperature to allow water flooding without thermally shocking the fuel assemblies or over-pressurizing the cask. The inner closure lid bolts are removed and the cask is placed either in the unloading area or in the pool. The cask is then returned to the designated preparation area where any cask cavity water is pumped back into the pool or any approved system, and the cask is decontaminated.

7.3 Preparation of Empty Package for Shipment

Preparation of an empty, i.e., previously used, package for shipment includes the following steps: (i) removal of the inner closure lid seal surface protector, (ii) contamination survey, (iii) installation of the inner closure lid followed by appropriate torque requirements for the bolts, (iv) installation of the inner closure lid port covers, if necessary, (v) removal of the outer closure lid seal surface protector, installation of the outer closure lid followed by appropriate torque requirements for the bolts, (vi) installation of the outer closure lid access port plug and access port cover, if necessary, (vii) positioning the packaging onto the transport equipment, (viii) installation of the impact limiters after removing the cask trunnions, (ix) installation of a ecurity

seal and is appropriate recording in the shipping documentation (x) installation of personnel barrier if desired, and (xi) packaging marking, labeling, and vehicle placarding

7.4 Evaluation Findings

To further ensure safe operation in maintaining containment integrity, the staff requested that a note be added to Section 7.2.2. of the application to ensure that the fuel is protected by an inert gas during package unloading.

The staff also requested that additional information related to the verification of the burnup be included in fuel loading operations to ensure that the package remains subcritical per 10 CFR 71.55 and 71.59: the applicant revised the package loading procedure to add adequate steps and guidance related to the alternatives for the verification of fuel assembly burnups, as described in Appendix 6F of the application.

The applicant clarified that the inner closure lid inner and outer seals are not installed with the inner closure lid underwater and described how the helium forced dehydration system will thoroughly dry the wetted containment boundary items and seal grooves to assure performance of the seals and ensure their perfect condition in compliance with 10 CFR 71.43(d).

The applicant has properly defined the seals that are classified as "containment boundary seals." The inner closure lid inner seal and vent/drain port cover inner seals are containment boundary components on the inner lid while the outer closure lid inner seal and access port plug seal are containment boundary components on the outer lid. The applicant correctly described the performance of the helium leak tests so that the tests effectively detect a potential leakage. Leak testing of the inner closure lid containment seals is performed by drawing a vacuum between their respective inner and outer seals and measuring the helium leak rate using the MSLD. Further to staff's request, the applicant also specified the purity and pressure requirements of the helium used for filling the inter-seal and inter-lid spaces prior to leak testing.

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

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

Chapter 8 of the application identifies the inspections, acceptance tests and maintenance programs to be conducted on the Model No. HI-STAR 180 package and verifies their compliance with the requirements of 10 CFR Part 71.

8.1 Acceptance Tests

Visual inspections and measurements ensure that the packaging conforms to the dimensions and tolerances specified on the licensing and fabrication drawings and that its effectiveness is not significantly reduced. Visual inspections and measurements include the repair and replacement of any important to safety component found to be under the minimum specified thickness, the verification that neutron absorber panels, basket shims and anti-rotation bars are present as required, the verification that the Fuel Impact Attenuators are present as required by

the packaging design, the proper marking and labeling of the package, and its inspection for cleanliness and preparation for transport in accordance with written and approved procedures.

The examination of the package welds is performed in accordance with the Licensing Drawings referenced in the Certificate of Compliance, applicable codes and standards listed in Table 2.1.13 of the application, including alternatives as specified in Table 2.1.14. In particular, specific weld requirements, outlined in Section 8.1.2 of the application, shall be followed for the containment boundary welds, the structural weld in the packaging and impact limiter and for the basket welds in order to verify fabrication. Such specific weld requirements are not applicable to NITS welds. NITS welds are examined and repaired in accordance with written and approved procedures.

The top trunnions, used for vertical lifting and handling of the package, are designed, tested and inspected in accordance with ANSI N14.6. Such requirements also apply to the bottom trunnions if they are to be used for horizontal lifting.

Pressure testing of the package inter-lid space in accordance with ASME Section III, Subsection NB, NB-6000, is required. In addition, the package containment boundary cavity space (package with inner lid installed) is hydrostatically tested at a pressure of 100 psig. Leakage rate tests on the containment system are performed in accordance with ANSI N14.5 requirements. Tables 8.1.1 and 8.1.2 of the application specify the allowable leakage rates as well as the components to be tested for fabrication, pre-shipment, and periodic and maintenance leakage rate tests. If the leakage rate does not meet the acceptance criterion, welds and seal surface are repaired and polished, the seal is changed, and a new test is performed until the acceptance criterion is satisfied.

Each manufactured lot of Holtite®-B neutron shielding material is tested to verify that the material composition, boron concentration, hydrogen density, and Holtite® bulk density meet the requirements specified in Section 1.2.15 of the application. Essential characteristics of Metamic-HT are described in Section 1.2 of the application. Each panel of Metamic-HT is visually inspected for damage, including void and discontinuities that could affect its functional effectiveness. Testing requirements to establish compliance of the manufactured panels with the purchasing specifications, their frequency and their intended purpose are summarized in Table 8.1.3 of the application. To ensure the test requirements are met, a sampling plan has been incorporated in the Metamic-HT Manufacturing manual's shop operating procedures.

Neutron shielding integrity is verified once for each package, and measurements are compared to calculated values representative of the loaded contents or the check source. Following the first fuel loading of each Model No. HI-STAR 180 package, a shielding effectiveness test is performed.

The first fabricated Model No. HI-STAR 180 unit shall be thermally tested to confirm its heat transfer capability. Section 8.1.7 of the application provides a basic description of the testing sequence and the condition for its acceptability.

8.2 Maintenance

A maintenance inspection and test program schedule is provided in Table 8.2.1 of the application.

A pre-shipment leakage rate test of the package double closure lid containment seals is performed after each fuel loading. This pre-shipment leakage rate test is valid for one year Removal of the closure fasteners requires the replacement of the closure seals and the performance of a maintenance leakage rate test for the seals classified as containment boundary seals

The neutron shield integrity is periodically verified within 5 years prior to each shipment. For each package, a periodic thermal performance test is performed at least once within the 5 years prior to each shipment to demonstrate that the thermal capabilities of the package remain within its design basis

Accessible external surfaces are visually inspected for damage, such as surface denting, surface penetrations, weld cracking, chipped or missing coating, prior to each fuel loading Cask trunnions are also inspected prior to each fuel loading to verify that no deformation, distortion, or cracking has occurred. Any evidence of deformation, distortion or cracking of the trunnion or adjacent cask areas requires repair of the trunnion and/or the packaging Following any major repair of a lifting trunnion, as defined in ANSI N14.6, the load testing is to be re-performed and the components are re-examined in accordance with the original procedure and acceptance criteria.

Wear and tear from normal use will not impact the safety of the package.

8.3 Evaluation findings

The staff requested pressure testing of the Model No. HI-STAR 180 containment boundary per 10 CFR 71.85(b) because the MNOP inter-lid space is above 35 kPa. The applicant revised Section 8.1.3.2 of the application to (i) require a pressure test of the inter-lid space and (ii) clarify that the MNOP applies to the cask cavity space only because the Model No. HI-STAR 180 package containment boundary is of a double closure lid design.

The application includes a high level description of a sampling plan to verify the acceptability of Metamic-HT panels and a detailed sampling plan HTSOP-108 "HT Sampling Plan" is contained in the Metamic-HT manufacturing manual. Test results are appropriately documented and part of the package final quality documentation report. The staff has reviewed the Metamic-HT acceptance testing criteria, and finds them adequate for the application.

The staff requested that the package containment boundary leakage testing be performed in accordance with the requirements of ANSI N14.5-1997 to determine compliance with 10 CFR 71.51, and the applicant revised Section 8.1.4 of the application.

The first fabricated Model No. HI-STAR 180 package shall undergo thermal testing to confirm its heat transfer capability. If the acceptance criteria specified in the application are not met, the package shall not be accepted until the root cause is determined, appropriate corrective actions are completed and the package is re-tested with acceptable results.

The staff reviewed the acceptance tests and maintenance programs for the Model No. HI-STAR 180 package and requested the addition of a number of tasks in Table 8.2.1 of the application, including the bolt replacement for the inner closure lid port cover bolts in compliance with 10 CFR 71.51. The applicant modified that section of the application.

The staff also requested that the cask containment boundary leakage testing be performed on all containment seals listed on Table 8.1.2 of the application prior to transport if the pre-shipment leakage rate test expires. The applicant decided that the test port plug seals are no longer classified as containment boundary seals and revised Table 8.1.2 of the application for the containment boundary seals to be tested. Staff found the maintenance inspection items acceptable.

Regarding the properties of Metamic-HT, a creep life based upon hours of operation is acceptable to staff. However, a creep life based upon a 0.4 percent strain limit criterion is not acceptable to staff because the failure strain was never achieved during the testing of this material. The Metamic-HT Sourcebook needs to be reviewed upon submittal of an amendment or renewal request.

Based on 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. Further, the Certificate of Compliance is conditioned to specify that each package must meet the Acceptance Tests and Maintenance Program of Chapter 8 of the application.

CONDITIONS

The following conditions are included in the Certificate of Compliance:

(a) The package shall be prepared for shipment and operated in accordance with Chapter 7 of the application.

(b) The package must be tested and maintained in accordance with Chapter 8 of the application.

(c) The personnel barrier shall be installed and remain installed during transport if necessary to meet package surface temperature and/or package dose rates.

(d) Air transport of fissile material is not authorized.

(e) The package may be used in the U.S. for shipment of UO_2 fuel meeting the above specifications.

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 180 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. 9325, Revision No. 0,
on October 1, 2009.