NONPROPRIETARY VERSION

SAFETY ANALYSIS REPORT

on

THE HI-STAR 180L Package

(Revision 1)

By

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14	Chapter 6	TH	05/25/2018	283190	HS	4/9/2020		
15	Chapter 7	LEH	05/25/2018	746462	JG	4/9/2020		
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In accordance with the Holtec Quality Assurance Manual and associated Holtec Quality Procedures (HQPs), this document is categorized as a:

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☐ Design Criterion Document (Per HQP 3.4) ☐ Design Specification (Per HQP 3.4)

☐ Other (Specify):

DOCUMENT FORMATTING

The formatting of the contents of this document is in accordance with the instructions of HQP 3.2 or 3.4 except as noted below:

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4. The revision of this SAR is the same as the latest revision of any Chapter in this SAR. Document portions that have not been revised have author, date and VIR # indicated with not applicable "N/A".

5. The figures in this document are not paginated; however, each figure is identified in the Table of Contents.

SAR REVISION STATUS, LIST OF AFFECTED SECTIONS AND REVISION SUMMARY

SAR Title: Safety Analysis Report on the HI-STAR 180L Package

SAR Report No.: HI-2177805	**SAR Revision Number:** 1

ABOUT THIS SAR

This SAR is submitted to the USNRC in support of Holtec International's application to secure a Certificate of Compliance (CoC) under 10 CFR Part 71.

REVISION STATUS AND CONFIGURATION CONTROL

SAR review and verification are controlled at the chapter level and changes are annotated at the chapter level. Chapters include chapter sections, chapter appendices and chapter supplements (as applicable). The revision of this SAR is the same as the latest revision of any chapter in this SAR; however, the whole SAR revision is also leveled up (via Chapter 1) when incorporating a new revision to a licensing drawing that did not require a corresponding change to the text of any SAR chapter. Licensing drawings are controlled individually within the Holtec drawing configuration control system and therefore have their own revision level.

A chapter section is identified by two numerals separated by a decimal (e.g. 1.1). A section in a chapter appendix is identified by a numeral followed by an alphabetical letter followed by a numeral each separated by a decimal (e.g. 1.A.1). Each section and appendix in a chapter begins on a fresh page.

Unless indicated as a "complete revision" in the summary description of change below, SAR changes are indicated by a "bar" in the right page margin and the revision number (annotated in the footer) of the entire chapter is changed. Those whole chapters that remain unchanged by a SAR revision will indicate the revision level corresponding to the initial revision or the last revision in which changes were made and thus will not match the revision of the whole SAR. Revision bars of chapters that remain unchanged by a SAR revision will not be shown.

REVISION SUMMARY

A summary description of change is provided below for each SAR chapter (by chapter section and chapter appendix as applicable). Minor editorial changes to this SAR may not be summarized in the description of change. Summary description of change of previous revisions of chapters, sections or appendices is replaced by "no changes".

Chapter 1: General Information (includes Glossary and Notation)	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
Glossary	Updated definitions of Cooling Time, Leaktight and Non-Fuel Hardware. Added definitions of Nil Ductility Transition (NDT) Temperature, Non-Fuel Waste (NFW), Metamic-HT, Inspection, Testing and Verification. Deleted Metamic. Other minor editorial changes.
1.0	Updated Table 1.0.1 with SI units and other editorial changes.
1.1	Updated Table 1.1.2 by removing repetitive units “inch” from the left column.
1.2	Section 1.2.1.1(b) edited to clarify difference between Waste Packaging and Fuel basket. Section 1.2.2 updated to reference Appendix 7D for allowable contents of waste package. Section 1.2.3 updated to clarify package Plutonium requirement. Other minor editorial changes to Section 1.2, including Table 1.2.2 and Table 1.2.4.
1.3	Updated Cask (10942 Rev. 3) and Baskets (10961 Rev. 4) Licensing Drawings.
1.4	No changes
1.5	Editorial changes to Tables 1.5.1 and 1.5.2.
1.6	No changes
References	No changes

Chapter 2: Structural Evaluation	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
2.0	Minor editorial changes.
2.1	Updated Table 2.1.13 to address Charpy impact testing of monolithic shield cylinders and bottom ring forging. Amended fracture toughness test criteria in Table 2.1.14. Other minor editorial changes.
2.2	Revised material properties in Table 2.2.6 to reflect SA-193 B8S material. Updated Tables 2.2.10 and 2.2.12. Added bolted joint data for inner closure lid port cover to Table 2.2.13. Other minor editorial changes.
2.3	Minor editorial changes.
2.4	No changes.

2.5	No changes.
2.6	Minor editorial changes.
2.7	Revised Subsection 2.7.1.4 and associated figures to reflect updated analysis. Other minor editorial changes.
2.8	No changes.
2.9	No changes.
2.10	No changes.
2.11	Minor editorial changes.
References	Added reference [2.2.10].
Appendix 2.A	No changes.
Appendix 2.B	New appendix.
Chapter 3: Thermal Evaluation	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
3.0	No changes.
3.1	Subsection 3.1.3 modified to reference Figure 7.D.2. Results in Tables 3.1.1, 3.1.2, 3.1.3 and 3.1.4 are revised.
3.2	Impact Limiter properties in Table 3.2.2 updated. Note 1 added in Table 3.2.3. Specific heat of air updated in Table 3.2.7. Values in SI units added in Table 3.2.8. Impact limiter temperature limits added in Table 3.2.10. Seal temperature limits updated in Table 3.2.12.
3.3	Text in subsection 3.3.5 modified to address revised heat load patterns. CFD method to calculated TTB added in subsection 3.3.9. Cyclic vacuum drying evaluation added in subsection 3.3.10 and Table 3.3.15. Figure 3.3.8 added. Evaluation of Gadolinium rods added in subsection 3.3.15 and Table 3.3.14. Figure 3.3.7 added. Note 1 added in Table 3.3.1. Text in Table 3.3.3 modified. Results in Tables 3.3.4, 3.3.5, 3.3.9, and 3.3.11 updated. Section references in Table 3.3.6 revised.
3.4	No changes.
References	References [3.3.5], [3.3.6], [3.3.7] added. Editorial changes made.
Chapter 4: Containment	**Revision Number.: 1**

Section or App.	Summary Description of Change
4.0	No changes.
4.1	Corrected reference to the overall licensing approach on HBF is summarized in Section 1.2. Added Figures 4.1.2, 4.1.3
4.2	No changes.
4.3	No changes.
4.4	No changes.
References	No changes.
Chapter 5: Shielding Evaluation	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
5.0	No changes
5.1	Updated text in Section 5.1.1. Results in Tables 5.1.1 – 5.1.4 are updated.
5.2	Added note about cobalt content in zircaloy. Added cobalt masses to Table 5.2.2/
5.3	Added note about dummy assemblies. Discussion about Holtite-B density and composition is added to Section 5.3.2. Updated Table 5.3.2.
5.4	Added Section 5.4.7 with lead slump sensitivity study. Results in Tables 5.4.2 – 5.4.6 are updated.
References	Added reference [5.4.8]
Chapter 6: Criticality Evaluation	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
6.0	No changes.
6.1	Editorial change in Section 6.1.1 and 6.2.2.
6.2	Editorial change in Section 6.2.2 and 6.2.3.
6.3	Editorial change in Section 6.3.1 and 6.3.2. Discussion of dummy assemblies added to 6.3.6. Section 6.3.10 is updated to reflect new methodology and analyses for partial gadolinium credit. Results in Table 6.3.19 are updated. New Tables 6.3.20 and 6.3.21 are added. Additional figures are added to Figure 6.3.5. New Figures 6.3.6, 6.3.7, and 6.3.9 are added.
6.4	No changes.
6.5	No changes.
6.6	Editorial change in Section 6.6.2.
6.7	No changes.
6.8	No changes.
References	References 6.3.7 and 6.3.8 are added.

Appendix 6.A	Editorial changes are made in Section 6.A.1.
Appendix 6.B	No changes.
Chapter 7: Package Operations	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
7.0	Removed redundant information and other editorial changes.
7.1	Added text for protecting pressure relief devices from pool water entry
	Added text for installation and removal of fuel spacers and quivers
	Added instructions for cleaning and installation of lid bolts
	Clarified requirements for inspections for seals and sealing surfaces
	Added note for equipment used for horizontal lifting of HI-STAR using bottom trunnions
	Updated torque values and notes for Table 7.1.1
	Updated quiver operational requirements
	Other editorial changes.
7.2	Added note for equipment used for horizontal lifting of HI-STAR using bottom trunnions
7.3	Added note for equipment used for horizontal lifting of HI-STAR using bottom trunnions
7.4	No changes
References	No changes
Appendix 7.A	Updated weights in Table 7.A.1 and update figures.
	Updated figures 7.A.3, 7.A.4, 7.A.5, and 7.A.6 to show 180L basket and text for Figure 7.A.8.
Appendix 7.B	Not Used
Appendix 7.C	Not Used
Appendix 7.D	Updated Tables 7.D.1, 7.D.3, 7.D.4, 7.D.5 and Figures 7.D.1 and 7.D.2.
Chapter 8: Acceptance Tests and Maintenance Program	**Revision Number.: 1**
Section or App.	**Summary Description of Change**
8.0	No changes

8.1	Section 8.1.1 updated with visual inspection requirements for Metamic-HT panels. Updated basket welds requirements in Section 8.1.2. Added radiographic testing for Structural and Pressure tests in Section 8.1.3. Updated Section 8.1.4 with requirements for the leak testing specialists that approve the leak testing procedures. Section 8.1.5.4 updated to remove requirement to maintain samples of manufactured lot of neutron shielding material. Section 8.1.5.5 (iii)(2) updated to require verification of FSW weld integrity by either radiography or bend testing of Metamic-HT panels welds, in lieu of requiring that both tests be performed to verify weld integrity. The updated requirements are in accordance with the ASME Code. Also, the requirement that at least one welded coupon from the population of Metamic-HT production panels used for manufacturing must pass the criteria and be documented in the equipment documentation package of the manufactured fuel baskets has been deleted. Section 8.1.8 edited to revise HBF package post-shipment temperature and shielding acceptance criteria and requirements. Other minor editorial changes to Section 8.1, including Tables 8.1.1 and 8.1.5. Updated Table 8.1.4 to better clarify the Metamic-HT Production Coupon Testing requirements. CoC incorporated text bolded throughout section.
8.2	Updated Section 8.2.2 with requirements for the leak testing specialists that approve the leak testing procedures.
References	Ref. [8.1.2] for NDE personnel qualification updated to remove reference to a specific year of the code. Instead the year of the Code as required by specific ASME or ASNT editions will be used.
Appendix 8.A	Seals specifications in Table 8.A-1 through 8.A-4 are updated.

End of Change Descriptions

TABLE OF CONTENTS

CHAPTER 1: GENERAL INFORMATION

CHAPTER 2: STRUCTURAL EVALUATION

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

CHAPTER 3: THERMAL EVALUATION

TABLE OF CONTENTS (continued)

CHAPTER 3 REFERENCES

CHAPTER 4: CONTAINMENT

TABLE OF CONTENTS (continued)

CHAPTER 5: SHIELDING EVALUATION

CHAPTER 5: SHIELDING EVALUATION

TABLE OF CONTENTS (continued)

CHAPTER 6: CRITICALITY EVALUATION

TABLE OF CONTENTS (continued)

CHAPTER 7: PACKAGE OPERATIONS

TABLE OF CONTENTS (continued)

CHAPTER 8: ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

TABLE OF CONTENTS (continued)

GLOSSARY AND NOTATION

GLOSSARY

AFR is an acronym for Away From Reactor

ALARA is an acronym for As- Low- As- Reasonably -Achievable.

AL-STAR is the trademark name of the impact limiter design used in the family of HI-STAR dual-purpose casks.

Basket Shims are aluminum alloy extrusions that serve to maintain the fuel basket coaxial with the cask's storage cavity.

BWR is an acronym for Boiling Water Reactor.

Cask is a generic term used to describe a device that is engineered to hold radioactive waste, as defined in the SAR, in a safe configuration.

C.G. is an acronym for Center of Gravity.

Closure Lid is a generic term to indicate a gasketed flat cover that connects to the top flange of the cask.

CoC is an acronym for Certificate of Compliance.

Commercial Spent Fuel (CSF) refers to nuclear fuel used to produce energy in a commercial nuclear power plant.

Containment Boundary means the enclosure formed by the cask inner shell welded to a bottom plate and top flange plus the closure lid with a gasket to create a hermetically sealed space.

Containment System means the assembly of containment components of the packaging intended to contain the radioactive material during transport.

Cooling Time (or post-irradiation decay time, PCDT) for a spent fuel assembly is the time between reactor shutdown and the time the spent fuel assembly is loaded into the cask. Cooling Time is also referred to as the "age" of the CSF.

Critical Characteristic means a feature of a component or assembly that is necessary for the component or assembly to render its intended function. Critical characteristics of a material are those attributes that have been identified, in the associated material specification, as necessary to render the material's intended function.

Criticality Safety Index (CSI) means the dimensionless number (rounded up to the next tenth) assigned to and placed on the label of a fissile material package, to designate the degree of control of accumulation of packages containing fissile material during transportation.

Damaged Fuel Assembly is a fuel assembly with known or suspected cladding defects, as determined by a review of records, greater than pinhole leaks or hairline cracks, empty fuel rod locations that are not filled with dummy fuel rods, whose structural integrity has been impaired such that geometric rearrangement of fuel or gross failure of the cladding is expected based on engineering evaluation, or that cannot be handled by normal means. Also see fuel defects.

Damaged Fuel Container (or Canister) (DFC) means a specially designed vessel for damaged fuel or fuel debris, which may permit gaseous and liquid media to escape while minimizing dispersal of gross particulates or which may be hermetically sealed. The DFC features a lifting location, which is suitable for remote handling of a loaded or unloaded DFC. Also see Quivers.

DBE means Design Basis Earthquake.

DCSS is an acronym for Dry Cask Storage System.

Design Heat Load is the computed heat rejection capacity of the HI-STAR package with a specific fuel basket with CSF stored in uniform storage with the ambient at the normal temperature and the peak cladding temperature (PCT) at 400^{o}C. The Design heat Load is less than the thermal capacity of the system by a suitable margin that reflects the conservatism in the system thermal analysis.

Design Life is the minimum duration for which the component is engineered to perform its intended function if operated and maintained in accordance with the instructions provided by the system supplier.

Design Report is a document prepared, reviewed and QA validated in accordance with the provisions of Holtec's Quality Program. The Design Report shall demonstrate compliance with the requirements set forth in the Design Specification. A Design Report is mandatory for systems, structures, and components designated as *Important-to-Safety*. The SAR serves as the Design Report for the HI-STAR 180L package.

Design Specification is a document prepared in accordance with the quality assurance requirements of 10CFR71 Subpart H to provide a complete set of design criteria and functional requirements for a system, structure, or component, designated as *Important-to-Safety*. The SAR serves as the Design Specification for the HI-STAR 180L package.

Dose Blocker Parts means the shielding components installed outside the Containment Boundary to enable the cask to meet the dose requirements of 10CFR71 during transport.

Enclosure Vessel (or MPC Enclosure Vessel) (EV) means the pressure vessel defined by the cylindrical shell, baseplate, port cover plates, lid, closure ring, and associated welds that provides confinement for the helium gas contained within the MPC. The EV and the fuel basket together constitute the multi-purpose canister.

Exclusive use means the sole use by a single consignor of a conveyance for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee. The consignor and the carrier must ensure that loading or unloading personnel have radiological training and resources appropriate for safe handling of the consignment. The consignor must issue specific instructions, in writing, for maintenance of exclusive use shipment controls, and include them with the shipping paper information provided to the carrier by the consignor.

Expanded Containment Boundary means a second barrier against leakage for radiological contents of the package engineered into the system for added safety or to meet a specific jurisdictional regulation.

FAT is an acronym for factory acceptance test.

Fastener Strain Limiter is a device to protect the impact limiter fastener bolts from experiencing excessive axial strain.

Fracture Toughness is a material property, which is a measure of the ability of the material to limit crack propagation under a suddenly applied load.

FSAR is an acronym for Final Safety Analysis Report.

Fuel Basket means a honeycombed cavity structure with square openings that can accept a fuel assembly of the type for which it is designed.

Fuel Debris is ruptured fuel rods, severed fuel rods and loose fuel pellets from damaged fuel assemblies and fuel assemblies with know or suspected defects which cannot be handled by normal means due to fuel cladding damage, including container and structures supporting these parts.

Fuel Impact Attenuator (FIA) is the deformable metallic compression element used to close the gap between a stored fuel assembly and the closure lid to eliminate axial rattling of fuel during transport.

GTCC is an acronym for Greater Than Class C waste.

High Burnup Fuel (HBF) is a commercial spent fuel assembly with an average burnup greater than 45,000 MWD/MTU.

HI-STAR is a generic term used to denote the family of metal casks consisting of HI-STAR 60, HI-STAR 100, HI-STAR 180, HI-STAR 180D, HI-STAR HB and HI-STAR ATB 1T.

HI-STAR 180L Cask or cask means the cask that receives and contains the spent nuclear fuel. It provides the containment system boundary for radioactive materials and fulfills all requirements of 10CFR71 to merit certification as a B(U) package.

HI-STAR 180L Package consists of the HI-STAR 180L cask and fuel basket with two impact limiters installed at the extremities, a personnel barrier if required, and the licensed radioactive contents loaded for transport.

HI-STAR 180L Packaging consists of the HI-STAR 180L package without the licensed radioactive contents loaded.

Holtite^{TM} is the trade name for the neutron shielding materials used in the Hi-STAR/HI-STORM family of casks.

Impact Limiters means a set of fully enclosed energy absorbers that are attached to the top and bottom of the cask during transport. The impact limiters are used to absorb kinetic energy resulting from normal and hypothetical accident drop conditions. The HI-STAR impact limiters are called AL-STAR.

Important-to-Safety (ITS) means a function or condition required to transport radioactive materials safely; and to provide reasonable assurance that radioactive materials can be received, handled, packaged, transported, and retrieved without undue risk to the health and safety of the public.

Incore Grid Spacers are fuel assembly grid spacers located within the active fuel region (i.e, not including top and bottom spacers).

Inner Closure Lid means the bolted plate-like structure that forms the Containment Boundary for the cask.

Inspection is an activity controlled by the QC department of the manufacturing plant and used to ensure that the manufactured part or assembly satisfies the specific *critical characteristics* of a *safety significant* SSC set down in its design specification. An inspection is characterized by a procedure-controlled or drawing-controlled examination on the actual SSC (not a specimen). Inspection includes non-destructive examination (NDE) of *safety significant* welds specified in the SAR, such as liquid penetrant examination, radiography, ultrasonic examination, and confirmation of as-built dimensions designated as a critical characteristic therein.

LLNL is an acronym for Lawrence Livermore National Laboratory.

Leaktight means the degree of package containment that, in a practical sense, precludes any significant release of radioactive materials. This degree of containment is achieved by demonstration of a leakage rate less than or equal to 1 x 10^{-7} ref-cm^3/s of air at an upstream pressure of 1 atmosphere (atm) absolute (abs) and a downstream pressure of 0.01 atm abs or less. (Note: Reference Cubic Centimeter per Second (ref-cm^3/s) means a unit of leakage rate of one cubic centimeter of dry air per second at 1 atm abs pressure (760 mm Hg) and 25°C and Reference Air Leakage Rate means the allowable leakage rate converted to reference cubic centimeter per second (ref-cm^3/s).)

License Life means the duration for which the system is authorized by virtue of its certification by the U.S. NRC.

Light Water Reactor (LWR): are nuclear reactors moderated by light water. Commercial LWRs typically utilize enriched uranium and/or the so-called MOX fuel for power generation.

Lowest Service Temperature (LST) is the minimum metal temperature of a part for the specified service condition.

Maximum Normal Operating Pressure (MNOP) means the maximum pressure that would develop in the containment system in a period of 1 year under the heat condition specified in 10CFR71.71(c)(1), in the absence of venting, external cooling by an ancillary system, or operational controls during transport.

Maximum Reactivity means the highest possible k-effective including bias, uncertainties, and calculational statistics evaluated for the worst-case combination of fuel basket manufacturing tolerances.

Metamic-HT is the trade name for the metal matrix composite made by imbedding nano-particles of aluminum oxide and fine boron carbide powder on the grain boundaries of aluminum resulting in improved structural strength properties at elevated temperatures. ("HT" stands for high temperature).

Minimum Enrichment is the minimum assembly average enrichment. Natural uranium blankets are not considered in determining minimum enrichment.

Moderate Burnup Fuel (MBF) is a commercial spent fuel assembly with an average burnup less than or equal to 45,000 MWD/MTU.

Moderator Exclusion means no moderator intrusion into the cask storage cavity under hypothetical accident conditions of transport.

Multi-Purpose Canister (MPC) means the sealed canister consisting of a honeycombed fuel basket for spent nuclear fuel storage, contained in a cylindrical canister shell (the MPC Enclosure Vessel).

NCT is an acronym for Normal Conditions of Transportation as defined in the applicable regulations.

Neutron Absorber Material is a generic term used in this SAR to indicate any neutron absorber material qualified for use in the HI-STAR/HI-STORM fuel basket.

Neutron Shielding means a material used to thermalize and capture neutrons emanating from the radioactive spent nuclear fuel.

Neutron Sources means specially designed inserts for fuel assemblies that produce neutrons for startup of the reactor.

Nil Ductility Transition (NDT) Temperature is defined as the temperature at which metal transfers from ductile phase to brittle phase.

Non-Fuel Hardware (NFH) is defined as Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs), Wet Annular Burnable Absorbers (WABAs), Rod Cluster Control Assemblies (RCCAs), Control Element Assemblies (CEAs), primary and secondary neutron source assemblies (NSAs), water displacement guide tube plugs, orifice rod assemblies, and vibration suppressor inserts. This SAR explicitly specifies which non-fuel hardware, if any, are approved contents.

Non-Fuel Waste (NFW) means high-level waste not used to produce thermal energy in the reactor.

Not-Important-to-Safety (NITS) is the term used where a function or condition is not deemed as *Important-to-Safety*. See the definition for *Important-to-Safety*.

O&M Manual is an abbreviation for operation and maintenance manual.

ORNL is an acronym for Oak Ridge National Laboratory

Outer Closure Lid means the bolted plate-like structure that forms the expanded Containment Boundary for the cask.

Overpack is an alternative term used to denote a cask that contains a basket with a separate enclosure vessel.

Planar-Average Initial Enrichment is the average of the distributed fuel rod initial enrichments within a given axial plane of the assembly lattice.

Post-Core Decay Time (PCDT) is synonymous with cooling time.

PWR is an acronym for Pressurized Water Reactor.

Quiver is a type of damaged fuel container for individual fuel rods which have been removed from their assembly. The fuel rods may be leaking, broken or fragmented (i.e. fuel debris) and purposely punctured (if needed) to relieve internal pressure. In this SAR, quivers are hermetically sealed.

Reactivity is used synonymously with effective neutron multiplication factor or k-effective.

Regionalized Fuel Loading is a term used to describe an optional fuel loading strategy used in lieu of uniform fuel loading. Regionalized fuel loading allows higher heat emitting fuel assemblies to be stored in certain fuel storage locations provided lower heat emitting fuel assemblies are stored in other fuel storage locations.

SAR is an acronym for Safety Analysis Report.

Service Life means the duration for which the component is reasonably expected to perform its intended function, if operated and maintained in accordance with the provisions of this SAR. Service Life may be much longer than the Design Life because of the conservatism inherent in the codes, standards, and procedures used to design, fabricate, operate, and maintain the component.

Short-term Operations means those normal operational evolutions necessary to support radioactive materials loading or unloading operations.

Single Failure Proof means that the handling system is designed so that a single failure will not result in the loss of the capability of the system to safely retain the load. Single Failure Proof means that the handling system is designed so that all directly loaded tension and compression members are engineered to satisfy the enhanced safety criteria of Paragraphs 5.1.6(1)(a) and (b) of NUREG-0612.

SNF is an acronym for Spent Nuclear Fuel (also referred to as CSF in this SAR).

STP is Standard Temperature (298K) and Pressure (1 atm) conditions.

SSC is an acronym for Structures, Systems and Components.

Surface Contaminated Object (SCO) means a solid object that is not itself classed as radioactive material, but which has radioactive material distributed on any of its surfaces. See 10CFR71.4 for surface activity limits and additional requirements.

Testing in this SAR means an activity carried out to quantify the margin of safety of a safety significant part or SSC. Hydrostatic test, Charpy impact test, Helium leak test and Drop weight test are examples of "Tests" invoked in this SAR. The protocol for performing the tests are generally available in national standards but can be superseded by NRC's review and approval of a specialized process developed by the certificate holder for a specific application.

Transport Index (TI) means the dimensionless number (rounded up to the next tenth) placed on the label of a package, to designate the degree of control to be exercised by the carrier during transportation. The transport index is determined as the number determined by multiplying the maximum radiation level in millisievert per hour at one meter (3.3 ft) from the external surface of the package by 100 (equivalent to the maximum radiation level in millirem per hour at one meter (3.3 ft)).

Transport Package consists of a HI-STAR Package with licensed radioactive contents loaded for transport. It excludes all lifting devices, tie-downs, longitudinal stops, rigging, transporters, welding machines, and auxiliary equipment (such as the drying system) used during radioactive wastes loading operations and preparation for off-site transportation.

Transport Packaging consists of a Transport Package without licensed radioactive contents loaded.

Uniform Fuel Loading is a fuel loading strategy where any authorized fuel assembly may be stored in any fuel storage location, subject to other restrictions in the CoC, such as those applicable to non-fuel hardware, and damaged fuel containers.

Undamaged Fuel Assembly is defined as a fuel assembly without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. Fuel assemblies without fuel rods in fuel rod locations shall not be classified as Undamaged Fuel Assemblies unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the original fuel rod(s).

Verification in this SAR means confirmation of the compliance of a characteristic that is not specified by the Code invoked in this SAR or called out as requiring inspection therein or determined by Certificate Holder's licensing organization to not be of significant safety consequence. A Verification can be performed by a person trained under the Certificate holder's quality organization program to establish compliance with a provision of minor safety import in the SAR. Verification covers the whole gamut of activities that don't lie within the purview of Inspection or testing.

Water Tight is defined as a degree of leaktightness that in a practical sense precludes any significant intrusion of water through all water exclusion barriers. This degree of leaktightness ranges from 1 x 10^{-2} std cm^3/s air to 1 x 10^{-4} std cm^3/s air in accordance with ASTM E1003-05 "Standard Test Method for Hydrostatic Leak Testing".

ZPA is an acronym for Zero Period Acceleration.

ZR means any zirconium-based fuel cladding material authorized for use in a commercial nuclear power plant reactor. Any reference to Zircaloy fuel cladding in this SAR applies to any zirconium-based fuel cladding material.

NOTATION

α	Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
d_{max}:	Maximum predicted crush of the impact limiters in a package free drop event.
e:	Elongation in percent (i.e., maximum tensile strain expressed in percentage at which the ASME Code test specimen will fail)
E	Young's Modulus, MPa x 10^4 (psi x 10^6)
f:	Factor-of-Safety (dimensionless)
m:	Metric for bolted joint leakage (Table 2.6.1)
P_b	Primary bending stress intensity
P_e	Expansion stress
$P_L + P_b$	Either primary or local membrane plus primary bending
P_L	Local membrane stress intensity
P_m	Primary membrane stress intensity
Q	Secondary stress
S_u	Ultimate Stress, MPa (ksi)
S_y	Yield Stress, MPa (ksi)
S_m	Stress intensity values per ASME Code
T_c:	Allowable fuel cladding temperature
T_p:	Peak computed fuel cladding temperature
α_{max}:	Maximum value measured or computed deceleration from a package drop event. α_{max} can be parallel or lateral to the centerline of the cask.
β:	Weight percent of boron carbide in the neutron shield

β_{max}: The value of maximum deceleration selected to bound all values of α_{max} for a package drop event. Values for β_{max} in axial and lateral directions are selected from the population of drop scenarios for a particular regulatory drop event (such as §71.73, free drop).

Γ: Total gasket spring back in the unloading cycle

Δ: Initial inter-part gap immediately before impact (Section 2.7)

δ: Lateral (global) deflection of the basket panel

δ_g: Maximum permissible gasket relaxation to maintain leak tightness

δ_{max}: Maximum value of δ

$\in$: Charpy lateral expansion at -28.9 ºC (-20ºF)

ξ: Weight percent of hydrogen in the neutron shield material

ρ: Density

φ: Coefficient of thermal expansion (average between ambient and the temperature of interest)

ψ: Thermal conductivity

θ Orientation of free drop (see Section 2.7.1)

CHAPTER 1: GENERAL INFORMATION

1.0 OVERVIEW

This Safety Analysis Report (SAR)[1] for the HI-STAR 180L Package is a compilation of information and analyses in the format suggested in Reg. Guide 7.9 [1.0.1] to support a United States Nuclear Regulatory Commission (USNRC) licensing review for certification as a spent nuclear fuel transportation package pursuant to the provisions of 10CFR71 Subpart D [1.0.2] and 49CFR173 [1.0.3]. For completeness, consistency with the state-of-the-art, and to facilitate convenient review, the necessary material from USNRC-docketed SARs of various HI-STAR models have been excerpted and placed in this safety analysis report with appropriate edits and with its provenance clearly indicated.

HI-STAR 180L is the model name of a transport cask engineered to serve as a type B(U)F-96 packaging for transporting radioactive material (including commercial spent fuel (CSF), reactor-related GTCC waste, and high-level waste) under exclusive use shipment pursuant to 10CFR71.47. This SAR considers only CSF as the package contents. Table 1.0.1 places the HI-STAR 180L in the context of the HI-STAR family of casks that have been previously licensed by the USNRC.

The HI-STAR 180 Version L transport cask, hereafter also referred to as “HI-STAR 180L” for brevity, is a longer variant of the HI STAR 180 transport cask initially licensed under Docket No. 71-9325 [1.0.4] in 2009. The design and construction of the containment components and shielding components, parallel those of HI-STAR 180 with minor dimensional adjustments to accommodate for a somewhat smaller diameter and longer cask cavity. The HI-STAR 180L Package uses the same set of impact limiters specified for the HI-STAR 180 Package and thus the same licensing drawing. Due to the retained geometric similarities overall, HI-STAR 180L’s shielding, heat rejection and structural performance can remain on par with HI-STAR 180.

The acceptance criteria and analysis models, previously employed in the SAR of HI-STAR 180 are mainly used herein with certain enhancements which are also previously employed in the SARs of HI-STAR 180D, HI-STAR 80 and HI-STAR 190. Therefore, no new acceptance criteria or analysis methodology (previously un-reviewed by the USNRC) has been introduced.

The licensing drawing package in Section 1.3 of this SAR provides the essential details of *important-to-safety* features (and certain details on *not-important-to-safety* features) that are necessary to define its interface dimensions and its physical, structural and shielding characteristics needed to perform the required safety evaluations. For the reader’s convenience and clarity, additional pictorials of the cask and packaging components are provided throughout the SAR.

In this SAR, SI units are the official units of measure (values in U.S. units, if provided, are for information only when accompanied by the equivalent SI unit value).

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[1] See Glossary for definition and abbreviation of terms used throughout this SAR.

Section 1.6 of this SAR discusses quality assurance program and package design control for the HI-STAR 180L Package.

Organization of this Safety Analysis Document

Within safety analysis document, all figures and tables cited are identified by the double decimal system m.n.i, where m is the chapter number, n is the section number, and i is the sequential number. Thus, for example, Figure 1.2.3 is the third figure in Section 1.2 of Chapter 1. Similarly, the following deci-numeric convention is used in the organization of chapters:

a. A chapter is identified by a whole numeral, say m (i.e., m=3 means Chapter 3).
b. A section is identified by one decimal separating two numerals. Thus, Section 3.1 is a section in Chapter 3.
c. A subsection has three numerals separated by two decimals. Thus, Subsection 3.2.1 is a subsection in Section 3.2.
d. A paragraph is denoted by four numerals separated by three decimals. Thus, Paragraph 3.2.1.1 is a paragraph in Subsection 3.2.1.
e. A subparagraph has five numerals separated by four decimals. Thus, Subparagraph 3.2.1.1.1 is a part of Paragraph 3.2.1.1.

Tables and figures associated with a section are placed after the text narrative. SAR review and verification are controlled at the chapter level and changes are annotated at the chapter level. The revision of the overall SAR is the same as the highest revision of any chapter in this SAR. Drawing packages are controlled separately within the Holtec QA program and have individual revision numbers; however, if a drawing is revised, then Chapter 1 is revised to incorporate the drawing. All changes to the SAR including the drawings are subject to a rigorous configuration control under Holtec's QA program approved by the USNRC under Docket No. 71-0784.

Table 1.0.1

HI-STAR Family of USNRC Docketed Transport Packages

Model No.	USNRC Docket and SAR Reference	Year First Certified	Content (Fuel Type or Other)	Approx. Cask Cavity Length (inch [mm])	Approx. Cask ID (inch [mm])	Fuel Package Type: Bare Basket (B) or Canisterized (M)
HI-STAR 100 (Classic)	71-9261 [1.0.7]	1998	BWR & PWR	191 1/8 [4855]	68 3/4 [1747]	M
HI-STAR 100 Version HB		2009	BWR	115 5/16 [2929]	68 3/4 [1747]	M
HI-STAR 100 Version HB GTCC		2018	NFW	115 3/8 [2931]	68 3/4 [1747]	N/A
HI-STAR 100MB	71-9378 [1.0.15]	2019	BWR & PWR	165 3/8 (SL) [4201] 191 1/8 (XL) [4855]	68 3/4 [1747]	M or B
HI-STAR 180	71-9325 [1.0.4]	2009	PWR	140 5/8 [3572]	72 7/8 [1851]	B
HI-STAR 180D	71-9367 [1.0.5]	2014	PWR	115 7/8 [2944]	72 7/8 [1851]	B
HI-STAR 190	71-9373 [1.0.6]	2017	BWR & PWR	190 3/4 (SL) [4845] 213 1/4 (XL) [5417]	76 [1931]	M

Table 1.0.1 (continued)

HI-STAR Family of USNRC Docketed Transport Packages

Model No.	USNRC Docket and SAR Reference	Year First Certified	Content (Fuel Type or Other)	Approx. Cask Cavity Length (inch [mm])	Approx. Cask ID (inch [mm])	Fuel Package Type: Bare Basket (B) or Canisterized (M)
HI-STAR 60	71-9336 [1.0.10]	2009	PWR	139 5/8 [3547]	42 1/2 [1080]	B
HI-STAR 180L	71-9381 This SAR	Foreseen 2021	BWR	178 7/8 [4543]	66 1/2 [1689]	B
HI-STAR 80	71-9374 [1.0.8]	2018	BWR, PWR & NFW	180 1/4 [4579]	48 7/8 [1242]	B
HI-STAR ATB-1T	71-9375 [1.0.9]	Foreseen 2021	NFW	N/A	N/A	N/A

Note: Dimensions are taken from respective licensing drawing packages approved at the time of this writing and are provided here for information only. Dimensions are nominal, may have been converted from SI units and/or may be rounded to the nearest 1/8 inch. N/A means “not applicable”.

1.1 INTRODUCTION TO THE HI-STAR 180L PACKAGE

The HI-STAR 180L Package, like the HI-STAR 180 Package, is a cylindrical metal cask with impact limiters engineered to be shipped by rail, road and seagoing vessel. The HI-STAR 180L cask is engineered as a variant of the HI-STAR 180 cask and as a result, all key design concepts have been previously demonstrated safe and reliable. Figures 1.1.1 and 1.1.2 provide pictorials of the exterior of the HI-STAR 180L Cask and HI-STAR 180L Packaging, respectively.

The HI-STAR 180L Cask containment system is engineered to parallel the anatomical design and construction of the containment system of HI-STAR 180 [1.0.4]. More specifically, the containment system materials of construction, welding joint details, NDE requirements, seal joint type, and Code of construction for the HI-STAR 180L Packaging, are identical or similar to those of the HI-STAR 180 Packaging. Furthermore, the double closure lid system of HI-STAR 180L is identical to the double closure lid system of HI-STAR 180.

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Finally, the structural design embodiment, construction, and materials for the HI-STAR 180L Package AL-STAR impact limiters are identical to those used in the HI-STAR 180 Package (Docket No. 71-9325) and are fully described in this SAR. In fact, the same impact limiter licensing drawing used in the HI-STAR 180 docket is used in the HI-STAR 180L docket.

The HI-STAR 180L Package complies with all of the requirements of 10CFR71 for a Type B(U)F-96 package. In particular, the prescribed maximum normal operating pressure (MNOP) of 700 kPa (100 lb/in^2) for a type B(U) package is observed. No pressure relief device or feature intended to allow continuous venting during transport is provided on the HI-STAR 180L containment boundary (10CFR71.43(e) and 10CFR71.43(h)). Therefore, there is no pressure relief device or feature that may permit release of radioactive material under the tests specified in 10CFR71.73. Analyses that demonstrate the compliance of the HI-STAR 180L Package with the requirements of Subparts E and F of 10CFR71 are provided in this SAR[1].

The criticality safety index (CSI) for the HI-STAR 180L Package is 0.0, as an unlimited number of packages will remain subcritical under the procedures specified in 10CFR71.59(a) (Subsection 6.1.3 provides the determination of the CSI). The transport index (TI) is in excess of 10 for the HI-STAR 180L Packaging with design basis fuel contents (Section 5.0 provides the determination of the TI). Therefore, the HI-STAR 180L Package must be transported by exclusive use shipment (10CFR71.47) for any shipment of spent nuclear fuel. An empty but previously loaded HI-STAR 180L Package may be shipped as an excepted package provided the descriptions and limits for surface contaminated objects (SCO) material set forth in 10CFR71.4 are satisfied.

The HI-STAR 180L Packaging is designed to ensure safe transport of SNF. Some of the key features of the HI-STAR 180L Packaging that enhance its effectiveness are:

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In this SAR, the HI-STAR 180L Package is demonstrated to muster acceptable response to normal and accident conditions that are deemed to meet the 10CFR71 certification requirements for post-NCT and post-HAC containment system integrity, maintenance of sub-criticality

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[1] The HI-STAR 180L package is also designed to comply with SSR-6 (2012) [1.1.1] Type B(U)F package requirements. Certain acceptable criteria, methodology etc. may be stated or specified to bound both 10CFR71 and SSR-6 requirements; however, no specific SSR-6 paras. are referenced in this SAR.

margin, radiation level limits, and adequate heat rejection capability. In particular, it is shown that:

i. The bolted double closure lid system provides the necessary set of barriers to preclude loss of sequestration of the Waste Package under the normal conditions or hypothetical accidents conditions of transport.
ii. The confinement of the fuel pellets by their fuel rods inside the cask's storage cavity is preserved in the wake of normal conditions and hypothetical accidents conditions of transport.
iii. The cask's containment boundary is preserved as prescribed in 10CFR71.51 in the wake of normal conditions and hypothetical accidents conditions of transport.
iv. The radiation level limits prescribed in 10CFR71.51 are met in the aftermath of normal conditions and hypothetical accidents conditions of transport.
v. The cask cavity space will not sustain water intrusion under the normal conditions and hypothetical accidents conditions of transport as discussed in Subsection 1.2.1 of this SAR.
vi. The cask cavity space will not sustain water intrusion under the deep submergence scenario of 10CFR71.61.
vii. The cask with fissile material waste packages will remain subcritical pursuant to 10CFR71.55.

In summary, the HI-STAR 180L Package will unconditionally satisfy the performance requirements for transport packages under the postulated normal and accident transport scenarios of 10CFR71.

This SAR supports a licensed life of the HI-STAR 180L package of 5 years, after which a renewal by the USNRC is based upon an affirmative safety assessment to support such renewal. Even though the safety analysis is not required to address more than 5 years, all safety evaluations are based on a design or service life of at least 60 years to provide a suitable degree of conservatism. This is accomplished by using materials of construction that have been exhaustively tested and determined capable of withstanding HI-STAR 180L's operating environments without degradation and with negligible reduction if any, in their capability to render their intended function (materials of construction and testing are discussed in Section 1.2 and Section 2.2 of this SAR). A maintenance program, as specified in Chapter 8, is implemented to ensure the HI-STAR 180L Package will meet its Design Life of 60 years. The technical considerations that assure the HI-STAR 180L performs its design functions throughout its Design Life include all areas germane to the long-term integrity of the system, such as:

- Consideration of Exposure to Environmental Effects
- Consideration of Material Corrosion, Degradation and Aging Effects
- Provision of Preventive Maintenance and Inspections
- Consideration of Structural Fatigue, Brittle Fracture and Creep Effects
- Maintenance of Helium Atmosphere
- Assurance of Fuel Cladding Temperatures below NRC Prescribed Limits
- Assurance of Long-Term Effectiveness of the Neutron Absorber

Table 1.1.1

Permissible "Waste Packages" for HI-STAR 180L (Note 1 and 2)

Waste Package Model No. (Notes 3 and 4)	Fuel Package or NFW Package	Fuel or Waste Type	Canisterized or Bare Basket	Basket Structural Material and Neutron Absorber	Damaged Fuel Container or Other Secondary Packaging
F-69L	Fuel Package	BWR	Bare Basket	Metamic-HT	Quivers (Notes 5)

Notes:

1. Refer to SAR Subsection 1.2.2 and Chapter 7 for specific package contents corresponding to the listed waste packages.
2. Canister-based fuel packages and non-fuel waste packages are not qualified for transportation at this time.
3. See licensing drawing package in SAR Section 1.3.
4. The numerical identifier in the fuel basket model name indicates the number of fuel storage locations and the maximum number of assemblies permitted for transport.
5. Refer to Subsection 1.2.2, Chapter 2 and Chapter 7 for specifications and limitations.

Table 1.1.2

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

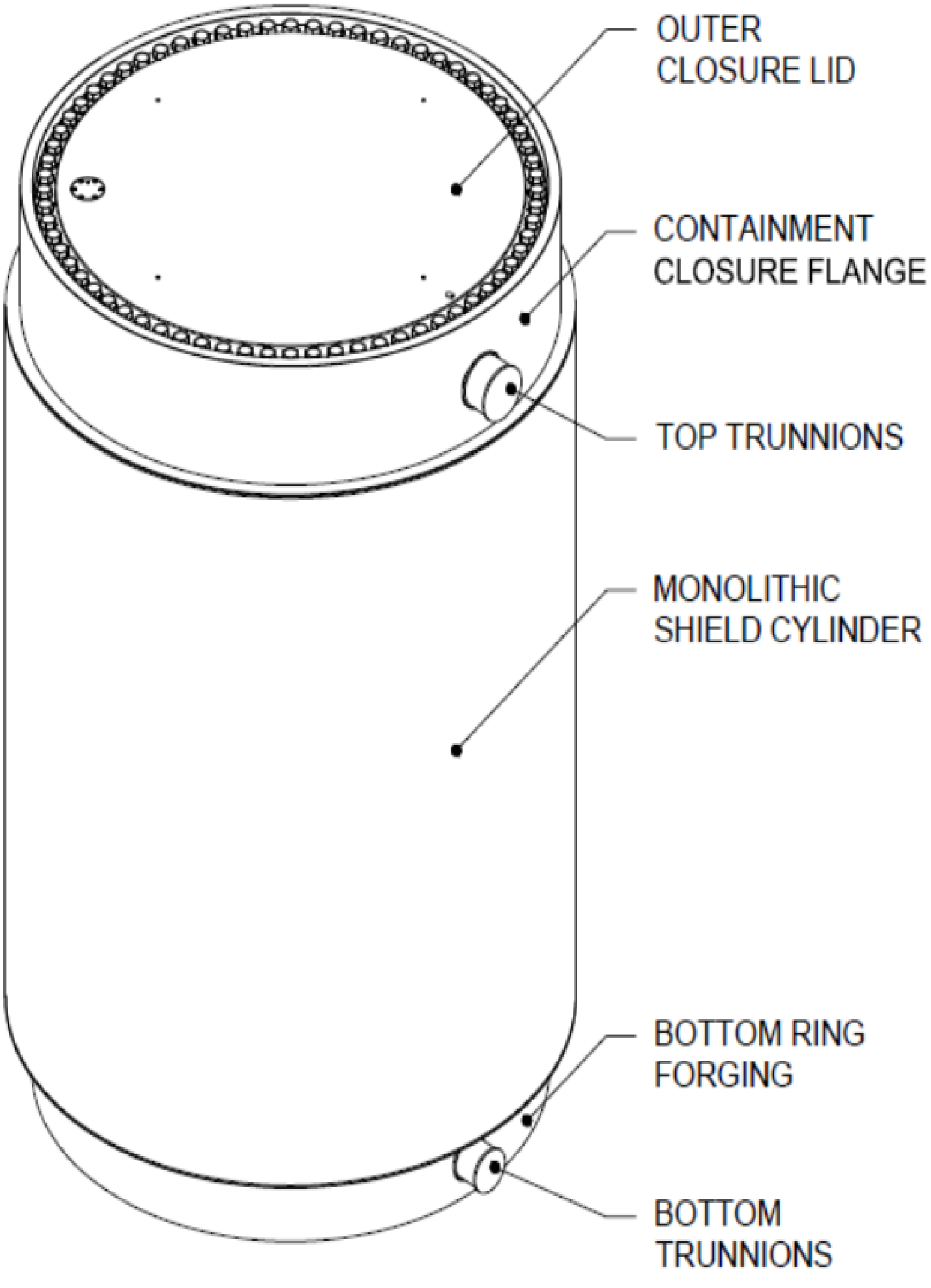
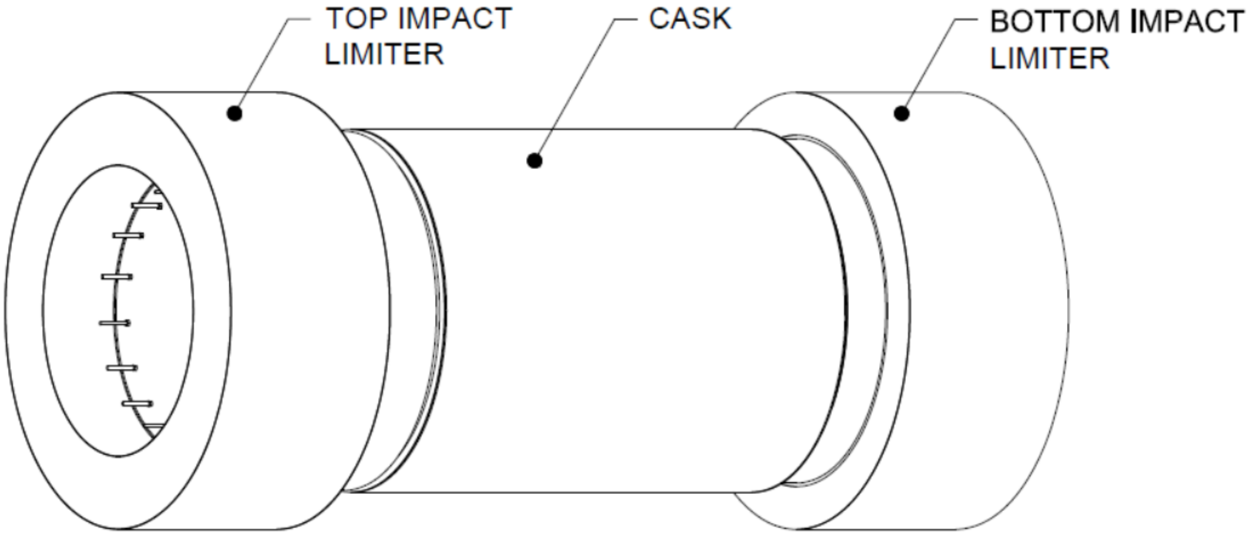


FIGURE 1.1.1 – EXTERIOR PICTORIAL VIEW OF THE HI-STAR 180L CASK

(Refer to the drawing package in Section 1.3 for details)



Note: Personnel Barrier Not Shown.

FIGURE 1.1.2 – EXTERIOR PICTORIAL VIEW OF HI-STAR 180L PACKAGING

(Refer to the drawing package in Section 1.3 for details)

1.2 DESCRIPTION OF PACKAGING COMPONENTS AND THEIR DESIGN & OPERATIONAL FEATURES

1.2.1 Packaging

1.2.1.1 Major Packaging Components and Packaging Supports and Restraints

The HI-STAR 180L Packaging consists of the four major components, namely the Cask, the Waste Packaging, Impact Limiters and Personnel Barrier discussed in (a) through (d) below. Additionally, auxiliary equipment, in the form of packaging supports and restraints typically necessary for package transport, is described in subparagraph (e) below.

a. Cask

The main function of the cask is containment and shielding. The containment of the radiological contents is provided by a nickel steel (also referred to as “cryogenic steel”) shell welded to a nickel steel baseplate at the bottom and a suitably machined nickel steel forging at the top, which is equipped with machined surfaces to fasten two independent cryogenic steel closure lids, each equipped with concentric metallic seals. The fully cryogenic steel weldment and the cryogenic steel closure lids define the “Containment System Boundary” for the cask. The Containment System Boundary, including both closure lids, is designed and manufactured to ASME Section III Division 1, Subsection NB [1.2.1] as clarified in this SAR. Cask design details are shown in the drawing package in Section 1.3.

For purposes of description, the HI-STAR 180L cask is divided into six constituent parts, each with distinct roles and features, as follows:

1) The Containment Shell: The innermost cylindrical member of the cask containment system.
2) Cask Bottom Region (CBR): The CBR consists of a thick nickel steel forging, equipped to enable a high integrity butt weld joint with the containment shell.
3) Cask Top Region (CTR): The CTR consists of a massive nickel steel forging, the Containment Top Forging: The CTR includes the trunnions which are the cask’s interfacing lift points.
4) Closure Lid System (CLS): The CLS consists of two specially shaped lids, each with two machined concentric grooves to provide containment protection. The bolted lid joints are “controlled compression” joints engineered to meet the leak-tight criterion of ANSI N14.5 [8.1.6] under the normal and hypothetical accident conditions of transport.
5) Gamma Capture Space (GCS): The GCS refers to the monolithic shield cylinders which renders the principal function of blocking gamma radiation.
6) Neutron Capture Space (NCS): The NCS refers to the sector pockets within the monolithic shield cylinders that are filled with Holtite-B and whose principal function is to block the neutrons accreted by the contained CSF. This space is non-structural. The sector pockets contain pressure relief protection (as shown in the drawing package

in Section 1.3) to prevent their over-pressurization in the case of off-gassing of the shield material under a fire accident.

The above description of the constituent parts is summarized in Table 1.2.1 for ease of reference.

As with the previously licensed HI-STAR 180 Cask, all materials used in the HI-STAR 180L Cask containment system boundary are widely used in low temperature applications and regardless of their product form, are of compatible metallurgical genre and thus are readily weldable to each other. The monolithic shield cylinder is made of alloy steel with excellent impact resistant properties at low temperatures. As shown in the drawing package in Section 1.3, the monolithic shield cylinder is configured from several short annular monolithic shield cylinders stacked on top of each other to provide gamma and neutron shielding around the containment shell and active fuel region to the maximum extent. The HI-STAR 180L monolithic shield cylinder is identical to the HI-STAR 180 monolithic shield cylinder in construction, material and design concept. The Holtite pocket width is optimized specifically for the HI-STAR 180L package contents described in Subsection 1.2.2 of this SAR.

As with the previously licensed HI-STAR 180 Cask, the capacity to reject heat in an efficient manner is further ensured by installing the monolithic cylinder on the Containment Shell using the classical shrink fit process. For this purpose, the external surface of the containment shell and the internal surfaces of the monolithic cylinders are machined with a high degree of accuracy. The manufacturing process followed to assemble the containment shell and monolithic shield cylinder is engineered to place the containment shell in a state of slight compressive hoop stress that is well below its material yield strength, and the monolithic shield cylinders in a modest tensile hoop stress state. The stress levels in the containment shell and monolithic shield cylinder are sufficiently small to prevent any inelastic effects, yet they help enhance the axial buckling strength of the containment shell under impactive axial loadings. However, this buckling capacity increase is conservatively not accounted for in the structural analyses of the Containment Shell in this SAR.

The HI-STAR 180L Cask features two removable top trunnions (inserted into the containment closure flange) qualified as lifting points. In addition, the HI-STAR 180L Cask is equipped with two removable bottom trunnions installed in the bottom forging. The bottom trunnions may be used as turning trunnions or may be used as lifting trunnions for horizontal lifting and handling in unison with the top trunnions.

b. Waste Packaging

Waste packages qualified for use with HI-STAR 180L are listed in Table 1.1.1. Waste packages may take various forms such as fuel packages or non-fuel waste (NFW) packages. Waste packages are also identified as either canisterized, where the waste package is sealed in a separate canister, or not canisterized (also referred to as a bare waste package). Therefore, the waste packaging discussed herein is dependent on the waste package. Quivers and dummy fuel assemblies are discussed in Subsection 1.2.2.

F-69L Fuel Basket

F-69L, a bare basket BWR fuel package, is currently the sole waste package qualified for use in the HI-STAR 180L Package. The F-69L fuel basket is the sole major component of the F-69L fuel package.

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c. Impact Limiters

Two impact limiters are installed at the two extremities of the HI-STAR 180L Cask and provide energy absorption capability for the normal and hypothetical accident conditions of transport. The impact limiters are referred to as AL-STAR 180 impact limiters since it is the same design used in the HI-STAR 180 Transport Package under Docket No. 71-9325. The impact limiters feature extremely rigid cylindrical barrels (backbone structures) that engage the top and bottom of the cask with a snug fit. Impact limiter adapters are used in order to enable the AL-STAR 180 impact limiters to properly attach to the HI-STAR 180L Cask as shown in the licensing drawing package in Section 1.3. Each impact limiter backbone is enveloped by crushable material, which in turn is enclosed by a stainless-steel skin. The selection of the crushable material ensures that the performance of the impact limiters will be essentially insensitive to the ambient environment (temperature and humidity). The following key design features typify the AL-STAR 180 impact limiters:

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Impact limiter and impact limiter attachment details are shown in the drawing package in Section 1.3. The *critical characteristics* and the attainment of the required critical characteristics through a comprehensive qualification process and production testing are discussed in Chapters 2 and 8, respectively.

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d. Personnel Barrier:

During transport the cask lies in a horizontal orientation with the two impact limiters on its two extremities. Pursuant to 10CFR71.43(g), a personnel barrier is placed over the cask to provide a physical barrier against manual access to hot, 50°C (122°F) or higher, accessible areas of the package and limit hot accessible areas of the package to less than 85°C (185°F). According to Chapter 3 of this SAR the temperature of the accessible surfaces of the package exceeds 50°C (122°F) but is maintained less than 85°C (185°F) with the use of the personnel barrier; therefore, transport of the HI-STAR 180L Package must be performed under exclusive use shipment and with the personnel barrier installed.

The personnel barrier is not a structural part of the HI-STAR 180L Packaging but is designated as a packaging component for routine conditions of transport. Since the personnel barrier is not a structural part of the HI-STAR 180L packaging, it is not required to remain in place under normal condition tests in 10CFR71.71.

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PROPRIETARY INFORMATION WITHHELD PER 2.390

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To meet the above design criteria, the Personnel Barrier is typically made as on open lattice, sturdy cage type structure to ensure the natural convection and radiation process are not significantly affected (Figure 1.3.2 shows an illustration of a typical Personnel Barrier). A typical personnel barrier has been analyzed and shown to have a minor effect on the transport package heat rejection (see Chapter 3). If a canopy type construction is employed then it must use optimally shaped louvers to promote up flow of heated air and wire mesh screens in a judicious combination to meet the above thermal criterion.

e. Packaging Supports and Restraints:

The HI-STAR 180L Package lends itself to a horizontal packaging assembly for transport as shown in Figure 1.3.1 and is engineered for shipment by seagoing vessel, railroads and roadways using appropriate supports and restraints. Illustrative examples of packaging supports and restraints for rail transport is provided in Figure 1.3.2. The arrangement of packaging supports and restraints may vary as long as the package is properly secured and qualified for the specific mode of transport. Tapered wedge shims that close the gap between the impact limiters and the axial restraints (longitudinal stops) of the transport vehicle are examples of auxiliary equipment that may be used to restrain the package against axial movement. Non-integral appurtenances to the cask, such as the transport cradle, longitudinal stops, support saddles, tie down system and wedge shims are not structural parts of the HI-STAR 180L Package and, as such, are not designated as packaging components.

Packaging supports and restraints shall be designed as appropriate for either rail, road (i.e. public highway) or seagoing vessel transport applications in compliance with the applicable requirements of 10CFR Part 71 and the applicable requirements of 49CFR as indicated by 10CFR71.5, with additional consideration to the applicable industry (railroad, road and sea transportation) standards. More specifically, 10CFR71.45(a) and (b) requirements must be complied with. For shipments outside the U.S., foreign competent authority requirements or other international guidance may apply.

In the HI-STAR 180L transport package configuration, the cask trunnions are not qualified to be used to lift the HI-STAR 180L Package (i.e., loaded cask with impact limiters) and in fact the skirts on the impact limiters prevent access to all trunnion areas. Therefore, in the package transport configuration, there are no lifting attachments remaining that are a structural part of the package and there is no other structural part of the package that could be inadvertently used to lift the package that must be rendered inoperable per 10CFR71.45(a).

1.2.1.2 Overall Packaging Dimensions and Weight

Overall packaging dimensions are provided in the drawing package in Section 1.3. Overall nominal and/or maximum weights for operational purposes are provided in Appendix 7.A and the drawing package in Section 1.3. Additional weights are provided in Section 2.1 for safety analysis purposes. The weight of the package contents is provided in Subsection 1.2.2 below and Appendix 7.D as applicable.

The maximum gross transport weight of the HI-STAR 180L Package, (without the personnel barrier) is marked on the packaging nameplate.

1.2.1.3 Containment Features

The Containment System forms an internal cylindrical cavity for housing the fuel basket. A schematic of containment system components is shown in the drawing package in Section 1.3 and also in figures in Chapter 4 of this SAR (all components with the primary function of containment are shown in these schematics). As shown in these schematics, the massive inner closure lid system defines the containment boundary. The outer closure lid system along with the inter-lid space also meets the design and manufacturing criteria to be merged with the inner containment space to define an expanded containment boundary. The expanded containment boundary will play its role only in the unlikely event that the boundary defined by the inner lid fails to hold.

Both closure lids have been engineered to perform the containment function with final qualification by leak testing according to ANSI N14.5 [8.1.6] as specified in Chapter 8, Table

8.1.2 and to the leakage acceptance criterion specified in Chapter 8, Table 8.1.1. Each closure lid joint features equally proficient seals, one seal serving as a back-up to the other seal.

1.2.1.4 High Burnup Fuel Transportation and Moderator Exclusion Features

The HI-STAR 180L packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF) in the same manner as HI-STAR 180 (docket number 71-9325) and HI-STAR 180D (docket number 71-9367). In recognition of the uncertainty surrounding the cladding material properties of HBF, a multi-layered safety-focused strategy to transport HBF has been adopted for HI-STAR 180L.

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The overall licensing approach (including the defense-in-depth approach) for HI-STAR 180L from both safety and regulatory compliance perspectives is summarized in Table 1.2.4.

In conclusion, the combination of conservative licensing approach including conservative assumptions and analyses in conjunction with a robust package design, provide a reasonable assurance that the HI-STAR 180L Package containing HBF will protect public health and safety under all operational scenarios postulated by 10 CFR Part 71.

1.2.1.5 Neutron and Gamma Shielding Features

The HI-STAR 180L Cask is equipped with shielding features similar to those of the HI-STAR 180 Cask. The HI-STAR 180L Packaging (with or without the personnel barrier) ensures the external radiation standards of 10CFR71.47 under exclusive shipment are met when loaded with design basis fuel. The drawing package in Section 1.3 provides information on the configuration of neutron and gamma shielding features.

The initial attenuation of gamma and neutron radiation emitted by the radioactive spent fuel is provided by the fuel basket and the fuel basket shims. However, most of the shielding in the transport package is contained in the body of the cask and consists of neutron and gamma shielding.

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The arrangement of the shielding materials shown in the licensing drawings reflects the design optimization carried out for the HI-STAR 180L cask.

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Throughout this SAR, the term "Holtite" when used refers to "Holtite-B".

1.2.1.6 Criticality Control Features

Criticality control in the HI-STAR 180L Packaging is provided by the coplanar grid work of the Fuel Basket honeycomb, made entirely of the Metamic™-HT extruded boron carbide impregnated metal matrix composite plates. Metamic-HT is the neutron absorber in the HI-STAR 180L Packaging. Thus the neutron absorber is not attached to the cell walls by a mechanical means that may be vulnerable to detachment. Hence, the locational fixity of the neutron absorber is guaranteed.

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There are no moderators in the HI-STAR 180L Packaging.

Metamic-HT was first certified by the USNRC in 2009 for use in the HI-STAR 180 transport application under Docket No. 71-9325 as the sole constituent material for the fuel basket types F-37 and F-32 for transporting high burn up and MOX fuel. Subsequently, MPC-68M, a Metamic-HT fuel basket equipped multi-purpose canister for BWR fuel was certified in the HI-STORM 100, Docket No. 72-1014. All fuel baskets presently used in HI-STORM FW (Docket No. 72-1032), HI-STORM UMAX (Docket No. 72-1040), HI-STAR 180D (Docket No. 71-9367) and HI-STAR 190 (Docket # 71-9373) utilize Metamic-HT for both neutron absorbing and structural functions. All fuel baskets developed in Holtec's dry storage and transport programs since 2007 employ Metamic-HT. The properties with minimum guaranteed values (MGVs) of primary properties are contained in Table 2.2.8. Secondary properties (invariant properties) are provided in Table 1.5.2

Additional criticality control contribution is provided by the fuel's own burn up; however, burnup is not presently credited in this SAR.

1.2.1.7 Lifting and Tie-Down Devices

Lifting trunnions are attached to the cask containment closure flange for lifting the cask body in vertical and horizontal positions. The lifting trunnions are located 180 degrees apart in the sides of the top flange. Two additional trunnions are attached near the bottom extremity of the cask and located 180° apart to provide a built-in pivoting axis for cask rotation. The bottom trunnions may be slightly off-center to facilitate the rotation direction of the cask. Lifting trunnions are conservatively qualified to independently lift the cask in compliance with NUREG 0612 stress limits. The bottom trunnions may also be used as lifting trunnions to lift, rotate and handle the cask from vertical to horizontal but must be used in conjunction with top lifting trunnions and qualified as specified in Section 8.1.

Lifting trunnions are designed in accordance with 10CFR71.45 and NUREG 0612 (per Chapter 2), load tested in accordance with ANSI N14.6 (per Chapter 8), manufactured from a high strength alloy.

The lifting, upending, and downending of the HI-STAR 180L Package requires the use of external handling devices. A lift yoke is typically utilized when the cask is to be lifted and handled vertically and to perform upending and downending. Upending and downending are typically performed with the cask pivoting on an ancillary tilting device specifically designed for this purpose. Lift yokes, other purposed structural/mechanical lifting devices, and/or slings may be used to lift the cask in the horizontal orientation.

There is no system of tie-down devices that is a structural part of the package. For additional discussion on tie-downs, see Subparagraph 1.2.1.1(e) on package supports and restraints.

1.2.1.8 Heat Transfer Features

The HI-STAR 180L Package can safely transport SNF by maintaining the fuel cladding temperature below the limits for normal and accident conditions consistent with the guidance in the NRC Interim Staff Guidance, ISG-11 Rev. 3 [1.2.7]. The temperature of the fuel cladding is dependent on the decay heat and the heat dissipation capabilities of the cask. The SNF decay heat is passively dissipated without any mechanical or forced cooling. The primary heat transfer mechanisms in the HI-STAR 180L Package are conduction and thermal radiation.

The free volume of the cask cavity containing the waste package and the cask inter-lid space are filled with high purity helium. Besides providing an inert dry atmosphere for the fuel cladding, the helium gas also provides conductive heat transfer between each assembly and the surrounding basket walls and across any gaps between the metal surfaces inside the containment system. Metal conduction transfers the heat throughout the fuel basket, through the containment system boundary, and finally through the monolithic shield cylinder and other exterior cask components. The cask storage cavity and inter-lid spaces are backfilled with helium to pressures specified in Table 7.1.4.

The distinguishing features of the HI-STAR 180L cask that enables it to dissipate heat efficiently are:

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1.2.1.9 Internal Support Features

The HI-STAR 180L Package is equipped with basket shims engineered to provide near conformal support for the fuel basket and facilitate heat transfer.

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1.2.1.10 Anti-Rotation Devices

The HI-STAR 180L Package is equipped with internal anti-rotation devices to prevent the rotation of the fuel basket and basket shims within the cask.

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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1.2.1.11 Packaging Markings

Each HI-STAR 180L Packaging shall have a unique identification plate with appropriate markings per 10CFR71.85(c). The identification plate shall not be installed on a HI-STAR 180L cask until it has successfully passed the various in-process tests and NDEs set forth in this safety analysis and satisfied the Final Acceptance Test (FAT) criteria under Holtec's Quality Assurance Program.

1.2.2 Contents of Package

The HI-STAR 180L Package is classified according to Regulatory Guide 7.11 [1.2.2] as a Category I Type B package to encompass all approved contents.

The allowable radioactive waste or "allowable content" corresponding to each qualified waste package identified in Table 1.1.1 is specified in Appendix 7.D. At this time, the allowable content specified in Appendix 7.D solely applies to F-69L.

The HI-STAR 180L package when equipped with a fuel package is designed for transportation of spent fuel from a nuclear power plant over the plant's entire life cycle, including transport of all fuel assemblies after the plant shutdown. The range of cask content may potentially encompass a wide range of fuel parameters, including the following:

- Spent fuel with a wide initial enrichment range; and
- Lower burnup fuel with long cooling times from earlier cycles of the plant; and
- High burnup fuel with intermediate cooling times from current plant operations; and
- High and moderate burnup fuel with short cooling times to be transported after plant shutdown.

The resulting loading conditions that need to be satisfied are discussed in the remainder of this subsection and provided in Appendix 7.D.

Table 7.D.1 lists the acceptable physical characteristics of the fuel assemblies qualified for transportation in the HI-STAR 180L package. Assemblies are limited to the maximum initial enrichment given in Table 7.D.1.

The maximum mass of radioactive material permitted for transport in the HI-STAR 180L Package is shown in Table 1.2.2.

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The radioactive and fissile material is in the form of solid fuel pellets with a maximum fuel density shown in Table 1.2.2. There are no moderating material 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.

The maximum weight of the radioactive payload is shown in Table 1.2.2.

Figure 7.D.1 provides cross sectional view of the fuel basket storage cell layout. The storage cells are numbered as shown in these figures to facilitate the specification of fuel loading conditions.

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1.2.3 Special Requirements for Plutonium

Plutonium (in any form) other than from spent fuel pellets is not authorized for transport.

1.2.4 Operational Features

The HI-STAR 180L Packaging has been developed to facilitate loading and unloading of fuel with ALARA protection against handling accidents and a minimum number of handling evolutions by simplicity of handling and optimum payload capacity. Operations are similar to other HI-STAR models (see Table 1.0.1) which means there are no complex operational features or steps that that may encumber the crew with excessive dose.

Similar to the HI-STAR 180 cask, the HI-STAR 180L cask closure lids are equipped with penetrations (ports) for drying and inerting the cask's content. The port configuration on the inner closure lid is configured to minimize radiation streaming as indicated in the drawing package in Section 1.3. The inner closure lid ports shown in the drawing package in Section 1.3 are typical ports equipped with port plugs. Port caps, in lieu of plugs, are equally effective and may be used. The configuration of the outer closure lid access port cover and port cover subcomponents likewise have redundant closure.

Operations can be briefly summarized as follows:

1. The water filled cask is loaded with authorized contents, then dewatered, dried, helium backfilled, bolted shut and leakage tested.
2. Impact Limiters are attached to the HI-STAR cask and the package is transported on a transport frame in the horizontal orientation with personnel barrier.

The HI-STAR 180L Packaging when loaded and sealed in accordance with the guidance in Chapter 7, is a completely passive system. Chapter 7 provides the essential elements of cask operations. Chapter 8 provides the acceptance criteria and maintenance requirements for the package and packaging.

Table 1.2.1

Major Constituent Parts of the HI-STAR 180L Cask

Item No.	Part Name	Principal Function	Comments
1	Cask Containment Shell (CCS)	Containment of radionuclides, pressure retention and radiation blockage	Items 1, 2, 3 and 4 comprise the cask's containment system; all parts must meet ASME Section III Subsection NB in all respects.
2	Cask Bottom Region (CBR)	Containment of radionuclides, pressure retention and radiation blockage; Mounting surface for the bottom impact limiter	The only structural welded joint is with the containment shell which is butt welded and volumetrically examined to meet the ASME code. The Cask Bottom Region provides the location for the cask bottom trunnions.
3	Cask Top Region (CTR)	Containment of radionuclides, pressure retention and radiation blockage; seating surface for the Double Closure Lid system and mounting surface for the top Impact Limiter	The only structural welded joint is with the containment shell which is butt welded and volumetrically examined to meet the ASME code. Top Forging provides the location for the cask top trunnions and the location for a fine-machined gasket seating surface for each Closure Lid.
4	Double Closure Lid System (DCLS)	Defines the top region of the Containment Boundary. Serves to provide access to the Waste Package within.	Must meet Section III Subsection NB of the ASME Code and must be sufficiently robust to withstand loadings under accident conditions of transport.
5	Gamma Capture Space (GCS)	Blockage of gamma radiation, rendered by the mass of monolithic steel cylinders fabricated and installed to preclude macro-voids and large spatial discontinuities.	The annular space defined by the external surface of the Containment Shell on its inside and the Monolithic Shield Cylinder on its outside. This annular space contains the Neutron Capture Space (NCS).
6	Neutron Capture Space (NCS)	Attenuation of neutrons, rendered by Holtite	The sector pockets within the monolithic shield cylinders that are filled with Holtite-B and whose principal function is to block the neutrons accreted by the contained CSF.

Table 1.2.2

Fuel Assembly and Package Payload Physical Characteristics

Fuel Assembly Type	BWR per Appendix 7.D
Clad Material	Zr
No. of Fuel Rod Locations	Refer to Table 7.D.1 and Table 7.D.2
Design Initial Heavy Metal Mass	
Fuel Rod Clad O.D.	
Fuel Rod Clad I.D.	
Fuel Pellet Dia.	
Fuel Rod Pitch	
Active Fuel Length	
No. of Water Rods	
Water Rod Thickness	
Channel Thickness	
Maximum Fuel Assembly Length	
Minimum Cooling Time for Assemblies	
Maximum Fuel Assembly Mass	
Maximum Fuel Assembly Initial Enrichment	
Maximum Package Payload (kg) (radioactive waste contents only)	22,770 (F-69L Fuel Basket)
Maximum Package Quantity of Radioactive Material (kg)	12,852
Maximum Package Quantity of Fissile Material (kg)	643
Maximum Fuel Oxide Pellet density (g/cc)	10.77
Maximum Overall Cask Heat Load (kW)	Table 7.D.1

Note 1: The supporting safety analyses consider tolerances as appropriate to the specific evaluation to achieve overall conservatism.

Table 1.2.3

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 1.2.4:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 1.2.1

[WITHHELD IN ACCORDANCE WITH 10CFR2.390]

1.3 ENGINEERING DRAWINGS

This section contains a HI-STAR 180L Drawing Package prepared under Holtec's QA Program. This drawing package contains the details of the safety features considered in the analysis documented in this SAR. In particular, this drawing package includes:

- A list of materials and parts, including their safety significance status.
- All dimensions that define the package's *Critical Characteristics*.
- All interface dimensions to ensure fit-up between mating parts.
- Requisite information on *safety significant* parts such as the containment boundary parts as well as processes such as welding, non-destructive examinations, including appropriate weld symbols and NDE acceptance criteria.
- Details on configuration of gasket joints germane to their sealing function.
- Identification of the Containment System Boundary.
- Design details on the impact limiters.

The manufacturing of the HI-STAR 180L components is required to be in strict compliance with the Drawing Package in this section.

Figure 1.3.1 provides an illustration of the assembled HI-STAR 180L Package for transport. Figure 1.3.2 provides an illustration of the HI-STAR 180L Package on a railcar with personnel barrier, support saddles and other typical components.

[PROPRIETARY DRAWINGS WITHHELD PER 10CFR2.390]

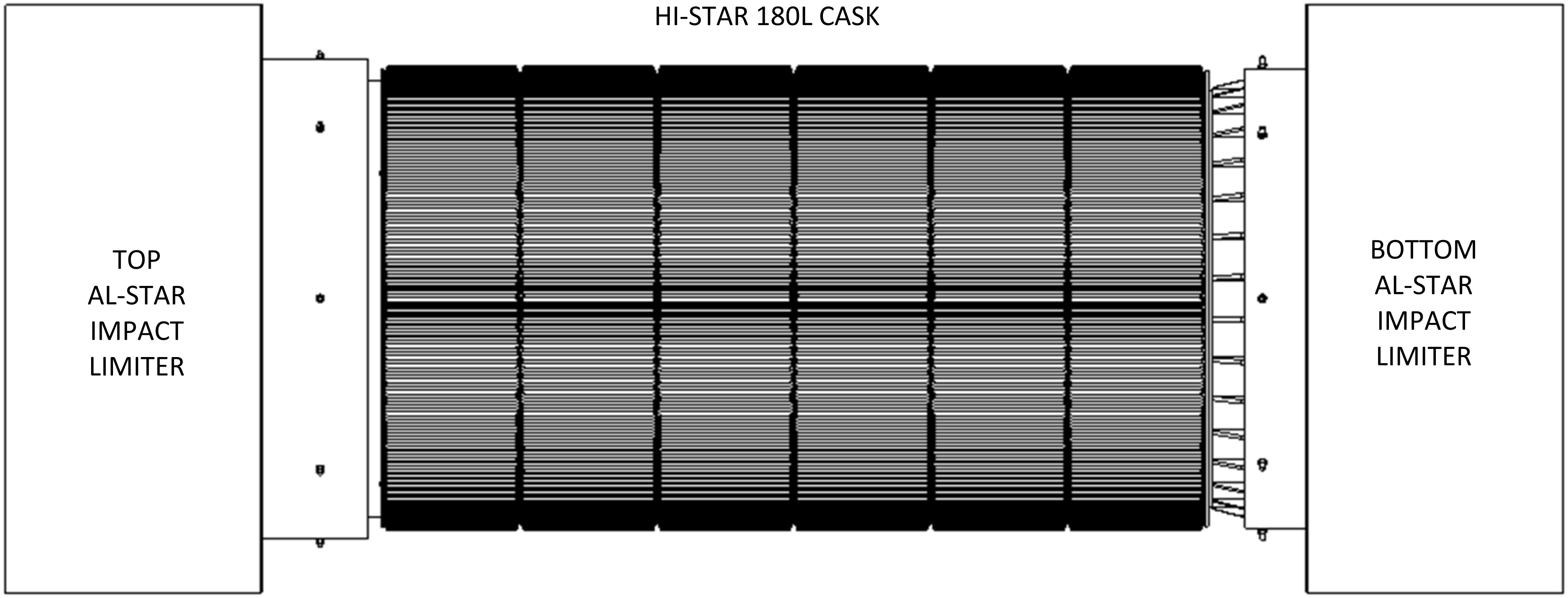

FIGURE 1.3.1: ILLUSTRATION OF HI-STAR 180L TYPICAL ASSEMBLY FOR TRANSPORT

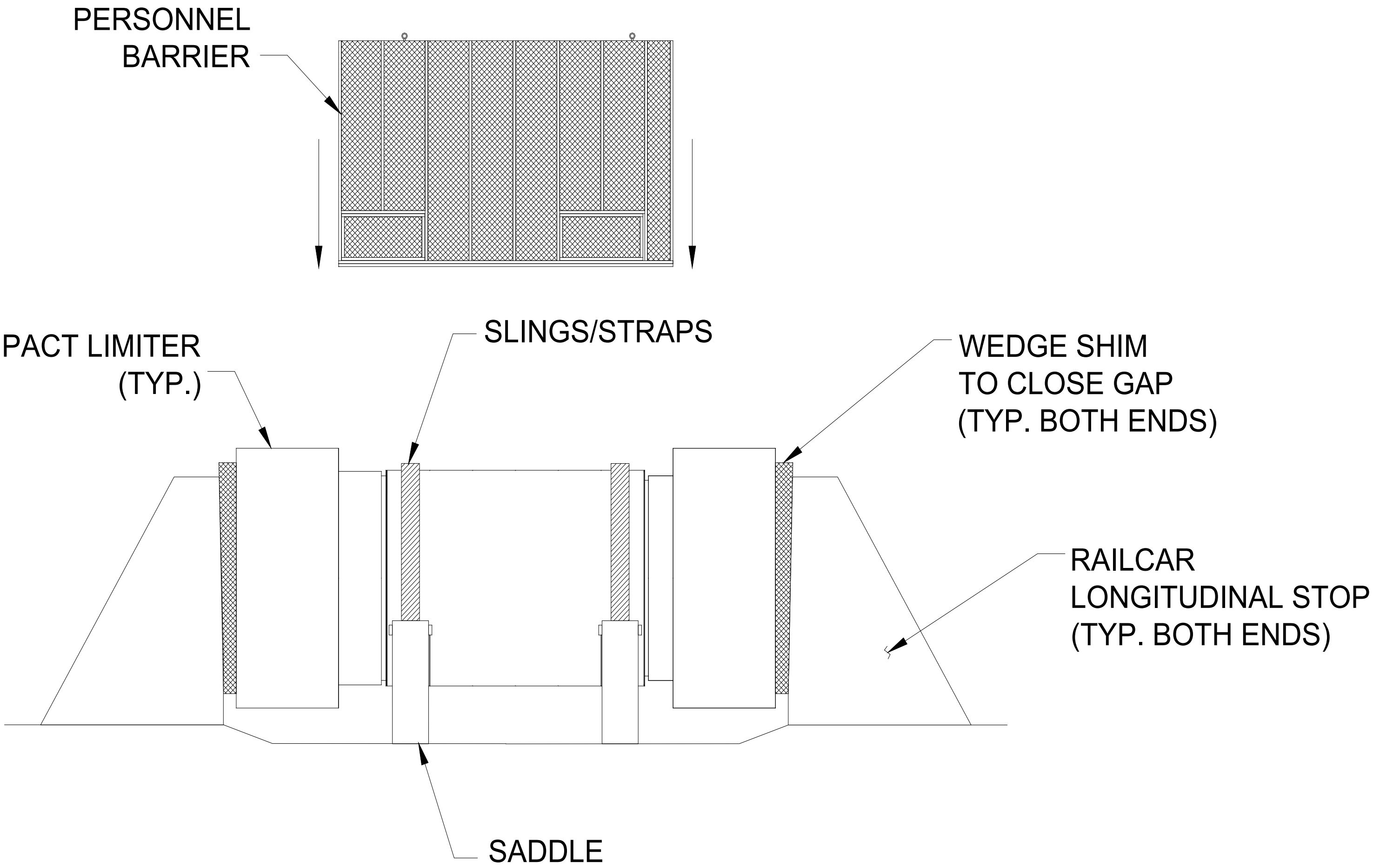

FIGURE 1.3.2: ILLUSTRATION OF HI-STAR 180L TYPICAL RAILCAR TRANSPORT CONFIGURATION

1.4 SUMMARY OF COMPLIANCE WITH 10CFR71 REQUIREMENTS

The HI-STAR 180L Package complies with the requirements of 10CFR71 for a Type B(U)F-96 package. Analyses which demonstrate that the HI-STAR 180L Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR. The HI-STAR 180L Package complies with the general standards for all packages, 10CFR71.43, as demonstrated in Chapter 2. Under the tests specified in 10CFR71.71 (normal conditions of transport) the HI-STAR 180L Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR 180L Package to meet the requirements of 10CFR71, Paragraphs 71.45, 71.51, and 71.55 (see discussion on high burnup fuel below). Under the tests specified in 10CFR71.73 (hypothetical accident conditions) and 10CFR71.61 (special requirement for irradiated nuclear fuel shipments), the damage sustained by the HI-STAR 180L Package is shown to be within the permissible limits set forth in 10CFR71, Paragraphs 71.51, and 71.55 (see discussion on high burnup fuel below).

The HI-STAR 180L Package meets the structural, thermal, containment, shielding and criticality requirements of 10CFR71, as described in Chapters 2 through 6. The package operations; and acceptance tests and maintenance program provided in Chapters 7 and 8 ensure compliance of the package with the requirements of 10CFR71.

The following is a summary of the information provided in Chapter 1, which in conjunction with the information provided in Chapters 2, 7 and 8 is directly applicable to verifying compliance with 10CFR71:

- The HI-STAR 180L Packaging description including the drawing package provided in Section 1.3 provides an adequate basis for evaluation of the HI-STAR 180L Packaging against the 10CFR71 requirements for each technical criterion. Each drawing is identified, consistent with the text of the SAR, and contains appropriate annotations to explain and clarify information on the drawing.

- The NRC-approved Holtec International quality assurance program for the HI-STAR 180L packaging has been identified.

- The applicable codes and standards for the HI-STAR 180L Packaging design, fabrication, assembly, and testing have been identified in the drawing package in Section 1.3, Chapter 2 and Chapter 8.

- Allowable contents in the HI-STAR 180L Packaging are specified in Section 1.2 and Appendix 7.D.

1.5 LOCATION OF PROPERTIES OF SPECIAL PURPOSE MATERIALS

Requirements for special purpose materials and parts (essentially non-code materials) utilized in the HI-STAR 180L package such as Holtite, containment seals, impact limiter crush materials, etc., are provided in their proper context in this SAR and are thus scattered across this document. To ensure that the applicable properties of such materials used in the safety analyses are correctly extracted in the Purchasing Specification for each special purpose material, Table 1.5.1 provides the location where the required information can be found in this SAR.

Table 1.5.1:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 1.5.2:

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

1.6 QUALITY ASSURANCE AND DESIGN CONTROL[1]

1.6.1 Quality Assurance Program:

The HI-STAR 180L Package design, material acquisition, fabrication, assembly, and testing shall be performed in accordance with Holtec International's QA program. Holtec International's QA program was originally developed to meet NRC requirements delineated in 10CFR50, Appendix B, and was expanded in the early 90s to include provisions of 10CFR71, Subpart H, and 10CFR72, Subpart G, for structures, systems, and components (SSCs) designated as *important-to-safety*. NRC approval of Holtec International's QA program is documented by the Quality Assurance Program Approval for Radioactive Material Packages (NRC Form 311), Approval Number 0784, Docket No. 71-0784.

1.6.2 Package Design Control:

The design information presented in this SAR is subject to validation, safety compliance, and configuration control in accordance with Holtec's NRC-approved quality assurance (QA) program which comports with the provisions of 10CFR71.107. Chapters 7 and 8 and the licensing drawing package collectively contain conditions to the CoC, and as such, they can be modified only through an NRC licensing action. The other chapters contain substantiating information to support the safety case and can be amended subject to the stipulations of 71.107(c).

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[1] This section is reproduced from Section 1.6 of the HI-STAR 190 SAR [1.0.6]

CHAPTER 1 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

[1.0.1] Regulatory Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Material", Revision 2, USNRC, March 2005.

[1.0.2] 10CFR Part 71, "Packaging and Transportation of Radioactive Materials", Title 10 of the Code of Federal Regulations, Office of the Federal Register, Washington, D.C.

[1.0.3] 49CFR173, "Shippers - General Requirements For Shipments and Packagings", Title 49 of the Code of Federal Regulations, Office of the Federal Register, Washington, D.C.

[1.0.4] “Safety Analysis Report for the HI-STAR 180 Package”, Holtec Report HI-2073681, latest revision, USNRC Docket No. 71-9325.

[1.0.5] “Safety Analysis Report for the HI-STAR 180D Package”, Holtec Report HI-2125175, latest revision, USNRC Docket No. 71-9367.

[1.0.6] “Safety Analysis Report for the HI-STAR 190 Package”, Holtec Report HI-2146214, latest revision, USNRC Docket No. 71-9373.

[1.0.7] “Safety Analysis Report for the HI-STAR 100 Package”, Holtec Report HI-951251, latest revision, USNRC Docket No. 71-9261.

[1.0.8] “Safety Analysis Report for the HI-STAR 80 Package”, Holtec Report HI-2146261, latest revision, USNRC Docket No. 71-9374.

[1.0.9] “Safety Analysis Report for the HI-STAR ATB-1T Package”, Holtec Report HI-2146312, latest revision, USNRC Docket No. 71-9375.

[1.0.10] “Safety Analysis Report for the HI-STAR 60 Package”, Holtec Report HI-951251, latest revision, USNRC Docket No. 71-9336.

[1.0.11] "Final Safety Analysis Report for the HI-STAR 100 Package", Holtec Report HI-2012610, latest revision, Docket No. 72-1008.

[1.0.12] "Final Safety Analysis Report on the HI-STORM 100 System", Holtec Report HI-2002444. Latest revision, Docket No. 72-1014.

[1.0.13] "Final Safety Analysis Report on the HI-STORM FW System", Holtec Report HI-2114830. Latest revision, Docket No. 72-1032.

[1.0.14] "Final Safety Analysis Report on the HI-STORM UMAX Canister Storage System", Holtec Report HI-2115090. Latest revision, Docket No. 72-1040.

[1.0.15] "Safety Analysis Report for the HI-STAR 100MB Package", Holtec Report HI-2188080, latest revision, USNRC Docket No. 71-9378.

[1.1.1] IAEA Safety Standards, Safety Requirements, No. SSR-6, "Regulations for the Safe Transport of Radioactive Material", International Atomic Energy Agency, 2012 Edition.

[1.2.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code", Section III, Div. 1, Subsection NB 2015 Edition.

[1.2.2] Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1m)", U.S. Nuclear Regulatory Commission, Washington, D.C., June 1991.

[1.2.3] Regulatory Guide 7.12, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater Than 4 Inches But Not Exceeding 12 Inches", United States Regulatory Commission, June, 1991.

[1.2.4] NUREG/CR-3826, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick.", Lawrence Livermore National Lab for USNRC, April 1984.

[1.2.5] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants", U.S. Nuclear Regulatory Commission, Washington, D.C., July 1980.

[1.2.6] ANSI N14.6-1993, "Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 Kg) or More", June 1993.

[1.2.7] Interim Staff Guidance ISG-11, Rev. 3, USNRC, November, 2003.

[1.2.8] Interim Staff Guidance ISG-19, Rev. 0, USNRC, May, 2003.

[1.2.9] "Holtite-B Sourcebook", Holtec Report HI-2167314, Latest Revision. (Holtec Proprietary)

[1.2.10] "Metamic-HT Qualification Sourcebook", Holtec Report No. HI-2084122, Latest Revision (Holtec Proprietary)

[1.2.11] "Sampling Procedures and Tables for Inspection by Attributes", Military Standard MIL-STD-105E, (10/5/1989).

[1.2.12] NUREG-1617, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, 2000.

[1.2.12] NRC Draft Regulatory Issue Summary (RIS) 2015-XX, "Consideration in Licensing High Burnup Spent Fuel in Dry Storage and Transportation", ADAMS Accession No. ML14175A203

[1.2.13] "Design Specification of the LTS BWR Quiver for KKL", Report NRT 14-079, Latest Revision (Westinghouse Electric Sweden AB Proprietary)

[1.2.14] Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels", Revision 1, March, 1978, U.S. Nuclear Regulatory Commission.

CHAPTER 2: STRUCTURAL EVALUATION

2.0 INTRODUCTION

This chapter presents a synopsis of the Design Criteria relevant to the mechanical and structural characteristics of the HI-STAR 180L Package that ensure compliance with the performance requirements of 10CFR71, and it summarizes all structural evaluations and analyses of the package, pursuant to the provisions of 10CFR§71.61, 10CFR§71.71, and 10CFR§71.73.

In particular, the objectives of this chapter are twofold:

a. To demonstrate that the structural performance of the HI-STAR 180L Package has been adequately evaluated for the normal conditions of transport and for the hypothetical accident conditions set forth in 10CFR§71.61, 10CFR§71.71, and 10CFR§71.73.

b. To demonstrate that the HI-STAR 180L Package design has adequate structural integrity to meet the regulatory requirements of 10CFR§71.61, 10CFR§71.71, and 10CFR§71.73.

Among the topical areas addressed in this chapter are:

i. Structural characterization of the cask and its appurtenances.
ii. Identification of the materials used in the package and their *critical characteristics*.
iii. Identification of the loads applied on the package during handling, normal conditions of transport and accident conditions. Definition of miscellaneous bounding conditions for design such as a fire and immersion in water.
iv. Derivation of acceptance criteria for the package's performance under the aforementioned various conditions of service from the ASME B&PV Codes and other reference standards.
v. Analyses of the package using appropriate methodologies to establish the margins of safety under each condition of service. In addition to the typical evaluations for normal and accident conditions, these analyses include:
    - Evaluation of the physical integrity of the spent fuel under the postulated impactive loading events.
    - A demonstration of the adequacy of the minimum acceptable Charpy impact values specified for the parts subject to potential impact loadings. This is based on a methodology that determines the fracture strength of a material using the Charpy impact strength data.

Appendix 2.A provides introductory information on the principal codes used in the structural analysis (ANSYS and LS-DYNA). Appendix 2.B provides a comprehensive summary of the three-stage benchmarking effort by Holtec International to establish the veracity of the LS-DYNA solution for predicting the peak deceleration of the package and crush performance of the AL-STAR impact limiters. A discussion of the finite element discretization level to ensure that the solutions are fully converged is also provided.

To facilitate regulatory review, throughout this chapter, the assumptions and conservatism inherent in the analyses are identified along with a complete description of the analytical methods, models, and acceptance criteria. A summary of other considerations germane to satisfactory structural performance, such as protection against corrosion, creep (in the Metamic-HT fuel basket), and brittle fracture, is also provided.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter are essentially identical to those used in the USNRC approved SARs for HI-STAR 180 (Docket #71-9325) and HI-STAR 180D (Docket #71-9367). Specifically, all the analysis methods (e.g., strength of materials and finite element analysis codes) employed to structurally qualify the HI-STAR 180L transport package and the corresponding acceptance criteria are identical to the HI-STAR 180 transport package. Furthermore, the structural analysis models developed for the HI-STAR 180L share similar design features as the HI-STAR 180 transport package models. The following Table compares the key design features between the HI-STAR 180L and the HI-STAR 180 transport packages.

Comparison of Major Design Features of HI-STAR 180 and HI-STAR 180L Casks

Cask Feature	HI-STAR 180	HI-STAR 180L
Containment Shell	64 mm thick SA203-E or SA350 LF3	64 mm thick SA203-E or SA350 LF3
Containment Closure Flange	355 mm thick SA350-LF3	364 mm thick SA350-LF3
Containment Baseplate	152 mm thick SA203-E or SA350 LF3	146 mm thick SA203-E or SA350 LF3
Monolithic Shield Cylinder (including holtite pockets)	361 mm thick A352-93-LCC or SA352-LCC	375 mm thick A352-93-LCC or SA352-LCC
Inner Lid	215 mm thick (at center) SA203-E or SA350 LF3	210 mm thick (at center) SA203-E or SA350 LF3
Inner Lid Bolts	(68) M42 bolts SA564-630 or SA705-630 or SA 320 L7 or SB637-N07718	(68) M42 bolts SA564-630 or SA705-630 or SA 320 L7 or SB637-N07718
Outer Lid	101 mm thick SA203-E or SA350 LF3	102 mm thick SA203-E or SA350 LF3
Outer Lid Bolts	(68) M42 bolts SA193-B7 or SA564-630 or SA705-630 or SB637-N07718	(68) M42 bolts SA193-B7 or SA564-630 or SA705-630 or SA 320 L7 or SB637-N07718
Fuel-to-Cask Axial Gap Control	FIA (spring and fuel spacer)	No FIA. See SAR Paragraph 1.2.1.9

Another feature that distinguishes HI-STAR 180L from HI-STAR 180 transport package is the storage of damaged (broken) fuel rods in precisely designed prismatic boxes referred as "Quivers". The external cross section dimensions of the Quivers emulate that of a standard HI-STAR 180L fuel assembly. Additional details pertaining the Quivers is discussed in Section 1.2.2 of Chapter 1.

2.1 STRUCTURAL DESIGN

2.1.1 Discussion

This subsection presents the essential characteristics of the principal structural members and systems that are important to the safe operation of the HI-STAR 180L Package. These members are the containment system components (together with those parts that render the radiation shielding function in the cask), the structural components that constitute the fuel basket and the surrounding support, and the impact limiters needed to protect the package in the event of a hypothetical accident event (§71.73).

2.1.1.1 Cask

The structural functions of the cask in the transport mode are:

- To provide a high integrity fuel basket.
- To serve as a penetration and puncture barrier for the fuel basket.
- To provide a high-integrity containment system.
- To provide a structurally robust support for the radiation shielding components.

The HI-STAR 180L cask consists of three discrete regions; namely:

1. the containment space
2. the inter-lid space
3. the supplemental shielding

The containment space (or space within the containment boundary as identified in the drawing package in Section 1.3 and described in Sections 1.2 and 4.1) is the heart of the package. It must ensure a leak-tight enclosure for its contents under all normal and accident conditions of transport.

Accordingly, it is designed to meet the most rigorous industry requirements, to the extent germane to its function, of Section III, Subsection NB of the ASME Boiler & Pressure Vessel Code [2.1.1]. Section 1.5.2.6 of NUREG-1617 [2.1.11] states the following:

“ASME has published Section III, Division 3, ASME Boiler and Pressure Vessel (B&PV Division 3) Code for the design and construction of the containment system of SNF transport packagings. NRC staff expects full compliance with the B&PV Division 3 Code for the containment system, including the services of an Authorized Inspection Agency. However, the SAR may justify alternatives as appropriate.”

In this SAR, ASME Section III, Division 1, Subsection NB is used for the design and construction of the HI-STAR 180L containment system, in lieu of the Division 3 Code, since Subsection NB has an established history of use and NRC approval for similar cask designs (e.g., HI-STAR 100, HI-STAR 60, HI-STAR 180 and HI-STAR 180D).

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The supplemental shielding consists primarily of the monolithic shield cylinders (or shield cylinders). [

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] To perform their function, they must not undergo body extensive damage resulting in an appreciable loss of shielding capacity under normal and accident conditions of transport.

To minimize the axial gap between the top of the fuel assemblies and the inner closure lid, the population of the fuel common to the host reactor plant is surveyed and the cask cavity length is accordingly controlled as discussed in Section 1.2. The same approach is applicable for the Quivers, which share identical external dimensions.

2.1.1.2 Fuel Basket and Fuel Basket Support

The structural function of the fuel basket and fuel basket support (basket shims) (see drawing package in Section 1.3) in the transport mode is to maintain the position of the fuel in a sub-critical configuration. In its role as the guarantor of subcriticality, the fuel basket must exhibit global physical integrity (i.e., no potential for large plastic deformation or structural failure in the active fuel region) under the most structurally demanding conditions of transport (see 2.1.2.2 (ii) for acceptance criterion).

2.1.1.3 Impact Limiters

The impact limiters used in the HI-STAR family of transport casks utilize shaped blocks of a crushable material arrayed around an extremely stiff cylindrical core in such a manner that the cask is protected from excessive inertia forces under a (hypothetical) uncontrolled drop event *regardless* of the orientation of drop. [

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The impact limiter configured on the above design platform is referred to as "AL-STAR" and is used in all models of HI-STAR transport packages, including the first package (HI-STAR 100), and subsequent packages labeled HI-STAR HB, HI-STAR 60, HI-STAR 180, HI-STAR 180D and the current package (HI-STAR 180L).

The structural function of the AL-STAR impact limiters (shown in the drawing package in Section 1.3) in the transport mode is to cushion the HI-STAR 180L cask and the contained fuel during normal transport package handling, and during a hypothetical drop accident. The AL-STAR impact limiters and other appurtenances such as the support saddles and the personnel barrier necessary for the transport package must also meet all applicable regulatory requirements.

In what follows, explicit design criteria for the components of the transport package and essential appurtenances are presented.

2.1.2 Design Criteria

Regulatory Guide 7.6 [2.1.2] provides guidance for design criteria for the structural analysis of shipping cask containment vessels. Loading conditions and load combinations for transport are defined in 10CFR71 [2.1.3] and in Regulatory Guide 7.8 [2.1.4]. Consistent with the provisions of these documents, the central objective of the structural requirements presented in this section is to ensure that the HI-STAR 180L Package possesses sufficient structural capability to meet the demands of both normal (§71.71) and hypothetical accident conditions (§71.73) of transport articulated in the regulatory guidance documents, specifically Reg. Guide 7.6. The following table provides a synoptic matrix to demonstrate the explicit compliance with the seven regulatory positions with respect to the Containment Boundary stated in Regulatory Guide 7.6.

USNRC's Regulatory Position regarding the Containment Boundary for the Transport Package
1. Material properties, design stress intensities, and fatigue curves are obtained from the ASME Code.
2. Under normal conditions of transport, the limits on stress intensity are those limits defined by the ASME Code for primary membrane and for primary membrane plus bending for Level A conditions.
3. Perform fatigue analysis for normal conditions of transport using ASME Code Section III methodology (NB) and appropriate fatigue curves.
4. The stress intensity S_n associated with the range of primary plus secondary stresses under normal conditions should be less than $3S_m$ where S_m is the primary membrane stress intensity from the ASME Code.
5. Buckling of the containment vessel should not occur under normal or accident conditions.
6. Under accident conditions, the values of primary membrane stress intensity should not exceed the lesser of $2.4S_m$ and $0.7S_u$ (ultimate strength), and primary membrane plus bending stress intensity should not exceed the lesser of $3.6S_m$ and S_u.
7. The extreme total stress intensity range should be less than $2S_a$ at 10 cycles as given by the

USNRC's Regulatory Position regarding the Containment Boundary for the Transport Package
appropriate fatigue curves.

The following design requirements are applicable to the remainder of the transport package:

- The shield cylinders are required to remain in place and functional after all Normal and Hypothetical Accident Conditions of Transport.
- The fuel basket is required to maintain its shape so as to ensure reactivity control after all Normal and Hypothetical Accident Conditions of Transport.
- The fuel basket supports are required to maintain global positioning of the fuel basket after all Normal and Hypothetical Accident Conditions of Transport.
- The impact limiters are required to have an appropriate shape and energy absorption capacity to ensure that impacts, resulting from hypothetical accident events, do not cause any of the containment and shielding components to fail to meet their specified requirements. The impact limiters are also designed to limit the accelerations in order to protect the Spent Nuclear Fuel cladding integrity and the structural performance of the Quivers.

2.1.2.1 Loading and Load Combinations

10CFR71 and Regulatory Guide 7.6 define two conditions that must be considered for qualification of a transport package. These are defined as "Normal Conditions of Transport" and "Hypothetical Accident Conditions".

The loadings applicable to the HI-STAR 180L package can be broadly divided into five categories, namely:

1. permanent loads
2. design condition loads
3. handling loads
4. normal condition of transport loads (§71.71)
5. hypothetical accident condition loads (§71.73)

1. Permanent Loads

Permanent loads in HI-STAR 180L arise from bolt pre-load to seat the gasketed joints. The pre-load applied to the cask lid bolts seats the metal seals and creates a contact pressure on the inside metal-to-metal annulus, referred to as the "land", to protect the joint from leakage under postulated impact loading events. Bolt pre-load produces a state of stress in the closure lids, the cask closure flange, and the cask inner shell region adjacent to the flange.

The stress field in the cask body and the lids from the bolt pre-load combines with the stresses produced under a specific event such as during the hypothetical accident condition (item #5 above). Thus, the bolt pre-load induced stress participates in every load combination analyzed for the cask.

The initial preload should be set to maintain a seal under the action of the internal pressure plus the effective pressure calculated as the cask content weight times the maximum rigid body deceleration from the free 9-meter end drop (see discussion below). This preload is much larger than the preload needed to balance the maximum normal operating internal pressure (MNOP specified in Table 2.1.1).

Finally, stresses from weld shrinkage endemic to every welded component also lie in the category of permanent stresses. However, because they are of the secondary genre (i.e., they arise to satisfy compatibility, not equilibrium) they are not computed or included in the load combinations.

2. Design Condition Loads

The ASME Codes [2.1.1] and [2.1.17] require that a pressure vessel be qualified to a design internal and external (if applicable) pressure. The Design Pressure should be selected to bound all normal operating condition pressures. The applicable Design Temperature, likewise, should be one that bounds the metal temperature of the affected pressure parts under all normal service conditions. For the HI-STAR 180L Package, the Design Internal Pressure and Design Temperatures, set down in Table 2.1.1, accordingly bound all service condition values.

Stress analysis of the containment system under the Design Pressure is required to demonstrate compliance with “NB” stress limits, as identified in [2.1.1], for the containment system material and to demonstrate the leak tightness of the bolted joints. The Design Temperature is utilized to establish the applicable allowable stress intensity, S_m, for the “pressure part” (a term used in the ASME B&PV Code). The following pressure loading scenarios are identified:

- Maximum Normal Operating Pressure (MNOP): The MNOP is defined in Table 2.1.1 for the containment system of the cask and bounds the calculated internal pressure values in Table 3.1.2. The coincident external pressure is atmospheric.

- Design Internal Pressure: A design internal pressure is defined in Table 2.1.1 for the containment system of the cask as a pressure vessel. The coincident external pressure is atmospheric.

- Accident Condition Internal Pressure: An accident condition internal pressure is defined in Table 2.1.1 for the containment cavity of the cask pressure vessel. The coincident external pressure is atmospheric.

- Accident Condition External Pressure: An accident condition external pressure with cavity depressurized is defined in Table 2.1.1. This loading, in conjunction with the buckling analysis of the cask containment shell, is intended to demonstrate that the containment system is in compliance with the requirements of 10CFR71.61. This loading bounds the external pressure specified by 10CFR71.73(c) (5) and (6); therefore, it is considered in Section 2.7.

Table 2.1.1 provides the above values of design basis internal and external pressures. The Design Internal Pressure of the Cask Cavity Space is conservatively set higher than the Cask Cavity Space MNOP.

The most adverse possible internal pressure state occurs under the simultaneous effect of fire and 100% rod rupture. This pressure is bounded by the accident condition internal pressure specified in Table 2.1.1.

The case of deep submergence (§71.61) is enveloped by the accident condition external pressure specified in Table 2.1.1.

As discussed in Paragraph 2.1.1.1, there is no additional restraint load from the fuel assemblies and the Quivers on the cask closure lid.

3. Handling Loads

The lifting attachments (or interfacing lift points) in the HI-STAR 180L cask are subject to the specific stress limits set forth by NUREG-0612 [2.1.5] and 10CFR71.45(a), which require that the primary stresses in a lifting point must be less than the smaller of 1/10 of the material ultimate strength and 1/3 of the material yield strength while subject to the lifted load that includes an appropriate dynamic load amplifier. These limits apply to the cask lifting trunnions and to the threaded holes in the lids. An associated requirement is an evaluation of the stress intensity state in the cask baseplate when the package is being lifted. Baseplate loads considered are the self-weight of the baseplate plus attached shielding, the fuel, the fuel basket, and the fuel basket shims (and supports). Under lifting (and handling) condition a 15% load amplifier is applied as discussed in Section 2.5. The HI-STAR 180L cask component acceptance limits are based on the Level A stress intensity allowables from ASME Code, Section III, Subsection NB.

Section 2.5 documents the lifting analyses applicable to the HI-STAR 180L package.

4. Normal Conditions of Transport Loads (§71.71)

The normal conditions of transport loads that warrant structural evaluation are:

a. Reduced external pressure 25 kPa (3.5 psia).
b. Increased external pressure (140 kPa or 20 psi absolute).
c. Free drop from 0.3-meter (1-foot) height in the most vulnerable orientation onto an essentially unyielding horizontal surface (henceforth called the “1- foot drop event”).
d. Normal vibratory loads incidental to transport.
e. Normal operating conditions (pressure and temperature).

External pressure loads ((a) and (b) above) are clearly enveloped by the design external pressure set by a deep submersion of the package (10CFR71.61). This condition is evaluated in Section 2.7. The normal operating conditions (e) are evaluated to demonstrate that the containment meets the requirements of the ASME Code (as clarified in Subsection 2.1.4) to be designated as a “pressure vessel”. The “1-foot drop event” (c) evaluation is the “Side Drop”. The HI-STAR 180L Package is assumed to drop with its axis parallel with respect to the horizontal surface, such that the collision of the two impact limiters with the target is coincident in time. Vibratory loads transmitted to the HI-STAR 180L Package (d) by the transport vehicle will produce negligibly small stresses in comparison with stresses that will be produced by the loadings described previously. Therefore, vibratory loading is neglected in the analyses performed herein. Fatigue considerations due to mechanical vibrations are further discussed in Section 2.6.

Based on the above considerations, the governing Load Combinations to be considered in Section 2.6, for both Heat and Cold conditions, are:

- Load Combination N1:
  Bolt pre-load plus Design Internal pressure and Normal operating temperature
- Load Combination N2:
  Free drop from 1 foot plus Bolt pre-load and Maximum Normal Operating Pressure (MNOP).

5. Hypothetical Accident Condition Loads (§71.73)

These loads pertain to hypothetical accident conditions. Specifically, they are:

a. Free Drop of 9 m (30 ft) (§71.73 (c) (1))
b. Puncture (§71.73 (c)(3))
c. Engulfing fire @ 800ºC (1475ºF) (§71.73 (c)(4))
d. Immersion in 15 m (50 ft) head of water (§71.73 (c) (6)).

a. Free Drop

The free drop event can be broken down into seven candidate scenarios with potential to cause maximum damage:

- Bottom End Drop: The packaging is assumed to drop vertically with its cask containment baseplate sustaining the impulsive load transmitted by the contents. The weight of the package is included in all drop load cases.

- Top End Drop: This drop condition is the opposite of the preceding case. The outer closure lid withstands the impact load transmitted through the impact limiter, and the inner closure lid withstands the impact from the contained fuel, fuel basket, and fuel basket supports (basket shims).

- Side Drop: The cask along with its contents drops with its longitudinal axis horizontal. The contents of the cask bear down on the cask as it decelerates under the resistance offered by the two impact limiters pressing against an essentially unyielding surface.

- Bottom Center-of-Gravity Over-the-Corner Drop: In this drop scenario, the HI-STAR 180L Package is assumed to impact an essentially unyielding surface with its center-of-gravity directly above its initial point of contact in the drop event.

- Top Center-of-Gravity Over-the-Corner Drop: This loading case is identical to the preceding case, except that the package is assumed to be dropping with its top end down and its center-of-gravity is aligned over the initial point of contact.

- Slapdown – Initial Impact at Top End: In this case, the package drops with its axis at a small angle with the horizontal with the top end impacting first. Subsequent to the primary impact, the package begins to rotate with the bottom end impacting the target at a later time (secondary impact). Higher decelerations are experienced during the secondary impact. The governing slapdown angle, θ, is determined based on prior investigative studies performed for the HI-STAR 180 transport package [1.0.4].

- Slapdown – Initial Impact at Bottom End: This case is the same as above, except for the location of primary and secondary impacts.

b. <u>Puncture</u>

The puncture event is broken down into two limiting scenarios, namely:

- Side Puncture: This event consists of a 1-m (40-in) free drop (impact limiters are ignored) onto a stationary and vertical mild steel bar of 15 cm (6 in) diameter with its leading edge (top edge) rounded to 6 mm (1/4-in) radius. The bar is assumed to be of such a length as to cause maximum damage to the cask. The package is assumed to be dropping horizontally with the penetrant force being applied at the mid-length of the cask.

- Top End Puncture: This event is similar to the preceding case except the penetrant force is assumed to act at the center of the outer closure lid. Because of the proximity of the bolted joints, this case is considered limiting for an end puncture.

The above loading events may occur under the so-called “hot” (maximum ambient temperature) or “cold” condition at -40ºC (-40ºF). In the latter thermal state, the effects of brittle fracture must also be evaluated.

Because the HI-STAR 180L Package operates at a relatively low internal pressure, the impact and puncture loadings under service conditions are orders of magnitude greater than pressure loadings. Nonetheless, for the governing normal transport condition drops, the cask internal pressure loading is considered in combination with the free drop impact loads.

c. <u>Fire</u>

Fire is not a mechanical loading event; its chief consequence is to challenge the integrity of the neutron shielding material. The results are presented in Chapter 3. The results show that the gas pressure inside the containment system remains below the accident pressure limit for the package (see Table 2.1.1). Based on the temperature changes established in Chapter 3, an evaluation is performed to demonstrate that the land compression load at the lid/flange joint does not degrade to an unacceptable value.

d. Immersion

Finally, from the structural standpoint, the 15-m (50-ft) immersion case is clearly bounded by the accident external pressure loading of 2 MPa (290 psi) deemed to satisfy the requirements of 10CFR71.61. The ability of the package to maintain moderator exclusion pursuant to §71.61 is discussed in Appendix 1.B and in Section 2.7.

Based on the above considerations, the Load Combinations that are considered in Section 2.7, for both Heat and Cold conditions, are:

Hypothetical Accident Load Cases*

9-m free drops
End and Side Puncture
Deep Submergence 2 MPa (290 psi)
Gasket Relaxation from Fire

* Permanent Loads are in-place at the start of every load case.

2.1.2.2 Acceptance Criteria

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2.1.3 Weights and Centers of Gravity

Table 2.1.9 provides the weights of the individual HI-STAR 180L components as well as the total Transport Package weights, and the weight of the heaviest loaded HI-STAR 180L Cask.

Table 2.1.10 provides the location of the center of gravity (CG) for the package relative to the bottom surface of the bottom impact limiter. The CG is assumed to be located on the cask centerline since the non-axisymmetric effects of the cask plus contents are negligible.

2.1.4 Identification of Codes and Standards for Package Design

The design of the HI-STAR 180L Package does not invoke ASME Code Section III in its entirety. Specific Code paragraphs in NB-3000 of Section III, Subsection NB of the ASME Boiler and Pressure Vessel Code (ASME Code) [2.1.1], and Appendix F [2.1.10] that are cited herein are invoked for design of the containment system of the HI-STAR 180L Package.

Table 2.1.11 lists each major structure, system, and component (SSC) of the HI-STAR 180L Packaging, along with its function, and applicable code or standard. The drawing package in Section 1.3 identifies whether items are “Important to Safety” (ITS) or “Not Important to Safety” (NITS); the identification is carried out using the guidance of NUREG/CR-6407, "Classification of Transportation Packaging and Dry Spent Fuel Storage System Components”. Table 2.1.13 lists some alternatives to the ASME Code where appropriate. Table 2.1.13 also provides applicable sections of the ASME Code and other documents for Material Procurement, Design, Fabrication, and Inspection, and Testing pursuant to the guidance in NUREG 1617 [2.1.11].

All materials and sub-components that do not constitute the containment system in the HI-STAR 180L cask are procured to ASTM or ASME Specifications, except for the fuel basket (made of Metamic-HT) and the neutron shield sold under the trade name Holtite B described in Chapter 1.

The *critical characteristics* of all materials set down in this SAR establish the minimum requirements that must be met by the material. The applicable *critical characteristics* for each part in the HI-STAR 180L cask are listed in Table 2.1.12 with the required limiting values, as applicable.

Table 2.1.1: [Withheld in Accordance with 10 CFR 2.390]

Table 2.1.2: Stress Intensity Limits for Different Service Conditions for Section III Class 1 Pressure Vessels (Elastic Analysis per NB-3220)

Stress Category	**Level A**	**Level D**
Primary Membrane, P_m	S_m	Lesser of $2.4S_m$ and $0.7S_u$
Local Membrane, P_L	$1.5S_m$	150% of P_m Limit
Membrane plus Primary Bending	$1.5S_m$	150% of P_m Limit
Primary Membrane plus Primary Bending	$1.5S_m$	150% of P_m Limit
Membrane plus Primary Bending plus Secondary	$3S_m$	N/A
Average† Primary Shear (Section in pure shear)	$0.6S_m$	$0.42S_u$

Notes:

1. Fatigue analysis (as applicable) also includes peak stress (denoted by “F” in the nomenclature of the ASME Code [2.1.1]).

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† Governed by NB-3227.2 or F-1331.1(d) of the ASME Code, Section III (NB or Appendix F)

Table 2.1.3: Stress Limits for Lid Closure Bolts (Elastic Analysis per NB-3230)

Stress Category	Level A	Level D
Average Service Stress	$2S_m$	Cannot exceed Yield Strength
Maximum Service Stress (tension + bending but no stress concentrations)	$3S_m$	Joint Remains Leak Tight (see Note 2). Cannot exceed Ultimate Strength

Notes:

1. Stress limits for Level A loading ensure that bolt remains elastic.
2. Limit set on primary tension plus primary bending for Level D loading is based on an elastic stress evaluation; however, the overriding acceptability of the joint design is performance based on an assured absence of leakage.
3. The closure lid bolt joints are friction type joints due to the large preload stress, they are not subjected to shear per ASME Code, Section III, Division 1, Subsection NF, NF-3324.6(a)(3)(b). Therefore, there is no need to include the shear and combined tensile and shear stress allowables in this table.

Table 2.1.4: Design, Levels A and B: Stress Intensity – SA-203 E

Code: ASME NB
Material: SA-203 E
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**					
	S_m	**P_m** (Note 1)	**P_L** (Note 1)	**$P_L + P_b$** (Note 1)	**$P_L + P_b + Q$**	**P_e** (Note 2)
-29 to 38 (-20 to 100)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
93,3 (200)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
149 (300)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
204 (400)	157.9 (22.9)	157.9 (22.9)	237.2 (34.4)	237.2 (34.4)	473.7 (68.7)	473.7 (68.7)
260 (500)	148.9 (21.6)	148.9 (21.6)	223.4 (32.4)	223.4 (32.4)	446.8 (64.8)	446.8 (64.8)

Definitions:

S_m = Stress intensity values per ASME Code
P_m = Primary membrane stress intensity
P_L = Local membrane stress intensity
P_b = Primary bending stress intensity
P_e = Expansion stress
Q = Secondary stress
$P_L + P_b$ = Either primary or local membrane plus primary bending

Notes:

1. Evaluation required for Design condition only per NB-3220.
2. P_e not applicable to vessels per Fig. NB-3221-1.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.

Table 2.1.5: Level D Stress Intensity – SA-203 E

Code: ASME NB
Material: SA-203 E
Item: Stress Intensity

Temperature ºC (ºF)	Classification and Value, MPa (ksi)		
	P_m	**P_L**	**$P_L + P_b$**
-29 to 38 (-20 to 100)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
93.3 (200)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
149 (300)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
204 (400)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
260 (500)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4 for stress classification definitions.

Table 2.1.6: Design, Levels A and B: Stress Intensity – SA-350 LF3

Code: ASME NB
Material: SA-350 LF3
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**					
	S_m	**P_m** (Note 3)	**P_L** (Note 3)	**$P_L + P_b$** (Note 3)	**$P_L + P_b + Q$**	**P_e** (Note 4)
-29 to 38 (-20 to 100)	160.6 (23.3)	160.6 (23.3)	240.9 (35.0)	240.9 (35.0)	481.9 (69.9)	481.9 (69.9)
93.3 (200)	157.9 (22.9)	157.9 (22.9)	236.9 (34.4)	236.9 (34.4)	473.7 (68.7)	473.7 (68.7)
149 (300)	152.4 (22.1)	152.4 (22.1)	228.6 (33.2)	228.6 (33.2)	457.2 (66.3)	457.2 (66.3)
204 (400)	147.5 (21.4)	147.5 (21.4)	221.3 (32.1)	221.3 (32.1)	442.5 (64.2)	442.5 (64.2)
260 (500)	140.0 (20.3)	140.0 (20.3)	210.0 (30.5)	210.0 (30.5)	420.0 (60.9)	420.0 (60.9)
316 (600)	129.6 (18.8)	129.6 (18.8)	194.4 (28.2)	194.4 (28.2)	388.8 (56.4)	388.8 (56.4)
371 (700)	116.5 (16.9)	116.5 (16.9)	174.8 (25.4)	174.8 (25.4)	349.5 (50.7)	349.5 (50.7)

Notes:

1. Source for S_m is Table 2A of ASME Section II, Part D.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. Evaluation required for Design condition only per NB-3220.
4. P_e not applicable to vessels per Fig. NB-3221-1.
5. See Table 2.1.4 for stress classification definitions.

Table 2.1.7: Level D, Stress Intensity – SA-350 LF3

Code: ASME NB
Material: SA-350 LF3
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**		
	P_m	**P_L**	**$P_L + P_b$**
-29 to 38 (-20 to 100)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
93.3 (200)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
149 (300)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
204 (400)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
260 (500)	335.8 (48.7)	506.8 (73.5)	506.8 (73.5)
316 (600)	311.0 (45.1)	462.6 (67.7)	462.6 (67.7)
371 (700)	279.9 (40.6)	419.9 (60.9)	419.9 (60.9)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4 for stress classification definitions.

Table 2.1.8: Design Stress Intensity – Bolting and Trunnion Material

Code: ASME NB
Material: SA-193 B7 and SA 320 L7 (Bolt < 2.5 inch diameter), SA-564/705 630 (H1025) & SB-637 N07718 (Bolt ≤ 6 inch diameter),
Item: Stress Intensity

Temperature ºC (ºF)	**Design Stress Intensity SA-193 B7/ SA 320 L7 MPa (ksi)**	**Design Stress Intensity SA-564/705 630 MPa (ksi)**	**Design Stress Intensity SB-637 MPa (ksi)**
-29 to 38 (-20 to 100)	241.3 (35)	333.0 (48.3)	344.7 (50)
93.3 (200)	224.8 (32.6)	333.0 (48.3)	330.9 (48)
149 (300)	216.5 (31.4)	333.0 (48.3)	323.4 (46.9)
204 (400)	210.3 (30.5)	324.1 (47.0)	317.8 (46.1)
260 (500)	203.4 (29.5)	317.8 (46.1)	314.4 (45.6)
316 (600)	195.8 (28.4)	313.0 (45.4)	310.95 (45.1)
343 (650)	-	309.6 (44.9)	-
371 (700)	185.5 (26.9)	-	308.9 (44.8)

Notes:

1. Level A and D limits per Table 2.1.3
2. Table 2.2.2 contains other mechanical and thermal properties of the bolting material.
3. Sources for design stress intensity values for SA-193 B7 and SB-637 N07718 is Table 4 and that for SA-564/705 630 material, is Table 2A of ASME Section II, Part D.
4. Values for SA-564/705 630 are conservatively based on age hardening at 1075ºF (H1075).
5. Since SA-193 B7 and SA-320 L7 has the similar chemical composition and strengths, SA-320 L7 stress intensity is considered identical to SA-193 B7.

Table 2.1.9: [Withheld in Accordance with 10 CFR 2.390]

Table 2.1.10: [Withheld in Accordance with 10 CFR 2.390]

Table 2.1.11: Applicable Codes and Standards for the Materials Used in The HI-STAR 180L Packaging

	Item	Principal Function	Applicable Codes and Reference Standard
1.	Containment Baseplate	Containment Boundary	ASME Code Section III Subsection NB
2.	Containment Shell	Containment Boundary	ASME Code Section III Subsection NB
3.	Containment Closure Flange	Containment Boundary	ASME Code Section III Subsection NB
4.	Inner Closure Lid	Containment Boundary	ASME Code Section III Subsection NB
5.	Outer Closure Lid	Containment Boundary	ASME Code Section III Subsection NB
6.	Inner Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
7.	Outer Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
8.	Vent and Drain Port Plugs	Containment Boundary	ASME Code Section II
9.	Seals and Gaskets	Containment Boundary	Non-Code (Manufacturer’s Catalog and Test Data)
10.	Fuel Basket (Metamic-HT)	Positioning of Fuel Assemblies and Quivers for Criticality Control	Non-Code (Manufacturer’s Test Data [1.2.10])
11.	Monolithic Shield Cylinders	Gamma Shielding	ASME Code Section II
12.	Holtite-B	Neutron Shielding	Non-Code (Holtite-B Sourcebook [1.2.9])
13.	Trunnions	Lifting and Handling	ASME Code Section II and ANSI N14.6
14.	Monolithic Shield Cylinder Top Cap	Holtite Cavity Space Enclosure (non-structural)	ASME Code Section II
15.	Monolithic Shield Cylinder Bottom Cap	Holtite Cavity Space Enclosure (non-structural)	ASME Code Section II

Table 2.1.11: Applicable Codes and Standards for the Materials Used in The HI-STAR 180L Packaging (Continued)

	Item	Principal Function	Applicable Codes and Reference Standard
16.	Basket Shims	Positioning of Basket in the Containment Cavity	ASTM B221
17.	Impact Limiter Backbone Plate Material	Structural Support of Impact Limiter	ASME Code Section II
18.	Impact Limiter Attachment Rods and Nuts	Structural Support of Impact Limiter	ASME Code Section II
19.	Impact Limiter Crush Material	Impact Energy Absorption	Non-Code (Manufacturer's Catalog and Test Data)
20.	Impact Limiter Fastener Strain Limiter	Protection of Impact Limiter Fasteners Against Excessive Stress/Strain	Non-Code (Manufacturer's Catalog and Test Data)

Notes:

1. Materials for ITS components not listed above shall meet ASME, ASTM, or other standard industrial codes, as approved by Holtec International. Materials for NITS components shall meet standard industrial codes or the manufacturer's product sheets as approved by Holtec International.

Table 2.1.12: [Withheld in Accordance with 10 CFR 2.390]

Table 2.1.13: ASME Code Requirements and Alternatives for the HI-STAR 180L Package

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Containment System	NB-1000	Statement of requirements for Code stamping of components.	Cask containment boundary is designed, and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
Cask Containment System	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Holtec approved suppliers will supply materials with CMTRs per NB-2000.
Cask Containment System	NB-7000	Vessels are required to have overpressure protection.	No overpressure protection is provided. Function of cask vessel is as a radionuclide containment boundary under normal and hypothetical accident conditions. Cask is designed to withstand maximum internal pressure and maximum accident temperatures.
Cask Containment System	NB-8000	States requirements for name, stamping and reports per NCA-8000.	HI-STAR 180L Package to be marked and identified in accordance with 10CFR71. Code stamping is not required. QA data package prepared in accordance with Holtec's approved QA program.

Table 2.1.13: ASME Code Requirements and Alternatives for the HI-STAR 180L Package (Continued)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Containment System	NB-2330	Establish TNDT and test base metal, heat affected zone and weld metal at TNDT + 60ºF	Rather than testing to establish the RTNDT as defined in paragraph NB-2331, the guidance from NUREG/CR 3826 is used for materials from greater than 4 and up to 20 inches thick. The Containment shell is nominally 2.5 inches thick, so the provisions Reg. Guide 7.11 are more applicable for the shell material. Reg. Guide 7.11 for materials up to 4 inches thick does have a reference to SA203 material and requires the TNDT to be <-70ºF. Since the specified TNDT for the shell material as reflected in Table 2.1.10 is significantly lower, it is in compliance with NB-2330. Table 2.1.10 summarizes the specific impact testing requirements for the Containment Boundary components per Reg. Guides 7.11, 7.12 and NUREG/CR-3826. All containment welds on the HI-STAR 180L will be involving the shell and have a nominal thickness of 2.5 inches. Therefore the TNDT for the containment welds will be the same as the TNDT for the containment shell as reflected in Table 8.1.5. Drop test to determine TNDT for containment weld is not required.

Table 2.1.13: ASME Code Requirements and Alternatives for the HI-STAR 180L Package (Continued)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Monolithic Shield Cylinders and Bottom Ring Forging	NB-4622	All welds, including repair welds, shall be post-weld heat treated (PWHT).	PWHT of monolithic shield cylinder-to-containment baseplate weld, monolithic shield cylinder top cap plate-to-containment closure flange weld, and bottom ring forging-to-containment baseplate weld do not require PWHT. These welds attach non-pressure retaining parts to pressure retaining parts. The pressure retaining parts are > 6 inches thick. Localized PWHT will cause material away from the weld to experience elevated temperatures that will have an adverse effect on the material properties.
Cask Containment System	NB-5120	Perform radiographic examination after post-weld heat treatment (PWHT).	Radiography of the helium retention boundary welds after PWHT is not required. All welds (including repairs) will have passed radiographic examination prior to PWHT of the entire containment boundary. Confirmatory radiographic examination after PWHT is not necessary because PWHT is not known to introduce new weld defects in nickel steels.

Table 2.1.13: ASME Code Requirements and Alternatives for the HI-STAR 180L Package (Continued)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Monolithic Shield Cylinders and Bottom Ring Forging	Section II, SA-352 and SA-350	Material to be Charpy Impact Tested at -50F and conform to specified absorbed energy requirements	SA-352 LCC and SA-350 LF2 are normally used as pressure retaining material, but in this application they are selected to provide a shielding and/or structural support function due to their low temperature fracture toughness properties. Because the components' primary function is as a structural support, Holtec has applied the requirements of ASME Section III, Subsection NF for the brittle fracture testing and is not relying on the Section II testing requirements applicable to pressure retaining parts. While the test temperature per NF is based on the Lowest Service Temperature (LST) and is 10 degrees higher than the Section II test temperature, the absorbed energy value is also higher making the use of the NF criteria conservative relative to Section II. Impact testing will be performed at the LST for the HI-STAR 180L Package (-40^{o}F). Per NF-2331 material acceptability may be based on Charpy absorbed energy values or Charpy lateral expansion values.

Table 2.1.14: [Withheld in Accordance with 10 CFR 2.390]

2.2 MATERIALS

2.2.1 Mechanical Properties and Specifications

This subsection provides the mechanical properties used in the structural evaluations. The properties include, as appropriate, yield stress, ultimate stress, modulus of elasticity, strength, weight density, and coefficient of thermal expansion. The property values are presented for a range of temperatures for which structural calculations are performed.

2.2.1.1 Structural Materials

2.2.1.1.1 Nickel Alloy, Low-Alloy Steel

The nickel alloy and low-alloy steels used in the HI-STAR 180L packaging are SA-203E and SA-350 LF3, respectively. The material properties (used in structural evaluations) of SA-203 E and SA-350 LF3 are given in Table 2.2.1.

Properties of steel, which are not included in any of the tables at the end of the section, are weight density and Poisson’s ratio. These properties are assumed constant for all structural analyses. The values used are shown in the table below.

Property	Value
Weight Density, kg/m^3 (lb/in^3)	7,833 (0.283) 8,027 (0.290) (for Stainless Steel)
Poisson's Ratio	0.30

2.2.1.1.2 Bolting and Trunnion Materials

Material properties (for structural evaluations) of the closure lid bolting and trunnion materials used in the HI-STAR 180L Package are given in Tables 2.2.2 and 2.2.3.

2.2.1.1.3 Fuel Basket

The Fuel Basket is made of Metamic-HT.

Metamic-HT, a high strength, nanotechnology-based counterpart of the classic Metamic neutron absorber material, is extensively characterized in the supplier’s report [1.2.10]. Minimum guaranteed values (MGVs) of Metamic-HT, based on the supplier’s test report [1.2.10] are provided in Table 2.2.8.

2.2.1.1.4 Weld Material

All weld filler materials utilized in the welding of the Code components, which excludes the Metamic-HT fuel basket, will comply with the provisions of the appropriate ASME Code Subsection (e.g., cited paragraphs of Subsection NB and with applicable paragraphs of Section IX). All non-Code welds and non-Metamic-HT welds will be made using weld procedures that meet ASME Section IX, AWS D1.1, D.1.2 or equivalent. The minimum tensile strength of the weld wire and filler material (where applicable) will be equal to or greater than the tensile strength of the base metal listed in the ASME Code.

All non-destructive examinations specifications will comply with Section V of the ASME Code.

Metamic-HT welding and examinations will be in accordance with Subparagraph 1.2.1.6.1, Subsection 8.1.2, and the drawing package in Section 1.3.

2.2.1.1.5 AL-STAR Impact Limiter

The AL-STAR impact limiter for the HI-STAR 180L Package is shown in the drawing package in Section 1.3. The impact limiter consists of a rigid cylindrical core, a cylindrical skirt that girdles the cask forging, the energy absorbing material, an outer skin, and attachment bolts. The energy absorbing material is positioned in the impact limiter to realize adequate crush modulus in all potential impact modes. The external surface of the impact limiter consists of a stainless steel skin to provide long-term protection against weather and inclement environmental conditions. Attachment bolts are also made of stainless steel, which imparts a high fracture toughness and high ductility in the entire temperature range of service.

Rail transport considerations limit the maximum diameter of the impact limiter. The axial dimension of the impact limiter is limited by the considerations of maximum permissible packaging weight for rail transport. Within the limitations of space and weight, the impact limiter should possess sufficient energy absorption capacity so as to meet the structural demands on the package under all postulated drop orientations. The sizing of the impact limiter internal structure is principally guided by the above considerations. For example, in order to ensure that a sufficient portion of the energy absorbing material participates in lateral impacts, a thick high strength steel shell, buttressed with gussets, provides a hard backing surface for the honeycomb material to crush against.

The material properties for the stainless and carbon steels, for structural evaluations, are provided in Tables 2.2.4 and 2.2.5, respectively. Material properties for the stainless steel impact limiter attachment bolts are provided in Table 2.2.6.

Two properties of the energy absorbing material germane to its function are the crush strength and the nominal density. The crush strength is the more important of the two properties; the density is significant in establishing the total weight of the package. The crush strength increases monotonically with density. Honeycomb materials with a wide range of density and crush strength are available. A characteristic load-crush relation for a honeycomb material is shown in Figure 2.2.1 for a constant crush area. The relation shows an initial sharp peak, then an essentially constant force over a large crush depth, and finally a significant increase of the force when the material becomes compacted. To eliminate the initial peak, which could potentially result in higher g-loads at the beginning of the impact, all honeycomb material for the HI-STAR 180L is pre-crushed by the material supplier. Table 2.2.10 documents the *critical characteristics* of the impact limiter material in tabular form.

For the HI-STAR 180L cask, two crush strengths are utilized to optimize the impact limiter's performance. The drawing package in Section 1.3 shows the location of the crush materials for predominately lateral impact (designated as Type 1) and for predominately longitudinal impact (designated as Type 2); Table 2.2.10 documents the impact limiter crush strengths in tabular form. The crush strength, being a critical characteristic, will be specified in the purchase specification for material procurement.

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2.2.1.1.6 Closure Lid Seals

The containment integrity of the HI-STAR 180L Package relies on a double closure lid system with metallic seals, as shown in the licensing drawings in Section 1.3. The sealing action against the release of the cask's contents is provided by the two self-energizing seals located in each of the two annular grooves per lid. Each seal acts autonomously, thus providing a double barrier against leakage for each closure lid.

To ensure that the effectiveness of the leak barriers is optimal, the grooves are machined in the precise configuration and surface finish called for the type of self-energizing gasket selected for this application. The gasket chosen for the HI-STAR 180L cask must fulfill the principal requirements set down in the following:

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The load required to "seat" the gaskets is a small percentage of the total applied bolt preload force; hence the required "seating load" (an ASME Boiler & Pressure Vessel code term) is not an important parameter. The size of the gasket in relation to the size of the groove, on the other hand, is a critical dimension that is based on the gasket supplier's test data and which must be controlled through the gasket Procurement Specification. The critical sealing dimensions consistent with seal manufacturers' data are provided in Appendix 8.A. Other critical characteristics of the HI-STAR 180L gasket that must be controlled to ensure a robust joint performance are listed in Table 2.2.13. The gaskets will be procured as an *Important-to-Safety* part.

Using the governing design features from Table 2.2.13, the closure seals have been conservatively specified to provide a high degree of assurance of leak tightness under normal and accident conditions of transport so that package service conditions at normal or accident pressures under high and low temperatures will not challenge the capabilities of cask closure seals. Creep of the cask closure seals, even under long term use in a loaded cask (50 years), is not credible due to its materials of construction and the nickel alloy seal spring. The specifications for the closure lid seals are provided below:

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Table 2.2.13 provides the data on the bolted joint loads, including the load needed to “seat” the closure plate gaskets.

2.2.1.2 Nonstructural Materials

2.2.1.2.1 Monolithic Shield Cylinder

The monolithic shield cylinder is not in the primary load path of the HI-STAR 180L cask during a lifting operation since it has no connection to the upper trunnions. The monolithic shield cylinders do, however, girdle the containment shell and thus may act in concert with the containment shell during Hypothetical Accident Conditions of Transport. Necessary structural properties for the monolithic shield, for analysis purposes, are the yield and ultimate strength; a representative set of properties is tabulated in Table 2.2.7, and *critical characteristics* are provided in Table 2.1.12.

2.2.1.2.2 Holtite Neutron Shielding Material

The non-structural properties of the neutron shielding material are provided in Table 2.2.12. Holtite B does not serve a structural function in the HI-STAR 180L package.

2.2.1.2.3 Fuel Basket Supports

The fuel basket supports (basket shims), made of aluminum alloy and stainless steel, provide the heat transfer bridge between the basket and the cask inside surface, and serve to position the fuel basket. Representative mechanical properties for the aluminum basket supports are tabulated in Table 2.2.9.

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2.2.1.2.4 Cask Coating

The HI-STAR 180L cask exterior steel surfaces are coated with a conventional surface preservative such as Carboguard® 890 (see www.carboline.com for product data sheet) and/or equivalent surface preservative. Carboguard ® 890 and equivalent surface preservatives have provided years of proven performance on HI-STAR 100 casks. In addition, exterior surfaces of the cask are easily inspected and recoated as necessary. For cask coatings, alternate surface preservatives are determined equivalent per the recommendation of a coating manufacturer and with Holtec approval. Carboguard 890 is the product name at the time of this SAR writing. Chemically identical products with different names are permitted. Other coatings that can be shown to have had proven performance in similar applications and environments are permitted.

2.2.1.2.5 Cask Liner

A cask liner is required to protect containment boundary steel components against increased corrosion from submersions into the spent fuel pools. The HI-STAR 180L cask cavity and inter-lid space carbon steel surfaces (except for threaded features) may be lined with either a) conventional surface preservative, b) an atomized deposit of a corrosion resistant layer such as aluminum oxide or c) other methods according to the drawing package in Section 1.3. Conventional surface preservative over aluminum oxide is also acceptable where supported by manufacturer recommendation.

a) Conventional Surface Preservative

The HI-STAR 180L cask interior steel surfaces may be coated with conventional surface preservatives such as Thermaline® 450 (see www.carboline.com for product data sheet) or equivalent surface preservative. Thermaline® 450 and equivalent surface preservatives have provided years of proven performance on HI-STAR 100 casks. Conventional surface preservatives refer to sprayed/rolled on and cured "paints". Although interior cask surfaces are not accessible for routine liner repair during loaded cask operation, the dry helium environment protects cask contents and internals, including cask liners from long-term degradation. Conventional surface preservatives shall be applied in accordance with the manufacturer's recommendation and to the recommended dry film thickness. Conventional surface preservatives shall not result in significant chemical reaction with borated water. Thermaline® 450 is the product name at the time of this SAR writing. Chemically identical products with different names are permitted. The following critical characteristics are specified conservatively for conventional surface preservatives and in order of importance to guide the in the selection of equivalent surface preservatives:

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b) Aluminum Oxide

Aluminum oxide provides excellent corrosion resistance and is compatible with the cask aluminum basket supports. [
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Aluminum oxide may be applied by the commonly used thermal spray method along the cask inner surfaces. Approved procedures will be developed for performing the operation taking into consideration or fully applying available guidance from recognized standards. The following standards are available for developing procedures and for qualifying thermal spray contractors or operators.

1) ANSI/AWS C2.18-93 "Guide for the Protection of Steel with Thermal Sprayed Coating of Aluminum and Zinc and Their Alloys and Composites"

2) NACE No. 12/AWS C2.23M/SSPC-CS 23.00 "Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel"

3) SSPC 04-13 SSPC-QP 6 “Standard Procedure for Evaluating the Qualifications of Contractors Who Apply Thermal Spray (Metallizing) for Corrosion Protection of Steel and Concrete Structures”

4) ANSI/AWS C2.16/C2.16M:2002 “Guide for Thermal Spray Operator Qualification”

Other standard processes for aluminum oxide thermal spray and its application, which are supported by recognized standards, may be used subject to a suitability assessment by Holtec International.

c) Other surface preservation methods.

The cask liner surfaces may be protected using other methods which provide suitable corrosion resistance along with the heat transfer characteristics used in the thermal analysis. These methods include weld overlay, explosive bonding, and lining with a thin corrosion resistant sheet material. Use of these alternate methods is permitted provided that the heat transfer effectiveness of the cask containment boundary with the liner maintains fuel cladding and cask component temperatures within the design limits. The heat transfer effectiveness is maintained provided the minimum emissivity valued for the cask interior surfaces meets or exceeds the value of listed in Table 3.2.6 and the through wall thermal conductivity of the cask is not significantly reduced.

2.2.1.2.6 Lead

Lead is not considered as a structural member of the HI-STAR 180L Package. However, it is included in the dynamic simulation models for Normal and Accident Conditions of Transport. Applicable mechanical properties of lead are provided in Table 2.2.11.

2.2.2 Chemical, Galvanic or Other Reactions

Similar to the HI-STAR 100 and HI-STAR 180 packaging, the HI-STAR 180L packaging combines low-alloy and nickel alloy steels, carbon steels, neutron and gamma shielding, and bolting materials. All of these materials have a long history of non-galvanic behavior within close proximity of each other. The external surfaces of the cask are coated to preclude surface oxidation. The internal surfaces of the cask are lined to preclude any significant surface oxidation. The coatings and liners do not chemically react significantly with borated water. The cask is dried and helium backfilled as discussed in Chapter 7 to eliminate any credible corrosion from moisture and oxidizing gases. Metamic-HT plate has high corrosion resistance, and anodizing to meet the required emissivity further enhances its corrosion resistance. Therefore, chemical, galvanic or other reactions involving the cask materials are unlikely and are not expected.

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In accordance with NRC Bulletin 96-04 [2.2.4], a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STAR 180L Package, its contents and the operating environment, which may produce adverse reactions, has been performed. As a result of this review, no operations were identified which could produce adverse reactions. No closure welding is performed and thus hydrogen generation while the cask is in the pool is of minor consequence to cask operations based on previous experience with the same cask materials. Because no welding activities are involved in the cask closure operations, the potential of a hydrogen ignition event does not exist.

2.2.3 Effects of Radiation on Materials

The general physical effects of radiation of metals by fast neutrons and other high-energy particles are summarized in the following table taken from a DOE Handbook on Material Science [2.2.3].

General Effect of Fast Neutron Irradiation on Metals	
Property Increases	Property Decreases
• Yield Strength • Tensile Strength • NDT Temperature • Young’s Modulus (Slight) • Hardness • High Temperature Creep Rate (During Irradiation)	• Ductility • Stress-Rupture Strength • Density • Impact Strength • Thermal Conductivity

The HI-STAR 180L Package is composed of materials that either have a proven history of use in the nuclear industry or have been extensively tested. The radiation levels from spent nuclear fuel do not affect the packaging materials. Gamma radiation damage to metals (e.g., aluminum, stainless steel, and carbon steel) does not occur until the fluence level reaches 10^{18} rads (10^{16} Gy) or more. The 50-year gamma fluence (assuming design basis fuel for 50 years without radioactive decay) from the spent nuclear fuel transported in the HI-STAR 180L Package is on the order of 1.25×10^{9} rads (1.25×10^{7} Gy) and reduces significantly as it penetrates through cask components. Moreover, significant radiation damage due to neutron exposure does not occur for neutron fluences below approximately 10^{19} n/cm^2 [2.2.3, 2.2.4, 2.2.5], which is far greater than the 50-year neutron fluence from spent nuclear fuel transported in the HI-STAR 180L Package, which is on the order of 1.25×10^{16} n/cm^2 assuming design basis fuel for 50 years without radioactive decay. Also, as indicated in reference [2.2.3], “The effects listed in the table above are generally less significant at elevated temperatures for a given fluence and some defects can be removed by heating (annealing).”

As discussed in Section 1.2 and its references, the Metamic-HT neutron absorber and Holtite have been tested extensively to prove that it will not degrade over the service life of the package. With the high nickel content in its spring, the cask closure seal materials are also most resistant to radiation. No adhesives are used in the cask packaging and packaging coatings (especially cask liners) are selected for the high radiation environment.

Table 2.2.1: Mechanical Properties of SA-350 LF3/SA-203 E

Temperature **ºC (ºF)**	**SA-350 LF3/SA-203 E for Cask Containment Boundary**					
	S_y	**S_u**	**E**	**α**	**S_y**	**S_u**
-73.30 (-100)	258.6 (37.5)	482.6 (70.0)	19.72 (28.6)	-	275.8 (40.0)	482.6 (70.0)
37.78 (100)	258.6 (37.5)	482.6 (70.0)	19.03 (27.6)	11.7 (6.5)	275.8 (40.0)	482.6 (70.0)
93.33 (200)	235.8 (34.3)	482.6 (70.0)	18.68 (27.1)	12.06 (6.7)	252.3 (36.6)	482.6 (70.0)
148.89 (300)	228.9 (33.2)	482.6 (70.0)	18.41 (26.7)	12.42 (6.9)	244.1 (35.4)	482.6 (70.0)
204.4 (400)	220.6 (32.0)	482.6 (70.0)	18.07 (26.2)	12.78 (7.1)	235.8 (34.2)	482.6 (70.0)
260 (500)	209.6 (30.4)	482.6 (70.0)	17.72 (25.7)	13.14 (7.3)	224.1 (32.5)	482.6 (70.0)
316 (600)	194.4 (28.2)	482.6 (70.0)	17.31 (25.1)	13.32 (7.4)	207.5 (30.0)	482.6 (70.0)
371 (700)	174.4 (25.3)	458.5 (66.5)	16.96 (24.6)	13.68 (7.6)	186.2 (27.0)	458.5 (66.5)

Definitions:

S_y = Yield Stress MPa (ksi)
S_u = Ultimate Stress MPa (ksi)
α = Coefficient of Thermal Expansion, cm/cm-ºC x 10^{-6} (in./in. per degree F x 10^{-6})
E = Young's Modulus MPa x 10^4 (ksi x 10^3)

Notes:
1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is ratioing S_m values.
3. Source for α values is material group 1 in Table TE-1 of [2.1.6].
4. Source for E values is material group B in Table TM-1 of [2.1.6].

Table 2.2.2: Outer Closure Lid Bolt (Optional Bolt Material) – Mechanical Properties

SA-193 Grade B7 or SA 320 L7 [less than 64 mm (2.5 in) diameter] for Containment Boundary Port Cover Bolts					
Temperature, ºC (ºF)	S_y	S_u	**E**	α	S_m
38 (100)	724.0 (105.0)	861.8 (125.00)	20.3 (29.5)	11.7 (6.5)	241.3 (35.0)
93.3 (200)	675.9 (98.0)	861.8 (125.00)	19.99 (29.0)	12.06 (6.7)	224.8 (32.6)
149 (300)	648.8 (94.1)	861.8 (125.00)	19.65 (28.5)	12.42 (6.9)	216.5 (31.4)
204 (400)	630.9 (91.5)	861.8 (125.00)	19.31 (28.0)	12.78 (7.1)	210.3 (30.5)
260 (500)	610.2(88.5)	861.8 (125.00)	18.89 (27.4)	13.14 (7.3)	203.4 (29.5)
316 (600)	588.1 (85.3)	861.8 (125.00)	18.55 (26.9)	13.32 (7.4)	195.8 (28.4)
371 (700)	555.72 (80.6)	824.6 (119.6)	18.06 (26.2)	13.68 (7.6)	185.5 (26.9)

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young's Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6] for ferrous materials.
2. Source for S_u values is Table U of [2.1.6] for ferrous materials, or from Section II, Part A. Where ultimate strength is unavailable, values above 300 deg. F are based on 100 deg.F value multiplied by ratio of yield strength at room temperature to yield strength at desired temperature.
3. Source for α values is Tables TE-1 and TE-4 of [2.1.6] for ferrous materials.
4. SA-705 630/SA-564 630 (H1025) per Table 2.2.3 is optional material for Port Cover Lid Bolts.

Table 2.2.3: Cask Trunnion and Inner/Outer Closure Lid Bolt - Mechanical Properties

SA-705 630, SA-564 630 (H1025 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	999.5 (145.0)	1068 (155)	19.7 (28.5)	11.16 (6.2)
93.3 (200)	924.4 (134.1)	1068 (155)	19.1 (27.8)	11.34 (6.3)
149 (300)	885.1 (128.4)	1068 (155)	18.8 (27.2)	11.52 (6.4)
204 (400)	854.1 (123.9)	1039 (150.7)	18.4 (26.7)	11.70 (6.5)
260 (500)	827.9 (120.1)	1018 (147.7)	18. (26.1)	11.70 (6.5)
288 (550)	816.2 (118.4)	1011 (146.6)	17.8 (25.8)	11.88 (6.6)
SB-637 N07718* (less than or equal to 6 inches diameter) (*If used as trunnion material, Table 2.1.12 must be satisfied instead)				
38 (100)	1034 (150.0)	1276 (185.0)	19.83 (28.76)	12.9 (7.1)
93.3 (200)	992.8 (144.0)	1225 (177.6)	19.51 (28.3)	13.0 (7.2)
149 (300)	970.1 (140.7)	1196 (173.5)	19.24 (27.9)	13.2 (7.3)
204 (400)	953.5 (138.3)	1176 (170.6)	18.96 (27.5)	13.4 (7.5)
260 (500)	943.2 (136.8)	1163 (168.7)	18.75 (27.2)	13.6 (7.6)
316 (600)	932.9 (135.3)	1151 (166.9)	18.48 (26.8)	13.9 (7.7)
371 (700)	926.7 (134.4)	1142 (165.7)	18.13 (26.3)	14.0 (7.8)

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young's Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for S_y values is ratioing design stress intensity values and Table Y-1 of [2.1.6], as applicable.
2. Source for S_u values is ratioing design stress intensity values and Table U of [2.1.6], as applicable.
3. Source for α values is Tables TE-1 and TE-4 of [2.1.6], as applicable. Values for α are for H1075 condition in lieu of H1025 condition.
4. Source for E values is Tables TM-1 and TM-4 of [2.1.6], as applicable.
5. SA-705 630 and SA-564 630 (both UNS No. S17400) have the same chemistry requirements and are considered equivalent for the intended application.

Table 2.2.4: Stainless Steel – Mechanical Properties (Minimum Values of SA-240 304, 304LN, 316, 316LN)

Temperature ºC (ºF)	S_y	S_u	α	E
-40 (-40)	206.8 (30.0)	517.1 (75.0)	14.58 (8.1)*	19.91 (28.88)
38 (100)	206.8 (30.0)	517.1 (75.0)	15.48 (8.6)	19.44 (28.2)
65.6 (150)	186.8 (26.7)	-	15.84 (8.8)	-
93.3 (200)	172.4 (25.0)	489.5 (71.0)	16.02 (8.9)	18.96 (27.5)
121 (250)	162.8 (23.6)	-	16.38 (9.1)	-
149 (300)	155.1 (22.5)	456.4 (66.2)	16.56 (9.2)	18.62 (27.0)
204 (400)	142.7 (20.7)	441.3 (64.0)	17.1 (9.5)	18.2 (26.4)

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young’s Modulus, MPa x 10^{4} (psi x 10^{6})

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is Table U of [2.1.6].
3. Source for α values is Table TE-1, Group 3 of [2.1.6]. * Value at –40 deg. F is extrapolated.
4. Source for E values is material group G in Table TM-1 of [2.1.6].
5. The listed yield and ultimate stress is the minimum value of SA-240 304, 304LN, 316, and 316LN.

Table 2.2.5: Miscellaneous Steel – Mechanical Properties

Temperature ºC (ºF)	**SA-36**			
	S_y	**S_u**	**α**	**E**
37,8 (100)	248.2 (36.0)	399.9 (58.0)	11.7 (6.5)	20.17 (29.26)
93,3 (200)	227.5 (33.0)	399.9 (58.0)	12.06 (6.7)	19.86 (28.8)
149 (300)	219.3 (31.8)	399.9 (58.0)	12.42 (6.9)	19.51 (28.3)
204 (400)	212.4 (30.8)	399.9 (58.0)	12.78 (7.1)	19.24 (27.9)
260 (500)	202.0 (29.3)	399.9 (58.0)	13.14 (7.3)	18.82 (27.3)
316 (600)	190.3 (27.6)	399.9 (58.0)	13.32 (7.4)	18.27 (26.5)
371 (700)	177.9 (25.8)	399.9 (58.0)	14.04 (7.8)	17.58 (25.5)

Table 2.2.5 (Continued): Miscellaneous Steel – Mechanical Properties

Temperature ºC (ºF)	**SA-516 Grade 70 or A516 Gr 70**			
	S_y	**S_u**	**α**	**E**
38 (100)	262.0 (38.0)	482.6 (70.0)	11.7 (6.5)	20.17 (29.26)
93.3 (200)	239.9 (34.8)	482.6 (70.0)	12.06 (6.7)	19.86 (28.8)
149 (300)	231.7 (33.6)	482.6 (70.0)	12.42 (6.9)	19.51 (28.3)
204 (400)	224.1 (32.5)	482.6 (70.0)	12.78 (7.1)	19.24 (27.9)
260 (500)	213.7 (31.0)	482.6 (70.0)	13.14 (7.3)	18.82 (27.3)
316 (600)	200.6 (29.1)	482.6 (70.0)	13.32 (7.4)	18.27 (26.5)
371 (700)	187.5 (27.2)	482.6 (70.0)	14.04 (7.8)	17.58 (25.5)

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young’s Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is Table U of [2.1.6].
3. Source for α values is material group 1 in Table TE-1 of [2.1.6].
4. Source for E values is “Carbon steels with C less than or equal to 0.30%” in Table TM-1 of [2.1.6].

Table 2.2.6: Yield and Ultimate Strength of SA-193 B8S Impact Limiter Attachment Bolts

Minimum Room Temperature Yield and Ultimate Stress for Attachment Bolt Calculations	
Item	**MPa (ksi)**
Yield Stress	344.7 (50)
Ultimate Stress	655.0 (95)

Definitions:

S_y = Yield Stress, MPa (ksi)
S_u = Ultimate Stress, MPa (ksi)

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is Table U of [2.1.6].
3.

Table 2.2.7: Monolithic Shield Cylinder – Mechanical Properties

SA-352 LCC / A352-93 LCC				
Temp. ºC (ºF)	**S_y**	**S_u**	**E**	**α**
37.8 (100)	275.8 (40.0)	482.6 (70.0)	20.2 (29.3)	11.7 (6.5)
93.33 (200)	252.3 (36.6)	482.6 (70.0)	19.86 (28.8)	12.06 (6.7)
148.89 (300)	244.1 (35.4)	482.6 (70.0)	19.51 (28.3)	12.42 (6.9)
204.2 (400)	235.8 (34.2)	482.6 (70.0)	19.24 (27.9)	12.78 (7.1)
260 (500)	224.8 (32.6)	482.6 (70.0)	18.82 (27.3)	13.14 (7.3)

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young's Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is Table U of [2.1.6].
3. Source for α values is Table TE-1 (for Group 1) of [2.1.6].
4. Source for E values is "Carbon Steels with C less than 0.25%" in Table TM-1 of [2.1.6].
5. ASTM A352-93 LCC is equivalent material per ASME Code Section II (same properties are considered to apply in any analysis).

Table 2.2.8: Minimum Guaranteed Values of Metamic-HT Primary Properties

Property (Note 1)	Temperature, °C	Property Value (Note 2)	Property Type
Yield strength, σ_y (ksi)	Ambient 200/300/350 450/500	19.5 15.0/13.8/10.0 7.7/5.4	Primary
Tensile strength, σ_u (ksi)	Ambient 200/300/350 450/500	28.2 18.8/15.6/11.9 8.1/5.9	Primary
Young's Modulus, E (Msi)	Ambient 200/300/350 450/500	11.8 10.8/8.8/6.9 3.8/3.3	Primary
Area Reduction (%)	Ambient 200/300/350 450/500	20 17.9/14.2/12.9 7.8/3.2	Primary

Note 1: All properties are critical characteristics.
Note 2: Properties can be interpolated, use 40°C for ambient when interpolating.

Table 2.2.9: Basket Shims – Nominal Mechanical Properties

Aluminum Alloy (B221 2219-T8511)					
Temp. ºC (ºF)	S_y	S_u	E	α	% Elongation
25 (75)	290 (42)	400 (58)	7.2 (10.5)	–	5
150 (300)	243 (35)	307 (44)	6.8 (9.8)	23.9 (13.3)	6.4
204 (400)	188 (27)	231 (34)	6.3 (9.1)	24.5 (13.6)	8.2
230 (450)	171 (25)	209 (30)	6.1 (8.8)	24.8 (13.8)	8.6
260 (500)	154 (22)	182 (26)	5.9 (8.5)	25.0 (13.9)	8.6
290 (550)	98 (14)	116 (17)	5.5 (8.0)	25.4 (14.1)	10.5
315 (600)	41.4 (6)	48.3 (7)	5.24 (7.6)	25.6 (14.2)	12

Definitions:

S_y = Yield Stress, MPa (ksi)
α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})
S_u = Ultimate Stress, MPa (ksi)
E = Young's Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for E values is "Properties of Aluminum Alloys", page 82 [2.2.7] (properties listed in the table above are not affected by time at temperature).
2. Source for S_y, S_u, and % Elongation values at room temperature is ASTM Specification B221M [2.2.9]. Values at elevated temperatures are obtained by scaling the room temperature values using the data from [2.2.7].
3. Source for α is Table TE-2 of [2.1.6] (values listed in TE-2 are also considered representative of Aluminum Alloy (2219-T8511) (UNS No. A92219)).

Table 2.2.10: [Withheld in Accordance with 10 CFR 2.390]

Table 2.2.11: Mechanical Properties of Lead

LEAD:	-40ºC (-40ºF)	-29ºC (-20ºF)	21ºC (70ºF)	93ºC (200ºF)	149ºC (300ºF)	316ºC (600ºF)
Yield Strength, MPa (psi)	4.83 (700)	4.69 (680)	4.41 (640)	3.38 (490)	2.62 (380)	0.138 (20)
Modulus of Elasticity, MPa (ksi)	1.65E+4 (2.4E+3)	1.65E+4 (2.4E+3)	1.59E+4 (2.3E+3)	1.38E+4 (2.0E+3)	1.31E+4 (1.9E+3)	1.03E+4 (1.5E+3)
Coefficient of Thermal Expansion, cm/cm/ºC (in/in/ºF)	28.1E-6 (15.6E-6)	28.3E-6 (15.7E-6)	29.0E-6 (16.1E-6)	29.9E-6 (16.6E-6)	31.0E-6 (17.2E-6)	36.4E-6 (20.2E-6)
Poisson's Ratio	0.40					
Density, kg/m^3 (lb/cubic ft.)	11,340 (708)					

Note: Values in this table are taken from [2.2.6].

Table 2.2.12: Properties of Holtite-B

Property (Note 1)	Property Value
Minimum Bulk Density, g/cm^3	1.251
Minimum Hydrogen Density, g/cm^3	0.1068
Minimum Boron Carbide Content, wt%	2
Minimum Copper Content, wt%	10
Design Temperature	Table 3.2.12
Thermal Conductivity	Table 3.2.2

Notes:
1. All properties are critical characteristics.

Table 2.2.13: [Withheld in Accordance with 10 CFR 2.390]

Table 2.2.14: Structural Capacity Data on the Quiver

Item	Data	Comment
Total weight	<291 Kg	Weight is less than a normal fuel assembly
Max permissible load on the handling device during normal handling operations	<5750 N	This limitation must be observed during plant operations
Free drop event under normal condition of transport [§71.71]	Drop from 30 cm in the most adverse orientation	No loss of radiological confinement capability
Accident condition of transport [§71.73]	Free drop from 9 meters on to an essentially rigid surface	The maximum deceleration axial or lateral sustained by the Quiver under the most adverse drop configuration shall be less than 100g per [2.2.10]
Maximum internal pressure	900 kPa	From any accident scenario leading to heating of the Quiver

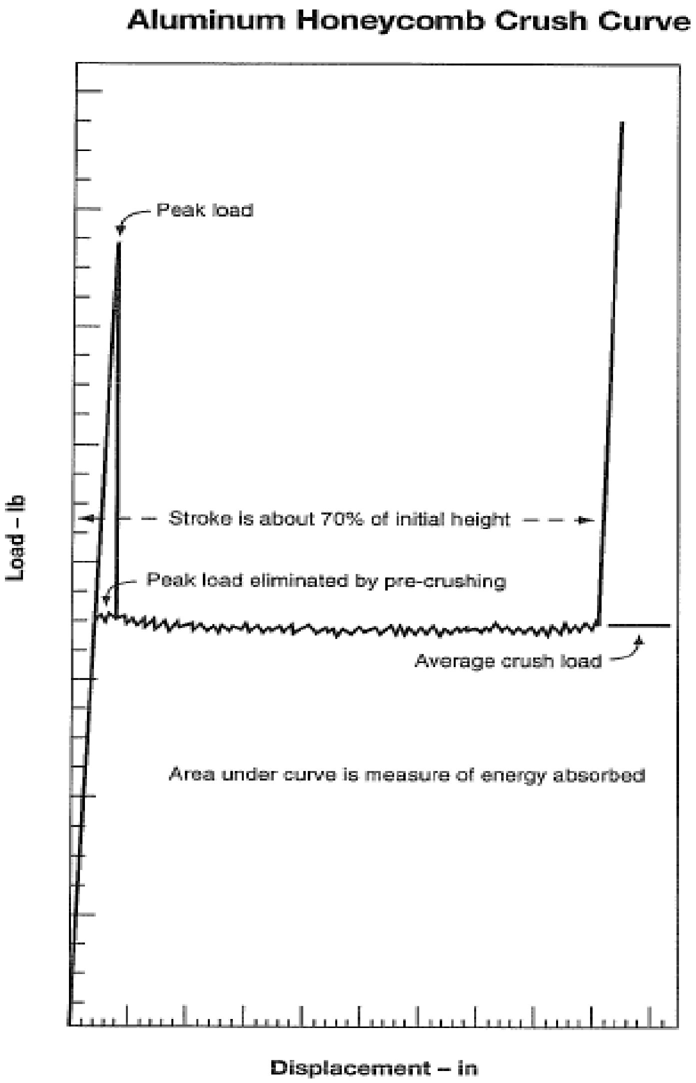

Figure 2.2.1: Aluminum Honeycomb Load vs. Crush Curve (Typical, reproduced from Ref. [2.1.1])

2.3 FABRICATION AND EXAMINATIONS

2.3.1 Fabrication

Consideration of the manufacturing process of a cask must be an integral part of its design evolution to ensure that the as-engineered cask can be manufactured to meet the intents of the design. For HI-STAR 180L, as in all other cask models, Holtec International utilizes the following key criteria during the design stage to ensure that design objectives will be realized during manufacturing:

i. The tolerances specified for the sub-components are achievable with state-of-the-art equipment and machinery.

ii. The design is not overly reliant on tight tolerances to ensure functional compliance.

iii. Suitable (compatible) material combinations are specified whenever two dissimilar materials are to be welded.

iv. Post-weld heat treatment and other means to alleviate weld shrinkage stresses are specified, as appropriate, to enhance the quality of the hardware and to comply with the applicable ASME Code.

v. The manufacturing sequence must permit all required non-destructive examinations to be performed and remedial repairs to be made to ensure compliance with the applicable codes and standards. This requirement is particularly relevant to the Containment Boundary in which the butt-welded joints must undergo 100% volumetric examination.

vi. The manufacturing sequence must permit machining of critical surfaces, such as the gasket seating surfaces in the top flange, to be carried out after all welding and forming related operations (that inevitably produce distortion) have been completed.

vii. The manufacturing steps do not involve operations that entail unnecessary risk to worker safety.

The above objectives are fully realized in the manufacturing process envisioned for HI-STAR 180L. Of course, there are several candidate manufacturing sequences that will meet the above criteria. In the following, an overview of one such acceptable fabrication sequence for the HI-STAR 180L is presented to illustrate its fabricability while meeting the above objectives. Other sequences may be used provided they meet the above criteria for quality fabrication

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As shown in the basket drawings in the licensing drawing package in Section 1.3, certain peripheral junctions in the fuel basket grid work are welded to provide additional dimensional fixity to the basket. Strictly speaking, these welds are not required for the basket to render its structural function. Nevertheless, they are incorporated in the basket's design, included in the structural finite element evaluations, and specified as structural welds in the drawing package in Section 1.3 of the SAR. Extensive comparative evaluation of candidate welding processes has shown that the "Friction Stir welding" (FSW) provides at least 30% greater joint strength than classical welding methods in Metamic-HT joints. Accordingly, FSW has been specified as the mandatory welding process for basket weld joints. As can be deduced from the licensing drawing package, the weld configuration in the fuel basket welds is of Category E, Type III (by virtue of being corner joint with essentially a thru-thickness "stir zone") per Section III Subsection NG.

The ASME Code allows the use of different code editions for different components: Per ASME Section III, NCA-1140, all items of a nuclear power plant may be constructed to a single Code Edition and Addenda, or each item may be constructed to individually specified Code Editions and Addenda. FSW weld procedure qualification was originally performed to the 2007 Edition of the ASME Code with certain essential variables that do not change. There is no requirement to requalify FSW weld procedures to a later edition of the Code. All welding by FSW process shall meet the applicable requirements of ASME Section IX per the edition specified in Chapter 8 of this SAR. The 2013 edition of the ASME Code is the first edition that incorporated FSW. Furthermore, per ASME Section IX, QG-108, joining procedures, procedure qualifications, and performance qualifications that were made in accordance with Editions and Addenda of Section IX, as far back as the 1962 Edition may be used in any construction for which the current Edition has been specified.

In the evaluation of the joint's structural strength, the fuel basket FSW joint is considered to emulate a full penetration weld with its thickness defined by the minimum depth of the friction stir zone per the licensing drawing package. Actual weld qualification testing on representative coupons prepared in accordance with the provisions of Section IX show section tensile strength of the FSW weld to be consistently in the range of the tensile strength of the base metal which provides the assurance that the weld joints internal to the fuel basket will have significant strength reserve compared to the structural demand placed on them. The bending and shear strength of the welded joints are computed using the weld tensile strength and weld depth determined from the coupon tests with the strength penalty factor applied in conformance with Table NG-3352-1.

Because of the extremely large thermal conductivity of the basket material (approximately 10 times that of austenitic stainless steel), the relatively thin wall of the Metamic-HT panels, and the slow rate of temperature changes in the containment cavity space due to the changes in the ambient conditions and the gradual decrease in the decay heat and absence of any constraints to the basket's free expansion, the cyclic stresses in the basket welds from thermal effects are assured to be minuscule. Likewise, the extent of fatigue expenditure in the basket due to vibration of the package during transport will be negligible because of the large section modulus of the basket structure (owing to its honeycomb construction) and small inertia loads associated with transportation. The structural stiffness of the basket, including its welds, is evidenced by its ability to withstand the inertia loads from the hypothetical accident condition (free drop from 9 meters) analyzed in Section 2.7. The vibration loads, which are a small fraction of the accident condition loads, can therefore be reasonably expected to produce cyclic stresses that are well below the endurance strength of the welds and panels in the basket. Therefore, it is concluded that the mechanical vibration and thermal effects are essentially ineffective as causative mechanisms for the loss of fatigue endurance capacity of the basket and the fatigue reduction factor for the corner welds in Table NG-3352-1 does not explicitly enter into the safety analysis. Thus, the conclusions reached in Subsection 2.6.5 with respect of absence of fatigue damage in the HI-STAR 180 transport package remain valid.

The basket shims used for the HI-STAR 180L are a combination of aluminum and stainless steel as shown in the drawing packages of Section 1.3. The aluminum shims are fabricated from a number of extrusions that are mated together to form the appropriate shape as shown in the drawings. The size and quantity of individual parts that form the cross section of the shim will vary depending upon the capacity of the extrusion press available for manufacture. The parts will be stacked together, mechanically joined together, or welded such that the overall shape is maintained, as shown in the drawing, and structural requirements are met. The stainless steel sections will be fabricated by welding stainless plate together to form an approximate shape and will then be finished machined to the proper profile. The shims will be installed in the cask after the basket has been positioned in the cask body and the bottom stainless steel shims will be installed first. The middle aluminum sections are then slid into place and then the top stainless steel section is installed.

The cask lid is fabricated as a separate assembly. The main center forging is first rough machined and then stainless steel weld overlay is applied to the sealing surface. The bottom cover plate support, the top lifting inserts, and the Holtite outer ring plate are then welded to the main lid forging. The lid is then heat treated as required in accordance with the ASME code. The lead shielding is then installed on the bottom of the lid and the lead coverplate is welded to the main forging and the bottom cover supports. The Holtite is then placed into the cavity on top of the lid and the Holtite cover plate is then welded to the outer ring plate and the lifting inserts. After the lid is fully welded, the lid is finished machined to size and to incorporate the seal grooves in the overlay surface. After machining, the overlay is PT examined to verify that it is free of voids which could compromise the seal.

2.3.2 Examinations

The design, material procurement, fabrication, and inspection of the HI-STAR 180L are performed in accordance with applicable codes and standards. The following fabrication controls and required inspections shall be performed on the HI-STAR 180L in order to assure compliance with the SAR and the Certificate of Compliance.

1. Materials of construction specified for the HI-STAR 180L are identified in the drawings. Important-to-safety (ITS) materials shall be procured with certification and supporting documentation as required by ASME Code, Section II (when applicable); the applicable subsection of ASME Code Section III (when applicable); and Holtec procurement specifications. Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to specification requirements, and traceability markings, as applicable. Material traceability is maintained throughout fabrication for ITS items through a computerized process that has been implemented by Holtec International in the manufacture of all safety-significant components.

2. Welding of Code materials, shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and the applicable ASME Section III Subsections. Welding of welds identified as NITS welds may be performed as described above for code welds or using welders and weld procedures that have been qualified in accordance with AWS D1.1 or AWS D1.2 as applicable. The weld requirements for Metamic-HT are summarize below in item 14.

3. Welds shall be examined in accordance with ASME Code Section V with acceptance criteria per ASME Code Section III. Acceptance criteria for NDE shall be in accordance with the applicable Code for which the item was fabricated. Weld inspections shall be detailed in a weld inspection plan that identifies the weld and the examination requirements, the sequence of examination, and the acceptance criteria. The inspection plan is subject to mandatory review and approval by Holtec International in accordance with its QA program prior to its use. NDE inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A as specified in Holtec's QA program. The requirements stated in this paragraph are not applicable to non-Code welds or Metamic-HT welds.

4. The HI-STAR 180L containment boundary shall be examined and tested by a combination of methods (including helium leak test, pressure test, UT, MT and/or PT, as applicable) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

All Category A and B welds are subject to 100% volumetric examination per Subsection NB of the ASME Code.

5. Grinding and machining operations of the HI-STAR 180L containment boundary shall be controlled through written and approved procedures and quality assurance oversight to ensure that material removal operations do not reduce base metal wall thicknesses of the boundaries beyond that allowed by the design. The thicknesses of base metals shall be ultrasonically tested, as necessary, in accordance with written and approved procedures to verify base metal thickness meets design requirements.

6. Dimensional inspections of the HI-STAR 180L shall be performed in accordance with written and approved procedures in order to verify compliance to design drawings and fit-up of individual components. All inspections of critical dimensions and functional fit-up tests shall be documented.

7. Lifting trunnions are provided for lifting and handling of the HI-STAR 180L. The trunnions are designed, inspected, and tested following guidance of ANSI N14.6. A carefully engineered design to eliminate local stress risers in the highly-stressed regions of the trunnion during lift operations and excellent stress margins ensure that the lifting trunnions will work reliably. Further, pursuant to the defense-in-depth approach of NUREG-0612, acceptance criteria for the lifting trunnions have been established in conjunction with other considerations applicable to heavy load handling.

   In order to ensure that the lifting trunnions do not have any hidden material flaws, the lifting trunnions shall be tested at 300% of the maximum design (service) lifting load. The load shall be applied for a minimum of 10 minutes to the pair of lifting trunnions. The accessible parts of the trunnions (areas outside the HI-STAR cask), and the local HI-STAR 180L cask areas shall then be visually examined to verify no deformation, distortion, or cracking has occurred. Testing shall be performed in accordance with written and approved procedures.

8. The containment boundary shall be hydrostatically or pneumatically pressure tested, if necessary, in accordance with the requirements of the ASME Code and 10CFR71. The test shall be performed in accordance with written and approved procedures. The written and approved test procedure shall clearly define the test equipment arrangement and acceptance criteria.

   After completion of the pressure testing, the internal surfaces shall be visually examined for cracking or deformation. Any evidence of cracking or deformation shall be cause for rejection or repair and retest, as applicable. Test results shall be documented and shall become part of the final quality documentation package.

9. The majority of materials used in the HI-STAR 180L cask body are ferritic steels.

ASME Code Section III and Regulatory Guides 7.11 and 7.12 require that certain materials be tested in order to assure that these materials are not subject to brittle fracture failures.

Drop weight testing and Charpy impact testing of each plate and forging for the HI-STAR 180L containment boundary are carried out in accordance with Table 8.1.5. Weld material used in welding the containment boundary is also tested as specified in Table 8.1.5.

Non-containment portions of the HI-STAR 180L, as required, shall be impact tested in accordance with Table 2.1.14. Test results shall be documented and shall become part of the final quality documentation record package.

10. A containment boundary leakage test of the welded structure shall be performed at any time after the containment boundary fabrication is complete. Preferably, this test should be performed at the completion of fabrication. The leakage test instrumentation shall have a minimum test sensitivity of one half of the leak test rate. Containment boundary welds shall have indicated leakage rates not exceeding leak test acceptance criteria. At the completion of fabrication, the helium leakage through all containment boundary penetrations shall be demonstrated to not exceed the leakage rate acceptance criteria. The leakage rate acceptance criteria is provided in Chapter 8.

11. All required inspections, examinations, and tests shall be documented. The inspection, examination, and test documentation shall become part of the final quality documentation package.

12. The HI-STAR 180L shall be inspected for cleanliness and proper preparation for shipping in accordance with written and approved procedures.

13. A completed quality documentation record package shall be prepared and maintained during fabrication of each HI-STAR 180L to include detailed records and evidence that the required inspections and tests have been performed for important to safety items. The quality document record package shall be reviewed to verify that the HI-STAR 180L has been fabricated and inspected in accordance with the governing Certificate-of-Compliance.

14. Metamic-HT welding and welder qualifications, requirements, and examinations will be in accordance with Paragraph 1.2.1.6, Subsection 8.1.2, and the drawing package in Section 1.3.

Figure 2.3.1: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.2: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.3: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.4: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.5: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.6: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.7: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.8: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.9: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.10: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.11: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.12: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.13: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.14: [Withheld in Accordance with 10 CFR 2.390]

2.4 GENERAL REQUIREMENTS

The compliance of the HI-STAR 180L Packaging to the general standards for all packaging, specified in 10CFR71.43, is demonstrated in the following subsections.

2.4.1 Minimum Package Size

As can be seen from the external dimensions of the packaging, in Section 1.3, the HI-STAR 180L Packaging meets the requirements of 10CFR71.43(a).

2.4.2 Tamper-Indicating Feature

During transport operations, a cover is installed over the access tube above one of the impact limiter attachment bolts as shown in the drawing package for the impact limiters in Section 1.3. A wire tamper-indicating seal with a stamped identifier is attached to hold the cover in place to indicate possible tampering with the upper impact limiter. The upper impact limiter must be removed to gain access to the closure lid bolting and the radioactive contents; thus, the absence of tampering is an indication that the radioactive contents of the package have not been accessed. This tamper seal satisfies the requirements of 10CFR71.43(b).

As shown in the drawing package for the cask in Section 1.3, the cask closure lid bolts may include holes for installation of wire tamper-indicating seals (security seals). The use of the security seals on the cask closure lid bolts is specified by the user or may be mandated by the authority designated to enforce and inspect such security features.

2.4.3 Positive Closure

There are no quick-connect/disconnect valves in the containment boundary of the HI-STAR 180L Packaging. [

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2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Lifting Devices

Per Reg. Guide 7.9, this subsection presents analyses for all lifting operations applicable to the transport of a HI-STAR 180L package to demonstrate compliance with requirements of paragraph 71.45(a) of 10CFR71.

The HI-STAR 180L Package has the following types of lifting attachments: two lifting trunnions located on the cask top flange and threaded holes on each closure lid that serve as attachment locations to lift the cask closure lids. The drawing package in Section 1.3 shows the location of the Lifting Trunnions.

The evaluation of the adequacy of the lifting devices entails careful consideration of the applied loading and associated stress limits. The load combination D+H, where H is the "handling load", is the generic case for all lifting adequacy assessments. The term D denotes the dead load. Quite obviously, D must be taken as the bounding value of the dead load of the component being lifted. Table 2.1.9 provides package component weights. In all lifting analyses considered in this document, the handling load H is assumed to be equal to 0.15D. In other words, the inertia amplifier during the lifting operation is assumed to be equal to 0.15g. This value is consistent with the guidelines of the Crane Manufacturer's Association of America (CMAA), Specification No. 70, 1988 [2.5.5], Section 3.3, which stipulates a dynamic factor equal to 0.15 for slowly executed lifts. Thus, the "apparent dead load" of the component for stress analysis purposes is $D^* = 1.15D$. Unless otherwise stated, all lifting analyses in this chapter use the "apparent dead load", D^*, in the lifting analysis.

For use as part of a transportation package, the lifting trunnions that are a part of the HI-STAR 180L package are designed to meet the requirements of 10CFR71.45(a) and NUREG-1617 [2.1.11]. Accordingly, the lifting trunnions are required to maintain a safety factor of 3 based on trunnion material yield strength. The lifting attachments that are part of the HI-STAR 180L package are required to meet the design provisions of NUREG-0612 [2.1.5], which specify safety factors of 10 on ultimate strength to ensure safe handling of heavy loads in critical regions within nuclear power plants. Satisfying the more conservative design requirements of NUREG-0612 ensures that the design requirements of 10CFR71.45(a) are met. Hence the lifting trunnions and the lifting attachments are conservatively analyzed to meet a minimum safety factor of 3 based on material yield strength and a safety factor of 10 based on material ultimate strength.

Unless explicitly stated otherwise, all stress results for lifting devices are presented in dimensionless form, as safety factors, defined as SF, where:

SF = (Allowable Stress Intensity in the Region Considered)/(Computed Maximum Stress Intensity in the Region)

It should be emphasized that in the results for the trunnion stress levels, the safety factor, SF represents the additional margin that is over and beyond the margin built into NUREG 0612 (e.g., a minimum safety factor of 10 on ultimate strength or 6 on yield strength).

2.5.1.1 Cask Trunnion Analysis

The lifting trunnion for the HI-STAR 180L cask is presented in the drawing package provided in Section 1.3. The two lifting trunnions for HI-STAR 180 are circumferentially spaced at 180-degrees. The trunnions are designed for a two-point lift and are sized to satisfy the aforementioned NUREG-0612 criteria. The trunnion material is identified in the drawing package shown in Section 1.3. There are also two (optional) trunnions at the base of the cask. These trunnions may be used as rotation supports when changing package orientation from vertical to horizontal (or vice- versa), or may be used to support 50% of the loaded cask when it is lifted in a horizontal orientation. In the former case, the lower trunnions may support 100% of the load but they are not acting as lifting trunnions so the requirements of a safety factor of 3 on yield strength and a safety factor of 10 against the material ultimate strength need not be satisfied. In the latter case, the lower trunnions are acting as lifting trunnions, but the maximum lifted load is 50% of the total load.

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As discussed previously, the bottom trunnion during an upending/downending operation experiences a load up to 100% of the cask weight. The bottom trunnion is similar to the top trunnion in terms of load bearing capacity and is not required to the meet the very stringent stress limits in NUREG-0612 and 10CFR71.45(a). Therefore, the structural evaluation of the bottom trunnion for the topending/downending operation scenario is enveloped by the top lifting trunnion analysis discussed above.

2.5.1.2 Cask Closure Lids and Baseplate During Lifting

2.5.1.2.1 Closure Lid Lifting Holes

The closure lids contain tapped lifting holes used to move the lids over and onto the closure flange of the cask. Since the cask contains fuel during this movement, the tapped lifting holes in the closure lids are sized so that adequate thread strength and engagement length exist using allowable stresses in accordance with NUREG-0612 requirements (which are more severe than 10CFR71.45(a) requirements). The method of analysis is based on an industry standard approach to determine the capacity of a threaded connection.

Minimum safety factors are computed in the Holtec Proprietary Report [2.1.12], and are summarized in Table 2.5.2.

2.5.1.2.2 Baseplate

During lifting of a loaded HI-STAR 180L the containment baseplate is subject to amplified dead load, D* from the spent fuel, from the fuel basket, from the fuel basket supports, from the self-weight of the baseplate and any attached shielding, and from internal pressure. [

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Details of the evaluation and locations of maximum stress intensity are provided in the calculation package [2.1.12]. The calculation package contains additional plots of the stress distribution in the containment shell and baseplate. The results from the analysis of the top-end lift, subject to Level A service load conditions, are summarized in Table 2.5.3, where the minimum safety factors for components in the load path are computed using the ASME Level A allowable stress intensities from Table 2.1.2.

2.5.1.3 Failure of Lifting Devices

10CFR71.45 also requires that the lifting attachments permanently attached to the cask be designed in a manner such that a structural failure during lifting will not impair the ability of the transportation package to meet other requirements of Part 10CFR71. The ultimate load carrying capacity of the lifting trunnions is governed by the cross section of the trunnion external to the cask rather than by any section within the cask. Loss of the external shank of the lifting trunnion will not cause loss of any other structural or shielding function of the HI-STAR 180L cask; therefore, the requirement imposed by 10CFR71.45(a) is satisfied.

2.5.2 Tie-Down Devices

There are no tie-down devices that are a structural part of the HI-STAR 180L package for transport in the U.S.. All tie-down devices (saddle, tie-down straps, and book ends), as illustrated in Figure 1.3.2, are part of the transport conveyance and accordingly are not designed in this SAR. Therefore, 10CFR71.45(b) is not applicable to the HI-STAR 180L Package.

The loads used to design these tie-down devices may be determined using the load amplifiers given by the American Association of Railroads (AAR) Field Manual, Rule 88 [2.5.4] or other appropriate standard.

2.5.3 Safety Evaluation of Lifting and Tie-Down Devices

Lifting devices have been considered in Subsection 2.5.1 and tie-down devices have been considered in Subsection 2.5.2. It is shown that requirements of 10CFR71.45(a)(lifting devices) and 10CFR71.45(b)(tie-down devices) are satisfied. All safety factors exceed 1.0.

No tie-down device is a permanent part of the cask. All tie-down devices (saddle, tie-down straps, etc.) are part of the transport conveyance and accordingly are not designed in this SAR.

Table 2.5.1: Key Safety Factors for HI-STAR 180L Trunnions

Item	Calculated Value	Safety Factor
Bending stress (Comparison with Yield Strength in Tension) - ksi (MPa)	43.84 (302.3)	2.83
Shear stress (Comparison with Yield Strength in Shear) - ksi (MPa)	11.18 (77.05)	6.65
Bearing Stress on Top Forging (Comparison with Yield Strength in Compression) - ksi (MPa)	28.8 (198.6)	1.11
Bearing Stress in Embeded Trunnion Region (Comparison with Yield Strength in Compression) - ksi (MPa)	28.8 (198.6)	4.3
Bending Moment (Comparison with Ultimate Moment) - kip-in (kN-m)	8113 (916.7)	1.4
Shear Force (Comparison with Ultimate Shear Force) - kip (MN)	1610 (7.16)	3.07

Notes:

As noted previously, safety factor in this table represents those above the mandated value of 3 against material yield strength per 10CFR71.45(a) and 10 against material ultimate strength per NUREG-0612.

Governing transport package weight from Table 2.1.9 is considered in this evaluation.

Only the governing top lifting trunnions safety results are presented in this Table.

Table 2.5.2: Key Safety Factors for HI-STAR 180L Closure Lid Lifting Holes

Item	Value, kg (lb.)	Capacity, kg (lb.)	Minimum Safety Factor
Inner Closure Lid Direct Load	9,092 (20,044)	33,250 (73,303)	3.66
Notes: As noted previously, safety factor in this table represents those above the mandated value of 3 on yield strength per 10CFR71.45(a) and 5 on ultimate strength per NUREG-0612.			

Table 2.5.3: Top End Lift – Safety Factors

Item	Value- MPa (ksi) (From Figure 2.5.2b)	Allowable- MPa (ksi)	Safety Factor
Containment Shell, Primary Membrane Stress	47.6 (6.76)	143.8 (20.85)	3.08
Baseplate (Center), Membrane + Bending Stress	57.9 (8.4)	215.6 (31.275)	3.72
Baseplate (Joint with Shell), Membrane + Bending +Secondary Stress Intensity	69.6 (10.1)	431.3 (62.55)	6.22
Notes: The loading case considers MNOP and temperature gradient on the applicable containment boundary in addition to the lifted load. Conservatively, bounding temperature is used to obtain the allowable stress limits.			

Figure 2.5.1: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.5.2a: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.5.2b: [Withheld in Accordance with 10 CFR 2.390]

2.6 NORMAL CONDITIONS OF TRANSPORT

In this section, the HI-STAR 180L package, consisting of the cask and the AL-STAR impact limiter, when subjected to the normal conditions of transport specified in 10CFR71.71, is shown to meet the design criteria in Section 2.1 (which are derived from the stipulations in 10CFR71.43 and 10CFR71.51). The vehicle utilized for the stress/deformation analysis is a comprehensive 3-D finite element simulation of the package on Q.A.-validated codes (see Appendix 2.A). 3-D finite element models of the cask, the fuel basket, and the two impact limiters have been prepared and assembled into a complete system to evaluate all of the Normal and Accident Conditions of Transport that involve an impact event. The stress analysis of the cask containment boundary is carried out using a 3-D finite element model or a simplified plate-and-shell theory solution, as appropriate. The stress intensity limits applicable to the containment boundary, as summarized below, are the central focus of the required qualifications.

> i. The containment boundary must meet ASME Code Level A stress intensity limits under the design internal pressure and under operating internal pressure plus temperature appropriate to the normal condition of transport. For conservatism, only the containment boundary is considered, i.e., the strengthening effect of the Dose Blocker parts that girdle the containment shell is neglected.
>
> ii. The containment boundary must also meet the same Level A stress limits when subject to a 0.3-meter (1 ft) side drop with impact limiters in place. For this dynamic analysis, the entire package is modeled and a comprehensive 3-D finite element simulation of the package drop performed using a public domain, QA validated computer code (Appendix 2.A). For this purpose, 3-D finite element models of the cask, the fuel basket, and the two AL-STAR impact limiters have been prepared.

As discussed in Appendix 2.B, the AL-STAR impact limiter was subjected to a series of “9-meter drop tests” on quarter-scale models during the licensing of HI-STAR 100 in the late 90’s. The scale model was of the type A-4 in the parlance of Reference [2.7.11]. The quarter-scale drop test results were correlated with a classical contact mechanics-based simulation model to predict the HI-STAR 100 Package’s response under *any* drop orientation [2.2.2, 2.7.9]. The test data and the analytical correlation model provided the basis of NRC’s transport certification of the HI-STAR 100 package in the late 90s (Docket # 71-9261).

The scale model test data from the H-STAR 100 certification effort has been used to develop an LS-DYNA-based dynamic simulation model to prognosticate the response of the AL-STAR impact limiter. As discussed in Appendix 2.B, the LS-DYNA model simulates the scale model crush tests with acceptable accuracy. Because of the benchmarked LS-DYNA model, it has been possible to simulate a far greater number of drop scenarios than could be done by physical testing. Equally important, the LS-DYNA solution provides insights into the crush phenomena, such as margin to failure, which was only crudely inferable from scale model physical tests.

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Section 2.7.1 contains a detailed discussion of the methodology and modeling associated with the package drop analyses. Analysis results germane to establish regulatory compliance are summarized in tabular form in this SAR. Details of the model input data and results can be perused in the Calculation Package [2.6.1].

2.6.1 Heat

This subsection, labeled "Heat", in the format of Regulatory Guide 7.9, contains information on all structural (including thermoelastic) analyses performed on the cask to demonstrate positive safety margins, except for lifting operations that are covered in Section 2.5. Accordingly, this subsection contains all necessary information on the applied loadings, differential thermal expansion considerations, stress analysis models, and results for all normal conditions of transport. Assessment of compliance under "Cold" conditions is presented in Subsection 2.6.2.

The thermal evaluation of the HI-STAR 180L package is reported in Chapter 3, wherein the material temperatures that are needed for the structural evaluations are discussed.

2.6.1.1 Summary of Pressures and Temperatures

Tables 2.1.1 and 2.6.2 summarize values for pressure and temperatures (based on the thermal analysis in Chapter 3) that are used as inputs, as necessary, for the analyses undertaken to structurally qualify the HI-STAR 180L under Normal (Hot) Conditions of Transport.

2.6.1.2 Differential Thermal Expansion

The effect of thermal expansion is closely related to the presence and consideration of gaps in the package, hence both thermal expansion and gaps are discussed together in this subsection.

The appropriate thermal solutions for the HI-STAR 180L fuel baskets, the fuel basket supports, and the cask are discussed in Chapter 3, for the Normal Conditions of Transport under hot conditions. Conservative estimates of free thermal expansion of the components in the HI-STAR 180L package are obtained using the computed temperatures, together with conservatively chosen coefficients of thermal expansion, and the calculations and results are documented in the thermal calculation package referenced in Section 3.3. Table 3.3.12 documents the radial and axial expansions prior to and after heat-up.

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2.6.1.3 Stress Calculations

In this subsection, the structural analysis of the package under the conditions of design pressure, normal operating pressure and temperature, together with the effects of bolt preload, is described. Also considered is the calculation of expenditure of fatigue life (usage factor) of the Containment Boundary parts under the above loads.

2.6.1.3.1 Structural Evaluation of the Package Subject to Pressure, Temperature, Bolt Preload – Normal Operating Condition and 1-foot Free Drop

The Package is analyzed for the Load Combinations N1 and N2 listed in Section 2.1 using the finite element codes ANSYS [2.5.2] and LS-DYNA [2.5.3], and the models described in Section 2.7 and in the Holtec Proprietary calculation packages [2.1.12] and [2.6.1]. For the simulation of the normal operating condition (Load Combination N1 consisting of design pressure and temperature), the package orientation is not significant. For the 1-foot free drop condition (Load Combination N2), the package is oriented at a 0-degree angle with respect to the horizontal rigid target, and the package has an initial downward vertical velocity given by

$V = \sqrt{2gH}$ H = 12 inches (0.3 meters)

so that V = 96.3 inch/sec (244.6 cm/sec)

The drop of the package is simulated on LS-DYNA with full representation of elastic-plastic response as discussed in Subsection 2.7.1. The details of the material models and contact surface definitions are documented in the Holtec Proprietary calculation package for the finite element analyses [2.6.1]. This same finite element model is used for both the Normal Condition of Transport (Load Combination N2) and the Hypothetical Conditions of Transport drop as well as puncture analyses reported in Section 2.7.

Results from the analysis of the one-foot drop case (Load Combination N2) are documented in the Holtec Proprietary finite element analysis calculation package [2.6.1]. A discussion of the analysis of the 1 foot drop event and key safety factors are reported in Subsection 2.6.1.4 below.

2.6.1.3.2 Fatigue Considerations

Regulatory Guide 7.9 [2.6.3] suggests consideration of fatigue due to cyclic loading under normal conditions of transport. Considerations of fatigue of individual components of the package, associated with long-term exposure to vibratory motion during normal conditions of transport, are presented below:

- Cask Fatigue Considerations

As shown in the following, the cask in the HI-STAR 180L Package does not require a detailed fatigue analysis because all applicable cyclic loadings are well within the range that permits exemption from fatigue analysis per the provisions of Section III of the ASME Code. Paragraph NB-3222.4 (d) of Section III of the ASME Code provides five criteria that are strictly material and design condition dependent to determine whether a component can be exempted from a detailed fatigue analysis. The sixth criterion is applicable only when dissimilar materials are involved, which is not the case in the HI-STAR 180L cask (the steel monolithic shield and the steel containment shell have essentially the same thermal expansion properties and the same Young’s Modulus).

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warrant a usage factor evaluation.

ii. Normal Service Pressure Fluctuation

Fluctuations in the service pressure during normal operation of a component are considered if the total pressure excursion δ_p exceeds Δ_p.

where

Δ_p = Design pressure * S/(3S_m)

S = Value of S_a for one million cycles.

Using the above mentioned tables and appropriate fatigue curves,

$$(\Delta_p)_{overpack} = \frac{(80)\,(12{,}500)}{(3)\,(21{,}400)} = 15.6\ psi\ \ (0.108\text{ MPa})$$

During normal operation the pressure field in the cask is steady state. Therefore, pressure fluctuations during normal operation are negligibly small and nowhere approach the limit computed (conservatively assuming a service temperature of 400 °F, 204.44 °C). Therefore, normal service pressure oscillations do not warrant a fatigue usage factor evaluation.

iii. Temperature Difference - Startup and Shutdown

Fatigue analysis is not required if the temperature difference ΔT between any two adjacent points on the component during normal service does not exceed $S_a/2E\alpha$, where S_a is the cyclic stress amplitude for the specified number of startup and shutdown cycles. E and α are the Young's Modulus and instantaneous coefficients of thermal expansion (at the service temperature). Assuming 1,000 startup and shutdown cycles, Table 2.2.1 (conservatively assuming a service temperature of 400 °F, 204.44 °C) and the appropriate ASME fatigue curve in Appendix I of Section III of the ASME Code give:

$$(\Delta T)_{\text{overpack}} = \frac{83{,}000}{(2)\,(26.2)\,(7.1)} = 223.1^\circ\text{F}\ \ (123.9^\circ\text{C})$$

There are no locations on the cask where ΔT between any two adjacent points approaches this value. Therefore, it is evident that this temperature criterion is satisfied for 1,000 startup and shutdown cycles.

iv. Temperature Difference - Normal Service

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In conclusion, the cask does not require fatigue evaluation under the exemption criteria of the ASME Code.

- Fatigue Analysis of Closure Bolts

The maximum tensile stress range, developed in the cask closure bolts during normal operating conditions, occurs during the preload operation. For the closure lids bolt material (SA-564 630/705 (H1025)), the value of S_m at 350°F (177°C) is 47.65 ksi (328.6 MPa) per Table 2.1.8, and the Young's modulus is 26,950 ksi (185,800 MPa) per Table 2.2.3. The maximum bolt stress is permitted to have the value equal to $2S_m$ (Table 2.1.3) and the alternating stress intensity in the bolt is equal to 1/2 of the maximum stress intensity. [

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Using Figure I-9.7 of [2.1.10], the permissible number of cycles is 277; this sets a limit on the number of permitted loadings if SB-637 N07718 material is used for the closure lid bolts.

- Fatigue Analysis of Inner Closure Lid Port Cover Bolts

The maximum tensile stress range, developed in the cask closure lid port cover bolts during normal operating conditions, occurs during the preload operation. The maximum bolt stress is permitted to have the value $2S_m$ (Table 2.1.3). [

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Using Figure I-9.4 of [2.1.10], the permissible number of cycles is 588; this sets a limit on the number of permitted loadings for the inner closure lid port cover bolts.

- Fatigue Considerations for the Containment Closure Flange Internal Closure Bolt Threads

Fatigue of the threads in the containment closure flange is also evaluated. Based on the nominal diameter and the thread engagement length, the total shear area of the cask closure bolt threads can be computed. [

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Using Figure I-9.1 of [2.1.10], the allowable number of cycles is approximately equal to 1500.

Therefore, the *maximum service life of the closure flange threads is 1500 cycles* of torque and un-torque of the cask closure system.

- Satisfaction of Regulatory Guide 7.6 Commitment (Condition 7 on Cyclic Stress Intensity Range

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2.6.1.3.3 Stability of the Metamic Fuel Basket Plates

Under certain conditions, the fuel basket plates may be under direct compressive load. Although the finite element simulations can predict the onset of an instability and post-instability behavior, the computation in this subsection uses (the more conservative) classical instability formulations to demonstrate that an elastic instability of the basket plates is not credible.

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] This demonstrates that basket plate instability by elastic buckling is not possible.

2.6.1.3.4 Closure Lid Flanged Joint

The closure lid-to-flange joint in all HI-STAR family of casks is engineered to be a “controlled compression joint” (see Figure 2.6.1) widely used in the pressure vessel industry (see [2.7.7, Chapter 3, pp 144-51]).

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2.6.1.3.5 Re-flood Event

During a cask re-flood event, water is introduced to the cask cavity through the lid drain line to cool-down the internals and support fuel unloading. This quenching operation induces thermal stresses and strains in the fuel rod cladding, which are at their maximum at the boundary interface between the rising water and the dry (gaseous) cavity. A bounding analysis has been performed in Section 3.4 of the HI-STORM FW FSAR [2.6.7], which shows that the maximum total strain in the fuel cladding due to the re-flood event is well below the failure strain limit of the material. Thus, the fuel rod cladding will not be breached due to a re-flood event.

The above referenced analysis in [2.6.7] is also bounding for the HI-STAR 180L cask for the following reasons:

1) it considers an instantaneous quenching of the fuel rod, wherein the upper half of the fuel rod is at the peak cladding temperature limit (752 °F or 400 °C) and the lower half of the fuel rod is at 80°F or 26.67 °C;
2) the analyzed cladding thickness is 2% less than the cladding thickness for the HI-STAR 180L fuel;
3) the yield strength of the Zircaloy cladding used as input in the analysis is 45% less than the value given in [2.11.4] for high burn-up fuel (which conservatively overestimates the cladding strain).

Based on the above, it is concluded that the results of the re-flood analysis presented in Section 3.4 of [2.6.7] are also valid for the HI-STAR 180L cask, and therefore the fuel rod cladding inside the HI-STAR 180L cask will not be breached due to the re-flood event.

2.6.1.4 Comparison with Allowable Stresses

Following Regulatory Guide 7.9, calculated stress intensities in the containment component of the package from all analyses are compared with the allowable stress intensities defined in Section 2.1 (Tables 2.1.2 through 2.1.8) as applicable for conditions of normal transport. The results of these comparisons are presented in the form of factors of safety (SF) defined as:

$$SF = \frac{\text{Allowable Stress}}{\text{Calculated Stress}}$$

For convenience, those specific allowable strengths, loads, etc., that are used to develop the safety factors are summarized in Table 2.6.3. Data from Sections 2.1 and 2.2 are used to construct Table 2.6.3.

Safety factors associated components identified as lifting and tie-down devices have been presented in Section 2.5 as set forth by Regulatory Guide 7.9.

2.6.1.4.1 Results for Pressure Boundary Stress Intensity

Results from the finite element analyses for Load Combinations N1 and N2 are tabulated for normal heat conditions of transport in Holtec Proprietary calculation packages [2.1.12] and [2.6.1], respectively. [

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The key results for Load Combinations N1 and N2 are summarized, in Tables 2.6.5 and 2.6.6, respectively, wherein the minimum safety factor for different components of the cask for each of the load combinations is presented. All safety factors are conservatively computed using allowable stresses based on the maximum normal operating temperatures (see Tables 2.1.1 and Table 2.6.2, for component temperatures, and Table 2.1.6 for allowable stress intensity).

2.6.1.4.2 Result Summary for Normal Heat Condition for Transport

- Maximum Cask Deceleration from Load Combination N2

Table 2.6.4 lists the maximum cask deceleration calculated for the 0.3-meter side drop using the LS-DYNA model.

- Stress Intensity Results from Overall Finite Element Analysis of the Cask

Table 2.6.5 is a summary table that includes primary and primary plus secondary stress intensity safety factors (per Table 2.1.2) for Load Combination N1 associated with the Normal (Heat) Conditions of Transport. Table 2.6.6 provides similar results for Load Combination N2. The tabular results demonstrate that all safety factors exceed 1.0 at the key locations for each component of the containment boundary.

- Status of Lid Bolts and Seals

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The inner closure lid port cover seals are analyzed using classical methods to demonstrate that the torque requirement for the inner closure lid port cover bolts (Tables 2.2.12 and 7.1.1) is sufficient to seat the gasket and maintain a positive contact load on the land under Normal Conditions of Transport.

Based on the results of the above analyses for normal heat conditions of transport, the following conclusions are reached.

i. No bolt overstress is indicated under any loading event associated with Normal Conditions of Transport. As expected, the tensile stress in the bolts remains essentially unchanged from its initial preload state for reasons discussed in Subsection 2.6.1.

ii. The closure lid seals do not unload beyond the minimum force corresponding to the useful springback (per Table 2.2.13) required to maintain the leak tightness under Load Combinations N1 and N2; therefore, the seals continue to perform their function under Normal Conditions of Transport.

- ASME Pressure Test Condition

See Paragraph 8.1.3.2 for pressure test specifications.

- Performance of Non-Containment Components of Package

The Holtec Proprietary calculation package documenting all of the finite element solutions [2.6.1] contains graphical visualizations of the stress intensity and deformation for every component in the HI-STORM 180L package. In particular, the fuel basket and the monolithic shield surrounding the containment shell are surveyed to evaluate their performance and compare with the acceptance criteria in Section 2.1. Table 2.6.7 summarizes the acceptance criteria for performance of the non-containment components of the HI-STAR 180L. From Table 2.6.7, it is established that the surveyed components meet the acceptance requirements stated for Load Combination N2.

- Summary of Results for Normal Heat Conditions of Transport

Tables 2.6.4 through 2.6.7 present a concise summary of safety factors and performance results for the HI-STAR 180L for the Normal Heat Condition of Transport.

Based on the results of all analyses, it is concluded that:

i. All safety factors reported in the text and in the summary tables are greater than 1.0.

ii. There is no buckling or plastic deformation distortion of the cask internals.

iii. All performance requirements are met for the non-containment components.

iv. The containment boundary seals, which includes the closure lid seals and the vent and drain port cover seals, do not unload beyond the minimum force required to maintain leak tightness (per Table 2.12).

Therefore, the HI-STAR 180L Package, under the Normal Heat Conditions of Transport, has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.

2.6.2 Cold

The Normal Cold Condition of Transport assumes a lower bound ambient environmental temperature of -40°F (-40°C). As discussed in Regulatory Guide 7.8, the cask should be evaluated for the case with no internal heat, minimum internal pressure and increased external pressure under the cold ambient temperature condition. A discussion of the resistance to failure due to brittle fracture is provided in Section 2.1.

The value of the ambient temperature has two principal effects on the HI-STAR 180L Package, namely:

i. The steady-state temperature of all material points in the cask will go up or down by the amount of change in the ambient temperature.

ii. As the ambient temperature drops, the absolute temperature of the contained helium will drop accordingly, producing a proportional reduction in the internal pressure in accordance with the Ideal Gas Law.

In other words, for a given heat load, the temperature gradients in the cask components under steady-state conditions will remain essentially the same regardless of the value of the ambient temperature. The internal pressure, on the other hand, will decline with the lowering of the ambient temperature. Since the stresses under normal transport condition arise principally from pressure and thermal gradients, it follows that the stress field in the cask under a bounding "cold" ambient would be smaller than the "heat" condition of normal transport, treated in the preceding subsection.

In addition, allowable stresses generally increase with decreasing temperatures. Safety factors, therefore, will be greater for an analysis at cold temperatures than at hot temperatures. Therefore, the safety factors reported for the hot conditions in Subsection 2.6.1 provide the limiting margins. However, since the bolt preloads may be altered by a change in the environmental temperature, the effect of bolt temperature changes on the level of preload, subsequent to the initial application of preload, must be considered and is evaluated in the Holtec Proprietary calculation package [2.1.12]. The results from that calculation are summarized below:

Evaluation of Environmental Temperature Changes on the Level of Preload	
Item	**Value**
Initial Bolt Prestress -Heat (Inner/Outer Lids) ksi (MPa)	76/55 (524/ 379.2)
% Change from Heat to Cold	< 1

Addition compression of the gaskets, enhances the sealworthiness and the overall performance of the gasket. Furthermore, the computed change in stress due to the assumption of a severe local low temperature condition is insignificant compared to the initial bolt stress and to the change in the allowable bolt stress because of the lowered temperature. It is concluded that the small change in bolt preload stress will have an insignificant effect on structural calculations and therefore safety factors and sealing are essentially unaffected by the environmental change.

As no liquids are included in the HI-STAR 180L Package design, loads due to expansion of freezing liquids are not considered.

The effect of environmental and component temperature changes on the stress from the interference between the monolithic shield and the inner containment shell is now considered. Because the coefficients of thermal expansion of the outer monolithic shield and the inner shell are essentially the same, the change of the cask's thermal state will not produce any significant internal or interface stresses under steady state conditions.

2.6.2.1 Differential Thermal Expansion

The methodology to determine differential thermal expansion in the Normal Heat Condition of Transport is presented in Chapter 3. The same methodology is applied for the Normal Cold Condition of Transport, and results are summarized in Chapter 3.

It can be verified by referring to the drawing packages in Section 1.3 that the clearances between the fuel basket and cask inside surface are sufficient to preclude temperature induced interference in the cold condition.

No further analysis is warranted for the cold condition since (a) the restraint of free thermal expansion is less under cold conditions and (b) material strength properties tend to be greater at lower temperatures, resulting in higher allowable stress limits.

It is concluded that the HI-STAR 180L package meets the requirement that there be no restraint of free thermal expansion, under Normal Cold Conditions of Transport, that would lead to primary stresses greater than the applicable ASME Level A limit.

2.6.3 Reduced External Pressure

The effects of a reduced external pressure equal to 25 kPa (3.5 psia) are bounded by results from the design internal pressure analysis for the cask (Load Combination N1). This case does not provide any bounding loads for other components of the cask containment boundary.

2.6.4 Increased External Pressure

The effect of an external pressure equal to 140 kPa (20 psia) on the package, which is stated in USNRC Regulatory Guide 7.8 [2.1.4], is bounded by the effect of the large value for the external pressure specified by 10CFR71.61 (2 MPa (290 psia)). Instability of the containment boundary shell, under this external pressure is examined in Section 2.7. Therefore, no additional analyses are performed herein to demonstrate package performance.

2.6.5 Vibration

During transport, vibratory motions occur which could cause low-level stress cycles in the package due to beam-like deformations. If any of the package components have natural frequencies in the flexible range (i.e., below 33 Hz), or near the flexible range, then resonance may amplify the low level input into a significant stress response. Strength of materials calculations are performed to establish that vibrations are not an issue in transport of the HI-STAR 180L.

The lowest frequency of vibration during normal transport conditions may occur due to vibrations of a fuel basket cell wall. An analysis to determine the lowest frequency of vibration of the component has been performed. For this computation, the fuel basket plate (cell wall) is assumed to vibrate like a simply supported beam. Based on the plate mass density and the plate dimensions, the lowest natural frequency is well in the rigid range (see the Holtec Proprietary calculation package [2.1.12]).

When in a horizontal position, the cask is supported over a considerable length of the shield cylinder. Conservatively considering the HI-STAR as a supported beam at only the two ends of the shield cylinder, and assuming the total mass of the fuel basket and its contents moves with the cask, a computation of the lowest natural frequency of the structure during transport provides a result in the rigid range. (See calculation package [2.1.12]).

Based on these frequency calculations, it is concluded that vibration effects are inconsequential to the structural integrity of the cask.

The capacity of the stored fuel assemblies (i.e., fuel rods) to withstand vibratory loads during normal conditions of transport has also been evaluated. For this evaluation, the fuel rod is conservatively analyzed as a simply supported beam whose length is equal to the longest span between adjacent grid spacers. The section properties of the fuel rod beam are based solely on the thickness and diameter of the fuel rod cladding. The mass of the fuel pellets is smeared along the length of the fuel rod beam. The key input data that defines the fuel rod beam model is summarized in Table 2.6.8.

The lowest natural frequency of the fuel rod beam is reported in Table 2.6.9, which shows that the fuel rod beam is nearly rigid. Therefore, for the stress analysis of the fuel rod, the fuel rod beam is considered to be rigid, and the maximum bending stress in the fuel rod cladding is calculated using a quasi-static approach.

The load applied to the fuel rod beam is a transverse acceleration of 5-g, which is consistent with the design load applicable to the tie-down devices on the transport package per 10CFR71.45. Under this load, the maximum calculated bending stress in the fuel rod cladding is an order of magnitude less than the yield strength of Zircaloy. Furthermore, the calculated stress is well below the endurance limit of Zircaloy per NUREG/CR-1132 [2.6.6]. The stress analysis results for the fuel rod are summarized in Table 2.6.9.

In summary, the fuel rods will not rupture due to the vibratory loads associated with normal conditions of transport since the maximum calculated bending stress in the fuel rod cladding is less than the yield strength and the fatigue endurance limit of Zircaloy by a factor of 10 or more.

2.6.6 Water Spray

The condition is not applicable to the HI-STAR 180L Package per [2.1.4].

2.6.7 Free Drop

The structural analysis of a 0.3-meter (1-foot) free drop under the heat condition is documented in Subsection 2.6.1.4. As demonstrated in Subsection 2.6.1.4 safety factors are well over 1.0 (see Table 2.6.6 for Load Combination N2). The discussion in subsection 2.6.2 demonstrates why the cold condition is not a bounding condition for the 0.3-meter (1-foot) free drop.

2.6.8 Corner Drop

This condition is not applicable to the HI-STAR 180L Package per [2.1.3].

2.6.9 Compression

This condition is not applicable to the HI-STAR 180L Package per [2.1.3].

2.6.10 Penetration

This condition is not applicable to the HI-STAR 180L Package per [2.1.4].

Table 2.6.1: [Withheld in Accordance with 10 CFR 2.390]

Table 2.6.2: [Withheld in Accordance with 10 CFR 2.390]

Table 2.6.3: Allowable Stresses for Level A and Level D Conditions (Normal Condition of Transport)

ITEM	LEVEL A[†]	LEVEL D[†]	TEMPERATURE
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	221.3 (32.1)	506.8 (73.5)	204°C (400°F)
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	228.6 (33.2)	506.8 (73.5)	149°C (300°F)
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	143.76 (20.85)	336.8 (48.85)	232°C (450°F)
Containment Shell – Primary + Secondary Stress Intensity – MPa (ksi)	431.27 (62.55)	NA	232°C (450°F)
Baseplate – Primary Membrane + Bending Stress Intensity – MPa (ksi)	221.3 (32.1)	506.8 (73.5)	204°C (400°F)
Baseplate – Primary + Secondary Stress Intensity – MPa (ksi)	442.5 (64.2)	NA	204°C (400°F)
Inner Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	601.2 (92.6)	862.0 (125.025)	191°C (375 °F)
Outer Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	433 (62.8)	648.8 (94.1)	149°C (300 °F)
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	862(125.025) [††]	1047.9 (151.99)	191°C (375 °F)
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	648.8 (94.1) [††]	861.85 (125)	149°C (300 °F)
Monolithic Shield Cylinder – Ultimate Strength – MPa (ksi)	NA	482.6 (70.0)	204.4°C (50 °F)

[†] Obtained from Section 2.1.

[††] Lesser of 3Sm and S_y is used for conservatism.

Table 2.6.4: Maximum Deceleration Under 0.3 Meter Free Drop Condition (Side Drop)

Method	α_{max} (g's)
Numerical (LS-DYNA) Solution	24.0

Notes:

This simulation considers the limiting upper bound crush strength for the impact limiter material.

Table 2.6.5: Containment Boundary Stress Intensities and Safety Factors – Load Combination N1 (Static Analysis)

Location and Stress Intensity Component	Calculated Value	Safety Factor
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	26.93 (3.91)	8.22
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	154.99 (22.47)	1.48
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	30.34 (4.4)	4.73
†Baseplate – Primary Membrane + Bending Stress Intensity at Center – MPa (ksi)	40.3 (5.84)	5.35
†Baseplate – Primary + Secondary Bending Stress Intensity at Periphery – MPa (ksi),	45.2 (6.56)	9.53

Note:
“SF” means Safety Factor.
† The containment shell and the baseplate are conservatively evaluated @ 232 ºC (450 ºF) temperature.

Table 2.6.6: Results for 1-Ft (0.3 m) Drop Analysis

Item	**Allowable from Table 2.6.3**	**Calculated Value**	**Safety Factor**
Primary Membrane stress intensity in the containment shell – MPa (ksi)	143.76 (20.85)	98.83 (14.3)	1.45
Primary + Secondary stress intensity in the containment shell – MPa (ksi)	431.27 (62.55)	138.3 (20.06)	3.12

Note: "SF" means the Safety Factor. †As an example, the stress distribution in the containment shell under 1-Ft (0.3 m.) side drop is shown in Figure 2.6.5.

Table 2.6.7: Key Performance Objectives for Non-Containment Components of the HI-STAR 180L

Criterion	Load Combination N1	Load Combination N2
Stress Intensity in Monolithic Shield – Primary Stress Intensity Below Ultimate Strength	-	Yes
Fuel Basket Deformation – Maximum Total Deflection < 0.74 mm	Yes	Yes

Table 2.6.8: Key Input Data for Fuel Rod Vibration Analysis

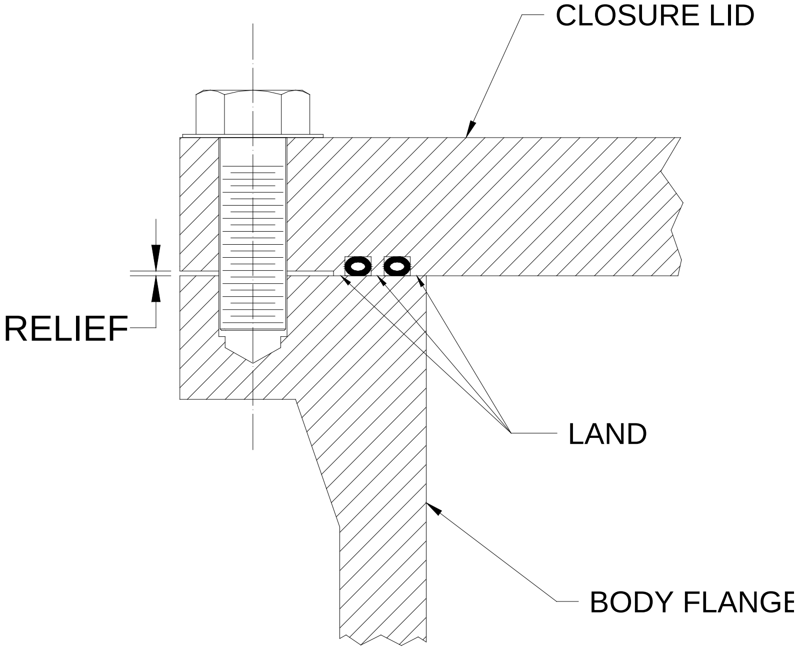
Item	**Value**
Minimum Length of Fuel Rod	160.3 in (4071.5 mm)
Bounding Weight of a Single Fuel Rod	5.83 lbf (2.64 kg)
Maximum Distance between Grid Spacers	20.16 in (512 mm)
Minimum Cladding Thickness, Considering Cladding Thinning due to Oxidation	0.0203 in (0.516 mm)
Cladding OD	0.379 in (9.62 mm)
Lower-bound Elastic Modulus of Zircaloy Cladding	9.61×10^6 psi (6.626×10^4 MPa)

Table 2.6.9: Results for Fuel Rod Analysis Under Normal Vibration Load

Result	**Calculated Value, Hz**
Lowest Natural Frequency of Fuel Rod Beam	54

Result	**Calculated Value, MPa (psi)**	**Fatigue Endurance Limit†, MPa (psi)**	**Safety Factor**
Maximum Bending Stress in Fuel Rod	21.8 (3,164)	177.5 (25,744)	8.1

† Per Section 2.1 of NUREG/CR-1132 [2.6.6].



Note:
The sealing grooves may be
located in the flange or the cover.

Figure 2.6.1: Essential Elements of a Classical "Controlled Compression Joint"

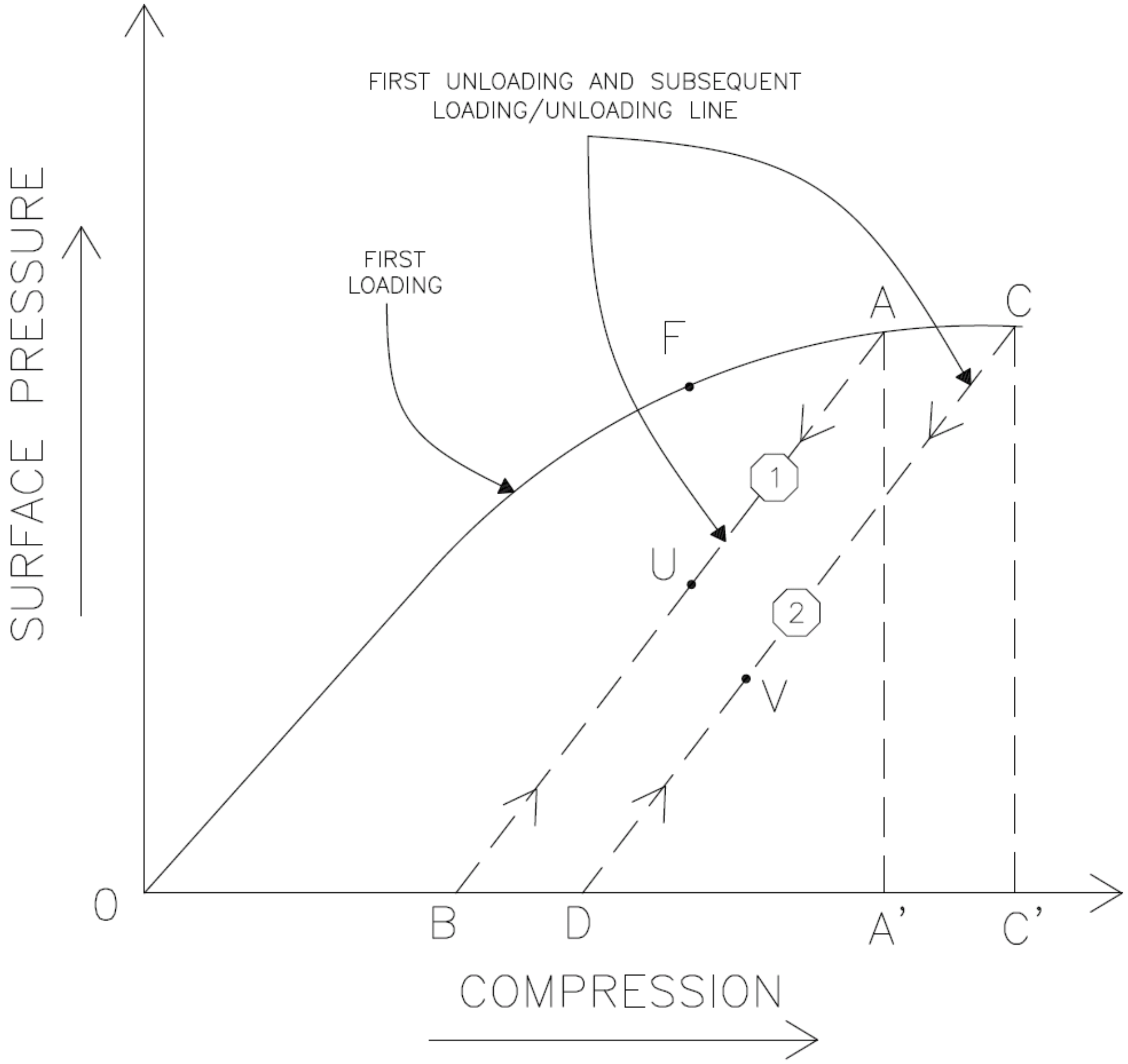


Figure 2.6.2: Loading and Unloading Curves for a Typical Gasket

Figure 2.6.3: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.4: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.5: [Withheld in Accordance with 10 CFR 2.390]

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

It is shown in the following subsections that the HI-STAR 180L Package meets the safety criteria set forth in 10CFR71 when it is subjected to the hypothetical accident conditions specified in 10CFR71.73. In particular, required technical data is presented herein to support the conclusion that HI-STAR 180L Package, when subjected to hypothetical accident conditions, will maintain its structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.

The hypothetical accident conditions, as defined in 10CFR71.73 and explained in Regulatory Guide 7.9, are applied to the HI-STAR 180L Package as a sequence of loading events. The package is first subject to a 9-meter (30-foot) drop. As required by the regulations, the “free drop” should be assumed to occur in the orientation that will cause maximum damage. To identify the most vulnerable orientation the drop simulation is performed in four candidate orientations. From the post-impact package configuration determined to have the most damaging orientation, the package is then subject to a 1-meter (40-inch) drop onto a 15 cm (6.0 inch) diameter mild steel pin (of length sufficient to impart the impact energy to the cask structure through penetrant action). In the third step, the package is subject to a 800°C (1475°F) temperature fire environment for 30 minutes. Finally the package is subject to water immersion.

As a separate loading event, the cask containment boundary is also subjected to deep immersion in accordance with 10CFR71.61.

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2.7.1 9-meter Free Drop

2.7.1.1 Problem Description and Dynamic Model

As specified in §71.73, the performance and structural integrity of the HI-STAR 180L Package must be evaluated for the most severe drop scenarios. The appurtenance that is critical to protecting the integrity of the containment boundary during a high momentum collision event is the AL-STAR impact limiter.

The central purpose of the impact limiter, defined as an essential package appurtenance in Section 1.2, is to limit the package maximum deceleration, α_{max}. The HI-STAR package, consisting of the loaded cask and top and bottom impact limiters, is essentially a cylindrical body with a very rigid interior (namely, the cask) surrounded by a pair of relatively soft crushable structures. The crushable structure (impact limiter) should deform and absorb the kinetic energy of impact without detaching itself from the cask, disintegrating, or otherwise malfunctioning. A falling cylindrical body may theoretically impact the target surface in an infinite number of orientations; the impact limiter must limit decelerations to insure that stress intensity and performance limits, as described in Section 2.1, are satisfied, and to ensure that the impact limiter does not detach from the cask, regardless of the impact orientation. In general, a drop event orientation is defined by the angle of the HI-STAR 180L longitudinal axis, "θ", with the impact surface. In this notation, $\theta = 0°$ means a side drop and $\theta = 90°$ implies a vertical or end drop scenario. In any orientation, the drop height is measured from the lowest point on the package.

An intermediate value of θ at which the point of impact is directly below the center of gravity (C.G.) of the HI-STAR package warrants special mention. This drop orientation is traditionally called the C.G.-over-corner (CGOC) configuration. The CGOC orientation, "θ_c", is the demarcation line between single and dual impact events. At $90° > \theta > \theta_c$ the leading end of the package (denoted as the "primary" impact limiter) is the sole participant in absorption of incident kinetic energy. At $\theta < \theta_c$ drop orientations, the initial impact and crush of the leading (primary) impact limiter is followed by the downward rotation of the package with the initial impact surface acting as the pivot, culminating in the impact of the opposite (secondary) impact limiter on the target surface. In the dual impact scenarios, the first and second impact limiter crush events are referred to as the "primary" and "secondary" impacts, respectively. It is reasonable to speculate that for certain values of θ, the secondary impact may be the more severe of the two. Figures 2.7.1 through 2.7.4 illustrate the orientation of a (generic) cask at the initiation of a drop event.

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Finally, the package design must satisfy all criteria in ambient temperature conditions (temperature and humidity) that may prevail during transport. Therefore, the impact limiter design must be functionally insensitive to the ambient temperature and humidity.

As the drawings in Chapter 1 indicate, in addition to the crushable material, the impact limiter contains a cylindrical shell that is stiffened with internal gussets. This buttressed steel shell is sized to be sufficiently robust to preclude gross plastic deformation or buckling during impact events and thus serve as the backbone of the impact limiter.

To summarize, the performance objectives of the impact limiter are set down as five discrete items, namely:

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The last two objectives are realized by utilizing crush material that is insensitive to the ambient psychrometric environment, and by using surface preservatives or corrosion resistant materials as indicated in the drawing package in Section 1.3. The stainless steel skin is procured to "bright annealed" finish to minimize absorption of solar thermal radiation.

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The remaining design objectives, namely, limiting of the maximum rigid body deceleration under the 9-meter drop event and preventing contact of the cask with the unyielding surface, is demonstrated by the LS-DYNA [2.5.3] finite element code, as discussed earlier. LS-DYNA has been benchmarked extensively by others [2.7.5, 2.7.6] and by Holtec using the test data from the static tests of the crush material and, more importantly, from the quarter-scale model 9-meter drop experiments carried out at the Oak Ridge National Laboratory in support of HI-STAR 100 Part 71 certification in the late 90s [2.7.4] (see Appendix 2.B). As discussed in Appendix 2.B, the LS-DYNA simulation model for the family of AL-STAR impact limiters is a credible and reliable vehicle for determining the HI-STAR 180L Package’s impact performance *with respect to the extent of crush and the peak g-load.* LS-DYNA has been used by Holtec International in a wide variety of impact scenarios in dry storage projects [2.7.10].

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The previously described key attributes implemented in the HI-STAR 180L LS-DYNA model take advantage of the state-of-art numerical analysis capability of the finite element code for simulating transient, nonlinear impact events. With good accuracy demonstrated in the benchmarking effort (Appendix 2.B) as well in the analysis independently performed by the NRC/PNNL investigators [2.7.5], the previously described HI-STAR 180L finite element model is deemed to be able to predict the impact performance of the package under various accidental drop conditions with reliable accuracy.

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2.7.1.2 Simulation of Drop Events

As discussed before, the free drop of the package from 9 meters onto an essentially unyielding surface is simulated for a number of orientations using LS-DYNA. The peak g-loads from each drop simulation, α_{max}, in both axial and lateral direction (to the cask's axis) are computed. The largest axial and lateral deceleration is then used to determine the regulatory compliance of the package using the so-called "static analysis" explained previously, with additional confirmatory results from the LS-DYNA analyses.

The postulated free drop events belong to four broad categories, namely:

1. Vertical-end drop
2. Lateral (side drop)
3. C.G.-over-corner
4. Oblique (slap down)

Under certain categories of events, there may be more than one drop "orientation". The orientation of drop, θ, is defined by the angle between the horizontal plane and the axis of the cask pointed from its base to its lid at the instant of impact. θ = 90º is a vertical-end drop event with bottom-down configuration (see Figure 2.7.1). Similarly, θ = 0 º means side (lateral) drop (see Figure 2.7.3).

The various drop orientations analyzed using LS-DYNA to identify the most damaging scenario with reasonable assurance are summarized in Table 2.7.3. Of these, the slap-down event warrants special mention because it often produces the bounding decelerations in transport packages and has two candidate orientations in an axially nonsymmetrical package, namely:

i. Wherein the top impact limiter strikes first, followed by the second impact at the bottom impact limiter.

ii. The obverse of case (i) wherein the primary impact occurs at the bottom impact limiter followed by a second impact at the top impact limiter.

As can be seen from Table 2.7.3, upper as well as lower bound properties of the crush material are analyzed in LS-DYNA to ensure that the largest value of α_{max} and maximum crush, d_{max}, have been identified and evaluated.

The initial velocity of the package corresponding to a free fall from 9 meters at impact in all impact scenarios is 13.392 m/sec (43.9 ft/sec).

Goverining free drop simulations are also performed for the partially loaded cask as defined in Table 7.D.1. The details of the analysis are documented in [2.6.1].

2.7.1.3 Summary of Results

Table 2.7.3 summarizes the maximum values of α_{max} for the axial and lateral direction from all of the drop scenarios simulated on LS-DYNA.

Certain observations from the LS-DYNA numerical simulations provide valuable information with respect to the structural performance of the package.

i. For the dual impact scenarios (i.e. slapdown drop accident), the secondary impact is always more severe than the primary impact. The maximum deceleration and impact limiter crush occur in the region of the secondary impact.

ii. All body bolt stresses meet the acceptance criteria from Table 2.1.3 demonstrating that there is no risk of failure of any bolt fastened to the top forging.

iii. The impact limiters remain connected to the cask subsequent to the drop accident.

iv. The closure lid seals are fully functional after the governing 9-m drop event, which is ensured by satisfying the stress criteria of the closure lid bolts.

v. The maximum axial/lateral deceleration sustained by the Quivers remain below the design limit specified in Table 2.2.14.

The effect of lateral deceleration is to cause flexing of the fuel basket cell panels transverse to the direction of the load under the magnified inertia load of the fuel, and to load the panels oriented in the direction of the inertia load in direct compression.

The outer closure lid, also a containment boundary part, does not experience the direct inertia load tending to unload the seals (as it does on the inner closure lid). Rather, a reaction load from the crushing of the impact limiter material acts on the outer surface of the outer lid, causing flexural action. While the gasketed joint is not directly challenged, the bending stress intensity in the outer lid must be shown to remain within Level D condition limits.

For convenience, the allowable stress limits necessary for the safety evaluation of each part are compiled in Table 2.6.3.

Based on the tabular results presented in Tables 2.7.4 through 2.7.7 it is concluded that:

- The primary stress intensities for the containment components are below the ASME NB limits for all drop configurations.

- The closure lid bolts show no gross yielding and the gaskets remain under a compressed state at the conclusion of the event. Therefore, continued bolted joint effectiveness in the wake of the 9-meter free drop event is assured.

- The monolithic shield surrounding the containment shell remains intact.

- The fuel basket does not undergo gross plastic deformation in the active fuel region, and the global average permanent deformation remains below the limit value established by the acceptance criteria in Section 2.1.

- The small quantity of lead, used for shielding in the HI-STAR 180L, is included in the LS-DYNA model. The lead is characterized by the properties given in Table 2.2.11. A review of all drop and puncture simulation results confirms that the predicted minor lead slump is bounded by the assumed value in the shielding evaluation (see Section 5.1).

- Since the ability to accurately predict and evaluate large displacements is included within the LS-DYNA algorithm, the effect of any instability is automatically accounted for. Based on the evaluated results, it is concluded that there is no buckling of the containment components during any of the postulated Hypothetical Accident events.

- Impact limiters remain attached to the cask subsequent to the drop event.

2.7.1.4 Fracture Analysis

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From the above simulation, it can be concluded that the minimum Charpy value prescribed for the shield cylinder is adequate to prevent a significant loss of shielding under all governing Part 71 impact events, and the minimum Charpy values prescribed for the closure lid bolts are adequate to prevent a loss of seal integrity. The details of this evaluation are documented in the Holtec proprietary calculation package [2.1.12].

2.7.2 Crush

An evaluation of package crush is not required for the HI-STAR 180L.

2.7.3 Puncture

10CFR71 specifies that a puncture event be considered as a hypothetical accident condition subsequent to the hypothetical 9-meter drop event. For this event, it is postulated that the package falls freely through a distance of 1 meter (40 inch) and impacts a 15 cm (6 inch) diameter mild steel bar. The effects of the puncture drop will, quite ostensibly, be most severe when the steel bar is perpendicular to the impact surface. Therefore, all puncture analyses assume that the bar is perpendicular to the impact surface. Puncture is considered on the sidewall, as discussed in Subsection 2.7.1.4, and on the top end (a puncture on the bottom end is not bounding since there is a full welded connection, rather than a bolted connection that needs to remain intact).

LS-DYNA simulation model is used to examine the hypothetical puncture accidents. The same FE model used for top-end drop is retained for the top end puncture analysis. A mild steel bar, having the appropriate dimensions, is added to the model, placed in the proper orientation, and fixed to the ground. The package is then assumed to have a known initial velocity at contact with the bar. Details of the simulation model and the results (all output figures) for the top end puncture and side puncture are provided in the Holtec Proprietary calculation package [2.6.1]. The key results of the puncture analysis are summarized in Table 2.7.5.

The results from the puncture analyses yield the following conclusions:

i. The bolted joint maintains its integrity; the margin-against-leakage parameter, m, (defined in Table 2.6.1) remains at the maximum possible value of 10.

ii. No thru-wall penetration of the containment boundary or dose blocker parts (shield cylinder) is indicated. The total depth of local indentation is a fraction of the available material thickness in the path of the penetrant. Although the outer region of the monolithic shield (where the neutron shield cavities are located) is not credited in the model, the steel bar is expected to penetrate this region in the case of a side puncture event (see Figure 2.7.23).

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

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

The above results confirm the structural adequacy of the package under the “puncture” event of §71.73.

2.7.4 Thermal

In this subsection, the structural consequences of the 30-minute fire event, which occurs after hypothetical drop and puncture events, are evaluated using the metal temperature data from Chapter 3 where a detailed analysis of the fire and post-fire condition is presented. Specifically, the evaluations show that:

1. The metal temperature, averaged across any section of the containment boundary, remains below the maximum permissible temperature for the Level A condition in the ASME Code for NB components. Strictly speaking, the fire event is a Level D condition for which Subsection NB of the ASME Code, Section III does not prescribe a specific metal temperature limit. The Level A limit is imposed herein for convenience because it obviates the need for creep considerations to ascertain post-fire containment integrity.

2. The outer surface of the cask, directly exposed to the fire does not slump (i.e., suffer primary or secondary creep). This condition is readily ruled out for steel components since the metal temperature remains below 50% of the metal melting point (approximately 3000 ºF or 1648.89 ºC).

3. Internal interferences among the constituents of the HI-STAR 180L Package do not develop due to their differential thermal expansion during and after the fire event.

4. Cask closure lid bolts do not unload; therefore, there is no reduction of compression load on the gasket surfaces to a level that may precipitate leakage of gaseous contents from the containment boundary.

Table 2.7.6 provides a summary of the key results obtained from the continued sealing analysis under the fire accident; the details of the solution are documented in the Holtec Proprietary calculation package [2.1.12]. An analysis methodology previously used for the HI-STAR 180, HI-STAR 80 licensing effort is used here, with the only loading being the temperature change of the bolted connection from the fire. Because of the differences in coefficient of thermal expansion between the lid and flange and the bolt, the bolt loads increase from their starting value, but the increase is balanced by increased compression on the lands. Therefore, the fire event, occurring after a 9-meter drop accident or a puncture, does not lead to loss of seal integrity in either lid. The package, therefore, meets all acceptance criteria set down in Section 2.1 for the postulated fire event.

2.7.4.1 Summary of Pressures and Temperatures

Section 3.4 contains a discussion of the peak temperatures occurring during and after the fire event. It is concluded in that section that:

1. The containment boundary, protected by the monolithic shield, remains below 500 ºF or 260 ºC (SA-203 E material).
2. The containment boundary that is within the confines of the impact limiters remains below 700 ºF or 371.11 ºC (SA-350 LF3 material).
3. The portion of the containment boundary directly exposed to the fire may have local outer surface temperatures in excess of 700 ºF or 371.11 ºC, but the bulk metal temperature of the material volume remains under 700 ºF or 371.11 ºC. All metal temperatures remain well below the “threshold damage temperature”.
4. The Holtite-B neutron shield material experiences temperatures in excess of its design limit, leading to a, minor loss in the cask’s neutron shielding capacity.

2.7.4.2 Differential Thermal Expansion

Differential thermal expansions under the limiting conditions of the fire event are evaluated in Subsection 3.4.4. The analyses show that, under the fire condition, there is no restraint of free thermal expansion of the fuel basket.

2.7.4.3 Stress Calculations

Strength of materials calculations are used to evaluate the performance of the bolted joint in the Containment Boundary. Analyses show that:

i. The primary stress intensities in the Containment Boundary remain well below the Level D (Faulted Condition) limits.

ii. The bolt stresses in the Containment Boundary joint, due to differential thermal expansion, rise but remain within Level D limits.

2.7.5 Immersion - Fissile Material

10CFR71.73(c)(5) specifies that fissile material packages, in those cases where water leakage has not been assumed for criticality analysis, must be evaluated for immersion under a head of water of at least 0.9 m (3 ft) in the attitude for which maximum leakage is expected. Accordingly, the analysis is performed to demonstrate that there will be no water leakage in the package subsequent to the fire.

A head of water at a depth of 0.9 m (3 ft) is equal to 1.3 psi (0.00896 MPa). The head of water (1.3 psi or 0.00896 MPa) is bounded by the hypothetical accident condition external pressure for the cask (10CFR71.61), which is considered later. Analyses summarized in this chapter demonstrate the containment component meets the applicable stress intensity allowables for normal conditions of transport and for hypothetical accident conditions (both conditions impose pressures larger than 1.3 psi (0.00896 MPa) on the components). Further, it is demonstrated that the sealing function is not impaired under these conditions. Therefore, there is no in-leakage of water into the cask under a head of water at a depth of 0.9 m (3 ft).

2.7.6 Immersion - All packages

This external pressure condition is bounded by the analysis in Subsection 2.7.7.

2.7.7 Deep Water Immersion Test

The HI-STAR 180L containment boundary is subject to an all-around external pressure of 2.0 MPa (290 psi) after applying initial bolt preload. Code Case N-284 is used to evaluate the propensity for containment shell instability assuming the monolithic shielding does not prevent the 2.0 MPa (290 psi) pressure from acting directly on the outer surface of the containment shell. The Holtec Proprietary calculation package [2.1.12] contains the supporting details; it is demonstrated there that there is no yielding of the vessel and that there is no elastic or plastic instability of the containment shell. Since the external pressure acts in a direction to add additional pressure to the lands of the lids, seal opening is not a concern for this accident. The primary stress intensity in the lids, assuming that the lids are subject to 2.0 MPa (290 psi) and are conservatively considered as simply supported plates at the bolt circle, meet the Level D ASME Code limits (this is easily demonstrated by examining the results for the N1 normal load condition summarized in Section 2.6). In-leakage of water through the containment system boundary seals is confirmed to be non-credible to satisfy the intent of ISG-19 [1.2.8]. Therefore, the package meets all acceptance criteria given in Section 2.1 under this immersion condition.

2.7.8 Summary of Damage

The results presented in Subsections 2.7.1 through 2.7.7 show that the HI-STAR 180L Package meets the requirements of 10CFR71.61 and 10CFR71.73. All (plausibly) vulnerable orientations of free drop have been analyzed. Two puncture events have also been considered and reported in the tables in Section 2.7. All safety factors are greater than 1.0 for the hypothetical accident conditions of transport, and the sealing function is maintained at the end of each event and at the end of the sequence. The fuel basket does not experience any primary plastic strain after any of the accidents simulated in this safety analysis effort. Therefore, the HI-STAR 180L package, under the hypothetical accident conditions of transport, has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.

Specifically, the analyses summarized in this section show that:

i. The HI-STAR 180L containment space will remain inaccessible to the moderator under the immersion event of §71.73, which follows free drop, puncture, and fire.

ii. Both lids will continue to maintain a positive contact load at their interfaces with the flange subsequent to the hypothetical accident event, indicating that both primary and secondary lid gaskets will remain functional to contain the radioactive material and as effective leakage barriers to moderator intrusion into the containment cavity. The torque requirement for the inner closure lid port cover bolts (Table 7.1.1) is also adequate to maintain compression on the port cover seals under Hypothetical Accident Conditions.

iii. Localized plastic deformation under the stabbing action of the mild steel bar is indicated. However, there is no through-wall puncture and the damage is superficial.

iv. The primary stresses in the Metamic-HT panels remain essentially elastic even under the inertia loads from the 9-meter drop event. (Maintaining elastic response, i.e., full deflection recovery after a drop event, imposed on the HI-STAR 180L fuel baskets is a far more stringent criterion than the ASME Level D service condition used in most packages).

Table 2.7.1: [Withheld in Accordance with 10 CFR 2.390]

Table 2.7.2: [Withheld in Accordance with 10 CFR 2.390]

Table 2.7.3: Nine-Meter Free Drop Simulations Results Using LS-DYNA

Case No.	Drop Scenario	θ	Maximum Computed Deceleration in g's α_{max}		Maximum Crush Inch (cm)		Reference Figure	Comments
			Axial	Lateral	Allowable* Value	Computed Value		
1.	End drop – bottom down (UB**)	90	59.50	-	15.12 (38.40)	8.16 (20.73)	2.7.1	
2.	End drop – top down (UB)	90	58.93	-	15.12 (38.40)	8.04 (20.42)	2.7.1	
3.	Side drop (UB)	0	-	60.27	13.48 (34.24)	10.95 (27.81)	2.7.3	
4.	C.G.-over-corner drop – top down (UB)	68.04	32.95	-	30.44 (77.32)	23.11 (58.70)	2.7.2	
5.	Oblique drop (slap down) – primary impact at the top end (UB)	6	-	82.2	13.48 (34.24)	10.44 (26.52)	2.7.4	Bounding results of the primary and secondary impacts are reported
6.	Oblique drop (slap down) – primary impact at the bottom end (UB)	6	-	88.1	13.48 (34.24)	10.71 (27.20)	2.7.4	Bounding results of the primary and secondary impacts are reported
7.	Side drop (LB)	0	-	59.3	13.48 (34.24)	11.83 (30.05)	2.7.3	

* Allowable crush based on distance to closest point on steel backbone, except for end drop where allowable crush is 63% of the distance to closest point.

** "UB" indicates Upper Bound crush strength values are used in drop simulation; "LB" indicates Lower Bound crush strength values are used in drop simulation.

Table 2.7.4: Fuel Assembly or Quiver Peak Deceleration

Case No.	Drop Scenario	θ	Maximum Axial Deceleration (g)	Maximum Lateral Deceleration (g)
1.	End drop – bottom down (UB[**])	90	66.61	
2.	End drop – top down (UB)	90	72.77	-
3.	Side drop (UB)	0	-	92.5
4.	C.G.-over-corner drop – top down (UB)	68.04	33.25	19.3
5.	Oblique drop (slap down) – primary impact at the top end (UB)	6	-	45.7
6.	Oblique drop (slap down) – primary impact at the bottom end (UB)	6	-	45.8
7.	Side drop (LB)	0	-	84.8

Table 2.7.5: - Bounding Results from 9-M Drop and 1-M Drop Puncture Simulations

Item	Allowable Value[†]	Calculated Value	Safety Factor	Governing Accident
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	506.8 (73.5)	300.89 (43.64)	1.68	1-M Top End Drop Puncture
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	506.8 (73.5)	326.5 (47.36)	1.55	9-M Top End Drop
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	336.8 (48.85)	246.3 (35.72)	1.36	9-M Side Drop
Cask Baseplate – Primary Bending Stress Intensity – MPa (ksi)	506.8 (73.5)	262.97 (38.1)	1.93	9-M Bottom End Drop
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	1047.9 (151.78)	830.4 (120.44)	1.26	9-M Slapdown (Bottom First)
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	861.85 (125)	779.52 (113.06)	1.11	9-M Slapdown (Top First)
Maximum Penetration into the Cask Body by the Puncture Bar mm (inches)	376 (14.8)	16 (0.63)	23.5	1-M Top End Drop Puncture
Lid Seals Remain Sufficiently Compressed after the Drop Accident?	Yes			
Fuel Basket Panel Lateral Deformation – Maximum Total Deflection < 0.74 mm	Yes			
Impact Limiters Remain Attached to the Cask	Yes			

Note: [†] Allowable stresses are obtained from Table 2.6.3. *The total penetration to the containment shell outer surface.

Table 2.7.6: Bolted Joint Performance Under the Fire Event

Item	Initial Preload Condition	Steady State Fire Condition
Inner Closure Lid Bolt – Average Service Stress MPa (ksi)	524 (76)	513 (74.35)
Outer Closure Lid Bolt – Average Service Stress MPa (ksi)	379 (55)	399.8 (57.98)

Table 2.7.7: Key Performance Objectives for Non-Containment Components of the HI-STAR 180L

Criterion	Result
Effective Stress in Monolithic Shield – Primary Effective Stress Below Ultimate Strength	Yes
Fuel Basket Deformation – Maximum Total Deflection[†] < 0.74 mm	Yes

[†] It is further shown that the average deflection of the basket panel remains below 0.5 mm.

Figure 2.7.1: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.2: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.3: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.4: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.5A: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.5B: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.5C: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.5D: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.6: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.7: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.8: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.9: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.10: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.11A: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.11B: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.11C: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.12: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.13: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.14: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.15: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.16: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.17: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.18: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.19: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.20: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.21: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.22: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.23: [Withheld in Accordance with 10 CFR 2.390]

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for air transport of plutonium and, therefore, does not address the accidents defined in 10CFR71.74.

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIALS FOR AIR TRANSPORT

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for air transport of fissile materials and, therefore, does not address the accidents defined in 10CFR71.55(f).

2.10 SPECIAL FORM

This section is not applicable to the HI-STAR 180L Package. This application does not seek approval for transport of special form radioactive material; therefore, the requirements of 10CFR71.75 are not applied.

2.11 FUEL RODS

The cladding of the fuel rods is the first boundary for confining radiological matter in the HI-STAR 180L Transport Cask. Analyses have been performed in Chapter 3 to ensure that the maximum temperature of the fuel cladding is well below ISG-11, Rev. 3 regulatory limits [2.11.1].

The vertical drop of the package, leading to a rapid axial deceleration of the stored fuel and the consequent flexural strains, is recognized as the most vulnerable free drop configuration from the standpoint of potential damage to the fuel [2.11.2, 2.11.3]. Fortunately, the problem of large inertial loading of fuel has been comprehensively studied in the published NUREG [2.11.5] and studies conducted by Pacific Northwest National Laboratory (PNNL) and USNRC [2.11.4], which obsolesces prior analyses and provides a robust and conservative basis for prognosticating fuel damage under vertical drop events.

[

Withheld in Accordance with 10 CFR 2.390

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Table 2.11.1: [Withheld in Accordance with 10 CFR 2.390]

Table 2.11.2: [Withheld in Accordance with 10 CFR 2.390]

Table 2.11.3: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.1: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.2: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.3: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.4: **[Withheld in Accordance with 10 CFR 2.390]**

Figure 2.11.5a: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.5b: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.5c: [Withheld in Accordance with 10 CFR 2.390]

Figure 2.11.6: [Withheld in Accordance with 10 CFR 2.390]

CHAPTER 2 REFERENCES

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[2.11.11] Hydride-Related Degradation of Spent-Fuel Cladding Under Repository Conditions, Energy Technology Division, Argonne National Laboratory, Argonne, IL.

[2.11.12] 15th International Symposium on Zirconium in the Nuclear Industry, June 2007, "Evaluation of Hydride Reorientation Behavior and Mechanical Property for High Burnup Fuel Cladding Tube in Interim Dry Storage".

Appendix 2.A: Description of Computer Codes for Structural Evaluation*

Two commercial computer programs, both with a well established history of usage in the nuclear industry, have been utilized to perform structural and mechanical numerical analyses documented in this submittal. These codes are ANSYS Mechanical and LS-DYNA. A brief synopsis of the capabilities of each code is presented below:

ANSYS Mechanical

ANSYS is the original (and commonly used) name for ANSYS Mechanical general-purpose finite element analysis software. ANSYS Mechanical is the version of ANSYS commonly used for structural applications. It is a self-contained analysis tool incorporating pre-processing (geometry creation, meshing), solver, and post processing modules in a unified graphical user interface. ANSYS Mechanical is a general purpose finite element modeling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems.

ANSYS Mechanical has been independently QA validated by Holtec International and used for structural analysis of casks, fuel racks, pressure vessels, and a wide variety of SSCs, for over twenty years.

LS-DYNA

LS-DYNA is a general purpose finite element code for analyzing the large deformation static and dynamic response of structures including structures coupled to fluids. The main solution methodology is based on explicit time integration and is therefore well suited for the examination of the response to shock loading. A contact-impact algorithm allows difficult contact problems to be easily treated. Spatial discretization is achieved by the use of four node tetrahedron and eight node solid elements, two node beam elements, three and four node shell elements, eight node solid shell elements, truss elements, membrane elements, discrete elements, and rigid bodies. A variety of element formulations are available for each element type. Adaptive re-meshing is available for shell elements. LS-DYNA currently contains approximately one-hundred constitutive models and ten equations-of-state to cover a wide range of material behavior.

In this safety analysis report, LS-DYNA is used to analyze all loading conditions that involve short-time dynamic effects.

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* This appendix contains generic information and is identical to the one submitted in the HI-STAR 60 SAR and HI-STAR 180 SAR. Under Holtec's configuration control, this appendix will be immediately revised in all submitted SARs if a USNRC request-for-additional-information (RAI) necessitates a change to its contents.

Appendix 2.B: [Withheld in Accordance with 10 CFR 2.390]

CHAPTER 3: THERMAL EVALUATION

3.0 INTRODUCTION

In this chapter, compliance of the HI-STAR 180L Package to 10CFR Part 71 [1.0.2] and ISG-11, Rev. 3 [1.2.7] thermal requirements is evaluated for normal transport and hypothetical accident conditions of transport. The analysis considers passive rejection of decay heat from the Spent Nuclear Fuel (SNF) to a 10CFR71- mandated environment for normal transport and hypothetical fire accident conditions.

The 10CFR Part 71 regulations define the thermal requirements of transport packages. The requirements are as follows:

1. A package must be designed, constructed, and prepared for shipment so that in still air at 38ºC (100°F) and in the shade, no accessible surface of the package would have a temperature exceeding 85ºC (185°F) in an exclusive use shipment [§71.43(g)].

2. With respect to the initial conditions for the events of normal conditions of transport and hypothetical accident conditions, the demonstration of compliance with the requirements of 10CFR71 must be based on the ambient temperature preceding and following the event remaining constant at that value between a bounding -40ºC (-40°F) and 38ºC (100°F) which is most unfavorable for the feature under consideration. The initial internal pressure within the containment must be considered to be the maximum normal operating pressure [§71.71(b) and §71.73(b)].

3. For normal conditions of transport, a heat event consisting of an ambient temperature of 38ºC (100°F) in still air and prescribed insolation must be evaluated [§71.71(c)(1)].

4. For normal conditions of transport, a cold event consisting of an ambient temperature of -40°C (-40°F) in still air and shade must be evaluated [§71.71(c)(2)].

5. Evaluation for hypothetical accident conditions is to be based on sequential application of the specified events, in the prescribed order, to determine their cumulative effect on a package [§71.73(a)].

6. For hypothetical accident conditions, a thermal event consisting of a fully engulfing hydrocarbon fuel/air fire with an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 802ºC (1475°F) for a period of 30 minutes [§71.73(c)(4)].

Section 3.1 describes the thermal design features of the HI-STAR 180L Package. Section 3.2 lists the material properties data required to perform the thermal analyses and the applicable temperature limits criteria required to demonstrate the adequacy of the HI-STAR 180L Package design under normal and hypothetical accident conditions. Thermal analyses to evaluate the normal transport are described and evaluated in Section 3.3. Thermal analyses for hypothetical accident conditions are described and evaluated in Section 3.4.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation for normal conditions of transport documented in this chapter are supported by those used in the SAR for HI-STAR 180, 180D and 190 casks certified in Dockets #71-9325, 71-9367 and 71-9373 [1.0.4, 1.0.5, 1.0.6].

3.1 DESCRIPTION OF THERMAL DESIGN

3.1.1 Design Features

Design details of the HI-STAR 180L Package are presented in Chapter 1 and structural and mechanical features are described in Chapters 1 and 2. The HI-STAR 180L Package geometry is detailed in Holtec drawings included in Section 1.3. All materials of construction are itemized in the drawings. The assembled packaging with impact limiters installed is shown in Figure 1.3.2. As shown in this figure, the HI-STAR 180L Package is equipped with a personnel barrier to prevent access to hot cask surfaces. The package consists of a Metamic-HT fuel basket inside a thick steel cask with twin (inner and outer) bolted closure lids. An F-69L basket design is engineered for storing up to 69 BWR fuel assemblies. The fuel basket is a honeycomb structure engineered with square-shaped compartments to store BWR fuel. Prior to lid closure, the cask cavity is backfilled with helium. This provides a stable and inert environment for the transport of the SNF. Heat is transferred from the cask to the environment by passive heat transport mechanisms only.

The HI-STAR 180L Package is designed to safely dissipate heat under passive conditions (no wind). During transport, the HI-STAR 180L Package is placed in a horizontal position with impact limiters installed at both ends of the cask. Under normal transport conditions, the cask contents (fuel basket, fuel and basket shims) rest on solid surfaces. Direct contact between the cask and its contents enhance heat dissipation. Prior to cask closure, the cask cavity is backfilled with helium. A double-lid design is engineered to eliminate air in-leakage during transport and to prevent water ingress under a hypothetical water immersion accident. Presence of a substantially more conductive medium (helium) relative to air in the cavity spaces aids heat transfer by minimizing gap resistances and dissipating heat by natural convection[1] in the cavity peripheral spaces.

The fuel basket is a matrix of square-shaped fuel compartments sized to store BWR Spent Nuclear Fuel (SNF). The basket is formed by a honeycomb structure of thick Metamic-HT plates. The fuel basket is surrounded by an array of shaped aluminum spacers (basket shims) inserted in the cask cavity peripheral spaces. Cross-sectional view of the fuel basket designs are provided in Chapter 1 drawings. Heat is dissipated in the fuel basket principally by conduction of heat in the highly conductive Metamic-HT plates arrayed in two orthogonal directions. Heat dissipation in the fuel basket peripheral spaces is by a combination of contact heat transfer, helium conduction and radiation across narrow peripheral spacer gaps and by conduction through the basket shims. The fuel basket and the basket shims reside in a containment boundary formed by the containment shell, containment closure flange, containment baseplate and two closure lids. The containment shell is enclosed in a shrink fitted thick section cask body engineered with neutron shield pockets. The cask body exterior is engineered with low profile fins to enhance heat transfer area and concomitant dissipation of heat. In the interest of conservatism dissipation of heat by fins is ignored.

The helium backfill gas is an integral part of the HI-STAR 180L thermal design. The helium fills all the spaces between solid components and provides an improved conduction medium (compared

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[1] Effect judged to be small due to sub-atmospheric design.

to air) for dissipating decay heat. Additionally, helium in the spaces between the fuel basket and the cask cavity is heated differentially and dissipates heat by the so-called “Rayleigh” convection. To ensure that the helium gas is retained and not diluted by lower conductivity air, the cask containment boundary is designed as an ASME Section III pressure vessel equipped with high integrity double seals in *both* the inner and outer closure lids. This ensures the presence of helium during transport. The helium gas is therefore retained in an undiluted state, and may be credited in the thermal analyses.

An important thermal design criterion imposed on the HI-STAR 180L Package is to ensure that the peak fuel cladding temperatures are below regulatory limits. An equally important design criterion is to minimize temperature gradients within the fuel basket to minimize thermal stresses. In order to meet these design objectives, the HI-STAR 180L fuel basket is designed to possess certain distinctive characteristics, which are summarized in the following.

The cask design minimizes resistance to heat transfer within the basket and basket periphery regions. This is ensured by designing the fuel basket with highly conductive Metamic-HT plates. In the fuel basket peripheral spaces thick Aluminum basket shims are inserted to facilitate basket-to-cask heat transfer. The cask design incorporates top and bottom plenums with interconnected downcomer paths to facilitate heat dissipation by internal helium circulation. This mode of heat transfer is active when the cask is tilted a few degrees from horizontal orientation. The top and bottom plenums are formed between the cask ends and fuel basket lateral flow holes in the top and bottom sections of each fuel cell wall. The fuel basket is designed to minimize structural discontinuities (i.e., gaps), which can introduce large thermal resistances to heat flow. Consequently, temperature gradients are minimized in this design, which results in lower thermal stresses within the basket. Low thermal stresses are also ensured by provisions in the cask design that permit unrestrained axial and radial thermal growth of the basket.

The HI-STAR 180L Package is designed to transport BWR spent fuel assemblies. As explained next, thermal analysis of the HI-STAR 180L Package considers all three fundamental modes of heat transfer: conduction, natural convection and thermal radiation. On the outside surface of the package, heat is dissipated to the environment by buoyancy induced convective air-flow (natural convection) and thermal radiation. Within the cask body, heat dissipation is principally by heat conduction. Inside the cask cavity heat dissipation is conservatively limited to conduction and radiation. Between surfaces (e.g., between neighboring fuel rods) heat is transported by a combination of conduction through a gaseous medium (helium) and thermal radiation. Finally buoyancy-induced convective heat transport occurs within the open spaces of the cask cavity. Heat transfer between the fuel basket external surface and enclosure shell inside wall is enhanced by the so-called “Rayleigh” effect in differentially heated cavities [3.1.1]. In the interest of conservatism convective heat transfer in the cavity spaces is neglected.

In Section 3.2 the thermal criteria for ensuring Spent Nuclear Fuel (SNF) integrity and cask effectiveness are provided. To ensure SNF integrity, the ISG-11 recommended cladding temperature limits [1.2.7] are adopted (Table 3.2.11). To ensure cask effectiveness the cask materials and components are required to be below the pressure and temperature limits for creep, yield, decomposition and melting (Tables 2.1.1, 3.2.10 and 3.2.12).

3.1.2 Contents Decay Heat

The fuel loading is required to comply with both the decay heat and burnup limits of fuel assemblies and Quivers as specified in Table 7.D.1 and Figure 7.D.1. The HI-STAR 180L Package is designed to allow fuel loading under a regionalized loading. The decay heat limits require compliance with cell location specific, quadrant specific and aggregate cask heat load limits specified in Table 7.D.1 and Figure 7.D.1. As evaluated in Section 3.3 bounding regionalized scenario is defined and adopted for safety evaluation in this chapter.

3.1.3 Summary Table of Temperatures

The HI-STAR 180L Package temperatures are analyzed for normal transport condition of BWR fuel loaded in F-69L fuel basket. The permissible loading patterns in Figure 7.D.1 and Figure 7.D.2 are evaluated and details on the bounding scenario are discussed in Subsection 3.3.5. The hypothetical fire accident event is evaluated for thermally bounding loading scenario. The modeling of the thermal problem is discussed in Sections 3.3 and 3.4. The analysis results are provided in Tables 3.1.1 and 3.1.3. The HI-STAR 180L normal transport and hypothetical accident temperatures comply with the normal and accident temperature limits specified in Tables 3.2.10, 3.2.11 and 3.2.12.

3.1.4 Summary Table of Maximum Pressures

The HI-STAR 180L Package containment boundary pressures are computed for normal transport condition and hypothetical fire accident event. The numerical modeling is discussed in Sections 3.3 and 3.4. The analysis results are provided in Tables 3.1.2 and 3.1.4. The HI-STAR 180L normal transport and hypothetical accident containment pressures comply with the pressure limits specified in Chapter 2, Table 2.1.1.

3.1.5 Cask Surface Temperature Evaluation

In accordance with the regulatory requirement specified in 10CFR71 (§71.43(g)), the cask surface temperature is computed in still air at 38^{o}C (100^{o}F) and in the shade. Under this scenario the maximum computed cask surface temperature reported in Table 3.1.5 is above the allowable surface temperature limit of 85^{o}C (185^{o}F). To meet the accessible surface temperature limit, a personnel barrier as defined in Chapter 1 will be required. The personnel barrier must be engineered to provide personnel protection without adversely impacting cask and fuel temperatures. In Section 3.3 a personnel barrier is conservatively defined and evaluated for the package at design basis heat load.

Table 3.1.1: HI-STAR 180L Normal Transport Maximum Temperatures[1]

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

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[1] Bounding Scenario 1 defined in Subsection 3.3.5 adopted herein.

Table 3.1.2: HI-STAR 180L Maximum Normal Operating Pressures (MNOP)

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.1.3: Hypothetical Fire Accident Maximum HI-STAR 180L Temperatures

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.1.4: Maximum HI-STAR 180L Hypothetical Fire Accident Pressures

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.1.5: HI-STAR 180L Normal Transport Surface Temperature in Shade

[PROPRIETARY INFORMATION WITHELD IN
ACCORDANCE WITH 10 CFR 2.390]

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

3.2.1 Material Properties

Materials present in the HI-STAR 180L Packaging include structural steels, aluminum, lead, neutron shielding material (Holtite-B), neutron absorber (Metamic-HT), impact limiter crush material and helium. In Table 3.2.1, a summary of references used to obtain cask material properties for performing all thermal analyses is presented.

Thermal conductivity data of cask structural steels, neutron shielding materials, impact limiters, lead, insulation and helium are provided in Table 3.2.2. Thermal conductivities of fuel, aluminum basket shims, stainless steel shim plates and fuel basket (Metamic-HT) are provided in Tables 1.5.2, 3.2.3, 3.2.4 and 3.2.5.

Surface emissivity data for key materials of construction are provided in Table 3.2.6. [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]. A theoretical bounding solar absorbtivity coefficient of 1.0 is applied to exposed cask surfaces.

In Table 3.2.7, the specific heat and density data of cask materials is presented. These properties are also used in performing transient (hypothetical fire accident condition) analyses. The viscosity of helium and air is presented in Table 3.2.8.

3.2.2 Component Specifications

The HI-STAR 180L Package materials and components which are required to be maintained below maximum pressure and temperature limits for safe operation, to ensure their intended functions, are summarized in Chapter 2 (Table 2.1.1) and Chapter 3 (Tables 3.2.10, 3.2.11 and 3.2.12). These materials and components do not degrade under exposure to extreme low temperatures. As defined by transport regulations, the HI-STAR 180L Package cold service temperature is conservatively limited to –40^{o}C (-40^{o}F).

Long-term stability of the neutron shield material (Holtite-B) under normal transport conditions is ensured when material exposure temperatures are maintained below Table 3.2.12 limits. The cask metallic seals ensure leak tightness of the closure plates if the manufacturer's recommended design temperature limits are not exceeded. Integrity of SNF during transport requires demonstration of HI-STAR 180L Package fuel cladding temperatures below regulatory limits for Moderate Burnup Fuel (MBF) and High Burnup Fuel (HBF). In the HI-STAR 180L thermal evaluation, the cladding temperature limits of ISG-11, Rev. 3 [1.2.7] are adopted (See Table 3.2.11). These limits are applicable to all fuel types, burnup levels and cladding materials approved for power generation. [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]. For conservatism temperature limits well below the threshold of material integrity[†] are adopted (See Tables 3.2.10, 3.2.11 and 3.2.12).

[†] [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

For evaluation of the HI-STAR Package’s thermal performance under hypothetical accident conditions, lowerbound material temperature limits for accident events are defined in Tables 3.2.10, 3.2.11 and 3.2.12.

Table 3.2.1: Summary of HI-STAR Packaging Materials Thermal Property References

Material	Emissivity	Conductivity	Density	Heat Capacity
Helium	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Zircaloy Cladding	EPRI [3.2.3]	NUREG [3.2.6]	Rust [3.2.4]	Rust [3.2.4]
UO_2	Not Used	NUREG [3.2.6]	Rust [3.2.4]	Rust [3.2.4]
Stainless Steel (machined forgings)	Kern [3.2.5]	ASME [3.2.7]	Marks' [3.2.1]	Marks' [3.2.1]
Stainless Steel Plates	ORNL [3.2.13], [3.2.14]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Carbon Steel	Kern [3.2.5]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Aluminum Basket Shims	Note 1	ASM [3.2.12]	ASM [3.2.12]	ASM [3.2.12]
Holtite-B	Not Used	Note 3		Polymer Handbook [3.2.9]
Metamic-HT	Note 1	Note 1	Note 1	Note 1
Impact Limiter Crush Material	NA	Note 2	Table 2.2.10	ASME [3.2.7]
Lead	NA	Handbook [3.2.2]	Handbook [3.2.2]	Handbook [3.2.2]
Air	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2.]

Note 1: The thermal properties of Metamic-HT used in the safety analysis are defined in Table 1.5.2.
Note 2: Nominal values of thermal conductivity are specified in Table 3.2.2.
Note 3: Thermo-physical data supported by Holtite-B Sourcebook [1.2.9] defined in Tables 2.2.12 and 3.2.2.

Table 3.2.2: Thermal Conductivity of HI-STAR 180L Cask Materials

Material	@ 37.8°C (100°F) W/m-°K (Btu/ft-hr-°F)	@ 93.3°C (200°F) W/m-°K (Btu/ft-hr-°F)	@ 232.2°C (450°F) W/m-°K (Btu/ft-hr-°F)	@ 371.1°C (700°F) W/m-°K (Btu/ft-hr-°F)	@537.8°C (1000°F) W/m-°K (Btu/ft-hr-°F)
Helium	0.1537 (0.0888)	0.1686 (0.0976)	0.2227 (0.1289)	0.2722 (0.1575)	0.3271 (0.1890)
Structural Steels	See Table 3.2.9				
Lead$^{\text{Note 3}}$	34.4 (19.9)	33.6 (19.4)	31.0 (17.9)	16.1 (9.30)	15.4 (8.89)
Air	0.0265 (0.0153)	0.0299 (0.0173)	0.0389 (0.0225)	0.047 (0.0272)	0.0582 (0.0336)
Impact Limiters$^{\text{Notes 1}}$	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]				
Holtite B$^{\text{Note 1}}$	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]				
Insulation Board	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]				

Notes:

1) Lowerbound values adopted during normal transport and post fire cooldown.(See Table 3.4.1).
2) Deleted.
3) Lead melts at 327°C (621°F). For temperature above melting temperature, thermal conductivity of molten lead tabulated.

Table 3.2.3: Thermal Conductivity of Fuel Assembly Materials

Fuel Cladding		Fuel (UO_2)Note 1	
Temperature °C (°F)	Conductivity W/m-°K (Btu/ft-hr-°F)	Temperature °C (°F)	Conductivity W/m-°K (Btu/ft-hr-°F)
200 (392)	14.3 (8.28)	37.8 (100)	6.02 (3.48)
300 (572)	15.1 (8.76)	231.1 (448)	6.02 (3.48)
400 (752)	16.6 (9.60)	298.9 (570)	5.60 (3.24)
500 (932)	18.06 (10.44)	422.8 (793)	3.94 (2.28)
Note 1: Gadolinium poisoned fuel conductivities addressed in Section 3.3.15.			

Table 3.2.4: Thermal Conductivity of Aluminum (Basket Shims Material)

Material	Conductivity W/m-ºK (Btu/ft-hr-°F)
[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]	

Table 3.2.5: Metamic-HT Thermal Conductivity Data

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.2.6: Summary of Materials Surface Emissivity Data

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.2.7: Materials Density and Specific Heat Properties Summary

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.2.8: Helium and Air Viscosity Variation with Temperature[1]

Temperature ºC (°F)	Helium Viscosity N-s/m^2 (Micropoise)	Temperature ºC (°F)	Air Viscosity N-s/m^2 (Micropoise)
75.2 (167.4)	2.205×10^{-5} (220.5)	0 (32.0)	1.72×10^{-5} (172.0)
93.5 (200.3)	2.282×10^{-5} (228.2)	21.4 (70.5)	1.824×10^{-5} (182.4)
147.4 (297.4)	2.506×10^{-5} (250.6)	126.8 (260.3)	2.294×10^{-5} (229.4)
174.9 (346.9)	2.618×10^{-5} (261.8)	170.2 (338.4)	2.463×10^{-5} (246.3)
239.4 (463.0)	2.887×10^{-5} (288.7)	297.3 (567.1)	2.93×10^{-5} (293.0)
281 (537.8)	2.998×10^{-5} (299.8)	372 (701.6)	3.167×10^{-5} (316.7)
392 (737.6)	3.388×10^{-5} (338.8)	581.2 (1078.2)	3.776×10^{-5} (377.6)

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[1] Obtained from Rohsenow and Hartnett [3.2.2].

Table 3.2.9: Thermal Conductivity of ASME Materials in HI-STAR 180L Cask

Material	SA203E SA350-LF3	SS-304	Carbon Steel
Temperature ºC (ºF)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)		
20 (68)	41.0 (23.70)	14.8 (8.55)	60.4 (34.91)
50 (122)	40.8 (23.58)	15.3 (8.84)	59.8 (34.56)
150 (302)	40.4 (23.35)	17.0 (9.82)	55.9 (32.31)
250 (482)	39.5 (22.83)	18.6 (10.75)	51.4 (29.71)
350 (662)	37.8 (21.85)	20.1 (11.62)	47.0 (27.16)
450 (842)	35.8 (20.69)	21.5 (12.43)	42.7 (24.68)
550 (1022)	33.9 (19.59)	22.9 (13.23)	38.2 (22.08)
700 (1292)	29.1 (16.82)	25.0 (14.45)	31.2 (18.03)
815 (1500)	26.1 (15.1)	26.5 (15.3)	26.8 (15.5)

Table 3.2.10: HI-STAR 180L Structural Materials Temperature Limits

Component	Material	Normal Condition Temperature Limits[(a)] °C (°F)	Short Term Operations & Accident Temperature Limits[(a)] °C (°F)
Fuel Basket	Metamic-HT	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]
Basket Shims	Aluminum Alloy	300 (572)[(f)]	500 (932)[(e)]
Stainless Steel Shim Plates	Stainless Steel	300 (572)[(c)]	371 (700)[(e)]
Containment Shell	Cryogenic Steel	232 (450)[(c)]	371 (700)[(d)]
Containment Baseplate and Closure Flange	Cryogenic Steel	204 (400)[(c)]	371 (700)[(d)]
Inner and Outer Closure Lids	Cryogenic Steel	204 (400)[(c)]	371 (700) (Structural Accidents)[(d)] 420 (788) (Fire Accident[(e)]
Monolithic Shield Surface	Carbon Steel	204 (400)[(c)]	371 (700) (Structural accidents)[(d)] 788 (1450) (Fire Accident[(e)]
Impact Limiter	Crush Material (Types 1 and 2)	-40 to 104 (-40 to 220)	-40 to 104 (-40 to 220) (Structural Accidents) N/A (Fire Accident)

Notes

(a) The ASME Code requires that the vessel design temperature be established with appropriate consideration of internal or external heat generation. In accordance with ASME Section III Code, Para. NCA-2142 the design temperature is set at or above the structural members' section temperature defined as the maximum through thickness mean metal temperature of the part under consideration. The section temperatures of the structural members shall not exceed the temperatures limits tabulated herein.

(b) The temperature limits of Metamic-HT are bounded by the maximum material qualification test temperatures [1.2.10].

(c) The normal condition temperature limits conservatively bound the ASME Code temperature limits.

(d) The accident temperatures of structural members must not exceed the ASME code temperature limits.

(e) To preclude melting the short term and fire accident temperature limits are set well below the melting temperature of structural steel, Metamic-HT and Aluminum Alloys.

(f) The normal condition temperature limit is bounded by Table 2.2.9.

Table 3.2.11: Fuel Cladding Temperature Limits

Component	Material	Normal Condition Temperature Limits ^oC (^oF)	Short Term Operations & Accident Temperature Limits ^oC (^oF)
Fuel Cladding (Moderate Burnup Fuel)	See Note 1	400 (752)	570 (1058)
Fuel Cladding (High Burnup Fuel)	See Note 1	400 (752)	400 (752) (Short Term Operations) 570 (1058) (Accident)

Notes

1. Fuel cladding temperature limits are applicable to all cladding materials approved for power generation [1.2.7].

Table 3.2.12: HI-STAR 180L Component Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Short Term Operations & Accident Temperature Limits °C (°F)
Inner and Outer Closure Lid Seals	Note 1	200 (392)	Note 5
Inner Lid Port Cover and Outer Lid Port Plug Seals	Note 1	200 (392)	Note 5
Gamma Shield	Lead	316 (600)	316 (600)^{Note4}
Impact Limiter Bulk	Aluminum Alloy	Table 2.2.10	NA^{Note 3}
Neutron Shield	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]		
<u>Notes</u> [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]			

3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

The HI-STAR 180L Package is designed to safely dissipate heat under passive conditions (no wind). Under normal transport conditions, the cask contents (fuel basket, fuel and basket shims) rest on solid surfaces. Direct contact between the cask and its contents enhances heat dissipation. Nevertheless to engineer a robust measure of conservatism a hypothetical bounding configuration (levitating fuel basket) is assumed. Under this assumption, the fuel, fuel basket, basket shims and cask are in concentric alignment (i.e. they do not make physical contact).

The HI-STAR 180L Package consists of an F-69L fuel basket geometry engineered to hold 69 BWR fuel assemblies. The cask design heat loads are defined in Chapter 7. The fuel basket designed as interlocking honeycomb Metamic-HT panels is same as in the F-32 and F-37 baskets licensed in the HI-STAR 180 cask [1.0.4].

The HI-STAR 180L Package thermal analysis is performed using the FLUENT CFD code [3.3.2]. FLUENT is a well-benchmarked CFD code validated by the code developer with an array of theoretical and experimental works from technical journals. Additionally, Holtec has Q.A. validated FLUENT within the company’s quality assurance program and confirmed the code's capability to reliably predict temperature fields in dry storage [3.3.4] using independent full-scale test data from a loaded cask [3.2.3]. The code has a long history of usage for obtaining NRC approval of fuel storage in transport and storage casks. A list of dockets wherein USNRC relied on FLUENT thermal models for cask certification is given in Table 3.3.3.

The HI-STAR 180L cask is designed to allow fuel loading under regionalized loading as defined in Figure 7.D.1. Bounding scenarios are evaluated in Subsection 3.3.5.

3.3.1 Fuel Region Effective Thermal Conductivity

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390].

The fuel region effective planar conductivity is defined as the calculated equivalent conductivity of the fuel storage cell by including conduction and radiation heat transfer. Because radiation is proportional to the fourth power of absolute temperature, the effective conductivity is a strong function of temperature. [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390] the effective thermal conductivity as a function of temperature obtained and presented in Table 3.3.1.

3.3.2 Heat Rejection from Cask and Impact Limiter Surfaces

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.3.3 Determination of Solar Heat Input

The intensity of solar radiation incident on exposed surfaces depends on a number of time varying parameters. The solar heat flux strongly depends upon the time of the day as well as on latitude and day of the year. Also, the presence of clouds and other atmospheric conditions (dust, haze, etc.) can significantly attenuate solar intensity levels. In the interest of conservatism, the solar attenuation effects of dust, haze, angle of incidence and latitude are neglected.

The insolation energy absorbed by the HI-STAR 180L Package is the product of incident insolation and the package absorbtivity. For conservatism theoretical bounding absorbtivity equal to unity is assumed for the cask surfaces. For polished surfaces solar absorbtivity obtained from robust sources is applied (See Table 3.2.6). The HI-STAR 180L Package thermal analysis is based on 12-hour daytime insolation specified in 10CFR71. During normal transport conditions, the HI-STAR Package is cyclically subjected to solar heating during the 12-hour daytime period followed by cooling during the 12-hour nighttime. However, due to the large mass of metal and the size of the Package, the dynamic time lag exceeds the 12-hour heating period. Accordingly, the HI-STAR Package model includes insolation at exposed surfaces averaged over a 24-hour time period. The 10CFR71 12-hour insolation is summarized in Table 3.3.2. In the interest of conservatism, overstated solar insolation values are applied in the thermal models.

3.3.4 HI-STAR 180L 3D Model

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Sectional and isometric views of the HI-STAR 180L thermal model are presented in Figures 3.3.3 and 3.3.4 respectively.

3.3.5 Screening Calculations to Ascertain Limiting Scenario

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The above scenarios under Pattern A are analyzed and results tabulated in Table 3.3.4. Similarly, Pattern B is also analyzed, and results presented in Table 3.3.4. As highlighted in this table highest temperatures are reached under Pattern A Scenario 1. Accordingly this scenario is adopted in the licensing basis analyses.

3.3.6 Grid Sensitivity Studies

To ensure mesh independent CFD results, a grid sensitivity study of the thermal model of F-69L basket in the HI-STAR 180L cask is performed with particular attention to mesh density in areas of high thermal resistance. The grid refinement is performed in the entire domain i.e. for both fluid and solid regions in both axial and radial directions.

A number of grids are generated to study the effect of mesh refinement on the fuel and temperatures. All sensitivity analyses were carried out for the case of F-69L with thermally bounding loading scenario defined in Section 3.3.5. Per ASME V&V [3.3.1], it is recommended that the mesh refinement in 3D be at approximately 2.2 times the previous mesh. This recommended criterion is satisfied by the meshes specified in Table 3.3.5.

As observed by review of Table 3.3.5, computed PCT is essentially the same for all the three meshes. The PCT difference between the meshes is small compared to the available safety margin. To provide further assurance of convergence, the sensitivity results are evaluated in accordance with the ASME V&V 20-2009 [3.3.1]. Towards this end, the apparent order of the method is calculated for Meshes 1, 2 and 3. [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]. Based on these results mesh convergence is demonstrated. As Mesh 1 grid yields bounding PCT itis adopted for the thermal analysis of the HI-STAR 180L Package.

3.3.7 Heat and Cold

3.3.7.1 Maximum Temperatures

As required by transport regulations the HI-STAR 180L Package is evaluated under hot ambient conditions defined in 10CFR71. These conditions are 38°C (100°F) ambient temperature, still air and insolation (Table 3.3.2). To ensure a bounding evaluation, design heat load and a limiting heat load distribution (See Subsection 3.3.5) are assumed. Under this array of adverse conditions, the maximum steady state temperature of the package structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3 and results reported in Subsection 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature (Table 3.1.1) is well within the ISG-11, Rev. 3 temperature limit (Table 3.2.11).
- The maximum temperature of fuel basket (Table 3.1.1) is well within the design temperatures (Table 3.2.10).
- The maximum temperatures of the containment boundary and lid seals (Table 3.1.1) are well below the design temperatures (Tables 3.2.10 and 3.2.12, respectively).
- The maximum temperatures of the basket shims (Table 3.1.1) are well below the design temperature limits (Table 3.2.10).
- The neutron shielding material (Holtite-B) temperature (Table 3.1.1) is within its design limit (Table 3.2.12).

The temperatures of the HI-STAR 180L Package during normal transport are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The above observations lead us to conclude that the temperature field in the HI-STAR 180L Package loaded with heat emitting SNF complies with all regulatory requirements for normal conditions of transport. In other words, the thermal environment in the HI-STAR 180L Package is conducive to safe transport of spent nuclear fuel.

3.3.7.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR 180L Package is evaluated for a cold environment at -40°C (-40°F). The HI-STAR Package design does not require minimum decay heat load restrictions for transport. Therefore zero decay heat load and no solar input are bounding conditions for cold evaluation. Under these conditions, the temperature distribution in the HI-STAR 180L Package uniformly approaches the cold ambient temperature. All HI-STAR 180L Package materials of construction satisfactorily perform their intended function in the transport mode at this minimum postulated temperature condition. Evaluations in Chapter 2 demonstrate the acceptable structural performance of the package materials at low temperature. The HI-STAR 180L shielding and criticality materials (Holtite-B and Metamic-HT) are unaffected by exposure to cold temperatures.

3.3.7.3 Personnel Barrier Evaluation

As defined in Chapter 1, personnel barrier is an open lattice cage placed around the HI-STAR 180L cask to prevent access to the hot surfaces (See Figure 1.3.2). The open structure ensures that movement of ambient air is not unduly restricted and the cask temperatures are not impacted. To provide an additional layer of assurance a thermal calculation was performed assuming bounding personnel barrier characteristics defined in Table 3.3.8. The thermal calculation deployed the same 3D HI-STAR 180L thermal model articulated in this section above except for the following major differences:

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The cask temperatures with the personnel barrier are tabulated in Table 3.3.9. The maximum computed personnel barrier temperature reported in Table 3.3.9 complies with the accessible surface temperature limit of 85ºC. The results also support the conclusion that fuel, basket and containment temperatures remain below safety limits with robust margins.

The HI-STAR 180L cask cavity pressures are computed using the methodology presented in

Section 3.3.8 and presented in Table 3.3.9. The computed pressures comply with the pressure limits specified in Chapter 2, Table 2.1.1.

3.3.8 Maximum Normal Operating Pressure (MNOP)

The HI-STAR 180L cavity is de-moisturized and backfilled with dry helium after fuel loading and prior to lid closures. The MNOP evaluation considers the following source of gases:

<u>Initial Backfill:</u>
The HI-STAR 180L cavity is assumed to be backfilled to the maximum permissible pressure (Table 7.1.4).

<u>Water Vapor:</u>
The HI-STAR 180L cavity and its stored fuel are de-moisturized to a very low vapor pressure (Table 7.1.2). As this pressure is dwarfed by the helium backfill pressure it is neglected in the MNOP calculations.

<u>Helium from radioactive decay:</u>
The helium from radioactive decay is dwarfed by the generation of fission products during power generation. These products are assumed to be released into the HI-STAR 180L cavity under hypothetical rod ruptures. As radioactive decay is a small fraction of the fission gas releases it is neglected in the MNOP calculations.

<u>Generation of flammable gases:</u>
The HI-STAR 180L Package uses non-reactive materials of construction. Generation of flammable gases is not credible.

<u>Fuel Rod Failures:</u>
In accordance with NUREG 1617 [3.1.3], 3% of the fuel rods are assumed to be breached.

<u>Quivers</u>
Loading scenarios involving Quivers (See Section 3.3.13) are evaluated under design maximum helium backfill as specified in Table 3.3.13.

During normal transport conditions, the gas temperature within the cavity rises to its maximum operating temperature as determined by the thermal evaluation described earlier. The gas pressure inside the cavity increases monotonically with rising temperature. The pressure rise is determined using the Ideal Gas Law.

The HI-STAR 180L Maximum Normal Operating Pressure (MNOP) is calculated for the §71.71(c)(1) heat condition (38ºC (100ºF) ambient, still air & insolation) and design maximum heat load. Based on a 30% release of the significant radioactive gases and 100% release of the rod fill gas from postulated cladding breaches (3%) the cask cavity space MNOP is computed and reported in Subsection 3.1.4. The HI-STAR 180L cavity pressures presented in Table 3.1.2 show that the MNOP is well below the design pressure of the containment boundary (Table 2.1.1).

The evaluation of pressures and temperatures reached during transport provides reasonable assurance of safe transport of spent nuclear fuel packaged in a HI-STAR 180L Package. This conclusion is based on the technical data and analyses presented in this chapter in conjunction with provisions of 10 CFR Part 71, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

3.3.9 Time-to-Boil Limits

In accordance with NUREG-1536 [3.1.2], water inside the HI-STAR 180L cavity is not permitted to boil during fuel loading operations. In this manner operational concerns due to vapor formation and two-phase conditions are avoided. To meet this requirement time limits are defined herein for completion of wet operations upon removal of a loaded HI-STAR 180L cask from the pool.

When the HI-STAR 180L cask is removed from the pool, the combined water, fuel and cask metal mass absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the cask with time, starting from an initial temperature of the contents. The rate of temperature rise is limited by the thermal inertia of the HI-STAR 180L. To obtain a bounding heat-up rate determination, the 3-D Fluent methodology articulated in this section may be deployed or alternatively a conservative adiabatic heat up calculation defined below may be adopted.

(a) Adiabatic Heatup Method

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Example values of t_{max} under design maximum heat load are tabulated in Table 3.3.6 at several representative $T_{initial}$ temperatures.

(b) CFD Method

To obtain a bounding heat-up rate determination, the 3-D FLUENT thermal model articulated in this section may be deployed with following modifications:

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The bulk water temperature inside the cask must remain below the boiling temperature i.e. 100^{o}C.

3.3.9.1 Additional Measures During Extended Duration Operations

In the unlikely event that the maximum allowable time provided in Table 3.3.6 is found to be insufficient to complete wet transfer operations, forced water circulation may be provided to remove the decay heat from the cask cavity. During forced circulation relatively cooler water enters the inner closure lid drain port connection and heated water exits from the vent port. The minimum water flow rate required to maintain the water temperature below boiling is determined as follows:

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.3.10 Fuel Temperatures During Moisture Removal Operations

The initial loading of SNF in the HI-STAR 180L requires that the water within the cask cavity be drained and replaced with helium. Since the design heat loads are high, this operation may be carried out using the cyclic vacuum drying approach as described in Section 3.3.10.1 limiting the fuel temperature excursions to ISG-11 criteria of 65ºC under cyclic drying or by a forced flow helium drying process as described in Subsection 3.3.10.2. During vacuum drying removal residual moisture from the HI-STAR 180L is accomplished by evacuating the cavity after draining the cask. Based on the cask heat load, the time duration for vacuum drying cycles will vary for cask containing one or more high burnup fuel assemblies.

3.3.10.1 Vacuum Drying

Prior to the start of the HI-STAR 180L draining operation, the cask cavity is flooded with water. The presence of water in the cask cavity ensures that the fuel cladding temperatures are lower than design basis limits by large margins. As the heat generating active fuel length is uncovered during the draining operation, the fuel and basket mass undergo a gradual heat up from the initially cold conditions when the heated surfaces were submerged under water. Following the draining operation the HI-STAR 180L cavity is lined up to vacuum pump and the cavity pressure substantially lowered to facilitate fuel drying. Fuel temperatures under long vacuum drying durations and Design Basis heat loads exceed ISG-11, Revision 3 limits. Under this scenario, cycles of vacuum drying resulting in heatup followed with cooling by helium are performed until drying criteria specified in Chapter 7 is met. As the permissible time for heatup/cooldown cycles is a function of cask heat loads a suitable methodology is prescribed below to compute heat load specific cyclic drying durations.

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[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.3.10.2 Forced Helium Dehydration

Demoisturization of the HI-STAR 180L cask loaded with high burnup fuel is conducted by the Forced Helium Dehydration (FHD) system.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

As a result, the peak fuel cladding temperatures will approximate the values reached during normal transport as described elsewhere in this chapter.

3.3.11 Fuel Reconfiguration

In accordance with defense-in-depth approach to safe transport of high burnup fuel defined in Table 1.2.4 a hypothetical fuel reconfiguration scenario is postulated and evaluated herein. As defense-in-depth, thermal analysis is performed [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390] to evaluate its impact on the containment boundary and its components.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The temperature results of such a steady state analysis for a defense-in-depth hypothetical scenario are reported in Table 3.3.7. The results show that all component temperatures are below their respective temperature limits. The cavity temperature and co-incident cavity pressure during normal conditions of transport remains unaffected. The containment boundary integrity is reasonably assured under postulated fuel reconfiguration.

3.3.12 Maximum Thermal Stresses

The HI-STAR 180L Package is designed to ensure a low state of thermal stress in the structural members. This is ensured by using high conductivity materials (Metamic-HT and low alloy steels) to minimize temperature gradients and liberal fit-up gaps to allow unrestrained thermal expansion of the package internals (fuel basket) under normal transport. Differential thermal expansion of the fuel basket under normal transport temperatures evaluated in Table 3.3.12 supports the design requirement to ensure low thermal stresses in the HI-STAR180L Package.

3.3.13 Quiver Evaluation

Quiver is defined in Chapter 1 as precision engineered box to store slightly or severely damaged fuel rods in a helium backfilled environment to preclude risk of in-service corrosion. Prior to loading in Quivers fuel rods are punctured and depressurized. The principal parameters germane to thermal evaluation of transporting Quivers in HI-STAR 180L package, viz. helium backfill, cladding temperature limit, design heat load and design pressure are defined in Table 3.3.13. Quiver loading in HI-STAR 180L is permitted in peripheral basket locations as defined in Figure 7.D.1 wherein relatively cooler temperatures prevail. Quivers loaded in HI-STAR 180L under design heat loads are analyzed using the methodology articulated herein and results tabulated in Table 3.3.11. The results support the following conclusions:

- Peak Cladding temperature and containment boundary pressure bounded by licensing basis evaluations (See Tables 3.1.1 and 3.1.2)
- Quivers stored fuel rods meet Table 3.3.13 temperature limits with robust margins
- Quiver pressure meets Table 3.3.13 limits with substantial margins

Leak tightness of quivers as required by Table 7.1.5 operational requirements is reasonably assured for the following reasons:

1. Maximum computed temperatures and pressure remain within quiver design limits (Table 3.3.13).
2. As concluded in Chapter 2, the structural integrity of the quivers is unaffected under all normal and accident conditions evaluated therein.

3.3.14 Dummy Fuel Evaluation

As described in Chapter 1 under certain loading scenarios dummy fuel is required in empty cell locations. Dummy fuel assemblies do not affect package temperatures as these do not add to the thermal payload of the HI-STAR 180L cask.

3.3.15 Evaluation of Gadolinium Fuel Rods[1]

BWR fuel is typically equipped with gadolinium rods defined as fuel rods having specific amounts of Gd_2O_3 mixed with the UO_2. BWR fuel contains upto 12 or 14 gadolinium rods containing 5 to 8wt. % Gd_2O_3. The principal effect of gadolinium is reduced conductivity of fuel pellets with a concomitant temperature increment θ of the gadolinium fuel rods.

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[1] Gadolinium rods data supported by Section 6.3.10.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The calculations adopt Design basis BWR 10x10 fuel and design maximum decay heat for Gadolinium rods evaluation. Fuel data required to compute θ is tabulated in Table 3.3.14.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.1: BWR Fuel Effective Conductivities

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.2: 10CFR71 Insolation Data

Surface Type	12-Hour Insolation	
	(g-cal/cm^2)	(W/m^2)
Horizontally Transported Flat Surfaces		
- Base	None	None
- Other Surfaces	800	774.0
Non-Horizontal Flat Surfaces	200	193.5
Curved Surfaces	400	387.0

Table 3.3.3: History of FLUENT for Securing Transport and Storage Cask Certifications[1]

USNRC Docket Number	Project
72-1008	HI-STAR 100 Storage
71-9261	HI-STAR 100/100HB/100 Version HB GTCC Transport
72-1014	HI-STORM Storage
72-22	Private Fuel Storage Facility
72-27	Humboldt Bay ISFSI
72-26	Diablo Canyon ISFSI
72-17	Trojan ISFSI
71-9325	HI-STAR 180 Transport
71-9336	HI-STAR 60 Transport
72-1032	HI-STORM FW Storage
71-9367	HI-STAR 180D Transport
71-9373	HI-STAR 190 Transport

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[1] Pending applications under USNRC review listed in Table 1.0.1.

Table 3.3.4: Fuel Loading Scenario Screening Evaluations

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.5: Mesh Sensitivity Studies

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.6: Maximum Allowable Time for Completion of Wet Transfer Operations

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.7: HI-STAR 180L Maximum Temperatures and Cavity Pressures Under Fuel Reconfiguration

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.8: Bounding Personnel Barrier Characteristics

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.9: Personnel Barrier Thermal Evaluation

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.10: Vacuum Drying Test Criteria

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.11: HI-STAR 180L Transport Analysis Results Under Quivers Loaded Scenario

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.12: Thermal Expansion of the Fuel and Fuel Basket during Normal Transport

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.13: Quiver Thermal Requirements

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.14: BWR 10x10 Fuel Data Supporting Gadolinium Fuel Temperature Evaluation

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.15: Permissible Time Limits for Multiple Vacuum Drying Cycles Note-1,2,3

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

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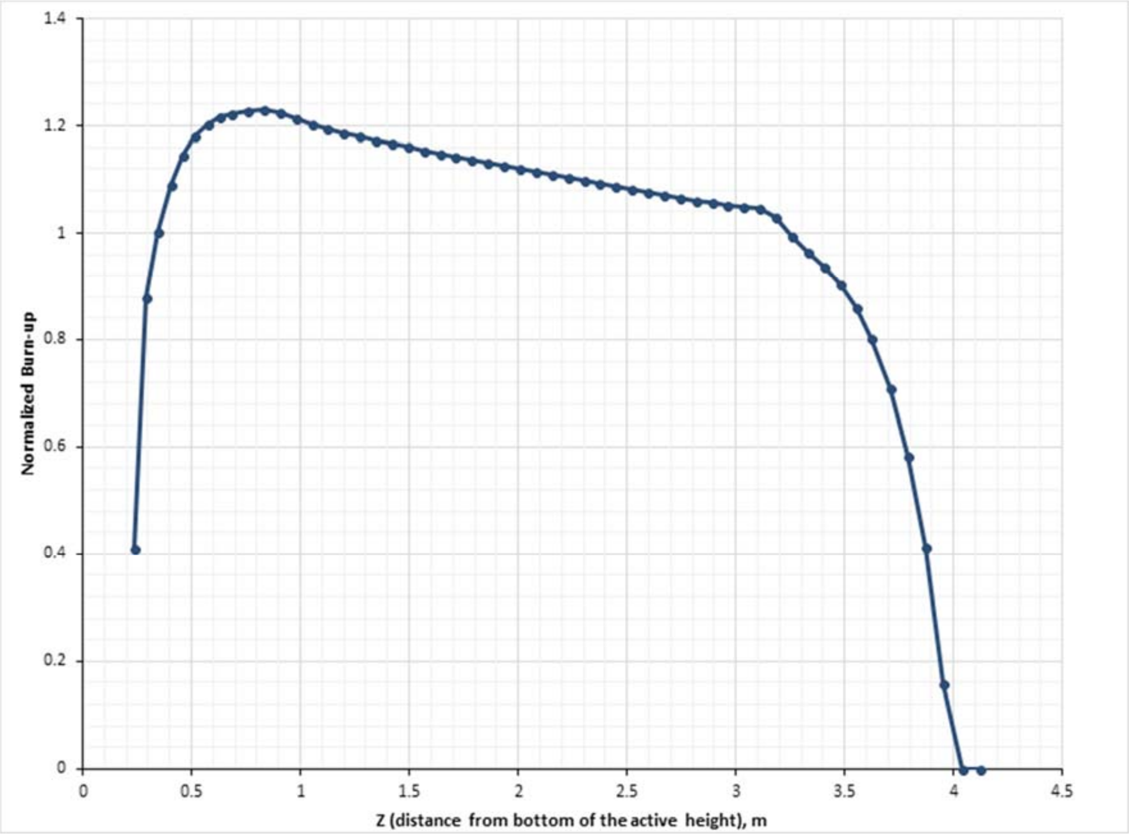

FIGURE 3.3.6: NORMALIZED AXIAL BURNUP PROFILE ADOPTED IN THE THERMAL DESIGN

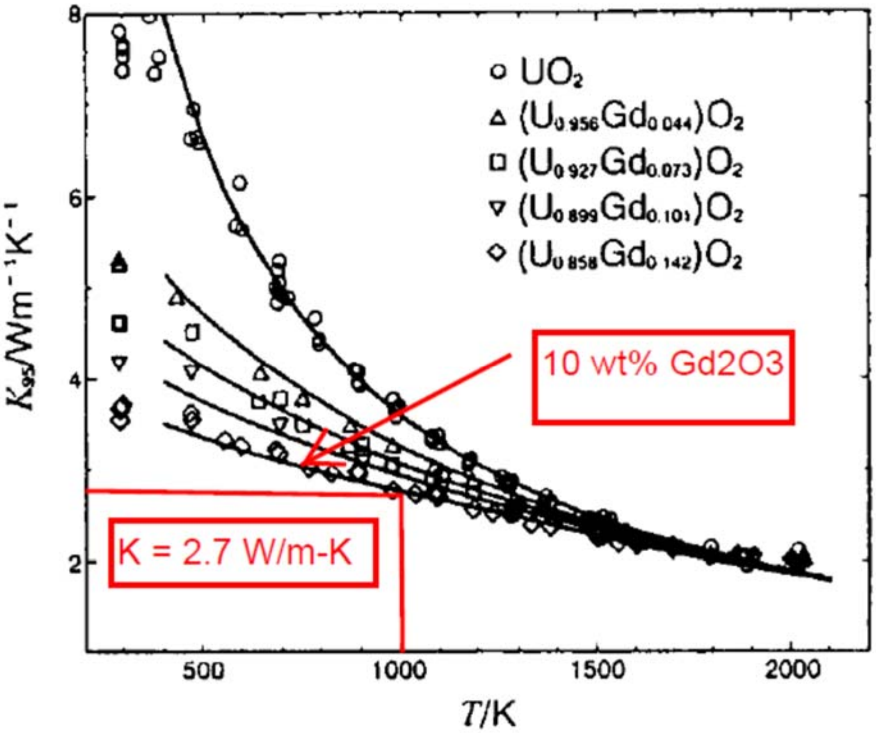

FIGURE 3.3.7: GADOLINIUM RODS FUEL CONDUCTIVITY [3.3.6]

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT

As mandated by 10 CFR Part 71 requirements, the HI-STAR 180L Package under the limiting F-69L fuel basket thermal loading is evaluated under a sequence of hypothetical accidents. The objective is to determine and assess the cumulative damage sustained by the package. The accident scenarios specified in order are: (1) a 9 m (30 foot) free drop onto an unyielding surface; (2) a 1 m (40-inch) drop onto a mild steel bar; (3) exposure to a 30-minute fire at 802ºC (1475°F) and (4) immersion under a 0.9 m (3 ft) head of water. The initial conditions for the fire accident specify steady state at an ambient temperature between -40ºC (-40°F) and 38ºC (100°F). In the HI-STAR 180L Package hypothetical fire accident evaluation, insolation with a theoretical bounding absorbtivity equal to unity is applied. The effects of the accidents (1), (2) and (4) are evaluated in Chapter 2. In this section, the effects of accident (3) are evaluated. The initial condition prior to fire accident is the hot ambient environment for normal transport and design heat load for F-69L basket (See Section 3.3). The fire accident evaluation is performed assuming an adverse combination of factors that overestimate heat input during fire followed by an underestimation of heat rejection to the environment after the fire.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

During fire a 10 CFR Part 71 mandated cask surface absorbtivity is assumed to maximize radiant heat input to the cask. During fire the resin bonding the impact limiter’s corrugated aluminum honeycomb layers is destroyed thus severely degrading the normal-to-layers direction conductivity. In the interest of conservatism the undegraded honeycomb conductivity is assumed during fire to maximize heat input and an opposite assumption is used to minimize post-fire heat dissipation by applying air conductivity for the normal-to-layers direction (see Table 3.4.1).

The temperature history of the HI-STAR Package is monitored during the 30-minute fire and during post-fire cooldown for a sufficient length of time for the cask and fuel to reach maximum temperatures. The impact of transient temperature excursions on HI-STAR 180L Package materials is evaluated.

3.4.1 Initial Conditions

In accordance with transport regulations the HI-STAR 180L Package fire accident is evaluated under hot ambient initial conditions (§10CFR71.71(c)(1) and §10CFR71.73(b)). These conditions are 38°C (100°F) ambient temperature, still air and insolation. The HI-STAR 180L bounding steady state temperature distribution under hot ambient conditions reported in Section 3.1.3 is adopted as the initial condition for fire accident evaluation.

3.4.2 Fire Conditions

As required by transport regulations the HI-STAR 180L Package is evaluated under an all-engulfing fire at 802°C (1475°F) lasting for 30 minutes (§10CFR71.73(c)(4)). The regulations specify a minimum fire emissivity (0.9) and lowerbound package absorbtivity (0.8) for hypothetical accident evaluation. In the HI-STAR 180L fire accident evaluation, the minimum specified emissivity and conservatively postulated absorbtivity are adopted.

Heat input to the HI-STAR 180L Package while engulfed in a fire is from a combination of radiation and forced convection heat transfer. This can be expressed by the following equation:

$$q_F = h_{fc}\,(T_F - T_s) + \sigma\alpha\,\varepsilon\,[T_F^4 - T_s^4]$$

where:

q_F = fire heat input, W/m^2 (Btu/ft^2-hr)
T_F = fire condition temperature 1075°K (1935°R)
T_S = package surface temperature °K (°R)
h_{fc} = forced convection heat transfer coefficient W/m^2-°K [Btu/ft^2-hr-°F] (See Table 3.4.3)
ε = flame emissivity (0.9 (min.) in accordance with transport regulations)
a = package absorbtivity (0.8 (min.) in accordance with transport regulations)
σ = Stefan-Boltzmann Constant $5.67\text{x}10^{-8}$ W/m^2-°K^4 (0.1714×10^{-8} Btu/ft^2-hr-°R^4)

For conservatism, the reported Sandia large pool fires forced convection heat transfer coefficient (See Table 3.4.2) is adopted. In Table 3.4.1 the principal fire accident assumptions are summarized.

The HI-STAR 180L package fire accident analysis is based on a 3D thermal model that properly accounts for radiation, conduction and external natural convection modes of heat transfer. The thermal model incorporates several conservative assumptions listed below.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

1. To maximize initial temperatures, the limiting decay heat pattern defined in Section 3.3 and bounding (steady state) temperatures are assumed.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

2. To maximize fire heating of the cask, an all-engulfing fire, a high flame emissivity (e = 0.9) and a theoretically bounding package absorbtivity are assumed.

   [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3. The Sandia laboratories reported forced convection heat transfer during large pool fires (See Table 3.4.2) is adopted.

   [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The fire accident thermal analysis is performed for the HI-STAR 180L Package with F-69L basket under bounding heat load pattern evaluated in Section 3.3. Using the model of HI-STAR 180L with F-69L basket, the transient heat up of the cask and it's internals during the 30-minute fire is computed. At the end of the fire the hot ambient condition is restored and a post fire cooldown of the cask for a duration sufficient to reach maximum package temperatures computed. The results of the analysis are evaluated in the next section.

3.4.3 Maximum Temperatures and Pressures

3.4.3.1 Maximum Temperatures

The HI-STAR 180L Package is evaluated under a hypothetical fire accident at 802°C (1475°F) lasting for 30 minutes. To ensure a bounding evaluation, the limiting decay heat scenario (See Subsection 3.3.5) and hot initial conditions are assumed. Under this array of adverse conditions, the maximum temperatures reached in the cask structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3, applying the fire accident thermal loads and computing the time-dependent response of the package to the 30-minute fire followed by a post fire cooldown for a sufficient duration to allow the cask and its contents to reach their maximum temperatures. The results of the critical components (cladding, basket, seals and containment shell) are reported in Subsection 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature (Table 3.1.3) is well within the ISG-11, Rev. 3 accident temperature limit (Table 3.2.11).

- The maximum temperature of fuel basket (Table 3.1.3) is well within its accident design temperature (Table 3.2.10).

- The maximum temperatures of the containment boundary and lid seals (Table 3.1.3) are well below the ASME Code limits (Tables 3.2.10 and 3.2.12, respectively).

- The maximum temperatures of the basket shims (Table 3.1.3) are well below the accident temperature limits (Table 3.2.10).

The HI-STAR 180L Package fire accident temperatures are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The thermal evaluation provides reasonable assurance of safety in the event of a fire. This conclusion is based on the technical data and analyses presented in this chapter in conjunction with provisions of 10 CFR Part 71, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

3.4.3.2 Maximum Pressures

The HI-STAR 180L containment pressure is computed based on the maximum temperatures of the cask contents (fuel basket and fuel) reached during the fire accident. The calculations use an array of conservative assumptions listed below:

i) Maximum initial fill pressure (See Table 7.1.4)
ii) 100% rods rupture
iii) 100% release of rods fills gas and 30% release of fission gases
iv) Lowerbound cavity free volume

The maximum containment pressures are tabulated in Subsection 3.1.4. The results show that the pressures are well below the containment boundary design pressure (Table 2.1.1).

3.4.4 Maximum Thermal Stresses

The HI-STAR 180L Package is designed to ensure a low state of thermal stress in the structural members. This is ensured by using high conductivity materials (Metamic-HT and low alloy steels) to minimize temperature gradients and large fit-up gaps to allow unrestrained thermal expansion of the package internals (fuel basket). The differential thermal expansion of the fuel basket under normal transport are evaluated in Table 3.3.12. These gaps are bounding under fire because of the expansion of the cask body under direct fire heating. As thermal interference is precluded during fire a low state of thermal stress prevails in the cask.

3.4.5 Fuel Reconfiguration Post Hypothetical Accident Drops

In accordance with defense-in-depth approach to safe transport of high burnup fuel defined in Table 1.2.4 a hypothetical fuel reconfiguration scenario is postulated and evaluated herein. As defense-in-depth, thermal analysis is performed assuming punitive 100% fuel rods failure to evaluate its impact on the containment boundary and its components. The details of the analysis are summarized below:

- [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]
- Steady state thermal analysis is performed for the bounding fuel loading pattern evaluated in Table 3.3.4.
- [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The above methodology is same as articulated in the HI-STAR 190 transport SAR [1.0.6]. Temperatures under the above hypothetical scenario are reported in Table 3.4.3. The results show that all component temperatures remain below accident limits. The overpack cavity bulk temperature and co-incident cavity pressures remain unaffected. The evaluation above reasonably supports containment boundary integrity under postulated 100% fuel reconfiguration.

Table 3.4.1: Hypothetical Fire Accident Assumptions

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.4.2: Sandia Pool Fire Test Data[1]

Test equipment	3 m (10 ft) OD propane railcar
Fuel	JP-4
Pool Size	9 m x 9 m (30 ft x 30 ft)
Fire Temperature	649^{o}C to 1093^{o}C (843^{o}C avg.) 1200^{o}F to 2000^{o}F (1550^{o}F avg.)
Convective Coefficient	25.5 W/m^2-^{o}K (4.5 Btu/ft^2-hr-^{o}F)

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[1] From Sandia large pool fires report [3.4.1], Page 41.

Table 3.4.3: HI-STAR 180L Hypothetical Accident Maximum Temperatures Under Fuel Reconfiguration

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

CHAPTER 3 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

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[3.1.2] NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” USNRC, (January 1997).

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[3.2.7] ASME Boiler and Pressure Vessel Code, Section II, Part D, 2015 Edition.,

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[3.2.11] “Fundamentals of Heat and Mass Transfer”, 4th Edition, F.P. Incropera and D.P. DeWitt, John Wiley & Sons, Inc., New York, 1996.

[3.2.12] Aluminum Alloy 2219 Material Data Sheet, ASM Aerospace Specification Metals, Inc., Pompano Beach, FL.

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[3.2.14] “Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year-Old PWR Spent Fuel”, ORNL/CSD/TM-149 TTC-0316, (1983).

[3.3.1] “Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer”, ASME V&V 20-2009.

[3.3.2] ANSYS FLUENT Computational Fluid Dynamics Software (ANSYS Inc., 2600 ANSYS Drive, Canonsburg, PA 15317).

[3.3.3] “Effective Thermal Properties of BWR Fuel in HI-STAR 180L Cask”, Holtec Report HI-2177894, Latest Revision (Holtec Proprietary).*

[3.3.4] “Topical Report on the HI-STAR/HI-STORM Thermal Model and its Benchmarking with Full-Size Cask Test Data,” Holtec Report HI-992252, Rev. 1, Holtec International, Marlton, NJ, 08053. (Holtec Proprietary).

[3.3.5] “Heat Transfer”, J.P. Holman, 4th Edition, pp. 34, McGraw-Hill Book Company.

[3.3.6] “Thermal Diffusivities and Thermal Conductivities of UO_2-Gd_2O_3”, M. Hirai and S. Ishimoto, Journal of Nuclear Science and Technology, 28(11), pp. 995-1000, November 1991.

[3.3.7] “Thermal Evaluation of HI-STAR 180L in Transport”, Holtec Report HI-2177931, Latest Revision (Holtec Proprietary).*

[3.4.1] “Thermal Measurements in a Series of Large Pool Fires”, Sandia Report SAND85 – 0196 TTC – 0659 UC 71, (August 1971).

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CHAPTER 4: CONTAINMENT

4.0 INTRODUCTION

This chapter demonstrates the HI-STAR 180L cask containment system compliance with the permitted activity release limits specified in 10CFR71 for both normal and hypothetical accident conditions of transport [4.0.1]. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the loaded HI-STAR 180L cask will not exceed the allowable radionuclide release rates.

The containment system for the HI-STAR 180L cask consists of the components, seals and welds identified in the drawing package in Section 1.3 and also in Figures 4.1.1, 4.1.2, and 4.1.3. Both the inner and outer closure lids are containment system components whose closure joints must be tested prior to shipment.

Chapter 2 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and [**Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Chapter 3 of this SAR shows that the peak containment system component temperatures and pressures are within the design basis limits for all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Since both the containment system is shown to remain intact and the temperature and pressure design bases are not exceeded, the design basis leakage rates are not exceeded during normal or hypothetical accident conditions of transport.

The HI-STAR 180L cask is subjected to a fabrication leakage rate test before the first loading. The fabrication leakage rate test is performed at the factory in accordance with ANSI N14.5 [8.1.6] as part of the HI-STAR 180L cask acceptance testing. The HI-STAR 180L cask is also subjected to a pre-shipment leakage rate test after each cask loading and closure. The pre-shipment leakage rate test is performed in accordance with ANSI N14.5 [8.1.6] by the user as final acceptance testing of the HI-STAR 180L cask containment system. The **[Withheld in Accordance with 10 CFR 2.390]** seals of the HI-STAR 180L cask are to be replaced and retested for each cask loading and closure.

Additional requirements and clarification are provided in Section 4.4 and Chapter 8.

4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

The containment system for the HI-STAR 180L cask consists of the containment shell, the containment base plate, the containment closure flange, the inner closure lid, the outer closure lid, inner and outer closure lid bolts, the inner closure lid port covers, the outer closure lid access port plug, and their respective **[Withheld in Accordance with 10 CFR 2.390]** seals and welds as specified in the drawing package in Section 1.3. The containment boundary and containment system components are shown in Figure 4.1.1 with additional detail on the inner and outer closure lids provided in Figures 4.1.2 and 4.1.3, respectively.

The containment system components for the HI-STAR 180L system are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NB [4.1.1], to the maximum extent practicable as clarified in Chapter 2 of this SAR. Chapter 1 specifies design criteria for the containment system. Section 2.1 provides the applicable code requirements. Exceptions to specific code requirements with complete justifications are presented in Table 8.1.8.

4.1.1 Containment Vessel

The cask containment vessel consists of components which form the inner containment space and expanded containment inter-lid space. The inner containment space is used to house the internal basket designs which hold spent nuclear fuel. The containment vessel is represented by the containment shell, containment base plate, containment closure flange, and inner and outer closure lids. These are the main containment system components that create an enclosed cylindrical cavity for the containment of the enclosed radiological contents. The materials of construction for the containment vessel are specified in the drawing package in Section 1.3. No valve or pressure relief device is specified on the HI-STAR 180L containment system.

4.1.2 Containment Penetrations

The cask containment system penetrations include the inner closure lid vent and drain ports, and the outer closure lid access port. Each penetration has redundant **[Withheld in Accordance with 10 CFR 2.390]** seals. The containment penetrations are designed and tested to ensure that the radionuclide release rates specified in 10CFR71.51 will not be exceeded.

4.1.3 Seals and Welds

The cask uses a combination of seals and welds designed and tested to provide containment during normal transport conditions, and during and after hypothetical accident conditions of transport. Seals and welds are individually discussed below.

The seals and welds provide for a containment system which is securely closed and, cannot be opened unintentionally or by an internal pressure within the package as required in 10CFR71.43(c).

4.1.3.1 Containment Seals

The containment system seals are designed and fabricated to meet the design requirements of the HI-STAR 180L cask specified in subparagraph 2.2.1.1.6 and in accordance with the manufacturer's recommendations. Chapter 7 describes the operating procedures required for proper seal function. Seal and closure details are provided in the drawing package in Section 1.3 and Appendix 8.A.

4.1.3.1.1 Inner Closure Lid

[Withheld in Accordance with 10 CFR 2.390]

4.1.3.1.2 Outer Closure Lid

[Withheld in Accordance with 10 CFR 2.390]

4.1.3.2 Containment Welds

The cask containment system welds consists of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment closure flange, and the full penetration weld connecting the containment base plate to the containment shell. All containment system boundary welds are fabricated and inspected in accordance with ASME Code Section III, Subsection NB. The weld details and examinations are shown in the drawing package in Section 1.3.

4.1.4 Closure Lids

[Withheld in Accordance with 10 CFR 2.390]

Bolt torquing patterns, lubrication requirements, and torque values are provided in Table 7.1.1. The torque values are established to maintain leaktight containment during normal and accident conditions of transport. Torque values for the inner and outer closure lid bolts preclude separation of the closure lids from the containment closure flange as clarified in Chapter 2. The closure lid bolts cannot be opened unintentionally or by a pressure that may arise within the package.

4.1.5 Moderator Exclusion Features for High Burnup Fuel

The HI-STAR 180L packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF). To address concerns with the structural integrity of HBF under accident conditions, and its potential impact on criticality safety, the design of HI-STAR 180L provides utmost assurance of water exclusion under a postulated 10CFR 71.73 accident scenario. The approach for HI-STAR 180L is based on moderator exclusion by package design (double closure lid and containment boundary integrity analysis). Details of the design measures and technical confirmation to meet the intent and performance objectives of ISG-19 are described in Appendix 1.A, where additional defense-in-depth measures to ensure sub-criticality compliance are also discussed. The overall licensing approach on HBF is summarized in Section 1.2.

Figure 4.1.1: **[Withheld in Accordance with 10 CFR 2.390]**

Figure 4.1.2: **[Withheld in Accordance with 10 CFR 2.390]**

Figure 4.1.3: **[Withheld in Accordance with 10 CFR 2.390]**

4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

Section 2.6 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and the **[Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all normal conditions of transport as defined in 10CFR71.71 [4.0.1]. Section 3.1 of this SAR shows that all containment system components are maintained within their peak temperature and pressure limits for all normal conditions of transport as defined in 10CFR71.71. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (see Table 8.1.1) will not be exceeded during normal conditions of transport.

4.2.1 Containment Criteria

The leaktight criteria as defined by ANSI N14.5 [8.1.6] shall be used for all containment system leakage tests. Compliance with the leaktight criteria of ANSI N14.5 precludes any significant release of radioactive materials and ensures that the radionuclide release rates specified in 10CFR71.51(a)(1) will not be exceeded during normal conditions of transport. Therefore, no containment analyses are performed for normal conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Table 8.1.1 and Table 8.1.2.

4.2.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5 (also see Table 8.1.1).

4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Section 2.7 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and the **[Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all hypothetical accident conditions of transport as defined in 10CFR71.73 [4.0.1]. Section 3.1 of this SAR shows that all containment system components are maintained within their peak temperature and pressure limits for all hypothetical accident conditions of transport as defined in 10CFR71.73. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (see Table 8.1.1) will not be exceeded during hypothetical accident conditions of transport.

4.3.1 Containment Criteria

The leaktight criteria as defined by ANSI N14.5 [8.1.6] shall be used for all containment system leakage tests. Compliance with the leaktight criteria of ANSI N14.5 precludes any significant release of radioactive materials and ensures that the radionuclide release rates specified in 10CFR71.51(a)(2) will not be exceeded during hypothetical accident conditions of transport. Therefore, no containment analyses are performed for hypothetical accident conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Table 8.1.1 and Table 8.1.2.

4.3.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5 (also see Table 8.1.1).

4.4 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

All leakage rate testing of the cask containment system shall be performed in accordance with the guidance in ANSI N14.5 [8.1.6]. Table 8.1.2 provides the containment system components to be tested and the type of leakage test to be performed for post-fabrication, pre-shipment, periodic, and maintenance qualification.

4.4.1 Fabrication Leakage Rate Test

The fabrication leakage rate test demonstrates that the containment system, as fabricated, provides the required level of containment. The fabrication leakage test for the HI-STAR 180L package is performed at the fabrication facility to ensure that the welded enclosure vessel will maintain its containment function.

Additionally, after fabrication of all components, the inner and outer closure lids are installed and the **[Withheld in Accordance with 10 CFR 2.390]** are tested to ensure that the fit-up of the inner and outer closure lids with the containment flange will meet the leakage rate acceptance criteria after fuel loading.

4.4.2 Pre-Shipment Leakage Rate Test

The pre-shipment leakage rate test demonstrates that the containment system closure has been properly performed. The initial pre-shipment leakage rate test is performed by the user before shipment, after the contents are loaded and the containment system is assembled. The pre-shipment leakage rate test remains valid for 1 year.

4.4.3 Periodic Leakage Rate Test

The periodic leakage rate test demonstrates that the containment system closure capabilities have not deteriorated over an extended period of use. A periodic leakage rate test is only required if the most current leakage rate test occurred more than twelve months prior to package transport. Periodic leakage rate testing is performed by the user before each shipment if the previous leakage rate test has expired. The periodic leakage rate test remains valid for 1 year.

4.4.4 Maintenance Leakage Rate Test

The maintenance leakage rate test demonstrates that the containment system provides the required level of containment after undergoing maintenance, repair and or containment component replacement; and shall be performed prior to returning a package to service.

CHAPTER 4 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table.

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CHAPTER 5: SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR 180L Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter. The HI-STAR 180L is designed to accommodate F-69L fuel basket.

In order to offer the user flexibility in fuel loading, the HI-STAR 180L offers several different loading patterns, where different positions in the basket are qualified for different burnup/cooling time/enrichment combinations. The bounding loading patterns used for shielding evaluations are obtained from fuel loading configurations described in Appendix 7.D. The loading patterns have been analyzed and found to be acceptable compared to the regulatory limits.

The transport index in 10CFR71 is defined as the number determined by multiplying the radiation level in milliSievert per hour (mSv/h) at one meter from the external surface of the package by 100. Since the HI-STAR 180L has been designed to meet a dose rate limit of 0.1 mSv/h at 2 meters from the surface of the vehicle, the dose rate at 1 meter from the package could be greater than 0.1 mSv/h and the transport index could exceed 10. Therefore, the HI-STAR 180L loaded with design basis fuel must be shipped by exclusive use shipment as discussed in Section 1.1.

The shielding analyses were performed with MCNP-5 1.51 [5.0.1] developed by Los Alamos National Laboratory (LANL). The source terms for all fuel assemblies were calculated with the TRITON and ORIGAMI sequences from the SCALE 6.2.1 systems [5.0.2]. This is a recent version on the SCALE code, providing substantial improvements over earlier versions such as SCALE 5.1 used in Holtec's approved Storage and Transportation FSARs and SAR under separate docket numbers [5.0.3]. Detailed descriptions of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter mirror those used in the SAR for HI-STAR 180 certified in Docket #71-9325 [5.0.4].

This chapter contains the following information:

- A description of the shielding features of the HI-STAR 180L.
- A description of the source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for the HI-STAR 180L.
- Analyses for the HI-STAR 180L's content and results to show that the 10CFR71.47 dose rate limits are met during normal conditions of transport and that the 10CFR71.51 dose rate limit is not exceeded following hypothetical accident conditions.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The principal design features of the HI-STAR 180L packaging with respect to radiation shielding consist of the fuel basket and basket support structures, the cask including the two lids, the cask body, and the central steel structures of the impact limiters. The main shielding is provided by the cask body. The cask body steel, the lids and base plate steel and lead provide the main gamma shielding, while the neutron shielding is provided by the Holtite neutron absorber embedded in those parts. In the radial direction, the neutron absorber is located in two overlapping rows of pockets near the outer surface of the cask. The fuel basket and the basket supports maintain the fuel assemblies in a fixed position within the package, and also provide additional gamma shielding. Any shielding effect of the crushable impact limiter material and its surrounding steel skin is neglected for both normal and accident conditions. The dimensions of the shielding components are shown in the drawing package in Section 1.3. The shielding material densities are listed in Table 5.3.2.

5.1.2 Summary of Maximum Radiation Levels

Configurations specified in Appendix 7.D were analyzed to determine shielding bounding patterns. Each pattern was independently analyzed and it was verified that the calculated dose rates were less than the regulatory limits. In this subsection, only the results for the bounding loading patterns that produce the highest dose rates at the surface and at 2 m under normal conditions, and at 1 m under accident conditions are presented. Dose rates for additional configurations are presented in Section 5.4.

The dose rates listed in the tables in this subsection are maximum values, considering axial, radial and azimuthal variations as applicable. This is achieved by specifying a reasonably fine grid of dose locations around the cask, and selecting the highest values. Details on dose locations are provided in Subsection 5.3.3.

Additionally, the dose rates reported in this subsection include the effect of all applicable uncertainties and other considerations, namely

[

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

]

[

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

]

5.1.3 Normal Conditions

As discussed in Section 1.1, HI-STAR 180L will be transported by exclusive use shipment and complies with 10CFR71.47(b).

Dose rates are calculated on the cask surface, at locations shown in Figure 5.1.1. Dose locations 1A and 3A are used to calculate the dose rates on the flange between the ends of the impact limiter's skirts and the cask radial neutron shield. Results are presented in Table 5.1.1.

All values are below 2 mSv/h, therefore showing that the HI-STAR 180L complies with 10CFR71.47(b)(1). It should be noted that the additional conditions stated in 10CFR71.47(b)(1)(i) through (iii) (closed vehicle; fixed position; no loading/unloading) do not have to be met by the HI-STAR 180L, since the surface dose rate do not exceed 2 mSv/h.

The calculated dose rates on the surface of the cask are below 2 mSv/h. Therefore, dose rates at any point on the outer surface of the vehicle will also be below 2 mSv/h. The HI-STAR 180L therefore complies with 10CFR71.47(b)(2).

The maximum dose rates for the HI-STAR 180L have been calculated at a distance of 2 m from impact limiter surfaces, for the locations shown in Figure 5.1.1. At 2 m, locations corresponding to 1A and 3A on the surface are included in locations 1 and 3. Results are presented in Tables 5.1.2, showing that all dose rates at that distance are below 0.1 mSv/h. Consequently, the dose rates at 2 m from the outer edges of the vehicle will also be below 0.1 mSv/h. The HI-STAR 180L package therefore complies with 10CFR71.47(b)(3).

Dose rates have been calculated to determine the distance necessary to comply with the 0.02 mSv/hr requirement specified in 10CFR71.47(b)(4) for any normally occupied space. The results presented in Table 5.1.3, identify the distances necessary from Dose Locations 4 and 5 (the top and bottom of the HI-STAR 180L, see Figure 5.1.1) for which exposed personnel of private carriers must maintain in order meet the 0.02 mSv/h requirement. Therefore, if the normally occupied space of the vehicle is at a distance less than the values specified in Table 5.1.3, radiation dosimetry is required for personnel to comply with 10CFR71.47(b)(4).

The analyses summarized in this section demonstrate HI-STAR 180L's compliance with the 10CFR71.47(b) limits.

5.1.4 Hypothetical Accident Conditions

The hypothetical accident conditions of transport presented in Section 2.7 have three bounding consequences that affect the shielding materials. These are the damage to the neutron shield as a result of the design basis fire, damage to the impact limiters as a result of the 9-meter (30 foot) drop, and lead slump as a result of the 9-meter (30 foot) drop. Conservatively, the shielding analysis of the hypothetical accident condition assumes the neutron shield is completely destroyed and replaced by a void. Further, the impact limiters are also not credited for the hypothetical accident conditions. Overall these are conservative assumptions since some portion of the neutron shield would be expected to remain after the fire, and the impact limiters were shown through the calculations in Chapter 2 to remain attached following impact.

To model the lead slump of the lead in the base plate (Bottom Gamma Shield) part of the lead is replaced with a void (see discussion in 5.3.1.1).

Throughout the hypothetical accident condition the axial location of the fuel will remain practically fixed within the baskets (see Subparagraph 5.3.1.2). Chapter 2 shows that the HI-STAR 180L package remains significantly unaltered throughout the hypothetical accident conditions. Localized damage of the cask outer surface could be experienced during the pin puncture, and small localized deformations of the basket might be possible during drop accidents. However, such localized deformations will have a negligible impact on the dose rate at 1 meter from the surface. The dose rate at 1 meter is determined assuming the neutron shielding is completely lost due to the fire accident event.

Figure 5.1.2 shows the dose locations at 1 meter from the surface for the conditions of the HI-STAR 180L Package after the postulated accident. Corresponding maximum dose rates are listed in Table 5.1.4. All values in these tables are below the regulatory limit of 10 mSv/h.

Analyses summarized in this section demonstrate the HI-STAR 180L Package's compliance with the 10CFR71.51 radiation dose limit.

Table 5.1.1

Maximum Dose Rates on the Surface of the HI-STAR 180L Package for Normal Conditions

Dose Point[†] Location	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
1					0.2326	2
1A					1.0800	2
2					0.5114	2
3					0.2231	2
3A					1.1778	2
4					0.1843	2
5					0.1605	2

[†] Refer to Figure 5.1.1.

Table 5.1.2

Maximum Dose Rates at 2 Meters from the HI-STAR 180L Package for Normal Conditions

Dose Point[†] Location	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
2					0.0969	0.1
4					0.0449	0.1
5					0.0477	0.1

[†] Refer to Figure 5.1.1.

Table 5.1.3

Distances for the 0.02 mSv/hr Dose Rate Requirement for the HI-STAR 180L Package for Normal Conditions

Dose Point[†] Location	Distance (meters)	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
4	4					0.0174	0.02
5	5					0.0170	0.02

[†] Refer to Figure 5.1.1.

Table 5.1.4

Maximum Dose Rates At 1 Meter from the HI-STAR 180L Package for Accident Conditions

Dose Point[†] Location	**[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**				**Totals with Uncertainties (mSv/hr)**	**10 CFR 71.51 Limit (mSv/hr)**
2					9.6112	10
4					0.9196	10
5					8.5003	10

[†] Refer to Figure 5.1.2.

FIGURE 5.1.1: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.1.2: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

5.2 SOURCE SPECIFICATION

The principal sources of radiation in the HI-STAR 180L are:

- Gamma radiation originating from the following sources (see Subsection 5.2.1)

    1. Decay of radioactive fission products
    2. Secondary photons from neutron capture in fissile and non-fissile nuclides
    3. Hardware activation products generated during core operations

- Neutron radiation originating from the following sources (see Subsection 5.2.2)

    1. Spontaneous fission
    2. α,n reactions in fuel materials
    3. Secondary neutrons produced by fission from subcritical multiplication
    4. γ,n reactions (this source is negligible)

The neutron and gamma source terms were calculated with the TRITON and ORIGAMI modules of SCALE 6.2.1 [5.0.2]. In performing the TRITON and ORIGAMI calculations, a single full power cycle was used to achieve the desired burnup. This assumption results in conservative source term calculations.

The assemblies to be qualified for transportation in the HI-STAR 180L contain BWR UO_2 assemblies. A description of the design basis fuel assemblies for the source term calculations is provided in Table 5.2.1. The steel and Inconel hardware masses for the design basis BWR assembly are listed in Table 5.2.2. Several other assembly types are included in the qualification. Based on a comparison of total fuel mass and/or fuel mass per unit length of the active region it was concluded that 8x8L2 fuel assembly bounds other assembly types.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix 7.D specifies the burnup, cooling time and enrichment configurations for spent nuclear fuel that were analyzed for transport in the HI-STAR 180L. While source terms for all combinations were calculated to determine shielding bounding patterns, it is not practical to present source terms for the large range of fuel parameters listed in Appendix 7.D. Therefore, in this subsection, source terms for a subset of all the burnup, cooling time and enrichment configurations listed in Appendix 7.D are presented.

The following Subsections 5.2.1 and 5.2.2 describe the calculation of the gamma and neutron source terms. Appendix 5.C discusses the uncertainties associated with the TRITON and ORIGAMI calculations related to reactor input parameters, decay heat generation, and source term calculations.

5.2.1 Gamma Source

Table 5.2.3 provides the gamma source in MeV/s and photons/s as calculated with TRITON and ORIGAMI for a subset of burnup and cooling time configurations from Appendix 7.D.

NUREG-1617 [5.2.1] states that "In general, only gammas from approximately 0.8 MeV-2.5 MeV will contribute significantly to the external radiation levels."

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ORIGAMI was used to calculate a ^{60}Co activity level for the desired burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.2] and is described here.

1. The activity of the ^{60}Co from ^{59}Co, steel and inconel is calculated using ORIGAMI. The flux used in the calculation was the in-core fuel region flux at full power.

2. The activity calculated in Step 1 for the region of interest was modified by the appropriate scaling factors listed in Table 5.2.4. These scaling factors were taken from Reference [5.2.2].

Table 5.2.5 provides the ^{60}Co activity utilized in the shielding calculations in the non-fuel regions of the assemblies for a subset of burnup and cooling time configurations from Appendix 7.D.

In addition to the two sources already mentioned, a third source arises from (n,γ) reactions in the material of the HI-STAR 180L cask. This source of photons is properly accounted for in MCNP when a neutron calculation is performed in a coupled neutron-gamma mode.

5.2.2 Neutron Source

It is well known that the neutron source strength for a UO_2 assembly increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel that increases the inventory of other transuranium nuclides such as Cm. . **[**

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Table 5.2.6 provide the neutron source in neutrons/s as calculated with TRITON and ORIGAMI for selected burnup and cooling time configurations utilized in the shielding calculations. **[**

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Table 5.2.1

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.2.2

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.2.3

Calculated Gamma Source Per Assembly for Selected Burnup and Cooling Times

Lower Energy	**Upper Energy**	30,000 MWd/mtU 3.5 Year Cooling 3.3 wt% ^{235}U	60,000 MWd/mtU 5 Year Cooling 4.5 wt% ^{235}U
(MeV)	(MeV)	(Photons/s)	(Photons/s)
0.45	0.7	1.00E+15	1.62E+15
0.7	1.0	2.88E+14	4.62E+14
1.0	1.5	4.70E+13	7.03E+13
1.5	2.0	2.81E+12	2.46E+12
2.0	2.5	2.88E+12	9.16E+11
2.5	3.0	1.59E+11	8.19E+10
Total		1.34E+15	2.15E+15

Table 5.2.4

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.2.5

Calculated ^{60}Co Source per Assembly for Selected Burnup and Cooling Times

Location	30,000 MWd/mtU 3.5 Year Cooling 3.3 wt% ^{235}U (Photons/s)	60,000 MWd/mtU 5 Year Cooling 4.5 wt% ^{235}U (Photons/s)
Bottom nozzle	1.99E+12	2.52E+12
Active fuel zone	7.33E+12	9.30E+12
Plenum	8.42E+11	1.07E+12
Top nozzle	5.76E+11	7.31E+11
Handle	6.64E+10	8.43E+10

Table 5.2.6

Calculated Neutron Source per Assembly for Selected Burnups and Cooling Times

Lower Energy (MeV)	**Upper Energy (MeV)**	30,000 MWd/mtU 3.5 Year Cooling 3.3 wt% ^{235}U (Neutrons/s)	60,000 MWd/mtU 5 Year Cooling 4.5 wt% ^{235}U (Neutrons/s)
1.0E-01	4.0E-01	2.84E+06	2.44E+07
4.0E-01	9.0E-01	6.20E+06	5.31E+07
9.0E-01	1.4	6.19E+06	5.30E+07
1.4	1.85	4.95E+06	4.23E+07
1.85	3.0	9.23E+06	7.84E+07
3.0	6.43	8.37E+06	7.16E+07
6.43	20.0	7.98E+05	6.91E+06
Totals		3.86E+07	3.30E+08

5.3 SHIELDING MODEL

The shielding analysis of the HI-STAR 180L was performed with MCNP 5 1.51 [5.0.1]. MCNP is a Monte Carlo transport code that offers a full three-dimensional combinatorial geometry modeling capability including such complex surfaces as cones and tori. This means that no gross approximations were required to represent the HI-STAR 180L in the shielding analysis. MCNP-5 is essentially the same code that is used for the shielding calculations of Holtec's other approved dry storage and transportation systems under separate dockets.

The MCNP model of the HI-STAR 180L Package for normal conditions has the neutron shield and parts of the impact limiters in place. The MCNP model for the hypothetical accident condition replaces the neutron shield with void and removes the impact limiters. Credit was taken for the outer dimensions of the impact limiters under normal conditions, i.e. the axial 2 m dose locations are based on the distance from the skin around the crush material.

The fuel loading patterns and the placement of the neutron absorber in the cask wall potentially results in azimuthal variations in the dose rates. Additionally, the axial burnup profiles of the fuel assemblies result in axial dose rate variations. To ensure that the maximum dose rate is identified, a sufficiently fine grid of dose locations is used, and the highest combined dose is calculated for each pattern in the areas identified in Figures 5.1.1 and 5.1.2.

5.3.1 Configuration of Shielding and Source

5.3.1.1 Shielding Configuration

Section 1.3 provides the drawings that describe the HI-STAR 180L Packaging. These drawings were used to create the MCNP models used in the radiation transport calculations. The drawing package also illustrates the HI-STAR 180L on a typical transport vehicle with a personnel barrier installed. The vehicle and barrier were not considered in the MCNP model, i.e. the outer dimensions of the vehicle are conservatively assumed to be identical to the outer dimensions of the package as modeled for normal conditions. Figure 5.3.1 shows the cross sectional views of the HI-STAR 180L cask loaded with F-69L fuel basket, as they were modeled in MCNP. The figure was created with the MCNP plotter and is drawn to scale. The figure illustrates the annular monolithic cylinders that are utilized to house the radial Holtite. Figure 5.3.2 shows the MCNP model of the F-69L fuel basket cell. Figure 5.3.3 shows a cross sectional view of the HI-STAR 180L. Figure 5.3.4 is an axial representation of the HI-STAR 180L cask. Figures 5.3.5 and 5.3.6 provide the as-modeled views of the impact limiters during normal conditions.

The conditions and tests specified in 10CFR 71.71 for normal conditions have no effect on the configuration of the cask. Therefore no additional considerations are necessary for these conditions and tests

The Drawings in Section 1.3 provide tolerances for selected dimensions. The dimensions where the effect of the tolerances are considered to have a significant effect of dose rates, with a special focus on those dose rates with smaller margins to the regulatory limits, are conservatively modeled as minimum values in the design basis calculations. For clarity, Table 5.3.3 lists all those dimensions together with their minimal values, and with the values used in the model.

During the MCNP modeling process a few modeling simplifications were made. The major simplifications between model and drawings are listed and discussed here.

F-69L Fuel Basket Modeling Simplifications

1. The rounded corners of the shims are not modeled. This is conservative since it neglects a small amount of material in the analyses.

HI-STAR Modeling Simplifications

1. The annular monolithic cylinders are modeled as one casting rather than multiple castings stacked on top of one another. This is acceptable since the gap between the castings is small, and the castings overlap to prevent any significant streaming.
2. In the modeling of the impact limiters, only the steel portions, shown in Figure 5.1.1, were represented.
3. The trunnions are not explicitly modeled.
4. The bolts utilized for closure of the inner and outer lid are not modeled, but rather the bolt hole locations are modeled as a solid material.
5. All empty spaces in and around the cask are represented by voids in the model. This is acceptable, since any absorption and scattering in air would have a very small effect in comparison to the dose rates at the close distances analyzed here.
6. In the MCNP model, the fuel is modeled as fresh UO_2 fuel with an enrichment of 2.0 wt%$_{235}$U. The U-235 enrichment of 2.0 wt% in this assumption is used to calculate the material compositions (i.e., mass fractions) for $_{235}$U and $_{238}$U in the active fuel region for MCNP. This is a conservative assumption since the actual spent fuel has fewer amounts of fissile isotopes as compared to using a $_{235}$U enrichment of 2.0 wt%. Also, fission products in the burned fuel, which decrease the neutron multiplication factor, are conservatively neglected.

The MCNP model of the HI-STAR 180L package for normal conditions has the neutron shield in place. The MCNP model for the hypothetical accident condition replaces the neutron shield with void, and also replaces 6.4 cm radially from the outer part of the lead in the base plate as a result of the lead slump.

5.3.1.2 Fuel and Source Configuration

In the model homogenized regions represent the fuel. Calculations were performed for the HI-STORM 100 (Subsection 5.3.1 of reference [5.0.3]) to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it is concluded that homogenization of the fuel assembly is acceptable without loss of accuracy. **[**

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Dummy assemblies are acceptable in any location, since they have no source term, but have about the same weight and exterior dimensions of a fuel assembly and are made of stainless steel.

5.3.1.3 Streaming Through Radial Steel Regions

The HI-STAR 180L cask utilizes Holtite as a neutron absorber in radial and axial directions.

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5.3.2 Material Properties

Composition and densities of the various materials used in the HI-STAR 180L shielding analyses are given in Table 5.3.2. Further information on the Holtite and Metamic neutron absorbers is provided in Section 1.2. All of the materials and their actual geometries are represented in the MCNP model. All steel in the cask was modeled as carbon steel.

To account for the thermal expansion of Holtite at operating temperatures, the material is installed with suitable gaps in cold conditions, which would close when the cask is fully loaded at operating conditions. Additionally, Holtite may experience some minor long-term weight loss from exposure to the temperatures. All this is considered in the model by utilizing a reduced density for the material, and a composition that is adjusted for the weight loss.

The following considerations are taken into account for Holtite-B density and composition calculations:

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Section 3.3 demonstrates that all materials used in the HI-STAR 180L remain at or below their design temperatures during all normal conditions. Therefore, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

During normal operations, the depletion of B-10 in the Metamic and the Holtite neutron shield is negligible. Based on calculations prepared for a similar cask model, the fraction of B-10 atoms that are depleted in 50 years is less than 1E-6 in both the Metamic and Holtite. Therefore, the shielding analysis does not need to address any changes in the composition of the Metamic or Holtite as a result of neutron absorption.

5.3.3 Tally Specifications

The dose rate values listed in Tables 5.1.1 through 5.1.4, with corresponding dose point locations illustrated in Figures 5.1.1 and 5.1.2, are computed using MCNP volume and surface tallies. In radial direction, the dose locations are represented by cylindrical rings with a thickness of 1 cm or 2 cm each at the surface, at 1 m and at 2 m from the package. In axial direction there are circle surfaces at various distances from the cask. The fuel loading patterns and the placement of the neutron absorber in the cask wall potentially results in azimuthal variations in the dose rates. Additionally, the axial burnup profiles of the fuel assemblies result in axial dose rate variations. To ensure that the maximum dose rate is identified, a sufficiently fine grid of dose locations is used, and the highest combined dose rates was calculated for each pattern in the areas identified in Figures 5.1.1 and 5.1.2. Further details are discussed below.

Radial Tallies

- Dose Location 2
  This dose location captures the maximum dose rate around the radial shield cylinder, i.e. the axial section of the cask that contains the Holtite pockets. . **[**

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- Dose Locations 1 and 3
  These are the dose locations adjacent to the impact limiter skirt surrounding the upper and lower forgings of the cask.

- Dose Locations 1A and 3A
  These are the dose locations adjacent to the gap between the impact limiter skirt and the radial shield cylinder, with a small length equal to the size of the gap.

Axial Tallies

The tally volumes located on the top and bottom surfaces, 1 meter and 2 meter positions of the cask were composed the following way:

- Dose Locations 4 and 5
  In axial direction, the tally volumes are circular disks that are divided into radial sections, each about 20 cm wide.

The dose locations for both radial and axial tallies are also described in Section 5.4.4.

Table 5.3.1

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Table 5.3.2

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Table 5.3.2 (Continued)

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.3.2 (Continued)

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Table 5.3.3

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 5.3.1: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.2: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.3: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.4: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.5: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.6: **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

5.4 SHIELDING EVALUATION

5.4.1 Methods

The MCNP-5 code [5.0.1] was used for all of the shielding analyses. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code. Continuous energy cross-section data is represented with sufficient energy points to permit linear-linear interpolation between these points. Cross section libraries are based on ENDF/B-V and ENDF/B-VI, except for Sn isotopes where the ENDL92 library is used, and uranium isotopes where LANL/T16 libraries are used. These are the default libraries for the MCNP code version used for the shielding analyses. The large user community has extensively benchmarked MCNP against experimental data. References [5.4.1], [5.4.2] and [5.4.3] are three examples of the benchmarking that has been performed. MCNP-5 is essentially the same code that has been used as the shielding code in all of Holtec's dry storage and transportation analyses. Note also that the principal approach in the shielding analysis here is identical to the approach in licensing applications previously reviewed and approved by the USNRC.

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5.4.2 Input and Output Data

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]The output of the post-processing are the dose rates listed in this chapter.

5.4.3 Flux-to-Dose-Rate Conversion

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5.4.4 External Radiation Levels

Table 5.1.1 provides the maximum dose rates on the surface of the package during normal transport conditions for the HI-STAR 180L with design basis fuel. Table 5.1.2 lists the maximum dose rate 2 m from the outer edge of the impact limiter during normal conditions. The burnup and cooling time configurations chosen for the tables in that section were the combinations that resulted in maximum dose rates for the normal operation on the surface and at 2 m from the outer edge of the impact limiter, as specified in the regulatory requirements. These configurations may not be all from the same loading condition, but show the highest dose rate at each individual dose location.

Figure 5.1.1 shows the dose locations on the surface and the condition of the HI-STAR 180L Package during normal transport. The azimuthal dose values are taken from the dose point locations that are shown in Figure 5.3.3. **[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]**

Dose locations 1, 2 and 3 shown in Figure 5.1.1 and Figure 5.1.2 do not correspond to single dose locations. Rather the dose rates for multiple axial and azimuthal segments were calculated and the highest value was chosen for the corresponding dose location. Dose location 2 is comprised of axial segments that range from the bottom of the monolithic cylinders to the top of the monolithic cylinders (the length of the Holtite pockets). The highest dose rate of these axial segments was chosen as the value for dose location 2. Dose location 1 corresponds to the axial extension of the lower impact limiter that spans between the bottom of the Holtite pockets and the crushable structure of the impact limiter. Dose location 3 corresponds to the axial extension of the upper impact limiter that spans between the crushable structure of the impact limiter and the top of the Holtite pockets. Dose locations 1A and 3A represent the small gap between the end of the impact limiter’s skirt and neutron shield cylinders. Dose location 4 corresponds to the surface location directly above the radial rib plates in the top impact limiter, and dose location 5 corresponds to the location directly below the radial rib plates in the bottom impact limiter.

The dose rates calculated to determine the distances necessary to comply with the 0.02 mSv/hr requirement specified in 10CFR71.47(b)(4) for any normally occupied space are presented in Table 5.1.3.

Table 5.1.4 presents the maximum dose rates at 1 m from the surface of the cask during hypothetical accident conditions.

Detailed results for different loading patterns are listed in Tables 5.4.4 through 5.4.6. These tables show the highest total dose rates at each dose location for each pattern in each basket.

5.4.5 Fuel Reconfiguration

The licensing approach for HBF reconfiguration is discussed in Section 1.4. the structural analyses demonstrate that fuel rod breakage under vibratory loads associated with the normal transport condition is not viable and therefore no noticeable impact on the dose rates is expected under normal condition. The structural analyses of fuel rods in Section 2.11 show that the fuel is expected to remain essentially undamaged during the hypothetical accident conditions. The principal calculational models for both design basis and hypothetical accident conditions therefore do not contain any reconfigured fuel.

Nevertheless, the current subsection presents additional calculations with some fuel reconfigurations under normal and accident conditions, and evaluates if any consideration of those need to be taken for the design basis calculations. It should be noted that the analyses performed in this subsection are conservatively performed for all loading patterns, independent from their fuel burnup, except when stated otherwise in the following sections.

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The results from the three scenarios described above along with a nominal reference case for accident conditions are shown in Table 5.4.2.

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Fuel Reconfiguration Under Normal Conditions

If there were some damage to the high burnup fuel (HBF) rods under normal conditions of transport, it would have been much less than the complete breakage of the fuel rods assumed for the accident conditions. Only local reconfiguration of fuel in the form of lattice deformation or rod/assembly sliding may be expected. Therefore the overall dose effect resulting from slight relocation of the radiation sources, if any at all, would be small.

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  - Upper and lower end fittings: unchanged, i.e. the support structure of the assembly is assumed to remain in place.
- Material Densities:
  - Active region: Fuel density (density of material in the active region) increased by 10% (by dividing the active-region density by 0.9).
  - Upper and lower end fittings: unchanged.
- Source Terms:
  - Active region: The source term per unit length is increased by 10%, so the total source term remains unchanged.
  - Upper and lower end fittings: unchanged.
- Axial Profile: The principal profile remains unchanged, but is compressed by 10% to match the active region.

For this scenario, only the neutron, (n,γ) and gamma MCNP calculations are performed for simplification, since the dose rates from end fittings are not expected to be changed.

The results from this scenario along with a nominal reference case for normal conditions are shown in Table 5.4.3. This scenario is explicitly considered for all bounding cases for normal conditions presented in Section 5.1, consistent with [5.4.7].

5.4.6 Combination of Uncertainties

If uncertainties (and their effects) are normally distributed, and are statistically independent, then uncertainties can be combined statistically. However, it is not clear, and it can not necessarily be demonstrated that those conditions are met. Hence all uncertainties are considered as a bias, and are added arithmetically. The combined list of adjustments is presented in Table 5.4.7.

These adjustments are applied to the total dose rate, but only for of the calculations to show compliance with the dose rate limits in Section 5.1. To show the effect of the adjustments, the total dose rate with and without the adjustment is shown in the tables in Section 5.1.

5.4.7 Sensitivity Study of the Accident Condition Model – Lead Slump Analysis

In the design basis calculations, to model the lead slump of the lead in the base plate (Bottom Lead Gamma Shield), it is conservatively assumed that 6.4 cm radially from the outer part of the lead are replaced with a void. To show that the design basis model of hypothetical accident conditions is conservative, this subsection presents a sensitivity study for the lead slump with a different geometry.

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Table 5.4.1

Flux-To-Dose Conversion Factors (from [5.4.6])

Gamma Energy (MeV)	(mSv/hr)/ (photon/cm^2-s) †
0.01	3.96E-05
0.03	5.82E-06
0.05	2.90E-06
0.07	2.58E-06
0.1	2.83E-06
0.15	3.79E-06
0.2	5.01E-06
0.25	6.31E-06
0.3	7.59E-06
0.35	8.78E-06
0.4	9.85E-06
0.45	1.08E-05
0.5	1.17E-05
0.55	1.27E-05
0.6	1.36E-05
0.65	1.44E-05
0.7	1.52E-05
0.8	1.68E-05
1.0	1.98E-05
1.4	2.51E-05
1.8	2.99E-05
2.2	3.42E-05

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† Values have been multiplied by 10 to convert rem, as given in [5.4.6], to mSv

Table 5.4.1 (Continued)

Flux-To-Dose Conversion Factors (from [5.4.6])

Gamma Energy (MeV)	(mSv/hr)/ (photon/cm^2-s) [†]
2.6	3.82E-05
2.8	4.01E-05
3.25	4.41E-05
3.75	4.83E-05
4.25	5.23E-05
4.75	5.60E-05
5.0	5.80E-05
5.25	6.01E-05
5.75	6.37E-05
6.25	6.74E-05
6.75	7.11E-05
7.5	7.66E-05
9.0	8.77E-05
11.0	1.03E-04
13.0	1.18E-04
15.0	1.33E-04

[†] Values have been multiplied by 10 to convert rem, as given in [5.4.6], to mSv

Table 5.4.1 (Continued)

Flux-To-Dose Conversion Factors
(from [5.4.6])

Neutron Energy (MeV)	Quality Factor	(mSv/hr)/(n/cm^2-s) [†], [††]
2.5E-8	2.0	3.67E-05
1.0E-7	2.0	3.67E-05
1.0E-6	2.0	4.46E-05
1.0E-5	2.0	4.54E-05
1.0E-4	2.0	4.18E-05
1.0E-3	2.0	3.76E-05
1.0E-2	2.5	3.56E-05
0.1	7.5	2.17E-04
0.5	11.0	9.26E-04
1.0	11.0	1.32E-03
2.5	9.0	1.25E-03
5.0	8.0	1.56E-03
7.0	7.0	1.47E-03
10.0	6.5	1.47E-03
14.0	7.5	2.08E-03
20.0	8.0	2.27E-03

[†] Values have been multiplied by 10 to convert mrem, as given in [5.4.6], to mSv

[††] Includes the Quality Factor

Table 5.4.2

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Table 5.4.3

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Table 5.4.4

Total Dose Rates on the Surface of the HI-STAR 180L Package for Normal Conditions for Different Loading Patterns (no Fuel Reconfiguration)

Dose Point Location	**Total Dose Rate (mSv/hr)**							**10 CFR 71.47 Limit (mSv/hr)**
	Loading Patterns							
	1	**2**	**3**	**4**	**5**	**6**	**7**	
1	0.1363	0.1052	0.1155	0.1430	0.1330	0.1277	0.1933	2
1A	0.6325	0.4861	0.5358	0.6634	0.6166	0.5920	0.8876	
2	0.3817	0.3789	0.3782	0.3808	0.4044	0.4153	0.4623	
3	0.1404	0.1075	0.1167	0.1469	0.1373	0.1318	0.2043	
3A	0.7672	0.5994	0.6465	0.8008	0.7526	0.7264	1.0787	
4	0.1111	0.0822	0.0904	0.1167	0.1081	0.1032	0.1687	
5	0.1056	0.0872	0.0925	0.1099	0.1043	0.1018	0.1329	

Table 5.4.5

Total Dose Rates at 2 Meters from the HI-STAR 180L Package for Normal Conditions for Different Loading Patterns (no Fuel Reconfiguration)

Dose Point Location	**Total Dose Rate (mSv/hr)**							**10 CFR 71.47 Limit (mSv/hr)**
	Loading Patterns							
	1	**2**	**3**	**4**	**5**	**6**	**7**	
2	0.0789	0.0807	0.0766	0.0770	0.0830	0.0864	0.0880	0.1
4	0.0263	0.0196	0.0214	0.0277	0.0256	0.0246	0.0403	
5	0.0348	0.0304	0.0319	0.0357	0.0344	0.0345	0.0429	

Table 5.4.6

Total Dose Rates at 1 Meter From the HI-STAR 180L Package for Accident Conditions for Different Loading Patterns (no Fuel Reconfiguration)

Dose Point Location	Total Dose Rate (mSv/hr)							10 CFR 71.51 Limit (mSv/hr)
	Loading Patterns							
	1	2	3	4	5	6	7	
2	7.8117	6.8674	6.6383	8.0809	8.0434	7.9529	8.8877	10
4	0.6469	0.5542	0.5358	0.6679	0.6603	0.6483	0.8466	
5	2.6057	2.2993	2.3093	2.7115	2.6974	2.6140	2.9411	

Table 5.4.7

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CHAPTER 5 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as "latest revision". Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company's Configuration Control system.

[5.0.1] X-5 Monte Carlo Team, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5," *LA-UR-03-1987*, Los Alamos National Laboratory (2003).

[5.0.2] B. T. Rearden and M. A. Jessee, Eds., *SCALE Code System*, ORNL/TM-2005/39, Version 6.2.1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (2016).

[5.0.3] HI-STAR 100 SAR, Rev. 12, October 2007 (Docket 71-9261), and HI-STORM FSAR, Rev. 7, August 2008 (Docket 72-1014)

[5.0.4] HI-STAR 180 SAR, latest revision, HI-2073681 (Docket #71-9325), Holtec International.

[5.2.1] NUREG-1617, SRP for Transportation Packages for Spent Nuclear Fuel, USNRC, Washington, DC, March 2000.

[5.2.2] A. Luksic, "Spent Fuel Assembly Hardware: Characterization and 10CFR 61 Classification for Waste Disposal," PNL-6906-vol. 1, Pacific Northwest Laboratory, June 1989.

[5.4.1] D. J. Whalen, et al., "MCNP: Photon Benchmark Problems," LA-12196, Los Alamos National Laboratory, September 1991.

[5.4.2] D. J. Whalen, et al., "MCNP: Neutron Benchmark Problems," LA-12212, Los Alamos National Laboratory, November 1991.

[5.4.3] J. C. Wagner, et al., "MCNP: Criticality Safety Benchmark Problems," LA-12415, Los Alamos National Laboratory, October 1992.

[5.4.4] Holtec International Report HI-2177989, "Preliminary Loading Plan Report for KKL", Latest Revision. (Holtec Proprietary).

[5.4.5] Holtec International Report HI-2188345, " Alternative Loading Plan Report for 35 kW Cask Heat Load limit", Latest Revision. (Holtec Proprietary).

[5.4.6] "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", ANSI/ANS-6.1.1-1977.

[5.4.7] NRC Draft Regulatory Issue Summary 2015-XX Considerations in Licensing High Burnup Spent Fuel in Dry Storage and Transportation, ML14175A203.

[5.4.8] Holtec International Report HI-2178014, “Shielding Analysis for HI-STAR 180L for Transport”, Latest Revision. (Holtec Proprietary)

Appendix 5.A

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Appendix 5.B

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

APPENDIX 5.C

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CHAPTER 6 CRITICALITY EVALUATION

6.0 INTRODUCTION

This chapter focused on providing the criticality evaluation of the HI-STAR 180L Cask for the packaging and transportation of radioactive materials, such as high burnup (HBF) and moderate burnup (MBF) fuel, in accordance with 10CFR71. The results of this evaluation demonstrate that an infinite number of HI-STAR 180L Packages with variations in internal and external moderation remain subcritical with a margin of subcriticality greater than 0.05Δk under all credible normal and hypothetical accident conditions of transport. This corresponds to a criticality safety index (CSI) of zero (0.0) and demonstrates compliance with criticality requirements in 10 CFR 71.55 and 10 CFR 71.59 for normal and hypothetical accident conditions of transport.

In addition to demonstrating that the criticality safety acceptance criteria are satisfied, this chapter describes the HI-STAR 180L design structures and components important to criticality safety and limiting fuel characteristics in sufficient detail to identify the package accurately and provides a sufficient basis for the criticality evaluation of the package.

Note that the analysis methodologies and modeling assumptions utilized in the safety evaluation documented in this chapter are based on those used in licensing of HI-STAR 100 in Docket #71-9261 [6.0.1], HI-STAR 180 in Docket #71-9325 [6.0.2], HI-STAR 180D in Docket #71-9367 [6.0.3], and HI-STAR 190 in Docket #71-9373 [6.0.4], except the following:

- No credit for fuel burnup is assumed, either in depleting the quantity of fissile nuclides or in producing fission product poisons;

- A partial gadolinium credit is used for certain BWR assembly classes with the fuel planar-average enrichment above the maximum allowable enrichment without gadolinium credit and up to 5.0 wt% ^{235}U.

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

The containment system of the HI-STAR 180L is a cylindrical shell with a flat bottom and flat bolted lids at the top. Inside the containment system, fuel assemblies are placed in a basket structure to maintain their location.
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For general details of these baskets see the description and drawings in Section 1.3. Sketches showing the basket details that are important for criticality safety are shown in Subsection 6.3.1 of this chapter. The basket loading configurations, discussed above, are graphically shown in Appendix 6.B, Section 6.B.5.

Criticality safety of HI-STAR 180L depends on the following principal design features:

- The inherent geometry of the fuel basket design within the cask;
- The incorporation of permanent fixed neutron-absorbing material in the fuel basket structure. [
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];
- An administrative limit on the maximum planar-average enrichment for BWR fuel;
- The ability of the cask to prevent water inleakage under accident conditions. [

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Applicable codes, standards, and regulations, or pertinent sections thereof, include the following:

- U.S. Code of Federal Regulations, “Packaging and Transportation of Radioactive Materials,” Title 10, Part 71.
- NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel” USNRC, Washington D.C., March 2000.
- U.S. Code of Federal Regulations, “Prevention of Criticality in Fuel Storage and Handling," Title 10, Part 50, Appendix A, General Design Criterion 62.
- USNRC Standard Review Plan, NUREG-0800, Section 9.1.2, “New and Spent Fuel Storage”, Rev. 4, March 2007.
- USNRC Interim Staff Guidance 19 (ISG-19), Revision 0, “Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)”.

6.1.2 Summary Table of Criticality Evaluations

The principal calculational results address the following conditions both for MBF and HBF:

- A single package, under the conditions of 10 CFR 71.55(b), (d), and (e);
- An array of undamaged packages, under the conditions of 10 CFR 71.59(a)(1); and
- An array of damaged packages, under the conditions of 10 CFR 71.59(a)(2).

Results are summarized in Table 6.1.1 for the most reactive configuration and fuel condition. The table contains the maximum k_{eff}, and the uncertainty for each case. The results are conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For package arrays, an infinite number of packages are analyzed. It is noted that the results for the internally flooded single package and package arrays are statistically equivalent. This shows that the physical separation between overpacks and the steel radiation shielding are each adequate to preclude any significant neutronic coupling between casks in an array configuration. In addition, the table shows the result for an unreflected, internally flooded cask. This configuration is used in many calculations and studies throughout this chapter, and is shown to yield results that are statistically equivalent to the results for the corresponding reflected package. Further analyses for the various conditions of flooding that support the conclusion that the fully flooded condition corresponds to the highest reactivity, and thus is most limiting, are presented in Subsection 6.3.4. These analyses also include cases with various internal and external moderator densities and various cask-to-cask spacings. The maximum k_{eff} value for all cases is below the limit of 0.95 recommended by NUREG-1617. The results therefore demonstrate that the HI-STAR 180L Package is in full compliance with 10CFR71 (71.55(b), (d), and (e) and 71.59(a)(1) and (a)(2)).

Additional results of the design basis criticality safety calculations for single fully reflected, internally flooded casks (limiting cases) are listed in Tables 6.1.2, conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For each of the fuel assembly class, Table 6.1.2 lists the bounding maximum k_{eff} value and the associated maximum allowable enrichment. The reference BWR fuel assembly is therefore defined as 10x10L7 fuel assembly in the F-69L basket since it is the fuel assembly class which has the maximum reactivity for the most reactive configuration. Additional results and discussions for each of the candidate fuel assemblies are given in Section 6.2.

A partial gadolinium credit is used to qualify 10x10L4 fuel assembly class with fuel enrichment above the maximum allowable enrichment specified in Table 6.1.2. The results of calculations are summarized in Table 6.1.3. Additional results and discussions for the partial gadolinium credit are provided in Subsection 6.3.10.

To assure the true reactivity will always be less than the calculated reactivity, the following conservative assumptions were made:

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6.1.3 Criticality Safety Index

The calculations for package arrays are performed for infinite arrays of HI-STAR 180L Packages under flooded conditions and results are below the NUREG-1617 limit of 0.95, i.e. N is infinite. Therefore, the criticality safety index (CSI) is zero (0.0).

Table 6.1.1

SUMMARY OF THE CRITICALITY RESULTS TO DEMONSTRATE COMPLIANCE WITH 10CFR71.55 AND 10CFR71.59

F-69L Basket, 10x10L7, 4.33 wt% ^{235}U, Configuration 3						
Configuration	% Internal Moderation	% External Moderation	Applicable Requirement	**Fuel Condition**	**Fuel Damage**	**Maximum[1] k_{eff}**
Single Package, Unreflected	100%	0%	n/a	MBF	No	0.9476
				HBF	Minor	0.9479
Single Package, Fully Reflected	100%	100%	10CFR71.55 (b) and (d)	MBF	No	0.9480
				HBF	Minor	0.9488
Containment, Fully Reflected	100%	100%		MBF	No	0.9483
				HBF	Minor	0.9490
Single Package, Damaged	0%	100%	10CFR71.55 (e)	MBF	No	0.4133
				HBF	Major	0.4183
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	MBF	No	0.4266
				HBF	Minor	0.4267
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	MBF	No	0.4151
				HBF	Major	0.4206

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[1] The term "maximum k_{eff}" as used here, and elsewhere in this document, means the highest possible k-effective, including bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.1.2

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS [1]

Fuel Assembly Class	Maximum Allowable Planar-Average Enrichment (wt% ^{235}U)	Maximum k_{eff}		
		Configuration 1	Configuration 2	Configuration 3
8x8L1	5.00	0.9400	0.9407	0.9462
8x8L2	5.00	0.9336	0.9348	0.9398
8x8L3	4.90	0.9398	0.9416	0.9457
8x8L4	4.80	0.9407	0.9423	0.9441
8x8L5	4.80	0.9446	0.9459	0.9471
9x9L1	4.60	0.9397	0.9406	0.9420
9x9L2	4.50	0.9402	0.9421	0.9440
10x10L1	4.70	0.9441	0.9437	0.9446
10x10L2	4.80	0.9443	0.9458	0.9470
10x10L3	4.80	0.9431	0.9437	0.9451
10x10L4 [2]	4.70	0.9435	0.9446	0.9450
10x10L5	4.80	0.9433	0.9440	0.9448
10x10L6	4.80	0.9429	0.9428	0.9449
10x10L7	4.33	0.9460	0.9476	0.9480
10x10L8	5.00	0.9333	0.9352	0.9359
10x10L9	5.00	0.9432	0.9438	0.9450
11x11L1	4.735	0.9466	0.9469	0.9465

---

[1] No gadolinium credit is taken into account in the BWR fuel assembly for calculations in this table.

[2] 10x10L4 fuel assembly class with the fuel enrichment more than 4.7 wt% and up to 5.0 wt% ^{235}U is also qualified for loading into the F-69L basket using a partial credit for gadolinium rods, see Table 6.1.3.

TABLE 6.1.3

BOUNDING MAXIMUM K$_{EFF}$ VALUES FOR THE F-69L BASKET WITH A PARTIAL GADOLINIUM CREDIT

10x10L4, Design basis with a partial gadolinium credit[1]		
Configuration	**Enrichment (wt% ^{235}U)**	**Maximum k$_{eff}$**
1	5.0	0.9368
2	5.0	0.9383
3	5.0	0.9375

---

[1] The design basis configurations of gadolinium rod locations are provided in Figure 6.3.5 (e) for 10x10L4 fuel assembly class. More details regarding partial gadolinium credit are discussed in Subsection 6.3.10.

6.2 FISSILE MATERIAL CONTENT

6.2.1 General

Due to the large number of minor variations in fuel assembly dimensions, the use of explicit dimensions in defining the authorized contents could limit the applicability of the HI-STAR 180L package. To resolve this limitation, bounding fuel dimensions are determined for each BWR fuel assembly class. The results of parametric studies justify using those bounding fuel dimensions for defining the authorized contents.

6.2.2 Fuel Parameters

Various BWR fuel assemblies are to be qualified for HI-STAR 180L. Each class of BWR fuel assembly has similar principal characteristics, such as array size, numbers and locations of fuel rods and water rods, which are listed in Table 7.D.1. However, fuel assemblies in the same class may differ in some of the details, such as fuel rod and water rods dimensions. Previous studies [6.0.1] have shown that the bounding conditions correspond to:

- Maximum Active Length;
- Maximum Pellet OD;
- Maximum Fuel Rod Pitch;
- Maximum Clad ID;
- Minimum Clad OD;
- Minimum Water Rod Thickness; and
- Maximum Channel Thickness.

To further demonstrate that the aforementioned characteristics are in fact bounding for HI-STAR 180L, parametric studies were performed on the reference BWR assembly determined in Subsection 6.1.2, namely BWR assembly class 10x10L7. The results of these studies for Configuration 1 are shown in Table 6.2.1, and verify the bounding parameters listed above. Consistent with previous work, the dimensions from the reference case are therefore used in all further analyses. Note that in the studies presented in Table 6.2.1, the fuel is with the maximum allowable initial planar-average enrichment. In addition, the fuel pellet diameter and cladding inner diameter are changed together. This is to keep the cladding-to-pellet gap, which is conservatively flooded with pure water in all cases (see Paragraph 6.3.4.3), at a constant thickness, to ensure the studies evaluate the fuel parameters rather than the moderation conditions.

In addition to those dimensions, additional fuel assembly characteristics important to criticality control are discussed below and the bounding fuel assembly characteristics are used in the HI-STAR 180L analysis. The assembly cross section for each class is provided in Appendix 6.B, Section 6.B.3.

BWR assembly classes 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4, 10x10L7, 10x10L8, 10x10L9 and 11x11L1 contain partial length rods (PLRs). There are differences in location of those partial length rods within the assembly that influence how those rods affect reactivity: some partial length rods are completely surrounded by full length rods, whereas some partial length rods are on the periphery of the assembly or facing the water gap, where they may directly face only two full length rods (see Appendix 6.B, Section 6.B.3). To determine a bounding configuration for each assembly class, calculations are performed for Configuration 1 with the maximum allowable initial planar-average enrichment of each assembly class that has partial length rods, and results are listed in Table 6.2.2 for the actual (real) assembly configuration and for the axial segments (assumed to be full length) with and without the partial length rods. The results show that the configurations with only the full length rods present, i.e. where the partial length rods are assumed completely absent from the assembly, is bounding for assembly classes 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4 and 11x11L1. Consequently, these assembly classes are analyzed with the partial length rods absent. For assembly classes 10x10L7, 10x10L8 and 10x10L9 which have all partial length rods on the periphery or facing the water gap, calculations with different assumptions for the length of the part-length rods show that reducing the length of the partial length rods reduces reactivity. This means that the reduction in the fuel amount is more dominating than the change in moderation for this configuration. For these fuel assembly classes, all rods are therefore assumed full length. Note that neither of the bounding case is the configuration with the actual partial length rods. The specification of the authorized contents has therefore no minimum requirement for the active fuel length of the partial length rods.

Each BWR assembly class is specified in Table 7.D.1 with a maximum planar-average enrichment. The analyses presented in this chapter use a uniform enrichment, equal to the maximum planar-average. Analyses presented in the HI-STAR 100 SAR ([6.0.1], Chapter 6, Appendix 6.B) show that this is a conservative approach, i.e. that a uniform enrichment bounds the distributed enrichments in terms of the maximum k_{eff}. To verify that this is applicable to the F-69L basket and confirm that this is also true for the higher enrichments analyzed here, additional calculations were performed and are presented in Table 6.2.1 in comparison with the results for the uniform enrichment for the reference 10x10L7 assembly. Since the actual (as-built) enrichment distributions are not available, several bounding cases are analyzed. To maximize the differences in enrichment under these conditions, the analyzed cases assume that some of the rods in the cross section are at the maximum rod enrichment of 5.0 wt% ^{235}U, while the balance of the rods are at a lower enrichment, resulting the maximum planar-average enrichment of 4.33 wt% ^{235}U. Calculations are performed for cross sections where all part-length rods are assumed as full-length rods, and for cross sections where only full-length rods are present. For each case, two conditions are analyzed that places the different enrichment in areas with different local fuel-to-water ratios. Specifically, one condition places the higher enriched rods in locations where they are more surrounded by other rods, whereas the other condition places them in locations where they are more surrounded by water, such as near the water-rods or the periphery of the assembly. The results in Table 6.2.1 show that in all cases, the calculated k_{eff} for the distributed enrichments are statistically equivalent to or below those for the uniform enrichments. Therefore, modeling BWR assemblies with distributed enrichments using a uniform enrichment equal to the planar-average value is acceptable and conservative. The assumed enrichment distributions are shown in Appendix 6.B, Section 6.B.4.

Note that for 9x9L1 fuel assembly, the Zircaloy water rod tubes are artificially replaced by water to remove the requirement for water rod thickness from the specification of the authorized contents. The bounding water rod thickness is thus listed as zero for 9x9L1 fuel assembly.

For 11x11L1 fuel assembly, various rod pitches may be present in the fuel assembly. Previous studies [6.2.1] have confirmed that using average rod pitch along the entire active fuel length is bounding. The average rod pitch is therefore used for 11x11L1 assembly.

In all cases, the gadolinia (Gd_2O_3) normally present in BWR fuel was conservatively neglected. However, a partial gadolinium credit qualifies 10x10L4 fuel assembly class with the enrichment larger than the maximum allowable fuel enrichment defined in Table 6.1.2 and up to 5.0 wt% ^{235}U. For more details see Subsection 6.3.10.

6.2.3 Fuel Debris in Quivers

The F-69L basket is designed to contain BWR fuel debris loaded into quivers. The quiver can be loaded with the maximum of 28 damaged fuel rods or fuel rod pieces resulting from rod inspections. The specifications, number and permissible location of quivers are provided in Subsection 1.2.2 and Chapter 7. Because the entire height of the fuel basket contains the neutron absorber (Metamic-HT), the quivers are covered by the neutron absorber even if they were to move axially.

Fuel debris can include a large variety of configurations ranging from whole fuel assemblies with severe damage down to individual fuel pellets. To identify the configuration or configurations leading to the highest reactivity, a bounding approach is taken, which is based on the analysis of the regular arrays of bare fuel rods without cladding.

In modeling the fuel debris in the quivers, the following conservative considerations are applied:

- The quiver house OD is assumed as fuel debris boundary. The head lid, bottom support as well as all structural materials in the quiver house, such as tubes, gabes and spaces, are replaced by water;
- Fuel debris in the quivers is arranged in regular, rectangular arrays of bare fuel rods. The fuel rod claddings in the BWR fuel are all replaced by water;
- To ensure the configuration with optimum moderation and highest reactivity is analyzed, the amount of fuel per unit length of the quiver is varied over a large range. This is achieved by changing the number of rods in the array and the rod pitch. The number of rods are varied between 16 (4x4) and 225 (15x15);

- The active length of these rods is assumed to be the same as for the intact fuel rods in the basket, even for more densely packed fuel rod arrays where it results in a total amount of fuel in the quivers that exceeds that for the intact assembly;
- The fresh fuel composition with 5.0 wt% ^{235}U is used.

All calculations are performed for full cask models, containing the maximum permissible number of quivers. As an example of the fuel debris model used in the analyses, Figure 6.2.1 shows the F-69L basket cell with a quiver containing a 9x9 array of bare fuel rods.

The results are listed in Table 6.2.3. The bounding condition is bolded in Table 6.2.3 and used in all subsequent calculations of the Configuration 2 which contains quivers.

In Paragraph 6.4.4.2 of HI-STORM 100 [6.2.2], additional studies for damaged fuel were performed to further show that the above approach using arrays of fuel rods is bounding. The studies considered conditions including

- Fuel assemblies that are undamaged except for various numbers of missing rods.
- Variations in the diameter of the bare fuel rods in the arrays.
- Consolidated fuel assemblies with cladded rods.
- Enrichment variations in BWR assemblies.

Results of those studies were shown in the HI-STORM 100 FSAR, Table 6.4.8 and 6.4.9 and Figure 6.4.13 and 6.4.14 (undamaged and consolidated assemblies); HI-STORM 100 FSAR Table 6.4.12 and 6.4.13 (bare fuel rod diameter); and HI-STORM 100 FSAR Subparagraph 6.4.4.2.3 and Table 6.4.8 (enrichment variations). In all cases the results of those evaluations are equivalent to, or bounded by those for the bare fuel rods arrays. Since the generic approach of modeling fuel debris is similar to HI-STORM 100, these evaluations are still applicable for HI-STAR 180L.

6.2.4 High Burnup Fuel

The F-69L basket is loaded into HI-STAR 180L for transport. While cladding damage to HBF is not expected, it is not feasible to physically examine the fuel and verify the fuel condition. However, for compliance with 10 CFR 71.55(b) flooding of the containment needs to be assumed and moderator exclusion cannot be applied. Under this condition, the criticality evaluations for HI-STAR 180L are performed considering already a certain level of fuel reconfiguration (see Subsection 6.3.5). Expressed differently, the definition of undamaged HBF for HI-STAR 180L for the purpose of criticality evaluation already includes consideration of a certain level of fuel reconfiguration.

The criticality analyses performed in Subsection 6.3.5 assuming reconfiguration of HBF were still performed under the conservative assumption that the fuel is fresh, consistent with the MBF. This simplifies the analysis. It could lead to the false impression that reconfigured HBF has the same or even less criticality margin then MBF, but note that the reactivity effect of potential fuel reconfiguration could be more than compensated by the additional minimum HBF burnup of 45GWd/mtU.

Table 6.2.1

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Table 6.2.2

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TABLE 6.2.3

CALCULATED k_{eff} VALUES IN THE F-69L BASKET WITH UNDAMAGED AND DAMAGED FUEL[1]

Rod Array inside the Quiver	**10x10L7 (4.33 wt% ^{235}U)**
	Configuration 2
4x4	0.9370
5x5	0.9365
6x6	0.9374
7x7	0.9386
8x8	0.9393
9x9	**0.9404**
10x10	0.9395
11x11	0.9400
12x12	0.9397
13x13	0.9389
14x14	0.9394
15x15	0.9386

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[1] All values are calculated k_{eff} values. The standard deviation (σ) of the calculations is about 0.0004. The bounding case is bolded.

FIGURE 6.2.1: PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

6.3 GENERAL CONSIDERATIONS

In compliance with the requirements of 10CFR71.31(a)(1), 10CFR71.33(a)(5), and 10CFR71.33(b), this section provides a description of HI-STAR 180L in sufficient detail to identify the package accurately and provide a sufficient basis for the evaluation of the package.

6.3.1 Model Configuration

Figures 6.3.1 through 6.3.3 show representative cross sections of the criticality models. Figure 6.3.1 shows a single cell from the basket. Figure 6.3.2 show the entire F-69L basket. Figure 6.3.3 shows a sketch of the calculational model in the axial direction.

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The basket geometry can vary due to manufacturing tolerances and due to potential deflections of basket walls as the result of accident conditions. The basket tolerances are defined on the drawings in Chapter 1. [

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] Based on the calculations, the conservative dimensional assumptions listed in Table 6.3.2 were determined. Because the reactivity effect (positive or negative) of the manufacturing tolerances is not assembly dependent, these dimensional assumptions were employed for all criticality analyses.

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Variations of other parameters, namely fuel density and water temperature in the cask, were analyzed using CASMO5. The results are presented in Table 6.3.4, and show that the maximum fuel density and the minimum water temperature (corresponding to a maximum water density) are bounding. These conditions are therefore used in all further calculations.

Calculations documented in Chapter 2 show that the baskets stay within the applicable structural limits during all normal and accident conditions. Furthermore, the neutron poison material is an integral and non-removable part of the basket material, and its presence is therefore not affected by the accident conditions. Except for the potential deflection of the basket walls that is already considered in the criticality models, damage to the cask under accident conditions is limited to damage to the neutron absorber on the outside of the cask. However, this external absorber is already neglected in the calculational models. Other parameters important to criticality safety are fuel type and enrichment, which are not affected by the hypothetical accident conditions. The calculational models of the cask and basket for the accident conditions are therefore identical to the models for normal conditions, and no separate models need to be developed for accident conditions.

As discussed in Chapter 2, the cask is designed so that water leakage under accident conditions is not considered credible. There are, however, differences between the normal and accident models in terms of internal and external water density and external reflections. The effect of these conditions is discussed in Subsection 6.3.4.

Additionally, studies are performed to evaluate the potential effect of fuel reconfiguration during accident conditions. These are presented in Subsection 6.3.5.

6.3.2 Material Properties

Composition of the various components of the principal designs of the HI-STAR 180L Package is listed in Table 6.3.5. In this table, the nuclide identification number (ZAID) presented for each nuclide includes the atomic number, mass number and the cross-section evaluation identifier, which are consistent with the ZAIDs used in the benchmarking calculations documented in Appendix 6.A.

HI-STAR 180L is designed such that the fixed neutron absorber will remain effective for a period greater than 60 years, and there are no credible means to lose it. A detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of the fixed neutron absorber are provided in Paragraph 1.2.1.6.

As specified in Table 8.1.3, the manufacturer's minimum B_4C content for the Metamic-HT fixed neutron absorber is 10 wt%. The continued efficacy of the fixed neutron absorber is assured by acceptance testing, documented in Paragraph 8.1.5.5, to validate the ^{10}B (poison) concentration in the fixed neutron absorber. In addition, based on calculations performed in Subsection 6.3.2 of the HI-STORM FW FSAR [6.3.1], the fraction of ^{10}B atoms destroyed during the service life in the fixed neutron absorber by neutron absorption is negligible (less than 10^{-7}). Therefore, there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

The only materials affected by the accident conditions are the Holtite neutron absorber on the outside of the cask, and the impact limiters. None of these materials are considered in the criticality model. Therefore, material properties of the materials used in the criticality analyses are not affected by the accidents.

6.3.3 Computer Codes and Cross Section Libraries

MCNP5-1.51 and CASMO5 Version 2.00.00 are used for the criticality analyses of the HI-STAR 180L Cask for the packaging and transportation of radioactive materials. Both codes were installed and validated on the Holtec International's computer following the documentations provided by the code developers.

The principal code for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP5 [6.3.2] developed at the Los Alamos National Laboratory. MCNP5 was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP5 design basis calculations used continuous energy cross-section data, based on ENDF/B-VII, as distributed with the code.

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CASMO5 [6.3.3 – 6.3.4] was used for determining some incremental reactivity effects (see Subsection 6.3.1). [

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6.3.4 Demonstration of Maximum Reactivity

The basket designs are intended to safely accommodate fuel with enrichments indicated in Appendix 7.D. The calculations were based on the assumption that the HI-STAR 180L cask was fully flooded with water. The principal characteristics of fuel assemblies discussed in Subsection 6.2.2 is also important for the various studies presented in this subsection. The studies are only performed for the bounding BWR assembly class, and the results are then generally applicable to all assembly classes. Note that this approach is consistent with that used for the HI-STAR 100 [6.0.1].

6.3.4.1 Internal and External Moderation

The regulations in 10CFR71.55 include the requirement that the package remains subcritical when assuming moderation to the most reactive credible extent. The regulations in 10CFR71.59 require subcriticality for package arrays under different moderation conditions. Paragraphs 6.3.4.1 through 6.3.4.4 present various studies to confirm or identify the most reactive configuration or moderation condition. Specifically, the following conditions are analyzed:
[

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The calculations that specifically demonstrate compliance with the individual requirements of 10CFR71.55 and 10CFR71.59 are presented in Sections 6.4 through 6.6.

Regarding the effect of low moderator density, it is noted that with a neutron absorber present (i.e., the neutron poison integral to the walls of the storage compartments), the phenomenon of a peak in reactivity at a hypothetical low moderator density (sometimes called "optimum" moderation) does not occur to any significant extent. In a definitive study, Cano, et al. [6.3.5] has demonstrated that the phenomenon of a peak in reactivity at low moderator densities does not occur when strong neutron absorbing material is present or in the absence of large water spaces between fuel assemblies. Nevertheless, calculations for a single reflected cask and for infinite arrays of casks were made to confirm that the phenomenon does not occur with low density water inside or outside HI-STAR 180L, and results are discussed in Subparagraph 6.3.4.1.1.

As discussed in Chapter 2, the cask is designed so that water inleakage under accident conditions is not considered credible. The main purpose of this design characteristic is to ensure that any potential reconfiguration of high burnup fuel under accident conditions is inconsequential from a criticality perspective. The calculations to demonstrate compliance with 10CFR55 and 10CFR59 under accident conditions are therefore performed with an internally dry cask. Nevertheless, the studies performed in the following subparagraphs that determine the optimum moderation conditions still conservatively consider internal water moderation under accident conditions.

6.3.4.1.1 Single Package Evaluation

The calculational model for a single package consists of the HI-STAR 180L Cask surrounded by a hexagonal box filled with water. The neutron absorber on the outside of HI-STAR 180L is neglected, since it might be damaged under accident conditions, and since it is conservative to replace the neutron absorber (Holtite) with a neutron reflector (water). The minimum water thickness on each side of the cask is 30 cm, which effectively represents full water reflection. The outer surfaces of the surrounding box are conservatively set to be fully reflective, which effectively models a three-dimensional array of casks with a minimum surface to surface distance of 60 cm. The calculations with internal and external moderators of various densities are shown in Table 6.3.7. For comparison purposes, a calculation for a single, unreflected cask (Case 1) is also included in Table 6.3.7. At 100% external moderator density, Case 2 corresponds to a single, fully-flooded cask, fully reflected by water. Figure 6.3.4 plots calculated k_{eff} values as a function of internal moderator density for 100% external moderator density (i.e., full water reflection).

Results listed in Table 6.3.7 and plotted in Figure 6.3.4 support the following conclusions:

- The calculated k_{eff} for a fully-flooded cask is independent of the external moderator (the small variations in the listed values are due to statistical uncertainties which are inherent to the calculational method (Monte Carlo)); and

- Reducing the internal moderation results in a monotonic reduction in reactivity, with no evidence of any optimum moderation. Thus, the fully flooded condition corresponds to the highest reactivity, and the phenomenon of optimum low-density moderation does not occur and is not applicable to HI-STAR 180L.

6.3.4.1.2 Evaluation of Package Arrays

In terms of reactivity, the normal conditions of transport (i.e., no internal or external moderation) are bounded by the hypothetical accident conditions of transport. Therefore, the calculations in this subparagraph evaluate arrays of HI-STAR 180L Packages under hypothetical accident conditions (i.e., internal and external moderation by water to the most reactive credible extent and no neutron shield present).

In accordance with 10CFR71.59 requirements, calculations were performed to simulate an infinite three-dimensional square array of internally fully-flooded (highest reactivity) casks with varying cask spacing and external moderation density. The maximum k_{eff} results of these calculations are listed in Table 6.3.8 and confirm that the individual casks in a square-pitched array are independent of external moderation and cask spacing.

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The calculations demonstrate that the thick steel wall of the overpack is more than sufficient to preclude neutron coupling between casks, consistent with the findings of Cano, et al [6.3.5]. Neglecting the Holtite neutron shielding in the calculational model provides further assurance of conservatism in the calculations.

6.3.4.2 Partial Flooding

To demonstrate that HI-STAR 180L would remain subcritical if water were to leak into the containment system, as required by 10CFR71.55, calculations in this paragraph address partial flooding in HI-STAR 180L and demonstrate that the fully flooded condition is the most reactive.

The reactivity changes during the flooding process were evaluated in both the vertical and horizontal positions. For these calculations, the cask is partially filled (at various levels) with full density (1.0 g/cm^3) water and the remainder of the cask is filled with steam consisting of ordinary water at partial density (0.0002 g/cm^3). Results of these calculations are shown in Table 6.3.12. In general, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is fully flooded. The fully flooded case therefore represents the bounding condition.

6.3.4.3 Clad Gap Flooding

The reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated. Table 6.3.13 presents calculated k_{eff} values that demonstrate the positive reactivity effect associated with flooding the pellet-to-clad gap regions. These results confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. For all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded.

6.3.4.4 Preferential Flooding

Preferential flooding of the F-69L basket itself is not possible [

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6.3.4.5 Eccentric Positioning of Assemblies in Fuel Storage Cells

In this paragraph, studies are presented to determine the reactivity effect of eccentric positioning of fuel assemblies in the fuel storage cells, and the conditions with the highest calculated k_{eff} are identified.

To conservatively account for eccentric fuel positioning in the fuel storage cells, the following different configurations are analyzed, and the results are compared to determine the bounding configuration:

- Cell Center Configuration: All assemblies centered in their fuel storage cell;
- Basket Center Configuration: All assemblies in the basket are moved as closely to the center of the basket as permitted by the basket geometry;
- Basket Periphery Configuration: All assemblies in the basket are moved furthest away from the basket center, and as closely to the periphery of the basket as possible; and
- Displacement towards Specific Cells Configuration (for Configuration 2 only): All quivers are moved as closely to the center of the basket as permitted by the basket geometry, while all other assemblies are moved furthest away from the basket center, and as closely to the periphery of the basket as possible.

It should be noted that the eccentric configurations are hypothetical, since there is no known physical phenomenon that could move all assemblies within a basket consistently to the center or periphery. However, since the configurations listed above bound all credible configurations, they are conservatively used in the analyses.

The results are presented in Table 6.3.14. The table shows the calculated k_{eff} value for centered and eccentric configurations for each condition, and the difference in k_{eff} between the centered and eccentric positionings. The results show that the basket centered configuration results in the highest reactivity. Therefore, all further calculations, including those that demonstrate compliance with 10CFR71 requirements, are performed with assemblies moved towards center of the basket unless otherwise stated.

6.3.5 Potential Fuel Reconfiguration

The cask is designed to remain internally dry under any normal or accident conditions. Therefore, any fuel reconfiguration would be of no consequences. Additionally, the evaluation of the fuel performance under accident conditions presented in Chapter 2 indicate that no fuel damage, and hence no fuel reconfiguration would be expected. Nevertheless, analyses are performed assuming coinciding fuel reconfiguration and flooding of the cask. It is important to recognize that the concerns about fuel reconfiguration are principally related to HBF, i.e. fuel with an assembly average burnup of about 45 GWd/mtU or more. However, fresh fuel was used in the analysis, which creates additional margin for the fuel of concern.

6.3.5.1 Potential Fuel Reconfiguration under Normal Conditions

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These results show that even if there would be any damage and minor reconfiguration of the fuel assemblies, and even if the cask would be flooded during the accident, there would be no significant effect on the reactivity of the package. Nevertheless, the evaluations of the HBF fuel are performed in Section 6.4 through Section 6.6 to show compliance with the NUREG-1617 limit of 0.95.

6.3.5.2 Potential Fuel Reconfiguration under Accident Conditions

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6.3.6 Partial Loading

Each basket cell is completely surrounded by the basket walls containing neutron absorber material (B_4C). Under a partial loading situation, i.e. where one or more basket locations are not occupied with fuel, the amount of fissile material is obviously reduced. Also, under the bounding condition of a fully flooded cask, the amount of water is increased. This will result in an increased moderation of neutrons in the empty cell locations. This increased moderation will increase the effectiveness of the surrounding thermal neutron absorber. Described differently, the now empty cell locations will act as additional flux traps. Therefore, due to the reduced amount of fissile material, and the increased neutron absorption, the reactivity of the package under partial loading conditions will be reduced, and will always be bound by the fully loaded conditions. No further evaluations of this condition are therefore necessary.

In addition, it is acceptable to load dummy assemblies at any basket cell location. The dummy fuel assemblies may displace a volume of water that is either smaller or larger than that displaced by the original fuel assemblies, thus either increase or decrease neutron absorption. However, the reactivity effect due to change in moderation is small, and the impact of reduction in fissile material is dominant. The reactivity of the cask with dummy assemblies will be reduced and bounded by the cask with fuel assemblies in all basket cell locations. No further evaluations are therefore necessary.

6.3.7 Fuel Assemblies with Missing Rods

For fuel assemblies that are qualified for transportation, missing fuel rods are possible. To determine the reactivity effect of missing rods in fuel assemblies, studies are performed with an assumption that fresh fuel assemblies are in every cell in the F-69L basket and every fuel assembly has up to 4 missing fuel rods replaced by water. All fuel assemblies are assumed to be centered in their fuel storage cells. Selected cases are evaluated which cover possible locations of the missing rod. The various missing rod locations analyzed for the reference fuel assembly (10x10L7) are shown in Figure 6.3.8.

The results of the calculations for the reference fuel assembly class are listed in Table 6.3.18, which show that for the design basis fuel assembly class the highest reactivity is obtained when the 4 missing fuel rods are surrounded by the regular fuel rods and each missing rod is at different corners. It is expected that the configuration of 4 missing fuel rods at different corners and surrounded by the regular fuel rods represents the bounding condition. While further evaluations of various patterns may potentially result in minor increase of reactivity, it will be statistically equivalent or bounded by the safety margin. All the other fuel assembly classes are also evaluated and the same conclusions derived are applicable to all fuel assembly classes. The bounding case is then considered in Configuration 3 for the 9 fuel assemblies that are with missing fuel rods, as defined in Subsection 6.1.2, while the remaining fuel assemblies are still without any missing rod, to determine the maximum reactivity.

Therefore, for fuel assemblies that are qualified for fuel transportation, up to 4 missing fuel rods are acceptable, and the fuel assemblies with missing fuel rods are only allowed to be loaded into up to 9 regular cells of the basket. However, if the missing fuel rods are replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods, then the fuel assemblies can be treated as fresh undamaged fuel assemblies and loaded at any cell of the basket.

In addition, for fuel assembly classes 9x9L1, 10x10L1, 10x10L2, 10x10L3, 10x10L4 and 11x11L1, any missing fuel rods at the locations of partial length fuel rods are acceptable, since the configuration with all the part length rods absent is bounding for those assembly classes, as stated in Paragraph 6.2.2.2.

6.3.8 Sealed Rods Replacing BWR Water Rods

Some BWR fuel assemblies may contain sealed rods filled with a non-fissile material instead of water rods. Compared to the configuration with water rods, the configuration with sealed rods has a reduced amount of moderator, while the amount of fissile material is maintained. Thus, the reactivity of the configuration with sealed rods will be lower compared to the configuration with water rods. Any configuration containing sealed rods instead of water rods is therefore bounded by the analysis for the configuration with water rods and no further analysis is required to demonstrate the acceptability. Therefore, for all BWR fuel assemblies analyzed, it is permissible that water rods are replaced by sealed rods filled with a non-fissile material.

6.3.9 Neutron Sources in Fuel Assemblies

Fuel assemblies containing start-up neutron sources are permitted for transport in the HI-STAR 180L system. The reactivity of a fuel assembly is not affected by the presence of a neutron source (other than by the presence of the material of the source, which is discussed later). This is true because in a system with a k_{eff} less than 1.0, any given neutron population at any time, regardless of its origin or size, will decrease over time. Therefore, a neutron source of any strength will not increase reactivity, but only the neutron flux in a system, and no additional criticality analyses are required. Sources are inserted as rods into fuel assemblies, i.e., they replace either a fuel rod or water rod (moderator). Therefore, the insertion of the material of the source into a fuel assembly will not lead to an increase of reactivity either.

6.3.10 BWR Fuel with a Partial Gadolinium Credit

6.3.10.1 Introduction and Background

Initially, calculations to qualify BWR fuel for the F-69L basket were only performed assuming fresh (unburned) fuel in the assembly, and neglecting any burnable absorber that may be present in the assembly. In order to ensure that the reactivities are below the acceptable limit specified in Section 6.1, this approach results in upper enrichment limits for the assemblies. These limits are listed for each fuel assembly class in Table 6.1.2. For more modern BWR assembly, however, actual enrichments may exceed those limits. Specifically, 10x10L4 fuel assembly class that needs to be qualified for the F-69L basket may have an increased enrichment up to 5.0 wt% ^{235}U.

One method to increase the allowed enrichment, as described in NUREG-7194 [6.3.6], is to apply a combination of burnup credit and credit for residual burnable absorber in BWR fuel. If credit is taken for the residual burnable absorber in BWR fuel, then the peak reactivity that occurs from rapid depletion of the burnable absorber must be accounted for. This is known as a peak reactivity method or “gadolinium credit” and applies credit for burnup. [

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In order to increase the upper enrichment limit for the 10x10L4 fuel assemblies, and ensure that the maximum reactivity for those higher enriched assemblies is below the limit of 0.95, an additional set of design basis calculations is presented in this subsection [PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390] Based on this approach, an upper enrichment limit of 5.0 wt% ^{235}U is qualified. The additional requirements with respect to the credit neutron absorber are clearly defined, and added to the specification of the allowable content in Appendix 7.D. The approach is termed “partial gadolinium credit”, due to the following:

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The following Paragraph 6.3.10.2 describes details of the methodology, Paragraph 6.3.10.3 describes the design basis calculations, Paragraph 6.3.10.4 presents various studies to show that the selected parameters are conservative, and Paragraph 6.3.10.5 presents a discussion on misloading.

6.3.10.2 Methodology

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6.3.10.3 Design Basis Calculations

Partial gadolinium credit is only applied to 10x10L4 fuel assembly class. The result of the corresponding design basis calculations is summarized in Table 6.1.3. Note that the result of the design basis calculations with the lower enrichment limits and no gadolinium credit for the 10x10L4 fuel assembly class is shown in Table 6.1.2 and remain valid, i.e. up to the enrichment limits listed in that table, requirements listed below are not needed.

In summary, for the 10x10L4 fuel assembly class with 5.0 wt% ^{235}U enrichment and partial gadolinium credit, the maximum k_{eff} is below the NUREG-1617 limit of 0.95 with the following administrative requirements:

- The gadolinium rod loading is not less than 3.0 wt% Gd_2O_3;
- The gadolinium rods located in the peripheral row of the fuel lattice cannot be credited;
- At least two gadolinium rods must be present; and
- No gadolinium rods are needed for fuel debris in quivers.

6.3.10.4 Studies

There are two assumptions in the methodology outlined in Paragraph 6.3.10.2 that are supported in this paragraph through studies, in order to verify that the assumptions result in a conservative methodology. [PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390] Additionally, a study is performed to indicate the margin preserved by the conservative methodology.

6.3.10.4.1 Gadolinium Rod Locations

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6.3.10.4.2 Fresh Fuel Assumption

Modern BWR assemblies with enrichments close to 5.0 wt% ^{235}U contain much more burnable absorbers in the form of gadolinium than considered here, due to the requirements for in core operation. As a result, those assemblies are not at their maximum reactivity when they are unburned. Instead, they show a peak reactivity at a burnup typically between 10 and 15 GWd/mtU. The reason is the large reactivity reduction of the burnable absorber for the fresh fuel condition, and the fact that the negative reactivity effect of the absorber reduces much faster with burnup then the reduction in reactivity from the depletion of the fissionable material with burnup. Hence in an approach where a large portion of the present burnable absorber is credited, using the fresh unburned condition of the fuel would not be the most conservative case. Note that such an approach can be useful if the targeted reactivity reduction is large (i.e. much larger than that needed here). However, since the method now applies burnup, the complexity of the calculations increases significantly (guidance for such an approach is specified in NUREG-7194 [6.3.6]).

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6.3.10.4.3 Margin

For the partial gadolinium credit used here, it is expected that there will be a significant margin between fresh unburned condition of design basis case and peak reactivity of a typical, modern BWR assembly. [

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Results of those calculations are presented in Table 6.3.21 and graphically in Figure 6.3.9. For all cases, the reactivity is shown as the difference to the design basis case at the fresh unburned condition. In all cases, the peak reactivities would be lower than that for the design basis case at the fresh unburned condition. This confirms that with the methodology presented for partial gadolinium credit here, a margin of at least 0.05 Δk is expected, compared to a real BWR assembly.

6.3.10.5 Misloading

Since the gadolinium is required for in-core operation, it is not expected that there would be any high enriched BWR assemblies without any gadolinium. Nevertheless, as a defense-in-depth, misloading with fuel not containing gadolinium is considered. The misloading studies are performed for the F-69L basket in HI-STAR 180L for the worst-case scenario of misloading, i.e., all fuel assemblies with gadolinium rods in the basket are replaced by fuel assemblies without any gadolinium rods. These calculations are performed for all three configurations, and the results are provided as “No Gd rod” case in Table 6.3.19. For any configuration, the results show that the cask remains subcritical, and the maximum keff values are still below the limit of 0.98 (i.e., a reduced safety margin of 0.02 Δk) recommended in ISG-8 Rev. 3 [6.3.8] for misloading conditions. The misloading analyses are fully detailed, use conservative assumptions ([PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]), and are fully benchmarked from a criticality perspective. This provides sufficient justification for the reduced safety margin.

Table 6.3.1

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Table 6.3.2

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Table 6.3.3

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Table 6.3.4

CASMO5 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter	**Δk Maximum Tolerance**	**Action/Modeling Assumption**
	F-69L basket, 10x10L7, 4.33 wt% ^{235}U	
Maximum UO_2 Density ([PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390])	Ref.	Assume max UO_2 pellet density
Decrease in UO_2 Density (10.57 g/cm^3)	-0.0044	
Increase in Temperature		
20°C	Ref.	Assume 20°C
40°C	-0.0037	
70°C	-0.0106	
100°C	-0.0190	
10% Void in Moderator		
20°C with no void	Ref.	Assume no void
20°C with 10% void	-0.0247	
100°C with 10% void	-0.0435	

Table 6.3.5

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Table 6.3.5 (continued)

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Table 6.3.5 (continued)

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Table 6.3.6

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Table 6.3.7

REACTIVITY EFFECT WITH REDUCED WATER DENSITIES FOR CASK ARRAYS[1]

Case Number	**Water Density**		**MCNP5 Results**		
			10x10L7, 4.33 wt% ^{235}U, Configuration 1		
	Internal	**External**	**Calculated k_{eff}**	**1 σ**	**EALF (eV)**
1	100%	single cask	0.9396	0.0004	0.4137
2	100%	100%	0.9394	0.0004	0.4130
3	100%	70%	0.9385	0.0004	0.4133
4	100%	50%	0.9396	0.0004	0.4128
5	100%	20%	0.9388	0.0004	0.4126
6	100%	10%	0.9386	0.0004	0.4146
7	100%	5%	0.9387	0.0004	0.4135
8	100%	0%	0.9390	0.0004	0.4124
9	70%	0%	0.8350	0.0004	1.0197
10	50%	0%	0.7326	0.0004	3.1559
11	20%	0%	0.5327	0.0003	150.57
12	10%	0%	0.4790	0.0002	1569.0
13	5%	0%	0.4636	0.0002	6386.4
14	10%	100%	0.4762	0.0002	1673.5

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[1] This table is for an infinite hexagonal array of casks with 60 cm spacing between cask surfaces.

Table 6.3.8

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Table 6.3.9

PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Table 6.3.10

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Table 6.3.11

PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Table 6.3.12

PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Table 6.3.13

PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Table 6.3.14

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Table 6.3.15

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Table 6.3.16

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Table 6.3.17

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Table 6.3.18

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Table 6.3.19

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Table 6.3.20

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Table 6.3.21

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FIGURE 6.3.1   PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

FIGURE 6.3.2 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

FIGURE 6.3.3 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.4 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.5 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.5 (Continued) PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.6 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.7 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.8 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.8 (Continued) PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.8 (Continued) PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.8 (Continued) PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

Figure 6.3.9 PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390

6.4 SINGLE PACKAGE EVALUATION

6.4.1 Configuration

The calculations in this subsection demonstrate that a single HI-STAR 180L Package remains subcritical for all credible conditions of moderation, and that the package fulfills all requirements of 10CFR71.55.

In modeling the single package, the following considerations are applied:

- The bounding geometric and temperature assumptions identified in Tables 6.3.2 and 6.3.4 are used;
- The assemblies are centered in the basket, which results in the highest k_{eff} as demonstrated in Paragraph 6.3.4.5;
- The pellet to clad gap is assumed to be flooded (see Paragraph 6.3.4.3);
- The basket is assumed to be loaded with the UO_2 fuel of the maximum permissible reactivity, i.e., the basket is loaded with the UO_2 fuel assemblies using one of the configurations defined in Appendix 7.D and shown in Section 6.B.5. [

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Normal Conditions

The studies in Paragraphs 6.3.4.1 through 6.3.4.4 demonstrate that the moderation by water to the most reactive credible extent corresponds to the internally fully flooded condition of the basket, with the pellet-to-clad gap in the fuel rods also flooded with water. The external moderation has a statistically negligible effect.

Under normal condition, water is assumed to leak into the package, consistent with 10 CFR 71.55. Flooding with full density water is assumed, since this is the bounding condition as shown in Subsection 6.3.4.

To demonstrate compliance with 10CFR71.55 under normal conditions, the following calculations are performed for the HI-STAR 180L design:

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To satisfy the requirements of 10CFR71.55 (b)(1), the calculations are performed

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Additional calculations (CASMO5) at elevated temperatures confirm that the temperature coefficients of reactivity are negative as shown in Table 6.3.4. This confirms that the calculations are conservative.

Accident Conditions

The analyses presented in Chapter 2 and Chapter 3 demonstrate that the damage resulting from the hypothetical accident conditions of transport are limited to a loss of the neutron shield material as a result of the hypothetical fire accident. Because the criticality analyses do not take credit for the neutron shield material (Holtite), this condition has no effect on the criticality analyses.

HI-STAR 180L is designed for high burnup fuel (HBF), i.e. for fuel with burnups larger than 45 GWd/mtU. For fuel of this burnup, there are concerns that the fuel cladding could be damaged under accident conditions, with a potential effect on reactivity. Chapter 2 demonstrates that the cask remains leaktight under all credible accident conditions. Further, the second lid provides additional assurance that water will not leak into the containment as a result of an accident. The package therefore satisfies the intent of USNRC ISG 19, and flooding of the containment system under accident condition is not considered in the design basis analyses.

In summary, the impact of the hypothetical transport accidents, which are important to criticality safety, are limited to potential major fuel reconfiguration discussed in Paragraph 6.3.5.2 and the effects on internal and external moderation evaluated in Paragraph 6.3.4.1.

To demonstrate compliance with 10CFR71.55 under accident conditions, the following calculations are performed for the HI-STAR 180L design:

- Single cask, internally dry, with full external water moderation. As for the single cask under normal conditions, the full external water moderation is modeled as water with a thickness of about 300 cm. The major fuel reconfiguration is applied to HBF instead of the minor fuel reconfiguration. All other fuel parameters are consistent with the single cask under normal conditions. The external neutron absorber is conservatively neglected in the model. This case addresses the requirement of 10CFR71.55 (e).

6.4.2 Results

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Appendix 6.A presents the critical experiment benchmarking for fresh UO_2 and MOX fuel and the derivation of the corresponding bias and standard error of the bias (95% probability at the 95% confidence level).

The maximum k_{eff} values for all these cases, calculated with 95% probability at the 95% confidence level, are listed in Table 6.4.1. Overall, these results confirm that the effective multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, does not exceed 0.95 under normal and accident conditions of transport.

Configuration 3 is selected for the evaluations of single package to show compliance with 10CFR71.55 in Section 6.4, and for the evaluations of package arrays to show compliance with 10CFR71.59 in the following Sections 6.5 and 6.6.

Table 6.4.1

HI-STAR 180L SINGLE PACKAGE WITH F-69L BASKET

Configuration	**% Internal Moderation**	**% External Moderation**	**Fuel Condition**	**Fuel Damage**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
Single Package, fully reflected	100%	100%	MBF	No	0.9480	0.0004	0.3977
			HBF	Minor	0.9488	0.0004	0.3981
Containment, fully reflected	100%	100%	MBF	No	0.9483	0.0004	0.3978
			HBF	Minor	0.9490	0.0004	0.3968
Single Package, Damaged	0%	100%	MBF	No	0.4133	0.0001	140090
			HBF	Major	0.4183	0.0001	153370

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

6.5.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator density have a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under normal conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally and externally dry, is modeled. All other modeling assumptions are identical to the modeling assumptions for the single package under normal conditions. The analyses are performed to address the requirement of 10CFR71.59 (a) (1) and the determination of the criticality safety index according to 10CFR71.59 (b).

6.5.2 Results

The results are presented in Table 6.5.1, and show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95. Since an unlimited number of packages can be placed in an array, the value of N is infinite, and the CSI is therefore zero (0).

Table 6.5.1

HI-STAR 180L PACKAGE ARRAYS UNDER NORMAL CONDITIONS

Basket	**% Internal Moderation**	**% External Moderation**	**Fuel Condition**	**Fuel Damage**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
F-69L	0%	0%	MBF	No	0.4266	0.0001	116720
			HBF	Minor	0.4267	0.0001	116740

6.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6.6.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator density have a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under accident conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally dry with full external water reflection, is modeled. This model is consistent with the model for the single cask under accident condition, and recognizes the fact that water intrusion under accident condition is not considered credible. This calculation addresses the requirement of 10CFR71.59 (a)(2)

6.6.2 Results

The results are presented in Table 6.6.1, and show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95. Since an unlimited number of packages can be placed in an array, the value of N is infinite, and the CSI is therefore zero (0).

As additional assurance that the package remains subcritical under hypothetical accident conditions, studies were performed for the major fuel reconfiguration under accident conditions with a fully flooded containment boundary. These studies, presented in Paragraph 6.3.5.2, show a reactivity increase in comparison to the reference case. Therefore, additional evaluations are performed for the major fuel reconfiguration with the coinciding flooding of the cask. The results are presented in Table 6.6.2, and show that even under the assumption of fuel damage and flooding, the package remains subcritical, and the maximum k_{eff} value is still below the limit of 0.98, which is often used as a limit for the unlikely accident conditions [6.3.8].

Table 6.6.1

HI-STAR 180L PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS

Basket	**% Internal Moderation**	**% External Moderation**	**Fuel Condition**	**Fuel Damage**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
F-69L	0%	100%	MBF	No	0.4151	0.0001	135800
			HBF	Major	0.4206	0.0001	147660

Table 6.6.2

HI-STAR 180L PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS (DEFENSE IN DEPTH)

Basket	**% Internal Moderation**	**% External Moderation**	**Fuel Condition**	**Fuel Damage**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
F-69L	100%	100%	HBF	Major	0.9648	0.0004	0.2942

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Not Applicable. The HI-STAR 180L package will not be transported by air.

6.8 BENCHMARK EVALUATIONS

Benchmark calculations have been made on selected critical experiments, chosen, insofar as possible, to bound the range of variables in the cask designs. The most important parameters are (1) the enrichment, (2) the cell spacing, and (3) the ^{10}B loading of the neutron absorber panels. Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included. Detailed benchmark calculations are presented in Appendix 6.A.

The benchmark calculations were performed with the same computer codes and cross-section data, described in Section 6.3, that were used to calculate the k_{eff} values for the cask. Further, all calculations were performed on the same computer hardware, specifically, personal computers under Microsoft Windows.

CHAPTER 6 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as "latest revision". Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company's Configuration Control system.

[6.0.1] Holtec International Report HI-951251, Safety Analysis Report HI-STAR 100 Cask System, USNRC Docket 71-9261, Revision 16.

[6.0.2] Holtec International Report HI-2073681, Safety Analysis Report on the HI-STAR 180 Package, USNRC Docket 71-9325, Revision 5.

[6.0.3] Holtec International Report HI-2125175, Safety Analysis Report on the HI-STAR 180D Package, USNRC Docket 71-9367, Revision 3.

[6.0.4] Holtec International Report HI-2146214, Safety Analysis Report on the HI-STAR 190 Package, USNRC Docket 71-9373, Revision 2.

[6.2.1] Holtec International Report HI-2146261, Safety Analysis Report on the HI-STAR 80 Package, USNRC Docket 71-9374, Revision 2.

[6.2.2] Holtec International Report HI-2002444, Final Safety Analysis Report on the HI-STORM 100 Cask System, USNRC Docket 72-1014, Revision 14.

[6.3.1] Holtec International Report HI-2114830, Final Safety Analysis Report on the HI-STORM FW System, USNRC Docket 72-1032, Revision 5.

[6.3.2] X-5 Monte Carlo Team, MCNP - A General Monte Carlo N-Particle Transport Code, Version 5, LA-UR-03-1987, Los Alamos National Laboratory, April 2003 (Revised 2/1/2008).

[6.3.3] "CASMO5/CASMO5M A Fuel Assembly Burnup Program Methodology Manual", SSP-08/405, Rev. 1, Studsvik Scandpower, Inc.

[6.3.4] "CASMO5 A Fuel Assembly Burnup Program, User's Manual," SSP-07/431, Rev. 4, Studsvik Scandpower, Inc.

[6.3.5] J.M. Cano, R. Caro, and J.M Martinez-Val, "Supercriticality Through Optimum Moderation in Nuclear Fuel Storage," Nucl. Technol., 48, 251-260, (1980).

[6.3.6] NUREG/CR-7194, Technical Basis for Peak Reactivity Burnup Credit for BWR

Spent Nuclear Fuel in Storage and Transportation Systems, USNRC, Washington, D.C., April 2015.

[6.3.7] Burn-up Credit Criticality Safety Benchmark Phase III-C, OECD/NEA, March 2016.

[6.3.8] "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks", ISG-8, Rev. 3, USNRC, Washington, D.C., 2012.

[6.4.1] M.G. Natrella, "Experimental Statistics", National Bureau of Standards, Handbook 91, August 1963.

[6.4.2] Holtec International Report HI-2177952, "Criticality Evaluation of the HI-STAR 180L Cask", Revision 0. (Holtec Proprietary) [1].

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[1] Supporting document submitted with the HI-STAR 180L License application.

Appendix 6.A

PROPRIETARY APPENDIX REMOVED PER 10 CFR 2.390

Appendix 6.B

PROPRIETARY APPENDIX REMOVED PER 10 CFR 2.390

CHAPTER 7: PACKAGE OPERATIONS

7.0 INTRODUCTION

This chapter provides a summary description of the essential elements and requirements necessary to prepare the HI-STAR 180L package for shipment and to ensure that it operates in a safe and reliable manner under normal and accident conditions of transport pursuant to the provisions of 10CFR71 [7.1.4], as described in this SAR. The information presented in this chapter, along with the technical basis of the package design described in Chapters 2 through 6 will be used by Holtec International's Site Services organization to develop more detailed generic procedures for users of the HI-STAR 180L Package. Equipment specific operating details such as valve manipulation, onsite cask transporter handling methods etc., will be provided to individual users of the HI-STAR 180L package based on the specific ancillary equipment selected by the user and the configuration of the site. It is the user's responsibility to utilize the information provided in this chapter, (treating it as an inviolable set of operation elements that must be included in the detailed operating procedures). In addition, the user must consult the conditions of the NRC issued Certificate of Compliance (CoC), equipment-specific operating instructions, and the plant's working procedures and apply them to develop the site-specific written loading, unloading, and handling procedures to ensure that the package is operated in accordance with the CoC and all applicable government regulatory requirements. The following generic criteria shall be used to qualify that the site specific operating procedures are acceptable for use:

- All heavy load handling instructions are in keeping with the guidance in industry standards, and Holtec's proprietary rigging manual.
- A careful technical evaluation of all potential modes of loss of load stability has been performed and accepted by Holtec International's site services organization.
- Procedures are in conformance with the essential elements and conditions of this Chapter and the CoC.
- The operational steps are ALARA.
- Procedures contain provisions for documenting successful execution of all safety significant steps for archival reference.
- Holtec's lessons learned database has been consulted to incorporate all applicable lessons learned from prior cask handling and loading evolutions.
- Procedures contain provisions for classroom and hands-on training and for a Holtec approved personnel qualification process to ensure that all operations personnel are adequately trained.
- The procedures are sufficiently detailed and articulated to enable craft labor to execute them in *literal compliance* with their content.

Operations described in this chapter assume that the fuel will be loaded into or unloaded from the HI-STAR cask submerged in a spent fuel pool. With some modifications, the information presented herein can be used to develop site-specific procedures for loading or unloading fuel into the system within a hot cell or other remote handling facility.

US Department of Transportation (USDOT) transportation regulations in 49CFR parts 172 [7.1.1] and 173 [7.1.2] applicable to the transport of the HI-STAR 180L package as well as USNRC regulations in 10CFR20 [7.1.3] are only addressed in this chapter to the extent required to ensure compliance with 10CFR71 regulations and to provide a more complete package operation description. Applicable 49CFR and 10CFR20 regulations, including those explicitly called out in 10CFR 71.5, shall be complied with for package use in the US and/or for US package export and import. For transport outside US territory and under the approval or jurisdiction of one or more foreign competent authorities, other requirements such as the ADR, “European Agreement Concerning the International Carriage of Dangerous Goods by Road” and the RID, “European Agreement Concerning the International Carriage of Dangerous Goods by Rail” may be imposed in place of the 49CFR. It is the user’s responsibility to comply with the latest revision of these transportation regulations as required by the applicable competent authority.

Users shall develop or modify existing programs and procedures to account for the transport operation of the HI-STAR 180L. Written procedures are required and will be developed or modified to account for such items as handling and storage of systems, structures and components identified as *important-to-safety*, heavy load handling, specialized instrument calibration, special nuclear material accountability, fuel handling procedures, training, equipment and process qualifications. Users shall implement controls to ensure that the lifted weights do not exceed the cask lifting trunnion design limit. Users shall implement controls to monitor the time limit for the removal of the cask from the spent fuel pool to the commencement of cask draining to prevent boiling. Users shall also implement controls to ensure that the cask cannot be subjected to a fire event in excess of design limits during loading operations.

For the determination of Time-To-Boil time limits or the determination of cyclic vacuum drying time limits, thermal evaluations may implement Fluent 3D models that are the same or consistent with the models used for safety analysis. Alternatively, other demonstrably conservative and appropriately benchmarked models may be utilized.

The procedures in this chapter contain generic ALARA notes and warnings to alert users to radiological issues. Actions identified with these notes and warnings are not mandatory and shall be implemented based on a determination by Radiation Protection.

The operations covered in this safety analysis address the following areas:

1. Preparation for loading a cask
2. Loading of cask contents

3. Preparation for shipment of a loaded cask
4. Package unloading
5. Preparation for shipment of an empty cask

Appendix 7.A provides general operational weights and illustrations of typical operations of the HI-STAR 180L Package. Additional weight information may be provided in the drawing package referenced in the CoC.

Appendix 7.D provides content conditions of the HI-STAR 180L Package.

Control of the package operation shall be performed in accordance with the user's Quality Assurance (QA) program to ensure critical steps are not overlooked and that the cask has been confirmed to meet all requirements of the CoC before being released for shipment.

Fuel assembly selection and verification shall be performed by the user in accordance with written, approved procedures that ensure that only SNF assemblies authorized in the CoC are loaded into the HI-STAR 180L cask. Fuel assembly selection, and some aspects of assembly verification, are typically performed well in advance of the actual loading date, specifically with respect to the selection and verification of the assemblies to meet the definition of undamaged fuel in the CoC. A typical approach to show compliance with the CoC definition of undamaged fuel may include the following steps:

- During reactor operation, the water chemistry is monitored. If no indication of fuel leakage is detected, all assemblies unloaded from the core are considered undamaged.
- If indication of leakage is found in the water during reactor operation, the population of the assemblies in the core that may have the leak may be narrowed down by a more detailed evaluation of the leaked isotopes, or by manipulating control blades in a BWR core.
- Once unloaded, further examination, such as sipping, may be performed to clearly identifying the leaking assembly or assemblies, out of the population identified.
- Once leaking assemblies are identified, they may simply be considered not meeting the CoC requirements and excluded from the selection, or further tests are performed to identify the extent of cladding damage.
- For channeled BWR assemblies, such further tests to identify the extent of the leak, and potentially qualify them as undamaged if the leak does not exceed the requirements in the CoC for undamaged assemblies, would require the removal of the channel.

Fuel handling shall be performed in accordance with written site-specific procedures.

7.1 PACKAGE LOADING

The HI-STAR 180L Package is used to load and transport spent fuel. The essential elements required to prepare the HI-STAR 180L Package for fuel loading, to load the fuel, and to ready the cask for transport as a Transport Package are described below.

7.1.1 Preparation for Loading a Cask

1. If the HI-STAR 180L Packaging has previously been used to transport spent fuel, the HI-STAR 180L is received and the personnel barrier, if attached, is removed and security seals, if used, are inspected to verify there was no tampering and that they match the corresponding shipping documents.
2. The HI-STAR 180L Packaging is visually receipt inspected to verify that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. Any issues are identified to site management. Any road dirt is washed off and any foreign material is removed.
3. Radiological surveys are performed in accordance with 49CFR173.443 and 10CFR20.1906. If necessary, the HI-STAR 180L Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties.
4. The impact limiters and impact limiter adapters, if attached, are removed and a second visual inspection to verify that there are no outward visual indications of impaired physical condition is performed.
5. The trunnion hole plugs, if installed, are removed and the cask trunnions are installed. The cask is upended and the neutron shield pressure relief devices are inspected to confirm that they are installed, intact, and not covered by tape or any other covering.
6. The cask lids are removed and used seals are removed and discarded. If equipped, the neutron shield pressure relief device(s) on the inner closure lid is inspected to confirm it is installed, intact, and not covered by tape or any other covering.
7. The containment closure flange inner and outer lid sealing surfaces are inspected for damage that may compromise the performance of the seal. Any damage to the sealing surfaces is repaired by welding and/or polishing/machining damaged areas as necessary. If the cask sealing surface is weld repaired, the sealing surfaces are faced with corrosion resistant veneers.
8. The inner and outer closure lid bolts are inspected for distortion and damaged threads and any suspect bolts are replaced.
9. Any foreign material is removed from inside the cask and the basket panels are visually checked to verify they are not damaged.
10. If used, lower fuel spacers may be installed at this time or during fuel loading operations.

11. If used, dummy fuel assemblies may be installed at this time or during fuel loading operations.

7.1.2 Loading of Cask Contents

7.1.2.1 Fuel Loading Operations

ALARA Note:
A bottom protective cover may be attached to the cask bottom or placed in the designated preparation area or spent fuel pool. This will help prevent embedding contaminated particles in the cask bottom surface and ease the decontamination effort. Waterproof tape placed over empty bolt holes, and bolt plugs may also reduce the time required for decontamination. Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

1. The cask containment closure flange sealing surfaces are covered with a protective cover or protective funnel. Caps or plugs are installed on the pressure relief devices attached to the neutron shielding enclosures. If used and not previously installed, lower fuel spacers are installed at this time. Removal and reinstallation are allowed during fuel loading if necessary. The cask storage cavity is filled with either spent fuel pool water or clean demineralized water and the cask is lowered into the spent fuel pool for fuel loading. The cask cavity may be filled by pumping water into the cask or by lowering the cask in the spent fuel pool and allowing water to overflow into the cask cavity.
2. If used, dummy fuel assemblies are installed at this time or during fuel loading. Removal and reinstallation are allowed during fuel loading if necessary.
3. Prior to loading the fuel, the user identifies the fuel to be loaded and the fuel is independently verified that it meets the conditions of the CoC and this chapter.
4. Quivers may be loaded with contents, dried, backfilled and leak tested prior to loading into the cask. Prior to loading the quiver with spent fuel rods, the user identifies the fuel rods or fuel debris to be loaded and the content is independently verified that it meets the conditions of the CoC.
5. Prior to loading quivers into the cask, the user identifies the quivers to be loaded and the quivers are independently verified that they meets the conditions of the CoC and the operational requirements in Table 7.1.5.
6. The pre-selected fuel assemblies, dummy fuel assemblies, and quivers are loaded into the cask and a visual verification of the assembly identification is performed. Any additional information required to be documented by Appendix 7.D for the shipping manifest must be recorded. If equipped, the neutron shield pressure relief device(s) on the inner closure lid is verified to be undamaged prior to fuel loading or prior to becoming inaccessible by the outer closure lid installation. Caps or plugs are installed on the pressure relief devices attached to the neutron shielding enclosures.

Caution:
The inner closure lid bolts are installed at any time after the inner closure lid is installed but before the cask is dried. When installing inner closure lid bolts, the bolts must remain loose until the inner closure lid vent port (and connected vent line) is opened to prevent pressure build-up in the cask. If installing inner closure lid bolts under water, then the inner closure lid vent port must be open.

7. While still underwater, the containment closure flange inner lid sealing surface protective cover is removed and the sealing surfaces for the inner closure lid are inspected for signs of damage and potential solid contamination that might affect the seal performance. Any particulate matter or damage that would prevent a seal is remedied. Prior to placing the inner lid in the water, its sealing surfaces are inspected to verify they are free of damage and contamination that might affect seal performance. Any particulate matter or damage that would prevent a seal is remedied. New seals are installed in the inner closure lid and the lid is then lowered into the water and installed on the cask. The lid is visually inspected to confirm 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 start of draining operations. The Time- to-Boil clock begins when the inner lid is placed on the cask. If it appears that the Time-to-Boil limit will be exceeded prior to draining operations, the user shall take appropriate action to either replace the water in the cask cavity with an inert gas, circulate water through the cask cavity to reset the Time-to-Boil clock, or return the cask to the spent fuel pool and remove the lid to allow for natural water circulation. If the inner closure lid vent port is open, the inner closure lid bolts may be installed at this time.

ALARA Note:
Activated debris may have settled on flat surfaces of the cask during fuel loading. Cask surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce decontamination time, the cask surfaces should be kept wet until decontamination begins.

8. The lift attachment is engaged to the cask lifting trunnions and the cask is raised out of the spent fuel pool after being cleared by Radiation Protection. As the cask is raised out of the spent fuel pool, the lift attachment and cask are sprayed with clean water to help remove contamination.
9. The accessible areas of the bottom of the cask and the cask bottom protective cover, if used, are decontaminated, the cask is placed in the designated preparation area and the lift attachment is removed. The top surfaces and accessible areas of the cask are decontaminated. Caps or plugs are removed from the pressure relief devices attached to the neutron shielding cavities.
10. At the discretion of Radiation Protection, dose rates are measured at the inner closure lid

and around the cask body to confirm appropriate radiological control.

11. The lid vent port is opened to prevent cask pressurization and temporary shielding (if used) is installed.
12. Any standing water is removed from the inner and outer closure lid bolt holes in the closure flange. The inner closure lid bolts are torqued after the vent port is opened and before the cask cavity is either drained or dried. Bolt torque requirements and recommended tightening procedure for containment boundary components are provided in Table 7.1.1 and Figure 7.1.1, respectively. If desired, the user may attach security seals to the inner closure lid bolts at this time.

ALARA Warning:
Personnel should remain clear of the drain lines any time water is being pumped or purged from the cask. Radiological crud, suspended in the water, may create a radiation hazard to workers. Dose rates will rise as water is drained from the cask. Continuous dose rate monitoring is recommended.
Caution:
An inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during loading operations.

13. For drying with forced helium, the Forced Helium Dehydration (FHD) System is connected to the cask and used to remove moisture from the cask cavity. There is no time limit on FHD drying. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. After the bulk water has been removed, the helium exiting the FHD demoisturizer is cooled to the temperature or dew point given in Table 7.1.2 and circulated through the duration given in Table 7.1.2 to ensure that the cask cavity is suitably dry.
14. For drying with vacuum, a vacuum drying system is connected to the cask and used to remove moisture from the cask cavity. The user performs a site-specific evaluation to determine whether cyclic vacuum drying with time limits is necessary to ensure the vacuum drying criteria is met. Users shall refer to Table 7.1.2 and Table 7.1.3 for vacuum drying criteria. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. The cask cavity is vacuum dried. Once it is demonstrated that the cask cavity pressure meets the pressure criterion given in Table 7.1.2 for the duration given in Table 7.1.2, with the valve closed, it shall be considered dry.
15. The cask cavity is backfilled to the requirements in Table 7.1.4 and the port caps/plugs are closed.

16. With the inner closure lid inter-seal test port plug (that will be located beneath the outer closure lid access port) removed, the inner closure lid inter-seal space is dried. The inner closure lid inner seal is leak tested through its respective inter-seal test ports. Test requirements and acceptance criteria are provided in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals. The leak testing of the inner closure lid main seal may be performed immediately after the lid bolts are installed and torqued such that if a leak is detected, the cask does not need to be reflooded. If the cask is to be transported within 12 months of closure and leakage testing, the inner closure lid inter-seal test port plugs are installed with new seals.
17. The sealing surfaces of the inner closure lid port covers and their respective mating surfaces on the inner closure lid are inspected for signs of damage. Any damage that would prevent a seal is remedied and new seals are installed. The space beneath the port covers are backfilled filled to the requirements in Table 7.1.4. The port cover bolts are torqued. Bolt torque requirements and recommended tightening procedure for containment boundary components are provided in Table 7.1.1 and Figure 7.1.1, respectively. The vent and drain port cover plate inner seals are leak tested through their respective inter-seal test port to the required test requirements and acceptance criteria provided in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals. Following the leakage test, the vent and drain poer cover plate inter-seal test port plugs are left removed.

7.1.2.2 Cask Closure

1. The inter-seal test port plugs of the inner closure lid are installed with new seals and torqued. The containment closure flange outer sealing surface protective cover is removed and the sealing surfaces for the outer closure lid are inspected for signs of damage and potential solid contamination that might affect the seal performance. Any particulate matter or damage that would prevent a seal is remedied. The user ensures that the inner closure lid inter-seal test port plug(s) are installed. Prior to installing the outer closure lid, its sealing surfaces are inspected to verify they are free of damage and contamination that might affect seal performance. Any particulate matter or damage that would prevent a seal is remedied. New seals are installed in the outer closure lid and the lid is then installed on the cask. The outer closure lid is installed using new seals. The outer closure lid bolts are installed and torqued. Bolt torque requirements and recommended tightening procedure for containment boundary components are provided in Table 7.1.1 and Figure 7.1.1, respectively. The user may attach security seals to the outer closure lid bolts at this time.
2. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4.
3. The outer closure lid access port plug, fitted with a new seal, is torqued to the requirements in Table 7.1.1.

4. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested in accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.
5. The outer closure lid access port cover is installed with a seal and port cover bolts are torqued. The outer closure lid inter-seal test port plug(s) is installed with new seal and torqued.

7.1.3. Preparation for Shipment of a Loaded Cask

1. If more than twelve months have elapsed since the performance of the leakage tests described in Subsection 7.1.2.1, a periodic leakage test shall be performed as follows:
   a. The outer closure lid access port plug and inner closure lid inter-seal test port plugs are removed.
   b. The inner closure lid inner seal and vent and drain port cover plate inner seals are leak tested through the inter-lid space in accordance with the requirements and acceptance criteria listed in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.
   c. The inner closure lid inter-seal test port plug is installed with a new seal.
   d. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4.
   e. The outer closure lid access port plug, fitted with a new seal, is torqued to the requirements in Table 7.1.1. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested to the requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.
   f. The outer closure lid inter-seal test port plug(s) is installed with new seal and torqued.
   g. The outer closure lid access port cover is installed with a seal and port cover bolts are torqued.
2. The cask neutron shield pressure relief devices are visually verified to be undamaged.

ALARA Warning:
Dose rates around the unshielded bottom end of the cask may be higher than other locations around the cask. After the cask is downended on the transport frame, the bottom impact limiter with adapter should be installed promptly. Personnel should remain clear and exercise other appropriate ALARA controls when working around the bottom end of the cask.

Note:
If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

3. The cask is moved to the transport location, downended, and placed on the transport vehicle.
4. A visual inspection for signs of impaired condition is performed. Any non-satisfactory conditions are remedied.
5. Contamination surveys are performed per 49CFR173.443. If necessary, the cask is further decontaminated to meet the survey requirements.
6. The cask trunnions are removed, and the trunnion hole plugs are installed.
7. Impact Limiters are assembled with corresponding Impact Limiter Adapters and bolt/nuts are torqued. Impact Limiters are installed on the cask and the impact limiter bolts/nuts are torqued. Bolt/Nut torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively.
8. The tie-down system is installed, a cover is installed over at least one of the access tubes on the top impact limiter, and a security seal is installed on the top impact limiter. Security seal serial number(s) are recorded in the shipping documents.
9. Final radiation surveys of the package surfaces per 10CFR71.47 [7.1.4] and 49CFR173.443 are performed and if necessary, the HI-STAR 180L Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents.
10. For packages containing HBF, the final radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The final location of measurements and the measurements shall be recorded in the shipping documents.
11. The surface temperatures of the accessible areas of the package are measured to confirm temperatures are within 10CFR71.43 requirements, if the personnel barrier will not be used.

12. For packages containing HBF, surface temperatures are measured as required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The final location of measurements, ambient conditions (air temperature, date, time of day, and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements.
13. The personnel barrier is installed. The personnel barrier is optional if the package surface temperature and the dose rates without the personnel barrier are within 10CFR71.43 and 10CFR71.47 requirements, respectively; and no applicable 49CFR requirements are violated.
14. The assembled package is given a final inspection to verify that the following conditions for transport have been met (inspection steps may be performed in any order):
    a. Verify that required radiation survey results are properly documented on the shipping documentation.
    b. Perform a cask surface temperature check. The accessible surfaces of the Transport Package (impact limiters and personnel barrier) shall not exceed the exclusive use temperature limits of 49CFR173.442.
    c. Verify that all required leakage testing has been performed, the acceptance criteria have been met, and the results have been documented on the shipping documentation.
    d. Verify that the receiver has been notified of the impending shipment and that the receiver has the appropriate procedures and equipment available to safely receive and handle the Transport Package (10CFR20.1906(e)).
    e. Verify that the carrier has the written instructions and a list of appropriate contacts for notification of accidents or delays.
    f. Verify that the carrier has written instructions that the shipment is to be Exclusive Use in accordance with 49CFR173.441.
    g. Verify that route approvals and notification to appropriate agencies have been completed.
    h. Verify that the appropriate labels have been applied in accordance with 49CFR172.403.
    i. Verify that the appropriate placards have been applied in accordance with 49CFR172.500.
    j. Verify that all required information is recorded on the shipping documentation.

Following the above checks, the Transport Package is released for shipment.

Table 7.1.1

HI-STAR 180L Package Torque Requirements (Note 6)

Fastener (See Note 1)	**Recommended Torque (N-m), τ** (See Note 2)	**Minimum Total Bolt Preload** kN (See Note 7)	**Comments**
Inner Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	39,990	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Outer Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	28,940	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Inner Closure Lid Port Cover Bolts	See Note 3	171	None
Outer Closure Lid Access Port Plug	See Note 3	38	None
Top and Bottom Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Top and Bottom Impact Limiter Adapters Bolts/Nuts	"Snug Tight"	N/A	None

Notes continued on next page:

Table 7.1.1

HI-STAR 180L Package Torque Requirements (continued)

Notes:

1. Fasteners shall be cleaned and inspected for damage or excessive wear (replaced if necessary) and coated with a light layer of lubricant, such as Fel-Pro Chemical Products, N-5000, Nuclear Grade Lubricant.
2. For conversion from Newton-meter (N-m) to foot pounds (ft-lb) divide by 1.356.
3. The nominal bolt torque, τ, is given by the semi-empirical formula,

   $\tau = (P_B)(K)(d)$

   where, K = Torque coefficient

   The torque coefficient, K, varies depending on bolt lubricant used (e.g. extremely effective lubricants such as Bowman Anti-Sieze have a K value = 0.12)

   P_B = Minimum Bolt Preload.

   d = Nominal bolt diameter (soft conversion between metric and US units is permitted)

   Fastener sizes are provided in the drawing package.
4. Detorquing shall be performed by turning the bolts counter-clockwise in 1/3 turn +/- 30 degrees increments per pass for three passes. The bolts may then be removed.
5. Values listed are for the minimum number of passes permitted. Additional intermediate passes are permitted.
6. For empty packages, alternate torque requirements may be used with Holtec approval.
7. To determine individual bolt preload required, divide the total shown by the number of bolts for the lid/cover.

Table 7.1.2

Cask Drying Method and Dryness Criteria

Fuel Burnup (MWD/MTU)	**Heat Load (kW)**	**Method of Moisture Removal (Note 1)**
All Fuel Assembly Burnups	Up to maximum cask heat load in Table 7.D.1 Q_{DB}	Forced Helium Dehydration
		Vacuum Drying (continuous and cyclic) (Note 2)
Recommended Dryness Criteria (Note 1)		
Forced Helium Dehydration	Temperature or dew point of gas exiting the FHD demoisturizer, T_{FHD}	≤ -5.0°C (22.9°F)
	Duration of gas circulation at T_{FHD}	≥ 30 minutes
Vacuum Drying (continuous and cyclic)	Cask cavity vacuum pressure, P_{VAC}	≤ 0.4 kPa (3 Torr)
	Duration of isolated cask cavity at P_{VAC}	≥ 30 minutes

Notes:
1. Users shall refer to Table 7.1.3 for criteria applicable to cask drying operations.
2. Time limits may be applicable.

Table 7.1.3

Criteria Applicable to Cask Drying Operations

Criterion	Specification
Fuel Cladding Temperature Limit	400°C (752°F) (High Burnup Fuel)
	570°C (1058°F) (Moderate Burnup Fuel)
Fuel Cladding Temperature Excursion During Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision
Thermal Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision

Table 7.1.4

Cask Backfill Requirements

Cask Space	**Reference Pressure or Pressure Range**
Cask Cavity Space (Notes 1 and 2)	20 kPa (2.9 psia) to 200 kPa (29 psia) absolute pressure
Cask Inter-Lid Space (Notes 1 and 3)	0 kPa (0 psig) to 17.2 kPa (2.5 psig) gauge pressure
Inner Closure Lid Port Space	atmospheric
Recommended Backfill Gas	
Type	Helium
Reference Purity	99.99% Nom.

Notes:

1. The reference pressure is based on a reference cask space bulk temperature of ≥ 21.1^{o}C (70^{o}F)
2. Following cask drying operations, the gas temperature inside the cask cavity will be higher than 21.1^{o}C (70^{o}F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the cask cavity pressure is within the pressure range is sufficient to establish the proper backfill conditions.
3. For ambient temperatures above 21.1^{o}C (70^{o}F), the gas temperature in the inter-lid cavity will be higher than 21.1^{o}C (70^{o}F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the inter-lid cavity pressure is sufficient to establish the proper backfill conditions. For ambient temperatures below 21.1^{o}C (70^{o}F), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1^{o}C (70^{o}F) using the ideal gas law. Use of pressure gauges to confirm that the inter-lid cavity pressure is between the adjusted limits is sufficient to establish the proper backfill conditions.

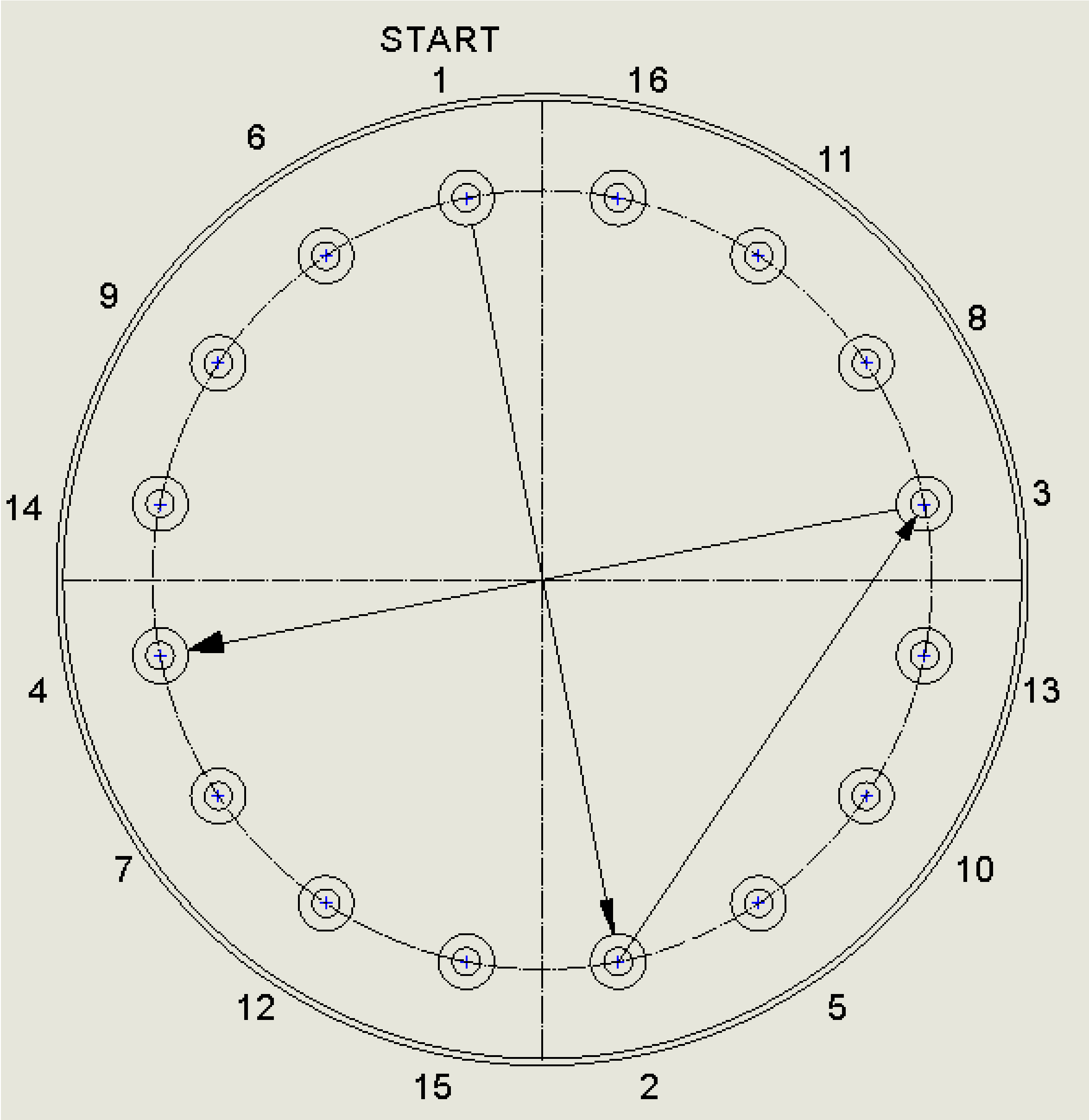
Table 7.1.5

Quiver Operational Requirements

Criterion	**Specification**
Condition of Fuel Rods	Either broken fuel rods or fuel debris or otherwise punctured fuel rods with nominal 3 mm or larger opening
Dryness	≤ 0.4 kPa (3 Torr)
Backfill Pressure	20 kPa (2.9 psig) to 40 kPa (5.8 psig) gauge pressure
Backfill Gas	99% Nom. purity Helium
Leaktightness	≤ $1\text{x}10^{-7}$ ref-cm^3/s air ($1\text{x}10^{-8}$ Pa-m^3/s air)

Notes:

1. The reference pressure is based on a reference quiver space bulk temperature of ≥ 21.1°C (70°F).
2. For ambient temperatures above 21.1°C (70°F), the gas temperature in the quiver cavity will be higher than 21.1°C (70°F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the quiver cavity pressure is sufficient to establish the proper backfill conditions. For ambient temperatures below 21.1°C (70°F), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1°C (70°F) using the ideal gas law. Use of pressure gauges to confirm that the quiver cavity pressure is between the adjusted limits is sufficient to establish the proper backfill conditions.



Note: It is important that all bolted joints be tightened uniformly and in a diametrically staggered pattern as shown in the reference illustration above. Due to the large diameter of the cask closure lids and other factors, the standard star pattern with added flexibility is permitted with Holtec approval. Tools designed to torque more than one bolt at a time (e.g. bolts 1 and 2 simultaneously) may be implemented and are recommended as good ALARA practice. Alternate patterns shall be approved by Holtec.

FIGURE 7.1.1

RECOMMENDED BOLT TIGHTENING PROCEDURE

7.2 PACKAGE UNLOADING

In the event the HI-STAR 180L Package needs to be unloaded, the essential elements required to prepare the package for fuel unloading, to cool the stored fuel assemblies in the cask, to flood the internal cavity, to remove the lids and bolts, to unload the spent fuel assemblies and quivers, and to recover the cask are described below.

7.2.1 Receipt of Package from Carrier

1. The HI-STAR 180L Package is received from the carrier and inspected to verify that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. Any issues are identified to site management.
2. The personnel barrier, if used, is removed and the security seal installed on the top impact limiter is inspected to verify there was no tampering and that it matches the corresponding shipping documents.
3. Radiological surveys are performed in accordance with 49CFR173.443 and 10CFR20.1906. If necessary, the HI-STAR 180L Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties. For packages containing HBF, the radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The location of measurements shall correspond to the same locations recorded for Subsection 7.1.3. The measurements shall be recorded in the shipping documents.
4. For packages containing HBF, surface temperature measurements shall include the surface temperature measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The location of measurements shall correspond to the same locations recorded for Subsection 7.1.3. Ambient conditions (air temperature, date, time of day and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements.

ALARA Warning:
Dose rates around the unshielded bottom end of the HI-STAR 180L cask may be higher than other locations around the cask. After the impact limiter is removed, the cask should be upended promptly. Personnel should remain clear of the bottom of the unshielded cask and exercise other appropriate ALARA controls.

5. The impact limiters with adapters and tie-down system are removed.
6. The cask is visually inspected to verify there are no outward visual indications of impaired physical conditions and a radiation survey and a removable contamination survey are performed to establish appropriate radiological controls. Any issues are identified to site management.

Note:

If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

7. The trunnion hole plugs are removed and the cask trunnions are installed. The cask is upended and returned to the fuel building or other unloading area.
8. The cask is placed in the designated preparation area.

7.2.2 Removal of Contents

1. The outer lid access port cover is removed and a gas sample is drawn from the inter-lid space to determine radiological conditions.
2. The inter-lid space gas is handled in accordance with Radiation Protection directions and the outer closure lid is removed.
3. The inner closure lid port covers are removed to access the vent and drain ports.

ALARA Warning:

Gas sampling is performed to assess the condition of the fuel cladding. If a leak is discovered in the fuel cladding, the user's Radiation Control organization may require special actions to vent the cask cavity.

Caution:

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

4. A temporary attachment is connected to the vent port to open the vent port tube cap/plug and a gas sample from inside the cask cavity is collected. A gas sample analysis is performed to assess the condition of the fuel assembly cladding. As necessary during preparation for lid removal, the gas inside the cask cavity is handled/vented to an approved location. Depending on cask cavity pressure, the cavity may require additional backfill or venting to equalize its pressure to atmospheric.
5. If the cask is to be unloaded under water, the cask is filled with water at a controlled rate to minimize thermal shock to the fuel assemblies and to avoid over-pressurizing the cask from the formation of steam. The effluent is directed to the spent fuel pool or other approved discharge point.

6. If the cask is not immediately moved to the spent fuel pool, water is circulated through the cask to cool the contents and allow for establishment of a Time-To-Boil time limit. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to placement of the cask in the spent fuel pool. If it appears that the Time-to-Boil limit will be exceeded prior to placement of the cask in the spent fuel pool, the user shall take appropriate action to circulate water through the cask cavity to reset the Time-to-Boil clock.

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

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

8. The lift attachment is engaged to the lifting trunnions and the cask is placed in the spent fuel pool or other appropriate unloading area. The inner closure lid is removed.

9. All fuel assemblies and quivers are returned to the spent fuel storage racks and the cask fuel cells are vacuumed to remove any assembly debris and crud.

10. The fuel cells are inspected for any remaining items to be removed as appropriate.

ALARA Warning:
Activated debris may have settled on flat surfaces of the cask during fuel unloading. Surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce contamination of the cask, the surfaces of the cask and lift yoke should be kept wet until decontamination can begin.

11. The cask is returned to the designated preparation area and any water is pumped back into the spent fuel pool, liquid radwaste system or other approved location as necessary.

12. The cask is decontaminated as directed by site Radiation Protection personnel. Outer surfaces of the cask are decontaminated to remove surface contamination to the level necessary to allow for proper cask transport, loading, or storage as applicable.

7.3 PREPARATION FOR SHIPMENT OF AN EMPTY CASK

7.3.1 Overview of Empty Package Transport

The essential elements and minimum requirements for preparing an empty package (previously used) for transport are similar to those required for transporting the loaded package with some differences. A survey for removable contamination is performed to verify that the removable contamination on the internal and external surfaces of the cask is ALARA and that the limits of 49CFR173.428 and 10CFR71.87(i) [7.1.4] are met. At the user's discretion, impact limiters and/or personnel barrier are installed. The procedures provided herein describe the installation of the impact limiters and personnel barrier. These steps may be omitted, as appropriate.

7.3.2 Preparation for Empty Package Shipment

1. The containment closure flange inner closure lid sealing surface protector is removed from the cask, if necessary.
2. The cask is surveyed for contamination and verified to be empty and contain less than 15 gm U-235 in accordance with 49CFR173.421(a)(5)
3. The inner closure lid is installed and the bolts are torqued. See Table 7.1.1 for torque requirements.
4. The inner closure lid port covers are installed if necessary.
5. The containment flange outer closure lid sealing surface protector is removed, if necessary, the outer closure lid is installed, and the bolts are torqued. See Table 7.1.1 for torque requirements. If desired, a security seal may be attached to the outer closure lid bolts.
6. The outer closure lid access port plug and access port cover are installed if necessary.

Note:

If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

7. The cask is downended and positioned on the transport equipment.
8. A final inspection of the cask is performed and includes the following:
   - A final survey for removable contamination on the accessible external surfaces of the cask in accordance with 49CFR173.443(a). If necessary, the cask is decontaminated to meet the survey requirements.

- A radiation survey of the cask to confirm that the radiation levels on any external surface of the cask do not exceed the levels required by 49CFR173.421(a)(2). Any issues are identified to site management and the cask is decontaminated as directed by site radiation protection.
- A visual inspection of the cask to verify that there are no outward visual indications of impaired physical condition except for superficial marks and dents and that the empty package is securely closed in accordance with 49CFR173.428(b).
- Verification that the cask neutron shield pressure relief devices are installed, are intact and are not covered by tape or other covering.

9. If desired, the cask trunnions are removed, the trunnion hole plugs are installed, the impact limiters are installed, and the impact limiter bolts/nuts are torqued. (See Table 7.1.1 for torque requirements.)
10. If desired, a security seal is installed on the top impact limiter.
11. Final radiation surveys of the empty package surfaces are performed per 10CFR71.47, and 49CFR173.428(a).
12. If desired, the personnel barrier and personnel barrier locks are installed, and the personnel barrier keys are transferred to the carrier.
13. A final check to ensure that the empty package is ready for release is performed and includes the following checks:
    - Verification that the receiver has been notified of the impending shipment.
    - Verification that any labels previously applied in conformance with Subpart E of 49CFR172 have been removed, obliterated, or covered and the "Empty" label prescribed in 49CFR172.450 is affixed to the packaging in accordance with 49CFR173.428(e).
    - Verification that the empty package for shipment is prepared in accordance with 49CFR173.422.
    - Verification that all required information is recorded on the shipping documentation.
14. The empty package is then released for shipment.

7.4 OTHER OPERATIONS

There are no other operations for the HI-STAR 180L Package with regard to provisions for any special operational controls (e.g., route, weather, shipping time restrictions, etc.). Essential operations and conditions are detailed in this chapter.

CHAPTER 7 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table.

[7.1.1] *U.S. Code of Federal Regulations,* Title 49 “Transportation”, Part 172 "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements and Security Plans."

[7.1.2] *U.S. Code of Federal Regulations,* Title 49 “Transportation”, Part 173, "Shippers – General Requirements for Shipments and Packagings,"

[7.1.3] *U.S. Code of Federal Regulations,* Title 10, “Energy”, Part 20 "Standards for Protection against Radiation".

[7.1.4] *U.S. Code of Federal Regulations,* Title 10, “Energy”, Part 71 "Packaging and Transportation of Radioactive Material"

APPENDIX 7.A

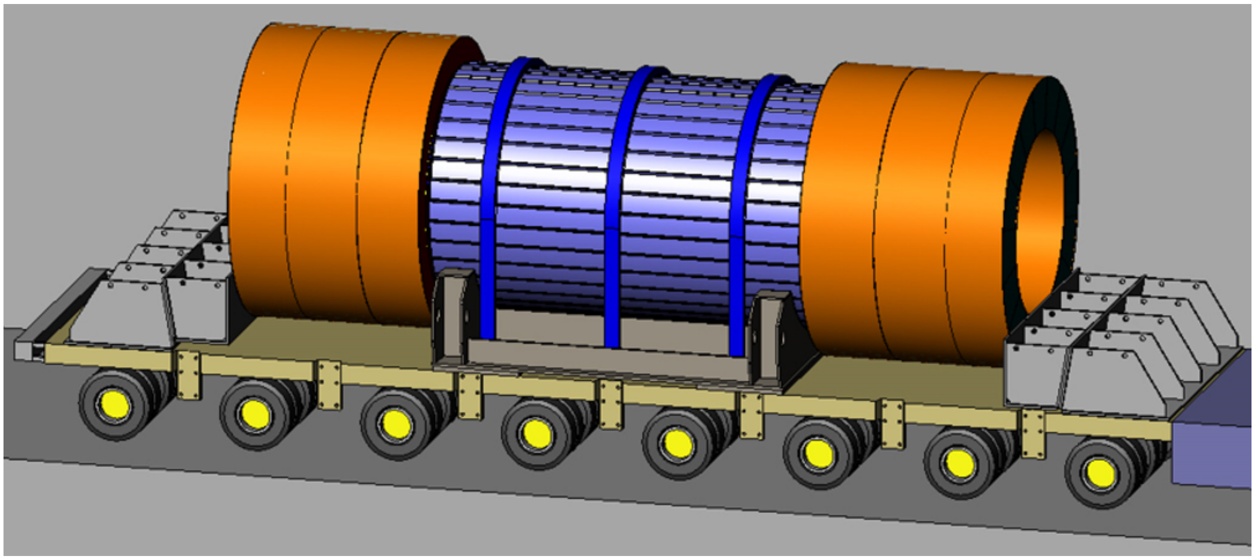
GENERAL WEIGHTS AND EXAMPLE ILLUSTRATIONS OF TYPICAL LOADING OPERATIONS

Table 7.A.1: General Transport Weights of HI-STAR 180L

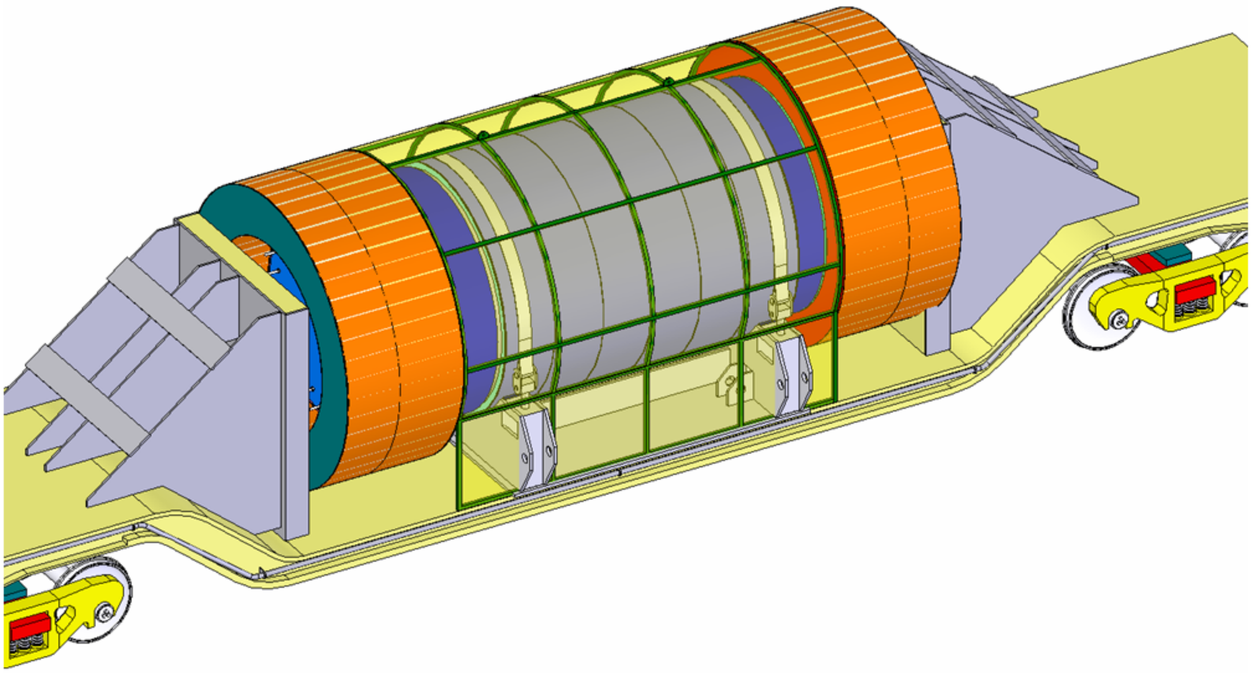
Item	**Value** (kg)
Maximum Gross Transport Weight of Package (includes Impact Limiters, F-69L Fuel Basket w/ authorized contents, no Personnel Barrier)	See Licensing Drawing Package
Maximum Weight of Loaded Cask (includes F-69L Fuel Basket w/ authorized contents)	See Licensing Drawing Package
Nominal Empty Packaging Weight (with Impact Limiters and Adapters, F-69L Fuel Basket and Basket Shims, no Personnel Barrier) – Note 1	129,560
Nominal Empty Cask (with F-69L Fuel Basket and Basket Shims) – Note 1	104,230
Nominal Empty Cask (no basket or shims) – Note 1	96,990

Notes:

1. Weight is representative based upon CAD models and provided for information only. Weights include cask lids and bolting. Lifting, handling and tie down evaluations are performed using bounding weights.



ROAD TRANSPORT WITH PERSONNEL BARRIER NOT INSTALLED



RAIL TRANSPORT WITH PERSONNEL BARRIER INSTALLED

FIGURE 7.A.1: GENERAL ARRANGEMENT OF THE HI-STAR 180L ON A TRANSPORT VEHICLE WITH IMPACT LIMITER, AND TIE-DOWNS ATTACHED. (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

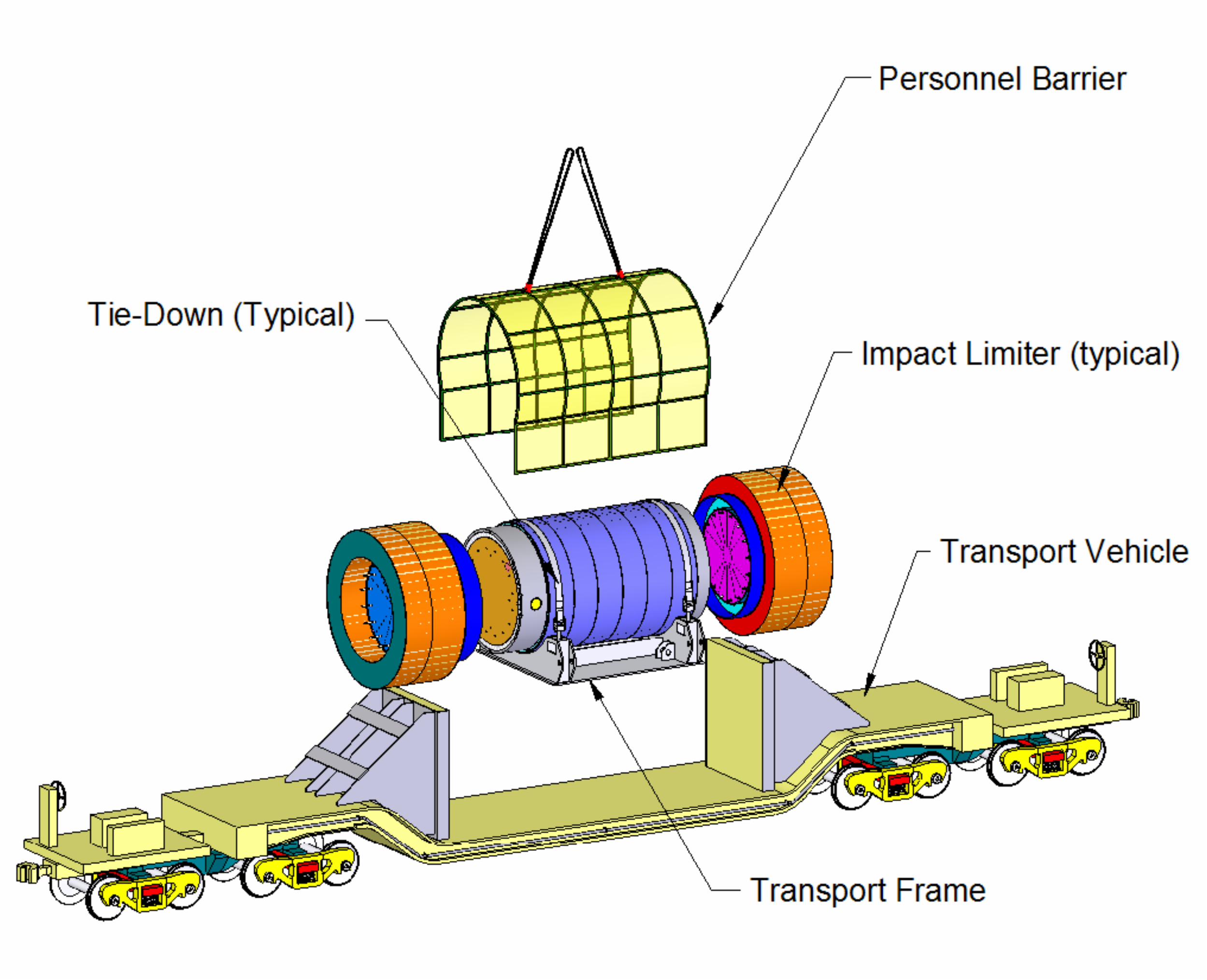


FIGURE 7.A.2: HI-STAR 180L TRANSPORT ASSEMBLY ON RAIL CAR
(EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

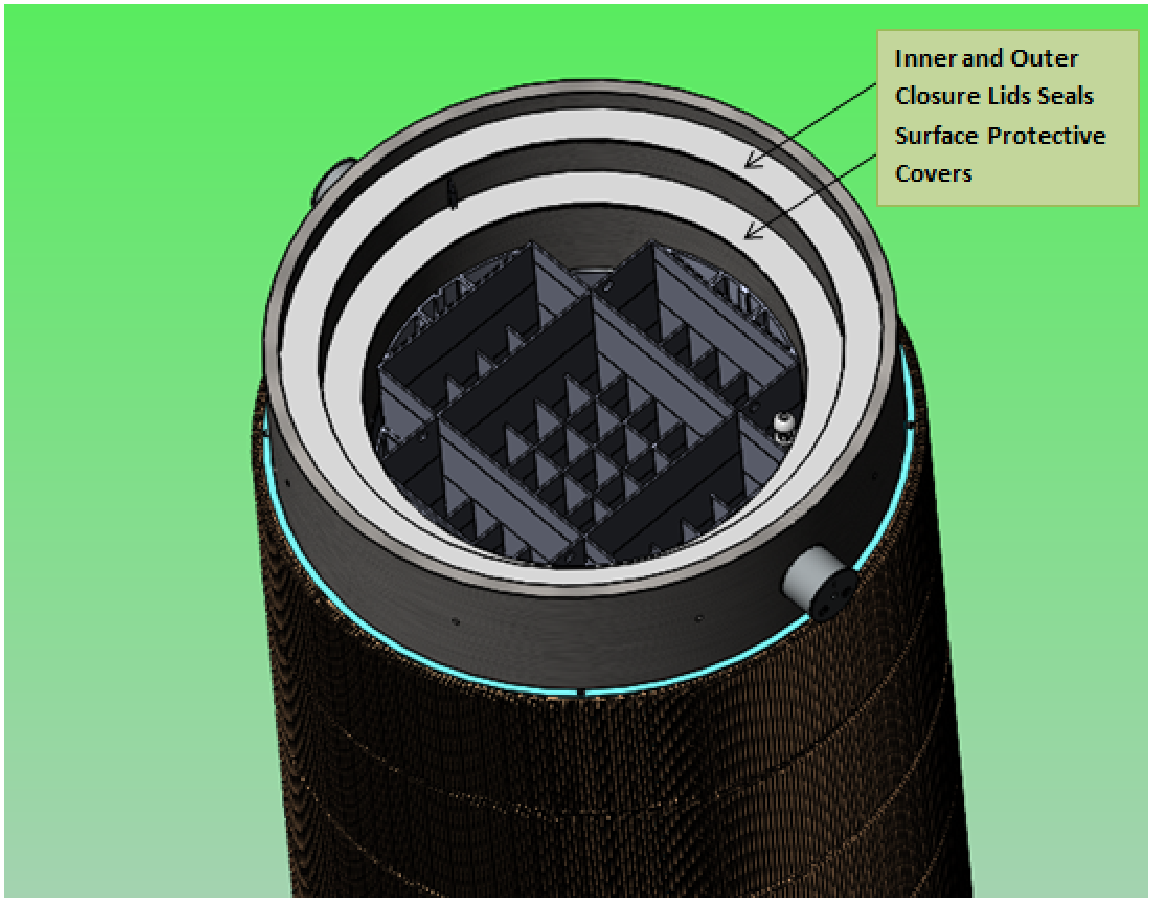


FIGURE 7.A.3: HI-STAR 180L SHOWN WITH INNER AND OUTER CLOSURE LIDS REMOVED AND SEALING SURFACE PROTECTIVE COVERS INSTALLED ON THE CONTAINMENT CLOSURE FLANGE (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

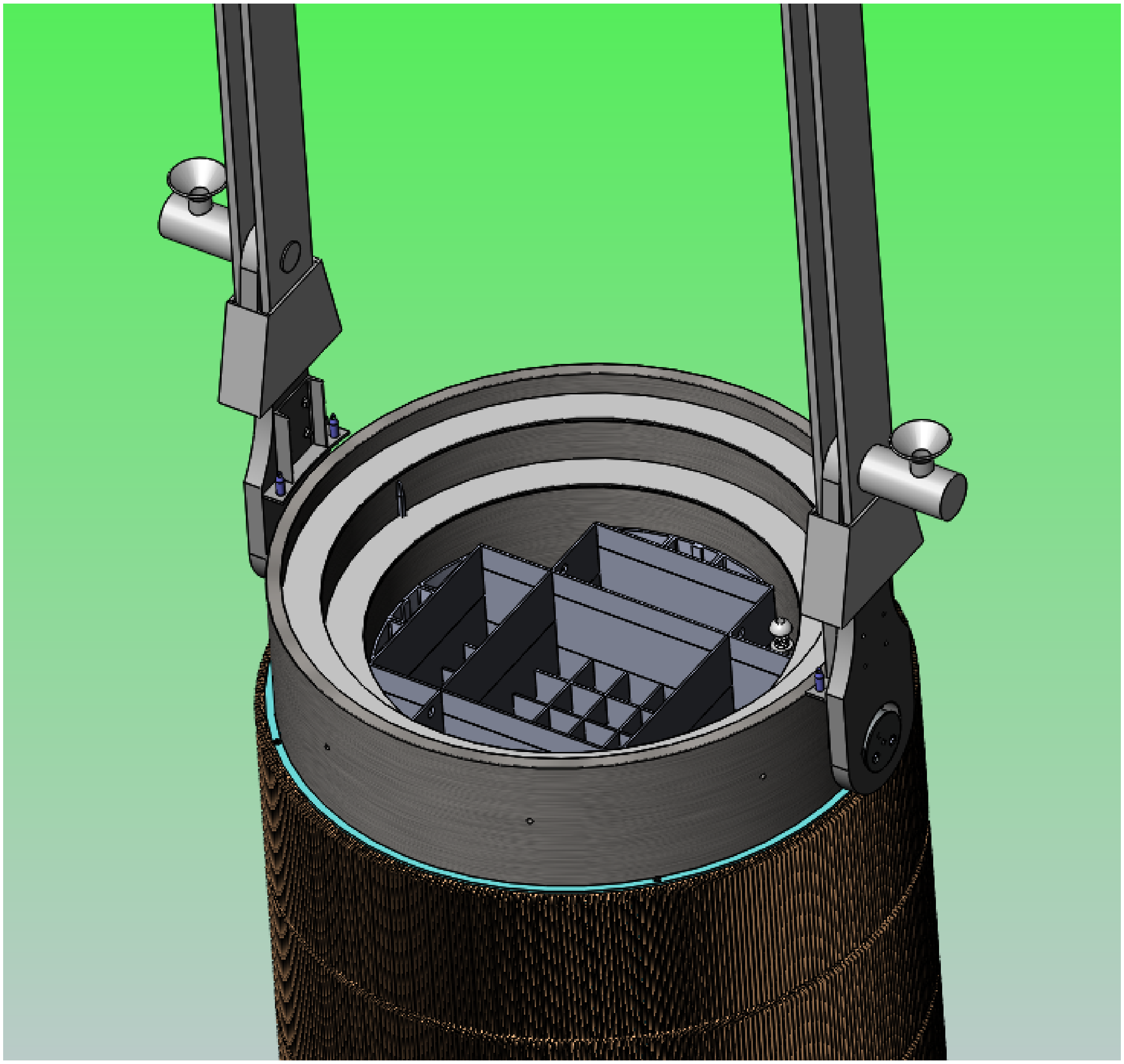


FIGURE 7.A.4: HI-STAR 180L SHOWN BEING LOADED INTO THE SPENT FUEL POOL (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

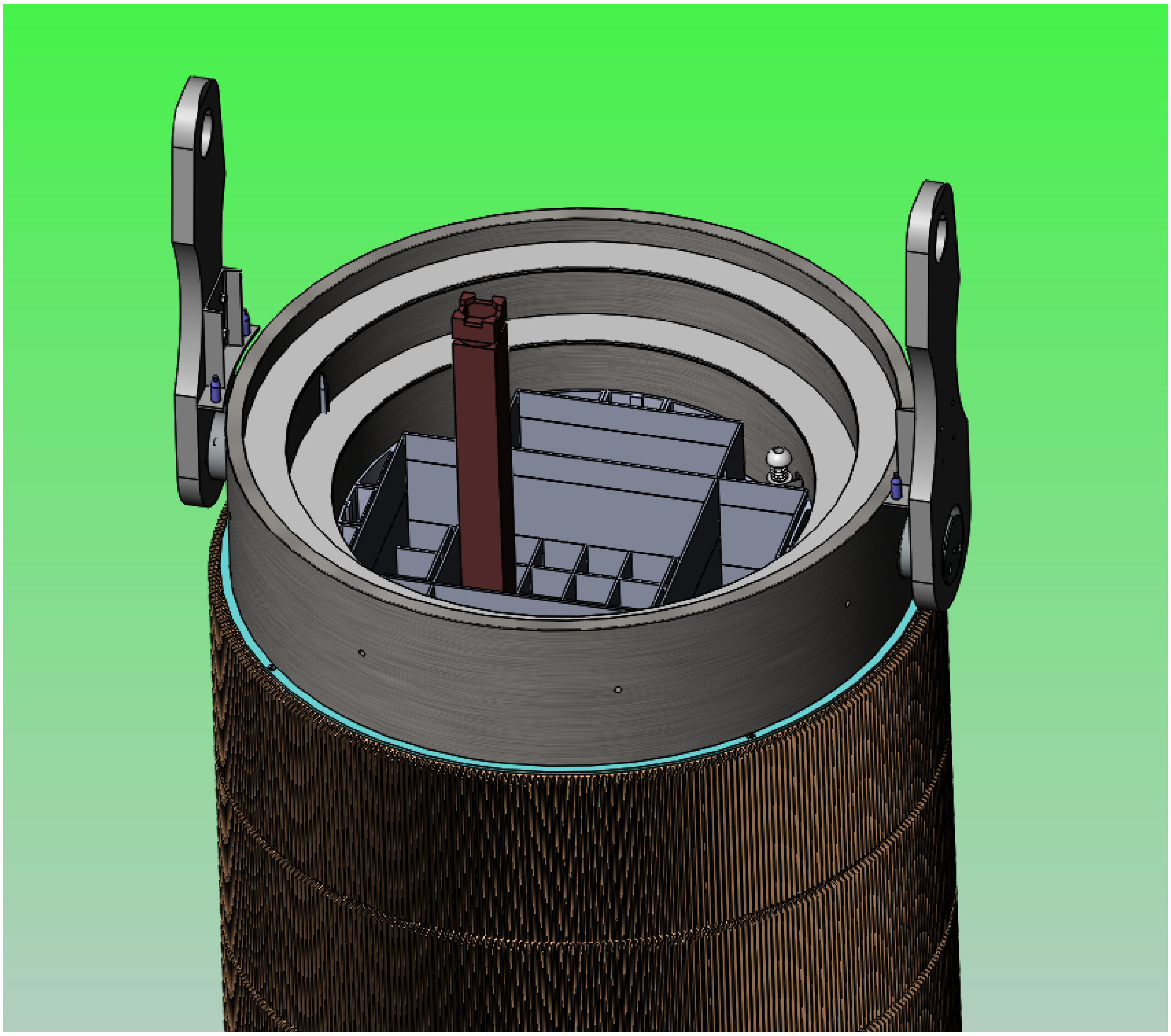


FIGURE 7.A.5: SPENT FUEL ASSEMBLY LOADING IN THE HI-STAR 180L (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

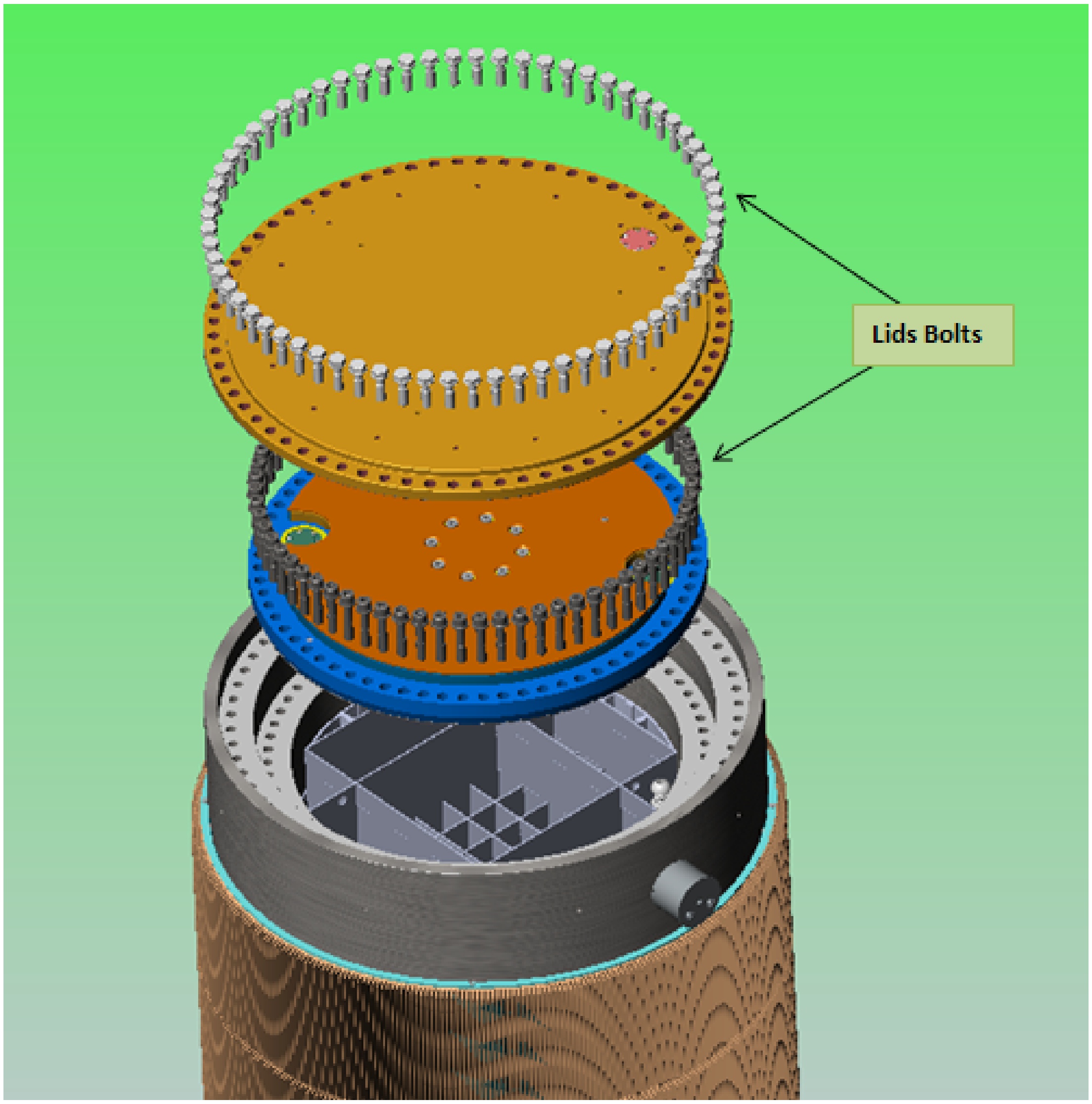


FIGURE 7.A.6: HI-STAR 180L INNER AND OUTER CLOSURE LIDS, AND BOLTS EXPLODED VIEW. NOTE INNER COSURE LID IS INSTALLED IN THE POOL FOLLOWING FUEL LOADING AND OUTER CLOSURE LID IS INSTALLED FOLLOWING REMOVAL OF LOADED CASK FROM THE POOL AND PLACEMENT IN THE DESIGNATED PREPARATION AREA

(EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

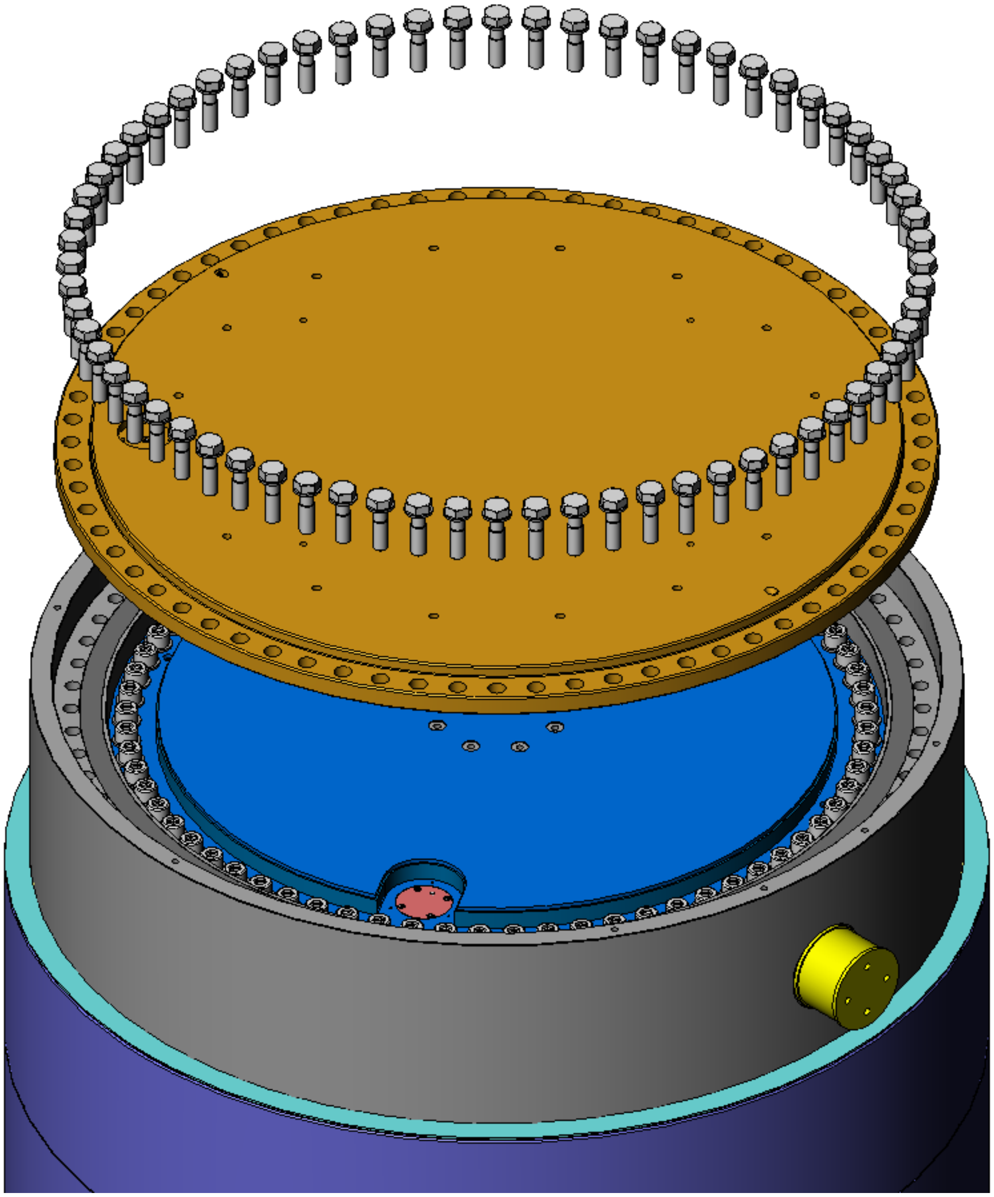


FIGURE 7.A.7: HI-STAR 180L OUTER CLOSURE LID EXPLODED VIEW (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

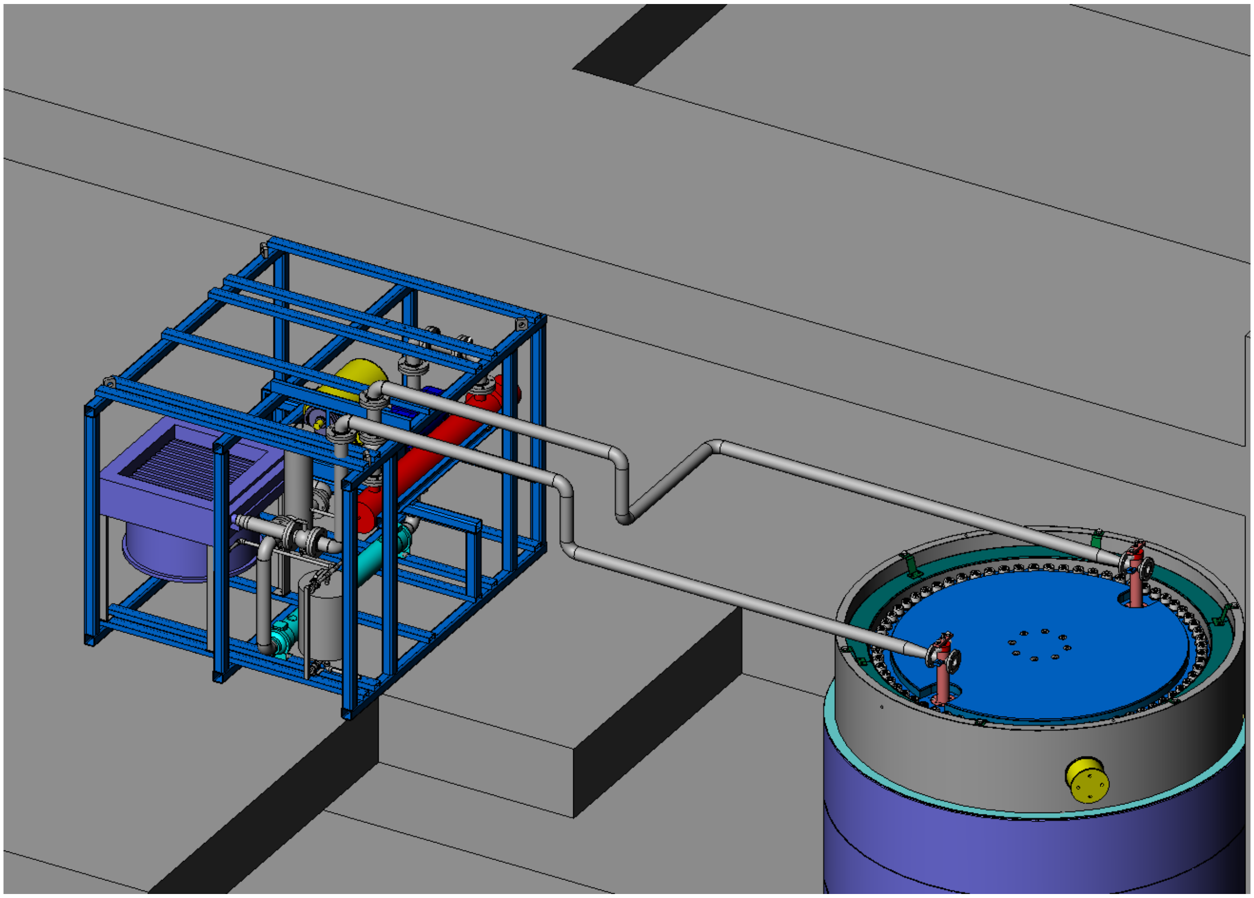


FIGURE 7.A.8: HI-STAR 180L SHOWN DURING DEWATERING, DRYING AND BACKFILL OPERATIONS, WHICH OCCURS PRIOR TO OUTER CLOSURE LID INSTALLATION (EXAMPLE CONFIGURATION FOR ILLUSTRATION ONLY, ACTUAL CONFIGURATION IS DEPENDENT UPON PLANT SYSTEMS)

APPENDIX 7.B AND APPENDIX 7.C

Intentionally Not Used

APPENDIX 7.D

CONTENT CONDITIONS OF THE HI-STAR 180L PACKAGE

Table 7.D.1

ALLOWABLE CONTENTS
(SHEET 1 of 2)

Item	Reference data
High Level Waste	Commercial Spent Nuclear Fuel (CSF): Uranium oxide ZR clad BWR SNF and separated fuel rods meeting the limits in Table 7.D.2 for the applicable array/class. Non-Fuel Hardware: None Non-Fuel Waste: None
Other Radioactive Waste	None
Ancillary Containers	Quivers
Fuel Cladding Type	ZR
Minimum Initial Fuel Rod Enrichment	0.7 wt. % U-235 (See Table 7.D.3 for other limitations)
Maximum Initial Fuel Rod Enrichment	5.0 wt. % U-235 (See Table 7.D.2 for other limitations)
Fuel assembly post-irradiation cooling time	2 years (See Table 7.D.3 for other limitations)
Fuel Assembly Post-Irradiation Maximum Average Burnup Per Assembly	66 GWd/MTU (See Table 7.D.3 for other limitations)
Fuel Assembly Length	≤ 4481 mm (nominal design) for fuel including fuel spacer ≤ 4495 mm (nominal design) for quiver
Fuel Assembly Weight	≤ 330 kg for fuel assembly including fuel spacer ≤ 330 kg for loaded quiver
Maximum Cask Heat Load	35 kW
Maximum Heat Load per Basket Quadrant	8.75 kW
Maximum Fuel Assembly Heat Load (per cell heat load)	See Figures 7.D.1 and 7.D.2
Maximum Quiver Heat Load (heat load for each quiver location)	0.5 kW

Table 7.D.1

ALLOWABLE CONTENTS
(SHEET 2 of 2)

Other Limitations
▪ Two general loading configurations are allowed as follows: Configuration 1: Up to 69 undamaged fuel assemblies and/or dummy fuel assemblies. Configuration 2: Up to 69 undamaged fuel assemblies and/or dummy fuel assemblies of which up to 4 may be quivers, each containing up to 28 fuel rods (fuel rods in quivers may be leaking, broken or fragmented and/or if needed, purposely punctured to relieve internal pressure). ▪ Partially loaded casks must contain at least 48 loaded basket locations (i.e. the equivalent mass of 48 fuel assemblies allowed by Table 7.D.2) with contents evenly spread to the extent practical. Dummy fuel assemblies may be used to achieve the required mass. ▪ Fuel assemblies may be channeled or unchanneled. ▪ Allowable fuel assembly array and class with associated fuel assembly characteristics are specified in Table 7.D.2. ▪ Allowable loading patterns are specified in Table 7.D.3 with fuel specifications for burnup, enrichment and cooling time in Table 7.D.4. ▪ Basket regions are defined in Table 7.D.5 and Figures 7.D.1 and 7.D.2. ▪ Quivers are restricted to the cell locations specified in Figures 7.D.1 and 7.D.2. Quivers must be prepared for loading as specified in Section 7.1 of this SAR and meet the requirements specified in Table 7.1.5. ▪ Contents must not exceed the maximum cask heat load, the maximum quadrant heat load and the per cell hear load. ▪ The maximum basket quadrant heat load must be met by each basket quadrant identified in Figures 7.D.1 and 7.D.2. The total additive heat load in each quadrant shall not exceed the quadrant heat load limit specified in this Table. Because the basket quadrants share storage cell locations, the following equations are specified to ensure total heat load per quadrant is not exceeded. o Quadrant No. 1: Actual quadrant heat load = (1/2)3 + 4 + 5 + (1/2)9 + 10 + 11 + 12 + (1/2)17 + 18 + 19 + 20 + 21 + (1/2)26 + 27 + 28 + 29 + 30 + (1/4)35 + (1/2)36 + (1/2)37 + (1/2)38 + (1/2)39 o Quadrant No. 2: Actual quadrant heat load = (1/4)35 + (1/2)36 + (1/2)37 + (1/2)38 + (1/2)39 + (1/2)44 + 45 + 46 + 47 + 48 + (1/2)53 + 54+ 55 + 56 + 57 + (1/2)61 + 62 + 63 + 64 + (1/2)67 + 68 + 69 o Quadrant No. 3: Actual quadrant heat load = (1/2)31 +(1/2)32 + (1/2)33 + (1/2)34 + (1/4)35 + 40 + 41 + 42 + 43 + (1/2)44 + 49 + 50 + 51 + 52 + (1/2)53 + 58 + 59 + 60 + (1/2)61 + 65 + 66 + (1/2)67 o Quadrant No. 4: Actual quadrant heat load = 1 + 2 + (1/2)3 + 6 + 7 + 8 + (1/2)9 + 13 + 14 + 15 + 16 + (1/2)17 + 22 + 23 + 24 + 25 + (1/2)26 + (1/2)31 + (1/2)32 + (1/2)33 + (1/2)34 + (1/4)35 Note: Values in fractions denote the quadrant's share of specific storage cell heat loads. Whole numbers in the above equations denote the decay heat in that cell number.

Table 7.D.2

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
(SHEET 1 of 6)

Fuel Assembly Array/Class	**8x8L1**	**8x8L2**	**8x8L3**	**8x8L4**	**8x8L5**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 5	≤ 5	≤ 4.9	≤ 4.8	≤ 4.8
No. of Fuel Rod Locations	62	62	62	60	64
Fuel Clad O.D. (mm)	≥12.268	≥12.268	≥12.2682	≥12.2682	≥ 11.63
Fuel Clad I.D. (mm)	≤10.643	≤10.414	≤10.7942	≤10.6426	≤ 10.15
Fuel Pellet Dia. (mm)	≤10.41	≤10.41	≤ 10.44	≤10.44	≤ 9.94
Fuel Rod Pitch (mm)	≤ 16.154	≤ 16.154	≤ 16.154	≤ 16.256	≤ 15.5
Active Fuel Length (mm) (Note 16)	≤ 3816.35	≤ 3816.4	≤ 3816.4	≤ 3816.4	≤ 3822.5
No. of Water Rods (Note 17)	2	2	2	1 (Note 2)	N/A (Note 3)
Water Rod Thickness (mm)	≥ 0.762	≥ 0.762	≥ 0.762	≥ 1.016	N/A
Channel Thickness (mm)	≤ 3.3782	≤ 3.3782	≤ 3.3782	≤ 4.5215	≤ 1.4

Table 7.D.2

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
(SHEET 2 of 6)

Fuel Assembly Array/Class	**9x9L1**	**9x9L2**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.6	≤ 4.5
No. of Fuel Rod Locations	74 (Note 4)	72
Fuel Clad O.D. (mm)	≥11.176	≥ 11
Fuel Clad I.D. (mm)	≤9.7536	≤ 9.5
Fuel Pellet Dia. (mm)	≤9.55	≤ 9.5
Fuel Rod Pitch (mm)	≤ 14.3764	≤ 14.3
Active Fuel Length (mm) (Note 16)	≤ 3714.8	≤ 3810
No. of Water Rods (Note 17)	2 (Note 5)	1 (Note 6)
Water Rod Thickness (mm)	≥ 0 (Note 19)	≥ 0.725
Channel Thickness (mm)	≤ 4.5215	≤ 3.048

Table 7.D.2

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
SHEET 3 of 6

Fuel Assembly Array/Class	**10x10L1**	**10x10L2**	**10x10L3**	**10x10L4**	**10x10L5**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.7	≤ 4.8	≤ 4.8	≤ 5.0 (Note 18)	≤ 4.8
No. of Fuel Rod Locations	92 (Note 7)	91 (Note 8)	91 (Note 9)	91 (Note 10)	96
Fuel Clad O.D. (mm)	≥ 10.26	≥ 10.05	≥ 10.28	≥ 10.28	≥ 9.62
Fuel Clad I.D. (mm)	≤ 8.94	≤ 8.84	≤ 9.04	≤ 9.04	≤ 8.38
Fuel Pellet Dia. (mm)	≤ 8.76	≤ 8.67	≤ 8.883	≤ 8.883	≤ 8.19
Fuel Rod Pitch (mm)	≤ 12.95	≤ 12.95	≤ 12.95	≤ 12.95	≤ 12.4
Active Fuel Length (mm) (Note 16)	≤ 3765.6	≤ 3818	≤ 3818	≤ 3818	≤ 3820.5
No. of Water Rods (Note 17)	2 (Note 2)	1 (Note 6)	1 (Note 6)	1 (Note 6)	5 (Note 11)
Water Rod Thickness (mm)	≥ 0.76	≥ 0.725	≥ 0.80	≥ 0.80	≥ 0.80
Channel Thickness (mm)	≤ 3.0505	≤ 3.1	≤ 3.1	≤ 3.105	≤ 2.5

Table 7.D.2

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
SHEET 4 of 6

Fuel Assembly Array/Class	**10x10L6**	**10x10L7**	**10x10L8**	**10x10L9**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.8	≤ 4.33	≤ 5	≤ 5
No. of Fuel Rod Locations	96	96 (Note 12)	96 (Note 13)	96 (Note 13)
Fuel Clad O.D. (mm)	≥ 9.62	≥ 9.62	≥ 9.84	≥ 9.84
Fuel Clad I.D. (mm)	≤ 8.36	≤ 8.94	≤ 8.63	≤ 8.63
Fuel Pellet Dia. (mm)	≤ 8.19	≤ 8.77	≤ 8.48	≤ 8.48
Fuel Rod Pitch (mm)	≤ 12.4	≤ 12.7	≤ 11.9	≤ 12.2
Active Fuel Length (mm) (Note 16)	≤ 3820.5	≤ 3820.5	≤ 3820.5	≤ 3820
No. of Water Rods (Note 17)	5 (Note 11)	5 (Note 11)	5 (Note 11)	5 (Note 11)
Water Rod Thickness (mm)	≥ 0.80	≥ 0.80	≥ 0.80	≥ 0.80
Channel Thickness (mm)	≤ 2.5	≤ 2.5	≤ 1.4	≤ 1.4

Table 7.D.2

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
SHEET 5 of 6

Fuel Assembly Array/Class	**11x11L1**
Maximum Planar-Average Initial Enrichment (wt.% ^{235}U)	≤ 4.735
No. of Fuel Rod Locations	112 (Note 14)
Fuel Clad O.D. (mm)	≥9.40
Fuel Clad I.D. (mm)	≤8.26
Fuel Pellet Dia. (mm)	≤8.11
Fuel Rod Pitch (mm)	≤ 11.95 (Note 15)
Active Fuel Length (mm) (Note 16)	≤ 3818
No. of Water Rods (Note 17)	1 (Note 6)
Water Rod Thickness (mm)	≥ 0.85
Channel Thickness (mm)	≤ 1.8

Table 7.D.2
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1)
SHEET 6 of 6

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/type.
2. Each water rod replacing 4 fuel rods.
3. The assembly is known as “QUAD+.” It has four rectangular water cross segments dividing the assembly into four quadrants.
4. Contains 74 total fuel rods; 66 full length rods and 8 partial length rods.
5. 2 water rods replacing 7 fuel rods.
6. 1 square water box replacing 9 fuel rods.
7. Contains 92 total fuel rods; 78 full length rods and 14 partial length rods.
8. Contains 91 total fuel rods; 83 full length rods and 8 partial length rods.
9. Contains 91 total fuel rods; 81 full length rods and 10 partial length rods.
10. Contains 91 total fuel rods; 79 full length rods and 12 partial length rods.
11. One diamond-shaped water rod replacing the four center fuel rods and four rectangular water rods dividing the assembly into four quadrants.
12. Contains 96 total fuel rods; 88 full length rods and 8 partial length rods.
13. Contains 96 total fuel rods; 84 full length rods, 8 long partial length rods and 4 short partial length rods.
14. Contains 112 total fuel rods; 92 full length rods, 8 long partial length rods and 12 short partial length rods.
15. Various rod pitches may present. However, a bounding average rod pitch along the entire active fuel length is listed and used.
16. Fuel assemblies with axial fuel blankets are allowed for loading.
17. These rods may be sealed at both ends and contain Zr material in lieu of water.
18. Fuel assemblies can be loaded with enrichment up to 4.7 wt% ^{235}U without any gadolinia credit. When loading the fuel assemblies with enrichment more than 4.7 wt% ^{235}U and up to 5.0 wt% ^{235}U, partial gadolinia credit must be considered. See Paragraph 6.3.10.3 for the details of administrative requirements.
19. Water rod tubes are artificially replaced by water in the bounding cases to remove the requirement for water rod thickness.

Table 7.D.3

LOADING PATTERNS FOR F-69L (NOTE 1)

Pattern	Fuel Specification	Cask Heat Load Limits	Quivers Locations
1	Table 7.D.4(a)	Figure 7.D.1	Figure 7.D.1
2	Table 7.D.4(b)	Figure 7.D.1	Figure 7.D.1
3	Table 7.D.4(c)	Figure 7.D.1	Figure 7.D.1
4	Table 7.D.4(d)	Figure 7.D.1	Figure 7.D.1
5	Table 7.D.4(e)	Figure 7.D.1	Figure 7.D.1
6	Table 7.D.4(f)	Figure 7.D.1	Figure 7.D.1
7	Table 7.D.4(g)	Figure 7.D.2	Figure 7.D.2

Note 1: Fuel assemblies transported in the package must conform to requirements of at least one of the loading patterns. In each loading pattern, the fuel specification, the cask heat load limits and the locations of Quivers must be satisfied.

Table 7.D.4 (a):
FUEL SPECIFICATIONS FOR LOADING PATTERN 1 (NOTE 1, 2, 3, 4)
(2 pages)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
1	5	0.7	6	2.5	2	2	2	2.2	2	2	2	2	2	2	3	2	2	2	2	3.1
1	30	1.7	21	15	6.4	2	3.8	16	2	2.1	4	2	2	4.6	6.6	2	4.5	3.8	4	7.2
1	35	2.2	24	17	7.6	2.1	4	19	2	2.2	4.3	2.1	2	5	7.4	2.2	4.9	4.1	4.3	8
1	45	2.5	45	38	16	2.7	4.8	37	3.6	2.9	6.2	3.9	2.4	9.6	13	2.8	9	5.1	5.9	12
1	60	3	69	61	34	12	15	60	16	12	19	16	12	24	27	12	24	16	18	27
1	50	3.1	46	38	16	2.8	4.9	38	3.8	3	6.4	4.1	2.5	10	13	2.9	9.4	5.3	6.2	13
1	43	3.3	27	20	8.4	2.2	4.3	20	2	2.3	4.6	2.2	2	5.4	8.2	2.3	5.3	4.3	4.6	8.8
1	45	3.3	32	25	10	2.4	4.4	24	2.2	2.5	4.9	2.5	2	6	8.6	2.4	5.8	4.5	4.9	9.4
1	48	3.3	39	31	13	2.6	4.6	31	2.8	2.7	5.4	3.1	2.2	7.8	11	2.6	7.4	4.8	5.5	11
1	50	3.3	43	36	15	2.7	4.8	35	3.3	2.8	5.9	3.6	2.4	9	12	2.7	8.6	5.1	5.9	12
1	46	3.4	33	26	11	2.4	4.5	25	2.3	2.5	5	2.6	2	6.2	8.8	2.4	5.9	4.5	5	9.6
1	47	3.4	35	28	12	2.4	4.5	27	2.4	2.6	5.1	2.8	2.1	6.7	9.2	2.5	6.4	4.6	5.2	10
1	48	3.4	38	30	12	2.5	4.6	30	2.6	2.6	5.3	3	2.2	7.4	9.8	2.6	7	4.7	5.4	11
1	62	3.6	60	51	27	6	8	51	10	6	12	10	6	18	20	6	17	10	12	20
1	39	3.7	19	13	4.8	2	3.9	14	2	2.1	4	2	2	4.5	7	2	4.5	3.9	4	7.6
1	49	3.7	36	28	12	2.5	4.6	28	2.5	2.6	5.2	2.8	2.1	6.8	9.4	2.5	6.5	4.7	5.3	11
1	51	3.7	40	32	13	2.6	4.8	32	2.9	2.7	5.6	3.2	2.3	8	11	2.6	7.6	5	5.6	11
1	61	3.7	60	52	26	4.8	7	52	8	5	11	8	4.7	17	20	4.8	17	8.6	11	19
1	55	3.8	47	39	17	2.9	5.1	39	3.9	3	6.6	4.2	2.6	11	13	2.9	9.6	5.6	6.6	13
1	50	3.9	35	28	11	2.5	4.6	27	2.4	2.6	5.2	2.7	2.1	6.6	9.4	2.5	6.3	4.7	5.2	11
1	52	3.9	40	32	13	2.6	4.8	32	2.8	2.7	5.6	3.1	2.3	7.8	11	2.6	7.4	5	5.6	11
1	59	4	53	45	20	3.2	5.4	44	5	3.4	7.8	5.2	3	13	15	3.2	12	6.3	7.8	15
1	61	4	57	48	22	3.5	5.7	48	6.1	3.7	9	6.2	3.3	14	17	3.5	13	6.9	8.8	16
1	54	4.1	41	34	14	2.7	4.9	33	3	2.8	5.9	3.3	2.3	8.2	11	2.7	7.8	5.1	5.9	12
1	56	4.1	45	38	16	2.8	5.1	37	3.5	3	6.4	3.9	2.5	9.6	13	2.9	9	5.5	6.4	13
1	58	4.1	49	41	18	3	5.3	41	4.3	3.2	7.2	4.6	2.8	11	14	3.1	11	5.9	7.2	14
1	63	4.1	59	51	25	3.7	5.8	50	6.8	3.9	9.6	6.8	3.6	15	18	3.7	15	7.4	9.4	18
1	56	4.2	44	36	15	2.8	5	36	3.3	2.9	6.3	3.7	2.5	9.2	12	2.8	8.6	5.4	6.2	12
1	57	4.2	46	38	16	2.9	5.1	38	3.7	3	6.6	4	2.6	9.8	13	2.9	9.4	5.6	6.5	13
1	60	4.2	52	44	20	3.2	5.4	44	4.8	3.4	7.8	5.1	3	12	15	3.2	12	6.3	7.6	15

Table 7.D.4 (a):
FUEL SPECIFICATIONS FOR LOADING PATTERN 1 (NOTE 1, 2, 3, 4)
(2 pages)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
1	54	4.3	39	31	13	2.6	4.8	31	2.7	2.7	5.6	3	2.2	7.6	10	2.6	7.2	5	5.6	11
1	66	4.5	60	51	25	4.1	6.3	51	7.4	4.3	11	7.4	4	16	19	4.1	16	8	10	19
1	15	4.6	6.2	3.1	2	2	2.6	2.9	2	2	2.7	2	2	2.9	4	2	2.9	2.6	2.7	4.1
1	20	4.6	8.2	3.9	2	2	2.9	3.5	2	2	3	2	2	3.2	4.5	2	3.2	2.9	3	4.6
1	35	4.6	14	8.4	2.9	2	3.6	8	2	2	3.7	2	2	3.9	6	2	3.9	3.5	3.7	6.4
1	40	4.6	17	11	3.7	2	3.8	11	2	2	3.9	2	2	4.3	6.8	2	4.3	3.7	3.9	7.4
1	63	4.6	53	45	20	3.3	5.6	44	5	3.5	8.2	5.3	3.1	13	16	3.3	12	6.5	8	16
1	65	4.6	57	48	23	3.6	5.8	48	6.1	3.8	9.2	6.2	3.4	15	18	3.6	14	7.2	9	17

Note 1: Deleted.

Note 2: For regions description see Table 7.D.5.

Note 3: Burnup represent the maximum allowed burnup, enrichment represents the required minimum initial enrichment and the cooling time represents the minimum required cooling time. Enrichments can be rounded to one decimal place to show compliance with this table.

Note 4: The decay heat load limits must be satisfied independently of fuel burnup, enrichment and cooling times listed in this table. The listed burnup, enrichment and cooling times are not intended to show the compliance with decay heat limits.

Table 7.D.4 (b):
FUEL SPECIFICATIONS FOR LOADING PATTERN 2 (NOTE 1)
(1 page)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
2	5	0.7	6	2.4	2	2	2	2.4	2	2	2.2	2	2	2	2.1	2	2	2	2.4	2.1
2	5	0.8	5.6	2.3	2	2	2	2.2	2	2	2.2	2	2	2	2.1	2	2	2	2.4	2.1
2	30	1.7	21	18	58	2	3.6	17	3.1	2.1	4.9	2.6	2	4.6	7	2.1	5.4	3.6	5.3	7.6
2	35	2.2	24	24	65	2.2	3.8	22	3.6	2.2	5.3	2.9	2	5.2	8	2.2	6.3	3.8	5.7	8.6
2	45	2.5	45	45	95	2.8	4.9	43	7.8	2.8	6.7	5.7	2.5	11	14	2.8	12	5.8	7.6	14
2	60	3	69	69	---	12	16	66	22	12	18	22	12	25	28	12	27	18	20	29
2	50	3.1	46	46	95	2.9	5.1	44	8.2	2.9	7	6	2.6	11	14	2.9	13	6	8	15
2	50	3.3	43	43	90	2.8	4.9	41	7.2	2.8	6.8	5.4	2.5	9.8	13	2.8	12	5.4	7.6	14
2	62	3.6	60	59	116	6	10	57	16	6	12	16	6	19	21	6	20	12	13	22
2	43	3.7	22	21	61	2.2	3.8	19	3.2	2.2	5.5	2.7	2	5.1	7.2	2.2	5.6	3.8	6	7.8
2	45	3.7	26	26	67	2.3	4	24	3.7	2.3	5.7	3	2	5.5	8.2	2.3	6.5	4	6.3	8.8
2	55	3.8	47	47	95	3	5.4	44	8.4	3	7.4	6.2	2.7	11	14	3	13	6.1	8.4	15
2	61	4	57	56	115	3.6	6.7	54	12	3.6	8.8	12	3.5	15	18	3.6	17	8.6	11	19
2	44	4.1	21	18	58	2.1	3.8	18	2.9	2.2	5.4	2.5	2	4.9	6.7	2.2	5.1	3.8	5.9	7.2
2	63	4.1	59	59	120	3.8	7.2	56	13	3.8	9.2	13	3.8	16	19	3.8	18	9.2	11	20
2	60	4.5	48	48	100	3.1	5.7	46	8.8	3.1	7.8	6.4	2.8	12	15	3.1	13	6.3	9	16
2	66	4.5	60	59	120	4.2	7.8	57	14	4.2	9.8	14	4.2	17	20	4.2	18	9.8	11	21
2	20	4.6	8.2	3.8	2.9	2	2.7	3.8	2	2	3.5	2	2	3.1	3.4	2	3.1	2.7	3.7	3.4
2	30	4.6	12	6.3	3.8	2	3.1	6.5	2	2	4.2	2	2	3.6	3.9	2	3.6	3.1	4.4	3.9
2	35	4.6	14	8.2	22	2	3.3	8.8	2	2	4.5	2	2	3.8	4.3	2	3.8	3.3	4.8	4.3
2	63	4.6	53	52	105	3.4	6.3	50	11	3.4	8.6	9.2	3.2	14	17	3.4	15	7.4	9.8	18
2	65	4.6	57	56	115	3.7	6.9	54	12	3.7	9.2	12	3.6	15	18	3.7	17	8.4	11	19

Note 1: See notes under Table 7.D.4(a).

Table 7.D.4 (c):
FUEL SPECIFICATIONS FOR LOADING PATTERN 3 (NOTE 1)
(1 page)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
3	5	0.7	6	2.6	2	2	2	2.5	2	2	2	2	2	2	2.1	2	2	2.3	2.2	2.2
3	5	0.8	5.6	2.4	2	2	2	2.4	2	2	2	2	2	2	2.1	2	2	2.3	2.2	2.1
3	30	1.7	21	18	58	2	4	18	2.8	2.1	4	4	2	4.6	38	2.1	4.5	4.9	4.9	8
3	35	2.2	24	24	65	2.2	4.2	22	3.2	2.2	4.3	4.6	2	5	45	2.2	5	5.3	5.3	9
3	45	2.5	45	45	95	2.8	5	43	7	2.8	5.9	9	2.5	9.6	67	2.8	9.8	6.6	6.7	15
3	60	3	69	69	---	12	15	66	21	12	18	23	12	24	100	12	24	18	18	35
3	50	3.1	46	46	95	2.9	5.2	44	7.4	2.9	6.1	9.4	2.6	10	68	2.9	11	6.9	7	16
3	44	3.3	30	29	75	2.3	4.5	27	3.7	2.4	4.7	5.4	2	5.7	50	2.4	5.8	5.8	5.8	10
3	50	3.4	42	41	90	2.7	5	39	6.1	2.7	5.6	8.2	2.4	8.6	63	2.8	8.8	6.6	6.7	14
3	62	3.6	60	59	116	6	9	57	15	6	12	17	6	18	86	6	18	12	12	27
3	31	3.7	14	8.6	20	2	3.6	9	2	2	3.6	2.1	2	3.8	4.1	2	3.8	4.4	4.4	4.1
3	39	3.7	19	14	49	2	4.1	15	2.3	2	4	3.2	2	4.5	30	2.1	4.4	5.1	5.1	6.4
3	40	3.7	20	14	52	2.1	4.1	16	2.4	2.1	4.1	3.4	2	4.7	33	2.1	4.5	5.2	5.2	6.8
3	46	3.7	29	28	70	2.3	4.6	26	3.6	2.4	4.7	5.2	2	5.7	49	2.4	5.6	5.9	5.9	9.8
3	55	3.8	47	47	95	3	5.4	44	7.6	3	6.4	9.6	2.7	11	69	3	11	7.2	7.4	16
3	63	4.1	59	59	120	3.8	6.2	56	12	3.8	9.2	14	3.8	15	85	3.8	15	9.2	9.2	26
3	44	4.2	21	17	56	2.1	4.3	18	2.6	2.2	4.3	3.7	2	4.9	37	2.2	4.8	5.4	5.4	7.4
3	66	4.5	60	59	120	4.1	6.7	57	13	4.1	9.8	15	4	16	85	4	16	9.6	9.8	26
3	15	4.6	6.2	3.2	2.6	2	2.7	3.1	2	2	2.7	2	2	2.9	3.1	2	2.8	3.2	3.2	3.1
3	20	4.6	8.2	4	2.9	2	3	4	2	2	3	2	2	3.2	3.4	2	3.1	3.6	3.5	3.4
3	30	4.6	12	6.6	3.8	2	3.5	6.9	2	2	3.4	2	2	3.7	4	2	3.6	4.2	4.2	4
3	35	4.6	14	8.6	22	2	3.7	9.2	2	2	3.7	2.1	2	4	5.1	2	3.8	4.5	4.5	4.3
3	60	4.6	47	47	95	3	5.5	44	7.6	3	6.6	9.6	2.8	11	69	3.1	11	7.6	7.8	16

Note 1: See notes under Table 7.D.4(a).

Table 7.D.4 (d):
FUEL SPECIFICATIONS FOR LOADING PATTERN 4 (NOTE 1)
(2 pages)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
4	5	0.7	2.4	2.3	2	2	2	2.1	2	2	2.2	2	2	2	3	2	2	2	2.2	2.9
4	30	1.7	16	15	5.5	2	3.5	16	2	2	4.8	2	2	4.3	6.7	2.1	4.4	4.2	4.8	6.4
4	35	2.2	22	17	6.6	2.1	3.7	18	2	2.2	5.2	2	2	4.7	7.4	2.2	4.8	4.5	5.1	7.2
4	45	2.5	43	37	14	2.7	4.3	35	3.4	2.7	6.6	3.6	2.3	8	12	2.8	8.2	5.3	6.4	11
4	60	3	67	60	31	12	14	57	15	12	18	15	12	22	26	12	22	16	18	25
4	50	3.1	44	38	15	2.8	4.4	35	3.5	2.8	6.9	3.8	2.4	8.4	12	2.9	8.6	5.5	6.7	12
4	45	3.3	30	24	8.8	2.4	4	22	2.1	2.4	5.8	2.4	2	5.5	8.8	2.4	5.5	4.9	5.7	8.4
4	48	3.3	37	31	12	2.6	4.2	28	2.6	2.6	6.3	2.9	2.1	6.4	9.8	2.6	6.6	5.2	6.2	9.4
4	44	3.4	26	20	7.6	2.3	3.9	20	2	2.3	5.7	2.1	2	5.1	8.4	2.3	5.2	4.8	5.6	8
4	46	3.4	31	25	9	2.4	4	23	2.2	2.4	5.9	2.4	2	5.6	9	2.5	5.6	5	5.8	8.6
4	47	3.4	33	27	9.8	2.4	4.1	25	2.3	2.5	6.1	2.6	2	5.8	9.2	2.5	5.9	5.1	6	8.8
4	62	3.6	57	51	25	6	8	48	9	6	12	9	6	16	19	6	16	9	11	18
4	43	3.7	19	16	5.8	2.1	3.7	17	2	2.2	5.4	2	2	4.7	8	2.2	4.9	4.6	5.3	7.6
4	49	3.7	34	27	10	2.5	4.1	25	2.3	2.5	6.2	2.6	2	6	9.6	2.6	6	5.2	6.1	9
4	50	3.7	35	29	11	2.5	4.2	27	2.5	2.6	6.3	2.8	2.1	6.2	9.8	2.6	6.3	5.2	6.2	9.2
4	51	3.7	38	31	12	2.6	4.3	29	2.7	2.6	6.5	3	2.2	6.6	11	2.7	6.8	5.4	6.4	9.6
4	55	3.7	46	40	16	3	4.6	37	3.9	3	7.4	4.1	2.6	9.2	13	3	9.2	5.8	7.2	12
4	61	3.7	58	51	24	4.6	6.6	49	7.6	4.6	11	7.6	4.5	15	19	4.6	15	8	11	18
4	55	3.8	45	38	15	2.9	4.5	36	3.6	2.9	7.4	3.9	2.5	8.6	13	3	8.8	5.8	7.2	12
4	52	3.9	37	31	12	2.6	4.3	29	2.6	2.6	6.5	3	2.2	6.6	11	2.7	6.7	5.4	6.4	9.6
4	58	4	48	42	17	3.1	4.7	40	4.3	3.1	7.8	4.5	2.7	9.8	14	3.2	10	6	7.6	13
4	61	4	54	47	20	3.5	5	45	5.7	3.5	8.8	5.8	3.2	12	16	3.6	12	6.5	8.6	15
4	51	4.1	32	26	9.6	2.5	4.1	25	2.2	2.5	6.2	2.5	2	5.9	9.6	2.5	6	5.2	6.1	9
4	54	4.1	39	33	13	2.7	4.4	30	2.8	2.7	6.7	3.1	2.2	7	11	2.7	7.2	5.5	6.6	10
4	57	4.1	45	39	15	2.9	4.6	36	3.6	2.9	7.4	3.9	2.5	8.8	13	3	8.8	5.9	7.2	12
4	63	4.1	57	50	23	3.7	5.4	47	6.4	3.7	9.4	6.4	3.4	13	17	3.8	13	6.7	9	16
4	55	4.2	40	33	13	2.7	4.4	31	2.9	2.7	6.9	3.2	2.3	7.2	11	2.8	7.4	5.6	6.7	10
4	56	4.2	42	35	14	2.8	4.5	33	3.1	2.8	7	3.5	2.4	7.6	11	2.9	7.8	5.7	6.9	11
4	60	4.5	46	40	16	3	4.7	37	3.8	3	7.8	4.1	2.6	9	13	3.1	9.2	6	7.4	13
4	66	4.5	57	50	23	3.9	5.9	48	6.9	3.9	9.8	6.9	3.8	14	18	3.9	14	7.2	9.6	17
4	15	4.6	3	2.9	2	2	2.4	2.8	2	2	3.2	2	2	2.8	4	2	2.8	2.8	3.1	3.9

Table 7.D.4 (d):
FUEL SPECIFICATIONS FOR LOADING PATTERN 4 (NOTE 1)
(2 pages)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
4	20	4.6	3.8	3.8	2	2	2.6	3.4	2	2	3.5	2	2	3.1	4.5	2	3.1	3.1	3.5	4.4
4	30	4.6	6.4	6.2	2.1	2	3.1	5.7	2	2	4.1	2	2	3.5	5.5	2	3.6	3.6	4.1	5.3
4	35	4.6	8.2	8	2.6	2	3.3	7.8	2	2	4.4	2	2	3.7	6.1	2	3.8	3.9	4.4	5.9
4	61	4.6	47	40	16	3.1	4.8	38	3.9	3.1	8	4.2	2.7	9.2	13	3.1	9.4	6.1	7.6	13
4	63	4.6	50	44	18	3.3	4.9	42	4.7	3.3	8.6	4.9	2.9	11	15	3.4	11	6.4	8.2	14
4	65	4.6	54	48	21	3.6	5.2	45	5.7	3.6	9.2	5.8	3.2	13	17	3.7	13	6.7	8.8	16

Note 1: See notes under Table 7.D.4(a).

Table 7.D.4 (e):
FUEL SPECIFICATIONS FOR LOADING PATTERN 5 (NOTE 1)
(1 page)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
5	5	0.7	2.4	3.7	2	2	2	2.4	2	2	2.1	2	2	2	2.9	2	2	2	2	2.1
5	30	1.7	19	19	6.4	2	3.8	17	2	2.1	4.7	2	2	4.4	6.5	2.1	4.7	4	4.4	5.6
5	35	2.2	24	22	7.8	2.2	4	20	2	2.2	5	2	2	4.8	7.2	2.3	5.1	4.2	4.7	6.4
5	45	2.5	45	38	17	2.8	4.8	37	3.5	2.8	6.3	3.7	2.5	8	11	2.9	9	5.2	5.8	11
5	60	3	69	61	38	12	14	60	15	12	17	15	12	22	25	12	23	16	18	25
5	50	3.1	46	38	18	2.9	4.9	38	3.7	2.9	6.5	3.9	2.6	8.4	11	3	9.4	5.4	6.1	12
5	45	3.3	32	26	10	2.4	4.4	24	2.2	2.5	5.6	2.4	2.1	5.6	8.4	2.5	6	4.7	5.2	7.8
5	48	3.3	39	31	13	2.6	4.6	31	2.8	2.7	6	3	2.3	6.4	9.4	2.7	7.4	5	5.6	9.4
5	46	3.4	33	26	11	2.4	4.5	25	2.2	2.5	5.7	2.5	2.1	5.7	8.6	2.5	6.1	4.7	5.3	7.8
5	50	3.4	42	34	14	2.7	4.8	34	3.1	2.8	6.3	3.3	2.4	7.2	9.8	2.8	8	5.2	5.7	11
5	62	3.6	60	51	30	6	8	51	9	6	11	9	6	16	18	6	17	9	11	18
5	39	3.7	12	17	4.8	2	3.9	15	2	2.1	4.8	2	2	4.4	6.9	2.1	4.7	4	4.5	4.8
5	44	3.7	24	22	7.6	2.2	4.2	20	2	2.3	5.3	2	2	5	8	2.3	5.4	4.4	4.9	6.1
5	48	3.7	34	27	11	2.5	4.5	25	2.3	2.5	5.8	2.5	2.1	5.8	8.8	2.5	6.3	4.8	5.3	8
5	55	3.8	47	39	18	3	5.1	39	3.8	3	6.9	4	2.7	8.6	12	3.1	9.6	5.7	6.4	12
5	51	3.9	37	30	12	2.6	4.7	29	2.6	2.6	6.1	2.8	2.3	6.3	9.4	2.7	6.9	5	5.6	8.8
5	61	4	57	48	27	3.6	5.7	48	6	3.7	8	5.9	3.5	12	14	3.7	13	6.7	8	15
5	63	4.1	59	51	29	3.8	5.8	50	6.8	3.9	8.4	6.5	3.8	13	17	4	14	7	8.8	16
5	54	4.2	40	32	14	2.7	4.8	32	2.8	2.7	6.4	3	2.4	6.7	10	2.8	7.6	5.2	5.8	9.4
5	55	4.2	42	34	14	2.8	4.9	34	3	2.8	6.5	3.3	2.5	7.2	11	2.8	8	5.4	5.9	10
5	56	4.2	44	36	15	2.8	5	36	3.3	2.9	6.7	3.5	2.6	7.6	11	2.9	8.6	5.5	6.2	11
5	60	4.4	50	42	21	3.1	5.3	41	4.2	3.2	7.4	4.4	2.9	9.4	13	3.2	11	6	6.9	13
5	66	4.5	60	51	30	4	6	51	6.9	4	9	7	4	14	17	4	15	7.6	9.4	17
5	20	4.6	3.8	5.4	2	2	2.9	3.8	2	2	3.4	2	2	3.1	4.4	2	3.2	3	3.2	3.3
5	30	4.6	6.4	8.8	2.3	2	3.3	6.5	2	2	4	2	2	3.6	5.4	2	3.8	3.5	3.8	3.8
5	35	4.6	8.2	11	2.9	2	3.6	8.8	2	2	4.3	2	2	3.8	6	2	4	3.7	4.1	4.2
5	65	4.6	57	48	27	3.7	5.8	48	6	3.7	8.4	5.9	3.6	13	15	3.8	14	6.9	8.4	15

Note 1: See notes under Table 7.D.4(a).

Table 7.D.4 (f):
FUEL SPECIFICATIONS FOR LOADING PATTERN 6 (NOTE 1)
(1 page)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
6	5	0.7	2.5	3.5	2	2	2	2.1	2	2	2.1	2	2	2	2	2	2	2	2	2
6	30	1.7	19	19	7.4	2	3.6	16	2	2	4.7	2.4	2	4.4	5.6	2	4.4	4.3	4.1	6.6
6	35	2.2	24	21	8.8	2.1	3.8	18	2	2.1	5	2.7	2	4.8	6.3	2.1	4.8	4.6	4.4	7.4
6	45	2.5	45	38	17	2.7	4.5	36	3.7	2.6	6.3	5.3	2.3	8.8	11	2.7	8.2	5.5	5.7	13
6	60	3	69	61	38	12	14	59	16	12	18	21	12	23	25	12	22	16	17	27
6	50	3.1	46	39	18	2.8	4.6	37	3.9	2.7	6.5	5.5	2.4	9.2	12	2.8	8.6	5.7	6	13
6	50	3.3	43	36	17	2.7	4.5	34	3.4	2.6	6.4	4.9	2.3	8.2	11	2.7	7.8	5.6	5.8	12
6	46	3.4	33	25	12	2.3	4.2	24	2.3	2.3	5.7	3.4	2	5.8	7.8	2.4	5.6	5.1	5.1	9.2
6	47	3.4	35	28	13	2.4	4.3	26	2.5	2.4	5.8	3.7	2	6.1	8.4	2.4	5.9	5.2	5.2	9.8
6	62	3.6	60	51	30	6	8	50	10	6	11	15	6	17	18	6	16	9	11	20
6	31	3.7	8.4	11	3.2	2	3.3	7.6	2	2	4.2	2	2	3.8	4	2	3.8	3.9	3.7	3.9
6	44	3.7	24	21	8.6	2.2	4	18	2	2.1	5.3	2.6	2	5.1	6.1	2.2	5	4.8	4.7	7.2
6	55	3.7	49	41	20	2.9	4.8	39	4.2	2.8	7	6	2.6	10	12	2.9	9.2	6	6.5	14
6	55	3.8	47	39	19	2.8	4.8	38	4	2.8	6.9	5.7	2.5	9.4	12	2.9	8.8	6	6.3	14
6	53	4	40	33	15	2.6	4.5	31	3	2.5	6.4	4.4	2.2	7.4	9.6	2.6	6.9	5.6	5.7	11
6	59	4	53	45	23	3.2	5.1	43	5.2	3.1	7.8	8.2	2.8	12	14	3.2	11	6.4	7.2	16
6	54	4.1	41	34	16	2.6	4.6	32	3.1	2.6	6.5	4.5	2.2	7.6	9.8	2.7	7.2	5.7	5.8	12
6	56	4.1	45	38	18	2.8	4.8	36	3.6	2.7	6.8	5.3	2.4	8.8	11	2.8	8.2	5.9	6.2	13
6	57	4.1	47	40	19	2.9	4.8	38	4	2.8	7	5.7	2.5	9.6	12	2.9	8.8	6.1	6.4	14
6	63	4.1	59	51	29	3.6	5.4	49	7	3.5	8.8	12	3.4	14	16	3.6	13	7	8.4	18
6	60	4.5	48	40	19	2.9	5	39	4.2	2.9	7.2	5.9	2.6	9.8	12	3	9.2	6.3	6.7	14
6	66	4.5	60	51	30	3.8	5.9	50	7.6	3.8	9.4	13	3.8	15	17	4	14	7.6	9	19
6	15	4.6	3.1	3.9	2	2	2.5	2.8	2	2	3.1	2	2	2.9	2.9	2	2.8	2.9	2.8	3
6	20	4.6	3.9	5.2	2	2	2.8	3.4	2	2	3.4	2	2	3.1	3.2	2	3.1	3.2	3.1	3.3
6	30	4.6	6.6	8.6	2.6	2	3.2	5.7	2	2	4	2	2	3.6	3.7	2	3.6	3.7	3.5	3.8
6	35	4.6	8.4	11	3.2	2	3.4	7.8	2	2	4.3	2	2	3.8	4.1	2	3.8	4	3.8	4.1
6	40	4.6	11	14	4.3	2	3.6	11	2	2	4.7	2	2	4.2	4.4	2	4.2	4.3	4	4.4
6	65	4.6	57	48	27	3.5	5.4	47	6.2	3.4	8.6	11	3.2	14	15	3.5	13	7	8.2	17

Note 1: See notes under Table 7.D.4(a).

Table 7.D.4 (g):
FUEL SPECIFICATIONS FOR LOADING PATTERN 7 (NOTE 1)
(1 page)

Pattern	Burnup (GWD/MTU)	Enrichment ((%)	Cooling time (years)																	
			Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Region 8	Region 9	Region 10	Region 11	Region 12	Region 13	Region 14	Region 15	Region 16	Region 17	Region 18
7	5	0.7	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
7	30	1.7	6.5	6.5	5	3	5	6.5	5	3	5	5	3	5	6	3	5	5	5	6
7	35	2.2	5.5	5.5	5	4	5	5.5	5	4	5	5	4	5	5.2	4	5	5	5	5.2
7	45	2.5	7	7	6	5	6	7	6	5	6	64	5	6	6.1	5	6	6	6	6.1
7	50	3.1	8.5	8.5	6.5	6	6.5	8.5	6.5	6	6.5	6.5	6	6.5	6.7	6	6.5	6.5	6.5	6.7
7	55	3.8	10	10	7.1	7	7.1	10	7.1	7	7.1	7.1	7	7.1	8.1	7	7.1	7.1	7.1	8.1
7	60	4.1	13	13	12	11	12	13	12	11	12	12	11	12	12	11	12	12	12	12
7	60	3.0	15	15	13	11	13	15	13	11	13	13	11	13	14	11	13	13	13	14
7	62	3.6	14	14	11	10	11	14	11	10	11	11	10	11	12	10	11	11	11	12
7	15	4.6	3.2	3.2	2.8	2.6	2.8	3.2	2.8	2.6	2.8	2.8	2.6	2.8	3	2.6	2.8	2.8	2.8	3
7	20	4.6	3.4	3.4	3	2.8	3	3.4	3	2.8	3	3	2.8	3	3.2	2.8	3	3	3	3.2
7	30	4.6	3.7	3.7	3.3	3	3.3	3.7	3.3	3	3.3	3.3	3	3.3	3.4	3	3.3	3.3	3.3	3.4
7	40	4.6	4.9	4.9	4	3.3	4	4.9	4	3.3	4	4	3.3	4	4.1	3.3	4	4	4	4.1
7	50	4.6	7.2	7.2	5.2	4.2	5.2	7.2	5.2	4.2	5.2	5.2	4.2	5.2	5.6	4.2	5.2	5.2	5.2	5.6
7	60	4.6	13	13	7.5	7.5	7.5	13	7.5	7.5	7.5	7.5	7.5	7.5	8.3	7.5	7.5	7.5	7.5	8.3
7	66	4.6	22	22	13	12	13	22	13	12	13	13	12	13	15	12	13	13	13	15

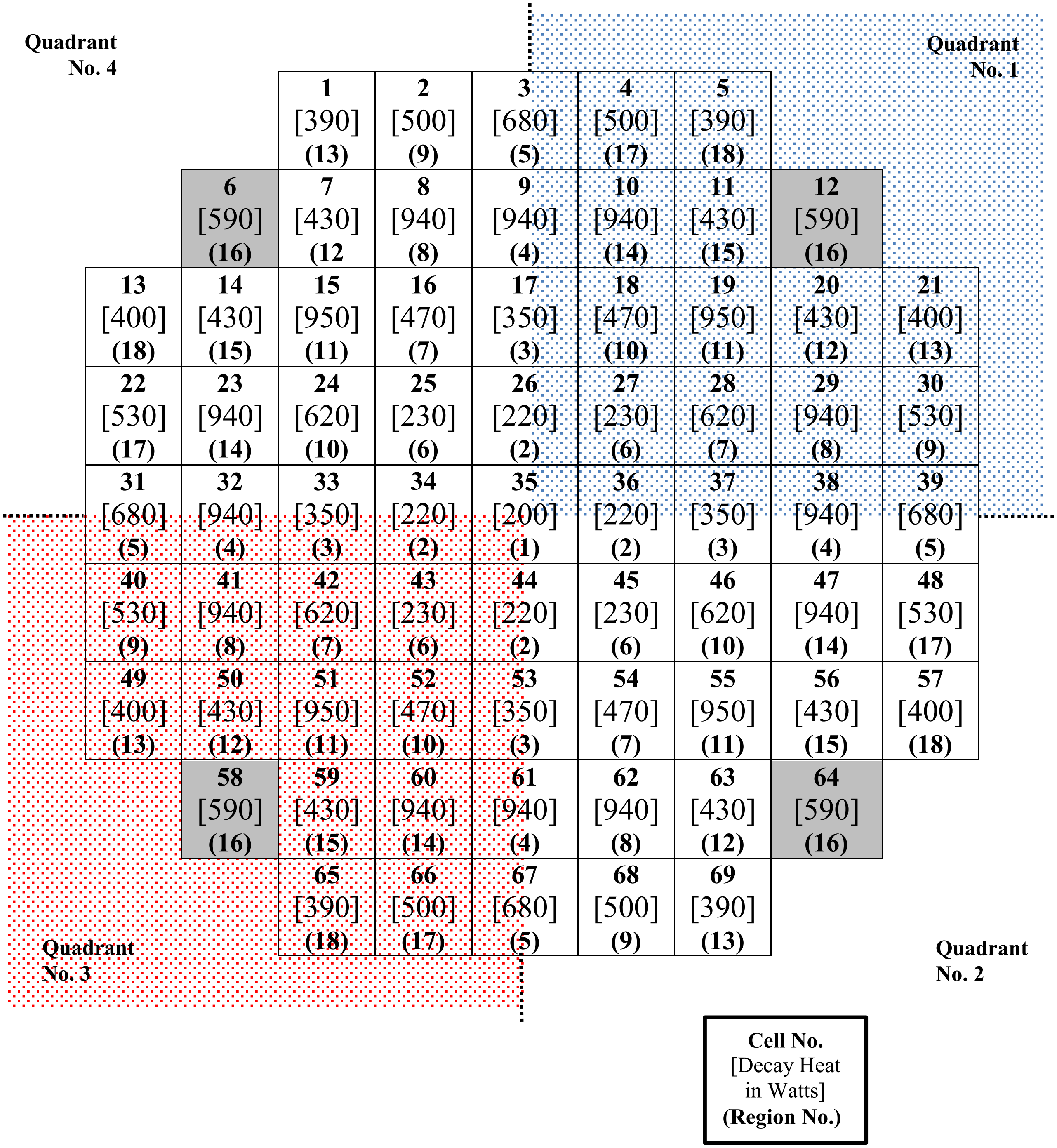
Note 1: See notes under Table 7.D.4(a).

Table 7.D.5

CELLS ASSIGNMENTS TO REGIONS FOR REGIONALIZED LOADING

Region	**Cells in Figure 7.D.1 and 7.D.2**			
1	35	-	-	-
2	26	34	36	44
3	17	33	37	53
4	9	32	38	61
5	3	31	39	67
6	25	27	43	45
7	16	28	42	54
8	8	29	41	62
9	2	30	40	68
10	18	24	46	52
11	15	19	51	55
12	7	20	50	63
13	1	21	49	69
14	10	23	47	60
15	11	14	56	59
16	6	12	58	64
17	4	22	48	66
18	5	13	57	65

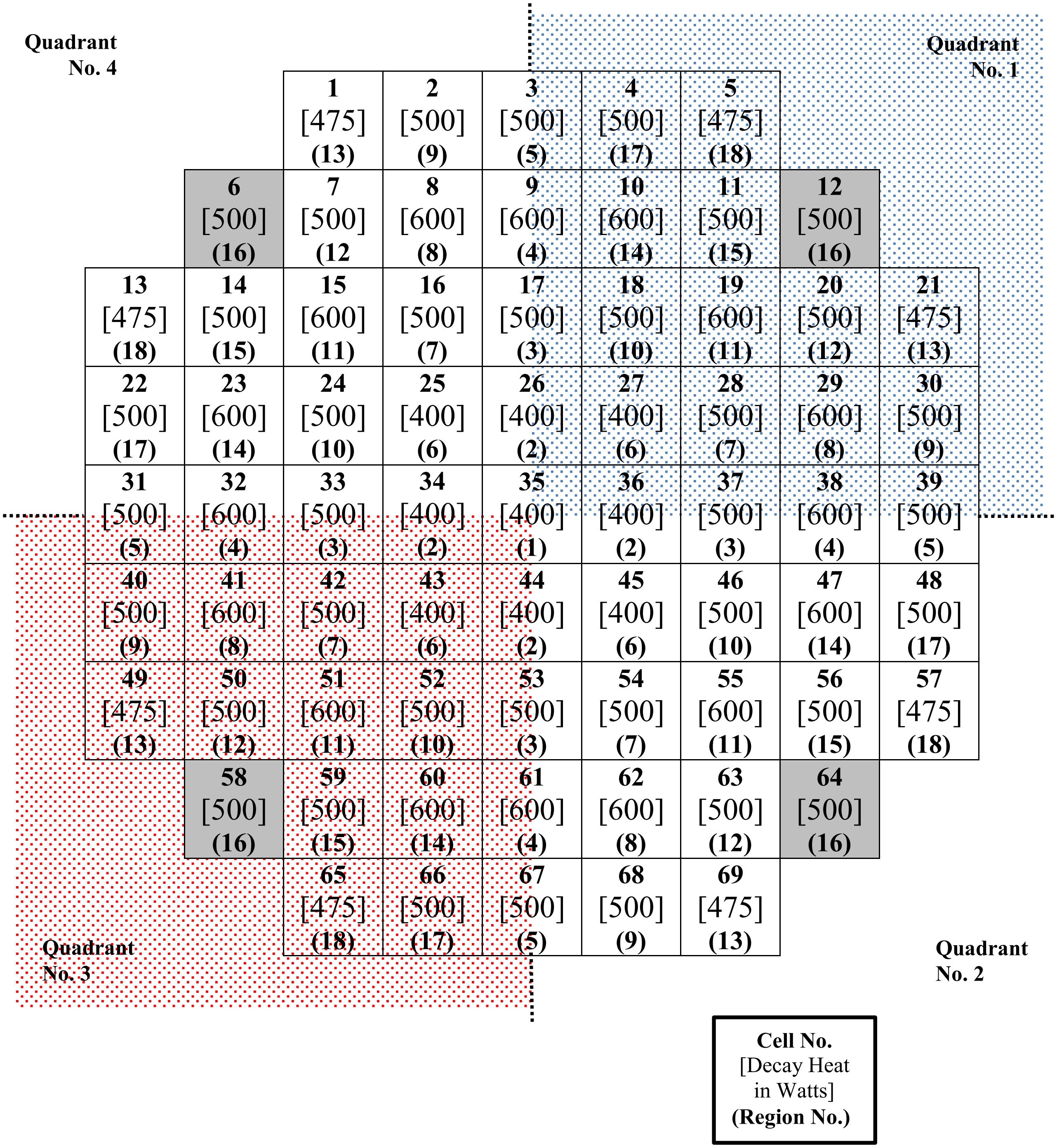
Note: Regions are reflected in Figure 7.D.1 and Figure 7.D.2.



		1 [390] (13)	2 [500] (9)	3 [680] (5)	4 [500] (17)	5 [390] (18)		
	6 [590] (16)	7 [430] (12	8 [940] (8)	9 [940] (4)	10 [940] (14)	11 [430] (15)	12 [590] (16)	
13 [400] (18)	14 [430] (15)	15 [950] (11)	16 [470] (7)	17 [350] (3)	18 [470] (10)	19 [950] (11)	20 [430] (12)	21 [400] (13)
22 [530] (17)	23 [940] (14)	24 [620] (10)	25 [230] (6)	26 [220] (2)	27 [230] (6)	28 [620] (7)	29 [940] (8)	30 [530] (9)
31 [680] (5)	32 [940] (4)	33 [350] (3)	34 [220] (2)	35 [200] (1)	36 [220] (2)	37 [350] (3)	38 [940] (4)	39 [680] (5)
40 [530] (9)	41 [940] (8)	42 [620] (7)	43 [230] (6)	44 [220] (2)	45 [230] (6)	46 [620] (10)	47 [940] (14)	48 [530] (17)
49 [400] (13)	50 [430] (12)	51 [950] (11)	52 [470] (10)	53 [350] (3)	54 [470] (7)	55 [950] (11)	56 [430] (15)	57 [400] (18)
	58 [590] (16)	59 [430] (15)	60 [940] (14)	61 [940] (4)	62 [940] (8)	63 [430] (12)	64 [590] (16)	
		65 [390] (18)	66 [500] (17)	67 [680] (5)	68 [500] (9)	69 [390] (13)		

Notes:
1. Shaded cells (cell no. 6, 12, 58 and 64) denote allowable locations for quivers. Maximum allowable heat load for quiver locations is specified in Table 7.D.1.
2. Maximum allowable total cask heat load and maximum allowable basket quadrant heat load and are specified in Table 7.D.1.

Figure 7.D.1: F-69L BASKET HEAT LOADS (PATTERN A)



		1 [475] **(13)**	**2** [500] **(9)**	**3** [500] **(5)**	**4** [500] **(17)**	**5** [475] **(18)**		
	6 [500] **(16)**	**7** [500] **(12**	**8** [600] **(8)**	**9** [600] **(4)**	**10** [600] **(14)**	**11** [500] **(15)**	**12** [500] **(16)**	
13 [475] **(18)**	**14** [500] **(15)**	**15** [600] **(11)**	**16** [500] **(7)**	**17** [500] **(3)**	**18** [500] **(10)**	**19** [600] **(11)**	**20** [500] **(12)**	**21** [475] **(13)**
22 [500] **(17)**	**23** [600] **(14)**	**24** [500] **(10)**	**25** [400] **(6)**	**26** [400] **(2)**	**27** [400] **(6)**	**28** [500] **(7)**	**29** [600] **(8)**	**30** [500] **(9)**
31 [500] **(5)**	**32** [600] **(4)**	**33** [500] **(3)**	**34** [400] **(2)**	**35** [400] **(1)**	**36** [400] **(2)**	**37** [500] **(3)**	**38** [600] **(4)**	**39** [500] **(5)**
40 [500] **(9)**	**41** [600] **(8)**	**42** [500] **(7)**	**43** [400] **(6)**	**44** [400] **(2)**	**45** [400] **(6)**	**46** [500] **(10)**	**47** [600] **(14)**	**48** [500] **(17)**
49 [475] **(13)**	**50** [500] **(12)**	**51** [600] **(11)**	**52** [500] **(10)**	**53** [500] **(3)**	**54** [500] **(7)**	**55** [600] **(11)**	**56** [500] **(15)**	**57** [475] **(18)**
	58 [500] **(16)**	**59** [500] **(15)**	**60** [600] **(14)**	**61** [600] **(4)**	**62** [600] **(8)**	**63** [500] **(12)**	**64** [500] **(16)**	
		65 [475] **(18)**	**66** [500] **(17)**	**67** [500] **(5)**	**68** [500] **(9)**	**69** [475] **(13)**		

Notes:

1. Shaded cells (cell no. 6, 12, 58 and 64) denote allowable locations for quivers. Maximum allowable heat load for quiver locations is specified in Table 7.D.1.

Figure 7.D.2: F-69L BASKET HEAT LOADS (PATTERN B)

CHAPTER 8: ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 INTRODUCTION

This chapter identifies the acceptance tests and maintenance program to be conducted on the HI-STAR 180L Package to verify that the structures, systems and components (SSCs) classified as *important-to-safety* have been fabricated, assembled, inspected, tested, accepted, and maintained in accordance with the requirements set forth in this Safety Analysis Report (SAR), all applicable regulatory requirements, and the Certificate of Compliance (CoC). The acceptance criteria and maintenance program described in this chapter is in full compliance with the requirements of 10CFR Part 71 Subpart G [8.0.1].

8.1 ACCEPTANCE TESTS

In this section the inspections and acceptance tests to be performed on the HI-STAR 180L Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR 180L Package has been fabricated, assembled and accepted for use and loading under the conditions specified in Chapter 7 of this SAR and the USNRC issued CoC in accordance with the requirements of 10CFR Part 71.

8.1.1 Visual Inspections and Measurements

The HI-STAR 180L Package shall be assembled in accordance with the drawing package referenced in the CoC. Dimensional tolerances that define the limits on the dimensions critical to the licensing basis analysis are included in these drawings. Fabrication drawings provide additional dimensional tolerances necessary to ensure fit-up of parts as well as compliance with the design conditions. A fabrication sampling plan shall be made and controls shall be exercised to ensure that the packaging conforms to the dimensions and tolerances specified on the licensing and fabrication drawings. These dimensions are subject to independent confirmation and documentation in accordance with the Holtec QA program approved in NRC Docket No. 71-0784.

The following shall be verified as part of visual inspections and measurements:

- Visual inspections and measurements shall be made to ensure that the packaging effectiveness is not significantly reduced. Any *important-to-safety* component found to be under the minimum thickness requirement shall be repaired or replaced as required.
- Visual inspections shall be made to verify that neutron absorber panels, basket shims, shim shield plates, fuel spacers, and anti-rotation bars are present as required by cask and basket design.
- The packaging shall be visually inspected to ensure it is conspicuously and durably marked with the proper markings/labels in accordance with 10CFR71.85(c).
- The packaging shall be inspected for cleanliness and preparation for shipping in accordance with written and approved procedures.

The visual inspection and measurement results for the HI-STAR 180L Package shall become part of the equipment documentation package.

Visual Inspection of Metamic-HT Panels:

- Each plate of neutron absorber shall be visually (or camera) inspected for damage such as scratches, cracks, burrs, foreign material embedded in the surfaces, voids, and delamination. Panels are also visually inspected for contamination on the surface as specified in the Metamic-HT Manufacturing Manual. Panels not meeting the acceptance criteria will be reworked or rejected. Unless the basket is fabricated at the same factory manufacturing Metamic-HT, all panels shall be inspected before being shipped to the cask manufacturing facility where they may be subject to receipt inspection prior to installation.

- These test results shall be documented and shall become part of the final quality documentation package.

8.1.2 Weld Examination

The examination of HI-STAR 180L Package welds shall be performed in accordance with the drawing package referenced in the CoC, applicable codes and standards, and applicable code alternatives. Weld examinations and repairs shall be performed as specified below. All code and Metamic-HT weld inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [8.1.2]. All required inspections, examinations, and tests shall become part of the equipment documentation package.

The following specific weld requirements shall be followed in order to verify fabrication in accordance with the drawings.

1. Containment boundary welds including any attachment welds (and temporary welds to the containment boundary) shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. Examinations, Visual (VT), Radiographic (RT), and Liquid Penetrant (PT) or Magnetic Particle (MT), apply to these welds as defined by the code. These welds shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450 and examined after repair in the same manner as the original weld. Weld overlays for cask sealing surfaces shall be VT and PT examined to ensure that a leakage path between the containment space and the outside environment that may violate the specified cask leak tightness criterion is detected and eliminated. Although ASME Code Section III, Subsection NB does not require visual examination of welds, the welds will be visually examined to ensure conformance with the fabrication drawings (e.g. proper geometry, workmanship etc.).

2. NF welds on the cask (other than containment boundary welds) and primary load bearing members in the impact limiter and fuel spacers, shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5300. These welds shall be repaired in accordance with ASME Code Section III, Article NF-4450 and examined after repair in the same manner as the original weld. These weld requirements are not applicable to NITS (non-code) welds (e.g. seal welds).

3. Basket welds connecting Metamic-HT panels shall be examined and repaired in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for welding Metamic-HT with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition). The basket welds, made by the Friction Stir Weld process, are classified as Category E per NG-3351.3 and belonging to Type III in Table NG-3352-1. These weld requirements are not applicable to basket welds identified as Non-Structural on the drawing package.

4. NITS (non-code) welds shall be examined and repaired in accordance with written and approved procedures

8.1.3 Structural and Pressure Tests

The cask containment boundary will be tested by combination of methods (including helium leak test, pressure test, RT, MT, and/or PT, as specified in this Chapter) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

8.1.3.1 Lifting Trunnions

Two top trunnions are provided for vertical lifting and handling of the loaded cask. The top trunnions are required to be tested and inspected in accordance with ANSI N14.6 [8.1.3]. Two bottom trunnions are provided for rotation of the loaded or empty cask for downending/upending operations and may be used for horizontal cask lifting and handling. If the bottom trunnions are to be used for horizontal lifting and handling of the loaded cask they must be tested and inspected in accordance with ANSI N14.6. Otherwise, the bottom trunnions may be tested and inspected in accordance to commercial specifications and requirements acceptable for similar nuclear applications and as clarified further below. Both top and bottom trunnions are rendered inoperable during package transport.

The top lifting trunnions shall be tested in accordance with ANSI N14.6 at 300% of the maximum design service lifting load (the full weight of the loaded cask at a minimum). Load tests may be performed in excess of the required test loads specified above provided an engineering evaluation is performed to ensure trunnions or other cask components will not be damaged by the load test. The test load shall be applied for a minimum of 10 minutes. The accessible parts of the top trunnions (areas outside the cask), and the local cask areas shall then be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and top trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require replacement of the trunnion and/or repair of the cask. Following any replacements and/or major repair, as defined in ANSI N14.6, the load testing shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria. Testing shall be performed in accordance with written and approved procedures. Certified material test reports verifying trunnion material mechanical properties meet ASME Code Section II requirements provide further verification of the trunnion load capabilities. Test results shall be documented and shall become part of the equipment documentation package.

The requirements for ANSI N14.6 regarding testing and inspection in the preceding paragraph for the top trunnions also apply to the bottom trunnions if they are to be used for horizontal lifting. The maximum rated load of the bottom trunnions shall be greater than or equal to one half the rated load of the top trunnions times a factor of 1.15. The 1.15 multiplier ensures a trunnion rating that conservatively accounts for offset in the cask center of gravity (C.G.). Bottom trunnions that will not be qualified for horizontal lifting of the cask must be load tested to 200% of the rated load for a minimum of 10 minutes and inspected in the same manner described in the foregoing.

8.1.3.2 Pressure Testing

Pressure testing of the HI-STAR 180L containment boundary (cavity space) and expanded containment boundary (inter-lid space) is required.

The cask cavity space shall be hydrostatically or pneumatically pressure tested at 125% or 110%, respectively, of the applicable cask cavity space design internal pressure in accordance with the provisions of the ASME Code Section III, Subsection NB, Article NB-6000. In addition, the cask cavity test pressure shall not be less than 150% of cask cavity maximum normal operating pressure per 10CFR71.85(b) and shall not be less than 100 psig.

The cask inter-lid space shall be hydrostatically or pneumatically pressure tested at 150% or 125%, respectively, of the applicable cask inter-lid space maximum operating pressure in accordance with the provisions of the ASME Code Section III, Subsection NB, Article NB-6000. In addition, the cask inter-lid space test pressure shall not be less than the test pressure used to qualify the cask cavity space.

The pressure test may be performed at any time during cask fabrication after containment boundary fabrication is completed. Pressure testing may be performed in various cask closure configurations as needed to ensure each containment boundary closure is pressure tested at least once; however, containment seals do not require pressure testing. Containment boundary closures may be tested with single temporary test seal.

All pressure testing shall be performed in accordance with written and approved procedures written by qualified personnel in accordance with the Holtec QA program. The written and approved test procedure shall clearly define the test equipment arrangement. SNT-TC-1A is not applicable to this test; however, for quality assurance, trained and qualified personnel shall perform the test and the leakage verification in accordance with written procedures and document the results. The leakage verification shall be performed in accordance with written quality assurance program.

Test results shall be documented and shall become part of the equipment documentation package.

8.1.4 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5 [8.1.6] specified in this Chapter. Tables 8.1.1 and 8.1.2 specify the allowable leakage rate and test sensitivity as well as components to be tested for fabrication and pre-shipment leakage rate tests.

A pre-shipment leakage rate test of cask containment seals is performed following loading of authorized contents into the cask. This pre-shipment leakage rate test is valid for 1 year or until the tested component(s) is opened or respective containment fasteners are untorqued.

In case of an unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

Fabrication leakage rate test results shall become part of the equipment documentation package. Pre-shipment leakage rate tests shall be documented in accordance with the user's quality assurance program.

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

8.1.5 Component and Material Tests

8.1.5.1 Seals

Cask closure seals are conservatively specified in the drawing package referenced in the CoC and in Appendix 8.A to provide a high degree of assurance of leak tightness under normal and accident conditions of transport. Seal tests under the most severe package service conditions including performance at pressure under high and low temperatures will not challenge the capabilities of these seals and thus are not required. Seal specifications are in accordance with the manufacturer recommendation.

8.1.5.2 Impact Testing

To provide protection against brittle fracture under cold conditions, facture toughness test criteria of cask ferritic components, including containment boundary welds, are specified in Table 8.1.5. Non-containment boundary ferritic steel package dose blocker parts on the exterior of the cask shall meet the Charpy impact testing requirement set forth for ASME Subsection NF Class 3 support material.

Test results shall become part of the equipment documentation package.

8.1.5.3 Impact Limiter Crush Material Testing

Verification of the transport impact limiter crush material crush strength is accomplished by performance of a crush test of sample blocks. The verification tests are performed by the crush material supplier or third party testing facility in accordance with Holtec approved procedures. Impact limiter material crush strength is specified in the drawing package referenced in the CoC.

The certified test results shall be retained by Holtec International as archive record for each batch of impact limiter crush material manufactured and used. Test results shall be documented and shall become part of the equipment documentation package.

8.1.5.4 Neutron Shielding Material

Manufacturing of Holtite neutron shielding material shall be conducted according to approved written procedures that shall ensure mix ratios and mixing methods are controlled in order to achieve proper material composition and distribution, and that emplacement is properly controlled. Each manufactured lot of Holtite-B neutron shield material shall be tested to verify that boron carbide content, hydrogen density, and bulk Holtite material density. Boron carbide content shall be verified by spectrochemical and/or gravimetric analysis. A manufactured lot is defined as the total amount of material used to make any number of mixed batches comprised of constituent ingredients from the same lot/batch identification numbers supplied by the constituent manufacturer. Testing shall be performed in accordance with written and approved procedures.

Test results for each manufactured lot of neutron shield material shall become part of the equipment documentation package.

8.1.5.5 Neutron Absorber Material

The manufacturing of Metamic-HT is governed by a set of quality validated standard procedures contained in the Metamic-HT Manufacturing Manual [8.1.8]. The material properties and characteristics have been tested and documented in the Metamic-HT Sourcebook [8.1.10]. Production testing requirements including acceptance criteria are provided in Table 8.1.3.

Metamic-HT panels will be manufactured to Holtec's purchase specification [8.1.9] that incorporates all requirements set forth in this chapter, the drawing package referenced in the CoC and the fabrication drawings. The supplier of raw materials must be qualified under Holtec's quality program for important to safety materials and components or alternatively each lot of raw material shall be tested in accordance with Table 8.1.3 requirements. The manufacturing of Metamic-HT is subject to all quality assurance requirements under Holtec International's NRC approved quality program.

The tests conducted on Metamic-HT to establish the compliance of the manufactured panels with Holtec's Purchasing Specification are intended to ensure that *critical characteristics* of the final product will meet the minimum guaranteed values (MGVs). Tests are performed at both the raw material and manufactured panels stages of production with the former serving as the insurer of the properties in the final product and the latter serving the confirmatory function. The testing is conducted for each lot of raw material and finished panels as prescribed in Table 8.1.3. A lot is defined as follows:

> "Lot" means a population of an item that shares identical attributes that are central to defining a critical performance or operational characteristic required of it. Thus, a lot of boron carbide powder procured to a certified Purchasing Specification used in the manufacturing of Metamic-HT is the bulk quantity of the powder that has the same particle size distribution. A lot of finished panels drawn from a powder mix and manufactured in an extrusion run have identical aluminum and boron carbide characteristics and the same extrusion conditions. However, the addition of macro-dispersoids from another lot to the mix renders it into a new lot.

The following tests are performed (see Table 8.1.3):

(i) Testing and certification of powder material

- All lots of aluminum and boron carbide powder shall be certified to meet particle size distribution and chemistry requirements in the Metamic-HT Manufacturing Manual.
- All lots of B_4C will be certified as containing Boron with the minimum isotopic B-10 per the boron carbide purchase specifications incorporated in the Metamic-HT Manufacturing Manual.
- Homogenized mixtures of Al powder(s) and boron carbide powder(s) from traceable lots, prepared for sintering and billet forming operations, shall have the minimum boron carbide wt% verified by wet chemistry testing of one sample from each lot of blended powders. The mixing/blending of the batch shall be controlled via approved procedures.

(ii) Testing of finished panels

The number of panels subject to testing shall be governed by Table 8.1.4. The panels that need to be tested per the statistical protocol of Table 8.1.4, hereafter referred to as test panels, shall be subject to the following evaluations:

- The Metamic-HT panels shall be tested for all mechanical properties in accordance with Table 8.1.4 sampling plan.
- The thickness of each panel will be measured using the procedure set down in the Metamic-HT Manufacturing Manual. The average measured value must

meet the minimum basket wall requirements specified in the Drawing Package referenced in the CoC.

- One coupon from a test panel drawn from cask manufactured lot shall be subject to neutron attenuation testing to quantify the boron carbide content for compliance with the minimum requirement in Table 8.1.3 using written procedures.

(iii) Testing of Basket

- Metamic-HT basket cells shall be tested by a dummy gage to insure that they are large enough to permit contents to be safely inserted.

FSW Procedure Qualification, Welder Operator Qualification and Welded Coupon Test:

1. Procedure qualification and welder operator qualification of the Friction Stir Welding (FSW) process shall meet the following requirements from ASME Section IX, 2013 Edition [8.1.1]:
    - The Procedure Qualification Record (PQR) shall meet the essential variable requirements of QW-267.
    - The Weld Procedure Specification (WPS) shall meet the essential variable requirements of QW-267, QW-361.1(e) and QW-361.2.
    - Welder operator performance qualifications shall meet the essential variable requirements of QW-361.2.
    - Welder operator may be qualified by volumetric NDE of a test coupon; or a coupon from their initial production welding within the limitations of QW-304 and QW-305; or by bend tests taken from a test coupon.

2. Procedure qualification of the Friction Stir Welding process may be accomplished by tensile testing the appropriate number of coupons per ASME Section IX (2007). Verification of weld soundness is performed by visual examination, and radiography or bend testing per approved written procedures (bend testing emulates ASME Section IX). Bend test qualification of a representative weld sample emulating ASME Section IX paragraph QW 160 at a bend radius that produces at least 150% of the average tensile strain developed in the friction stir welded joint under the hypothetical free drop accident condition. The bend radius shall be recorded on the PQR. The bend test sample must meet the acceptance criteria of Section IX QW-163 and visual examination acceptance criteria of ASME Section III Subsection NG 5362 with any additional requirements per Holtec approved written procedure.

8.1.6 Shielding Tests

A shielding effectiveness test of each fabricated cask must be performed after loading with approved contents but prior to the first shipment as specified in the following paragraph.

A shielding effectiveness test shall be performed to verify the effectiveness of the shielding using written and approved procedures. The test may be performed with the loaded cask in the vertical or horizontal configurations (no impact limiters) or in the horizontal orientation with impact limiters, as long as the configuration is appropriately taken into account. Calibrated radiation detection equipment shall be used to take measurements at the surface of the HI-STAR package. Measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the shielding. The calculated values shall be representative of the loaded contents (e.g. fuel type, enrichment, burnup, cooling time, etc.). Measurements shall be documented and become part of the equipment documentation package.

8.1.7 Thermal Tests

The first fabricated HI-STAR cask shall be tested to confirm its heat dissipation capability.

A thermal test performed for a similar cask design (e.g. HI-STAR 180 USNRC Docket 71-9325) may be used as proof of heat transfer capability in lieu of thermal testing of the HI-STAR 180L. In case of a proof with similar cask, an engineering evaluation between HI-STAR 180L and the previously-tested cask shall be documented and become part of the equipment documentation package.

The test shall be conducted after fabrication is complete. A test cover plate shall be used to seal the cask cavity. The cavity will be heated with steam.

Twelve (12) calibrated thermocouples shall be installed on the external walls of the cask using four thermocouples, equally spaced circumferentially, at three different elevations. Three calibrated thermocouples shall be installed on the internal walls of the cask in locations to be determined by procedure. Additional temperature sensors shall be used to monitor ambient temperature, steam supply temperature, and condensate drain temperature. The thermocouples shall be attached to strip chart recorders or other similar mechanism to allow for continuous monitoring and recording of temperatures during the test. Instrumentation shall be installed to monitor cask cavity internal pressure.

After the thermocouples have been installed, dry steam will be introduced through an opening in the test cover plate previously installed on the cask and the test initiated. Temperatures of the thermocouples, plus ambient, steam supply, and condensate drain temperature shall be recorded at hourly intervals until thermal equilibrium is reached. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of potential ambient test conditions and incorporated into the test procedure. In general, thermal equilibrium is expected approximately 12 hours after the start of steam heating. Air will be purged from the cask cavity via venting during the heatup cycle. During the test, the steam condensate flowing out of the cask drain shall be collected and the mass of the condensate measured with a precision weighing instrument.

Once thermal equilibrium is established, the final ambient, steam supply, and condensate drain temperatures and temperatures at each of the thermocouples shall be recorded. The strip charts, hand-written logs, or other similar readout shall be marked to show the point when thermal equilibrium was established and final test measurements were recorded. The final test readings along with the hourly data inputs and strip charts (or other similar mechanism) shall become part of the equipment documentation package for the HI-STAR 180L Package.

The heat rejection capability of the cask at test conditions shall be computed using the following formula:

$$Q_{hm} = (h_1 - h_2)\, m_c$$

Where:

Q_{hm} = Heat rejection rate of the cask (kW)

h_1 = Enthalpy of steam entering the cask cavity (KJ/kg)

h_2 = Enthalpy of condensate leaving the cask cavity (KJ/kg)

m_c = Average rate of condensate flow measured during thermal equilibrium conditions (kg/s)

Based on the HI-STAR 180L cask thermal model, a design basis minimum heat rejection capacity (Q_{hd}) shall be computed at the measured test conditions (i.e., steam temperature in the cask cavity and ambient air temperature). The thermal test shall be considered acceptable if the measured heat rejection capability is greater than the design basis minimum heat rejection capacity ($Q_{hm} > Q_{hd}$).

If the acceptance criteria above are not met, then the HI-STAR 180L 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.

Testing shall be performed in accordance with written and approved procedures similar to the Holtec standard procedure used for the test performed on the HI-STAR 100 overpack and documented in Holtec Document DOC-5014-03 [8.1.7].

8.1.8 Miscellaneous Tests

Shipment Fuel Integrity Acceptance Test

For packages containing HBF, cask surface temperatures and cask surface dose rates shall be measured in accordance with the procedures in Chapter 7 as a practical means of monitoring the condition of the fuel assemblies. Fuel reconfiguration and significant fuel cladding damage is not expected after the transportation period of each shipment.

A total of six measurements of both temperature and dose rate shall be recorded before and after each shipment with the loaded cask configured horizontally with impact limiters and no personnel barrier. Three measurements are taken from each side of the package at least 45 degrees below the cask axial centerline (below the top cask trunnion, at or near the cask circumferential centerline midway between the top and bottom trunnions, and below the bottom cask trunnion). The user may select measurement locations within the areas defined by the zones shown in Figure 8.1.1. The post-shipment measurement locations shall correspond to the pre-shipment measurement locations for proper comparison.

The post-shipment surface temperature measurements should not significantly exceed the pre-shipment surface temperature measurements after adjusting for ambient conditions (ambient temperature, solar insolation, etc.). The temperature criteria may be adjusted to account for the difference in ambient conditions such as solar insolation.

The post-shipment surface dose rate measurements should not significantly exceed the pre-shipment surface dose rate measurements**.**

Post-transportation measurements indicating surface temperature and dose rates significantly exceeding the pre-transportation measurements may require that the user exercises special precautions during unloading of contents from the package, in accordance with Section 7.2.2 of this SAR (Step 3). If damage is observed to previously undamaged fuel during unloading operations, it shall be documented and processed in accordance with the user's corrective action program. The report shall include pre and post-transportation temperature and dose rate measurement results, description of package contents pre and post transportation (i.e. loading and unloading) and engineering evaluation of potential causes of damage to fuel during transportation.

No additional tests are required prior to using the packaging.

Table 8.1.1
Containment System Performance Specifications

Design Attribute	Design Rating
Reference Air Leakage Rate (L_R) Acceptance Criterion	$1x10^{-7}$ ref-cm^3/s air ($1x10^{-8}$ Pa-m^3/s air) (Leaktight as defined by ANSI N14.5)
Leakage Rate Test Sensitivity	$5x10^{-8}$ ref-cm^3/s air ($5x10^{-9}$ Pa-m^3/s air) (½ of the leakage rate acceptance criterion per ANSI N14.5)

Notes:

1. During leakage rate tests appropriate conversion factors will be employed using written and approved procedures to account for actual backfill/tracer gas. For helium as the tracer gas, the Leakage Rate Acceptance Criterion and Test Sensitivity are multiplied by a factor of 1.85.
2. “Leaktight” criteria specified herein is applicable to Fabrication, Maintenance, Pre-shipment and Periodic leakage tests.

Table 8.1.2 (Sheet 1 of 2)
Leakage Rate Tests For The HI-STAR 180L Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5, App. A)	Allowable Leakage Rate
Fabrication Leakage Rate Test	• Containment Shell • Containment Baseplate • Containment Closure Flange • Inner Closure Lid • Outer Closure Lid • Inner Closure Lid Vent and Drain Port Cover Plates • Outer Closure Lid Access Port Plug • Containment Shell Welds • Containment Shell to Containment Baseplate Weld • Containment Shell to Containment Closure Flange Weld	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1
Pre-Shipment Leakage Rate Test	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 2 of 2)
Leakage Rate Tests For The HI-STAR 180L Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5, App. A)	Allowable Leakage Rate
Maintenance Leakage Rate Test	• Containment Shell • Containment Baseplate • Containment Closure Flange • Inner Closure Lid • Outer Closure Lid • Inner Closure Lid Vent and Drain Port Cover Plates • Outer Closure Lid Access Port Plug • Containment Shell Welds • Containment Shell to Containment Baseplate Weld • Containment Shell to Containment Closure Flange Weld	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1
Periodic Leakage Rate Test	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1

Note: For a Leakage Rate Acceptance Criterion specified in Table 8.1.1 as “Leaktight as defined by ANSI N14.5”, the summation of individual component leakage rates of the containment boundary of a package is not required.

Table 8.1.3
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
i.	B_4C powder (raw material) (see note 1)	Particle size distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchasing Specification [8.1.9]
		Purity	One sample per lot	To verify material supplier's data sheet	ASTM C-750
ii.	Al Powder (raw material)	Particle Size Distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchasing Specification [8.1.9]
		Purity	One sample per lot	To verify material supplier's data sheet	Must be 99% (min.) pure aluminum
iii.	B_4C/Al Mix	B_4C Content (by the wet chemistry method)	One sample per mixed/blended powders lot	To ensure wt.% B_4C requirements compliance	The weight density of B_4C must lie in the range of 10 to 11% Nom.

Table 8.1.3 (Continued)
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
iv.	Finished Metamic-HT panel	Thickness and width, straightness, camber and bow	Holtec QA Program Sampling Plan	To ensure fabricability of the basket	Per Holtec's Purchasing Specification [8.1.9]
		Mechanical & Structural MGV Properties (see Note 2)	Per Sampling Plan Table 8.1.4	To ensure structural performance.	MGVs Per Holtec's Purchasing Specification [8.1.9]
		B_4C content by areal density measurements (neutron attenuation method)	One sample from a panel from each Metamic-HT manufactured lot	To ensure criticality safety	The B_4C content by weight shall be ≥ 10 wt. %

Notes:
1. The B_4C testing requirements apply if the raw material supplier is not in Holtec's Approved Vendor List.
2. All properties shall be measured at room temperature on extruded coupons.

Table 8.1.4: Tier System for Metamic-HT Production Coupon Testing

Tier No. (Note 1)	Number of Extrusions Tested per Lot (Note 4)	Number of Continuous Lots that Must Pass to Drop Down to the Next Tier (Note 2 and note 3)
1 (most sampling)	20 %	5
2	12.5 %	5
3	5 %	10
4 (least sampling)	1 %	N/A

Note 1: Tier No. 1 is associated with the most amount of required extrusion testing while Tier 4 is associated with the least amount of required extrusion testing. A test coupon (i.e. test sample) is taken from each extrusion that is required to be tested.

Note 2: The last column reflects the logic where in order to reduce sampling and ultimately achieve Tier No. 4, MGV properties must be met on a consistent basis. For example, if Tier No. 1 applies, then to achieve Tier No. 2, five lots in a row must pass. On the other hand, a stringent penalty applies as specified in Note 4.

Note 3: Testing shall be moved up the table to the next tier (a greater amount of sampling) if any MGV property (accounting for the application of the two replacement coupons per Note 4) fails in two consecutive lots. For example, if Tier No. 2 applies and an MGV property fails on two lots in a row then Tier No. 1 must be applied going forward.

Note 4: If a coupon fails with respect to any MGV property, then it may be replaced by two coupons from the extrusion that produced the failed coupon. If both of the replacement coupons pass the failed MGV property, then the lot can be accepted. If either of the replacement coupons is unsuccessful in meeting the failed MGV property, then the entire lot is rejected. An MGV on a coupon is not considered failed if the replacement coupons pass the failed MGV property. As an alternative to rejecting the entire lot, testing of the failed MGV value on all extrusions within the lot is permitted to isolate acceptable panels.

Table 8.1.5: Fracture Toughness Test Criteria: Containment System
(Sheet 1 of 3)

Item	Material	Thickness mm (in.)	Qualification to LST of -29^{0}C (-20^{0}F) (Note 4)		Qualification to LST of -40^{0}C (-40^{0}F) (Note 4)	
			Charpy V-Notch (Note 2)	**Drop Test Temperature (Note 3)**	**Charpy V-Notch (Note 2)**	**Drop Test Temperature (Note 3)**
Weld Metal for NB Welds	As required	NA	$T_{NDT} \leq -74.7^{o}$C (-102.5^{o}F) Testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	Drop Test Not Required	$T_{NDT} \leq -85.8^{o}$C (-120^{o}F) Testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	Drop Test Not Required
Containment Shell	SA-203 E/ SA-350 LF3	64 (2.5)	$T_{NDT} \leq -74.7^{o}$C (-102.5^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -74.7^{o}$C (-102.5^{o}F) per R.G. 7.11 and NUREG 1815	$T_{NDT} \leq -85.8^{o}$C (-122.5^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -85.8^{o}$C (-122.5^{o}F) per R.G. 7.11 [8.1.4] and NUREG 1815
Containment Closure Flange	SA-350 LF3	364 (14.33)	$T_{NDT} \leq -79.0^{o}$C (-110.2^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -79.0^{o}$C (-110.2^{o}F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 5 and 6)	$T_{NDT} \leq -90.1^{o}$C (-130.2^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -90.1^{o}$C (-130.2^{o}F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 5 and 6)
Containment Baseplate	SA-203 E/ SA-350 LF3	146 (5.75)	$T_{NDT} \leq -89.1^{o}$C (-128.3^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -89.1^{o}$C (-128.3^{o}F) per R.G 7.12 [8.1.5].	$T_{NDT} \leq -70.8^{o}$C (-95.4^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq -70.8^{o}$C (-95.4^{o}F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 5 and 6)

Table 8.1.5: Fracture Toughness Test Criteria: Containment System (Sheet 2 of 3)

Item	Material	Thickness mm (in.)	Qualification to LST of -29^{0}C (-20^{0}F) (Note 3)		Qualification to LST of -40^{0}C (-40^{0}F) (Note 3)	
			Charpy V-Notch (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch (Note 2)	Drop Test Temperature (Note 3)
Inner Closure Lid	SA-203 E/ SA-350 LF3	210 (8.3)	$T_{NDT} \leq$ -92.9^{o}C (-135.3^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -92.9^{o}C (-135.3^{o}F) per R.G. 7.12	$T_{NDT} \leq$ -79.5^{o}C (-111^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -79.5^{o}C (-111^{o}F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 5 and 6)
Outer Closure Lid	SA-203 E/ SA-350 LF3	102 (4.02)	$T_{NDT} \leq$ -86.2^{o}C (-123.1^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -86.2^{o}C (-123.1^{o}F) per R.G. 7.12	$T_{NDT} \leq$ -64.5^{o}C (-84.1^{o}F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -64.5^{o}C (-84.1^{o}F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 5 and 6)

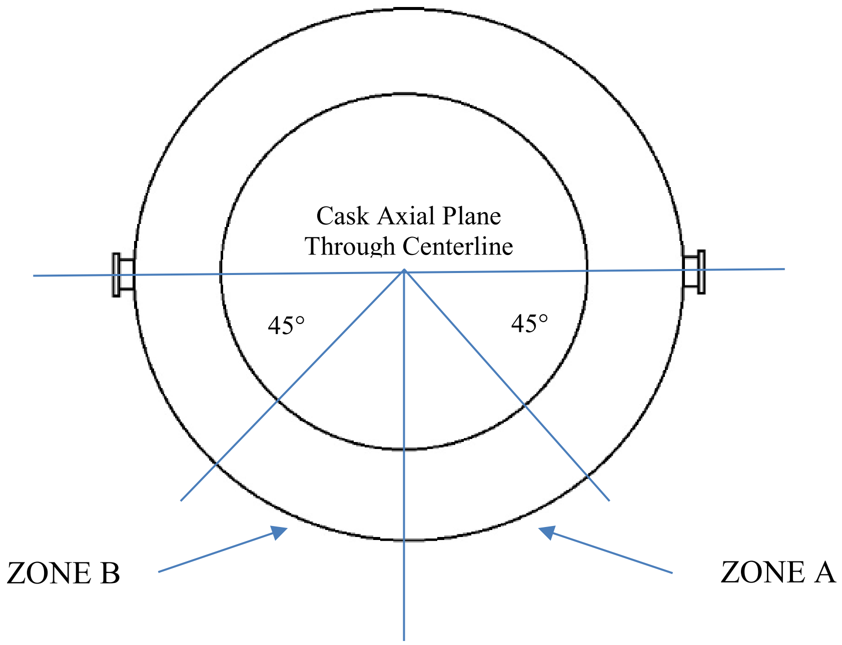
Table 8.1.5: Fracture Toughness Test Criteria: Containment System
(Sheet 3 of 3)

Item	Material	Thickness mm (in.)	Qualification to LST of -29^{0}C (-20^{0}F) (Note 3)		Qualification to LST of -40^{0}C (-40^{0}F) (Note 3)	
			Charpy V-Notch (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch (Note 2)	Drop Test Temperature (Note 3)
Inner Closure Lid Bolt	SA-564 630 / SA-705 630	42 (1.65)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -29^{o}C	No requirements	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -40^{o}C	No requirements
Outer Closure Lid Bolt	SA-564 630 / SA-705 630/SA 320-L7	42 (1.65)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -29^{o}C	No requirements	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -40^{o}C	No requirements
Inner Closure Lid Port Cover Bolt	SA 564-630/Inconel	14 (0.55)	No requirement per Table NB-2333-1	No requirements	No requirement per Table NB-2333-1	No requirements

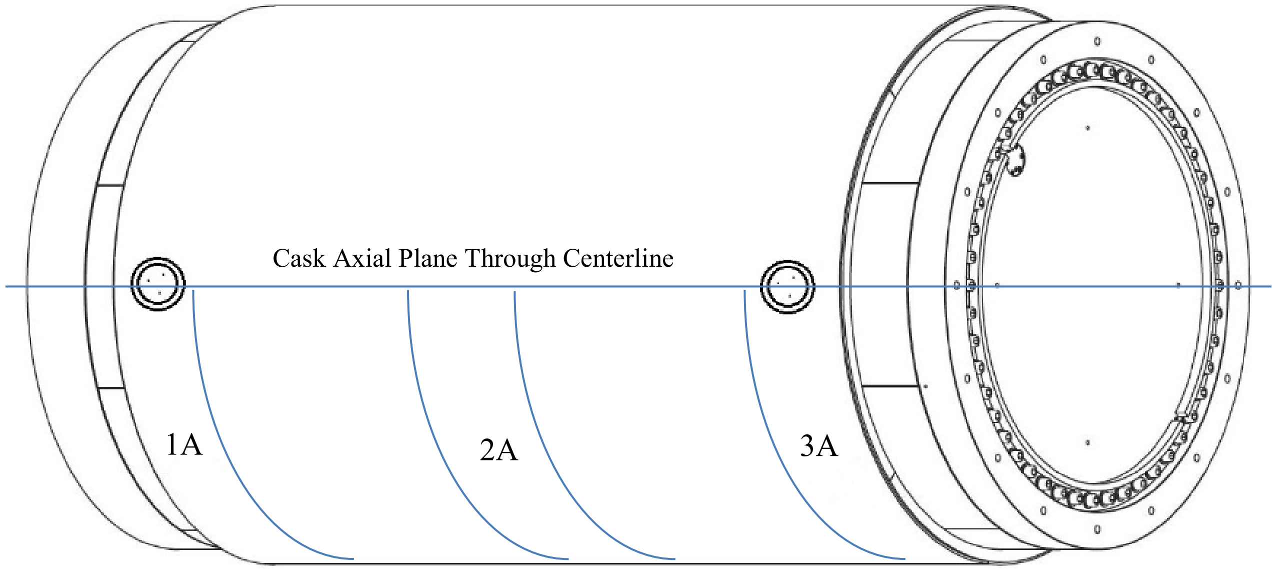
Notes:

1. Containment system components exempt from brittle fracture in accordance with ASME Section III NB-2300 are not listed in this table. Containment system component materials are provided in the licensing drawing package in Section 1.5.

2. Component material to be charpy impact tested in accordance with ASTM A370.
3. Component material to be drop weight tested in accordance with ASTM E208-87a or subsequent edition.
4. Per reference [8.1.12], the LST which applies to impactive loads is -29^{0}C (-20^{0}F). The cask may be qualified to either to an LST of either -29^{0}C (-20^{0}F) or -40^{0}C (-40^{0}F).
5. Component to undergo 100% volumetric examination to confirm absence of flaws which exceed the critical values as defined in NUREG/CR-3826 Table 3. 100% volumetric re-examination is required for cask components qualified per NUREG/CR-3826 following cask operations which result in impactive or impulsive loadings in excess of those defined in the normal conditions of transport.
6. For components greater than 4 inches thick and up to 12 inches thick and qualified to LST of -40^{0}C (-40^{0}F), qualification per R.G. 7.12 may be applied in lieu of qualification per NUREG/CR-3826.



CASK BOTTOM END VIEW (SHOWN WITHOUT IMPACT LIMITERS)



NOTE: THREE SUBZONES WITHIN "ZONE A" AS SHOWN. THREE SUBZONES WITHIN "ZONE B" ON THE OPPOSING SIDE OF THE CASK MIRRORING THE "ZONE A" SUBZONES. THE WIDTH OF THE SUBZONES IS 2 FEET NOMINAL.

HORIZONTAL CASK (SHOWN WITHOUT IMPACT LIMITERS)

Figure 8.1.1: Measurements Zones for the Post Shipment Fuel Integrity Acceptance Test

8.2 MAINTENANCE PROGRAM

An ongoing maintenance program for the HI-STAR 180L Package will be prepared and issued prior to the delivery and first use of the HI-STAR 180L Package as a part of its O&M Manual. This document shall delineate the detailed inspections, testing, and parts replacement necessary to ensure continued radiological safety, proper handling, and containment performance of the HI-STAR 180L Package in accordance with 10CFR71 regulations, conditions in the Certificate of Compliance, and the design requirements and criteria contained in this Safety Analysis Report (SAR).

The HI-STAR 180L package is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions. As a result, only minimal maintenance will be required over its lifetime, and this maintenance would primarily result from weathering effects, and pre- and post-usage requirements for transportation. Typical of such maintenance would be the reapplication of corrosion inhibiting materials on accessible external surfaces, seal replacement, and leak testing following seal replacement. Such maintenance requires methods and procedures no more demanding than those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR 180L Package is provided in Table 8.2.1.

8.2.1 Structural and Pressure Tests

No periodic structural or pressure tests on the packaging following the initial acceptance tests are required to verify continuing performance.

8.2.2 Leakage Tests

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

If the pre-shipment leakage rate test (Section 8.1.4) expires, a periodic leakage rate test of the containment seals must be performed prior to transport. This periodic leakage rate test shall be performed at the frequency indicated in Table 8.2.1.

Maintenance leakage rate testing shall be performed prior to returning a package to service following maintenance, repair (such as a weld repair), or replacement of containment system components (such as containment seal replacement and/or removal of closure bolts/plugs). Only that portion of the containment system that is affected by the maintenance, repair or component replacement needs to be leak tested. In case of unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

Periodic and maintenance leakage rate test results shall be documented and maintained in accordance with the user's quality assurance program.

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

8.2.3 Component and Material Tests

8.2.3.1 Relief Devices

The neutron shield relief devices shall be visually inspected for damage or indications of excessive corrosion at the frequency indicated in Table 8.2.1. If the inspection determines an unacceptable condition, the neutron shield relief devices shall be replaced. Additionally, the neutron shield relief devices may be replaced periodically while the cask is in service if required by the manufacturer's O&M manual.

8.2.3.2 Shielding Materials

Periodic verification of the neutron shield integrity shall be performed at the frequency indicated in Table 8.2.1 using written and approved procedures. Calibrated radiation detection equipment shall be used to take measurements (with either loaded contents or a check source) at the surface of the package. At a minimum, measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the neutron shield. The calculated values shall be representative of the loaded contents (i.e., fuel type, enrichment, burnup, cooling time, etc…) or the particular check source used for the measurements.

The test results shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.3 Packaging Surfaces

Accessible external surfaces of the packaging (including impact limiters) shall be visually inspected for damage at the frequency indicated in Table 8.2.1 to ensure that the packaging effectiveness is not significantly reduced. Visual inspections of the cask and impact limiters shall be performed for external surface coating and component damage including surface denting, surface penetrations, weld cracking, chipped or missing coating. Where necessary, cask coatings shall be reapplied. Damage shall be evaluated for impact on packaging safety and shall be repaired or replaced accordingly. Wear and tear from normal use will not impact cask safety. Repairs or replacement in accordance with written and approved procedures, as set down in the O&M manual, shall be required if unacceptable conditions are identified.

Prior to installation or replacement of a closure seal, the cask sealing surface shall be cleaned and visually inspected for scratches, pitting or roughness, and affected surface areas shall be polished smooth or repaired as necessary in accordance with written and approved procedures.

8.2.3.4 Packaging Fasteners

Cask and impact limiter fasteners shall be visually inspected for damage such as excessive wear, galling, or indentations on the threaded surfaces at the frequency indicated in Table 8.2.1. Threaded fasteners shall be examined in accordance with paragraph NB-2582, ASME Section III, Subsection NB. Fasteners without sufficient usable thread length meeting the requirements of NB-2582 shall be replaced. Damaged fasteners shall be replaced accordingly. Damaged internal threads (including bushings, welded/helical inserts and other threaded components) may be repaired per standard industry practice. The use of Helicoil type inserts for thread repairs is permitted. Any repair shall be evaluated to ensure ASME Code stress limits applicable to bolted closure joints are met. Any required material or manufacturing process testing would also be performed in accordance with ASME Section III, Subsection NB or Subsection NF as applicable.

Bolting of both Inner and Outer Closure Lids, including Inner Closure Lid Port Covers, shall be replaced as guided by fatigue analysis per the provisions of Section III of the ASME Code. The maintenance program in Table 8.2.1 provides a bolt change out schedule to insure that the cumulative damage factor accumulated by a bolt shall be less than 1.0 with sufficient margin. One bolting cycle is the complete sequence of torquing and removal of bolts.

Containment Closure Flange internal threads for closure bolts and Inner Closure Lid internal thread for Port Cover Bolts have a maximum service life limit based on bolting cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. The bolting cycles specified in Table 8.2.1 shall not be exceeded. Inserts, plugs and bushings used in containment components have a maximum service life limit based on bolting or torqueing/untorqueing cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. One bolting cycle is the complete sequence of torquing and removal of bolts.

Maintenance of important to safety fasteners including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.5 Cask Trunnions and Trunnion Replacement Plugs

Cask trunnions shall be inspected at the frequency indicated in Table 8.2.1. The accessible parts of the trunnions (areas outside the cask), and the local cask areas shall be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require repair or replacement of the trunnion and/or repair of the cask. The repair process shall involve removal of the trunnion from the cask and inspection of all surfaces of the trunnion for further defects that may require repair.

Cask trunnion replacement plugs shall be inspected at the frequency indicated in Table 8.2.1. Cask trunnion replacement plugs shall be visually examined to for deformation, distortion, or cracking has occurred of threads to the extent necessary to ensure smooth installation and removal.

Following any replacements and/or repair, the load testing (Subsection 8.1.3) shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user’s quality assurance program.

8.2.3.6 Closure Seals

The HI-STAR 180L Packaging is equipped with metallic closure seals on the inner and outer closure lids and other penetration closure joints as specified in the drawing in the CoC. The closure seals are shipped from the factory pre-inspected and carefully packaged. Once installed and compressed, the seals should not be disturbed by removal of closure fasteners. Removal of closure fasteners requires replacement of closure seals and performance of a Maintenance Leakage Rate Test for closure seals classified as containment boundary seals. Closure seals are specified for long-term use and do not require additional maintenance.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user’s quality assurance program.

8.2.3.7 Fuel Basket

No additional tests are required for the HI-STAR 180L fuel basket assembly.

8.2.3.8 Fuel Spacer

Fuel spacers shall be visually inspected for damage at the frequency indicated in Table 8.2.1. If inspection determines an unacceptable condition, the fuel spacer shall be replaced in accordance with written and approved procedures.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.4 Thermal Tests

Periodic thermal performance test shall be performed in accordance with written and approved procedures at the frequency indicated in Table 8.2.1 to demonstrate that the thermal capabilities of the cask remain within its design basis.

This test may be performed immediately after a HI-STAR 180L Package is loaded with spent nuclear fuel. The in-service test is performed to verify a continued adequate rate of heat dissipation from the cask to the environment. Acceptable performance under test conditions ensures that design basis fuel cladding temperature limits to which the HI-STAR 180L Package is qualified under design basis heat loads will not be exceeded during transport.

Prior to performing the test, thermal equilibrium of the HI-STAR 180L Package shall be verified by measuring the temperature at a defined point near the mid-plane of the HI-STAR 180L Package at one hour intervals using a calibrated thermocouple or surface pyrometer. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of ambient test conditions and incorporated into the test procedure.

After thermal equilibrium is established, temperatures shall be measured and recorded using a calibrated thermocouple or surface pyrometer at four equally spaced circumferential locations at the mid height of the active fuel. The decay heat load and fuel cycle history of the fuel assemblies loaded in the HI-STAR 180L Package shall also be recorded.

The HI-STAR 180L Package is considered acceptable if the average measured surface to ambient temperature differential defined in the procedure, suitably adjusted for environmental conditions, is not exceeded.

The test results shall be documented and maintained in accordance with the user's quality assurance program.

8.2.5 Miscellaneous Tests

No additional tests are required for the HI-STAR 180L Packaging, packaging components, or packaging materials.

Table 8.2.1 (Sheet 1 of 2)
Maintenance Inspections and Tests Program Schedule

Task	Schedule
Periodic leakage rate test of containment system seals (See Subsection 8.2.2)	Prior to transport if period from last test exceeds 1 year.
Maintenance Leakage Rate Test (See Subsection 8.2.2)	Following maintenance, repair or replacement of containment system components
Neutron shield relief device visual inspection (See Paragraph 8.2.3.1)	• Prior to fuel loading • Prior to each transport
Neutron shield relief device replacement (See Paragraph 8.2.3.1)	If required by the manufacturer's O&M manual
Shielding Test (See Paragraph 8.2.3.2)	• Within 5 years of the last shielding effective test or last periodic shielding verification prior to shipment. • Prior to shipment following major repairs and maintenance activities.
Packaging external surface visual inspection. (See Paragraph 8.2.3.3)	• Prior to fuel loading • Prior to each transport
Cask closure fasteners/bolts visual inspection (See Paragraph 8.2.3.4)	• Prior to installation • Prior to each transport if damage is suspected
Impact limiter fasteners visual inspection (See Paragraph 8.2.3.4)	• Prior to installation • Prior to each transport if damage is suspected
Bolt replacement (*Service Life*) for Inner Closure Lid (See Paragraph 8.2.3.4)	Every 225 bolting cycles for SA-564/705 630 Every 277 bolting cycles for SB-637
Bolt replacement (*Service Life*) for Outer Closure Lid (See Paragraph 8.2.3.4)	Every 588 bolting cycles for SA 193-B7 Every 588 bolting cycles for SA 320-L7 Every 225 bolting cycles for SA-564/705 630 Every 277 bolting cycles for SB-637
Bolt replacement (*Service Life*) for Inner Closure Lid Port Cover Bolts (See Paragraph 8.2.3.4)	Every 588 bolting cycles for SA 193-B7 Every 288 bolting cycles for SA 320-L7
Containment Closure Flange internal closure bolt thread *Service Life* (See Paragraph 8.2.3.4)	1500 bolting cycles

Table 8.2.1 (Sheet 2 of 2)
Maintenance Inspections and Tests Program Schedule

Task	**Schedule**
Inner Closure Lid internal thread *Service Life* for Port Cover Bolts (See Paragraph 8.2.3.4)	1500 bolting cycles
Cask Trunnion visual inspection (See Paragraph 8.2.3.5.)	• Prior to fuel loading • Prior to transport if period from last visual inspection exceeds 1 year
Cask Trunnion Replacement Plug visual inspection (See Paragraph 8.2.3.5.)	Prior to transport
Seal replacement for Inner and Outer Closure Lids (See Paragraph 8.2.3.6)	Following removal of closure bolting
Seal replacement for Outer Closure Lid Access Port Plug (See Paragraph 8.2.3.6)	Following removal of access port plug
Seal replacement for Inner Closure Lid Port Covers (See Paragraph 8.2.3.6)	Following removal of port cover fasteners
Fuel Spacer Inspection (See Paragraph 8.2.3.8)	Prior to loading into cask.
Thermal Test (See Subsection 8.2.4)	Within 5 years prior to shipment

8.3 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages or Technical Reports, which are the repository of all relevant licensing and design basis calculations, are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

[8.0.1] U.S. Code of Federal Regulations, Title 10, "Energy", Part 71, "Packaging and Transportation of Radioactive Materials.”

[8.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2015 Edition (Section IX, 2013 for FSW only unless otherwise indicated).

[8.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, Revision as required by the ASME Code [8.1.1] or as required by ANSI N14.5 [8.1.6].

[8.1.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

[8.1.4] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1m)," Regulatory Guide 7.11, June 1991.

[8.1.5] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1m) But Not Exceeding 12 Inches (0.3m)," Regulatory Guide 7.12, June 1991.

[8.1.6] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials Leakage Tests on Packages for Shipment", ANSI N14.5, 2014.

[8.1.7] Holtec International Document DOC-5014-03, “Acceptance Testing of First HI-STAR Overpack (Thermal and He Leak Tests)”, September 2006

[8.1.8] "Metamic-HT Manufacturing Manual", Latest Revision, Holtec International (Holtec Proprietary)

[8.1.9] "Metamic-HT Purchasing Specification", Holtec Document ID PS-11, Latest Revision, (Holtec Proprietary)

[8.1.10] "Metamic-HT Qualification Sourcebook", HI-2084122, Latest Revision, Holtec International (Privileged Intellectual Property)

[8.1.11] M. W. Schwartz (under Lawrence Livermore National Laboratory contract to the NRC), "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick", U.S. Nuclear Regulatory Commission, NUREG/CR-3826, July 1984.

[8.1.12] Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material", Revision 1, March, 1989, U.S. Nuclear Regulatory Commission.

Appendix 8.A: CONTAINMENT BOUNDARY SEAL DATA

The information in Tables 8.A-1, 8.A-2, 8.A-3 and 8.A-4 provides the complete description of containment boundary seal options for the HI-STAR 180L package. The critical characteristics of containment seals include the Seal Cross Section Diameter, Groove Depth, Seating Load, Seal Springback, Minimum Seal/Groove radial clearance, Sealing Surface Finish Range, and Seal Materials and Material Combinations. The approved seal designs and corresponding seal part/drawing numbers are defined in the tables that follow. Use of other seal designs or changes to critical characteristics as defined in the tables requires prior NRC approval.

Table 8.A-1 Inner Lid Seals

Seal Property	Seal Option 1	Seal Option 2
Seal Manufacturer	Technetics	Reserved for future use
Seal Part/Drawing Number	HN-200 / 111-0210165 & 111-0210182	Reserved for future use
Inner Seal Groove OD “ODg” (mm [inches])	1777.20 +1.52/-0.00 [69.969 +0.060/-0.000]	Reserved for future use
Inner Seal, Seal OD “ODs” (mm [inches])	1776.11 +/-0.25 [69.926 +/-0.010]	Reserved for future use
Outer Seal Groove ID “IDg” (mm [inches])	N/A	Reserved for future use
Outer Seal, Seal ID “IDs” (mm [inches])	N/A	Reserved for future use
Outer Seal Groove OD “ODg” (mm [inches])	1827.00 +1.52/-0.00 [71.929 +0.060/-0.000]	Reserved for future use
Outer Seal Seal OD “ODs” (mm [inches])	1825.91 +/-0.25 [71.886 +/-0.010]	Reserved for future use
Groove Width “W” (mm [inches])	17.91 +/-0.76 [0.705 +/-0.03]	Reserved for future use
Groove Height “H” - Min/Max (mm [inches])	10.7 +/- 0.127 [0.421 +/- 0.005]	Reserved for future use
Seal Cross Section Diameter – Min / Max (mm [inches])	11.80 +0.60/-0.05 [0.465 +0.024/-0.002]	Reserved for future use
Seal Seating Load, +/-10% (N/mm [lbs/inch])	540 / 3084	Reserved for future use
Surface Finish Requirement for Sealing Surfaces (μm [μin])	1.6-3.2 c [63-125c]	Reserved for future use
Component Materials	Spring: Nimonic 90 Inner lining: SS Sealing lining: Silver	Reserved for future use

Table 8.A-2 Outer Lid Seals

Seal Property	Seal Option 1	Seal Option 2
Representative Seal Manufacturer	Technetics	Reserved for future use
Seal Part/Drawing Number	HN-200 / 111-0210134 & 111-0210151	Reserved for future use
Inner Seal Groove OD "ODg" (mm [inches])	2077.20 +1.52/-0.00 [81.78 +0.060/-0.000]	Reserved for future use
Inner Seal, Seal OD "ODs" (mm [inches])	2076.1 +/-0.25 [81.736 +/-0.010]	Reserved for future use
Outer Seal Groove ID "IDg" (mm [inches])	N/A	Reserved for future use
Outer Seal, Seal ID "IDs" (mm [inches])	N/A	Reserved for future use
Outer Seal Groove OD "ODg" (mm [inches])	2126.98 +1.52/-0.00 [83.739 +0.060/-0.000]	Reserved for future use
Outer Seal Seal OD "ODs" (mm [inches])	2125.88 +/-0.25 [83.696 +/-0.010]	Reserved for future use
Groove Width "W" (mm [inches])	17.91 +/-0.76 [0.705 +/-0.03]	Reserved for future use
Groove Height "H" - Min/Max (mm [inches])	10.7 +/- 0.127 [0.421 +/- 0.005]	Reserved for future use
Seal Cross Section Diameter – Min / Max (mm [inches])	11.80 +0.60/-0.05 [0.465 +0.024/-0.002]	Reserved for future use
Seal Seating Load +/-10% (N/mm [lbs/inch])	540 / 3084	Reserved for future use
Surface Finish Requirement for Sealing Surfaces (µm [µin])	1.6-3.2 c [63-125c]	Reserved for future use
Component Materials	Spring: Nimonic 90 Inner lining: SS Sealing lining: Silver	Reserved for future use

Table 8.A-3 Inner Port Cover Seals

Seal Property	Seal Option 1	Seal Option 2
Seal Manufacturer	Technetics	Reserved for future use
Seal Part/Drawing Number	HN-200 / 111-0215637 & 111-0215634	Reserved for future use
Inner Seal Groove OD "ODg" (mm [inches])	95.00 +0.10/-0.00 [3.740 +0.004/-0.000]	Reserved for future use
Inner Seal, Seal OD "ODs" (mm [inches])	94.50 +0.20/-0.20 [3.720 +0.008/-0.008]	Reserved for future use
Outer Seal Groove ID "IDg" (mm [inches])	N/A	Reserved for future use
Outer Seal, Seal ID "IDs" (mm [inches])	N/A	Reserved for future use
Outer Seal Groove OD "ODg" (mm [inches])	110.49 +0.10/-0.00 [4.350 +.004/-0.000]	Reserved for future use
Outer Seal Seal OD "ODs" (mm [inches])	110.00 +0.20/-0.20 [4.331 +0.008/-0.008]	Reserved for future use
Groove Width "W" (mm [inches])	4.35 MIN [0.171 MIN]	Reserved for future use
Groove Height "H" - Min/Max (mm [inches])	2.20 +.05/-.05 [0.087 +0.002/-0.002]	Reserved for future use
Seal Cross Section Diameter – Min / Max (mm [inches])	3.00 +0.40/-0.05 [0.118 +0.016/-0.002]	Reserved for future use
Seal Seating Load +/-10% (N/mm [lbs/inch])	230 / 1313	Reserved for future use
Surface Finish Requirement for Sealing Surfaces (µm [µin])	1.6-3.2 c / 63-125c	Reserved for future use
Component Materials	Spring: Alloy 90 Inner Lining:304L SS Sealing Lining: Silver	Reserved for future use

Table 8.A-4 Outer Lid Access Port Plug Seal		
Seal Property	Seal Option 1	Seal Option 2
Seal Manufacturer	Technetics	Reserved for future use
Seal Part/Drawing Number	HLR-200	Reserved for future use
Seal Groove OD “ODg” (mm [inches])	40.50 +0.20/-0.00 [1.594 +0.008/-0.00]	Reserved for future use
Seal OD “ODs” (mm [inches])	40.00 [1.574]	Reserved for future use
Seal ID “IDs” (mm [inches])	31.80 +/- 0.20 [1.252+/-0.008]	Reserved for future use
Seal Cross Section Diameter (mm [inches])	4.10 +0.4/- 0.05 [0.161 +0.016/- 0.002]	Reserved for future use
Groove Height “H” (mm [inches])	2.35 +/- 0.05 [0.093 +/- 0.002]	Reserved for future use
Seal Seating Load +/- 10% (N/mm [lbs/inch])	180 [1028]	Reserved for future use
Surface Finish Requirement for Sealing Surfaces (μm [μin])	0.4-1.6c [16-63c]	Reserved for future use
Component Materials	Spring: Nimonic 90 Inner lining: SS Sealing lining: Silver	Reserved for future use