NON-PROPRIETARY VERSION

SAFETY ANALYSIS REPORT
on
THE HI-STAR 100MB PACKAGE

(Revision 0)

by

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ABOUT THIS SAR

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

REVISION STATUS AND CONFIGURATION CONTROL

SAR review and verification are controlled at the chapter level and changes are annotated at the section level and appendix level. The revision of this SAR is the same as the latest revision of any chapter in this SAR, except when the whole SAR revision is leveled up to reflect the revision to a licensing drawing that did not require a change to the text of any SAR chapter. Similarly the revision number of any given chapter is the same as the latest revision of any section or appendix to that chapter. Licensing drawings are controlled individually within Holtec's drawing configuration control system.

A section in a chapter 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 and begins on a fresh page.

Unless indicated as a "complete revision" in the summary description of change below, if any change in the content is made, then the change is indicated by a "bar" in the right page margin and the revision number (annotated in the footer) of the entire section including applicable figures is changed. Those chapter sections and chapter appendices 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. Similarly the revision level of whole chapters (as indicated in this revision status) for chapters that remain unchanged by a SAR revision will not match the revision of the whole SAR. Revision bars may or may not be shown for those sections of older revisions.

REVISION SUMMARY

A summary description of change is provided below for each SAR chapter (by section or 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.: 0**
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Chapter 8: Acceptance Tests and Maintenance Program		Revision Number.: 0
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GLOSSARY AND NOTATION
(HI-STAR 100MB)

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 parts (typically 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 high level waste, including spent nuclear fuel, in a safe configuration.

Cask Bottom Region (CBR) refers to the bottom thick nickel steel forging with a Holtite insert

Cask Top Region (CTR) refers to the top nickel steel forging with a Holtite insert

CG is an acronym for Center of Gravity.

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

Closure Lid System (CLS) refers to the specially shaped lid with concentric grooves. The bolted lid joint is engineered to meet the leak-tight criterion of ANSI N14.5.

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 dual closure lids with seal(s) and associated penetration port closure(s) and seal(s).

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 to 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 evaluations, or that cannot be handled by normal means. Also see fuel debris.

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.

DBE means Design Basis Earthquake.

DCSS is an acronym for Dry Cask Storage System.

Design Heat Load or Design Basis Heat Load is the computed heat rejection capacity of the cask system with the ambient at the normal temperature and the peak cladding temperature (PCT) at 400ºC. 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 100MB 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 100MB 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) 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.

EV is an acronym for the Enclosure Vessel defined above.

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 of radiological contents of the package engineered into the system for added safety or to meet a specific jurisdictional regulation.

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 rods and loose fuel pellets from damaged fuel assemblies, and fuel assemblies with known or suspected defects which cannot be handled by normal means due to fuel cladding damage, including containers and structures supporting these parts.

Fuel Package is the generic term to represent the physical embodiment consisting of the batch of CSF contained in a Fuel Basket (bare Fuel Package) or the MPC (containerized Fuel Package).

Gamma Capture Space (GCS) means the annular space defined by the Containment shell and the Intermediate Composite Shell occupied by lead.

GTCC is an acronym for Greater Than Class C waste.

HAC is an acronym for Hypothetical Accident Condition under 10 CFR 71.73

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 190, HI-STAR 100MB and HI-STAR HB.

HI-STAR 100MB 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 100MB Package consists of the HI-STAR 100MB cask and MPC with two impact limiters installed at the extremities, a personnel barrier if required, and the licensed radioactive contents loaded for transport.

HI-STAR 100MB Packaging consists of the HI-STAR 100MB Package without the licensed radioactive contents loaded.

Holtite™ 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 spent nuclear fuel safely; to prevent damage to spent nuclear fuel; and to provide reasonable assurance that spent nuclear fuel 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).

Intermediate Shell is the cylinder between the Gamma Capture Space and the Neutron Capture Space

LLNL is an acronym for Lawrence Livermore National Laboratory.

Leaktight (is defined in this SAR to be same as defined in ANSI N14.5) means a 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 absolute and a downstream pressure of 0.01 atmosphere absolute or less. Reference cubic centimeter per second (ref-cm^3/s) means a volume of one cubic centimeter of dry air per second at 1 atmosphere absolute pressure (760 mm Hg) and 25°C. Finally, 1 x 10^{-7} ref-cm^3/s air is equal to 4.09 x 10^{-12} gram-moles/s of dry air or helium and is approximately equivalent to 2 x 10^{-7} ref-cm^3/s helium.

Licensing Drawings or Licensing Drawing Package is an integral part of this SAR wherein the essential geometric and material information on HI-STAR 100MB is compiled to enable the safety evaluations pursuant to 10 CFR 71 to be carried out.

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.

Load-and-Go is a term used in this SAR that means the practice of loading authorized contents into the HI-STAR System packaging and placing the packaging into transportation service under 10 CFR 71, without first deploying the system at an Independent Spent Fuel Storage Installation (ISFSI) under 10 CFR 72. A transfer cask may be loaded under 10CFR72 and used to transfer the sealed canister into the HI-STAR cask without first deploying at an ISFSI.

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™ is a trade name for an aluminum/boron carbide composite neutron absorber material qualified for use in the HI-STAR/HI-STORM fuel baskets.

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)

MGDS is an acronym for Mined Geological Depository System.

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 strength welded 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 Condition of Transport"

NDT is an acronym for Nil Ductility Transition, which is defined as the temperature at which the fracture stress in a material with a small flaw is equal to the yield stress in the same material if it had no flaws.

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 Capture Space (NCS) means the annular space defined by the Intermediate Shell and the outer shell filled with Holtite.

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.

Non-Fuel Hardware (NFH) means high-level waste not used to produce thermal energy in the reactor. Examples of NFH are 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), water displacement guide tube plugs, orifice rod assemblies, Instrument Tube Tie Rods (ITTRs), Guide Tube Anchors (GTAs), and vibration suppressor inserts.

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

Overpack is an alternative term used in this SAR to denote a cask containing a Fuel Package.

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.

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.

SCG is an acronym for the intermediate spent fuel storage container building located at the Doel Site.

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 fuel loading or fuel 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).

Specific Heat Load means the heat emission rate from one fuel assembly. Sum of the Specific Heat loads of all fuel assemblies in a Fuel Package is referred to as the Aggregate heat Load.

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.

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 a set of support saddles, a personnel barrier and 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 and helium backfill system) used during fuel 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).

Water Tight is defined as a degree of leak-tightness that in a practical sense precludes any significant intrusion of water through all water exclusion barriers. This degree of leak-tightness 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. This SAR permits Zircaloy 2, Zircaloy 4, ZIRLO and M5 fuel cladding material as allowable contents.

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

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

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 (-20 ºF)

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

CHAPTER 1: GENERAL DESCRIPTION OF THE HI-STAR 100 VERSION MB TRANSPORT PACKAGE

1.0 GENERAL INFORMATION

HI-STAR 100 Version MB is the model name of a transport package engineered to serve as a type B(U)F-96 package for transporting radioactive material including commercial spent fuel (CSF), reactor-related non-fuel waste, and high-level waste.

This safety analysis document for the HI-STAR 100MB 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 49 CFR 173 [1.0.3].

The HI-STAR 100 Version MB transport cask hereafter referred to as "HI-STAR 100MB" for brevity, is an enhanced embodiment of the HI-STAR 100 transport cask initially licensed in docket [71-9261] in 1998. The fuel storage cavity of HI-STAR 100MB is fully compatible with all MPCs previously licensed in this docket. However, improvements in the cask's shielding, heat rejection and structural capacity have been made by emulating the design features of the recently licensed HI-STAR 190 cask [1.0.4][1]. Like HI-STAR 190, HI-STAR 100MB can be used to transport high burnup (HB) fuel. Like HI-STAR 190, two limiting cask cavity lengths, termed Type XL (extra-long) and Type SL (Short length) are considered to accommodate the variety of lengths in which commercial nuclear fuel is burned in LWRs. Each safety analysis summarized in this submittal considers the limiting lengths using the most limiting configuration to perform a bounding analysis. The acceptance criteria and analysis models, previously employed in the SAR of HI-STAR 190 are also used herein and thus, no new analysis methodology (previously un-reviewed by the USNRC) has been introduced. For completeness and to facilitate convenient review, the necessary material from HI-STAR 190 SAR has been excerpted and placed in this safety analysis (with appropriate edits) with its provenance clearly indicated to avoid confusion. Information pertaining to the HI-STAR 100MB system is contained in the chapters of the HI-STAR 100 SAR.

Certain other design features of HI-STAR 100MB noted below speak to its future service as a universal transport cask for MPCs and bare basket fuel packages:

- HI-STAR 100MB provides a storage cavity for the Fuel Package that is intended to transport both MPCs (currently MPC-32M) compatible with the HI-STAR 100 cask ID and bare baskets.
- For transporting Moderate Burn-up fuel (MBF) a single containment barrier suffices. However, for transporting High Burn-up Fuel (HBF), pursuant to ISG-19 [1.0.5], a

[1] All references cited herein are listed in Section 1.7 at the end of this chapter.

double containment barrier system is required. The double containment system for HBF is provided by the MPC lid and cask lid, in the manner of HI-STAR 190, if the fuel package is canisterized; however, to transport HBF in a bare basket, two cask lids, each qualified to serve as a stand-alone containment boundary, in the manner of HI-STAR 180 [1.0.6] and HI-STAR 180D [1.0.7], are employed.

Figures 1.0.1 and 1.0.2 provide pictorials of the exterior of the HI-STAR 100MB Cask and HI-STAR 100MB Packaging, respectively. The drawing package in Section 1.3 details the important-to-safety features considered in the packaging evaluation and includes certain details on *not-important-to-safety* features. For clarity, additional pictorials of the cask and packaging components are provided throughout the chapters, as appropriate.

Organization of this safety document

This safety document is organized in a series of chapters. Each chapter is identified by the chapter number.

A section within a chapter is identified by a sequential numeric after the chapter's ID; thus Section 3 in Chapter 2 is denoted by 2.3.

Subsections to a section are identified by the numeric separated by a "dot" after the Section ID. The Figures and tables are numbered sequentially in each section. The revisions to this document will be controlled at the section level.

The numbering of references, is at the section level. Thus, the references in Chapter 2 Section 2 are numbered 2. 2.1 ,2.2.2, et seq.

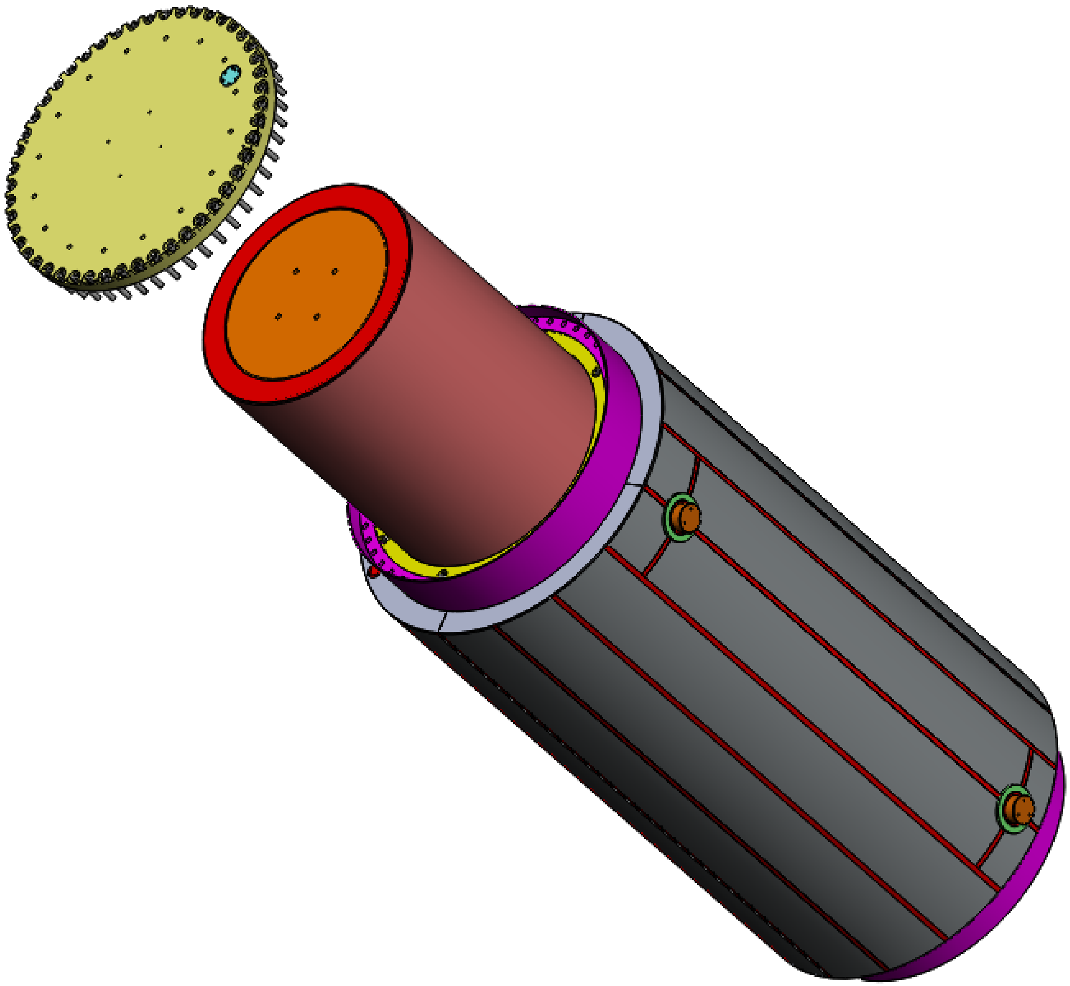

FIGURE 1.0.1: PICTORIAL OF HI-STAR 100MB WITH AN MPC FUEL PACKAGE

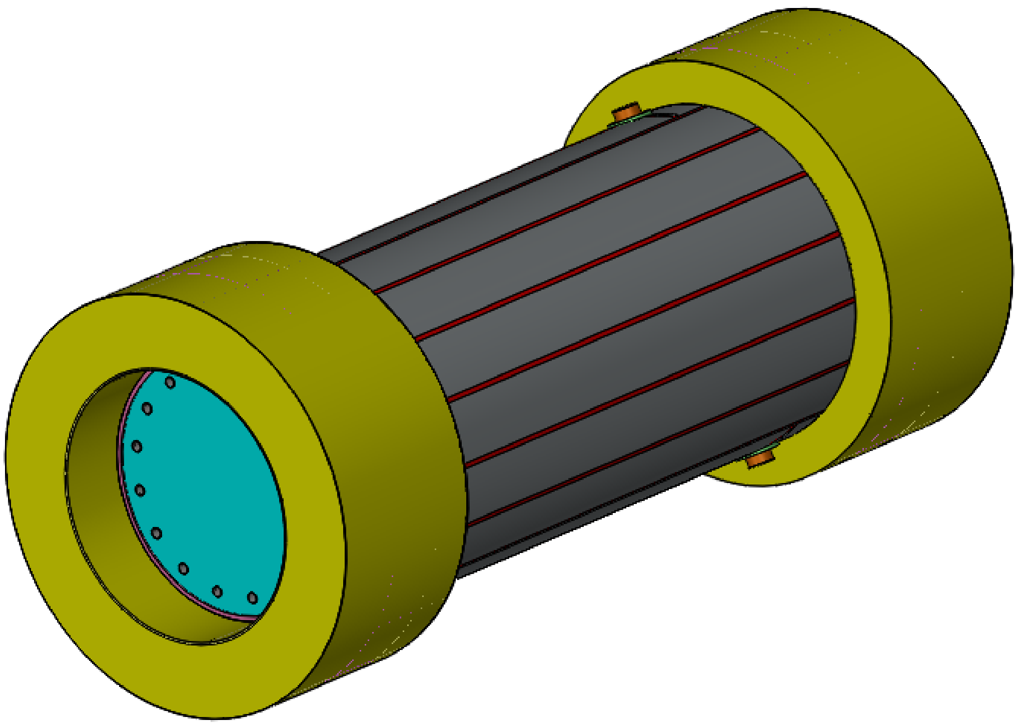

FIGURE 1.0.2: PICTORIAL OF HI-STAR 100MB PACKAGING

1.1 INTRODUCTION

The HI-STAR 100MB is designed to serve as a versatile transport cask, essentially a successor transportation cask to HI-STAR 100 which had been licensed in 1998 (and renewed periodically since then) to transport the "medium" size MPCs that are currently in use in the HI-STORM 100 system (Docket number 72-1014) at dozens of ISFSIs across the US and overseas.[1] Table 1.1.1 places the HI-STAR 100MB in the context of the HI-STAR family of casks that have been previously licensed by the USNRC. Although HI-STAR 100MB has been designed to transport all MPCs that are currently in use in the HI-STORM 100 system, Table 1.1.2 lists the new MPC and bare baskets for which approval is sought with initial licensing of the HI-STAR 100MB. Specifically, MPC-32M (Metamic HT variation of the previously licensed Alloy X-based MPC-32) and F-32M and F-24M (bare basket configuration) are the *Fuel Packages*[2] that are sought to be licensed on the strength of this safety documentation. As illustrated in the Licensing Drawings in Section 1.3, the safety analyses in this submittal consider two limiting cask cavity lengths, denoted as Type XL (Extended Length) and Type SL (Standard Length).

All design and design concepts of the HI-STAR 100MB Package are directly adapted from Holtec's various licensed transport, storage, and transfer cask systems. There are no important design concepts utilized in HI-STAR 100MB that have not been previously utilized and licensed in a Holtec storage or transport system. Design features and basic approach worthy of note include:

- Containment design & manufacturing**:** The containment system is engineered to parallel the anatomical design and construction of the classic HI-STAR 100. More specifically, the containment system welding joint details, NDE requirements, seal joint type, and the ASME code of construction are identical to those of the HI-STAR 100 first licensed in 1998.
- Double Containment for High Burnup Fuel**:** Qualification to transport high burnup fuel (HBF) in the bare basket form follows the double barrier approach in the certified HI-STAR 180 and HI-STAR 180D. Accordingly, for transporting bare basket Fuel packages, two containment closure lids are employed. For transporting MPCs containing HBF, however, a single bolted lid provides one leakage barrier and the second barrier is formed by the MPC inside the HI-STAR in the manner of HI-STAR 190 [1.0.4]
- Burnup Credit: MPC-32M and fuel basket F-32M in Table 1.1.2 utilize burnup credit as a criticality control contributor in the manner of HI-STAR 190 and that previously approved for the MPC-32 in the HI-STAR 100. The approach in this safety analysis is based on the latest NRC guidance followed in the HI-STAR 190 docket. It should be noted that with the

[1] The "medium" sized MPCs refer to those that are compatible with the HI-STORM 100 system. The "large MPCs" are sized to be stored in the HI-STORM FW (72-1032) and HI-STORM UMAX systems (72-1040) and transported in HI-STAR 190 system. HI-STAR 100 model casks are too small in diameter to accommodate large MPCs.
[2] Fuel Package is a generic term that indicates an MPC or a bare basket containing used nuclear fuel.

presence of the Metamic-HT basket, the required fuel burnup credit is significantly reduced compared to the MPC-32 (Alloy X basket with a separate neutron absorber).

- Metamic-HT Baskets**:** Metamic-HT™ is the principal constituent material for the latest generation of fuel baskets in Holtec's storage and transport systems. Metamic-HT has been qualified for transport in an array of HI-STAR casks including HI-STAR 180, HI-STAR180D, and HI-STAR 190. The new fuel baskets introduced in this submittal (Please see Table 1.1.2) also utilize Metamic HT.
- Gamma Shielding**:** Gamma shielding performance is optimized by using lead as the radial gamma shielding material. The gamma shielding material and design employed herein is similar to that used in the recently licensed HI-STAR 190.
- Neutron shielding**:** Neutron shielding performance is optimized by installing Holtite B as the neutron shielding material within the annular sectors formed by the outer-most shell and the intermediate shell, joined by an array of circumferentially equally spaced radial connectors. The type and placement of the neutron shielding material in HI-STAR 100MB is also identical to that used in HI-STAR 190.
- Impact Limiters: The design embodiment and cask interface features of the HI-STAR 100MB AL-STAR impact limiters are similar to those for the HI-STAR 180, the HI-STAR 180D and the HI-STAR 190 AL-STAR impact limiters. The outer surfaces of the top and bottom forgings provide the cylindrical interface to the impact limiter "skirt" with a tight annular clearance to essentially restrain the impact limiter from rotating out of axial alignment with the cask's centerline. The top and bottom forgings present conformal bearing surfaces for the Impact Limiters' skirts.
- Figures 1.0.1 and 1.0.2 provide pictorials of the exterior of the HI-STAR 100MB Cask and HI-STAR 100MB Packaging, respectively. The drawing package in Section 1.3 details the *important-to-safety* features considered in the packaging evaluation and also includes certain details on *not-important -to-safety* features. For the reader's convenience and clarity, additional pictorials of the cask and packaging components are provided throughout this safety analysis.

This safety analysis report supports a transport packaging License Life of 5 years, after which a renewal by the USNRC will be required. However, all safety evaluations are based on a design or service life that is substantially longer than 5 years, to provide a suitable basis for future license renewals. This is generally accomplished by using materials of construction that have been exhaustively tested and determined capable of withstanding HI-STAR 100MB's operating environments with little or no 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, Section 2.2 and Chapter 8).

Chapter 8 of this SAR specifies a maintenance program that is implemented to ensure the cask will meet a Design Life of at least 50 years. The technical considerations that assure the packaging 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
- Assurance of Long-Term Effectiveness of the Neutron Absorber

Each MPC will only be in the HI-STAR 100MB cask for a limited amount of time during transport. Defining a license and design life for MPCs for transport operations is therefore not meaningful. Additional considerations and acceptance criteria necessary for the MPC to provide a containment barrier during transport are specified in Chapters 7 and 8 of this SAR.

The criticality safety index (CSI) for the HI-STAR 100MB 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 100MB Packaging with design basis fuel contents (Section 5.0 provides the determination of the TI). Therefore, the HI-STAR 100MB Package must be transported by exclusive use shipment (10CFR71.47). If the HI-STAR 100MB Package is not loaded with design basis radioactive material contents, then it may be shipped in a non-exclusive use conveyance, provided the threshold limits of 10CFR71.47 are not exceeded. An empty but previously loaded HI-STAR 100MB 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.

Table 1.1.1: HI-STAR FAMILY OF TRANSPORT PACKAGES

Model Name	USNRC Docket and SAR Reference	Year First Certified	Content (Fuel Type)	Cask Cavity Length (inch)	Cask ID (inch)	Cask OD (inch)	Fuel package type: Bare basket (B) or Canisterized (M)
HI-STAR 100	71-9261 [1.1.1]	1998	BWR & PWR	191 1/8	68 ¾	86 ¼	M
HI-STAR 100MB	71-9378	TBD	PWR	165 3/8(SL) 191 1/8(XL)	68 ¾	99 ¼	M or B
HI-STAR 60	71-9336 [1.1.2]	2009	PWR	139 19/32	42 1/2	82	B
HI-STAR 180	71-9325 [1.0.6]	2009	PWR	140 21/32	72 13/16	106 ¾	B
HI-STAR 180D	71-9367 [1.0.7]	2014	PWR	115 28/32	72 13/16	106 ¾	B
HI-STAR 190	71-9373 [1.0.4]	2017	BWR & PWR	190 3/16 (SL) 213 5/16 (XL)	76	106 ½	M
Note: All dimensions are nominal and taken from respective licensing drawing packages approved at the time of this writing.							

TABLE 1.1.2: APPLICABLE "FUEL PACKAGE" TYPES FOR HI-STAR 100MB

Canister/ Basket ID	Fuel Type	Fuel Package Type	Max number of fuel assemblies in the Fuel Package	Currently licensed to be stored in HI-STAR 100	Basket Structural Material
MPC-32M	PWR	MPC(M)	32	no	Metamic-HT
F-32M	PWR	Bare Basket(B)	32	no	Metamic-HT
F-24M	PWR	Bare Basket(B)	24	no	Metamic-HT

1.2 DESCRIPTION OF PACKAGING COMPONENTS AND THEIR DESIGN AND OPERATIONAL FEATURES

1.2.1 Major Packaging Components and Packaging Supports and Restraints

The HI-STAR 100MB Packaging consists of the four major components (Cask, Fuel Package (MPC or bare basket), 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. When transporting HBF, the cask containment system is considered the outer containment boundary and credited as a barrier for moderator exclusion. The containment of the radiological contents is provided by a nickel steel (also referred to as "cryogenic steel") shell welded to a nickel steel bottom flange at the base of the cask and a suitably machined nickel steel top flange at the top, which is equipped with machined surfaces to fasten a high integrity closure lid system equipped with concentric elastomeric seals. The top flange is equipped with two lids when used to transport a bare basket Fuel Package. When transporting an MPC (which, when qualified per the provisions of this SAR serves as an autonomous containment boundary), a single closure lid is adequate to serve in the role of the outer containment. The low temperature-capable steel weldment and the cryogenic steel closure lid define the "Containment Boundary" for the cask. The Containment Boundary, including the closure lid system, is designed and manufactured to ASME Section III Division 1, Subsection NB [1.2.1] as further clarified in this SAR.

For purposes of description, the HI-STAR 100MB 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 flange, 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 Flange.
4) Closure Lid System (CLS): The CLS consists of up to two specially shaped lids, each with two machined concentric grooves to provide containment protection. The bolted lid joint is engineered to meet the leak-tight criterion of ANSI N14.5 [1.2.2] under the normal and hypothetical accident conditions of transport.
5) Gamma Capture Space (GCS): The GCS refers to the annular space around the Containment shell containing lead, which is enclosed by the "intermediate shell" (IS) and strengthened by radial gussets. The space is non-structural in its function and renders the principal function of blocking gamma radiation.
6) Neutron Capture Space (NCS): The NCS is the outermost annular space, which is enclosed by a ductile shell buttressed by radial gussets and filled with Holtite-B whose principal function is to block the neutrons accreted by the contained CSF. This space is also non-structural.

(b) The Fuel Package

The Fuel Package can be in the form of a fuel basket enclosed by an Enclosure Vessel with the combined component referred to as the Multi-Purpose Canister (MPC), or a bare fuel basket installed in the cask cavity.

The fuel basket is an essential part of the transport package; it may be installed in the cask cavity without the Enclosure Vessel (the so-called "bare basket" design) or within an Enclosure Vessel known as the MPC in this SAR. All fuel basket designs used in this submittal feature the honeycomb construction with the cell walls arrayed in two orthogonal planes; consequently, the walls of the cells are either completely coplanar (no offset) or orthogonal with each other. The coplanar honeycomb design of the basket renders it extremely rugged under lateral drop scenarios. Furthermore, the cell-to-cell connectivity inherent in the honeycomb basket structure provides an uninterrupted heat transmission path, making the HI-STAR fuel basket an effective heat rejection device.

The MPCs consist of the stainless steel Enclosure Vessel (EV) and the honeycomb basket made from panels of Metamic-HT. The MPC model applicable to this submittal is listed in Table 1.1.2.

The Enclosure Vessel is a seal-welded and leak-tight pressure vessel which provides additional protection against the release of radionuclides, in addition to that provided by the cask's containment enclosure. When transporting HBF, the EV is considered the inner containment boundary and credited as an additional barrier for moderator exclusion.

In MPCs precision extruded and/or machined blocks of aluminum alloy with axial holes (basket shims) are installed in the peripheral space between the fuel basket and the enclosure vessel to provide conformal contact surfaces between the basket shims and the fuel basket and between the basket shims and the EV shell. The axial holes in the basket shims serve as the passageway for the flow of the helium gas under natural convection.

In the bare fuel basket construction, the basket shims close the peripheral gap between the basket and the cask's inner cylindrical surface.

Table 1.1.2 provides a list of the MPC and bare baskets configurations analyzed in this SAR. Their design details relevant for the safety analyses are illustrated in the drawings in Section 1.3.

(c) Impact Limiters

Two AL-STAR MB impact limiters are installed at the two extremities of the HI-STAR 100MB Cask (Please see Figure 1.0.2); they provide energy absorption capability for the normal and hypothetical accident conditions of transport. The impact limiters feature extremely rigid cylindrical barrels (backbone structures) that engage the top and bottom of the cask with a snug fit. 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 AL-STAR MB impact limiters are of the same design genre as the AL-STAR 180 used in the HI-STAR 180 Package (Docket No. 71-9325) and AL-STAR 190 used with HI-STAR 190 cask. The following key design features typify the AL-STAR MB impact limiters:

- Each impact limiter is configured in such a manner that under all potential free-fall scenarios, the collision of the package with the regulatory target surface will always occur in the crush material space (i.e. will be cushioned by the impact limiter crush material).

- The impact limiter will protect the cask under all angular drop orientations onto the regulatory strike surface.

- External surface of the impact limiter surrounding the crushable material is made of stainless steel- a ductile, corrosion-resistant material.

- Axial (longitudinal) tension rods of high-strength material fasten the impact limiter to the two extremities of the cask body.

- Both impact limiters feature a skirt (shell) that fits the outside of the cask forging with a small radial clearance.

- The fasteners are engineered to be readily installable and removable for ALARA purposes.

- Each impact limiter is designed to render its intended function in the entire range of applicable ambient temperature conditions of the package.

Impact limiter 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.

(d) Personnel Barrier

During transport, the cask lies in a horizontal orientation with the two impact limiters on its two extremities. The personnel barrier is placed over the cask to provide a physical barrier to prevent manual access to hot, 85°C (185°F) or higher, areas of the cask when configured for transportation as required by 10 CFR 71.43(g) and 10 CFR 71.51(2). The personnel barrier for HI-STAR 100MB only envelopes the cask body, not the impact limiters as shown in Figure 1.2.1.

The personnel barrier is not a structural part of the HI-STAR 100MB Packaging but is designated as a packaging component when in use. Since the personnel barrier is not a structural part of the HI-STAR 100MB Packaging, it is not required to remain in place under normal condition of service under 10 CFR 71.71.

[

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

]

(e) Packaging Supports and Restraints

The HI-STAR 100MB Package lends itself to horizontal transport and is engineered for shipment by seagoing vessel, railroads, and roadways using appropriate supports and restraints. An illustrative example of packaging supports and restraints is provided in Figure 1.2.1. 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. Packaging supports and restraints such as support saddles, transport cradle, longitudinal stops, slings or straps and wedge shims are not structural parts of the HI-STAR 100MB Package and as such are designated as auxiliary equipment.

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 10 CFR 71 and 49 CFR as indicated by 10 CFR 71.5, with additional consideration to the applicable industry (railroad, road and sea transportation) standards. More specifically, 10 CFR 71.45(a) and (b) requirements must be complied with.

In the transport package configuration, the HI-STAR 100MB cask trunnions are not qualified to be used to lift the HI-STAR 100MB Package (i.e., loaded cask with impact limiters). In the transport package configuration, the HI-STAR 100MB cask trunnions remain attached to the package and are rendered inoperable during transport or are removed prior to transportation for compliance with 10CFR71 when HI-STAR 100MB is configured as a transport package (i.e. loaded cask with impact limiters).

1.2.1.2 Overall Packaging Dimensions and Weight

The gross weight of the HI-STAR 100MB System depends on which of the MPC or bare basket fuel package is loaded into the HI-STAR 100MB overpack for shipment. Table 2.1.11 summarizes the maximum calculated component weights for the HI-STAR 100MB overpack, impact limiters, and MPC or bare basket loaded to maximum capacity with design basis SNF. The maximum gross transport weight of the HI-STAR 100MB System is required to be marked on the packaging nameplate.

1.2.1.3 High Burnup Fuel Transportation and Moderator Exclusion Features

The HI-STAR 100MB has enhanced shielding and improved thermal features to support transport of high burnup fuel and fuel with shorter cooling times. The HI-STAR 100MB packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF).

Qualification to transport high burnup fuel (HBF) follows the double barrier approach in the (certified) HI-STAR 180. In the bare basket configuration, HI-STAR 100MB has two bolted lids, with each lid equipped with two concentric seals as in the HI-STAR 180 or HI-STAR180D casks. However, when used in conjunction with an MPC, HI-STAR 100MB utilizes a single bolted lid with the second containment barrier formed by the MPC located inside the cask cavity.

In recognition of the uncertainty surrounding the cladding material properties of HBF, a multi-layered safety-focused strategy to transport HBF, similar to HI-STAR 180 [1.0.6] and HI-STAR 190

[1.0.4], has been adopted for HI-STAR 100MB. The principal approach consists of assurance of moderator exclusion under accident conditions, following the intent and performance objectives of ISG-19. The approach is supplemented by defense-in-depth evaluations including structural evaluations of fuel performance under accident conditions, and criticality evaluations of reconfigured fuel. The following consideration are germane to the specific scenarios applicable to HI-STAR 100MB:

- For HI-STAR 100MB in the bare basket configuration, there is a volumetrically examined weldment of the bottom forging and cylindrical thick walled body mated with a double barrier bolted closure. This double barrier system with two bolted lids is used to assure moderator exclusion and meet the intent of ISG-19. This is similar to the HI STAR 180D [1.0.7] and HI-STAR 180 [1.0.6] design approach.

- For HI-STAR 100MB in the MPC configuration, the double barrier system consists of a cask containment body with a single bolted lid in conjunction with the seal welded MPC. This configuration is equivalent to the dual lid closure system used for the bare basket Fuel Package, as it provides two autonomous barriers against water intrusion as the two closure lids are independent from each other.

- The second (inner) containment boundary formed by the MPC enclosure vessel is only credited for moderator exclusion when HBF is present in the MPC. For MBF, the MPC, when present, serves as a defense-in-depth additional barrier against water in-leakage and radiological release.

- MPCs are loaded into the HI-STAR 100MB for transport as “load-and-go” transport or after a period of interim storage. While cladding damage to HBF is not expected during the interim storage period, it is not feasible to physically examine the fuel at that time to verify its 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 the HI-STAR 100MB are performed considering a certain level of assumed subcriticality-adverse fuel reconfiguration. Consequently, the definition of undamaged HBF for the HI-STAR 100MB for the purpose of criticality evaluation includes consideration of a certain level of fuel reconfiguration.

  Nevertheless, in addition to considering fuel defects of HBF, additional acceptance criteria and supplemental requirements need to be satisfied before an MPC with HBF can be accepted for transport, these criteria and supplemental requirements are described in Section 8.1.

- The criticality analyses assuming re-configuration of HBF have been performed, similar to HI-STAR 190, with assumptions of either fresh fuel or burned fuel (fuel with burnup). These analyses could lead to the false impression that reconfigured HBF has the same or even less criticality margin than MBF. To disprove this, some criticality calculations for the HI-STAR 100MB apply a minimum burnup for the HBF, and hence show that the reactivity effect of potential fuel reconfiguration is more than compensated by the higher burnup. Chapter 6 contains the description of the analysis methodology and results.

Table 1.2.1 shows the approach used for the criticality evaluations for the various cases required to show compliance with 10 CFR 71.55 and 10 CFR 71.59. Thermal analysis and shielding analysis in

Chapters 3 and 5 of this safety analysis, respectively, evaluate the package under the assumption of reconfigured fuel.

As the structural defense-in-depth evaluations for the Normal Condition of Transport (NCT) and for the Hypothetical Accident Condition (HAC), a best-estimate rod integrity safety case is made by a series of realistic, but conservative assumptions based on the HI-STAR 190 approach. The summary in Chapter 2 of this safety analysis demonstrates that the fuel rods are not expected to undergo failure under the normal conditions of transport described in 10 CFR 71.71 nor during the hypothetical accident conditions in 10 CFR 71.73. A positive safety margin against a primary failure of the fuel rods is determined to exist even under the worst-case accident scenario.

The overall licensing approach (including the defense-in-depth) from both safety and regulatory compliance perspectives is summarized in Table 1.2.2.

Other aspects of the design and analyses that support the conclusion that HBF can safely be transported in the HI-STAR 100MB are summarized below.

1. The adoption of ANSI N14.5 reference leakage rate of “leak-tight” conservatively precludes any containment concerns with HBF under NCT and HAC.
2. The honeycomb fuel baskets minimize the criticality safety implications of potential HBF reconfiguration under all conditions of transport.
3. Containment boundary integrity is maintained under hypothetical 100% rod rupture with coincident hypothetical fire accident consistent with RG 7.6 [1.2.3] (HAC).
4. Cask handling drops are rendered non-credible through NUREG-0612 qualification of cask interfacing lift points (loading/unloading), the use of ANSI N14.6 compliant lifting devices, and robust handling procedures.
5. Compliance with ISG-11 Rev. 3 [1.2.4] for all conditions of transport has been demonstrated in Chapter 6.

Further details of the design measures and technical confirmation to meet the intent and performance objectives of ISG-19 are described in Chapter 6 adapted from the HI-STAR 190 SAR [1.0.4] Appendix 1.A.

In conclusion, the combination of conservative assumptions and analyses with a robust design, provides reasonable assurance that the HI-STAR 100MB Package containing HBF will protect public health and safety under all operational scenarios postulated by 10 CFR Part 71.

1.2.1.4 Containment Features

The HI-STAR 100MB has the option of a double lid when used in the bare basket configuration. The Containment System forms an internal cylindrical cavity for housing the fuel basket. The Containment Boundary is formed by a cryogenic steel inner shell (containment shell) welded at the bottom to a thick bottom plate (containment baseplate) and welded at the top to a heavy top flange (containment closure flange). The inner closure lid is completely recessed into the containment closure flange and configured to protect the closure bolts and seals in the event of a large lateral impactive load such as during a drop accident. The outer closure lid interfaces with the inside diameter of the containment closure flange with a very small clearance to ensure that the flange will be buttressed against ovalization during an adverse drop event and the flange is also configured to protect the closure bolts and seals in the event of a drop accident. Both the inner closure lid and the

outer closure lid concentric seals and inter-seal test ports are closed by threaded port plugs. This is similar to the containment features of the HI-STAR 180D [1.0.7].

Both closure lids have been engineered to perform the containment function with final qualification by leak testing according to ANSI N14.5 [1.2.2] as specified in Chapter 8, Table 8.1.2 and to the leakage acceptance criterion specified in Table 8.1.1. Each closure lid joint features equally proficient seals, one seal serving as a back-up to the other seal.

When used with an MPC, a single lid system is used. The MPC provides an additional leak tight barrier identical to the classical HI-STAR 100 cask.

1.2.1.5 Neutron and Gamma Shielding Features

The HI-STAR 100MB shielding features are similar to those in the HI-STAR 190 cask [1.0.4]. The HI-STAR 100MB Cask Containment is circumscribed by the Gamma Capture Space (GCS) and the Neutron Capture Space (NCS), described in the foregoing, that respectively attenuate gamma radiation and neutron fluence emitted from the contained fuel to minimal practical levels consistent with ALARA principles.

While most of the shielding in the transport package is contained in the body of the cask and specifically in the Gamma Capture Space (GCS) and the Neutron Capture Space (NCS), a certain amount of shielding is also provided by the Fuel Basket, the Basket Shims, impact limiters, shim liners and the Enclosure Vessel. The arrangement of the shielding materials shown in the licensing drawings reflects the shielding optimization carried out for the HI-STAR 100MB cask.

Critical Characteristics of the Holtite Neutron Shielding Material used in the safety analyses are provided in Table 2.2.13 and 2.2.14.

1.2.1.6 Criticality Control Features

Criticality control in the HI-STAR 100MB Packaging is provided by the coplanar grid work of the Fuel Basket honeycomb. As can be seen from the licensing drawings in Section 1.3, criticality control is via the honey comb basket used in the HI-STAR 100MB system which is made entirely of Metamic™-HT extruded borated metal matrix composite plates.

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 equipped fuel basket 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.

Additional criticality control contribution is provided by the fuel's own burn up (called burnup credit) following the guidance in ISG-8 Rev. 3 [1.2.5]. Burnup credit is taken for fuel stored in the F-32M basket and MPC-32M in Table 1.1.2.

1.2.1.7 Lifting and Tie-Down Devices

Two top lifting trunnions located at 180 degrees apart are attached via the trunnion support structure to the neutron shield ribs for lifting and for rotating the cask body between vertical and horizontal positions. Two additional trunnions are attached near the bottom extremity of the cask and located diametrically apart.

The HI-STAR 100MB overpack is equipped with two lifting trunnions located just below the top flange. The lifting trunnions are designed in accordance with 10CFR71.45, NUREG-0612 and Regulatory guide 3.6.1. The cask trunnions are not qualified to be used to lift the Package (defined as the loaded cask with impact limiters) and must therefore be rendered inoperable according to 10CFR71.45(a) during routine conditions of transport. The cask trunnions are also designed to collapse in the event of a drop accident to a completely flush position. Upending and down-ending are typically performed with the cask pivoting on an ancillary tilting device specifically designed for this purpose.

Figure 1.2.2 provides a conceptual illustration of a typical transport configuration. The support saddles provide attachment points for belly slings/straps around the cask body to prevent excessive vertical or lateral movement of the cask during normal transportation. The impact limiters affixed to both ends of the cask are designed to transmit the design basis axial transport loads into the longitudinal stops.

1.2.1.8 Heat Transfer Features

The HI-STAR 100MB 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 [1.2.4].

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 100MB Package are conduction and thermal radiation.

The entire free space inside the cask cavity containing a bare basket is filled with high purity helium. Similarly, the free volume in the MPC enclosure vessel (Inner Containment) is filled with high purity helium during fuel loading operations. The free volume between the MPC and the cask is also filled with high purity helium during on-site storage or off-site transport. 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 any metal surfaces inside the containment systems. Metal conduction transfers the heat throughout the fuel basket, through the containment system boundaries, and finally through the Gamma Capture Space and the Neutron Capture Space to the external surface of the package.

1.2.1.9 Internal Support Features

When used in the bare basket configuration, the HI-STAR 100MB Package is equipped with basket shims engineered to provide a substantially conformal support to the fuel basket around its periphery to facilitate efficient heat transfer.

The axial gap generated by the difference in length between the fuel assembly and the MPC cavity is minimized by controlling the MPC cavity length during fabrication to the dimensional requirements in the drawing package in Section 1.3 and where necessary by the use of fuel spacers. The fuel spacers and/or shims are detailed in the drawing package in Section 1.3.

1.2.1.10 Anti-Rotation Devices

When used in the bare basket configuration, the HI-STAR 100MB Package is equipped with internal anti-rotation devices to prevent the rotation of the fuel basket and basket shims within the cask. The anti-rotation devices are steel components that may be welded or fastened to the cask containment shell located on the inner diameter as shown in the drawing package in Section 1.3. The anti-rotation devices are not important-to-safety.

1.2.1.11 Packaging Markings

Each HI-STAR 100MB Packaging shall have a unique identification plate with appropriate markings per 10 CFR 71.85(c). The identification plate shall not be installed on a HI-STAR 100MB 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.

1.2.1.12 Post-Accident Package Performance

In the series of chapters that constitute HI-STAR 100MB's safety analysis, the Package is demonstrated to muster acceptable response to accident conditions that are deemed to meet the certification requirements for post-accident containment system integrity, maintenance of sub-criticality margin, ALARA dose rates, and adequate heat rejection capability. In particular, it is shown that:

i. The double containment boundary system (either through two Closure Lids or through a Closure Lid in conjunction with the all-welded MPC) provide the necessary set of barriers to preclude loss of sequestration of the Fuel Package space under the normal condition of transport or the set of hypothetical accidents pursuant to §71.73.
ii. The confinement of the fuel pellets by their fuel rods inside the Cask's storage cavity is preserved in the wake of the postulated accident events set forth in §71.73.
iii. The dose limit prescribed in §71.51 is met in the aftermath of the hypothetical accident events of §71.73.
iv. The Fuel cavity space will not sustain water intrusion under the deep submergence scenario of §71.61.

In summary, the HI-STAR 100MB Package will unconditionally satisfy the performance requirements for transport Packages under the postulated normal and accident transport scenarios of §71.

1.2.2 Contents of Package

The HI-STAR 100MB package is designed to transport moderate and high burnup in-tact fuel assemblies, canisterized damaged fuel & fuel debris and fuel assemblies with shorter cooling times than that permitted under the presently certified (classic) HI-STAR 100 package.

Chapter 7 contains the allowable contents for the HI-STAR 100MB, including heat load, burnup and cooling time restrictions of the fuel assemblies. The information is placed in Chapter 7 (where all CoC-relevant information is deposited) to facilitate a convenient single reference of this information by the CoC.

1.2.3 Special Requirements for Plutonium

The contents of the package provided in Section 1.2.2 and to be transported in the HI-STAR 100MB Package contain plutonium in solid form and in varying quantities.

1.2.4 Operational Features

The HI-STAR 100MB Packaging has been developed to facilitate loading and unloading of fuel with ALARA protection against handling accidents and a minimum number of handling evolutions (i.e., simplicity of handling). Similar to the MPC closure lids loaded in HI-STAR 100 and HI-STORM 100 overpacks, the HI-STAR 100MB 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 caps. Port plugs, in lieu of caps, 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. The HI-STAR 100MB Packaging is a completely passive system once loaded and sealed in accordance with the instructions in Chapter 7. The abbreviated narrative below on typical loading operations helps illustrate the overall simplicity of the loading process. Chapter 7 provides the essential elements of cask operations.

<u>Typical Loading Operations</u>

(i) Cask with bare basket

The loading of an empty cask typically begins with the wet transfer of fuel to its cask cavity in the pool.

At the start of loading operations, the cask is configured with the closure lids removed and the fuel basket installed. The cask is lowered into the spent fuel pool for fuel loading. Pre-selected assemblies are loaded into the fuel basket cells and a visual verification of the assembly identification is performed.

While still underwater, the inner closure lid is installed. The cask is removed from the pool and placed in the designated preparation area.

The Forced Helium Dehydration (FHD) System is connected to the cask and used to remove all bulk water and water vapor so as to reduce the level of moisture in the cask cavity to acceptable levels. This is accomplished by recirculating dry, heated helium through the cask cavity to absorb the moisture. The HI-STORM FSAR [1.2.6] provides the Design Criteria for the FHD system.

Alternatively, cavity drying may be carried out using the classical vacuum drying system, if it is ensured that the fuel temperature remains within acceptable limits per the requirements in Chapters 3 and 7.

Following the fuel drying operations, the cask cavity is backfilled with helium gas and the vent/drain ports are sealed. The inner Containment Boundary seals are then leak tested to the leakage acceptance criteria specified in Chapter 8 of this safety analysis.

The outer closure lid is installed, followed by evacuation of the inter-lid space using the outer lid's port openings and backfilling with helium. The outer lid (expanded) containment boundary seals are then also leak tested to the leakage acceptance criteria specified in Chapter 8 of this safety analysis.

The cask is next secured on the transport vehicle with impact limiters attached, a security seal (tamper device) is attached, and the personnel barrier is installed (if required). The HI-STAR 100MB Package is then ready for transport.

The inspections and tests (acceptance criteria and maintenance requirements) required to prepare the package for shipment are specified in Chapter 8 in this safety analysis.

(ii) Loading an MPC in HI-STAR 100MB

Transporting a loaded and sealed MPC is a straightforward operation because the canister is already in an inerted and ready-to-ship state. However, it is necessary to ensure that the MPC is transport-worthy prior to its loading. For this purpose, it is necessary to demonstrate that the entire set of acceptance criteria and supplemental requirements set down in Chapter 8 have been met.

The process to load the MPC in HI-STAR 100MB consists of the following major steps:

a. Verify the MPC meets the acceptance criteria and supplemental requirements in Chapter 8.
b. Transfer the MPC to the HI-TRAC transfer cask with the aid of the Mating Device (following the procedure in the storage cask's FSAR).
c. Stack the transfer cask atop HI-STAR 100MB with the Mating Device interposed between them, and lower the MPC into HI-STAR 100MB.
d. Remove the transfer cask and the Mating Device. Install the Cask Closure Lid.
e. If HBF is transported, perform the MPC pre-shipment leakage rate test to confirm the integrity of the MPC containment boundary.
f. Evacuate the cask cavity and fill the cask cavity space with helium.
g. Close the closure lid port plug and install closure lid cover plate.
h. Perform the necessary leakage tests on the cask containment seals

The cask is next secured on the transport vehicle with impact limiters attached, a security seal (tamper device) is attached, and the personnel barrier is installed (if required). The HI-STAR 100MB Package is then ready for transport.

The inspections and tests (acceptance criteria and maintenance requirements) required to prepare the package for shipment are specified in Chapter 8 herein.

TABLE 1.2.1:
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 1.2.2:
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 1.2.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

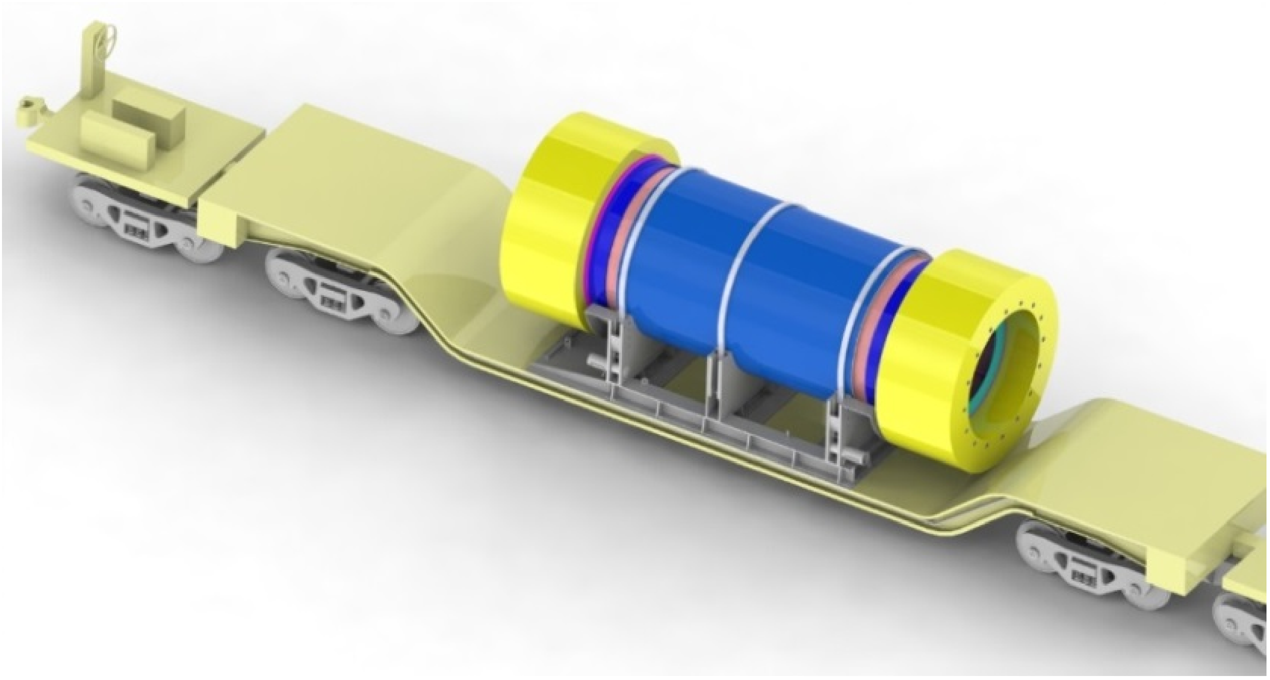

FIGURE 1.2.2: ILLUSTRATION OF HI-STAR 100MB TYPICAL TRANSPORT CONFIGURATION

1.3 ENGINEERING DRAWINGS

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

1.4 SUMMARY OF COMPLIANCE WITH 10CFR71 REQUIREMENTS

The safety analyses which demonstrate that the HI-STAR 100MB Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR. HI-STAR 100MB 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. The HI-STAR 100MB containment boundary (10CFR71.43(e) and 10CFR71.43(h)) contains no pressure relief device, rupture disc, or any other means of unplanned (involuntary) communication with the external environment. Therefore, accidental venting of the containment space during transport is not possible. Indeed, there is no design feature that may permit release of radioactive material from HI-STAR 100MB under the tests specified in 10CFR71.73. Analyses that demonstrate the compliance of the HI-STAR 100MB Package with the requirements of Subparts E and F of 10CFR71 are provided in this SAR\.

The criticality safety index (CSI) for the HI-STAR 100MB Package is 0.0, as an unlimited number of packages will remain subcritical under the provisions of 10CFR71.59(a). The transport index (TI) is in excess of 10 for the HI-STAR 100MB Packaging with design basis fuel contents (Section 5.0 provides the determination of the TI). Therefore, the HI-STAR 100MB Package must be transported by exclusive use shipment (10CFR71.47). An empty but previously loaded HI-STAR 100MB 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 100MB 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 100MB Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR 100MB Package to meet the requirements of 10CFR71, Paragraphs 71.45, 71.51, and 71.55 (see discussion on high burnup fuel in Subsection 1.2.1.3). 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 100MB 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 in Paragraph 1.2.1.3).

The HI-STAR 100MB 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 HI-STAR 100MB's compliance with 10CFR71:

- The HI-STAR 100MB Packaging description including the drawing package provided in Section 1.3 provides an adequate basis for evaluation of the HI-STAR 100MB 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 100MB packaging has been identified. (see also Section 1.6)

- The applicable codes and standards for the HI-STAR 100MB Packaging design, fabrication, assembly, and testing have been identified in the drawing package in Section 1.3 and in Chapter 2.

- Allowable contents in the HI-STAR 100MB Packaging are specified in Section 1.2 (referencing Chapter 7).

1.5 LOCATION OF PROPERTIES OF SPECIAL PURPOSE MATERIALS

Properties of special materials used in this SAR are listed in Tables 1.5.1 and 1.5.2

TABLE 1.5.1: LOCATION OF PROPERTIES OF SPECIAL PURPOSE MATERIALS IN THIS SAR

Item No.	Material	Location
1	Holtite-B [1.5.1]	Table 2.2.13
2	Holtite-A [1.5.2]	Table 2.2.14
3	Metamic –HT [1.5.3]	Table 1.5.2 Table 2.2.12 Table 8.1.3
4	Containment Seals	Table 2.2.10 Table 2.2.11
5	AL-STAR Impact Limiter Crush Material	Table 2.2.8 Table 3.2.1 Table 3.2.7

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 100MB 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).

[1] This section is reproduced from Section 1.6 of the HI-STAR 190 SAR[1.0.4]

1.7 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. 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] 49CFR Part 173, "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 on HI-STAR 190 transport package, Holtec Report HI-2146214. Latest revision, Docket # 71-9373 (USNRC)

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

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

[1.0.7] “Safety Analysis Report on HI-STAR 180D transport package, Holtec Report HI-2125175. Latest revision, Docket # 71-9367 (USNRC)

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

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

[1.2.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code", Section III, Div. 1, Subsection NB 2007 Edition, 2008 Addenda.

[1.2.2] 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.

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

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

[1.2.5] Interim Staff Guidance (ISG)-8, Revision 3, USNRC, September 2012.

[1.2.6] "HI-STORM 100 Final Safety Analysis Report", Holtec Report HI-2002444, latest revision, Docket No. 72-1014.

[1.2.7] "NRC Draft Regulatory Issue Summary 2015-XX Consideration in Licensing High Burnup Spent Fuel in Dry Storage and Transportation," US NRC, Docket ID NRC-2015-0047.

[1.5.1] "Performance Characterization of Holtite-B as a Neutron Shielding Material", Holtec Report HI-2073684, Latest Revision. (Holtec Proprietary)

[1.5.2] Holtite-A: Development History and Thermal Performance Data", Holtec Report No. HI-2002396, Latest Revision. (Holtec Proprietary)

[1.5.3] "Metamic-HT Qualification Sourcebook," Holtec Report N. HI-2084122, Latest Revision, (Holtec Proprietary).

CHAPTER 2: STRUCTURAL EVALUATION OF THE HI-STAR 100 VERSION MB TRANSPORT PACKAGE

2.0 INTRODUCTION

This chapter presents a synopsis of the Design Criteria relevant to the mechanical and structural characteristics of the HI-STAR 100MB Package that ensure compliance with the performance requirements of 10CFR71. It also 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 100MB 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 100MB 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 enclosed Fuel Package.
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.

Consistency with the recently approved methods of safety analysis is a key cornerstone of the safety analyses performed for HI-STAR 100MB. Accordingly, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter are consistent with those used in the recent transport SARs such as HI-STAR 180 certified in Docket #71-9325, HI-STAR 180D certified in Docket #71-9325 and HI-STAR 190 certified in Docket #71-9373.

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.

Appendix 2.B of HI-STAR 180 SAR [1.0.6] 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 using aluminum honeycomb as the impact energy absorber. In this safety analysis report, LS-DYNA is used to analyze all loading conditions that involve dynamic effects of short durations.

2.1 STRUCTURAL DESIGN

2.1.1 Discussion

This section presents the essential characteristics of the principal structural members and systems that are important to the safe operation of the HI-STAR 100MB 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 Package* (the Multi-purpose canister or bare fuel basket) and the surrounding support, and the impact limiters needed to protect the cask 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 house the Fuel Package.
- To serve as a penetration and puncture barrier to protect the contained fuel.
- To provide a high-integrity containment system.
- To provide a structurally robust enclosure shielding of the radiation emitted by the fuel.

The body of the HI-STAR 100MB cask consists of three discrete regions; namely:

1. the containment space
2. the gamma capture space
3. the neutron capture space

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 Safety Analysis, ASME Section III, Division 1, Subsection NB is used for the design and construction of the HI-STAR 100MB 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., classic HI-STAR 100, HI-STAR 60, HI-STAR 180, HI-STAR 180D, HI-STAR 190 etc.).

The gap between the Fuel Package and the Cask lid is minimized to the extent practicable with due recognition of the increase in the length of fuel assembly due to irradiation and thermal

 Holtec Non-Proprietary Version

expansion such that there is no risk of restraint of free end expansion of the fuel under any transport condition.

The gamma and neutron capture spaces consist primarily of lead, steel and Holtite™. To perform their functions, these dose blocker parts must not undergo body extensive damage resulting in an appreciable loss of their shielding capacity under normal and accident conditions of transport.

2.1.1.2 Fuel Package

As stated in Chapter 1, the Fuel package can be in the form of a fuel basket enclosed by an Enclosure Vessel with the combined component referred to as the Multi-Purpose Canister (MPC) or a bare Fuel Basket.

The MPC's Enclosure Vessel is designated as the inner Containment Boundary which requires that it be qualified to demonstrate compliance with the same "NB" stress limits as the outer Containment Boundary provided by the overpack under all postulated service and accident conditions.

The structural function of the fuel basket and fuel basket support (basket shims) contained in the MPC or alone as a bare Fuel Basket (drawing package 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 (please 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 suitably shaped blocks of a crushable material arrayed around a 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. The three defining characteristics of the HI-STAR 100MB impact limiter are:

(i) An essentially rigid steel cylindrical core,
(ii) A steel cylindrical skirt integrally welded to the core that girdles the cask's forging (at its two extremities) and thus prevents any significant rigid body rotation of the core under a drop event, and
(iii) A set of ductile alloy steel fasteners that provide the necessary connectivity between the cask and the impact limiter.

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 (classic HI-STAR 100), and subsequent packages labeled HI-STAR HB, HI-STAR 60, HI-STAR 180, HI-STAR 180D, HI-STAR 190 and the current package (HI-STAR 100MB).

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 100MB 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 saddle 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 100MB 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 Regulatory 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 appropriate fatigue curves.

The Holtec Manufacturing Manual contains detailed instructions for manufacturing of the subassemblies and the complete component in accordance with the applicable Codes and Standards. The Holtec Manufacturing Manual is a compilation of procedures, travelers, weld maps, specifications, standards, Metamic-HT Manufacturing Manual and other documents as applicable, to ensure the manufacturing of the components are in full accord with the design conditions of the CoC. The latest issues of the manufacturing manual(s) are maintained in the company's network under Holtec's configuration control system. Applicable ASME Code requirements are listed in Tables 2.1.16 and 2.1.17.

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

- The lead and Holtite™ dose blocker parts are required to remain in place and functional after all Normal and Hypothetical Mechanical Accident Conditions of Transport.
- The fuel basket is required to maintain its shape 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.

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 100MB 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 100MB arise from bolt preload to seat the gasketed joints. The preload applied to the cask lid bolts seats the lid 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 preload produces a state of stress in the closure lid, the cask closure flange, and the cask shell region adjacent to the flange.

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

The initial preload should be set to maintain a seal under the maximum internal pressure. It is acceptable for the seal to experience instantaneous relaxation under the action of the maximum

normal operating internal pressure (MNOP specified in Table 2.1.1) plus the effective pressure calculated as the cask content weight times the maximum rigid body deceleration from the free 9-meter top end drop.

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

2. Design Condition Loads

The ASME Code [2.1.1] requires 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 100MB Package, the Design Internal Pressure and Design Temperatures, set down in Table 2.1.1, accordingly bound all service condition values. When used with an MPC, the HI-STAR 100MB Package has two Containment Boundaries, therefore, Table 2.1.1 has pressure and temperature data on both the MPC Enclosure Vessel and the overpack pressure boundary.

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 MNOPs for the cask and MPC containment boundaries are given in Table 2.1.1 as the internal pressures under normal conditions of transport and bound the calculated internal pressure values reported in Table 3.1.2. The coincident external pressure of the cask is atmospheric. The MNOP value for MPC in Table 2.1.1 is identical to the value specified in the HI-STAR 100 SAR [2.1.19].

- 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 of the cask is atmospheric. The design internal pressure for the MPC remains identical to that specified in the HI-STORM 100 FSAR [1.2.6].

- External Pressure under Normal Condition of Transport: The external pressures for the cask overpack and the MPC are 0.0 psig and 40.0 psig, respectively in Table 2.1.1. The external pressure of the cask under this condition is atmospheric, and the increased cask external pressure (20 psia) specified in 10CFR§71.71 is bounded by the minimum cask overpack backfill pressure. The external pressure value for MPC is identical to the value specified in the HI-STAR 100 SAR [2.1.19]. Moreover, the required MPC and cask overpack backfill pressures ensure that the MPC internal pressure is always greater than

the pressure in the overpack cavity.

- 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 for the cask overpack. 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 10CFR§71.61. This loading bounds the external pressure specified by 10CFR§71.73(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 Cask Cavity Space MNOP is conservatively set higher than the calculated pressures in Table 3.1.2.

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.

3. Handling Loads

The lifting attachments (or interfacing lift points) on the HI-STAR 100MB cask are designed to meet the 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, and the Fuel Package. Under lifting (and handling) condition a 15% load amplifier is applied as discussed in Section 2.5. The 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 100MB 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 (10CFR§71.61). 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 100MB 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 100MB 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 preload plus Design Internal pressure and Normal operating temperature.
- Load Combination N2:
  Free drop from 1 foot plus Bolt preload 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 cask's closure lid withstands the impact load transmitted through the impact limiter.

- Horizontal 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 100MB 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 by a parametric analysis.

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

b. Puncture

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

- Side Puncture Force Event: 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 Force: This event is similar to the preceding case except the penetrant force is assumed to act at the center of the 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 -29ºC (-20ºF). In the latter thermal state, the effects of brittle fracture must also be evaluated.

Because the HI-STAR 100MB Package operates at a relatively low internal pressure, the impact and puncture loadings under service conditions are orders of magnitude greater than pressure loadings. Thus, the effects of internal pressure are neglected in the drop and puncture events.

c. Fire

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).

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 10CFR§71.61. The ability of the package to maintain moderator exclusion pursuant to §71.61 is discussed 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)

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

2.1.3 Acceptance Criteria

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PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

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2.1.4 Weights and Centers of Gravity

Table 2.1.11 provides the weights of the individual HI-STAR 100MB components as well as the total Transport Package weights, and the weight of the heaviest loaded HI-STAR 100MB Cask.

Table 2.1.13 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.

2.1.5 Identification of Codes and Standards for Package Design

The design of the HI-STAR 100MB 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 100MB Package.

Table 2.1.14 lists each major structure, system, and component (SSC) of the HI-STAR 100MB 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 2.1.17 lists some alternatives to the ASME Code where appropriate. Table 2.1.16 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 100MB cask are procured to ASTM or ASME Specifications, except for the fuel basket (made of Metamic-HT) and the neutron shield identified by the trade name Holtite B described in Chapter 1.

The *critical characteristics* of all materials set down in this safety analysis establish the minimum requirements that must be met by the material. The applicable *critical characteristics* for each part in the HI-STAR 100MB cask are listed in Table 2.1.15 with the required limiting values, as applicable.

Table 2.1.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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]).

† 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	2/3 Yield Strength	Yield Strength
Maximum Service Stress (tension + bending but no stress concentrations)	Yield Strength	Ultimate Strength Joint Remains Leak Tight (see Note 2)

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. Since the cask closure lid bolt joint is a friction type connection as explained below, the bolts are exempt from shear stress evaluation per ASME Section III, F-1135.2 and NF-3324.6. The closure lid bolt joint is sufficiently preloaded (Table 2.2.10), and the friction force (based on a conservatively assumed static friction coefficient of 0.5) at the lid-to-flange interface can prevent the lid from sliding under the cask's maximum deceleration . Therefore, the bolt joint is qualified as a friction type connection per ASME Section III, NF-3324.1.

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 °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)	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 Material

Code: ASME NB
Material: SA-193 B7 (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 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. Tables 2.2.2a and 2.2.2b contain 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).

Table 2.1.9: Design, Levels A and B: Stress Intensity

Code: ASME NB
Component: MPC Enclosure Vessel
Material: Alloy X
Service Conditions: Design, Levels A and B (Normal and Off-Normal)
Item: Stress Intensity

Temp. (Deg. F)	Classification and Numerical Value					
	S_m	P_m †	P_L †	$P_L + P_b$ †	$P_L + P_b + Q$ ††	P_e ††
-20 to 100	20.0	20.0	30.0	30.0	60.0	60.0
200	20.0	20.0	30.0	30.0	60.0	60.0
300	20.0	20.0	30.0	30.0	60.0	60.0
400	18.6	18.6	27.9	27.9	55.8	55.8
500	17.5	17.5	26.3	26.3	52.5	52.5
600	16.5	16.5	24.75	24.75	49.5	49.5
650	16.0	16.0	24.0	24.0	48.0	48.0
700	15.6	15.6	23.4	23.4	46.8	46.8
750	15.2	15.2	22.8	22.8	45.6	45.6
800	14.8	14.8	22.2	22.2	44.4	44.4

Notes:

1. S_m = Stress intensity values per Table 2A of ASME II, Part D.
2. Alloy X S_m values are the lowest values for each of the candidate materials at corresponding temperature.
3. Stress classification per NB-3220.
4. Limits on values are presented in Table 2.1.2.
5. P_m, P_L, P_b, Q, and P_e are defined in Subsection 2.1.2 and in Subsection NB of the ASME Code, Section III.
6. This Table is reproduced from Table 3.1.7 of the HI-STORM FW FSAR [2.1.13].

† Evaluation required for Design condition only.
†† Evaluation required for Levels A, B conditions only. P_e not applicable to vessels.

Table 2.1.10: Level D: Stress Intensity

Code:	ASME NB
Component	MPC Enclosure Vessel
Material:	Alloy X
Service Conditions:	Level D (Accident)
Item:	Stress Intensity

Temp. (Deg. F)	Classification and Value (ksi)		
	P_m	P_L	$P_L + P_b$
-20 to 100	48.0	72.0	72.0
200	48.0	72.0	72.0
300	46.3	69.45	69.45
400	44.6	66.9	66.9
500	42.0	63.0	63.0
600	39.6	59.4	59.4
650	38.4	57.6	57.6
700	37.4	56.1	56.1
750	36.5	54.8	54.8
800	35.5	53.25	53.25

Notes:

1. Level D stress intensities per ASME NB-3225 and Appendix F, Paragraph F-1331.
2. The average primary shear strength across a section loaded in pure shear may not exceed 0.42 S_u.
3. This Table is reproduced from Table 3.1.8 of HI-STORM FW FSAR [2.1.13].

Table 2.1.11: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.1.12: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.1.13: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Holtec Non-Proprietary Version

Table 2.1.14: Applicable Codes and Standards for the Materials Used in the HI-STAR 100MB 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.	Closure Lids	Containment Boundary	ASME Code Section III Subsection NB
5.	Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
6.	MPC Enclosure Vessel	Containment Boundary	ASME Code Section III Subsection NB
7.	Vent and Drain Port Plugs	Containment Boundary	ASME Code Section II
8.	Seals and Gaskets	Containment Boundary	Non-Code (Manufacturer's Catalog and Test Data)
9.	Fuel Basket (Metamic-HT)	Positioning of Fuel Assemblies/ Criticality Control	Non-Code (Manufacturer's Test Data [1.5.3])
10.	Lead in the Gamma Capture Space (GCS)	Gamma Shielding	Non-code
11.	Holtite-B	Neutron Shielding	Non-Code (Manufacturer's Test Data [1.5.1])
12.	Lifting Trunnions	Lifting and Handling	ASME Code Section II, NUREG-0612, and 10CFR71.45(a)
13.	Steel in Neutron Capture Space (NCS) and Gamma Capture Space (GCS)	Positioning of Shielding Materials/Protection Against Puncture Drop	ASME Code Section II

Table 2.1.14: Applicable Codes and Standards for the Materials Used in the HI-STAR 100MB Packaging (Continued)

Item		Principal Function	Applicable Codes and Reference Standard
14.	Basket Shims	Positioning of Basket in the Containment Cavity	ASTM B221 [2.1.15]
15.	Impact Limiter Backbone Plate Material	Structural Support of Impact Limiter	ASME Code Section II
16.	Impact Limiter Attachment Rods and Nuts	Structural Support of Impact Limiter	ASME Code Section II
17.	Impact Limiter Crush Material	Impact Energy Absorption	Non-Code (Manufacturer's Catalog and Test Data)
18.	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 2.1.15: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.1.16 (Sheet 1 of 2): Applicability of ASME Code Boiler & Pressure Vessel Code and Other Standards

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Methodology	Welding (Fabrication and Qualifications)	Inspection	Testing
Cask Containment System (pressure vessel except closure seals)	ASME Code Section III Subsection NB-2000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-4000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-5000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-6000 and Chapter 8 of this SAR
MPC Containment System/Pressure Boundary	ASME Code Section III Subsection NB-2000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-4000	ASME Code Section III Subsection NB-5000	ASME Code Section III Subsection NB-6000
Cask Top Lifting Trunnions	ASME Code Section II	NUREG-0612	NUREG-0612	Not Applicable	Chapter 8 of this SAR	Chapter 8 of this SAR
Cask Neutron Shielding Material	Holtec Manufacturing Manual	Holtec Qualification Sourcebook	Not Applicable	Not Applicable	Holtec Manufacturing Manual (Note 1)	Chapter 8 of this SAR
MPC Metamic-HT Fuel Basket	Chapter 8 of this SAR	Deflection limited to ensure subcriticality	Deflection Evaluation	Holtec Manufacturing Manual (Note 1)	Holtec Manufacturing Manual (Note 1)	Chapter 8 of this SAR
Cask Dose Blocker Steel Components	ASME Code Section II and/or ASTM	No gross failure leading to significant loss of shielding	ASME Code Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V	Chapter 8 of this SAR
Impact Limiter Backbone Components	ASME Code Section II and/or ASTM	No gross yielding or buckling	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Chapter 8 of this SAR

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Table 2.1.16 (Sheet 2 of 2): Applicability of ASME Code Boiler & Pressure Vessel Code and Other Standards

Notes:

1. The Holtec Manufacturing Manual contains detailed instructions for manufacturing of the subassemblies and the complete component in accordance with the applicable Codes and Standards. The Holtec Manufacturing Manual is a compilation of procedures, travelers, weld maps, specifications, standards, Metamic-HT Manufacturing Manual and other documents as applicable, to ensure the manufacturing of the components are in full accord with the design conditions of the CoC. The latest issues of the manufacturing manual(s) are maintained in the company's network under Holtec's configuration control system.

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Table 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 1 of 6)

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 100MB is 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.
Cask Containment System	NB-2330	Establish TNDT and test base metal, heat affected zone and weld metal at TNDT + 60°F	Rather than testing to establish the RTNDT as defined in paragraph NB-2331, the guidance from Reg Guide 7.11 [2.1.7] is used for materials less than 4 inches thick and Reg Guide 7.12 & NUREG/CR 3826 are used for materials from greater than 4 up to 12 inches thick. Table 8.1.5 summarizes the specific impact testing requirements for the Containment Boundary components per Reg. Guides 7.11 endorsement of NUREG 1815, Reg. Guide 7.12 and NUREG/CR-3826 as applicable. All containment welds on the HI-STAR 100MB will be involving the shell and have a nominal thickness of 38mm (1.5 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.

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Table 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 2 of 6)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask • Containment Shell • Containment Top Forging • Containment Bottom Forging • All non-pressure retaining components attached to containment boundary components by welding.	NB-4622	All welds, including repair welds, shall be post-weld heat treated (PWHT).	All attachment welds less than 1/2 in. (13mm) joining non-pressure retaining material (non-containment boundary components) to pressure retaining material (containment boundary components) over 5/8 in. (16 mm) thick are exempt from PWHT per Table NB-4622.7(b)-1.
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 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 3 of 6)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Enclosure Vessel	Subsection NCA	General Requirements. Requires preparation of a Design Specification, Design Report, Overpressure Protection Report, Certification of Construction Report, Data Report, and other administrative controls for an ASME Code stamped vessel.	Because the MPC is not an ASME Code stamped vessel, none of the specifications, reports, certificates, or other general requirements specified by NCA are required. In lieu of a Design Specification and Design Report, the HI-STAR SAR includes the design criteria, service conditions, and load combinations for the design and operation of the MPCs as well as the results of the stress analyses to demonstrate that applicable Code stress limits are met. Additionally, the fabricator is not required to have an ASME-certified QA program. All important-to-safety activities are governed by the NRC-approved Holtec QA program. Because the cask components are not certified to the Code, the terms “Certificate Holder” and “Inspector” are not germane to the manufacturing of NRC-certified cask components. To eliminate ambiguity, the responsibilities assigned to the Certificate Holder in the Code, as applicable, shall be interpreted to apply to the NRC Certificate of Compliance (CoC) holder (and by extension, to the component fabricator) if the requirement must be fulfilled. The Code term “Inspector” means the QA/QC personnel of the CoC holder and its vendors assigned to oversee and inspect the manufacturing process.
MPC Enclosure Vessel	NB-1100	Statement of requirements for Code stamping of components.	MPC Enclosure Vessel 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.
MPC Enclosure Vessel	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Materials will be supplied by Holtec approved suppliers with Certified Material Test Reports (CMTRs) in accordance with NB-2000 requirements.

Table 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 4 of 6)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Enclosure Vessel	NB-3100 NF-3100	Provides requirements for determining design loading conditions, such as pressure, temperature, and mechanical loads.	These requirements are subsumed by the HI-STAR SAR, serving as the Design Specification, which establishes the service conditions and load combinations for the storage system.
MPC Enclosure Vessel	NB-4120	NB-4121.2 and NF-4121.2 provide requirements for repetition of tensile or impact tests for material subjected to heat treatment during fabrication or installation.	In-shop operations of short duration that apply heat to a component, such as plasma cutting of plate stock, welding, machining, and coating are not, unless explicitly stated by the Code, defined as heat treatment operations.
MPC Enclosure Vessel	NB-4220	Requires certain forming tolerances to be met for cylindrical, conical, or spherical shells of a vessel.	The cylindricity measurements on the rolled shells are not specifically recorded in the shop travelers, as would be the case for a Code-stamped pressure vessel. Rather, the requirements on inter-component clearances (such as the MPC-to-cask) are guaranteed through fixture-controlled manufacturing. The fabrication specification and shop procedures ensure that all dimensional design objectives, including inter-component annular clearances are satisfied. The dimensions required to be met in fabrication are chosen to meet the functional requirements of the cask components. Thus, although the post-forming Code cylindricity requirements are not evaluated for compliance directly, they are indirectly satisfied (actually exceeded) in the final manufactured components.

Table 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 5 of 6)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Enclosure Vessel	NB-4122	Implies that with the exception of studs, bolts, nuts and heat exchanger tubes, CMTRs must be traceable to a specific piece of material in a component.	MPCs are built in lots. Material traceability on raw materials to a heat number and corresponding CMTR is maintained by Holtec through markings on the raw material. Where material is cut or processed, markings are transferred accordingly to assure traceability. As materials are assembled into the lot of MPCs being manufactured, documentation is maintained to identify the heat numbers of materials being used for that item in the multiple MPCs being manufactured under that lot. A specific item within a specific MPC will have a number of heat numbers identified as possibly being used for the item in that particular MPC of which one or more of those heat numbers (and corresponding CMTRs) will have actually been used. All of the heat numbers identified will comply with the requirements for the particular item.
MPC Lid and Closure Ring Welds	NB-4243	Full penetration welds required for Category C Joints (flat head to main shell per NB-3352.3)	MPC lid and closure ring are not full penetration welds. They are welded independently to provide a redundant seal.
MPC Closure Ring, Vent and Drain Cover Plate Welds	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Root (if more than one weld pass is required) and final liquid penetrant examination to be performed in accordance with NB-5245. The closure ring provides independent redundant closure for vent and drain cover plates. Vent and drain port cover plate welds are helium leakage tested.
MPC Lid to Shell Weld	NB-5230	Radiographic (RT) or ultrasonic (UT) examination required.	Only progressive liquid penetrant (PT) examination is permitted. PT examination will include the root and final weld layers and each approx. 3/8" of weld depth.

Table 2.1.17: ASME Code Requirements and Alternatives for the HI-STAR 100MB Package (Sheet 6 of 6)

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
MPC Enclosure Vessel and Lid	NB-6111	All completed pressure retaining systems shall be pressure tested.	The MPC vessel is seal welded in the field following fuel assembly loading. The MPC vessel shall then be pressure tested as defined in Chapter 8. Accessibility for leakage inspections preclude a Code compliant pressure test. All MPC enclosure vessel welds (except closure ring and vent/drain cover plate) are inspected by volumetric examination. MPC shell and shell to baseplate welds are subject to a fabrication helium leak test prior to loading. The MPC lid-to-shell weld shall be verified by progressive PT examination. PT must include the root and final layers and each approximately 3/8 inch of weld depth. The inspection results, including relevant findings (indications) shall be made a permanent part of the user's records by video, photographic, of other means which provide an equivalent record of weld integrity. The video or photographic records should be taken during the final interpretation period described in ASME Section V, Article 6, T-676. The vent/drain cover plate and the closure ring welds are confirmed by liquid penetrant examination. The inspection of the weld must be performed by qualified personnel and shall meet the acceptance requirements of ASME Code Section III, NB-5350.
MPC Enclosure Vessel	NB-7000	Vessels are required to have overpressure protection.	No overpressure protection is provided. Function of MPC enclosure vessel is to contain radioactive contents under normal, off-normal, and accident conditions of storage. MPC vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
MPC Enclosure Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000.	The HI-STAR 100MB System is to be marked and identified in accordance with 10CFR71 and 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Holtec approved QA program.

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 100MB overpack 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 Materials

Material properties (for structural evaluations) of the closure lid bolting materials used in the HI-STAR 100MB Package are given in Tables 2.2.2 and 2.2.3.

2.2.1.1.3 Fuel Package

The Fuel Baskets are 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 [1.5.3]. Minimum guaranteed values (MGVs) of Metamic-HT are provided in Table 2.2.12.

The structural components that are part of the Enclosure Vessel for the MPC-32M are made of a hypothetical material termed Alloy X, which was previously introduced in the HI-STORM 100 FSAR [2.2.1]. The material properties of Alloy X are the least favorable values from the set of candidate stainless alloys. The purpose of a "least favorable" material definition is to ensure that all structural analyses are conservative, regardless of the actual MPC Enclosure Vessel material. Table 2.2.4 lists the numerical values for the material properties of Alloy X versus temperature.

These values, taken from the ASME Code, Section II, Part D [2.1.6], are used to complete all structural analyses. Two properties of Alloy X which are not included in Table 2.2.4 are weight density and Poisson’s ratio. These properties are assumed constant for all structural analyses, regardless of the temperature. The values used are shown in the table below.

PROPERTY	VALUE
Weight Density (lb./in^3)	0.290
Poisson's Ratio	0.30

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). Inter-panel Metamic-HT welds will be made using the Friction Stir welding (FSW) process in conformance with Section IX of the Code. Subsection 1.2.1, Subsection 8.1.2, and the drawing package in Section 1.3 provide additional information and requirements on joining of Metamic-HT panels.

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.

2.2.1.1.5 AL-STAR Impact Limiter

The AL-STAR impact limiter for the HI-STAR 100MB 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.

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 impact energy absorbing 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 impact limiter attachment bolts are provided in Table 2.2.6.

Two properties of the impact 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. A characteristic load-crush relation for the crush material is shown in Figure 2.2.1 for a constant crush area. The relation shows an essentially constant force over a large crush depth, followed by a “hockey

stick" rise in the force when the material becomes compacted. Table 2.2.8 documents the *critical characteristics* of the impact limiter material in tabular form.

Table 2.2.8 also contains the required *critical characteristics* of the Fastener Strain Limiters (FSL), which protect the impact limiter attachment bolts against excessive tensile strains during a drop accident.

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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2.2.1.1.6 Closure Lid Seals

The containment integrity of the HI-STAR 100MB Package relies on a closure lid system with elastomeric seals, as shown in the licensing drawings in Section 1.3.

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 100MB cask must fulfill the principal requirements set down in the following:

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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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 the HI-STAR 100MB cask drawing in Section 1.3. The gaskets will be procured as an *Important-to-Safety* part.

The closure seals for the HI-STAR 100MB overpack 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 material of construction. The specifications for the closure lid seals are provided below:

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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[[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]]

2.2.1.2 Nonstructural Materials

2.2.1.2.1 Gamma Shielding Material

Lead is not considered as a structural member of the HI-STAR 100MB 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 2.2.9.

2.2.1.2.2 Neutron Shielding Material

The non-structural properties of the neutron shielding material Holtite B are provided in Section 1.2. Holtite™ B does not serve a structural function in the HI-STAR 100MB package.

2.2.1.2.3 Fuel Basket Supports

Representative mechanical properties for the fuel basket supports (shims) are tabulated in Table 2.2.7.

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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2.2.1.2.4 Protection of the Cask's Exterior Surface

The licensing drawing in Section 1.3 shows that, as an option, the outer shell of the cask to be made of austenitic stainless steel to insure a rust-free external surface. However, for users concerned with seepage of micro-contaminants into the stainless steel surface (known to occur in some cases such as a turgid fuel pool) or for outer shells made of carbon steel, a conventional

surface preservative such as Carboguard® 890 (see www.carboline.com for product data sheet) or equivalent may be employed. Carboguard® 890 and equivalent surface preservatives have provided years of proven performance on classic HI-STAR 100 casks. Chemically equivalent products with different trade names that can be shown to have had proven performance in similar applications and environments are permitted. The proposed exterior surface coating is not important to safety, since its failure would not reduce the package shielding effectiveness and would not adversely affect public health and safety.

Performance Criteria for Conventional Surface Preservative Liner (when used)

Rank	Criteria
1	Chemical Immersion Resistance (suitable for short-term immersion in borated water)
2	High Temperature Resistance (suitable for 220°C for the cask cavity surfaces and long-term dry helium environment)
3	High Radiation Resistance (suitable for $1x10^8$ Rad)
4	Good Adhesion Characteristics (adhesion to steel or aluminum oxide as applicable)
5	Good Structural Performance (bendability/ductility/cracking resistance/abrasion resistance)
6	Emissivity in compliance with thermal analysis

The performance criteria are specified conservatively for conventional surface preservatives in order of importance to guide in the selection of preservatives.

2.2.1.2.5 Cask Liner

A cask liner or stainless steel weld overlay may be used to protect containment boundary steel components against increased corrosion from submersions into the spent fuel pools. Alternatively, the HI-STAR 100MB cask cavity and inter-lid space alloy steel surfaces (except for threaded features) may be lined with conventional surface preservative. The cask liner is not important to safety, since its failure would not reduce the package shielding effectiveness and would not adversely affect public health and safety.

The HI-STAR 100MB 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 classic 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 safety analysis composition. Chemically identical products with different names are permitted.

2.2.1.3 Chemical, Galvanic or Other Reactions

Similar to the classic HI-STAR 100, HI-STAR 180 and HI-STAR 190 packagings, the HI-STAR 100MB 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. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390] Therefore, chemical, galvanic or other reactions involving the cask materials are unlikely and are not expected.

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
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In accordance with NRC Bulletin 96-04 [2.2.3], a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STAR 100MB 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.

Use of stainless clad or overlay, as indicated in the licensing drawing package, removes the concern of surface degradation from pitting, rusting, etc., altogether.

2.2.2 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 excerpted from a DOE Handbook on Material Science [2.2.2].

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

• High Temperature Creep Rate (During Irradiation)	

The HI-STAR 100MB 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 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 100MB Package is on the order of 1.25 x 10^{9} rads 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 [2.2.2, 2.2.3, 2.2.4], which is far greater than the 50-year neutron fluence from spent nuclear fuel transported in the HI-STAR 100MB Package, which is on the order of 1.25 x 10^{16} n/cm^2 assuming design basis fuel for 50 years without radioactive decay. Also, as indicated in reference [2.2.2], "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. Elastomeric seal compounds selected demonstrate a proven and predictable response to absorbed 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 °C (°F)	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)

Definitions:

S_y = Yield Stress MPa (ksi)
S_u = Ultimate Stress MPa (ksi)
α = Coefficient of Thermal Expansion, cm/cm-°C 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 2.2.2a: Mechanical Properties of SA-193 Grade B7

SA-193 Grade B7 [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. Sources for α values are Tables TE-1 and TE-4 of [2.1.6] for ferrous materials.

Table 2.2.2b: Closure Lid Bolt Material – 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)	1068.7 (155)	19.7 (28.5)	11.16 (6.2)
93.3 (200)	924.4 (134.1)	1068.7 (155)	19.1 (27.8)	11.34 (6.3)
149 (300)	885.1 (128.4)	1068.7 (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				
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)

Definitions:

S_m = Design stress intensity MPa (ksi)
S_y = Yield Stress MPa (ksi)
α = Mean Coefficient of thermal expansion (in./in. per degree F x 10^{-6})
S_u = Ultimate Stress MPa (ksi)
E = Young's Modulus MPa 10^4 (psi x 10^6)

Notes:

1. Source for S_m values is Table 4 of [2.1.6].
2. Source for S_y values is ratioing design stress intensity values and Table Y-1 of [2.1.6], as applicable.
3. Source for S_u values is ratioing design stress intensity values and Table U of [2.1.6], as applicable.
4. Source for E values is Tables TM-1 and TM-4 of [2.1.6], as applicable.
5. Source for α values is Table TE-1 of [2.1.6] for ferrous materials. Values for α are for H1075 condition in lieu of H1025 condition.
6. 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 2.2.3: Lifting Trunnions – Mechanical Properties

SA-705 630, SA-564 630 (H1025 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	792.9 (115)	965.3 (140)	19.8 (28.68)	11.16 (6.2)
93.3 (200)	732.9 (106.3)	965.3 (140)	19.1 (27.8)	11.34 (6.3)
149 (300)	701.9 (101.8)	965.3 (140)	18.8 (27.2)	11.52 (6.4)
204 (400)	677.8 (98.3)	938.4 (136.1)	18.4 (26.7)	11.70 (6.5)
260 (500)	656.4 (95.2)	919.8 (133.4)	18. (26.1)	11.70 (6.5)
288 (550)	647.8 (93.95)	912.9 (132.4)	17.8 (25.8)	11.88 (6.6)
SB-637 N07718				
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)
288 (550)	938.0 (136.0)	1157 (167.8)	18.62 (27.0)	13.75 (7.65)

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_m values is Table 4 of [2.1.6].
2. Source for S_y values is ratioing design stress intensity values and Table Y-1 of [2.1.6], as applicable.
3. Source for S_u values is ratioing design stress intensity values and Table U of [2.1.6], as applicable.
4. Source for E values is Tables TM-1 and TM-4 of [2.1.6], as applicable.
5. Source for α values is Table TE-1 of [2.1.6] for ferrous materials. Values for α are for H1075 condition in lieu of H1025 condition.
6. 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: Alloy X – 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 °C (°F)	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-°C x 10^{-6} (in/in-°F 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 Impact Limiter Attachment Bolts

SA-193 B8S (≤ 2.5 inches) MPa (ksi)		
Temperature °C (°F)	**S_y**	**S_u**
Room Temperature	344.7 (50.0)	655.0 (95.0)
121.1 (250)	246.1 (35.7)	NA

Definitions:

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

Notes:

1. Source for S_y and S_u values is Part D of the ASME B&PV code [2.1.6].

Table 2.2.7: 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 (9.5)	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

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 [2.2.6].
2. Source for the S_y, S_u, and % Elongation values at room temperature is ASTM Specification B221 [2.1.15]. Strength values at elevated temperatures are factored lower-bound values corresponding to 10,000 hours at temperature from [2.2.6]. The strength reduction factor is taken as the ratio of the strength value at room temperature from [2.1.15] to the typical strength value at room temperature from [2.2.6]. Elongation values at elevated temperatures are obtained in the same manner.
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 2.2.8: Critical Characteristics of the AL-STAR Impact Limiter Crush Material, and Fastener Strain Limiters

Item & Property Category	Value	Comment
Crush strength (nominal), σ_c, of crush material, psi (Primary property) • Type 1 • Type 2 • Type 3	(Target volumetric average value) See impact limiter drawing in Section 1.3	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Density (reference) of crush material, lb/ft^3 (kg/m^3) (Secondary property) • Type 1 • Type 2 • Type 3	See impact limiter drawing in Section 1.3	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.2.9: Mechanical Properties of Lead

LEAD:	-40°C (-40°F)	-29°C (-20°F)	21°C (70°F)	93°C (200°F)	149°C (300°F)	316°C (600°F)
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/°C (in/in/°F)	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: References [2.2.5] and [2.2.7] provide the yield strength data for lead. The modulus of elasticity of lead can be found from Reference [2.2.8], and the Poisson's ratio and density data for lead are documented in Reference [2.2.9].

Table 2.2.10: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.2.11: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.2.12: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.2.13: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.2.14: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

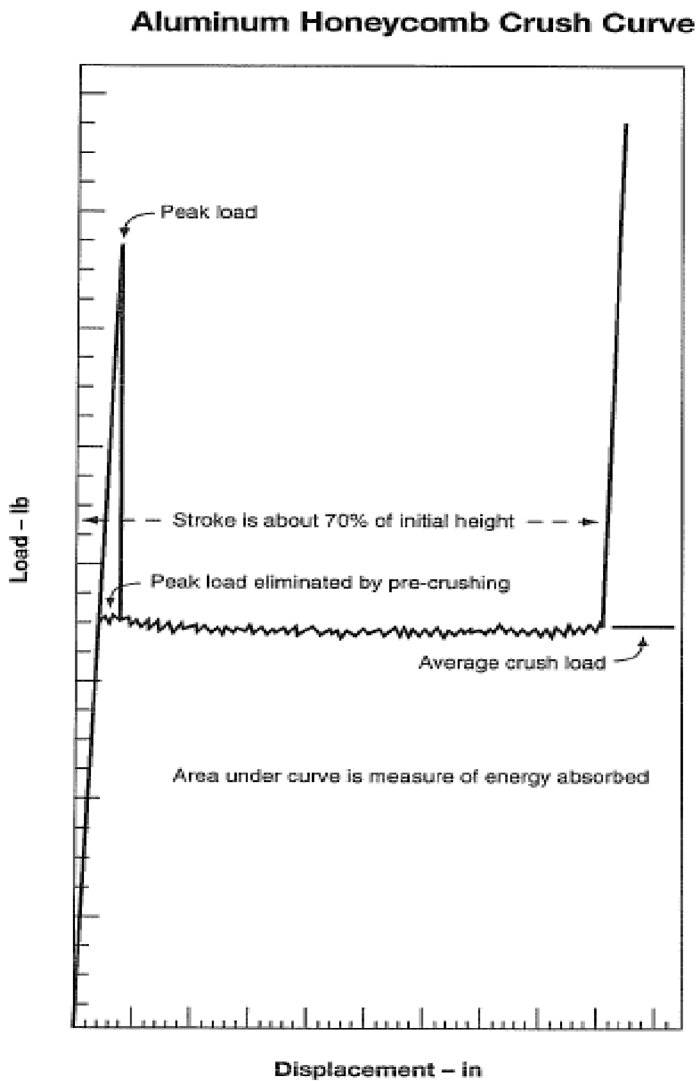

Figure 2.2.1: Aluminum Honeycomb Load vs. Crush Curve (Typical, reproduced from Ref. [2.2.1])

2.3 FABRICATION AND EXAMINATIONS[1]

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 100MB, 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 100MB. Of course, there are several candidate manufacturing sequences that will meet the above criteria. A different manufacturing sequence may be used provided they meet the above criteria for quality fabrication.

[

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

1 The material presented was adopted from the previously approved HI-STAR 190 FSAR [1.0.4] with minor editorial changes specific to HI-STAR 100MB.

]

[

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

]

2.3.2 Examinations

The design, material procurement, fabrication, and inspection of the HI-STAR 100MB are performed in accordance with applicable codes and standards. The following fabrication controls and required inspections shall be performed on the HI-STAR 100MB in order to assure compliance with the SAR and the Certificate of Compliance.

1. Materials of construction specified for the HI-STAR 100MB 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.

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 100MB 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 100MB 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 100MB 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. 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.

8. The majority of materials used in the HI-STAR 100MB 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 100MB 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 100MB, as required, shall be impact tested in accordance with Section 8.1.5 of this SAR. Test results shall be documented and shall become part of the final quality documentation record package.

9. 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 criterion is provided in Chapter 8.

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

11. The HI-STAR 100MB shall be inspected for cleanliness and proper preparation for shipping in accordance with written and approved procedures.

12. A completed quality documentation record package shall be prepared and maintained during fabrication of each HI-STAR 100MB 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 100MB has been fabricated and inspected in accordance with the governing Certificate-of-Compliance.

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FIGURE 2.3.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.2: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.3: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.4: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.5: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.6: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 2.3.7: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

2.4 GENERAL REQUIREMENTS[2]

The compliance of the HI-STAR 100MB Packaging to the general standards for all packaging, specified in 10CFR§71.43, 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 100MB Packaging meets the requirements of 10CFR§71.43(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 10CFR§71.43(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 100MB Packaging. The only access to the cask cavity space is through the closure lid, which is too heavy to be handled by manual means and requires a specially engineered powered handling device; smaller openings (openings too small for manual access) in the cask are through the cask vent and drain ports, which are sealed and protected by bolted port covers and port caps/plugs. The closure lid is fastened to the cask flange with heavy bolts, which are pre-tensioned to create a high integrity seal. Opening of the cask vent and drain port would require removal of the bolted port cover and unthreading of the port cap/plug. Inadvertent opening of the cask is not feasible; opening a cask requires mobilization of special tools and a source of power. The cask containment boundary is analyzed for normal and accident condition internal pressure and is found to possess large margins with respect to both the sealworthiness of the bolted joints and stress intensity levels.

2 The material presented in this section was adopted from the previously approved HI-STAR 190 FSAR [1.0.4] with minor editorial changes

2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Interfacing Lifting Points

Per Regulatory Guide 7.9, this subsection presents analyses for all lifting operations applicable to the transport of a HI-STAR 100MB package to demonstrate compliance with requirements of paragraph 71.45(a) of 10CFR71.

The HI-STAR 100MB Cask has the following types of interfacing lifting points: two lifting trunnions located on the upper cask body for lifting the loaded and unloaded cask and threaded holes on the cask closure lids that serve as attachment locations to lift the lid. In addition, two trunnions are located in the lower cask body for rotation of the loaded and unloaded cask.

The evaluation of the adequacy of the interfacing lifting points 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 2.1.11 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 [2.5.3], 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 100MB package are designed to meet the requirements of 10CFR§71.45(a) and NUREG 1617 [2.1.11]. Accordingly, the lifting trunnions are required to maintain a safety factor of 3 based on the material yield strength. The lifting attachments that are part of the HI-STAR 100MB package and conservatively considered as lifting devices are required to meet the design provisions of NUREG-1536 [2.5.4] and NUREG-0612 [2.1.5], which specify higher safety factors of 6 on yield strength and 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 10CFR§71.45(a) are met. Hence the lifting trunnions are conservatively analyzed to meet a minimum safety factor of 6 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 stress levels in the lifting trunnions, 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 Stress Analysis of Lifting Operations:

The lifting trunnion for the HI-STAR 100MB cask is presented in the drawing package provided in Section 1.3. The two top lifting trunnions for HI-STAR 100MB are circumferentially spaced at 180 degrees and are engaged to perform the lifting operations. 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 trunnions near the base of the cask body. These trunnions may be used as rotation supports when changing cask 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 need not be satisfied. In the latter case, the lower trunnions are acting as lifting trunnions and must show a minimum safety factor of 3 on yield strength, but the maximum lifted load is 50% of the total load.

The embedded trunnion is analyzed as a cantilever beam subjected to a line load applied at the outer edge of the trunnion (see Figure 2.5.1). This assumption is clearly very conservative because the moment arm of the load has been maximized. In reality the loading is distributed over the exposed surface of the trunnion with the resultant force acting closer to the root of the cantilever than the mid-span location. A Strength of Materials methodology (classical beam theory) is used to represent the trunnion as a cantilever beam with a solid circular cross section. The bending moment and shear force at the root of the trunnion cantilever are compared against allowable values based on either yield or ultimate strength. Calculations demonstrate (Holtec Proprietary Report [2.1.12]) that the stresses in the upper and lower trunnions, computed in the manner of the foregoing, comply with requirements of paragraph 71.45(a) of 10CFR71 and also satisfy NUREG-0612 strength limits.

Key stress results are presented in Table 2.5.1 along with the corresponding safety factors demonstrating that the HI-STAR 100MB trunnions are a NUREG-0612 compliant handling appurtenance.

2.5.1.2 Cask Closure Lids and Baseplate During Lifting

2.5.1.2.1 Closure Lid Lifting Holes

The inner and outer closure lids contains tapped lifting holes used to move each lid over and onto the closure flange of the cask. Since the cask contains fuel during this movement, the tapped lifting holes in the closure lid are sized so that adequate thread strength and engagement length exist using allowable stresses in accordance with 10CFR§71.45(a) requirements. Since the size and number of the tapped lifting holes is the same for the inner and outer lids, a bounding calculation is performed based on the heavier of the two lids (i.e., inner closure lid). 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 100MB the containment baseplate is subject to amplified dead load, D*, from the loaded MPC, from the self-weight of the baseplate and any attached shielding, and from the overpack internal pressure. Note that the internal pressure loading bounds the weight of the water inside the cask, which acts on the baseplate during cask lifting from the loading pool. To analyze this condition, the baseplate and a portion of the containment shell is modeled using the ANSYS finite element code [2.5.1] and a static analysis performed. The lid is included in the model, and the bolted connection is simulated by merged nodes (common nodes) at the lid to shell interface. In addition to the load applied to the baseplate from the loaded MPC, the maximum normal operating pressure (MNOP) load is applied normal to the surface of the containment boundary (viz. the baseplate, the containment shell and the lid). In this load case, the 15% amplifier is applied to the lifted load. Figure 2.5.2a shows the model and applied loads; the distribution of temperature on the containment boundary is also shown in the figure. Stress intensity results obtained from the finite element analysis are presented in Figure 2.5.2b.

Details of the evaluation and locations of maximum stress intensity are provided in the calculation package [2.1.12]. 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 allowable stress intensities from Table 2.1.2.

2.5.1.3 Failure of Lifting Devices

10CFR§71.45 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 10CFR71. The ultimate load carrying capacity of the lifting trunnion is governed by the cross section of the trunnion outboard of the

cask rather than by any section within the cask. Loss of the external shank of the trunnion, therefore, will not cause loss of any other structural or shielding function of the HI-STAR 100MB cask; therefore, the requirement imposed by 10CFR§71.45(a) is satisfied.

2.5.2 Tie-Down Devices

There are no tie-down devices that are a structural part of the package. It should be noted that the cask trunnions are made inaccessible during transport per Subsection 7.1.5. Therefore, 10CFR§71.45(b) is not applicable to the HI-STAR 100MB Package.

The saddle supports under the cask, the straps, and the front and rear end structures that resist longitudinal load are not part of the HI-STAR 100MB package. The loads used to design these components may be determined using the load amplifiers given by the American Association of Railroads (AAR) Field Manual, Rule 88 [2.5.2] 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 10CFR§71.45(a) (lifting devices) and 10CFR§71.45(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 evaluated in this safety analysis.

2.5.4 MPC Lifting

The Enclosure Vessel for the MPC-32M is the same as the previously licensed MPC-32 in the HI-STORM 100 FSAR [1.2.6]. The threaded holes on the MPC lid used for MPC lifting operations have been demonstrated in the HI-STORM 100 FSAR [1.2.6] to maintain a minimum safety factor of 3 based on material yield strength and a minimum safety factor of 10 based on material ultimate strength. Therefore, the applicable stress requirements of NUREG 1617 [2.1.11], 10CFR§71.45(a) and NUREG-0612 [2.1.5] for lifting attachments or interfacing lift points are all satisfied, and there is no need to repeat the structural evaluation for the MPC lift points in this safety analysis report.

Table 2.5.1: Key Safety Factors for HI-STAR 100MB Trunnions

Item	Calculated Value	Minimum Safety Factor
Upper Solid Trunnion Bending Stress - ksi (MPa)	9.84 (67.8)	2.10†
Upper Solid Trunnion Shear Stress - ksi (MPa)	4.69 (32.3)	2.47†
Bearing Stress on Upper Hollow Trunnion - ksi (MPa)	17.30 (119.3)	1.78
Bearing Stress on Upper Solid Trunnion - ksi (MPa)	17.30 (119.3)	7.16
Lower Solid Trunnion Bending Stress - ksi (MPa)	8.20 (56.5)	2.52†
Lower Solid Trunnion Shear Stress - ksi (MPa)	3.91 (27.0)	2.97†
Bearing Stress on Lower Hollow Trunnion - ksi (MPa)	15.38 (106.0)	2.00
Bearing Stress on Lower Solid Trunnion - ksi (MPa)	15.38 (106.0)	8.06

† Represents the additional margin that is over and beyond the mandated safety factors per NUREG-0612 (i.e., a minimum safety factor of 10 on ultimate strength and 6 on yield strength)

Table 2.5.2: Key Safety Factor for HI-STAR 100MB Closure Lid Lifting Holes

Item	Value, kg (lb.)	Capacity, kg (lb.)	Minimum Safety Factor
Closure Lid Direct Load	7,824 (17,250)†	12,140 (26,760)	1.55

† Based on bounding lid weight of 15,000 lb. Includes 15% inertia load.

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	< 23.4 (3.40)	143.7 (20.85)	> 6.13
Baseplate (Center), Membrane + Bending Stress	< 57.2 (8.30)	215.6 (31.28)	> 3.77
Shell (Joint with Baseplate), Membrane + Bending + Secondary Stress Intensity	< 102.0 (14.80)	431.3 (62.55)	> 4.23

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.

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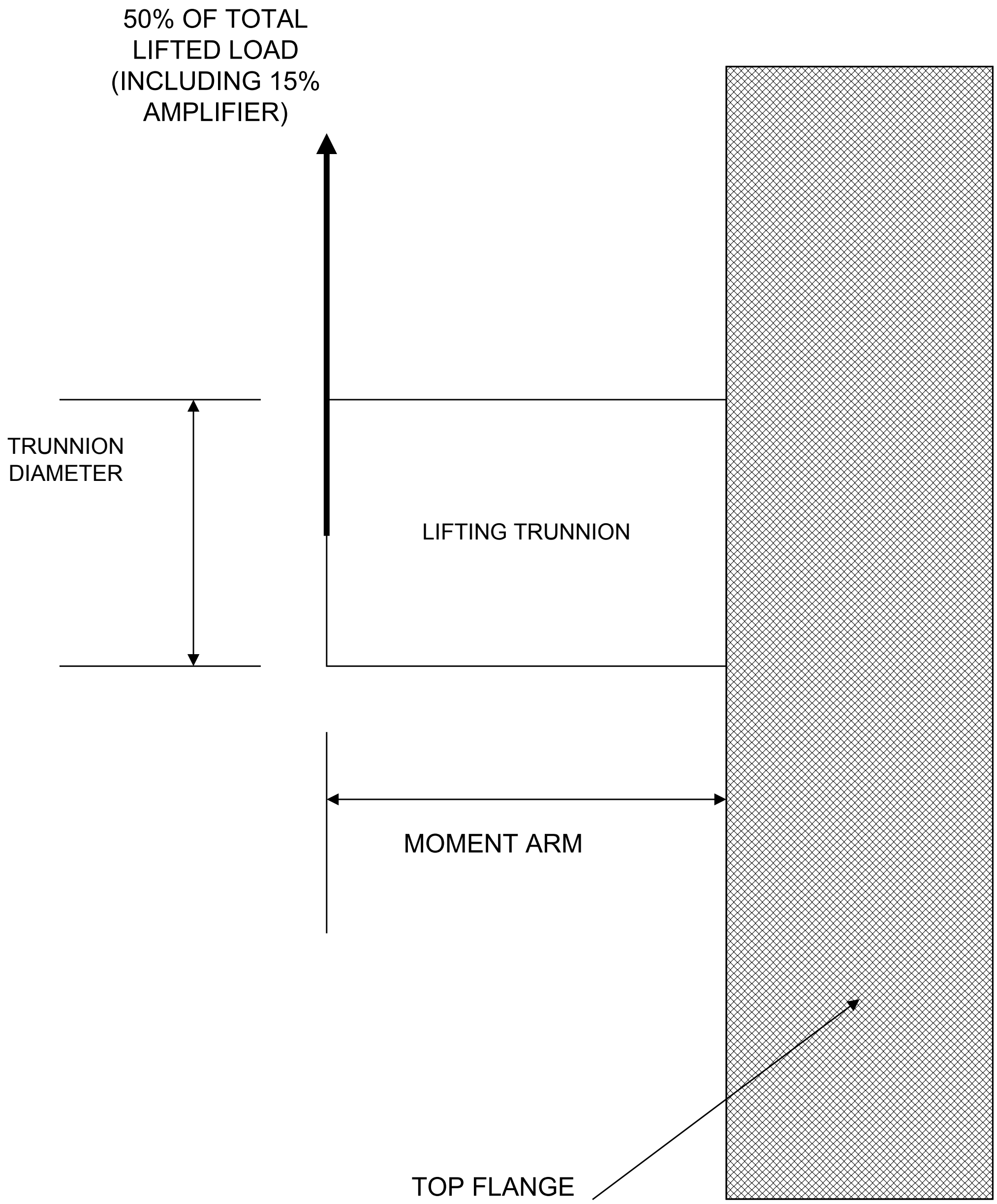

Figure 2.5.1: Top Lifting Trunnion with Applied Force

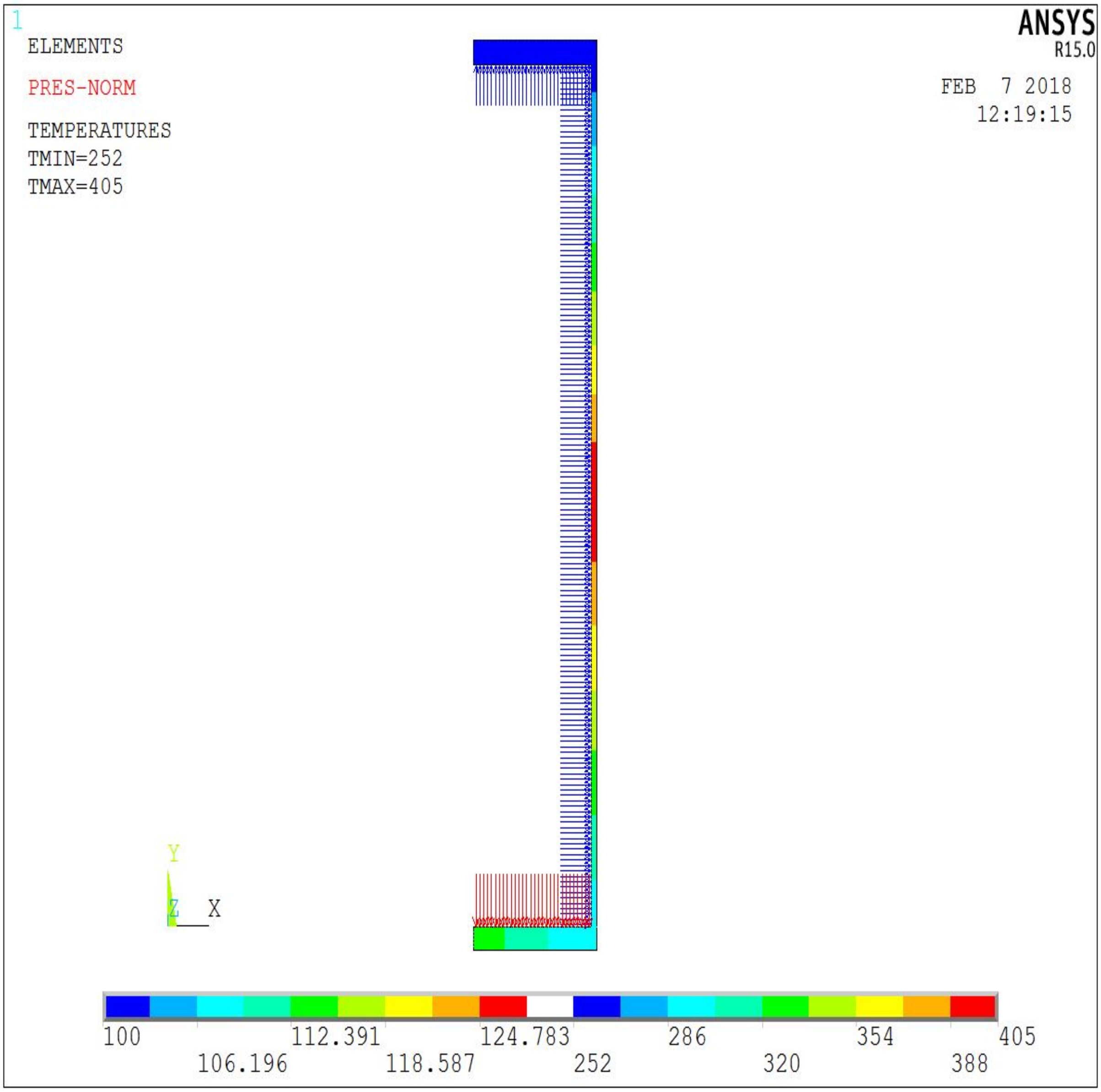

Figure 2.5.2a: Shell and Baseplate Finite Element Model for Lifting Load Case (Loaded MPC, MNOP and Self Weight)

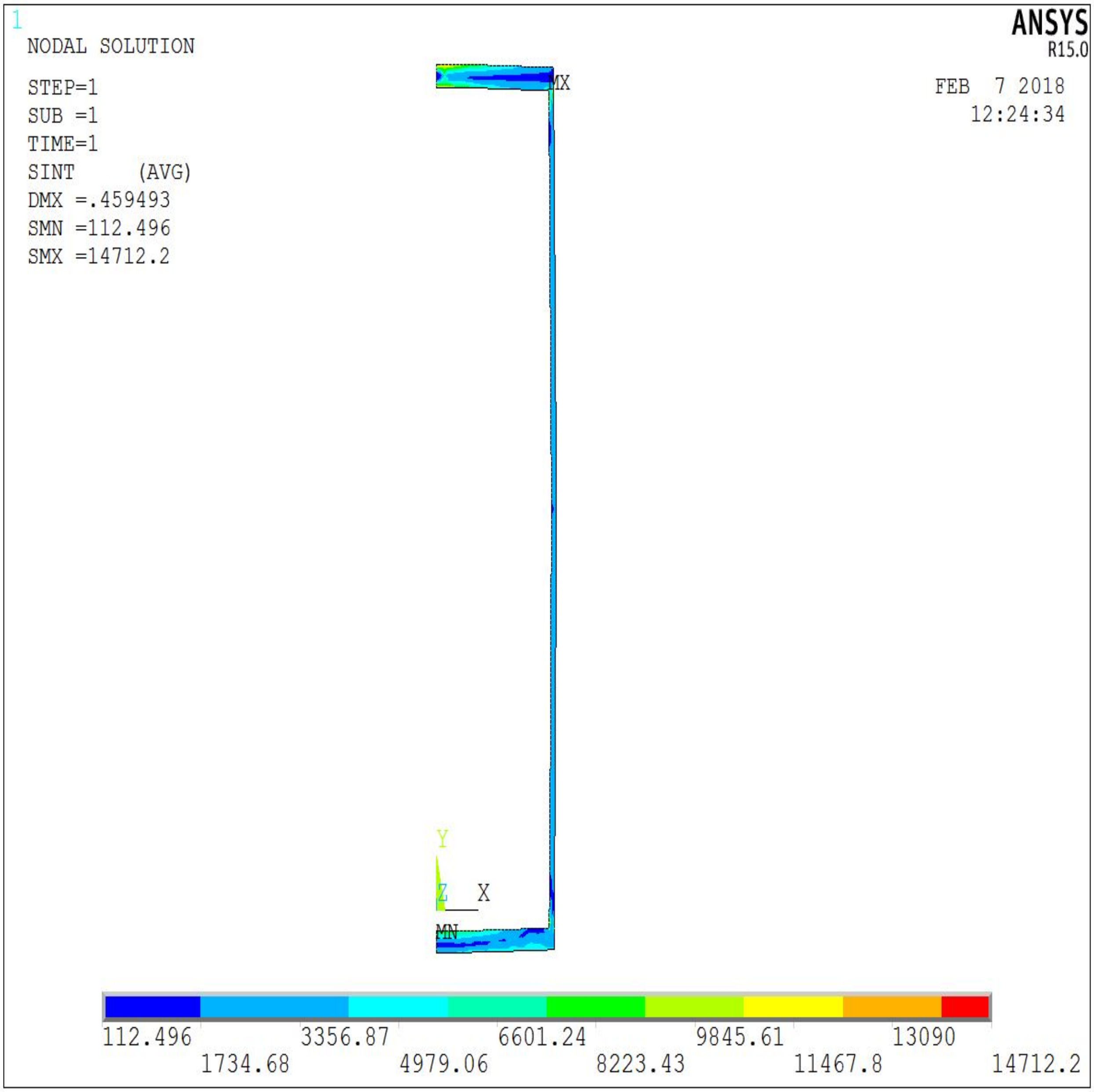

Figure 2.5.2b: Containment Boundary Under Normal Handling (with MNOP) - Stress Intensity Plot

2.6 NORMAL CONDITIONS OF TRANSPORT

In this section, the HI-STAR 100MB package consisting of the cask and the AL-STAR impact limiter, is shown to meet the design criteria in Section 2.1 (which are derived from the stipulations in 10CFR§71.43 and 10CFR§71.51) when subjected to the normal conditions of transport specified in 10CFR§71.71. The vehicle utilized for the stress/deformation analysis is a comprehensive 3-D finite element simulation of the package on Q.A.-validated codes. 3-D finite element models of the cask, the fuel package, and the two impact limiters have been prepared and assembled into a complete system to evaluate 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. For this purpose, 3-D finite element models of the cask, the fuel package, and the two AL-STAR impact limiters have been prepared.

The AL-STAR impact limiter was subjected to a series of “9-meter drop tests” on quarter-scale models during the licensing of the classic HI-STAR 100 in the late 90’s. The scale model was of the type A-4 in the parlance of Reference [2.6.11]. The quarter-scale drop test results were correlated with a classical contact mechanics-based simulation model to predict the classic HI-STAR 100 Package’s response under *any* drop orientation [2.1.19, 2.6.10]. The test data and the analytical correlation model provided the basis of NRC’s transport certification of the classic HI-STAR 100 package in the late 90s (Docket # 71-9261).

The scale model test data from the classic 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 of [1.0.6], 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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2.6.1 Heat

This subsection, labeled "Heat", in the format of Regulatory Guide 7.9, contains information on all structural (including thermo-elastic) analyses performed on the cask to demonstrate positive safety margins under the normal condition of transport, 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 100MB package is reported in Chapter 3, wherein the material temperatures that are needed for the structural evaluations are defined.

2.6.1.1 Summary of Pressures and Temperatures

Table 2.6.2 summarizes 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 100MB 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 100MB system 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 100MB 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 3.4. Table 3.3.6 documents the radial and axial expansions prior to and after heat-up.

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In summary, under Normal Hot Conditions of Transport, the HI-STAR 100MB package internals are not subject to restraint of free thermal expansion. Therefore, subsequent buckling or significant MPC deformation due to differential thermal expansions is not credible for the HI-STAR 100MB package.

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 [2.5.1] and LS-DYNA [2.6.1], and the models described in Section 2.7 and in the Holtec Proprietary calculation packages [2.1.12] and [2.6.2]. 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 [2.6.2]. This same finite element model is used for both the Normal Conditions of Transport (Load Combination N2) and the Hypothetical Accident Conditions of Transport (drop as well as puncture analyses reported in Section 2.7).

Results from the analysis of the 1-foot drop case (Load Combination N2) are documented in the Holtec Proprietary finite element analysis calculation package [2.6.2]. 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 100MB 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 pertains to bonded dissimilar materials subject to severe thermal ramps. Because of the large mass and thermal inertia of the cask and the relatively tepid rate of ambient temperature change associated with normal operations, fatigue effects are minimal in HI-STAR 100MB, as demonstrated by the simplified calculations below.

The Design Fatigue curves for the cask materials are given in Appendix I of Section III of the ASME Code. Each of the five ASME criteria is considered in the following:

i. <u>Atmospheric to Service Pressure Cycle</u>

The number of permissible cycles, n, is bounded by $f(3S_m)$, where f(x) means the number of cycles from the appropriate fatigue curve at stress amplitude of "x" psi. In other words

$$n < f(3S_m)$$

From Tables 2.1.4 and 2.1.6 for normal conditions at a bounding temperature of 450^{o}F, and from the fatigue curve in ASME Code Appendix I, the number of permissible cycles for the containment boundary is

$$n\ (cask) \leq 1{,}600\ (3S_m = 62{,}500\ psi)\ (\text{Figure I-9.1 of ASME Appendix I})$$

Since 1,000 pressurizations in the 50-year life of the cask is an upper bound estimate, it is concluded that projected pressurizations of the HI-STAR 100MB components do not 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,

$$(\Delta_p)_{overpack} = \frac{(100)(12{,}500)}{(3)(20{,}850)} = 19.98 \ psi \ \ (0.138 \text{ MPa})$$

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. 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 450°F) and the appropriate ASME fatigue curve in Appendix I of Section III of the ASME Code give:

$$(\Delta T)_{overpack} = \frac{83{,}000}{(2)(25.95)(7.2)} = 222.1^{\circ}\text{F} \ \ (123.4^{\circ}\text{C})$$

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

Significant temperature fluctuations that require consideration in this criterion are those

in which the range of temperature difference between any two adjacent points under normal service conditions is larger than S/2Eα where S corresponds to 10^6 cycles. Substituting gives:

$$(\Delta T)_{overpack} = \frac{12{,}500}{(2)(25.95)(7.2)} = 33.45°F \ (18.6°C)$$

During normal operation, the temperature field in the cask is steady state. Therefore, normal temperature fluctuations are negligibly small. Therefore, normal temperature fluctuations do not warrant a fatigue usage factor evaluation.

v. Mechanical Loads

Mechanical loadings of appreciable cycling occur in the HI-STAR 100MB Package only during transportation. The stress cycling under transportation conditions is considered significant if the stress intensity amplitude is greater than S_a corresponding to 10^6 cycles. It, therefore, follows that the stress intensity range that exempts the cask is 25,000 psi (172.4MPa).

Inertia loads typically associated with rail transport will produce stress intensity ranges in the cask that are a small fraction of the above limits. Therefore, the potential for large fatigue expenditure in the cask materials, under transportation conditions, is not credible.

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. The maximum bolt stress is permitted to have the value $2S_m$ (Table 2.1.3). For the closure lid bolt material (SA-564 630/705 (H1025)), the value of S_m at 275°F (135°C) is 48.3 ksi (333.0 MPa) per Table 2.1.8, and the Young's modulus is 27,350 ksi (188,600 MPa). Therefore, incorporating a fatigue strength reduction factor of 4, the effective stress intensity amplitude using Figure I-9.4 (ASME Code, Section III Appendices [2.1.10]) is (ratioing the modulus used in the figure to the modulus used here):

$$S_a = \frac{(48.3)(4)(30e+06)}{27.35e+06} = 211.9ksi = 1461MPa$$

Using Figure I-9.4 of [2.1.10], the permissible number of cycles is 225; this sets a limit on the number of permitted loadings for a set of closure lid bolts.

A similar fatigue evaluation for an alternative closure lid bolting material SB-637 N07718 is performed and the corresponding permissible number of cycles is determined as follows:

$$S_a = \frac{(47.2)(4)(29.8e+06)}{28.0e+06} = 200.9ksi = 1385MPa$$

Using Figure I-9.7 of [2.1.10], the permissible number of cycles is 253; 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 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). At a temperature of 350°F (177°C), Table 2.1.8 shows that the closure lid port cover lid bolt material (SA-193 B7) may be pre-stressed to a value not to exceed 61.9 ksi (426.8MPa). The alternating stress intensity in the bolt is equal to 1/2 of the maximum stress intensity, or 30.95 ksi (213.4MPa). Per Table 2.2.2, the Young's modulus is 28,250 ksi (194,800 MPa). Therefore, incorporating a fatigue strength reduction factor of 4, the effective stress intensity amplitude using Figure I-9.4 (ASME Code, Section III Appendices) is (ratioing the modulus used in the figure to the modulus used here):

$$S_a = \frac{(30.95)(4)(30e+06)}{28.25e+06}$$
$$= 131.5 \text{ ksi} = 906.7MPa$$

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 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. The maximum shear stress on the threaded area of the flange is calculated using 86.55 ksi (the maximum Level A allowable stress of the bolt per Table 2.6.3) as bolt stress. The resulting shear stress is less than:

$$\tau = 18 \text{ ksi} \ (124.1 \text{ MPa})$$

The primary membrane stress intensity in the closure flange threads is equal to twice the maximum shear stress, and the alternating stress intensity in the threads, S_a, is equal to 1/2 of the total stress. Conservatively, using the cask design temperature (450 °F per Table 3.2.10), the Young's Modulus (Table 2.2.1) is 25,950 ksi (178,900 MPa).

The effective stress amplitude accounting for the fatigue strength reduction and Young's

Modulus effects is given by

$$S_a = \frac{(18)(4)(30)}{25.95} = 83.3\,\text{ksi} \qquad (573.9\,MPa)$$

Using Figure I-9.1 of [2.1.10], the allowable number of cycles is approximately equal to 1000.

Therefore, the *maximum service life of the closure flange threads is 1000 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

The minimum alternating stress range, S_a, at 10 cycles from all appropriate fatigue curves is 580 ksi. Calculated stress intensities in the containment boundary under any of the analyses performed in this safety analysis under the required load combinations for Normal Conditions of Transport are less than the ultimate strength of the containment vessel material (70 ksi). Conservatively assuming a stress concentration of 4 regardless of specific location produces a stress intensity range below 4 x (70 ksi) = 280 ksi (< 580 ksi). Therefore, satisfaction of the Regulatory Guide 7.6 commitment on alternating stress intensity range is assured.

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. The following computation demonstrates that an elastic instability of Metamic-HT basket plates is not credible.

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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 [2.6.9, Chapter 3, pp 144-51]).

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2.6.1.3.5 Re-flood Event

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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 2.1.4 through 2.1.10) 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 with 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 [2.6.2], respectively. For Load Combination N1, a static axi-symmetric finite element model is constructed using ANSYS [2.5.1] using layered Plane42 elements to model the through-thickness behavior of the containment shell and the baseplate. The tabular results include contributions from mechanical and thermal loading and are needed to insure satisfaction of primary and primary plus secondary stress limits for normal conditions of transport. For the purpose of this calculation only, the closure lid-shell junction is modeled assuming a clamped connection in recognition that the large preload from the closure lid bolts, necessary to insure continued sealing during the drop events, will preclude relative rotations at the joint under the internal pressure. The analysis considers the combined effects of the design internal pressure in Table 2.1.1 and the operating temperature distribution from the thermal analysis described in Section 3.3. Figure 2.6.3 shows the axi-symmetric finite element model, and Figure 2.6.4 shows the graphical results, both reproduced from [2.1.12].

For Load Combination N2, a dynamic finite element model implemented in LS-DYNA [2.6.1] is used to determine the peak deceleration of the cask and evaluate stresses in the cask components. Note that the MPC enclosure vessel is not explicitly modeled in the HI-STAR 100MB package

LS-DYNA model. However, the MPC enclosure vessel of HI-STAR 100MB is identical to that of HI-STAR 190 in terms materials, component thicknesses, and weld sizes. Moreover, the weight of the HI-STAR 190 MPC contents is bounding. Therefore, the MPC enclosure vessel stress results for Load Combination 2 are conservatively obtained by ratioing the stress results obtained from the HI-STAR 190 package 1-ft drop analysis based on the peak decelerations of the two packages.

Results are evaluated against Level A stress intensity limits for locations in the containment shell, and in the baseplate, which together with the closure lid, make up the containment boundary. The bolted connection of the lid to the closure flange is not modeled for Load Combination N1, as this solution is not meant to evaluate the sealing performance of the gaskets.

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 2.6.2 for component temperatures, and Table 2.6.3 for allowable stress intensities).

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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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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The closure lid port cover seals are analyzed using classical methods to demonstrate that the torque requirement for the closure lid port cover bolts (Tables 2.2.10 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, including port cover seals, do not unload beyond the minimum force 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.

- Performance of MPC Enclosure Vessel

The MPC enclosure vessel under Load Combination N1 has been structurally qualified in HI-STORM 100 FSAR [1.2.6], where the MPC enclosure vessel was evaluated at bounding temperatures since the MPC is hotter when it's in HI-STORM 100. The LS-DYNA simulation results for Load Combination N2 demonstrate that all safety factors of the MPC enclosure vessel structural components are greater than 1.0, as shown in Table 2.6.6.

- 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 [2.6.2] contains graphical visualizations of the stress intensity and deformation for every component in the HI-STAR 100MB package. Table 2.6.7 summarizes the acceptance criteria for performance of the non-containment components of the HI-STAR 100MB. 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 100MB 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 useful springback required to maintain leak tightness (per Table 2.10).

Therefore, the HI-STAR 100MB 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 an ambient environmental temperature of -20°F (-29°C) and maximum decay heat. A special condition of extreme cold is also defined in Regulatory Guide 7.8 where the package and environmental temperature is at -40°F (-40°C) and the package is exposed to increased external pressure with minimum internal pressure. 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 100MB 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, the temperature gradients in the cask components under steady-state conditions will remain 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.
Furthermore, the change in bolt stress due to the assumption of a severe local low temperature

condition is insignificant compared to the initial bolt preload 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 100MB Package design, loads due to expansion of freezing liquids are not considered.

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 MPC 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 100MB 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 10CFR§71.61 (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 100MB.

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 dose blocker parts. Conservatively considering the HI-STAR as a supported beam at its two extremities 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 Holtec proprietary 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.

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2.6.6 Water Spray

The condition is not applicable to the HI-STAR 100MB 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 all 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 100MB Package per [2.1.3].

2.6.9 Compression

This condition is not applicable to the HI-STAR 100MB Package per [2.1.3].

2.6.10 Penetration

This condition is not applicable to the HI-STAR 100MB Package per [2.1.4].

Holtec Non-Proprietary Version

Table 2.6.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.6.2: Summary of Operating Pressure Difference and Bounding Average Metal Temperatures for Normal Condition of Transport ("Heat" Condition)

Location	Pressure kPa (psig)	Component Temperature Used in the Safety Factor Evaluation °C (°F) ††
Containment Shell	Refer to Table 2.1.1	191 (375)
Containment Baseplate		149 (300)
Containment Top Flange		135 (275)
Outer Closure Lid		135 (275)
Closure Lid Seal and Bolt		135 (275)
Cylindrical Lead Layer		177 (350)
Intermediate Shell		177 (350)
Inner Closure Lid		191 (375)
Outer Shell		135 (275)
Base Lead		149 (300)
MPC Lid		177 (350)
MPC Shell		204 (450)
MPC Baseplate		177 (350)
Fuel Basket – Middle Periphery		325 (617)
Fuel Basket – Middle Center		350 (662)
Fuel Basket – Top and Base		300 (572)

Notes:

††Temperatures listed bound the calculated temperature results obtained from the thermal analysis discussed in Chapter 3. Added conservatism may be noted in some of the structural calculations where bounding temperatures are considered while evaluating the minimum safety margins.

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

ITEM	LEVEL A†	LEVEL D†	TEMPERATURE
Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	230.97 (33.5)	506.8 (73.5)	135°C (275°F)
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	148.75 (21.575)	337.8 (49.0)	191°C (375°F)
Containment Shell – Primary Membrane + Bending Stress Intensity – MPa (ksi)	223.2 (32.375)	506.8 (73.5)	191°C (375°F)
Containment Shell – Primary + Secondary Stress Intensity – MPa (ksi)	446.26 (64.725)	NA	191°C (375°F)
Baseplate – Primary Membrane + Bending Stress Intensity – MPa (ksi)	228.6 (33.2)	506.8 (73.5)	149°C (300°F)
Baseplate – Primary + Secondary Stress Intensity – MPa (ksi)	457.2 (66.3)	NA	149°C (300°F)
Lid Bolts (SA-564/750 630) – Average Service Stress – MPa (ksi)	596.74 (86.55)	895.112 (129.825)	135°C (275°F)
Lid Bolts (SA-564/750 630) – Maximum Service Stress at Extreme Fiber – MPa (ksi)	895.112 (129.825)	1068.7 (155)	135°C (275°F)
Lid Bolts (SB-637 N07718) – Average Service Stress – MPa (ksi)	650.52 (94.35)	975.78 (141.525)	135°C (275°F)
Lid Bolts (SB-637 N07718) – Maximum Service Stress at Extreme Fiber – MPa (ksi)	975.78 (141.525)	1203.3 (174.525)	135°C (275°F)
MPC Enclosure Vessel Primary Membrane Stress Intensity – MPa (ksi)	124.45 (18.05)	298.5 (43.3)	232°C (450 °F)
MPC Enclosure Vessel Primary Membrane and Bending Stress Intensity – MPa (ksi)	186.98 (27.12)	447.8 (64.95)	232°C (450 °F)
MPC Enclosure Vessel Primary + Secondary Stress Intensity – MPa (ksi)	399.2 (57.9)	NA	177°C (350 °F)

† Obtained from Section 2.1.

Table 2.6.4: Maximum Deceleration under 1-Ft (0.3-M) Free Drop Condition (Horizontal Drop)

Method	α_{max} (g's)
Numerical (LS-DYNA) Solution	21.15
Note: This simulation considers the limiting upper bound crush strength for the impact limiter material.	

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

Location and Stress Intensity Component†	Calculated Value*
Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	< 38.6 (5.60) SF > 5.58
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	< 17.9 (2.60) SF > 8.02
Containment Shell/Baseplate Joint – Primary + Secondary Stress Intensity – MPa (ksi)	< 72.4 (10.50) SF > 5.96
Baseplate – Primary Membrane + Bending Stress Intensity at Center – MPa (ksi)	< 48.3 (7.00) SF > 4.47

Note:
* "SF" means Safety Factor; safety factors are calculated conservatively based on allowable stresses at a bounding temperature of 450 °F, instead of the less conservative values listed in Table 2.6.3.
† Except for Load Combination N2, the MPC enclosure vessel is subjected to identical Level A pressure loadings under both normal storage (in HI-STORM 100) and transport (in HI-STAR 100MB) conditions. Moreover, the MPC enclosure vessel is hotter in HI-STORM 100. Therefore, the structural integrity of the MPC containment boundary has been qualified in the HI-STORM 100 FSAR [1.2.6] for Level A pressure loading conditions (including Load Combination 1), except for Load Combination N2 which is reported in Table 2.6.6. Therefore, this table only reports the overpack containment boundary results for Load Combination N1.

Table 2.6.6: Key Containment Boundary Stress Intensities and Safety Factors – Load Combination N2 (1-Ft Drop, Dynamic Analysis)

Item	Allowable from Table 2.6.3	Calculated Value	Safety Factor
Primary Stress Intensity of the Containment Shell – MPa (ksi)	223.2 (32.375)	193.0 (28.0)	1.16
Primary + Secondary Stress Intensity of the Containment Shell – MPa (ksi)	446.3 (64.725)	289.4 (41.98)	1.54
Primary + Secondary Stress Intensity of the MPC – MPa (ksi)	399.21 (57.9)	340.5 (49.4)	1.17

Notes:
1. Safety factors are calculated based on the allowable stresses defined in Table 2.6.3.
2. 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 100MB

Criterion	Load Combination N1	Load Combination N2
Stress Intensity in the steel dose blocker parts – Primary Stress Intensity Below Ultimate Strength	-	Yes
Fuel Basket Deformation – Maximum Deflection < 1 mm	Yes	Yes

Table 2.6.8: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.6.9: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

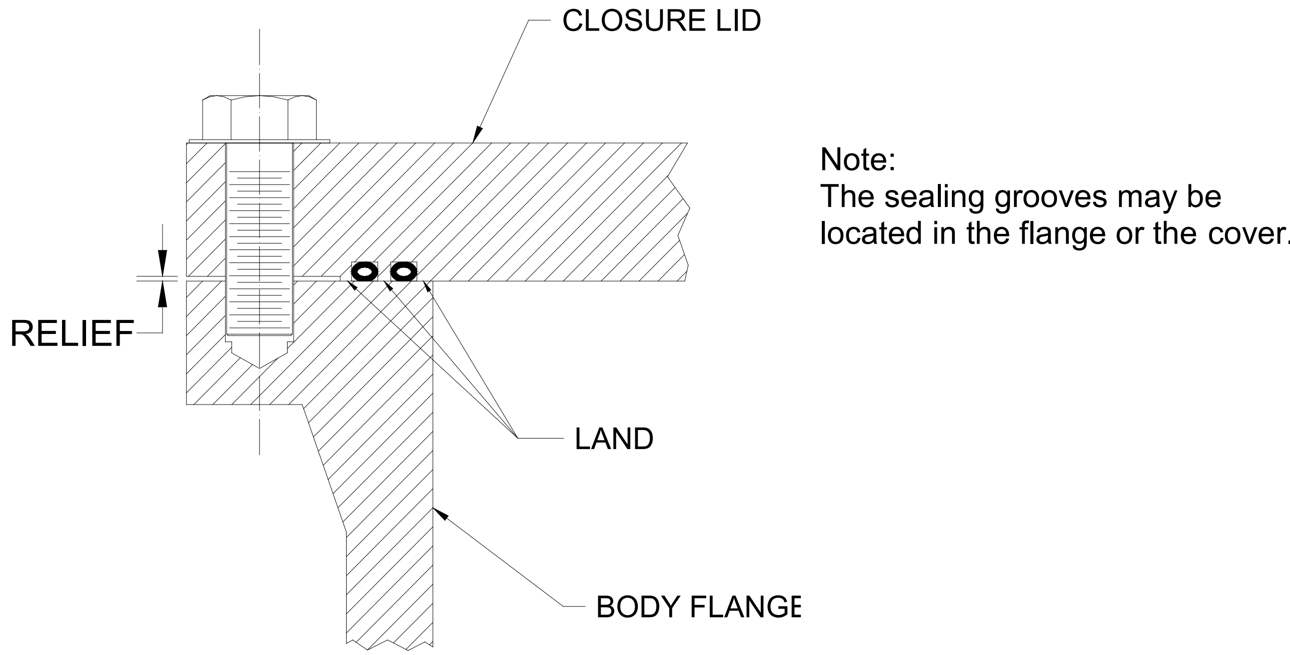

Figure 2.6.1: Essential Elements of a Classical "Controlled Compression Joint"

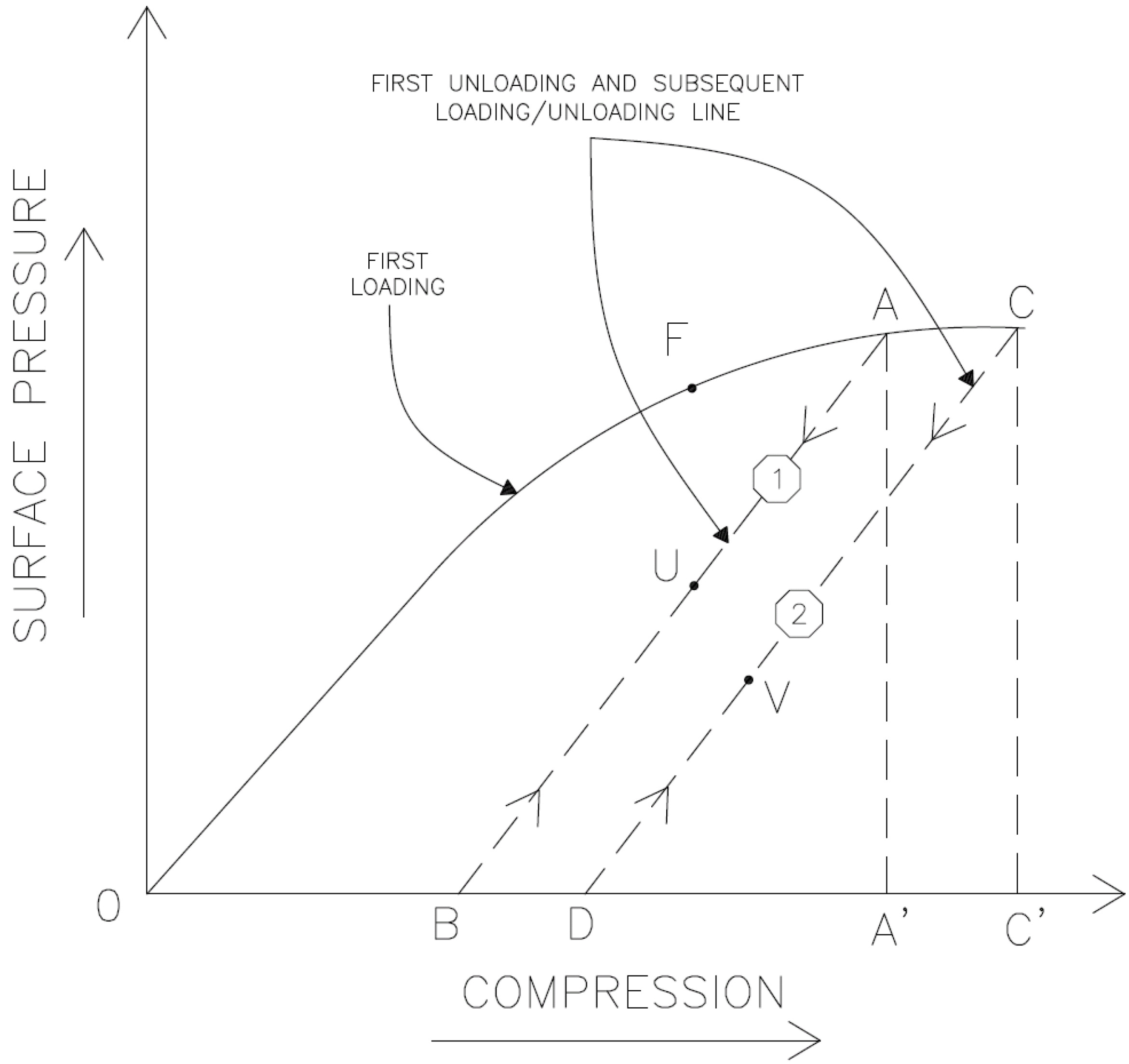

Figure 2.6.2: Loading and Unloading Curves for a Typical Gasket

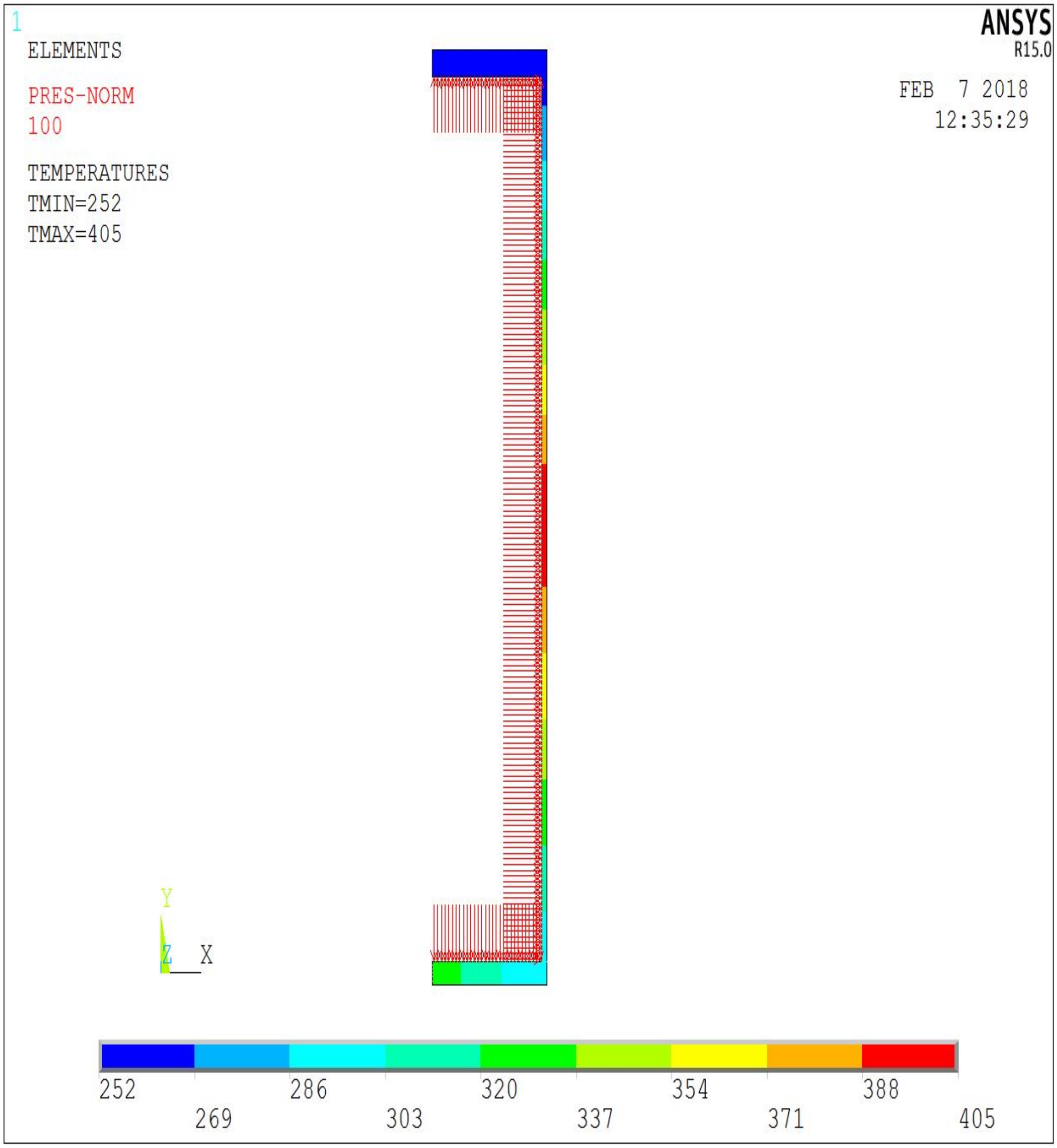

Figure 2.6.3: HI-STAR 100MB Overpack Containment Boundary Finite Element Model for Load Combination N1

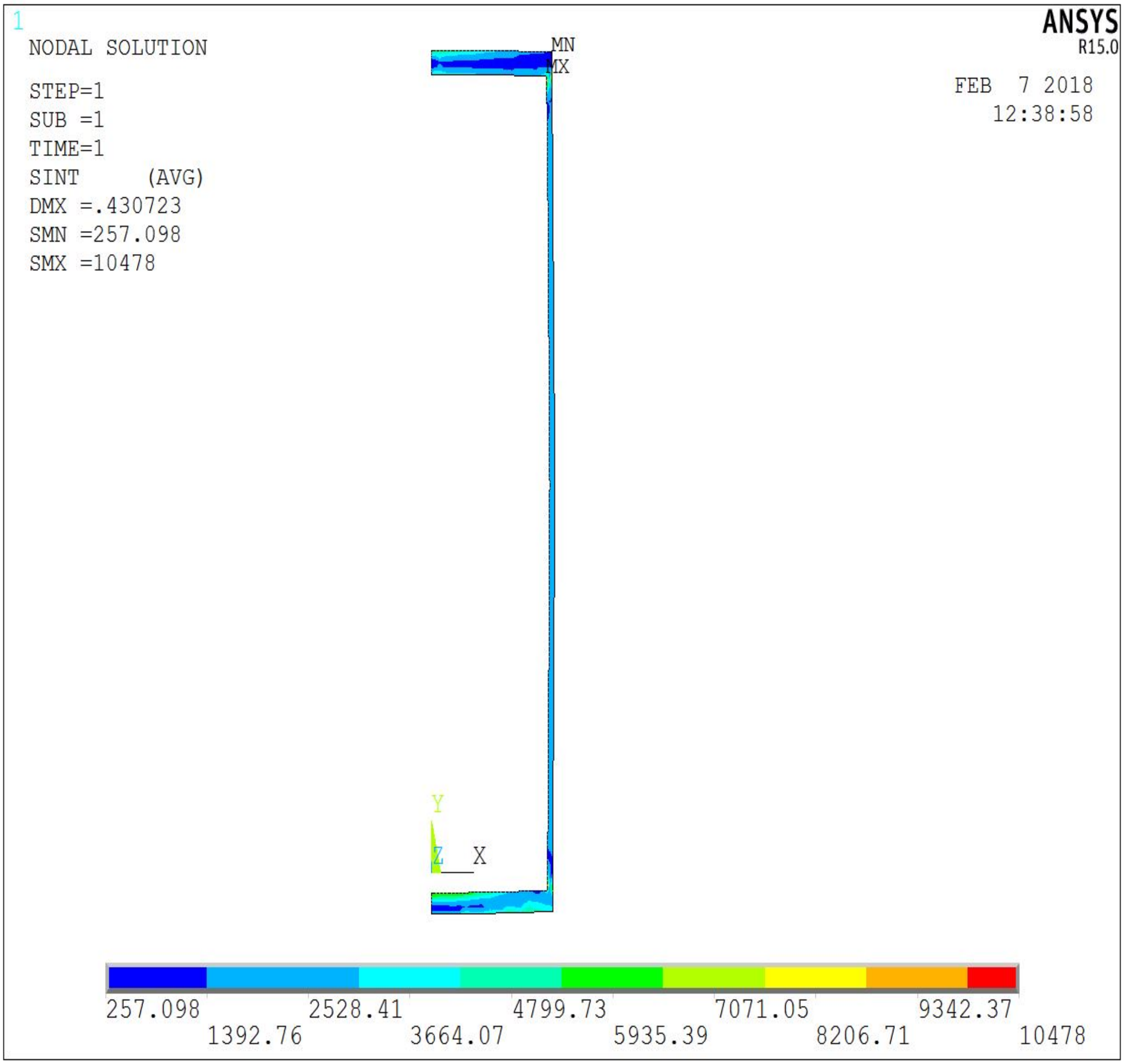

Figure 2.6.4: HI-STAR 100MB Overpack Stress Intensity Results for Load Combination N1

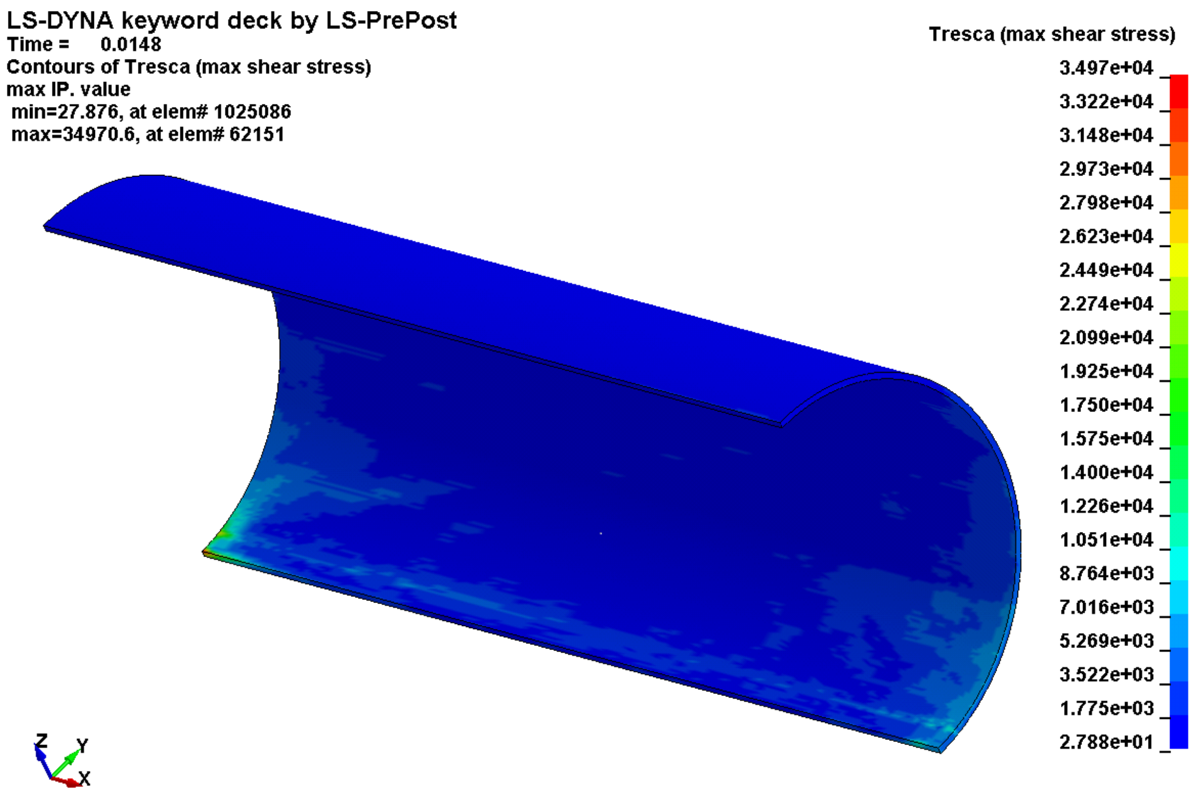

Figure 2.6.5: Maximum Shear (1/2 Times Stress Intensity) Distribution in Containment Shell for Load Combination N2 (1-Ft Side Drop)

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

It is shown in the following subsections that the HI-STAR 100MB Package meets the safety criteria set forth in 10CFR71 when it is subjected to the hypothetical accident conditions specified in 10CFR§71.73. In particular, required technical data is presented herein to support the conclusion that HI-STAR 100MB 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 10CFR§71.73 and explained in Regulatory Guide 7.9, are applied to the HI-STAR 100MB 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 10CFR§71.61.

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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 100MB 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 ensure 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 100MB longitudinal axis, "θ", with the impact surface. In this notation, $\theta = 0°$ means a horizontal 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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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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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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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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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 [2.6.1] finite element code, as discussed earlier. LS-DYNA has been benchmarked extensively by others [2.7.2, 2.7.3] 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 [2.6.8] (see Appendix 2.B of [1.0.6]). As discussed in Appendix 2.B of [1.0.6], the LS-DYNA simulation model for the family of AL-STAR impact limiters is a credible and reliable vehicle for determining the HI-STAR 100MB 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 [2.7.4]. More recently Holtec performed additional LS-DYNA benchmark analyses against two well documented DOE drop tests conducted for a multi-canister overpack (without impact limiter). The LS-DYNA simulation results of the tests obtained by Holtec consistently match the test data (i.e., deformation measurements) and the simulation results predicted by another finite element code ABAQUS as demonstrated in Holtec report HI-2156765 [2.7.6]. This additional benchmark work, along with the previous result comparisons between ANSYS and LS-DYNA for the HI-STAR 180, HI-STAR 60, and HI-STAR 180D transport casks [1.0.6, 1.1.2, 1.0.7], provides the technical basis for using LS-DYNA in this application to predict not only the peak package deceleration, but also the structural response of the cask as part of one comprehensive analysis.

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The previously described key attributes implemented in the HI-STAR 100MB 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 of [1.0.6] and [2.7.6]) as well in the analysis independently performed by the NRC/PNNL investigators [2.7.2], the previously described HI-STAR 100MB finite element model is deemed to be able to predict the structural response 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, as well as the stresses and strains in the HI-STAR 100MB package.

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

1. Vertical drop
2. Horizontal (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. $\theta = 90^o$ is a vertical drop event with bottom-down configuration (see Figure 2.7.1). Similarly, $\theta = 0^o$ means horizontal (side) drop (see Figure 2.7.3).

The various drop orientations analyzed using LS-DYNA to identify the most damaging scenarios with reasonable assurance are summarized in Table 2.7.2. Detailed discussion regarding the selection of the governing drop scenarios for analysis is presented in Reference [2.6.2]. The slap-down event where the top impact limiter strikes first warrants special mention because it produces the bounding lateral deceleration in transport packages. It is demonstrated in [2.6.2] that the bounding lateral impact cannot result in a rigid body sliding of the closure lid relative to the cask top flange due to the preload stress applied to the closure lid bolts. A conservative bending stress analysis for the closure lid bolt is performed in [2.6.2] based on the available lateral clearance between the lid and the top flange.

As can be seen from Table 2.7.2, 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).

2.7.1.3 Summary of Results

Table 2.7.2 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 occur in 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.

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. All three types of Metamic-HT PWR fuel baskets (F-24M, F-32M and MPC-32M) designed for the HI-STAR 100MB package are essentially replicas of the Metamic-HT PWR fuel baskets licensed under HI-STAR 180, HI-180D, and HI-STAR 190 in terms of key design parameters such as cell size and basket panel thickness. Moreover, the maximum number of fuel assemblies that can be carried by the HI-STAR 100 MB package is 32, which is smaller than that of the above-mentioned packages (37 fuel assemblies). Finally, the maximum heat load of the HI-STAR 100MB package is equal to or less than the allowable heat loads of the three packages. Therefore, under a smaller lateral deceleration as shown in Table 2.7.2, the HI-STAR 100MB fuel baskets have a greater margin of safety than those in the above-mentioned HI-STAR transport packages approved by the USNRC.

For convenience, the allowable stress limits necessary for the safety evaluation of each part are compiled in Table 2.6.3. The corresponding results from the LS-DYNA runs are listed in Tables 2.7.3 and 2.7.5.

Based on the results presented in Tables 2.7.3 and 2.7.5, 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 dose blocker parts surrounding the containment shell remain 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 lead, used for shielding in the HI-STAR 100MB, is included in the LS-DYNA model. The lead is characterized by the properties given in Table 2.2.9. A review of all drop simulation results leads to the conclusion that the degree of lead slump is less than the limiting values assumed in the shielding evaluation (see Section 5.3.1).

- 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.

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2.7.1.4 Fracture Analysis

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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2.7.2 Crush

An evaluation of package crush is not required for the HI-STAR 100MB.

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 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).

The geometric configuration of the HI-STAR 100MB cask overpack is similar to that of HI-STAR 190. Moreover, the HI-STAR 190 package is significantly (over 40%) heavier than the HI-STAR 100MB package per Table 2.1.12 of HI-STAR 190 SAR. Therefore, the 1-m horizontal drop puncture accident is considered to be acceptable for the HI-STAR 100MB package, as both casks have identical puncture resistance (i.e., same intermediate shell material and thickness) for the horizontal drop orientation. An estimate of local puncture damage is obtained by using Nelms' equation [2.7.7] that is generally applicable for lead backed shells. The equation is applied using an ultimate strength of 70,000 psi that is appropriate for the selected impact regions. Nelms' equation predicts a minimum thickness of material necessary to preclude significant puncture damage. Similarly, the 1-m top end drop accident is acceptable for the HI-STAR 100MB package, since the puncture resistance of the HI-STAR 100MB outer lid is almost identical to that of HI-STAR 190 in terms of lid material, thickness, total number of bolts. The heavier weight and larger lid diameter of the HI-STAR 190 package are more than enough to offset the effect of a slightly (4.3%) smaller lid thickness for HI-STAR 100MB. The key results of the puncture analysis performed in [2.6.2] are summarized in Table 2.7.3.

Since the HI-STAR 100MB package puncture event is enveloped by that of the HI-STAR 190 package, the following conclusions are made for the puncture evaluation of the HI-STAR 100MB package:

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 complete penetration of the dose blocker parts that surround the containment shell is indicated. The total depth of local indentation does not yield unacceptable shielding consequences.

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

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 <u>any</u> 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 3000ºF).

3. Internal interferences among the constituents of the HI-STAR 100MB 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.

The structural integrity of HI-STAR 100MB closure lid bolt joints, as well as the continued sealing of the closure lid, is predominantly governed by the bending stress of the closure lid bolt developed due to the differential thermal expansion between the lid and the top flange along the radial direction of the cask. The top forging, closure lid, and the closure lid bolts of HI-STAR

100MB are fabricated from the same materials as HI-STAR 190, and the bolt diameter and total number of bolts are identical. Moreover, the following two design features make the HI-STAR 100MB bolt joints less vulnerable than HI-STAR 190 under the postulated fire accident:

1. The HI-STAR 100MB top flange is significantly thinner than that of HI-STAR 190, which means a smaller thermal resistance in the HI-STAR 100MB top flange to the heat transfer from the postulated 800˚C fire to the cask closure lid. Compared with HI-STAR 190, therefore, HI-STAR 100MB has a smaller differential thermal expansion between the lid and the top flange in the radial direction.

2. The HI-STAR 100MB closure lid bolts are about 2 inches longer than that of HI-STAR 190. Under the same bending deflection caused by the differential thermal expansion between the lid and the cask top flange, the HI-STAR 100MB closure lid bolts are less stressed than HI-STAR 190.

Table 2.7.4 provides a summary of the key results obtained from the continued sealing analysis under the fire accident; these results are taken from HI-STAR 190 SAR and are considered to be bounding for HI-STAR 100MB. The analysis methodology is same as that previously used for the HI-STAR 180 licensing effort, 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 load increases from the starting value, but the increase is balanced by increased compression on the land. 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 dose blocker parts, remains below 500 degrees F (SA-203 E material).
2. The containment boundary that is within the confines of the impact limiters remains below 700 degrees F (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 degrees F, but the bulk metal temperature of the material volume remains under 700 degrees F. 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. The loss of the cask’s neutron shielding material due to the fire accident is considered in the shielding evaluation.
5. The maximum MPC internal pressure during the fire event does not exceed the 200 psi pressure limit under accident conditions of storage specified in the HI-STORM 100 FSAR [1.2.6].

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.

The MPC stress analysis documented in the HI-STORM 100 FSAR [1.2.6] reported a minimum safety factor of 1.16 for the 200 psi internal pressure load case, which also envelops the fire accident condition during transport. Therefore, the MPC containment boundary can be maintained under the fire accident condition.

2.7.5 Immersion - Fissile Material

10CFR§71.73(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. The head of water (1.3 psi) is bounded by the hypothetical accident condition external pressure for the cask (10CFR§71.61), which is considered later, and is also bounded by the accident external pressure of 55 psi for the MPC (see Table 2.1.1). Analyses summarized in this chapter demonstrate the containment components meet the applicable stress intensity allowables for Normal Conditions of Transport and for Hypothetical Accident Conditions (both conditions impose pressures larger than 1.3 psi 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 (i.e., a head of water at a depth of 15 m or 50 ft) mandated in 10CFR§71.73 is applicable to both overpack and MPC containment boundaries. This loading condition is bounded by the analysis in Subsection 2.7.7 for the overpack containment boundary.

Moreover, this external pressure is bounded by the accident pressure of 60 psi for the MPC (see Table 2.1.1).

2.7.7 Deep Water Submergence

Pursuant to 10CFR§71.61, the loaded HI-STAR 100MB is subject to an all-around external pressure of 2.0 MPa (290 psi). Note that when used with an MPC, HI-STAR 100MB features two containment boundaries (the MPC and the overpack containment boundary) that must survive the hypothetical accidents described in 10CFR§71.73, but only the overpack containment boundary needs to be demonstrated that it can withstand the deep submergence pressure (DSP) without collapse, buckling, or inleakage of water.

Code Case N-284 is used to evaluate the propensity for containment shell instability assuming the outer dose blocker parts do not prevent the 290 psi pressure from acting directly on the outer surface of the containment shell. The Holtec Proprietary calculation package for HI-STAR 100MB [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 land of the lid, seal opening is not a concern for this accident. The primary stress intensity of the lid resulting from the 290 psi pressure loading meets the Level D ASME Code limit (this is easily demonstrated by examining the results for the N1 normal load condition summarized in Section 2.6). Inleakage of water through the containment system boundary seals is confirmed to be non-credible to satisfy the intent of ISG-19 [1.0.5]. 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 100MB Package meets the requirements of 10CFR§71.61 and 10CFR§71.73. 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. Therefore, the HI-STAR 100MB 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 100MB containment space and the MPC will individually remain inaccessible to the moderator under the immersion event of §71.73, which follows free drop, puncture, and fire.

ii. The overpack lid will continue to maintain a positive contact load at their interfaces with the flange subsequent to the hypothetical accident event, indicating that the seals will

remain functional as effective leakage barriers to moderator intrusion into the containment cavity. The torque requirement for the closure lid port cover bolts (Tables 7.1.1 and 7.1.3) is also determined to be 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 of either containment boundary.

iv. The average basket panel deflection in the active fuel region is less than the limit (1 mm) specified in Table 2.6.7.

Table 2.7.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.7.2: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.7.3: - Bounding Results from 9-M Drop and 1-M Drop Puncture Simulations

Item	Allowable Value†	Calculated Value	Safety Factor	Governing Accident
Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	506.8 (73.5)	235.3 (34.12)	2.15	9-M Top End Drop
Containment Shell – Primary Membrane Stress Intensity – Mpa (ksi)	337.8 (49.0)	270.8 (30.68)	1.60	9-M Oblique Drop
Containment Shell – Primary Membrane + Bending Stress Intensity – Mpa (ksi)	506.8 (73.5)	337.0 (48.88)	1.50	9-M Oblique Drop
Cask Baseplate – Primary Bending Stress Intensity – Mpa (ksi)	506.8 (73.5)	268.2 (38.96)	1.89	9-M Bottom End Drop
MPC Enclosure Vessel – Primary Membrane + Bending Stress Intensity – Mpa (ksi)♥	447.8 (64.95)	323.2 (46.88)	1.39	9-M Slapdown Drop (Bottom End First)
Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi) *	895.1 (129.8)	613.6 (89.0)	1.46	9-M Top End Drop
Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi) *	1068.7 (155)	742.0 (107.6)	1.44	9-M Top End Drop
Maximum Penetration into the Cask Body by the Puncture Bar (inches)	13.75	9.514	1.354¥	1-M Horizontal Drop
Maximum Axial Lead Slumps (inches)	5.0*	4.2	1.19	9-M Bottom End Drop
Lid Seals Remain Sufficiently Compressed after the Drop Accident?	Yes			

Note: †Allowable stresses are obtained from Table 2.6.3; *Assumed lead slump values in Subsection 5.3.1 for the shielding evaluation. ¥ Calculated based on the total equivalent steel thickness outside of the lead layer. ♥ Conservatively taken as the same value of the HI-STAR 190 MPC enclosure vessel during the 9-m drop accident (see justification discussed in Subsections 2.6.1.4.1).

Table 2.7.4: Bolted Joint Performance Under the Fire Event3

ITEM	AT PEAK OF FIRE	BEFORE AND AFTER FIRE†
Closure Lid Bolt – Average Service Stress MPa (ksi)	417.8 (60.6)	310.3 (45)
† The tensile stress in each closure bolt under the preload condition is 45,000 psi.		

3 The material presented was adopted from the previously approved HI-STAR 190 FSAR [1.0.4].

Table 2.7.5: Key Performance Objectives for Non-Containment Components of the HI-STAR 100MB

Criterion	Result
No Tearing of the Circumscribing Enclosures in the Dose Blocker Parts - Primary Effective Stress below Ultimate Strength	Yes
Fuel Basket Deformation – Maximum Deflection < 1 mm	Yes

Figure 2.7.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.2: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.3: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.4: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.5: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.6: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.7: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.8: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.9: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.10A: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.10B: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.11: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.12: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.13: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.14: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.15: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.7.16: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

This section is not applicable to the HI-STAR 100MB Package. This application does not seek approval for air transport of plutonium and, therefore, does not address the accidents defined in 10CFR§71.74.

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2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIALS FOR AIR TRANSPORT

This section is not applicable to the HI-STAR 100MB Package. This application does not seek approval for air transport of fissile materials and, therefore, does not address the accidents defined in 10CFR§71.55(f).

2.10 SPECIAL FORM

This section is not applicable to the HI-STAR 100MB Package. This application does not seek approval for transport of special form radioactive material; therefore, the requirements of 10CFR§71.75 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 100MB 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 [1.2.4].

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 [2.11.1, 2.11.2]. Fortunately, the problem of large loading of fuel has been comprehensively studied in the published NUREG [2.11.4] and studies conducted by Pacific Northwest National Laboratory (PNNL) and USNRC [2.11.3], which obsolesces prior analyses and provides a robust and conservative basis for prognosticating fuel damage under vertical drop events.

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Table 2.11.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.11.2: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 2.11.3: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.2: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.3: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.4: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.5a: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.5b: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.5c: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.5d: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.6a: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Figure 2.11.6b: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

2.12 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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CHAPTER 3: THERMAL EVALUATION

3.0 INTRODUCTION

In this chapter, compliance of the HI-STAR 100MB Package to 10CFR Part 71 [1.2] and ISG-11, Rev. 3 [1.16] thermal requirements is evaluated for normal transport conditions and for hypothetical accident conditions. 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 as follows:

1. A package must be designed, constructed, and prepared for shipment so that in still air at 38°C (100°F) and in the shade, no accessible surface of the package would have a temperature exceeding 85°C (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 -40°C (-40°F) and 38°C (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 38°C (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 802°C (1475°F) for a period of 30 minutes [§71.73(c)(4)].

Section 3.1 describes the thermal design features of the HI-STAR 100MB 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 100MB 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.

3.1 THERMAL DESIGN FEATURES OF HI-STAR 100MB

3.1.1 Design Features

The principal design and performance objective for the HI-STAR 100MB cask is transportation of used fuel and high level waste packaged in a bare basket or an MPC. (The term "Fuel Package" is used to denote both a bare basket and an MPC). Two versions of HI-STAR 100MB cask are defined in Chapter 1 for loading viz. Type SL (short length) for bare basket fuel package and Type XL (extra-long) for MPC equipped fuel package. The thermal analysis considers both versions with their applicable fuel packages and limiting Fuel Package evaluated for compliance with transport regulations. When packaged in a bare basket, the transport Package may be immediately readied for off-site transport. Design details of the HI-STAR 100MB Package and its structural features are presented in the Licensing Drawings and text matter in the preceding chapters. All materials of construction are itemized in the drawings. The assembled packaging with impact limiters installed is shown in Figure 1.2.1. As shown in this figure, the HI-STAR 100MB Package is equipped with a personnel barrier to prevent access to hot cask surfaces. The package consists of a loaded Fuel Package inside a thick steel cask with a bolted closure lid.

Fuel basket design in the HI-STAR 100MB Package emulates a honeycomb structure with square-shaped compartments to store fuel assemblies. It is heuristically apparent that the honeycomb construction of the fuel basket would provide for a most efficient transmission of heat from the interior of the basket to its periphery. The space in and around the Fuel package is filled with helium to insure a stable and inert environment enveloping the fuel cladding. Heat is transferred from the cask to the environment by passive heat transport mechanisms only. In the MPC- type Fuel Package, the MPC's Enclosure Vessel serves as the pressure boundary with pressurized helium serving as the conductive and convective medium for heat rejection. The narrow space between the cask cavity and the MPC also contains slightly pressurized high purity helium. In the bare basket type Fuel package, the entire cask cavity is at the same helium pressure.

The HI-STAR 100MB Package is designed to safely dissipate heat under passive conditions (no wind). During transport, the HI-STAR 100MB Package is placed in a horizontal position with impact limiters installed at both ends of the cask. Under normal transport conditions, the cask contents (i.e., the Fuel package) rest on solid surfaces. Direct contact between the cask and its contents enhances heat dissipation. Prior to cask closure, the cavity space between the MPC and cask overpack is backfilled with helium.

The fuel baskets are a matrix of square-shaped fuel compartments sized to store PWR Spent Nuclear Fuel (SNF). Baskets available for loading fuel are defined in Table 1.1.2. These are engineered as a honeycomb structure of thick Metamic-HT plates. The fuel basket is surrounded by suitably shaped basket shims installed to minimize the resistance to lateral transmission of heat. Heat dissipation from the fuel basket to the cask occurs by a combination of contact heat transfer, convection, conduction and radiation. The overpack is a multi-shell cylindrical cask body that is made of three concentric shells joined to a solid annular top flange and a solid

annular bottom flange. All three shells are fixed in place by longitudinal ribs which serve as radial connectors between the shells. These radial connectors provide a continuous path for radial heat transfer. The space between the innermost and middle shell is occupied by lead which provides the bulk of the cask's gamma radiation shielding capability. The space between the middle and outermost shell is occupied by neutron shield material (Holite-B) which provides the bulk of the cask's neutron radiation shielding capability.

The overpack containment boundary is designed as ASME Code Section III pressure vessel. It is equipped with high integrity double seals in the closure lid. The overpack containment boundary is leak-tight as described in Chapter 4 of this SAR which ensures the presence of helium during transport. The helium gas is therefore retained and undiluted during transport, and the transport package is maintained in a sequestered state from the environment at all times.

3.1.2 Decay Heat of the Cask's Contents

The permissible fuel types and their allowable heat loads in the HI-STAR 100MB Package are set down in Chapter 7. The heat generation in each fuel assembly is non-uniformly distributed over the active fuel length to account for design basis fuel burnup distribution as discussed in Chapter 5. The complete HI-STAR 100MB Package consisting of the overpack, impact limiters and the Fuel Package under transport conditions is analyzed for the Design Basis Heat Loads (DBHLs) set down in Chapter 7.

3.1.3 Thermally Governing Fuel Packages

A *thermally governing Fuel Package* is defined as one that would develop the highest peak cladding temperature, T under Design Basis Heat Load (DBHL), Q, when stored inside the HI-STAR 100MB overpack in the transport configurations under 10CFR 71 mandated hot ambient temperature. Fuel Packages approved for transport in the HI-STAR 100MB are defined in Table 1.1.2. Governing Fuel Package is ascertained in Section 3.3.

3.1.4 Governing Regionalization Configuration

Fuel loading in the HI-STAR 100MB is permitted under uniform loading configuration wherein all storage cells are generating heat at maximum permissible rate q or under regionalized loading which allows hot fuel placement in certain regions of the fuel basket without challenging fuel cladding temperatures. The above loading configurations are articulated in the following.

The thermal calculations in this Chapter are performed assuming the design heat load, Q, be uniformly distributed amongst the fuel assemblies. In other words, the *specific* heat load (heat load of a particular fuel assembly) is the same throughout the basket; q= Q/n, where n is the number of storage cells in the Fuel Package.
This uniform heat load case bounds all regionalized storage arrangements that meet the following requirements:

i. The heat load ascribed to in each quadrant is .25Q

ii. The decay heat load q at a radial location closer to the centerline may be reduced by an amount "delta" and the decay heat increased by an equal amount "delta" at a location farther from the centerline keeping the aggregate heat load in the quadrant constant (@ .25Q).
iii. The maximum cell heat load complies with Table 7.7.5 regionalized limits.

This uniform heat load case bounds every other regionalization pattern that meets the above two criteria.

3.1.5 Summary Table of Temperatures

The HI-STAR 100MB temperatures are analyzed under Fuel Package configurations defined in Table 1.1.2. Results are evaluated in Section 3.3.3 and Governing Fuel Package under F-32M transport obtained. This configuration is adopted for evaluation under 10CFR Part 71 [1.2] defined normal and hypothetical fire accident conditions. HI-STAR 100MB thermal modeling under these transport scenarios are articulated in Sections 3.3 and 3.4. The analysis results are provided in Tables 3.1.1 and 3.1.3. The HI-STAR 100MB normal transport and hypothetical accident temperatures comply with the applicable normal and accident temperature limits specified in Tables 3.2.10, 3.2.11 and 3.2.12.

3.1.6 Summary Table of Maximum Pressures

The internal helium pressures are computed for the normal transport condition and the hypothetical fire accident event for the Governing Fuel Package using the standard Holtec 3-D Fluent model which is identical to that used in all recent transport certifications. The analysis results are provided in Tables 3.1.2 and 3.1.4. All internal helium pressures computed under the 10CFR 71 specified hot ambient temperature for compliance with the pressure limits specified in Chapter 2.

3.1.7 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 for the limiting thermal scenario (see Section 3.3.3) 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 to prevent access to hot surfaces with suitable access to ambient air for cask cooling[1].

1 Personnel barrier design same as licensed in other HI-STAR transport dockets (HI-STAR180/180D/190 [1.4, 1.8, 1.9]). Cited dockets support suitability of the design to provide reasonable access to ambient air without impacting cask temperatures.

Table 3.1.1: HI-STAR 100MB Normal Transport Maximum Temperatures

Material/Component	F-32M Note 4 Temperature ^{o}C (^{o}F)
Fuel Cladding	362 (684)
Fuel Basket	347 (657)
Basket Shims	254 (489)
Containment Shell Note 2	208 (406)
Neutron Shield Note 7	203 (397)
Lead	206 (403)
Enclosure Shell	154 (309)
Containment Bottom Flange Note 3	140 (284)
Containment Top Flange Note 3	119 (246)
Closure Lid Inner Outer	 123 (253) 109 (228)
Containment Seals Note 5 Inner Lid Seals Outer Lid Seals	 121 (250) 107 (225)
Impact Limiter Crush Material Note 6 Bulk Maximum	 80 (176) 97 (207)

Note 1: Temperatures under Governing Fuel Package configuration (see Section 3.3.3).
Note 2: In accordance with temperature limits Table 3.2.10 Note (a) maximum section temperatures of structural members are reported.
Note 3: Bulk temperatures of components tabulated.
Note 4: Results under bounding F-32M bare basket Fuel Package transport tabulated herein. Safe operating temperatures of MPC lid, shell and baseplate germane to MPC-32M transport evaluated in supporting calculation package [3.1.3].
Note 5: The temperatures on lid seals relied upon for containment function are reported herein. The containment boundary seals are described in Chapter 4.
Note 6: The temperature of the impact limiter crush material with the highest temperature is reported.
Note 7: Maximum neutron shield temperature tabulated.

Table 3.1.2: HI-STAR 100MB Normal Transport Maximum Operating Pressures[1]

Condition	Gauge Pressure psig
	F-32M / MPC-32M(Note 2)
Fuel Cavity MNOP[2]	
Normal Condition	52.3 / 69.7
With 3% Rods Rupture(Note 1)	55.8 / 72.6
HI-STAR 100MB Annulus & Inter-Lid Spaces	
Normal Condition	
Annulus	NA / 28.9
Inter-lid	7.9 / NA

Note 1: In accordance with NUREG-1617 [3.1.1], 3% of the rods are assumed to be breached releasing 100% fill gas and 30% fission gas to containment.

Note 2: Evaluated to address the higher MPC-32M backfill limits specified in Chapter 7.

[1] Pressure analysis in accordance with heat condition specified in 10 CFR 71.71(c)(1) in the absence of venting, external ancillary cooling or operational controls.

[2] The MPC cavity MNOP is calculated based on an initial MPC cavity helium backfill pressure limits specified in Tables 7.1.2, 7.1.4 and 7.1.8. For a bounding evaluation the upperbound limit is used in the pressure calculations.

Table 3.1.3: Hypothetical Fire Accident Maximum Temperatures Under Governing Fuel Package Transport[Note 4] in HI-STAR 100MB[1]

Material/Component	During Fire °C (°F)	Post Fire Cooldown °C (°F)
Fuel Cladding	362 (684)	401 (754)
Fuel Basket	347 (657)	388 (730)
Basket Shims	254 (489)	298 (568)
Containment Shell[Note 1]	216 (421)	276 (529)
Containment Bottom Flange [Note 2]	174 (345)	225 (437)
Containment Top Flange [Note 2]	204 (399)	218 (424)
Outer Closure Lid [Note 1]	247 (477)	281 (538)
Inner Closure Lid[Note 1]	162 (324)	198 (388)
Containment Seals [Note 3] Inner Seal Outer Seal	 200 (392) 189 (372)	 208 (406) 233 (451)
Note 1: In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported. Note 2: A bulk average temperature of the components is reported herein. Note 3: The temperatures on lid seals relied upon for containment function are reported herein. The containment boundary seals are described in Chapter 4. Note 4: Results under bounding F-32M bare basket Fuel Package transport tabulated herein. Safe operating temperatures of MPC lid, shell and baseplate germane to MPC-32M transport evaluated in supporting calculation package [3.1.3].		

[1] As evaluated in Section 3.3.3 F-32M in Table 1.1.2, is the governing Fuel package for the Fire accident.

Table 3.1.4: Maximum HI-STAR 100MB Hypothetical Fire Accident Pressures

Condition	Gauge Pressure psig	
	MPC-32M	F-32M
Fuel Cavity MNOP Note 2		
No Rods Rupture With assumed 100% Rods Rupture Note 3	76.8 183.8	57.9 183.3
HI-STAR 100MB Annulus & Inter-Lid Spaces		
Accident Condition Annulus Inter-Lid	33.4 NA	NA 11.5

Note 1: Governing F-32M Fuel Package pressures reported herein.

Note 2: The cavity pressure for the most limiting combination of fuel cavity free volume, contribution from BPRAs and cavity average temperature reported herein.

Note 3: Pressure analysis is based on NUREG 1617 [3.1.1] requirements: Release of 100% of the rods fill gas and 30% of the significant radioactive gases from ruptured rods.

Table 3.1.5: HI-STAR 100MB Normal Transport Maximum Surface Temperature in Shade

Material/Component	Temperature °C (°F)
Cask Surface	145 (293)

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS[1]

3.2.1 Material Properties

Materials present in the HI-STAR 100MB Packaging include structural steels, stainless steel, aluminum, lead, neutron shielding material (Holtite-A and Holtite-B), 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 neutron shielding material, impact limiter, lead, and helium are provided in Table 3.2.2. Thermal conductivities of fuel, aluminum basket shims, and fuel basket (Metamic-HT) are provided in Tables 3.2.3, 3.2.4 and 3.2.5. Thermal conductivity of ASME Code materials provided in Table 3.2.9.

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]

In Table 3.2.7, the specific heat and density data of cask materials are presented. These properties are also used in performing transient (hypothetical fire accident condition) analyses. The viscosity of helium and air are presented in Table 3.2.8.

3.2.2 Component Specifications

The HI-STAR 100MB 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 Table 2.1.1 and 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 100MB 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 the permissible limits. The cask closure lid seals ensure leak tightness of the closure plate if the manufacturer's recommended design temperature limits are not exceeded. Integrity of SNF during transport requires demonstration of HI-STAR 100MB Package fuel cladding temperatures below regulatory limits for Moderate Burnup Fuel (MBF) and High Burnup Fuel (HBF). In the HI-STAR 100MB thermal evaluation, the cladding temperature limits of ISG-11, Rev. 3 [1.16] are adopted (See Table 3.2.11). These limits are applicable to all fuel types, burnup levels and cladding materials approved for power generation. Neutron absorber material (Metamic-HT)

1 This Section, which contains material properties data, is excerpted from the HI-STAR 190 FSAR [1.0.4] with minor editorial changes only

used for criticality control is stable in excess of 538°C (1000°F). 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).

For evaluation of the HI-STAR 100MB Package's thermal performance under hypothetical accident conditions, lower-bound material temperature limits for short-duration 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 (Note 3)	EPRI [3.2.3]	NUREG [3.2.4]	Rust [3.2.5]	Rust [3.2.5]
UO_2	Not Used	NUREG [3.2.4]	Rust [3.2.5]	Rust [3.2.5]
Stainless Steel (machined forgings)	Kern [3.2.1]	ASME [3.2.6]	Marks' [3.2.7]	Marks' [3.2.7]
Stainless Steel Plates	ORNL [3.2.8], [3.2.9]	ASME [3.2.6]	Marks [3.2.7]	Marks [3.2.7]
Carbon Steel	Kern [3.2.1]	ASME [3.2.6]	Marks [3.2.7]	Marks [3.2.7]
Aluminum Basket Shims	Note 1	ASM [3.2.10]	ASM [3.2.10]	ASM [3.2.10]
Holtite-B	Not Used	Sourcebook [1.5.1]		
Holtite-A	Not Used	Sourcebook [1.5.2]		
Metamic-HT	Table 1.5.2	Table 1.5.2	Table 1.5.2	Table 1.5.2
Impact Limiter Crush Material	NA	Note 2	Table 2.2.8	ASME [3.2.6]
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: Basket shims required to be anodized to yield same emissivity as specified for Metamic-HT.
Note 2: Nominal values of thermal conductivity are specified in Table 3.2.2.
Note 3: The SAR permits Zircaloy 2, Zircaloy 4, ZIRLO and M5 claddings.

Table 3.2.2: Thermal Conductivity of HI-STAR 100MB Cask Materials

Material	At 200°F (Btu/ft-hr-°F)	At 450°F (Btu/ft-hr-°F)	At 700°F (Btu/ft-hr-°F)	At 1000°F (Btu/ft-hr-°F)
Helium	0.0976	0.1289	0.1575	0.1890
Air Note 1	0.0173	0.0225	0.0272	0.0336
Lead Note 4	19.4	17.9	9.3	8.89
Holtite-B Note 2	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]			
Holtite-A Note 2	[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]			
Impact Limiter Crush Material Note 3 (Btu/ft-hr-°F)	High Density: 12.6, Low Density Block-I: 11.3, Low Density Block-II: 12.6			

Note 1: At lower temperatures, air conductivity is between 0.0139 Btu/ft-hr-°F at 32°F and 0.0176 Btu/ft-hr-°F at 212°F.

Note 2: [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Note 3: As the impact limiters are located at cask ends and peak temperatures are seen at approximately fuel mid height, the thermal conductivity of impact limiter does not affect the cask peak temperatures. For modeling completeness, conservatively lower values are used in thermal evaluations of normal conditions. However, no penalty in thermal conductivity is assumed during fire conditions.

Note 4: 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 (Note 1)		Fuel (UO_2)	
Temperature (°F)	Conductivity (Btu/ft-hr-°F)	Temperature °C (°F)	Conductivity (Btu/ft-hr-°F)
392	8.28	100	3.48
572	8.76	448	3.48
752	9.60	570	3.24
932	10.44	793	2.28 (Note 2)

Note 1: See Table 3.2.1, Note 3.
Note 2: Lowest values of conductivity used in the thermal analyses for conservatism.

Table 3.2.4: Thermal Conductivity of Extruded Basket Shims and Solid Shims Material

Material	Conductivity (Btu/ft-hr-°F)
[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]	69.3

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 (°F)	Helium Viscosity (Micropoise)	Temperature (°F)	Air Viscosity (Micropoise)
167.4	220.5	32.0	172.0
200.3	228.2	70.5	182.4
297.4	250.6	260.3	229.4
346.9	261.8	338.4	246.3
463.0	288.7	567.1	293.0
537.8	299.8	701.6	316.7
737.6	338.8	1078.2	377.6

[1] Obtained from Rohsenow and Hartnett [3.2.2].

Table 3.2.9: Thermal Conductivity of ASME Materials in HI-STAR 100MB Cask

Material	SA203E SA350-LF3	SA-304	Carbon Steel
Temperature °C (°F)	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 100MB Materials Temperature Limits

Component	Material	Normal Condition Temperature Limits[a] °C (°F)	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	400 (752)[b]	500 (932)[b]
MPC Shell	Stainless Steel	316 (600)[b]	427 (800)[b]
MPC Lid	Stainless Steel	316 (600)[b]	427 (800)[b]
MPC Baseplate	Stainless Steel	204 (400)[b]	427 (800)[b]
Containment Shell	Cryogenic Steel	232 (450)[c]	371 (700)[d]
Containment Bottom and Top Flange	Cryogenic Steel	232 (450)[c]	371 (700) (Structural Accidents)[d] 788 (1450) (Fire Accident[e]
Closure Lid	Cryogenic Steel	232 (450)[c]	371 (700) (Structural Accidents)[d] 788 (1450) (Fire Accident[e]
Remaining Cask Steel	Carbon Steel	232 (450)[c]	371 (700) (Structural accidents)[d] 788 (1450) (Fire Accident)[e]

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 MPC, fuel basket and basket shims are the same as that in HI-STORM FW FSAR [1.8].

(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.

Table 3.2.11: Fuel Cladding Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Accident Temperature Limits °C (°F)
Fuel Cladding (Moderate or High Burnup Fuel)	See Note 1	400 (752)	570 (1058)

Notes

1. Fuel cladding temperature limits are applicable to all cladding materials approved for power generation [1.2.4].

Table 3.2.12: HI-STAR 100MB Component Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Short Term Operations & Accident Temperature Limits °C (°F)
Lid Seal	Note 1	Table 2.2.11	Table 2.2.11
Neutron Shield	Holtite-B	204 (400)	Note 2
Neutron Shield	Holtite-A	149 (300)	Note 2
Gamma Shield	Lead	316 (600)	316 (600)[Note4]
Impact Limiter Bulk	Aluminum Crush Material	Table 2.2.8	NA[Note 3]
Notes [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]			

3.3 THERMAL EVALUATION UNDER NORMAL CONDITION OF TRANSPORT

3.3.1 Overview of the Thermal Model

The HI-STAR 100MB Package is designed to safely dissipate heat under quiescent ambient conditions (ie, without any assist from wind). Under normal transport conditions, the cask's contents would rest on solid surfaces which would enhance heat dissipation. For conservatism, the contents are assumed to be levitating inside the cask cavity (ie, no contact). Under this assumption, the fuel, fuel basket, basket shims, MPC and cask are in concentric alignment (i.e. they do not make physical contact).

The HI-STAR 100MB Package thermal analysis is performed using the FLUENT CFD code [3.3.1]. 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 [3.3.2] 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 3.3.2.

The thermal model described below is identical to the ones utilized in the HI-STAR 190, HI-STAR 180 and HI-STAR 180D SARs which are the recent vintage transport applications certified by the NRC incorporating same methodologies as described below:

As discussed in Chapter 1, the governing Fuel Package configurations are listed in Table 1.1.2. The aggregate heat load, as discussed in the preceding section, is assumed to be uniformly distributed amongst all fuel assemblies in the thermal simulations. This assumption places certain restrictions on the acceptable heat load distribution which is discussed in Subsection 3.1.4.

- The Fluent model utilizes the standard approach for characterizing equivalent planar and axial conductivity of fuel loaded in basket cells as articulated in prior HI-STAR/HI-STORM systems as cited in Chapter 1 ([1.0.4], [1.0.6], [1.0.7], [1.1.1], [1.1.2]). In this approach, the cross section bounded by the inside of the storage cell is replaced with an "equivalent" square section characterized by an effective thermal conductivity in the planar and axial directions. The computed effective properties are reported in supporting calculation package [3.3.5]. Figure 3.3.1 pictorially illustrates this concept. The two conductivities are unequal because while in the planar direction heat dissipation is interrupted by inter-rod gaps; in the axial direction heat is dissipated through a continuous medium (fuel cladding).
- The exposed surfaces of the HI-STAR 100MB Package dissipate heat by radiation and natural convection. Radiation is modeled using classical equations for radiation heat transfer (Incropera and DeWitt [3.3.4]) [PROPRIETARY INFORMATION WITHELD

IN ACCORDANCE WITH 10 CFR 2.390]

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- 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 100MB Package is the product of incident insolation and the package absorptivity. The emissivity and absorptivity data is provided in the preceding section. For conservatism absorbtivity equal to 1 applied in the thermal models.
- The HI-STAR 100MB Package thermal analysis is based on the 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 3.3.1. This methodology is exactly the same as that approved in all previously licensed HI-STAR family of casks (Table 1.1).

As discussed in Chapter 1, Fuel Package configurations permitted in the HI-STAR100MB are specified in Table 1.1.2. Two versions of HI-STAR 100MB cask are available for loading viz. Type SL (short length) for bare basket fuel package and Type XL (extra-long) MPC equipped fuel package. The FLUENT model is capable of simulating these Fuel Package types. The aggregate heat load, as discussed in the preceding section, is assumed to be uniformly distributed amongst all fuel assemblies in the thermal simulations. This assumption places certain restrictions on the acceptable heat load distribution which is discussed in Section 3.1.4.

3.3.2 Description of HI-STAR 100MB 3D Thermal Model

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The essentials of the HI-STAR 100MB 3D thermal model, also used in other recent HI-STAR SARs, follow below:

The HI-STAR 100MB Package thermal analysis is based on a 3D thermal model of the HI-STAR 100MB cask that properly accounts radiation, conduction and external natural convection modes of heat transfer. The model is constructed using an array of conservative assumptions to bias the results of the thermal analysis towards much reduced computed margins. The thermal assumptions are listed below.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Sectional and isometric views of the HI-STAR 100MB thermal model are presented in Figures 3.3.2 and 3.3.3.

3.3.3 Screening Calculations to Ascertain Governing Fuel Package

To ascertain the governing fuel package for transport evaluation in the HI-STAR 100MB cask the Fuel Packages specified for transport in Table 1.1.2 are analyzed using the FLUENT thermal model articulated herein. The principal result of the analysis which is the maximum computed fuel temperature is tabulated in Table 3.3.3. The results support the conclusion that highest temperatures are obtained in the F-32M Fuel Package. Accordingly, this Package is adopted for licensing basis evaluation of the HI-STAR 100MB.

3.3.4 Heat and Cold

3.3.4.1 Maximum Temperatures

As required by transport regulations the HI-STAR 100MB Package is evaluated under hot ambient conditions defined in 10CFR71. To ensure a bounding evaluation, the design basis heat load and fuel assembly uniform specific heat load are assumed and maximum steady state temperature of the package structural members and its contents (SNF) computed using the 3D thermal model articulated above. The results are tabulated in Table 3.1.1. 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 permissible temperatures (Table 3.2.10).
- The maximum temperatures of the containment boundary and lid seals are well below design temperatures (Tables 3.2.10 and 3.2.12, respectively).
- The maximum temperatures of basket shims are well below design temperatures (Table 3.2.10).
- The neutron shielding material (Holtite-B) temperature is within design limit (Table 3.2.12).

The above observations support the conclusion that the temperature field in the HI-STAR 100MB 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 100MB Package is conducive to the safe transport of spent nuclear fuel.

3.3.4.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR 100MB Package is evaluated for a cold environment at -40°C (-40°F) denoted as the "cold condition". 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 100MB Package uniformly approaches the cold ambient temperature. All HI-STAR 100MB Package materials of construction satisfactorily perform their intended function under the "cold condition". Evaluations in Chapter 2 demonstrate the acceptable structural performance of package materials at low temperature. The HI-STAR 100MB shielding and criticality materials (Holtite-B, lead and Metamic-HT, stainless steel, etc.) are unaffected by exposure to the "cold condition".

3.3.5 Maximum Normal Operating Pressure (MNOP)

The Fuel package types listed as eligible for transport in Table 1.1.2 are both of the MPC and bare basket genre. The MPC or cask cavity as applicable is initially filled with dry helium to Chapter 7 specifications. Additionally, the HI-STAR 100MB annular space is backfilled with dry helium under MPC loading scenario and inter-lid space helium backfilled under bare basket scenario. During normal transport conditions, the gas temperature within cavities rise to its maximum operating temperature as determined by the thermal analysis with concomitant gas pressure increase. The pressure rise is determined using the Ideal Gas Law which states that the absolute pressure of a fixed volume of entombed gas is proportional to its absolute temperature. The cask cavities consider following source of gases in the MNOP analysis:

<u>Initial Backfill:</u>
The cask cavities are assumed to be backfilled to the maximum permissible pressure (See Chapter 7, Tables 7.1.2, 7.1.4, 7.1.8).

<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 fuel 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 100MB Package uses non-reactive materials of construction. Generation of flammable gases is not credible.

<u>Fuel Rod Failures:</u>
The fueled cavity pressure is also subject to pressure rise under hypothetical rod ruptures and gas inventory from non-fuel hardware (PWR BPRAs). In accordance with NUREG 1617 [3.1.3], 3%

of the fuel rods are assumed to be breached.

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 cavity maximum gas pressure is computed for the postulated release of fission product gases from fuel rods into this free space and the resulting total pressures computed. Based on fission gases release fractions (NUREG 1536 criteria [3.1.2]), rods' net free volume and initial fill gas pressure, maximum gas pressure with 3% (normal) rod rupture is tabulated in Table 3.1.2.

The Maximum Normal Operating Pressure (MNOP) is calculated under the §71.71(c)(1) heat condition (38^{o}C (100^{o}F) ambient, still air & insolation) and design 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 fueled cavity space MNOP is computed and reported in Subsection 3.1.6. The cavity pressures tabulated in Table 3.1.2 show that the MNOP is 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 100MB 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.

3.3.6 Loading Operations

3.3.6.1 Time-to-Boil Limits

In accordance with NUREG-1536 [3.1.2], water inside the fueled cavity is not permitted to boil during fuel loading operations. In this manner, the 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 100MB cask from the pool.

When the HI-STAR 100MB 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 100MB. To obtain a bounding heat-up rate determination, the following methodology is adopted:

i. Obtain the heat input Q from the fuel assemblies loaded in the cask.
ii. Heat dissipation to air by natural convection and radiation from the cask is neglected.

iii. Water mass in the MPC cavity understated.

The rate of temperature rise of the cask under adiabatic heat up (assumption (ii) above) is computed as follows:

$$\frac{dT}{dt} = \frac{Q}{C_h}$$

where:

Q = cask heat load, W (Btu/hr)
C_h = thermal inertia of the loaded cask, J/°C (Btu/°F)
T = cask temperature, °C (°F)
t = time after inner closure lid is placed on the loaded cask while under water OR time after time to boil clock has been reset, s (hr)

The maximum permissible time duration, t_{max} for fuel to be submerged in water is computed as follows:

$$t_{max} = \frac{T_{boil} - T_{initial}}{(dT/dt)}$$

where:
T_{boil} = lowerbound boiling temperature of water (100°C (212°F) at the water surface)
$T_{initial}$ = initial cask temperature (pool temperature during in-pool fuel loading operations)

Example values of t_{max} for F-32M under design maximum heat load are tabulated in Table 3.3.5 at several representative $T_{initial}$ temperatures.

3.3.6.2 Fuel Temperatures During Moisture Removal Operations

The initial loading of SNF in the HI-STAR 100MB requires that the water within the cask cavity be drained and replaced with helium. This operation may be carried out by vacuum drying or by a forced flow helium drying process described in the following.

(a) Vacuum Drying

Prior to the start of the HI-STAR 100MB 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 draining operations the HI-STAR 100MB cavity is lined up to vacuum pump and the cavity pressure substantially lowered to facilitate fuel drying. As fuel temperatures are

challenged under decay heat approaching design basis thermal loads cycles of vacuum drying resulting in heatup followed with cooling by helium is necessary. [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

† A sufficient margin to temperature limit of 400°C (HBF) and 570°C (MBF) is maintained.

(b) Forced Helium Dehydration

Forced Helium Dehydration (FHD) is a conventional, closed loop dehumidification system consisting of a condenser, a de-moisturizer, a compressor, and a pre-heater. The FHD is utilized to extract moisture from the cask's cavity through forced circulation of dry heated helium. During fuel drying operations the FHD system provides concurrent fuel cooling by forced convection heat transfer. The enhanced heat transfer occurring during operation of the FHD system ensures that the fuel cladding temperature will remain well below peak cladding temperatures reached under normal conditions of transport, which is below the high burnup cladding temperature limit 400^{o}C (752^{o}F) for all combinations of SNF type, burnup, decay heat, and cooling time authorized for loading in the HI-STAR 100MB cask. Because the FHD operation induces a state of forced convection heat transfer in contrast to the quiescent mode of cooling under normal transport it is readily concluded that the peak fuel cladding temperature under the latter condition will be greater than that during the FHD operation phase. In the event that the FHD system malfunctions, the forced convection state will degenerate to natural convection in the vertical orientation, which bounds the condition of normal transport in the horizontal orientation. The FHD, therefore, provides a safe process to dry the cask's cavity and its contents with built-in assurance to prevent overheating of the used nuclear fuel.

3.3.7 Maximum Thermal Stresses

The HI-STAR 100MB 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 adequate clearances to allow unrestrained thermal expansion of the package internals (fuel basket) during normal transport. The differential thermal expansion of the fuel basket and MPC during normal transport is calculated and results provided in Table 3.3.6.

3.3.8 Fuel Reconfiguration Under Normal Transport

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.1: 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 3.3.2: FLUENT Usage history in Transport and Storage Cask Certifications

USNRC Docket Number	Project
72-1008	HI-STAR 100 Storage
71-9261	HI-STAR 100 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
71-9367	HI-STAR 180D Transport
72-1032	HI-STORM FW Storage
72-1040	HI-STORM UMAX Storage
71-9373	HI-STAR 190 transport

Table 3.3.3: Fuel Package Screening Evaluations[Note 1]

Fuel Package	Max. Fuel Cladding Temperature, ^{o}C (^{o}F)
MPC-32M	354 (669)
F-32M	**362 (684)**[Note 2]
F-24M	333 (631)
Note 1: Fuel Packages Approved for Transport in the HI-STAR 100MB defined in Table 1.1.2. Note 2: Bounding temperature shown highlighted. Coincident Fuel Package adopted as governing configuration for licensing basis evaluations.	

Table 3.3.4: Personnel Barrier Specifications

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

Table 3.3.5: Maximum Permissible Time Under Flooded HI-STAR 100MB Conditions

Initial Temperature °C (°F)	Time Duration (hours)			
	@ 15 kW	@ 20 kW	@ 25 kW	@ 32 kW
37.8 (100)	45.5	34.1	27.3	21.3
43.3 (110)	41.5	31.1	24.9	19.4
48.9 (120)	37.4	28.0	22.4	17.5
54.4 (130)	33.4	25.0	20.0	15.6
60.0 (140)	29.3	21.9	17.6	13.7
65.6 (150)	25.2	18.9	15.1	11.3

Table 3.3.6: Differential Thermal Expansion during Normal Conditions of Transport

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

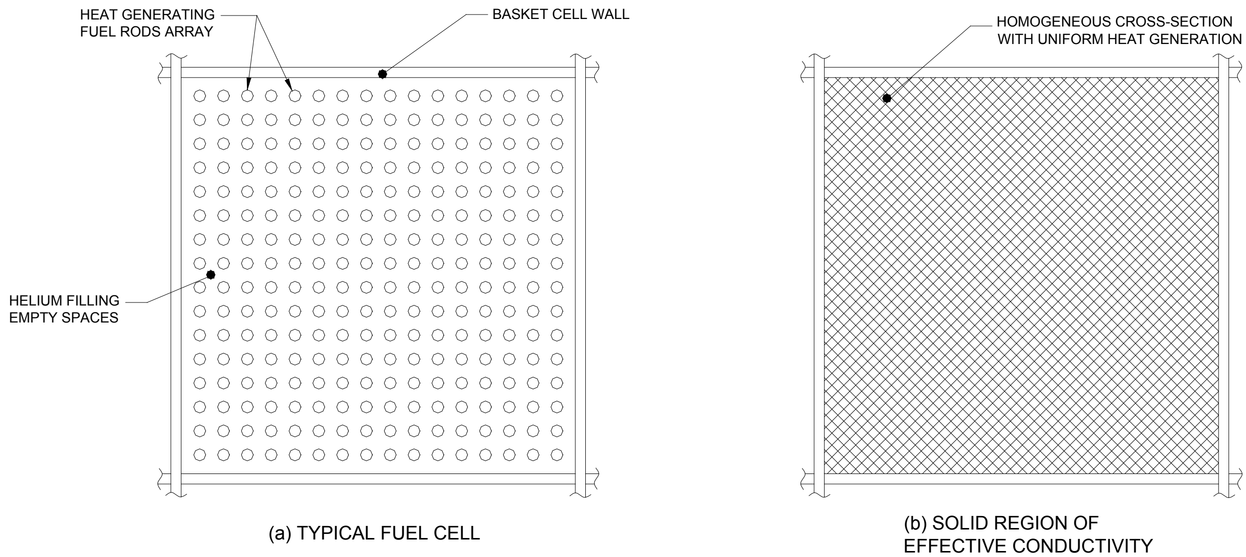

FIGURE 3.3.1: HOMOGENIZATION OF THE STORAGE CELL CROSS-SECTION

FIGURE 3.3.2: [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

FIGURE 3.3.3: [PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT CONDITIONS

10 CFR Part 71.73 mandates a sequence of hypothetical accidents for a transport package such as the HI-STAR 100MB Package. The objective of the safety analysis is to determine and assess the cumulative damage sustained by the package. The accident scenarios specified in the precise sequential order are:

(1) 9 m (30 foot) free drop onto an essentially unyielding surface;
(2) 1 m (40-inch) drop onto a mild steel bar;
(3) Exposure to a 30-minute fire at 802°C (1475°F), and
(4) Immersion under a 0.9 m (3 ft) head of water.

The effects of the accidents (1), (2) and (4) are evaluated in Chapter 2 wherein it is shown that:

- During drop events, material in the impact limiter is locally crushed. However, the impact limiters survive the drop events without structural collapse and remain attached to the cask during and after the event.
- During a puncture event the cask's exterior shell may be locally pierced but with no gross damage to the cask or its internals.

The Design Basis Fire event (Event #3) is assumed to initiate with the package at steady state under the Design Basis heat load with the ambient temperature between -40°C (-40°F) and 38°C (100°F).

The thermal consequence of a postulated re-arrangement of the fuel rods under the hypothetical accident conditions are also evaluated in this section.

3.4.1 Design Basis Fire Event

In accordance with transport regulations the HI-STAR 100MB 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 100MB bounding steady state temperature distribution under the Governing F-32M Fuel Package case evaluated in Section 3.1.5 is adopted as the initial condition for fire accident evaluation. Fire accident temperatures computed under this scenario bounds MPC-32M because of higher heat load and higher initial temperatures as well as resistance to fire heat input by helium annulus under MPC-32M transport.

During drop and puncture accidents some neutron shield pockets can rupture thereby reducing the ability of the package to reject heat after the fire. To conservatively evaluate this hypothetical accident condition, the neutron shield's thermal conductivity is assumed to remain in-tact during fire to maximize heat input, and the neutron shield is replaced by air in the neutron shield pockets during post-fire cooldown to minimize post-fire cooling rate.

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

The temperature history of the HI-STAR 100MB 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 100MB Package materials is evaluated.

3.4.2 Conditions of Fire

As required by transport regulations the HI-STAR 100MB Package is evaluated under an all-engulfing fire at 802^{o}C (1475^{o}F) lasting for 30 minutes (§10CFR71.73(c)(4)). The regulations specify a minimum fire emissivity (0.9) and lower-bound package absorbtivity (0.8) for hypothetical accident evaluation. In the HI-STAR 100MB fire accident evaluation, the above emissivity and absorptivity values employed.

Heat input to the HI-STAR 100MB Package while engulfed in a fire is from a combination of radiation and forced convection heat transfer. For conservatism, the reported Sandia large pool fires forced convection heat transfer coefficient (See Table 3.4.1) is adopted. The HI-STAR 100MB package fire accident analysis is based on a 3D thermal model that is fully consistent with the Fluent model described in the preceding section and properly accounts for radiation, conduction and external natural convection modes of heat transfer.

3.4.3 Maximum Temperatures and Pressures

The maximum temperatures and pressures reached during fire accident event are reported in Tables 3.1.3 and 3.1.4. 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 temperatures of fuel basket and MPC components (Table 3.1.3) are well within their accident design temperature (Table 3.2.10).
- The maximum temperatures of the cask containment boundary and seals are well below their temperature limits (Tables 3.2.10 and 3.2.12, respectively).

- The maximum temperatures of the basket shims are well below the accident temperature limits (Table 3.2.10).
- The maximum pressures are well within the containment boundary design pressures specified in Chapter 2.

3.4.4 Fuel Reconfiguration under Accident Conditions

[PROPRIETARY INFORMATION WITHELD IN ACCORDANCE WITH 10 CFR 2.390]

3.4.5 Maximum Thermal Stresses

The HI-STAR 100MB 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 adequate clearances to allow unrestrained thermal expansion of the package internals (fuel basket) during normal transport. As evaluated in Table 3.3.6 the design ensures robust margins under normal transport conditions. As supported by thermal calculations [3.1.3] these gaps are not challenged under fire accidents. The evaluation above supports a restraint free design wherein internal stresses in the structural members remain low under the fire accident event.

Table 3.4.1: 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)

[1] From Sandia large pool fires report [3.4.1], Page 41.

3.5 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.

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[3.3.3] Jakob, M. and Hawkins, G.A., "Elements of Heat Transfer," John Wiley & Sons, New York, 1957.

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[3.3.5] "Effective Fuel Properties in HI-STAR 100MB Fuel Baskets", HI-2177974, 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

The compliance of the HI-STAR 100MB cask containment system with the permitted activity release limits specified in 10CFR71 for both normal and hypothetical accident conditions of transport [4.0.1] is evaluated in this chapter. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the loaded HI-STAR 100MB cask will not exceed the allowable radionuclide release rates.

HI STAR 100MB utilizes one cask design with options for a single lid when used with an MPC and a double lid when used with a bare basket. Both options are qualified to transport high burnup fuel (HBF). When used to transport HBF, both configurations consist of an independent redundant double containment to prevent the release of radioactive materials to the environment. The single and each of the double lids are engineered to meet the leaktight criterion of ANSI N14.5 [8.1.3] under the normal and hypothetical accident conditions of transport. When used with an MPC containing HBF, additional testing is required to demonstrate the MPC meets the criteria for radiological confinement. The dual lids of the cask used with the bare basket provide the redundant radiological confinement. When used with moderate burn-up fuel, redundant radiological confinement is not required and therefor the additional testing required for HBF is not required on the MPC containing only moderate burn-up fuel MBF.

4.1 DESCRIPTION OF THE OUTER CONTAINMENT SYSTEM

The outer containment system for the HI-STAR 100MB cask consists of the containment shell, containment top flange, containment bottom flange, port cover plates, port cover bolts, outer closure lid with closure lid bolts for single lid for MPC system, with inner closure lid and closure lid bolts for bare basket and their respective elastomeric seals and welds as specified in the drawing package in Section 1.3. The outer Containment Boundary is delineated in the licensing drawing package in Section 1.3. The principal layout of the dual lid cask containment boundary and containment system components is shown in Figure 4.1.1.

The containment system components for the HI-STAR 100MB 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 safety analysis. Chapter 1 specifies design criteria for the containment system. Section 2.1 provides the applicable code requirements.

4.1.1 Containment Vessel

The cask containment vessel consists of components which form the containment space. The containment vessel is represented by the containment shell, containment top flange, containment bottom flange, and either a single (outer) or dual (inner and outer) closure lid. For the single lid cask, the containment space houses the MPC that holds the spent nuclear fuel. For the dual lid cask, the containment vessel consists of an inner containment space, created with the inner closure lid and closure lid bolts and expanded containment inter-lid space, formed with the outer closure lid. The inner containment space is used to house the internal basket designs which hold spent nuclear fuel. 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 100MB containment system.

4.1.2 Containment Penetrations

For the single lid cask, the outer containment system penetrations include the closure lid vent/drain port. For the dual lid cask, the containment system penetrations also include the inner closure lid vent/drain ports. Each penetration has redundant elastomeric 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.

The seals and welds provide for a containment system that is securely closed and cannot be opened unintentionally or by the internal pressure within the package as required in 10CFR71.43(c).

The containment system seals are designed and fabricated to meet the design requirements of the HI-STAR 100MB cask specified in Section 2.1 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 Chapter 2.

The cask outer containment system welds consist of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment top flange, and the full penetration weld connecting the containment bottom flange 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 Single Closure Lid - MPC

For the single lid cask, the cask closure lid uses two concentric elastomeric seals to form the closure with the containment top flange surface. In the outer closure lid, the inner seal is the containment seal. To protect the sealing surfaces against corrosion, a stainless steel weld overlay is provided during manufacturing on both the outer closure lid and the mating containment closure flange. The outer closure lid inner seal is tested for leakage through an inter-seal test port. The inter-seal test port provides access to the volume between the two elastomeric lid seals. Following leakage rate testing of the outer closure lid inner seal, a threaded cover test plug with an elastomeric seal is installed in the inter-seal test port hole to provide redundant containment.

The closure lid's containment sealing surfaces are not subject to corrosion due to the presence of redundant closure features that prevent exposure to the environment external to the cask. The seal materials of construction are highly corrosion resistant and the seal design is proven for the application.

The cask outer closure lid is secured using multiple closure bolts around the perimeter. Pre-tensioning of closure lid bolts compresses the concentric elastomeric seals between the closure lids and the containment top flange forming the outer closure lid seal.

Closure of the outer closure lid vent and drain port cover plate is provided using multiple port cover plate bolts around the perimeter. Pre-tensioning of the port cover bolts compresses the port cover plate concentric elastomeric seals between the port cover plate and the outer closure lid to establish containment.

Bolt torquing patterns, lubrication requirements, and torque values are provided in Chapter 7. The torque values are established to maintain leak-tight containment during normal and accident conditions of transport. The bolt pre-tension values for the body bolts preclude separation of the closure lids from the containment top flange as clarified in Chapter 2. The closure lid bolts cannot be opened unintentionally or by a pressure rise that may occur within the package during normal or accident conditions of transport.

4.1.5 Dual Closure Lid - Bare Basket

4.1.5.1 Inner Closure Lid - Bare Basket

The cask inner closure lid uses two concentric elastomeric seals to form the closure with the containment top flange surface. In the inner closure lid, the inner seal is the containment seal. To protect the sealing surfaces against corrosion, a stainless steel weld overlay is provided during manufacturing on both the inner closure lid and the mating containment closure flange. The inner closure lid inner seal is tested for leakage through an inter-seal test port. The inter-seal test port provides access to the volume between the two elastomeric lid seals. Following leakage rate testing of the inner closure lid inner seal, a threaded cover test plug with an elastomeric seal is installed in the inter-seal test port hole to provide redundant closure. On the inner closure lid, the outer elastomeric seal provides redundant closure.

Closure of the inner closure lid vent and drain ports is achieved via a bolted port cover plates with two concentric elastomeric seals. In both port covers, the inner seal is the containment seal. The elastomeric seals are compressed between the underside of the port cover and the inner closure lid to form the seal. The vent and drain port cover inner seals are tested for leakage through an inter-seal test port in the port cover. The inter-seal test port provides access to the volume between the two elastomeric port cover seals. On the inner closure lid port covers, the outer elastomeric port seal provides redundant closure.

The inner closure lid containment boundary and redundant boundary sealing surfaces are not subject to corrosion due to the presence of the outer closure lid and inter-lid cavity helium backfill. In any case, the seal materials of construction are highly corrosion resistant.

4.1.5.2 Outer Closure Lid - Bare Basket

The cask closure outer lid uses two concentric elastomeric seals to form the closure with the containment top flange surface. In the cask closure outer lid, the inner seal is the containment seal. To protect the sealing surfaces against corrosion, a stainless steel weld overlay is provided during manufacturing on both the closure lid and mating containment closure flange. In the cask outer closure lid, the containment boundary seal is tested for leakage through an inter-seal test port. The inter-seal test port provides access to the volume between the two elastomeric lid seals. Following leakage rate testing of the cask closure outer lid inner seal, a threaded cover test plug with an elastomeric seal is installed in the inter-seal test port hole to provide redundant closure. On the outer closure lid, the outer elastomeric seal provides redundant closure.

Closure of the outer closure lid access port is achieved via a threaded port cover test plug with a single elastomeric seal. The port cover test plug seal is the containment seal. The elastomeric seal is compressed between the underside of the threaded port cover test plug and the outer closure lid to form the seal. The port plug cover test seal is independently tested for leakage to verify containment performance. A bolted port cover plate, with a elastomeric seal, is installed over the port cover rest plug to provide redundant closure.

The outer closure lid containment sealing surfaces are not subject to corrosion due to the presence of redundant closure features that prevent exposure to the environment external to the cask. In any case, the seal materials of construction are highly corrosion resistant.

Figure 4.1.1 PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

4.2 DOUBLE CONTAINMENT CREDITED FOR SINGLE LID CASK WITH MPC CONTAINING HIGH BURNUP FUEL (HBF)

The HI-STAR 100MB packaging is designed to transport both moderate burn-up (MBF) and high burn-up fuel (HBF). 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 100MB. The MPC's enclosure vessel serves as the inner Containment Boundary when loaded with HBF. MPC's loaded with HBF are tested for leak-tightness at the time of shipment to confirm the integrity of the MPC.

For MBF, the MPC, while present, just serves as unquantified additional barrier against water inleakage and radiological release.

As stated in Chapter 1, the HI-STAR 100MB package is designed to transport and store high burnup in- tact fuel assemblies, canisterized damaged fuel &fuel debris and fuel assemblies with shorter cooling times than that permitted under the presently certified (classic) HI-STAR 100 package. All fuel to be transported in MPC in HI-STAR 100MB must be packaged in a MPC that has been certified as a *leak tight* [8.1.3], [4.2.1] Confinement Boundary under the regulations of 10CFR72. In addition, the MPC must possess the features and undergo testing measures listed in Chapter 8 of this SAR that protect against migration of its contents to the environment. These features and measures listed in Chapter 8 provide reasonable assurance that the MPC can be relied upon to provide effective radiological confinement to the spent fuel during transport.

The HI-STAR 100MB MPC is designated as the "welded" containment boundary, during the transport of high burnup fuel. In addition, HI-STAR 100MB has a classical gasketed containment boundary that is integral to the body of the overpack, which is the only barrier credited during transport of moderately burned fuel.

The HI-STAR 100MB single lid cask containment system consists of:

1. A welded containment defined by the Enclosure Vessel of the MPC, hereafter also referred to as the Inner Containment.

2. A gasketed containment made up of the overpack's Section III Subsection NB pressure retention boundary, hereafter also referred to as the "Outer Containment".

The outer containment system for the HI-STAR 100MB cask described in Section 4.1 consists of the components, seals, and welds identified in the drawing package in Section 1.3. The closure lid is a containment system component whose gasketed joint must also be tested prior to shipment.

Chapter 2 of this SAR shows that both containment systems continue to maintain leak-tightness, and seals in the outer containment boundary remain compressed after all normal and hypothetical accident conditions of transport defined in 10CFR71.71 and 10CFR71.73, respectively. 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.

Specifically, it is shown that under the most severe accident condition of transport:

1. The stresses in the welded (inner) containment remain within the ASME Section Subsection NB limits and that there is no risk of buckling instability in the Enclosure Vessel pressure (MPC) boundary.

2. The seals in the outer containment boundary remain compressed before and after the accident event.

3. No failure of the body bolts in the outer containment is indicated.

4. No breach of the outer containment boundary under the postulated part 71 penetration event is indicated.

The HI-STAR 100MB single lid 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 the requirements of ANSI N14.5 [8.1.3] specified in Chapter 8 as part of the HI-STAR 100MB single lid cask acceptance testing. The HI-STAR 100MB single lid cask is also subjected to a pre-shipment leakage rate test after the cask is loaded for shipment. The pre-shipment leakage rate test is performed as described in Chapter 8. The elastomeric seals of the HI-STAR 100MB single lid cask are required to be retested for each cask loading and closure operation.

The above considerations form the logical basis for the safety conclusion that both containment systems in HI-STAR 100MB single lid cask are independently and autonomously capable of maintaining radiological isolation in the wake of all postulated transport accidents in part 71.

Sections 4.1 - 4.4 contain a detailed evaluation of the outer containment's integrity under all applicable transport loadings.

Sections 4.6 - 4.8 provide the corresponding evaluations for the inner containment (the MPC).

Section 4.9 provides a summation of the safety case for the leak tightness of both containments under all applicable part 71 loadings.

4.3 OUTER CONTAINMENT INTEGRITY UNDER NORMAL CONDITIONS OF TRANSPORT

Section 2.6 of this SAR shows that all outer containment system components are maintained within their code-allowable stress limits and the elastomeric 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 outer 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 outer containment system remains in full compliance with the applicable regulatory temperature and pressure limits, it is reasonable to conclude that the design basis leakage rate (see Table 8.1.1) will not be exceeded during normal conditions of transport.

4.3.1 Containment Criteria

The leak-tight criteria, as defined by ANSI N14.5 [8.1.3], are to be used for all outer containment system leakage tests. Compliance with the leak-tight 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 release 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.

The sensitivity for the leakage test instrument shall be as described in Table 8.1.1.

4.4 OUTER CONTAINMENT INTEGRITY UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Section 2.7 of this SAR shows that all outer containment system components are maintained within their code-allowable stress limits and the elastomeric seals remain compressed during the hypothetical accident conditions of transport as defined in 10CFR71.73 [4.0.1]. Section 3.1 of this SAR shows that all outer 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.

4.4.1 Containment Criteria

The leak-tight criteria as defined by ANSI N14.5 [8.1.3] shall be used for all outer containment system leakage tests. Compliance with the leak-tight 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 release rate 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. The sensitivity for the leakage test instrument shall be as described in Table 8.1.1.

4.5 LEAKAGE INTEGRITY TESTS FOR THE HI-STAR 100MB OVERPACK

A helium leak test is the principal means for ascertaining the integrity of the outer containment boundary in the HI-STAR 100MB system. All leakage rate testing of the cask containment system shall be performed in accordance with the guidance in ANSI N14.5 [8.1.3].

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. The leak tests performed to ensure containment integrity at different stages in the cask's life cycle are summarized below.

4.5.1 Fabrication Leakage Rate Test

After fabrication of all overpack components, the closure lid is installed and the seals are tested to ensure that the fit-up of the lid with the containment flange will meet the leakage rate acceptance criteria after fuel loading.

4.5.2 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.

4.5.3 Periodic Leakage Rate Test

The periodic leakage rate test demonstrates that the containment system closure capabilities have not deteriorated over time. 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.

4.5.4 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.

4.6 DESCRIPTION OF THE INNER CONTAINMENT SYSTEM

The MPC's enclosure vessel constitutes the inner containment system that is credited for HBF. The MPC enclosure vessel is a cylindrical weldment designed to provide a robust and impermeable barrier against release of radioactive matter from its cavity space. radioactive matter from its cavity space. As shown in the drawings in Section 1.3, each MPC enclosure vessel consists of a bottom flange, a cylindrical canister shell and a closure lid.

The MPC enclosure vessel is a fully welded enclosure, which provides the confinement for the stored fuel and radioactive material. The MPC baseplate and shell are made of stainless steel (Alloy X, see Appendix 1.A [4.6.1]). The lid is a thick plate designed to provide confinement of radionuclides and pressure retention and handling operations. The confinement boundary in storage and the containment boundary in transport are both defined by the MPC baseplate, shell, lid and port covers.

The MPC incorporates a redundant closure system. The MPC lid is edge-welded (welds are depicted in the licensing drawing in Section 1.3) to the MPC outer shell. The lid is equipped with vent and drain ports that are utilized to remove moisture from the MPC and backfill the MPC with a specified amount of inert gas (helium). The vent and drain ports are closed tight and covered with a port cover (plate) that is seal welded.

As explained in Appendix 1.A of [4.6.2], Alloy X may be one of the following materials.

Type 316
Type 316LN
Type 304
Type 304LN

Any stainless steel part in an MPC may be fabricated from any of the acceptable Alloy X materials listed above.

The Alloy X group approach is accomplished by qualifying the MPC for all mechanical, structural, radiological, and thermal conditions using material thermo-physical properties that are the least favorable for the entire group for the analysis in question. For example, when calculating the rate of heat rejection to the outside environment, the value of thermal conductivity used is the lowest for the candidate material group. Similarly, the stress analysis calculations use the lowest value of the ASME Code allowable stress intensity for the entire group. Stated differently, a material has been defined that is referred to as Alloy X, whose thermo-physical properties, from the MPC design perspective, are the least favorable of the above candidate materials.

The Alloy X approach is conservative because no matter which material is ultimately utilized in the MPC construction, it guarantees that the performance of the MPC will exceed safety analysis. The following design features of the MPC Enclosure Vessel are relevant to its performance as a high integrity containment boundary:

1. All pressure boundary materials are 100% ultrasonically tested per ASME Section III, NB requirements to ensure absence of thru-thickness flaws.

2. All shop welds are radiographed to Section III NB acceptance criteria.

3. The field weld made to close the lid subsequent to fuel loading is a deep groove weld with a minimum of eight passes and whose depth exceeds the thickness of the shell being joined.

4. The vent and drain penetrations are confined to the lid and are also sealed by strength welding.

5. There is no reliance on seals or gaskets for radiological containment.

6. The vapor pressure in the MPC is reduced to less than 3 tors by a proven dehydration process to ensure that there will be negligible pressure rise during a thermal accident event such as fire.

7. The stresses in the enclosure vessel must remain below the applicable ASME code limit under all applicable storage and transport scenarios.

8. There will be no breach of the enclosure vessel pressure boundary under any of the postulated part 71 accident events.

9. Under the transport condition, the MPC lies in the cylindrical overpack cavity without any intervening protruding parts that may “stab” it under a transport accident event causing a potential breach in its pressure boundary.

10. The MPC is subject to a helium leak test upon completion of manufacturing. The fabrication leakage rate test demonstrates that the containment system, as fabricated, provides the required level of containment. The fabrication leakage test for the MPC for the HI-STAR 100MB package is performed at the fabrication facility to ensure that the welded enclosure vessel (inner containment) will maintain its containment function.

References [4.6.2] and [4.6.3] from the published literature contain additional discussion of the structural capacity of the Holtec MPCs to withstand large mechanical loads encountered in transport conditions.

4.7 INNER CONTAINMENT SYSTEM UNDER NORMAL CONDITION OF TRANSPORT

4.7.1 Applicable Loadings and System Performance

Section 2.6 of this SAR shows that the inner containment system (credited for HBF) components are maintained within their code-allowable stress limits 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 in full compliance with the applicable regulatory temperature and pressure limits, it is reasonable to conclude that the design basis leakage rate (see Table 8.1.1) will not be exceeded during normal conditions of transport.

4.7.2 Containment Criteria

The leak-tight criterion, as defined by ANSI N14.5 [8.1.3], is applicable for all containment system leakage tests. Compliance with the leak-tight 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 release 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.

The sensitivity for the leakage test instrument shall be as described in Table 8.1.1.

4.8 INNER CONTAINMENT INTEGRITY UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

4.8.1 Applicable Loadings and Package Performance

Section 2.7 of this SAR shows that all inner containment system components are maintained within their code-allowable stress limits during all hypothetical accident conditions of transport as defined in 10CFR71.73 [4.0.1]. Chapter 3 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 inner 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.

4.8.2 Containment Criteria

The leak-tight criterion, as defined by ANSI N14.5 [8.1.3], is applicable to inner containment system leakage tests. Compliance with the leak-tight 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 release rate 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. The sensitivity for the leakage test instrument shall be as described in Table 8.1.1.

4.9 SAFETY CASE FOR THE INTEGRITY OF INNER AND OUTER CONTAINMENTS

Table 4.9.1 provides a concise evaluation of the ability of the two containment boundaries in the HI-STAR 100MB system to *individually* maintain leak-tightness under the various loading conditions germane to the HI-STAR 100MB package's certification under 10CFR 71.

Table 4.9.1: Transport Condition Loads and Containment Integrity				
Number	Condition of Service	Loading	Inner Containment	Outer Containment
1	Normal Transport	Does the analysis in Chapter 3 show that the pressure inside the containment boundary remains below the limit necessary to ensure leak tightness?	Yes	Yes
2.	Normal Transport	Does the analysis in Chapter 3 show that the temperature of the seals in the containment boundary remains below their limits specified by the seal manufacturer for normal service?	Not applicable; there are no seals or gaskets in the inner containment	Yes
3	Normal Transport	Does the analysis in Section 2.6 show that the containment boundary will not leak under the 1-foot free drop event?	Yes	Yes
4	Normal Transport	Does the analysis in Section 2.6 show that the bolted joint in the containment boundary maintains its leak-tightness under reduced external pressure (3.5 psia) or increased external pressure (20 psia)?	Yes	Yes
5	Normal Transport	Will the containment Boundary remain leak tight if the environmental temperature dropped to the “cold” condition defined in Section 2.6.2?	Yes	Yes
6	Accident–Design Basis Fire	Do the containment boundary seals remain below their permissible temperature under the Design Basis Fire Event defined in subsection 2.7.4?	N/A; the Inner Containment Boundary has no seals or gaskets.	Yes
7	Accident-Free Drop from 9 meters	Does containment boundary remain leak-tight after the Free drop from 9 meters described in subsection 2.7.1?	Yes	Yes
8	Accident–deep submergence	Does the containment boundary remain leak tight under 290 feet of submergence in water as defined in subsection 2.7.7?	Yes	Yes
9	Accident-impact with a penetrant (puncture)	Does the containment boundary maintain its integrity in the wake of a free drop of the package from 40 inches on to a 6 inch diameter mild steel bar oriented in the most adverse configuration as defined in subsection 2.7.3?	Yes; the indent caused by the bar does not reach the MPC surface.	Yes

4.10 REGULATORY COMPLIANCE

This chapter has been prepared to summarize the containment features and capabilities of the HI-STAR 100MB packaging. The containment boundary of the HI-STAR 100MB packaging are designed and tested to ensure that the radionuclide release rates specified in 10CFR71.51 [4.0.1] will not be exceeded.

The containment features and capabilities of the HI-STAR 100MB packaging can be summarized in the following evaluation statements:

1. The HI-STAR 100MB packaging, as presented in Chapter 4, complies with all applicable codes and standards for the containment system as identified in the chapter.

2. The containment boundary is securely closed by using multiple bolts and plugs. The closure of the containment boundary is sufficient to prevent unintentional opening or opening by pressure that may arise in the package as required by 10CFR71.43(c).

3. The materials of construction for the packaging containment are specified in the Bills-of-Material in Section 1.4. All materials and construction assure that there will be no significant chemical, galvanic, or other reaction as required by 10CFR71.43(d).

4. The overpack and MPC penetrations are designed to prevent leakage and protect against unauthorized operation by using cover plates to provide redundant closure as required by 10CFR71.43(e).

5. The inner containment system boundary for the HI-STAR 100MB single lid cask packaging consists of the MPC shell; MPC baseplate; MPC top lid; and welded joints, seams, and penetrations. Section 7.1 of Reference [4.6.2] provides further information on MPC welds.

6. The outer containment system for the HI-STAR 100MB cask consists of the containment shell, containment top flange, containment bottom flange, port cover plates, port cover bolts, outer closure lid and closure lid bolts for single lid for MPC system, with inner closure lid and closure lid bolts for bare basket and their respective elastomeric seals .

7. The HI-STAR 100MB packaging is designed, constructed, and prepared for shipment so that under the tests specified in 10CFR71.71 (normal conditions of transport), the package satisfies the containment requirement of 10CFR71.43(f) with no dependence on filters or a mechanical cooling system as required by 10CFR71.51(c).

8. The HI-STAR 100MB packaging satisfies the containment requirements of 10CFR71, and the packaging meets the leak tight containment criteria of ANSI N14.5 [8.1.3].

4.11 REFERENCES

The following generic industry and Holtec produced references, directly or indirectly, undergird the safety evaluations reported in this chapter. Where explicitly cited, the reference number is identified (within square brackets) in the SAR text or table, as appropriate.

[4.0.1] 10CFR71. "Packaging and Transportation of Radioactive Materials," Title 10 of the Code of Federal Regulations, Office of the Federal Register, Washington, D.C.

[4.1.1] American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, Class 1 Components, 2007 Edition, 2008 Addenda.

[4.2.1] Holtec Proprietary Report HI-2022850, Revision 0, "Summary Report on MPC Leak Tightness Test", April 2002.

[4.6.1] USNRC Docket # 72-1032, HI-STORM FW FSAR, Holtec International Report number HI-2114830, USNRC, Washington D.C., 2011.

[4.6.2] "The Multi-Purpose Canister: A Bulwark of Safety in the Post-9/11 Age", Krishna P. Singh and John Zhai, 2003 International High Level Radioactive Waste Management Conference, Las Vegas, NV, March 30-April 2, 2003.

[4.6.3] American Society of Mechanical Engineers, "Management of Spent Nuclear Fuel", Tony Williams and K.P. Singh, Companion Guide to the ASME Boiler & Pressure Vessel Code, Third Edition, Volume 3, Chapter 56, Edited by Dr. K.R. Rao (2009).

CHAPTER 5 - SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR 100MB Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter. HI-STAR 100MB is designed to accommodate the fuel packages (canisters and bare baskets) outlined in Table 1.1.2.

The HI-STAR 100MB is directly based on the HI-STAR 190 [5.0.1], just with different dimensions, and the addition of bare fuel baskets as fuel packages. Also, the assembly types qualified for the HI-STAR 100MB are the same as those evaluated for the HI-STAR 190. The entire methodology, the calculational approach, the codes used, and the structure of this chapter are therefore directly based on and adopted from the HI-STAR 190. Additionally, due to the close similarity in design and analysis methodology, the results and conclusions of the numerous studies performed for the HI-STAR 190 are considered to be directly applicable to the HI-STAR 100MB and referenced here instead of being repeated, with appropriate justification of their applicability.

The loading configurations including fuel specifications used for shielding evaluations are described in Section 7.7. All configurations were 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 HI-STAR 100MB is designed to meet the dose rate limit of 10 mrem/hr (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 10 mrem/hr (0.1 mSv/h) and the transport index could exceed 10. Therefore, HI-STAR 100MB loaded with design basis fuel must be shipped by exclusive use shipment as discussed in Chapter 1.

The shielding analyses are performed with MCNP5 Version 1.51 [5.0.2] developed by Los Alamos National Laboratory (LANL). The source terms for the design basis fuels were calculated with the TRITON and ORIGAMI sequences from the SCALE 6.2.1 system [5.0.3]. Detailed descriptions of the MCNP models and the source term calculations are presented in Sections 5.2 and 5.3, respectively.

This chapter contains the following information:

- A description of the shielding features of HI-STAR 100MB.
- A description of the source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for HI-STAR 100MB.

- Analyses for the HI-STAR 100MB'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.

To facilitate convenient access to the referenced material, Table 5.0.1 provides a listing of the material adopted in this chapter by reference to the applicable documents.

TABLE 5.0.1

APPLICABLE SECTIONS OF THE REFERENCED DOCUMENTS

Location in HI-STAR 100MB SAR	Reference Information	Location in Reference Document	Technical Justification of Applicability to HI-STAR 100MB
Subsection 5.2.1	Cobalt impurity level in fuel hardware	Subsection 5.2.1 of [5.0.1]	The cobalt impurity level in fuel hardware is not a cask specific property.
Subsection 5.3.1	Fuel homogenization	Subsection of 5.3.1 of [5.0.1]	The related information about fuel homogenization is not cask specific.
Subsection 5.4.1	Neutron source strength as a function of burnup	Subsection 5.4.1 of [5.0.1]	The neutron source strength is not cask specific.
Subsection 5.4.5	Fuel reconfiguration	Subsection 5.4.5 of [5.0.1]	The related information about fuel reconfiguration is not cask specific.
Paragraph 5.4.6.2	Uncertainties on inputs to the source term calculations	Subsection 5.4.6 of [5.0.1]	The HI-STAR 100MB is directly based on the HI-STAR 190
Paragraph 5.4.6.3	Axial burnup profile	Subsection 5.4.6 and Appendix 5.C of [5.0.1]	The HI-STAR 100MB is directly based on the HI-STAR 190
Paragraph 5.4.6.5	Combination of uncertainties	Subsection 5.4.6 of [5.0.1]	The related information combination of uncertainties is not cask specific.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The principal design features of the HI-STAR 100MB Package with respect to radiation shielding consist of the fuel package, and the cask including the lid(s) and the cask body.

The main shielding is provided by the cask body. The cask body steel, cask body lead, the lid(s) and base plate provide the main gamma shielding, while the neutron shielding is provided by the Holtite neutron absorber. In the radial direction, the neutron absorber is located near the outer surface of the cask. For MPCs, a spacer may be utilized to limit the axial movement of the MPC if it is shorter than the cavity. The dimensions of the shielding components are shown in the drawing package in Section 1.3. The shielding material compositions and densities are listed in Table 5.3.2.

5.1.2 Summary of Maximum Radiation Levels

The Westinghouse 17x17 (WE 17x17) and B&W 15x15 assemblies are selected as design basis assemblies for the HI-STAR 100MB with a canister (i.e., an MPC). The B&W 15x15 assembly is evaluated since it contains a slightly larger fuel mass, which could lead to higher dose rates in some locations. The WE 17x17 assembly is selected since it is widely used throughout the industry and it has a larger fuel mass than other fuel assemblies that may be loaded into HI-STAR 100MB, except B&W 15x15.

The WE 17x17 assembly is selected as design basis assembly for the HI-STAR 100MB with a bare basket. The WE 17x17 assembly is selected since it has a larger fuel mass than other fuel assemblies that may be loaded into HI-STAR 100MB with a bare basket, as the amount of fuel material that can be loaded in each basket cell is restricted in Section 7.7.

The tables in this section present the bounding dose rates over all those assembly types, and all evaluated loading and fuel configurations. With this approach, the dose rates presented in Section 5.1 bound all assemblies and loading specifications listed in Section 7.7.

The dose rates listed in the tables in this section represent maximum total values for each dose location, considering axial, radial and azimuthal variations as applicable. This is achieved by specifying a reasonably fine grid of dose locations around the cask, and searching for the highest total dose rate for each location. Details on dose locations are provided in Subsection 5.3.3.

Finally, all burnup, enrichment and cooling time combinations specified in Section 7.7 were analyzed for each assembly, and for each dose location. The combination resulting in the highest total dose rate was identified and used for the results in the tables in this section.

In summary, the reported dose rates for each dose location in the tables in this section present the maximum total dose rate over all parameters, namely all assembly types; all burnup, enrichment

and cooling time combinations; and all relevant axial, radial and azimuthal areas for the respective location. The reported individual dose components for each location represent the contribution to the maximum total value, but may or may not be a maximum in itself.

Additionally, the dose rates reported in this subsection include the effect of all applicable uncertainties and other considerations, namely

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5.1.3 Normal Conditions

As discussed in Chapter 1, HI-STAR 100MB is transported by exclusive use shipment and complies with 10CFR71.47(b).

The removable HI-STAR transport impact limiters consist of aluminum crush material arranged around a carbon steel structure and enclosed by a stainless steel shell, all of which would provide additional shielding. The neutron absorber (Holtite-A) in the top impact limiter, and lower and upper strongbacks in the bottom and top impact limiters are credited for 2 m dose rates. The impact limiter skirts and other materials are neglected.

Surface dose rates were calculated on the cask surface, at locations shown in Figure 5.1.1. Results are presented in Tables 5.1.1 and 5.1.2 for different fuel packages.

All values are below 200 mrem/hr, therefore showing that HI-STAR 100MB 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 HI-STAR 100MB, since the surface dose rates do not exceed 200 mrem/hr.

Since the calculated dose rates on the surface of the cask are below 200 mrem/hr, the dose rates at any point on the outer surface of the vehicle will also be below 200 mrem/hr. The HI-STAR 100MB Package therefore complies with 10CFR71.47(b)(2).

For 2-m dose rates for HI-STAR 100MB with an MPC, the outer dimensions of the package impact limiters are used instead of the outer edges of the vehicle. The maximum 2-m dose rates for HI-STAR 100MB with a bare basket are conservatively calculated at 2 m from the surfaces of the cask. The dose locations are shown in Figure 5.1.1, and the results are presented in Tables 5.1.3 and 5.1.4 for different fuel packages. The HI-STAR 100MB Package therefore complies with 10CFR71.47(b)(3).

Dose rates were also calculated to determine the distance necessary to comply with the 2 mrem/hr requirements specified in 10CFR71.47(b)(4) for any normally occupied space. The results presented in Tables 5.1.5 and 5.1.6 for different fuel packages, identify the distances necessary from Dose Locations 4 and 5 (the top and bottom of HI-STAR 100MB, see Figure 5.1.1) which exposed personnel of private carriers must maintain in order meet the 2 mrem/hr requirement. If the normally occupied space of the vehicle is at a distance less than the values specified in Tables 5.1.5 and 5.1.6, radiation dosimetry is required for personnel to comply with 10CFR71.47(b)(4).

The analyses summarized in this section demonstrate HI-STAR 100MB'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. They are the damage to the neutron shield as a result of the design basis fire, the damage to the impact limiters as a result of the 9-meter (30 foot) drop, and the lead slump as a result of the 9-meter (30 foot) drop. The shielding analysis of the hypothetical accident condition assumes the neutron shield is completely lost and replaced by a void. Further, the impact limiters are also not credited in shielding for the hypothetical accident conditions. 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, part of the lead is replaced with a void (see discussion in Paragraph 5.3.1.1).

Chapter 2 shows that the HI-STAR 100MB package remains essentially 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.

Figure 5.1.2 shows the dose locations at 1 meter from the surface for the conditions of the HI-STAR 100MB Package after the postulated accident. Corresponding maximum dose rates are listed in Tables 5.1.7 and 5.1.8 for different fuel packages. All values in these tables are below the regulatory limit of 1000 mrem/hr.

Analyses summarized in this section demonstrate the HI-STAR 100MB Package's compliance with the 10CFR71.51 radiation dose limit.

TABLE 5.1.1

MAXIMUM DESIGN BASIS DOSE RATES ON THE SURFACE OF THE HI-STAR 100MB PACKAGE WITH A BARE BASKET FOR NORMAL CONDITIONS

Dose Point† Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
1					100.73	200
2					149.45	
3					163.13	
4					145.78	
5					141.91	

† Refer to Figure 5.1.1.

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TABLE 5.1.2

MAXIMUM DESIGN BASIS DOSE RATES ON THE SURFACE OF THE HI-STAR 100MB PACKAGE WITH THE MPC-32M FOR NORMAL CONDITIONS

Dose Point† Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
1					62.29	200
2					142.95	
3					97.87	
4					82.10	
5					30.35	

† Refer to Figure 5.1.1.

TABLE 5.1.3

MAXIMUM DESIGN BASIS DOSE RATES AT 2 METERS FROM THE HI-STAR 100MB PACKAGE WITH A BARE BASKET FOR NORMAL CONDITIONS

Dose Point† Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
2					9.71	10
4					8.57	
5					8.09	

† Refer to Figure 5.1.1.

TABLE 5.1.4

MAXIMUM DESIGN BASIS DOSE RATES AT 2 METERS FROM THE HI-STAR 100MB PACKAGE WITH THE MPC-32M FOR NORMAL CONDITIONS

Dose Point[†] Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
2[†††]					8.85	10
4[†††]					2.02	
5[†††]					1.01	

† Refer to Figure 5.1.1.

††† Radially, the outer diameter of the impact limiter is credited. Axially, 1 m of the impact limiter height is credited.

TABLE 5.1.5

DISTANCES FOR THE 2 mrem/hr DOSE RATE REQUIREMENT FOR THE HI-STAR 100MB PACKAGE WITH A BARE BASKET FOR NORMAL CONDITIONS

Dose Point† Location	Distance from Cask Surface (meters)	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
4	5					1.64	2
5	5					1.62	

† Refer to Figure 5.1.1.

TABLE 5.1.6

DISTANCES FOR THE 2 mrem/hr DOSE RATE REQUIREMENT FOR THE HI-STAR 100MB PACKAGE WITH THE MPC-32M FOR NORMAL CONDITIONS

Dose Point[†] Location	Distance from Cask Surface (meters)	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.47 Limit (mrem/hr)
4	4					1.27	2
5	2					1.95	

[†] Refer to Figure 5.1.1.

TABLE 5.1.7

MAXIMUM DESIGN BASIS DOSE RATES AT 1 METER FROM THE HI-STAR 100MB PACKAGE WITH A BARE BASKET FOR ACCIDENT CONDITIONS

Dose Point† Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.51 Limit (mrem/hr)
2					734.31	1000
4					48.27	
5					160.10	

† Refer to Figure 5.1.2.

TABLE 5.1.8

MAXIMUM DESIGN BASIS DOSE RATES AT 1 METER FROM THE HI-STAR 100MB PACKAGE WITH THE MPC-32M FOR ACCIDENT CONDITIONS

Dose Point† Location	[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]				Totals with Uncertainties (mrem/hr)	10 CFR 71.51 Limit (mrem/hr)
2					753.46	1000
4					22.59	
5					172.29	

† Refer to Figure 5.1.2.

FIGURE 5.1.1: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.1.2: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

5.2 SOURCE SPECIFICATION

The principal sources of radiation in HI-STAR 100MB 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 the SCALE 6.2.1 system [5.0.3] using the 252-group library.

The assemblies to be qualified for transportation in HI-STAR 100MB contain UO_2 fuel. A description of the design basis fuel assemblies for the source term calculations is provided in Table 5.2.1 and Table 5.2.2.

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Some of the fuel parameters listed in Table 5.2.1, and **[**

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Section 7.7 specifies the burnup, cooling time and enrichment combinations for spent nuclear fuel that were analyzed for transport in HI-STAR 100MB. **[**

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The following Subsections 5.2.1 and 5.2.2 describe the calculation of the gamma and neutron source terms. Subsection 5.2.5 discusses the effect of uncertainties in the input parameters to the source term calculations.

5.2.1 Gamma Source

Table 5.2.3(a) and Table 5.2.3(b) provide the gamma source in MeV/s and photons/s as calculated with TRITON and ORIGAMI for selected burnup and cooling time combinations utilized in the shielding calculations.

NUREG-1617 [5.2.3] 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 [5.2.5] and is described here.

1. The activity of the ^{60}Co from ^{59}Co in steel and Inconel was 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 [5.2.5].

Table 5.2.5 provides the ^{60}Co activity utilized in the shielding calculations in the non-fuel regions of the assemblies for a selected burnup and cooling time combinations.

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5.2.2 Neutron Source

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. The gamma source also varies with enrichment, although only slightly. Because of this effect, a relatively low enrichment was selected for each fuel burnup listed in Section 7.7, and used to develop the source terms.

Table 5.2.6 provides the neutron source in neutrons/s as calculated with TRITON and ORIGAMI for selected burnup and cooling time combinations utilized in the shielding calculations.

The spontaneous fission of ^{244}Cm isotopes accounts for approximately 95 % of the total number of neutrons produced. Alpha,n reactions in ^{244}Cm account for approximately 1% of the neutrons produced. In addition, any neutrons generated from subcritical multiplication, (n,2n) or similar reactions are properly accounted for in the MCNP calculation.

5.2.3 Non-Fuel Hardware

Non-fuel hardware devices are integral but removable parts of a PWR fuel assembly. These devices are currently not permitted for transport in HI-STAR 100MB. They may be added at a later date.

5.2.4 Fuel Assembly Neutron Sources

Neutron source assemblies (NSAs) are used in reactors for startup. The NSAs are currently not permitted for transport in HI-STAR 100MB. They may be added at a later date.

5.2.5 Source Term Input Uncertainties

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TABLE 5.2.1

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.2

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.3 (a)

CALCULATED PWR FUEL GAMMA SOURCE PER ASSEMBLY FOR SELECTED BURNUP AND COOLING TIMES (WE 17x17)

Lower Energy	Upper Energy	25000 MWd/mtU 5 Year Cooling 2.1 wt% ^{235}U	50000 MWd/mtU 13 Year Cooling 3.5 wt% ^{235}U
(MeV)	(MeV)	(Photons/s)	(Photons/s)
0.45	0.7	1.71E+11	1.53E+09
0.7	1.0	2.37E+12	1.54E+10
1.0	1.5	3.43E+12	1.65E+12
1.5	2.0	6.70E+13	4.67E+13
2.0	2.5	3.90E+14	1.12E+14
2.5	3.0	1.69E+15	1.86E+15
Total		2.15E+15	2.02E+15

TABLE 5.2.3 (b)

CALCULATED PWR FUEL GAMMA SOURCE PER ASSEMBLY FOR SELECTED BURNUP AND COOLING TIMES (WE 17x17)

Lower Energy	Upper Energy	25000 MWd/mtU 5 Year Cooling 2.1 wt% ^{235}U	50000 MWd/mtU 13 Year Cooling 3.5 wt% ^{235}U
(MeV)	(MeV)	(MeV/s)	(MeV/s)
0.45	0.7	4.70E+11	4.21E+09
0.7	1.0	5.33E+12	3.47E+10
1.0	1.5	6.00E+12	2.88E+12
1.5	2.0	8.38E+13	5.83E+13
2.0	2.5	3.31E+14	9.50E+13
2.5	3.0	9.71E+14	1.07E+15
Total		1.40E+15	1.23E+15

TABLE 5.2.4

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TABLE 5.2.5

CALCULATED PWR ^{60}Co SOURCE PER ASSEMBLY FOR SELECTED BURNUP AND COOLING TIMES (WE 17x17)

Location	**25000 MWd/mtU 5 Year Cooling 2.1 wt% ^{235}U**	**50000 MWd/mtU 13 Year Cooling 3.5 wt% ^{235}U**
	(Curies)	(Curies)
Upper End Fitting	24.42	12.29
Gas Plenum Spacer	5.08	2.56
Gas Plenum Springs	7.16	3.60
Incore Grid Spacers	152.46	76.71
Lower End Fitting	36.72	18.47

TABLE 5.2.6

CALCULATED PWR NEUTRON SOURCE PER ASSEMBLY FOR SELECTED BURNUPS AND COOLING TIMES (WE 17x17)

Lower Energy (MeV)	Upper Energy (MeV)	25000 MWd/mtU 5 Year Cooling 2.1 wt% ^{235}U	50000 MWd/mtU 13 Year Cooling 3.5 wt% ^{235}U
		(Neutrons/s)	(Neutrons/s)
1.0E-01	4.0E-01	1.79E+06	9.36E+06
4.0E-01	9.0E-01	1.88E+07	9.78E+07
9.0E-01	1.4	2.08E+07	1.08E+08
1.4	1.85	1.11E+07	5.78E+07
1.85	3.0	1.39E+07	7.23E+07
3.0	6.43	1.39E+07	7.24E+07
6.43	20.0	6.39E+06	3.32E+07
Totals		8.69E+07	4.50E+08

TABLE 5.2.7

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.8

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

5.3 SHIELDING MODEL

The shielding analysis of HI-STAR 100MB was performed with MCNP5 Version 1.51. 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 HI-STAR 100MB in the shielding analysis. MCNP is the same principal code that is used for the shielding calculations of Holtec's other approved dry storage and transportation systems under separate dockets.

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 100MB package. These drawings were used to create the MCNP models used in the radiation transport calculations. The drawing package also illustrates HI-STAR 100MB on a typical transport vehicle with a personnel barrier installed, with the barrier aligned with the diameter of the impact limiters. The vehicle and barrier were not considered in the MCNP model; however, the outer dimensions of the vehicle are assumed for the analyses to be identical to the outer envelope of the package with impact limiters. Figures 5.3.1 and 5.3.2 show the cross sectional views of the HI-STAR 100MB cask loaded with the F-24M and F-32M fuel package respectively, as they were modeled in MCNP. Figure 5.3.3 shows the MCNP model of a basket cell. Figure 5.3.4 shows a cross sectional view of HI-STAR 100MB. Figures 5.3.5 and 5.3.6 are axial representations of the HI-STAR 100MB cask as modeled in MCNP for surface and 2 meters dose rate calculations, respectively. The figures were created with the MCNP plotter and are drawn to scale.

The conditions and tests specified in 10CFR 71.71 for normal conditions have no effect on the configuration of the cask, as concluded in Chapter 2. 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 is 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 5.3.4 lists all those dimensions together with their minimal values, and with the values used in the model.

Additionally, during the MCNP modeling process, a few modeling simplifications were made. The major simplifications resulting in a difference between model and drawings are listed and discussed here.

Basket Modeling Simplifications

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HI-STAR Modeling Simplifications

1. [
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2. [

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3. The shielding spacer (if present) is not modeled. This is conservative since it removes materials that may provide additional shielding.

4. The bolts utilized for closure lid(s) are not modeled, but rather the bolt hole locations are modeled as a solid material. This is acceptable since the difference in the amount material is small, and not in an area where peak dose rates occur.

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6. 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.

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8. To model the lead slump of the lead in the annular space around the Containment Shell (Gamma Shield), it is conservatively assumed that 5.08 cm (2 inches) of the lead in the top and bottom areas are replaced with void. The lead slump assumption is conservative since in reality no lead would be removed.

9. The MCNP model of the HI-STAR 100MB 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 part of the lead gamma shield with void as a result of the lead slump.

10. The elevations of bottom and top trunnions are conservatively modeled slightly closer to the fuel active region than the dimensions provided on the licensing drawing. Also, the part of the trunnions that extend beyond the outer diameter of the cask is conservatively not modeled.

11. The height of the HI-STAR 100MB XL design cask is modeled about 1 cm more than the dimension provided on the licensing drawing. The effect of this deviation is insignificant.

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13. The anti-rotation bar and its hole are not explicitly modeled, but modeled as part of the surrounding shim. The effect of this deviation is small since the gaps are relatively small.

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 [5.2.1]) 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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5.3.1.3 Streaming Through Radial Steel Ribs

The HI-STAR 100MB cask utilizes Holtite-B as a neutron absorber in radial direction and axial-bottom direction. **[**

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5.3.2 Material Properties

Composition and densities of the various materials used in the HI-STAR 10MB shielding analyses are given in Tables 5.3.2 and 5.3.3. Further information on the Holtite and Metamic neutron absorbers is provided in Chapters 2 and 8, respectively. All of the materials and their actual geometries are represented in the MCNP model.

The Holtite-B density, hydrogen density and B_4C content used in shielding analysis are equal or less than those provided in Chapter 2.

Section 3.3 demonstrates that all materials used in HI-STAR 100MB 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, except for Holtite-B.

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 5.1.8, with corresponding dose point locations illustrated in Figures 5.1.1 and 5.1.2, are computed using MCNP volume tallies. In radial direction, the dose locations are represented by cylindrical rings with a thickness of about 1 cm

each at the surface, at 1 m, 2 m from the cask, and at 2 m from the package, respectively. In axial direction there are circular surfaces at various distances from the cask. The fuel loading specifications 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 specification in the areas identified in Figures 5.1.1 and 5.1.2. Further details are discussed below.

5.3.3.1 Radial Tallies

- Dose Locations 1 and 3
  These are the dose locations adjacent to the bottom and top flanges of the cask. **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

- Dose Locations 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.

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5.3.3.2 Axial Tallies

The tally volumes located on the top and bottom surfaces, 1 meter and 2 meter positions of the cask are 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.

TABLE 5.3.1

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

Holtec Non-Proprietary Version

TABLE 5.3.2 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

Holtec Non-Proprietary Version

TABLE 5.3.3

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.4

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.4 (CONTINUED)

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

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FIGURE 5.3.1: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.2: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.3: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.4: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.5: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

FIGURE 5.3.6: **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]**

5.4 SHIELDING EVALUATION

5.4.1 Methods

The MCNP5 code [5.0.2] was used for all 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. The MCNP5 default cross section libraries are 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 was performed. MCNP5 is essentially the same code that was used as the shielding code in all Holtec's dry storage and transportation analyses. Also, 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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[
PROPRITERY INFORMATION WITHHELD PER 10CFR2.390
] 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

Tables 5.1.1 and 5.1.2 provide the maximum dose rates of all loading specifications on the surface of the cask during normal transport conditions for HI-STAR 100MB with design basis fuel. Tables 5.1.3 and 5.1.4 list the maximum dose rate of all loading specifications at 2 m from the outer edge of the package during normal conditions.

Figure 5.1.1 shows the dose locations on the surface and the condition of the HI-STAR 100MB package during normal transport. Each of these dose locations has a corresponding location at 2 m from the outer edge of cask or package. The azimuthal dose values are taken from the surface dose point locations that are shown in Figure 5.3.4. **[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390**
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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 in on the outer edge of the cask and covers the whole side of the cask. The highest dose rate of the axial segments was chosen as the value for dose location 2. Dose location 1 corresponds to the surface location directly below the neutron shield. Dose location 3 corresponds to the surface location directly above the neutron shield in the upper part of the cask. Dose location 4 corresponds to the surface location directly above the cover plate, and dose location 5 corresponds to the location directly below the bottom of the cask.

5.4.5 Fuel Reconfiguration

The licensing approach for HBF reconfiguration is discussed in Paragraph 1.2.1.3. According to Section 2.11, 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.

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5.4.6 Effect of Uncertainties and Sensitivity Studies

This subsection contains a brief summary description of the uncertainties considered, with a reference to the section in this SAR or, as applicable, the SAR of the HI-STAR 190 where the detailed evaluation or discussion is presented. As stated in Section 5.1, the uncertainties considered are

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5.4.7 Dose Rate Evaluation

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TABLE 5.4.1

**FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.5])**

Gamma Energy (MeV)	(mrem/hr)/ (photon/cm^2-s)
0.01	3.96E-06
0.03	5.82E-07
0.05	2.90E-07
0.07	2.58E-07
0.1	2.83E-07
0.15	3.79E-07
0.2	5.01E-07
0.25	6.31E-07
0.3	7.59E-07
0.35	8.78E-07
0.4	9.85E-07
0.45	1.08E-06
0.5	1.17E-06
0.55	1.27E-06
0.6	1.36E-06
0.65	1.44E-06
0.7	1.52E-06
0.8	1.68E-06
1.0	1.98E-06
1.4	2.51E-06
1.8	2.99E-06
2.2	3.42E-06

TABLE 5.4.1 (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS (FROM [5.4.5])

Gamma Energy (MeV)	(mrem/hr)/ (photon/cm^2-s)
2.6	3.82E-06
2.8	4.01E-06
3.25	4.41E-06
3.75	4.83E-06
4.25	5.23E-06
4.75	5.60E-06
5.0	5.80E-06
5.25	6.01E-06
5.75	6.37E-06
6.25	6.74E-06
6.75	7.11E-06
7.5	7.66E-06
9.0	8.77E-06
11.0	1.03E-05
13.0	1.18E-05
15.0	1.33E-05

TABLE 5.4.1 (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS (FROM [5.4.5])

Neutron Energy (MeV)	Quality Factor	(mrem/hr)/(n/cm^2-s) †
2.5E-8	2.0	3.67E-06
1.0E-7	2.0	3.67E-06
1.0E-6	2.0	4.46E-06
1.0E-5	2.0	4.54E-06
1.0E-4	2.0	4.18E-06
1.0E-3	2.0	3.76E-06
1.0E-2	2.5	3.56E-06
0.1	7.5	2.17E-05
0.5	11.0	9.26E-05
1.0	11.0	1.32E-04
2.5	9.0	1.25E-04
5.0	8.0	1.56E-04
7.0	7.0	1.47E-04
10.0	6.5	1.47E-04
14.0	7.5	2.08E-04
20.0	8.0	2.27E-04

† Includes the Quality Factor.

TABLE 5.4.2

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.4.3

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.4.4

[PROPRITERY INFORMATION WITHHELD PER 10CFR2.390]

5.5 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] Safety Analysis Report on the HI-STAR 190 Package, HI-2146214 (Docket No. 71-9373), latest revision, Holtec International).

[5.0.2] X-5 Monte Carlo Team, “MCNP – A General Monte Carlo N-Particle Transport Code, Version 5,” LA-UR-03-1987, Los Alamos National Laboratory (2003).

[5.0.3] 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).

[5.2.1] HI-STORM 100 FSAR, Revision 12 (Docket 72-1014).

[5.2.2] HI-STORM FW FSAR, Revision 4 (Docket No. 72-1032).

[5.2.3] NUREG-1617, SRP for Transportation Packages for Spent Nuclear Fuel, USNRC, Washington, DC, March 2000.

[5.2.4] HI-STAR 100 SAR, Revision 15 (Docket 71-9261).

[5.2.5] A. Luksic, "Spent Fuel Assembly Hardware: Characterization and 10CFR 61 Classification for Waste Disposal," PNL-6906-vol. 1, Pacific Northwest Laboratory, June 1989.

[5.2.6] B.L. Broadhead, “Recommendations for Shielding Evaluations for Transport and Storage Packages,” NUREG/CR-6802 (ORNL/TM-2002/31), Oak Ridge National Laboratory, May 2003.

[5.3.1] NRC Draft Regulatory Issue Summary 2015-XX Considerations in Licensing High Burnup Spent Fuel in Dry Storage and Transportation, ML14175A203.

[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] HI-STAR 180 SAR, latest revision, HI-2073681 (Docket No. 71-9325), Holtec International.

[5.4.5] "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", ANSI/ANS-6.1.1-1977.

[5.4.6] S.E. Turner, "Uncertainty Analysis - Axial Burnup Distribution Effects," presented in "Proceedings of a Workshop on the Use of Burnup Credit in Spent Fuel Transport Casks", SAND-89-0018, Sandia National Laboratory, Oct., 1989.

Appendix 5.A

[Propritery Information withheld per 10CFR2.390]

Appendix 5.B

[Propritery Information withheld per 10CFR2.390]

CHAPTER 6: CRITICALITY EVALUATION

6.0 INTRODUCTION

This chapter documents the criticality evaluation of the HI-STAR 100MB Cask for the transportation of spent nuclear fuel, such as high burnup (HBF) and moderate burnup (MBF) fuel, in accordance with 10CFR71. The results of this evaluation demonstrate that, for the designated fuel assembly classes and basket configurations, an infinite number of HI-STAR 100MB Packages with variations in internal and external moderation remain subcritical with a subcriticality margin, respectively, of at least 0.02Δk for the misload conditions and greater than 0.05Δk under all the other conditions. This corresponds to a criticality safety index (CSI) of zero (0.0) and demonstrates compliance with criticality requirements in USNRC Interim Staff Guidance (ISG-8 Rev. 3), 10CFR71.55 and 10CFR71.59 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 100MB 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 the licensing of HI-STAR 100 in Docket #71-9261 [6.0.1] and HI-STAR 190 in Docket # 71-9373 [6.0.2].

Finally, HI-STAR 100MB is designed as the transportation cask for the MPCs certified for storage in HI-STORM 100 in Docket #72-1014 [6.0.3] under 10CFR72. The HI-STAR 100MB is designed to support the permissible fuel loading content utilized in the licensing of HI-STORM 100; however, this chapter licenses only those fuel packages described in Chapter 1, specifically MPC-32M, F-32M and F-24M, and the fuel types described in Chapter 7.

To facilitate convenient access to the referenced material, Table 6.0.1 provides a listing of the material adopted in this chapter by reference to the applicable documents.

6.0.1 Methodology for Generic Studies

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TABLE 6.0.1

APPLICABLE SECTIONS OF THE REFERENCED DOCUMENTS

Location in HI-STAR 100MB SAR	Reference Information	Location in Reference Document	Technical Justification of Applicability to HI-STAR 100MB
Section 6.2	Fissile material contents	Section 6.2 of [6.0.2]	Subsection 6.0.1
Subsection 6.2.2	Definition of assembly classes	Table 2.1.3 of [6.0.3]	Subsection 6.2.2
Subsection 6.2.2	Analyses of the fuel dimensional variations	Section 6.2 of [6.0.1]	Subsection 6.2.2
Subsection 6.2.2	Additional fuel assembly characteristics	Subsection 6.2.1 of [6.0.4]	Subsection 6.2.2
Subsection 6.2.3	Annular pellets	Subsection 6.2.3 of [6.0.2]	Subsection 6.0.1
Subsection 6.2.3	15x15I with and without the guide rods	Subsection 6.2.1 of [6.0.4]	Subsection 6.2.3
Subsection 6.2.6	Reconfiguration of PWR HBF	Subsection 6.3.5 of [6.0.2]	Subsection 6.2.6
Tables 6.2.1, 6.2.2, 6.2.4	Parametric studies for PWR fuel assemblies	Tables 6.2.1, 6.2.2, 6.2.4 of [6.0.2]	Subsection 6.0.1
Subsection 6.3.2	^{10}B depletion during the service life of Metamic-HT	Subsection 6.3.2 of [6.0.4]	Subsection 6.3.2
Paragraph 6.3.4.1	Internal and external flooding	Subsection 6.3.4.1 of [6.0.2]	Subsection 6.0.1
Paragraph 6.3.4.2	Partial flooding	Subsection 6.3.4.2 of [6.0.2]	Subsection 6.0.1
Paragraph 6.3.4.3	Pellet-to-clad gap flooding	Subsection 6.3.4.3 of [6.0.2]	Subsection 6.0.1
Paragraph 6.3.4.4	Preferential flooding	Paragraph 6.4.2.4 of [6.0.1]	Paragraph 6.3.4.4
Tables 6.3.1, 6.3.3, 6.3.4, 6.3.7, 6.3.8, 6.3.9, 6.3.10, 6.3.11, 6.3.12	MPC-37 demonstrations of maximum reactivity	Tables 6.3.1, 6.3.3, 6.3.4, 6.3.7, 6.3.8, 6.3.9, 6.3.10, 6.3.11, 6.3.12 of [6.0.2]	Subsection 6.0.1
Figure 6.3.6	Calculated k_{eff} as a function of internal moderator density	Figure 6.3.6 of [6.0.2]	Subsection 6.0.1
Appendix 6.A	Applicability of criticality benchmark calculations	Appendix 6.A of [6.0.2]	Subsection 6.0.1
Appendix 6.B	Burnup Credit for MPC-37	Appendix 6.B of [6.0.2]	Subsection 6.0.1
Appendix 6.E	Verification of assembly burnup in the HI-STAR 100MB Cask	Appendix 6.E of [6.0.2]	Subsection 6.0.1
Subsection 6.B.2.1	Core operation parameters	Appendix A of [6.B.4]	Subsection 6.B.2.1
Subsection 6.B.2.1	Soluble boron concentration	Section 6.E.2.1 of [6.0.1]	Subsection 6.B.2.1
Subsection 6.B.2.1	Ratio applied to the core operation parameters	Table 6.E.3 of [6.0.1]	Subsection 6.B.2.1
Subsection 6.B.2.1	Fuel temperature calculation	Paragraph 6.E.2.1.4 of [6.0.1]	Subsection 6.B.2.1
Subsection 6.B.2.2	Axial power shaping rods	Subsection 6.E.2.2 of [6.0.1]	Subsection 6.B.2.2
Paragraph 6.B.2.2.1	Fuel inserts and burnable poisons analysis	Paragraph 6.E.2.2.1 of [6.0.1]	Paragraph 6.B.2.2.1
Subsection 6.B.4.1	Bounding axial burnup profiles	Subsection 6.E.4.1 of [6.0.1], Appendix D of [6.B.4]	Subsection 6.B.4.1

Paragraph 6.B.4.3.1	Isotopic compositions interpolation step	Paragraph 6.E.4.3.1 of [6.0.1]	Paragraph 6.B.4.3.1
Paragraph 6.B.4.3.2	Assembly average vs. pin specific isotopic composition	Paragraph 6.E.4.3.2 of [6.0.1]	Paragraph 6.B.4.3.2

TABLE 6.0.2

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6.1 DESCRIPTION OF CRITICALITY DESIGN

In conformance with the principles established in 10CFR71 [6.1.1], NUREG-1617 [6.1.2], and NUREG-0800 Section 9.1.2 [6.1.3], the results in this chapter demonstrate that the effective multiplication factor (k_{eff}) of the HI-STAR 100MB package, including all biases and uncertainties evaluated with a 95% probability at the 95% confidence level, does not exceed 0.95 under all credible normal and hypothetical accident conditions of transport. For misloading conditions that are recommended by ISG-8 Rev. 3 [6.B.1], a reduced safety margin of no less than 0.02 delta-k (i.e. a maximum k_{eff} limit of 0.98) is applied. These criteria provide a large subcritical margin, sufficient to assure the criticality safety of the HI-STAR 100MB package when fully loaded with fuel of the highest permissible reactivity.

6.1.1 Design Features

The HI-STAR 100MB package consists of the HI-STAR 100MB transport cask and fuel packages for PWR fuel (see Chapter 1). The HI-STAR 100MB package is designed such that the fixed neutron absorber will remain effective for a period greater than 50 years, and there are no credible mechanisms that would cause its loss or a diminution of its effectiveness (see Chapter 2 and Paragraph 8.1.5.5 for further information on the qualification and testing of the neutron absorber material). Therefore, there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

In the fuel package, the fuel assemblies are placed in a basket structure to maintain their location. During the normal and accident conditions of transport, the HI-STAR 100MB package is dry (no moderator), and thus, the reactivity is very low (k_{eff} < 0.60). However, to demonstrate a compliance with 10CFR71 the HI-STAR 100MB package is flooded, and thus, represents the limiting case in terms of reactivity. The calculational models for these conditions conservatively include: full flooding with ordinary water, corresponding to the highest reactivity, and the worst case (most conservative) combination of manufacturing and fabrication tolerances.

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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.

Criticality safety of HI-STAR 100MB depends on the following principal design features:

- The inherent geometry of the fuel basket design;
- The incorporation of permanent fixed neutron-absorbing material in the fuel basket structure.[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
- An administrative limit on the maximum enrichment for PWR fuel [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
- An administrative limit on the minimum average assembly burnup for PWR[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390] The burnup credit methodology is described in detail in Appendix 6.B of this chapter and [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390] and
- The ability of the cask to prevent water inleakage under accident conditions.[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

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)".

- USNRC Interim Staff Guidance - 8 (ISG-8), Revision 3, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks".

6.1.2 Summary Table of Criticality Evaluations

Confirmation of the criticality safety of the HI-STAR 100MB package was accomplished with the three-dimensional Monte Carlo code MCNP5 [6.3.1]. K-factors for one-sided statistical tolerance limits with 95% probability at the 95% confidence level were obtained from the National Bureau of Standards (now NIST) Handbook 91 [6.4.1].

To assess the reactivity effects due to temperature and fuel density changes, CASMO5, a two-dimensional transport theory code [6.3.2 - 6.3.3] for fuel assemblies was used. CASMO5 was not used for quantitative information, but only to qualitatively indicate the direction and approximate magnitude of the reactivity effects. Additionally, CASMO5 was used to determine the isotopic composition of spent fuel for burnup credit in the HI-STAR 100MB (see Appendix 6.B).

Benchmark calculations were made to compare the primary code package (MCNP5) with experimental data, using critical experiments selected to encompass, insofar as practical, the design parameters of the HI-STAR 100MB package. The most important parameters are (1) the enrichment, (2) cell spacing, and (3) the ^{10}B loading of the neutron absorber panels. The critical experiment benchmarking work is summarized in Appendix 6.A.

To assure that the true reactivity will always be less than the calculated reactivity, the following conservative assumptions were made:

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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)

The results are summarized in Table 6.1.3 for all fuel packages and for the most reactive configurations and fuel condition in each basket. The results are conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and include the calculational bias, uncertainties, and calculational statistics. For package arrays, an infinite number of packages is analyzed. It is noted that the results for the internally flooded single package and package arrays are statistically equivalent for each basket. 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 for each fuel package. 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 Section 6.4. These analyses also include cases with various internal and external moderator densities and various cask-to-cask spacing's. The maximum k_{eff} value for all cases is below the limit of 0.95 recommended in NUREG-1617. The results therefore demonstrate that

the HI-STAR 100MB Package is in full compliance with 10CFR71 (71.55(b), (d), and (e) and 71.59(a)(1) and (a)(2)). The maximum k_{eff} value for misloading conditions is below the limit of 0.98 recommended in ISG-8 Rev. 3 (see Appendix 6.E).

Additional results of the design basis criticality safety calculations for single unreflected, internally flooded casks (limiting cases) are listed in Table 6.1.1 and Table 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 basket designs and fuel assembly classes†, Tables 6.1.1 through 6.1.2 list the bounding maximum k_{eff} value, the associated maximum allowable enrichment, and the minimum required assembly average burnup (if applicable), as required by 10CFR71.33(b)(2). The maximum enrichment and minimum burnup acceptance criteria are defined in Chapter 1. Additional results for each of the candidate fuel assemblies, that are bounded by those listed in Tables 6.1.1 through 6.1.2, are given in Section 6.2.

6.1.3 Criticality Safety Index

The calculations for package arrays are performed for infinite arrays of HI-STAR 100MB 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).

† For each array size (e.g., 14x14, 15x15, 16x16, etc.), the fuel assemblies have been subdivided into a number of assembly classes, where an assembly class is defined in terms of the (1) number of fuel rods; (2) pitch; (3) number and location of guide tube; and (4) cladding material. The assembly classes for PWR fuel are defined in Section 6.2.

TABLE 6.1.1

BOUNDING MAXIMUM k_{eff} VALUES FOR MBF IN MPC-32M AND F-32M

Cooling Time, Years	Maximum Allowable Enrichment (wt% ^{235}U)	MPC-32M, F-32M	
		Minimum Required Assembly Average Burnup[1] (GWd/mtU)	Maximum[2] k_{eff}[3]
15x15B, C, D, E, F, H, I and 17x17A, B, C			
3.0	2.0	0.00	0.9317
	3.0	17.03	0.9454
	4.0	31.16	0.9467
	5.0	41.86	0.9479
16x16A, B, C			
3.0	2.25	0.00	0.9355
	3.0	7.83	0.9474
	4.0	20.02	0.9463
	5.0	30.12	0.9489

[1] Other combinations of maximum enrichment and minimum burnup have been evaluated which result in the same maximum k_{eff}. See Appendix 6.B for a bounding polynomial function.
[2] 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.
[3] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.

TABLE 6.1.2

BOUNDING MAXIMUM k_{eff} VALUES FOR MBF IN F-24M

Fuel Assembly Class	Maximum Allowable Average Enrichment (wt% ^{235}U)	Maximum k_{eff}
14x14A	5.0	0.9262
14x14B	5.0	0.9203
14x14C	5.0	0.9271
14x14D	5.0	0.8803
15x15A	5.0	0.9402
15x15B	4.5	0.9383
15x15C	4.5	0.9364
15x15D	4.5	0.9343
15x15E	4.5	0.9372
15x15F	4.5	0.9381
15x15G	4.5	0.9000
15x15H	4.5	0.9481
15x15I	5.0	0.9275
16x16A	5.0	0.9296
16x16B	5.0	0.9335
16x16C	5.0	0.9062
17x17A	4.7	0.9496
17x17B	4.95	0.9486
17x17C	4.95	0.9476

TABLE 6.1.3

SUMMARY OF THE CRITICALITY RESULTS
TO DEMONSTRATE COMPLIANCE WITH 10CFR71.55 AND 10CFR71.59

MPC-32M, F-32M Assembly Class 15x15B						
Configuration	**% Internal Moderation**	**% External Moderation**	**Applicable Requirement**	**Fuel Condition**	**Fuel Damage**	**Maximum k_{eff}[1]**
Single Package, unreflected	100%	0%	n/a	MBF	No	0.9476
				HBF	Minor	0.9492
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	MBF	No	0.9483
				HBF	Minor	0.9488
Containment, fully reflected	100%	100%		MBF	No	0.9473
				HBF	Minor	0.9484
Single Package, Damaged	0%	100%	10CFR71.55 (e)	MBF	No	0.4720
				HBF	Major	0.4700
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	MBF	No	0.5085
				HBF	Minor	0.5086
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	MBF	No	0.4755
				HBF	Major	0.4744

[1] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.

TABLE 6.1.3 (continued)

SUMMARY OF THE CRITICALITY RESULTS
TO DEMONSTRATE COMPLIANCE WITH 10CFR71.55 AND 10CFR71.59

F-24M						
Configuration	**% Internal Moderation**	**% External Moderation**	**Applicable Requirement**	**Fuel Condition**	**Fuel Damage**	**Maximum k_{eff}**
Single Package, unreflected	100%	0%	n/a	MBF	No	0.9484
				HBF	Minor	0.9492
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	MBF	No	0.9496
				HBF	Minor	0.9491
Containment, fully reflected	100%	100%		MBF	No	0.9477
				HBF	Minor	0.9473
Single Package, Damaged	0%	100%	10CFR71.55 (e)	MBF	No	0.3735
				HBF	Major	0.3715
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	MBF	No	0.4073
				HBF	Minor	0.4070
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	MBF	No	0.3780
				HBF	Major	0.3759

6.2 FISSILE MATERIAL CONTENTS

The following discussions within this section are directly taken from the HI-STAR 190 SAR [6.0.2] with editorial modifications to place it within this chapter. Section and table numbers are preserved for continuity. See Subsection 6.0.1 for justification.

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 100MB package. To resolve this limitation, a number of fuel assembly classes for PWR fuel types are defined based on bounding fuel dimensions. The results of parametric studies justify using those bounding fuel dimensions for defining the authorized contents.

6.2.2 Definition of Assembly Classes

For each array size (e.g., 14x14, 15x15, 16x16, etc.), the fuel assemblies have been subdivided into a number of classes, where a class is defined in terms of the (1) number of fuel rods; (2) pitch; and (3) number and locations of guide tubes. The assembly classes are defined in Chapter 7 tables. It should be noted that these assembly classes are consistent with the class designations of HI-STORM 100 FSAR [6.0.3]. Specifically, assembly classes with the same identifier refer to the same set of limiting dimensions.

In Section 6.2 of HI-STAR 100 SAR [6.0.1], extensive analyses of fuel dimensional variations have been performed. These calculations demonstrate that the maximum reactivity corresponds to:

- maximum active fuel length,
- maximum fuel pellet diameter,
- maximum fuel rod pitch,
- minimum cladding outside diameter (OD),
- maximum cladding inside diameter (ID), and
- minimum guide tube thickness.

The reason that those are bounding dimensions, i.e. that they result in maximum reactivity is directly based on, and can be directly derived from the three main characteristics affecting reactivity, namely 1) characteristics of the fission process; 2) the characteristics of the fuel assemblies and 3) the characteristics of the neutron absorber in the basket. These affect the reactivity as follows:

- The neutrons generated by fission are fast neutrons while the neutrons that initiate the fission need to be thermal neutrons. A moderator (water) is therefore necessary for the nuclear chain reaction to continue.

- Fuel assemblies are predominantly characterized by the amount of fuel and the fuel-to-water (moderator) ratio. Increasing the amount of fuel, or the enrichment of the fuel, will increase the amount of fissile material, and therefore increase reactivity. Regarding the fuel-to-water ratio, it is important to note that commercial PWR assemblies are undermoderated, i.e. they do not contain enough water for a maximum possible reactivity.
- The neutron poison in the basket walls uses ^{10}B, which is an absorber of thermal neutrons. This poison therefore also needs water (moderator) to be effective. This places a specific importance on the amount of water between the outer rows of the fuel assemblies and the basket cell walls. Note that this explains some of the differences in reactivity between the different assembly types in the same basket, even for the same enrichment, where assemblies with a smaller cross section, i.e. which have more water between the periphery of the assembly and the surrounding wall, generally have a lower reactivity.

Based on these characteristics, the following conclusions can be made:

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Since all assemblies have the same principal design, i.e. consist of bundles of cladded fuel rods, most of them with embedded guide/instrument tubes, the above conclusions apply to all of them, and the bounding dimensions are therefore also common to all fuel assemblies analyzed here.

Nevertheless, to clearly demonstrate that the main assumption is true, i.e. that all assemblies are undermoderated, a study was performed for all assembly types where the pellet-to-clad gap is empty instead of being flooded (a conservative assumption for the design basis calculations, see Paragraph 6.4.2.3). The results are listed in Table 6.2.1, in comparison with the results of the cases with the flooded gap for those assembly types. In all cases, the reactivity is reduced compared to the reference case. This verifies that all assembly types considered here are in fact undermoderated, and therefore validates the main assumption stated above. All assembly types are therefore behaving in a similar fashion, and the bounding dimensions are therefore applicable to all assembly types. This discussion and the corresponding conclusions not only affect fuel behavior, but also other moderation effects, and is therefore further referenced in Subsections 6.3.1 and 6.3.4.

As a result, the authorized contents in Chapter 7 are defined in terms of those bounding assembly parameters for each class.

Nevertheless, to further demonstrate that the aforementioned characteristics are in fact bounding for HI-STAR 100MB, parametric studies were performed on a reference PWR assembly, namely assembly class 15x15B. The results of these studies are shown in Table 6.2.2 and verify the bounding parameters listed above. Note that in the studies presented in Table 6.2.2, 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 6.4.2.3), at a constant thickness, to ensure the studies evaluate the fuel parameters rather than the moderation conditions, as discussed above.

In addition to those dimensions, an additional fuel assembly characteristic important to criticality control is the location of guide tubes. These are identified in the assembly cross sections provided in Appendix 6.D, Section D.5 and extensively analyzed in Subsection 6.2.1 of the HI-STORM FW FSAR [6.0.4]. The bounding fuel assembly characteristics are used in the HI-STAR 100MB analysis. Since the considered fuel assembly classes as well as the MPCs are identical to those analyzed in the HI-STORM FW FSAR, the calculations and conclusions are applicable to this analysis. They are discussed in the following subsections and the bounding fuel assembly characteristics are used in the HI-STAR 100MB analysis.

6.2.3 PWR Fuel Assemblies

Typically, PWR fuel assemblies are designed with solid fuel pellets throughout the entire active fuel length. However, some PWR assemblies contain annular fuel pellets in the top and bottom 6 to 8 inches of the active fuel length. This changes the fuel to water ratio in these areas, which could have an effect on reactivity. However, the top and bottom of the active length are areas with high neutron leakage, and changes in these areas typically have no significant effect on reactivity. Studies with the annular pellets at the top and bottom of the active length were performed in Subsection 6.2.3 of the HI-STAR 190 SAR [6.0.2] and confirm this conclusion. The above conclusion is applicable to HI-STAR 100MB; see Subsection 6.0.1 for justification. The results of these studies are shown in Table 6.2.4, and confirm no significant reactivity effects, even if the annular region of the pellet is flooded with pure water. All calculations for

PWR fuel assemblies are therefore performed with solid fuel pellets along the entire length of the active fuel region, and the results are directly applicable to those PWR assemblies with annular fuel pellets.

For PWR assembly class 15x15I (see Section 6.D.5), calculations with and without the guide rods were performed in Subsection 6.2.1 of the HI-STORM FW FSAR [6.0.4]. Based on the results of these calculations, the case without the guide rods is used as the design basis case for this assembly type in the HI-STAR 100MB analysis, therefore, no specific restriction on the location and number of the guide rods exists.

6.2.6 High Burnup Fuel

Fuel is loaded into HI-STAR 100MB for transport after a possible long period of storage. While cladding damage to HBF is not expected during the storage period, it may not be feasible to physically examine the fuel at that time 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 100MB 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 100MB for the purpose of criticality evaluation already includes consideration of a certain level of fuel reconfiguration.

Criticality calculations done for HI-STAR 190 [6.0.2] apply additional burnup for the HBF, and hence showed that the reactivity effect of potential fuel reconfiguration is more than compensated by the higher burnup. While PWR HBF is defined as burnup not less than 45 GWd/mtU, criticality calculations for HI-STAR 100MB conservatively do not apply additional burnup for the HBF.

TABLE 6.2.1

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TABLE 6.2.2

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TABLE 6.2.3 – Intentionally Deleted

TABLE 6.2.4

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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 the HI-STAR 100MB package in sufficient detail to identify the package accurately and provides a sufficient basis for the evaluation of the package.

6.3.1 Description of Calculational Model

Figures 6.3.1 through 6.3.4 show representative cross sections of the criticality models for the three baskets. Figures 6.3.1 and 6.3.2 show a single cell from MPC-32M/F-32M and F-24M. Figures 6.3.3, 6.3.4.A and 6.3.4.B show the entire MPC-32M, F-32M, and F-24M basket, respectively. Figure 6.3.5.A shows a sketch of the calculational model in the axial direction for the type XL cask (MPC-32M basket). Figures 6.3.5.B and 6.3.5.C show a sketch of the calculational model in the axial direction for the type SL cask (F-32M and F-24M basket).

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The discussion provided in Subsection 6.2.2 regarding the principal characteristics of neutron poison is also important for the various studies presented in this section, and supports the fact that those studies only need to be performed for a single PWR assembly type, and that the results of those studies are then generally applicable to all assembly types. The studies and the relationship to the discussion in Subsection 6.2.2 are discussed below. Note that this approach is consistent with that used for HI-STAR 190 [6.0.2].

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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 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, fuel burnup 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. There are, however, differences between the normal and accident models in terms of internal and external water density, external condition and level of potential fuel reconfiguration. The effect of these conditions is discussed in Subsections 6.3.4 and 6.3.5.

6.3.2 Material Properties

Composition of the various components of the principal designs of the HI-STAR 100MB package is listed in Table 6.3.5. The nuclide identification number (ZAID), presented for each nuclide in Table 6.3.5, 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 Section 6.8. In this table, only the composition of fresh fuel is listed. For a discussion of the composition of spent fuel for burnup credit see Appendix 6.B.

HI-STAR 100MB is designed such that the fixed neutron absorber will remain effective for a period greater than 50 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 and Chapter 2.

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 Section 8.1, 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 [6.0.4], 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 100MB package for the 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 [6.3.1] 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 [6.3.2 – 6.3.3] 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 and burnups (if applicable) indicated in Chapter 7. The calculations were based on the assumption that the HI-STAR 100MB cask was fully flooded with water. The discussion provided in Subsection 6.2.2 regarding the principal characteristics of fuel assemblies and basket poison is also important for the various studies presented in this section, and supports the fact that those studies only need to be performed for a single PWR assembly type, and that the results of those studies are then generally applicable to all assembly types. The studies and the relationship to the discussion in Subsection 6.2.2 are presented below. Note that this approach is consistent with that used for

HI-STAR 100 [6.0.1].

6.3.4.1 Internal and External Flooding

The following discussions within this subsection are copied directly from the HI-STAR 190 SAR [6.0.2] with editorial modifications to place it within this chapter. Section and table numbers are preserved for continuity. See Subsection 6.0.1 for justification.

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. Subparagraphs 6.3.4.1.1 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. [6.3.4] have 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 100MB.

6.3.4.1.1 Single Package Evaluation

The calculational model for a single package consists of the cask surrounded by a hexagonal box filled with water. The neutron absorber on the outside of HI-STAR 100MB 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 infinite 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 6.3.6 plots calculated k_{eff} values as a function of internal moderator density for with 100% external moderator density (i.e., full water reflection).

Results listed in Table 6.3.7 and plotted in Figure 6.3.6 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 Monte Carlo calculational method); 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 the HI-STAR 100MB package.

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 section evaluate arrays of HI-STAR 100MB 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 calculated 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 wall of the overpack is more than sufficient to preclude neutron coupling between casks, consistent with the findings of Cano [6.12], et al. Neglecting the Holtite neutron shielding in the calculational model provides further assurance of conservatism in the calculations.

6.3.4.2 Partial Flooding

The following discussions within this subsection are copied directly from the HI-STAR 190 SAR [6.0.2] with editorial modifications to place it within this chapter. Section and table numbers are preserved for continuity. See Subsection 6.0.1 for justification.

To demonstrate that HI-STAR 100MB would remain subcritical if water were to leak into the containment system, as required by 10CFR71.55, calculations in this section address partial flooding in HI-STAR 100MB 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 for all basket types.

6.3.4.3 Pellet-to-Clad Gap Flooding

The following discussions within this subsection are copied directly from the HI-STAR 190 SAR [6.0.2] with editorial modifications to place it within this chapter. Section and table numbers are preserved for continuity. See Subsection 6.0.1 for justification.

The reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated in Subsection 6.2.2. The results, presented in Table 6.2.1,

confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. Thus, for all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded.

6.3.4.4 Preferential Flooding

One of the potential conditions of preferential flooding that are considered in Paragraph 6.4.2.4 of the HI-STAR 100 SAR [6.0.1] is preferential flooding of the basket itself (i.e. different water levels in different basket cells). It was concluded that the fuel baskets cannot be preferentially flooded.

For HI-STAR 100MB, preferential flooding of the basket itself is not possible [

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6.3.4.5 Eccentric Positioning of Assemblies in Fuel Storage Cells

A fuel assembly located in the center of a basket cell is surrounded by equal amounts of water on all sides, and hence the thermalization of the neutrons that occur between the assembly and the poison in the cell wall, and also the effectiveness of the poison are equal on all sides. For an eccentric positioning, the effectiveness of the poison is now reduced on those sides where the assembly is located close to the cell walls, and increased on the opposite sides. This creates a compensatory situation for a single cell, where the net effect is not immediately clear. However, for the entire basket, and for the condition where all assemblies are located closest to the center of the basket, the four assemblies at the center of the basket are now located close to each other, separated by poison plates with a reduced effectiveness since they are not surrounded by water on any side. This now becomes the dominating condition in terms of reactivity increase. This effect is applicable to all assembly types, since those assemblies are all located close to the center of the basket, i.e. the eccentric position with all assemblies moved towards the center will be bounding regardless of the assembly type.

Nevertheless, to conservatively account for eccentric fuel positioning in the fuel storage cells, three different configurations are analyzed for each basket configuration, and the results are compared to determine the bounding positioning of the assemblies:

- Cell Center Configuration: All assemblies are 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; and
- 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.

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 6.3.13. The table shows the calculated k_{eff} values for centered and the two eccentric configurations for each condition, and the difference in k_{eff} between the centered and eccentric positioning. In most of the cases, moving the assemblies in the regular and specific cells to the periphery of the basket results in a reduction in reactivity, compared to the cell centered position, while moving the assemblies towards the center results in an increase in reactivity, compared to the cell centered position. All calculations are therefore performed with assemblies moved towards the center of the basket.

6.3.5 Potential Fuel Reconfiguration

The cask is designed to remain internally dry under any normal or accident condition. 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 is expected. However, the concerns about fuel damage, discussed in the following subsections, are principally related to HBF, i.e. fuel with an assembly average burnup of about 45 GWd/mtU or more; nevertheless, a lower burnup presented in Table 6.1.1 is conservatively assumed for HBF.

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.

6.3.7 Fuel Assemblies with Missing Rods

For fuel assemblies that are qualified for damaged fuel storage, missing and/or damaged fuel rods are acceptable. However, for fuel assemblies to meet the limitations of undamaged fuel assembly storage, missing fuel rods must be replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods in the active region.

6.3.8 Non-Fuel Hardware in PWR Fuel Assemblies

Non-fuel hardware, as discussed in Subsection 5.2.3, is permitted for storage with all PWR fuel types. Non-fuel hardware is inserted in the guide tubes of the assemblies, except for ITTRs,

which are placed into the instrument tube. Similar to discussion in Subsection 6.3.8, the presence of the non-fuel hardware reduces the amount of moderator, while the amount of fissile material is maintained, and, therefore, the reactivity of the configuration with non-fuel hardware will be lower compared to the configuration with water in guide or instrument tubes. Therefore, non-fuel hardware inserted into PWR assemblies is acceptable for all allowable PWR types, and, depending on the assembly class, can increase the safety margin.

6.3.9 Neutron Sources in Fuel Assemblies

Fuel assemblies containing start-up neutron sources are permitted for transport in the HI-STAR 100MB 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 (moderator). Therefore, the insertion of the material of the source into a fuel assembly will not lead to an increase of reactivity either.

TABLE 6.3.1

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.2

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.3

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.4

CASMO5 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE[1]

Changes in Parameters	**Δk Maximum Tolerance**	**Action/Modeling Assumption**
	MPC-37, 15x15B, 5.0 wt% ^{235}U, 40 GWd/mtU, 3 years	
Maximum UO_2 Density Decrease in UO_2 Density (10.52 g/cm^3)	Reference -0.0017	Assume max UO_2 density
Increase in Temperature 20°C 40°C 70°C 100°C	 Reference -0.0027 -0.0079 -0.0142	Assume 20°C
10% Void in Moderator 20°C with no void 20°C 100°C	 Reference -0.0214 -0.0360	Assume no void

[1] This table's results are copied directly from the HI-STAR 190 SAR [6.0.2] and are considered directly applicable to all HI-STAR 100MB fuel packages and fuel types, see Subsection 6.0.1 for justification.

TABLE 6.3.5

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.5 (continued)

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.6

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.6 (continued)

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.7

MAXIMUM REACTIVITIES WITH REDUCED MODERATOR DENSITIES
FOR CASK ARRAYS[1,2]

Case Number	Moderator Density		MPC-37, 15x15B, 5.0 wt% ^{235}U, 40 GWd/mtU, 3 years		
	Internal	External	Calculated k_{eff}	1 σ	EALF (eV)
1	100%	single cask	0.9296	0.0004	0.4487
2	100%	100%	0.9295	0.0004	0.4471
3	100%	70%	0.9292	0.0004	0.4489
4	100%	50%	0.9302	0.0004	0.4473
5	100%	20%	0.9294	0.0004	0.4510
6	100%	10%	0.9295	0.0004	0.4490
7	100%	5%	0.9301	0.0004	0.4477
8	100%	0%	0.9295	0.0003	0.4490
9	70%	0%	0.8250	0.0004	1.0940
10	50%	0%	0.7233	0.0003	3.2578
11	20%	0%	0.5218	0.0003	122.57
12	10%	0%	0.4555	0.0002	1503.9
13	5%	0%	0.4318	0.0002	7529.0
14	10%	100%	0.4504	0.0002	1649.2

[1] This table is for an infinite hexagonal array of casks with 60 cm spacing between cask surfaces.
[2] This table's results are copied directly from the HI-STAR 190 SAR [6.0.2] and are considered directly applicable to all HI-STAR 100MB fuel packages and fuel types, see Subsection 6.0.1 for justification.

TABLE 6.3.8

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.9

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.10

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.11

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.12

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.13

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.14

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.15

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.16

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.17

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.18

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

TABLE 6.3.19

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.3: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.4.A: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.4.B: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.5.A: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.5.B: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.5.C: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

FIGURE 6.3.6: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

6.4 SINGLE PACKAGE EVALUATION

6.4.1 Configuration

The calculations in this section demonstrate that a single HI-STAR 100MB 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 baskets are assumed to be loaded with fuel of the maximum permissible reactivity, i.e.

[

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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 10CFR71.55. 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 190 design:

[

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[

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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 100MB is designed for high burnup fuel (HBF). 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 cask lid provides additional assurance that water will not leak into the containment system 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 impacts of the hypothetical transport accidents, which are important to criticality safety, are limited to potential major fuel reconfiguration 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 100MB 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, except the conservative assumption of the fresh fuel assembly with 5.0 wt% ^{235}U for MBF and HBF in the MPC-32M and F-32M basket. 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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Section 6.8 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). See Appendix 6.B, Section 6.B.3, for the benchmarking of spent fuel.

The maximum k_{eff} values, calculated with 95% probability at the 95% confidence level, are listed in Table 6.4.1 for the MPC-32M and F-32M basket and in Table 6.4.2 for the F-24M basket. 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.

TABLE 6.4.1

HI-STAR 100MB SINGLE PACKAGE WITH MPC-32M AND F-32M BASKET

Configuration	% Internal Moderation	% External Moderation	Fuel Condition	Fuel Damage	Max. k_{eff}[1]	1 σ	EALF (eV)
Single Package, fully reflected	100%	100%	MBF	No	0.9483	0.0004	0.4799
			HBF	Minor	0.9488	0.0004	0.4606
Containment, fully reflected	100%	100%	MBF	No	0.9473	0.0004	0.4793
			HBF	Minor	0.9484	0.0003	0.4617
Single Package, Damaged[2]	0%	100%	MBF	No	0.4720	0.0001	141720
			HBF	Major	0.4700	0.0001	141480

[1] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.
[2] The fresh fuel assembly with 5.0 wt% ^{235}U is conservatively assumed for MBF and HBF.

TABLE 6.4.2

HI-STAR 100MB SINGLE PACKAGE WITH F-24M 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	0.9496	0.0004	0.2688
			HBF	Minor	0.9491	0.0004	0.3468
Containment, fully reflected	100%	100%	MBF	No	0.9477	0.0004	0.2704
			HBF	Minor	0.9473	0.0004	0.3479
Single Package, Damaged	0%	100%	MBF	No	0.3735	0.0001	160290
			HBF	Major	0.3715	0.0001	159650

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

6.5.1 Configuration

The studies in Subsection 6.3.4 show that the spacing and external moderator densities 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 planar and axial direction, internally and externally dry, is modeled. All other modeling assumptions are identical to the ones for the single package under normal conditions, except the conservative assumption of the fresh fuel assembly with 5.0 wt% ^{235}U for MBF and HBF in the MPC-32M and F-32M basket. The analyses are performed for all three baskets. This addresses 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 presented in Table 6.5.1 show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95 for both baskets. 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 100MB PACKAGE ARRAYS UNDER NORMAL CONDITIONS

Basket	% Internal Moderation	% External Moderation	Fuel Condition	Fuel Damage	Max. k_{eff}	1 σ	EALF (eV)
MPC-32M and F-32M[1, 2]	0%	0%	MBF	No	0.5085	0.0001	95513
			HBF	Minor	0.5086	0.0001	95897
F-24M	0%	0%	MBF	No	0.4073	0.0001	103000
			HBF	Minor	0.4070	0.0001	102650

[1] The fresh fuel assembly with 5.0 wt% ^{235}U is conservatively assumed for MBF and HBF.
[2] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.

6.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6.6.1 Configuration

The studies in Subsection 6.3.4 show that the spacing and external moderator density has 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 planar 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 presented in Table 6.6.1 show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95 for both baskets. 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 Subsection 6.3.5, 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.

TABLE 6.6.1

HI-STAR 100MB PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS

Basket	% Internal Moderation	% External Moderation	Fuel Condition	Fuel Damage	Max. k_{eff}	1 σ	EALF (eV)
MPC-32M and F-32M[1, 2]	0%	100%	MBF	No	0.4755	0.0001	134290
			HBF	Major	0.4744	0.0001	134240
F-24M	0%	100%	MBF	No	0.3780	0.0001	150280
			HBF	Major	0.3759	0.0001	149790

[1] The fresh fuel assembly with 5.0 wt% ^{235}U is conservatively assumed for MBF and HBF.
[2] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.

TABLE 6.6.2

HI-STAR 100MB PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS
(DEFENSE IN DEPTH)

Basket	% Internal Moderation	% External Moderation	Fuel Condition[1]	Fuel Burnup, GWd/mtU	Max. k_{eff}	1 σ	EALF (eV)
MPC-32M and F-32M[2]	100%	100%	HBF	41.86	0.9697	0.0004	0.4107
F-24M	100%	100%	HBF	0	0.9558	0.0004	0.3037

[1] The major fuel reconfiguration is applied to HBF.
[2] The maximum k_{eff} is the highest k_{eff} determined from MPC-32M and F-32M analyses reported.

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Not Applicable. The HI-STAR 100MB 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 used to calculate the k_{eff} values for the cask as described in Section 6.3. Further, all calculations were performed on the same computer hardware, specifically, personal computers under Microsoft Windows.

Additional isotopic benchmark calculations performed for the burnup methodology for HI-STAR 100MB are presented in Appendix 6.B.

6.9 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 17.

[6.0.2] Holtec International Report HI-2146214, Safety Analysis Report HI-STAR 190 Cask System, USNRC Docket 71-9373, Revision 2.

[6.0.3] Holtec International Report HI-2002444, Final Safety Analysis Report for the HI-STORM 100 Cask System, USNRC Docket 72-1014, Revision 14.

[6.0.4] Holtec International Report HI-2114830, Final Safety Analysis Report on the HI-STORM FW System, USNRC Docket 72-1032, Revision 5.

[6.1.1] U.S. Code of Federal Regulations, "Packaging and Transportation of Radioactive Materials," Title 10, Part 71.

[6.1.2] NUREG-1617, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, USNRC, Washington, D.C., March 2000.

[6.1.3] USNRC Standard Review Plan, NUREG-0800, Section 9.1.2, Spent Fuel Storage, Rev. 2 - July 1981.

[6.3.1] X-5 Monte Carlo Team, MCNP - A General Monte Carlo N-Particle Transport Code, Version 5, LA-UR-03-1987, Los Alamos National Laboratory, April 2003 (Revised 2/1/2008).

[6.3.2] "CASMO5/CASMO5M A Fuel Assembly Burnup Program Methodology Manual", SSP-08/405, Rev. 1, Studsvik Scandpower, Inc.

[6.3.3] "CASMO5 A Fuel Assembly Burnup Program, User's Manual," SSP-07/431, Rev. 4, Studsvik Scandpower, Inc.

[6.3.4] J.M. Cano, R. Caro, and J.M Martinez-Val, "Supercriticality Through Optimum Moderation in Nuclear Fuel Storage*," Nucl. Technol.*, 48, 251-260, (1980).

[6.4.1] M.G. Natrella, "Experimental Statistics", National Bureau of Standards, Handbook 91, August 1963.

[6.4.2] Holtec International Report HI-2156424, "Criticality Evaluation of HI-STAR 190", latest revision. (Holtec Proprietary)[1].

[1] Supporting document submitted with the HI-STAR 190 License application

Appendix 6.A
Proprietary Appendix Withheld per 10 CFR 2.390

Appendix 6.B

Proprietary Appendix Withheld per 10 CFR 2.390

Appendix 6.C

Propreitary Appendix Withheld per 10 CFR 2.390

Appendix 6.D
Proprietary Appendix Withheld per 10 CFR 2.390

Appendix 6.E
Proprietary Appendix Withheld per 10 CFR 2.390

CHAPTER 7: PACKAGE OPERATIONS

7.0 INTRODUCTION[1]

This chapter provides a summary description of the essential elements and requirements to prepare the HI-STAR 100MB 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. 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 100MB 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 100MB 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.
- A technical evaluation is also performed for site specific conditions (such as thermal and shielding considerations) that may impact operational steps.
- 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.

[1] The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [7.1.7]- with minor editorial changes

- Procedures contain provisions for classroom and hands-on training and for a Holtec approved personnel qualification process to insure 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.

The operations described in this chapter assume that either the MPC has been loaded with fuel in accordance with its governing CoC and has met the requirements set forth in this safety analysis to merit designation as a competent containment barrier or that the fuel will be loaded into or unloaded directly from the HI-STAR 100MB cask submerged in a spent fuel pool using a bare fuel basket.

US Department of Transportation (USDOT) regulations in 49CFR applicable to the transport of the HI-STAR 100MB Package 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 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 100MB. 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, MPC handling procedures, training, equipment and process qualifications. Users shall implement controls to ensure that the lifted weights do not exceed the design limit of the lifting appurtenance. The cask user shall implement controls to ensure that the cask cannot be subjected to a fire event in excess of design limits during loading operations.

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 site specific conditions.

The operations covered in this safety analysis address the following areas:

HI -STAR 100MB - MPC

1. Transfer of the MPC from the HI-TRAC transfer cask to HI-STAR 100MB
2. Preparing packaging for off-site transport
3. Unloading of the MPC at the shipping destination

4. Fuel loading of MPC for the "load and go" scenario
5. Fuel unloading of MPC in a spent fuel pool or appropriate facility

HI -STAR 100MB – Bare Fuel Basket

6. Fuel loading of the bare basket cask
7. Fuel unloading of the bare basket cask
8. Preparation for shipment of an empty cask

Section 7.5 contains additional requirements for the transport of HBF including the qualification of the MPC as an inner containment boundary, the confirmation of the integrity of the HBF and the surface inspection of MPCs with HBF.

Section 7.6 provides burnup verification conditions of the HI-STAR 100MB Package.

Section 7.7 specifies the content conditions of the HI-STAR 100MB 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 determined to meet all requirements of the CoC before being released for shipment.

Holtec Non-Proprietary Version

7.1 PACKAGE LOADING[1]

The essential elements required to prepare the HI-STAR 100MB Package for MPC loading or loading fuel directly into the cask in a bare basket and to ready the cask for transport as a Transport Package are described below .

7.1.1 Preparation of the Overpack for Loading (MPC or Bare Basket)

1. If the HI-STAR 100MB Packaging has previously been used to transport spent fuel, the HI-STAR 100MB 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 100MB 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 [7.1.1] and 10CFR20.1906 [7.1.2]. If necessary, the HI-STAR 100MB Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties.

4. The impact limiters, 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 cask is upended neutron shield relief devices are inspected to confirm that they are installed, intact and not covered by tape or any other covering.

6. The cask lid is removed and used seals are removed, and discarded if necessary.

7. The containment closure flange 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 shall be re-faced with a corrosion resistant veneer.

8. The closure lid bolts are inspected for distortion and damaged threads and any suspect bolts are replaced.

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[1] The material presented in this section was adopted from the previously approved HI-STAR 190 FSAR [7.1.7]with minor editorial changes

9. Any foreign material is removed from inside the cask.

7.1.2 Acceptance of an MPC with HBF

An MPC containing HBF must pass the acceptance criteria in Section 7.5 to be deemed suitable as an inner containment boundary. Lastly, an MPC containing high burn-up fuel and stored under the provisions of 10CFR 72 shall undergo an MPC enclosure vessel shell surface defect inspection prior to shipment according to Section 7.5.

7.1.3 Transfer of MPC to the HI-STAR 100MB overpack

Note:
HI-STAR 100MB receipt inspection and preparation may be performed independent of procedural sequence, but prior to transfer of the loaded MPC.

1. Perform a HI-STAR receipt inspection and cleanliness inspection in accordance with a site-approved inspection checklist, if required.

Note:
MPC transfer may be performed at any location deemed appropriate by the licensee. The following steps describe the general transfer operations. The HI-STAR 100MB may be positioned on an air pad, roller skid or any other suitable equipment in the cask receiving area or at the ISFSI. The HI-STAR 100MB or HI-TRAC may be handled using any equipment specifically designed for such a function. The licensee is responsible for assessing and controlling floor loading conditions during the MPC transfer operations. Installation of the lid and other components may vary according to the cask movement methods and location of MPC transfer. The operations for MPC fuel loading for the “load and go” scenario are provided in Subsection 7.1.6.

2. Position an empty HI-STAR 100MB at the designated MPC transfer location.
3. Remove any road dirt with water. Remove any foreign objects from cavity locations.
4. Transfer the HI-TRAC to the MPC transfer location.
5. Install the mating device on top of the HI-STAR 100MB.
6. Position HI-TRAC above HI-STAR 100MB.
7. Align HI-TRAC over HI-STAR 100MB and mate the components.
8. Attach the MPC to the lifting device in accordance with the site-approved rigging procedures.
9. Raise the MPC slightly to remove the weight of the MPC from the mating device.
10. Remove the HI-TRAC bottom lid using the mating device.

ALARA Warning:
Personnel should remain clear (to the maximum extent practicable) of the mating device open end during MPC lowering due to radiation streaming. The mating device may be used to supplement shielding during removal of the MPC lift rigging.

11. Lower the MPC into HI-STAR 100MB.

12. Disconnect the MPC lifting slings from the lifting device.

13. Remove HI-TRAC from on top of HI-STAR 100MB with or without the HI-TRAC bottom lid.

14. Remove the MPC lift rigging and install plugs in the empty MPC bolt holes*.

15. Remove the mating device from on top of HI-STAR 100MB.

7.1.4 Cask Closure (MPC)

1. The test port plugs on the inter-seal test ports of the closure lid and closure lid port covers are installed with new seals and torqued. The containment closure flange's sealing surface protective cover is removed. The sealing surfaces on the closure lid are inspected for signs of damage or particulate matter that might affect the seal performance. Any particulate matter or sealing surface damage that would prevent a seal is remedied. The closure lid is installed using either new or existing seals. The closure lid bolts are installed and torqued. Bolt torque requirements and recommended tightening procedure 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. If the MPC contains HBF, then the cask cavity is leak tested to the required acceptance criteria in chapter 8. Unacceptable leakage rates will require unloading of the MPC. Note – this leak test is for MPCs that contain HBF. The leak test of the overpack closure devices, which is performed regardless of MPC contents, is described below.
3. The cask cavity is dried, evacuated and backfilled to the requirements in Table 7.1.2.
4. The closure lid access port plug is closed.
5. The closure lid inner-seal and closure lid access port plug seal are leak tested to the required acceptance criteria in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

7.1.5 Preparation for Transport (MPC)

1. A periodic leakage test of the overpack's containment boundary shall be performed unless such test has been performed less than a year ago:

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* Upon installation, studs, nuts, and threaded plugs shall be cleaned and inspected for damage or excessive thread wear (replaced if necessary) and coated with a light layer of Loctite N-5000 High Purity Anti-Seize (or equivalent).

a. If installed, the closure lid inter-seal test port plug(s) and closure lid port cover inter-seal test port plug are removed. The closure lid inner seal and vent and drain port cover plate inner seals are leak tested to the required acceptance criteria set forth in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

b. If necessary, the closure lid inter-seal test port plug, closure lid port cover, cover plate inter-seal test port plug installed with new seals.

c. The closure lid bolts are installed and torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The user may attach security seals to the closure lid bolts at this time.

d. The overpack containment space is dried, evacuated and backfilled to the requirements in Table 7.1.2.

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 should be installed promptly. Personnel should remain clear and exercise other appropriate ALARA controls when working around the bottom end of the cask.

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. If required, the cask lifting appurtenance is removed. The 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.

7. The cask trunnions are made inaccessible by cap or cover or other appropriate ancillary device that renders the trunnions inoperable. The package tie-down and restraint system is installed, a cover is installed over at least one of the access tubes on the top impact limiter. A security seal may be installed on the top impact limiter. If applicable, the security seal serial number(s) are recorded in the shipping documents.

8. Final radiation surveys of the package surfaces per 10CFR71.47 [7.1.3] and 49CFR173.443 [7.1.1] are performed and if necessary, the HI-STAR 100MB Packaging

is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents. 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. The final location of measurements and the measurements shall be recorded in the shipping documents.

9. The surface temperatures of the accessible areas of the package are measured if the personnel barrier will not be used.

10. For packages containing HBF, surface temperatures are measured as required by the post-shipment fuel integrity acceptance test specified in chapter 8. 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.

11. 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.

12. 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 [7.1.4].

    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 transport.

7.1.6 Loading the MPC with Spent Fuel ("Load and Go" Scenario)

Note, the HI-STAR 100MB is dry loaded with an MPC using the HI-TRAC transfer cask. This section describes the operational steps for the "load and go," scenario.

1. Visually inspect the MPC to ensure that it is clean and free of debris.

2. Place the MPC in the transfer cask.

3. Place the transfer cask containing the MPC into the spent fuel pool.

4. Prior to loading the fuel into the MPC, the user identifies the fuel to be loaded. A pre-loading verification is made to assure that damaged fuel and fuel debris will be placed in damaged fuel containers and that the DFCs will occupy authorized locations in the MPC. The fuel is independently verified to see that it meets the conditions of the CoC.

5. Install the drain line to the underside of the MPC lid, then install MPC lid and remove the transfer cask containing the loaded MPC from the spent fuel pool.

6. Lower the MPC internal water level in preparation for MPC lid-to-shell welding.

7. Perform combustible gas monitoring and purge the space under the MPC lid with an inert gas to ensure that there is no combustible mixture present in the welding area.

8. Weld the MPC lid, using the Automated Welding System (AWS), in accordance with the licensing drawings using approved procedures. Repair any weld defects in accordance with the applicable code and re-perform the NDE until the weld meets the required acceptance criteria.

9. Perform MPC lid-to-shell weld pressure testing in accordance with site-approved procedures.

10. Repeat liquid penetrant examination on the final pass of the MPC lid-to-shell weld, and repair any defects in accordance with the applicable code requirements and re-perform the NDE in accordance with approved procedures.

11. Drain the MPC.

12. Dry and backfill the MPC using either the Vacuum Drying System or Forced Helium Dehydration. Drying method restrictions are located in Table 7.1.5.

    a. Vacuum Drying System (VDS) Method

i. Attach the VDS to the vent and drain port RVOAs. Other equipment configurations that achieve the same results may also be used.

ii. Start the VDS system and slowly reduce the MPC pressure to below 3 torr.

iii. When the MPC is dry in accordance with the acceptance criteria in Table 7.1.5, then backfill the MPC in accordance with Table 7.1.4 .

iv. Close the drain and vent port RVOAs .

b. Forced Helium Dehydration Method

i. Attach the moisture removal system to the vent and drain port RVOAs. Other equipment configurations that achieve the same results may also be used.

ii. Circulate the drying gas through the MPC while monitoring the circulating gas for moisture. Collect and remove the moisture from the system as necessary.

iii. Continue the monitoring and moisture removal until Table 7.1.5 requirements are met for MPC dryness.

iv. Adjust the helium pressure in the MPC to provide a fill pressure as required by Table 7.1.4.

13. Weld the vent and drain port cover plates and perform NDE in accordance with the applicable code and re-perform the NDE until the weld meets the required acceptance criteria.

14. Perform a leakage test of the MPC vent port cover plate and drain port cover plate in accordance with site-approved procedures.

15. Weld the MPC closure ring to the MPC shell and the MPC lid, and perform NDE in accordance with approved procedures. Repair any weld defects in accordance with the applicable code and re-perform the NDE until the weld meets the required acceptance criteria.

16. Decontaminate the external surface of the transfer cask to the limits established for the site, as required.

17. Proceed with the steps for MPC transport in HI-STAR 100MB, 7.1.5.

7.1.7 Loading the Bare Basket Cask with Spent Fuel[2]

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. The cask storage cavity is filled with either spent fuel pool water or clean borated 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. 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. The pre-selected assemblies are loaded into the cask and a visual verification of the assembly identification is performed.
3. 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 to determine if the sealing surface is clear of potential solid contamination and free from gross damage that might affect the seal performance. Any contamination or damage that would prevent a seal is remedied. Prior to placing the inner lid in the water, any old seals are removed and the sealing surfaces are inspected to verify they are free of damage and contamination that might affect seal performance. Any contamination 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. 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. Inner closure lid bolts may be installed at any time after the inner closure lid is installed but before the cask is dried.

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[2] The material presented in this section was adopted from the previously approved HI-STAR 180D SAR [7.1.5] with minor editorial changes

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.

4. 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.
5. 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.
6. Dose rates are measured at the inner closure lid and around the cask body to confirm appropriate radiological control.
7. The lid vent line is opened to prevent cask pressurization and temporary shielding (if used) is installed.
8. The inner closure lid bolts are torqued after the vent line is opened and before the cask cavity is drained. Bolt torque requirements and recommended tightening procedure 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.

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.

9. For moderate or high burnup fuel, the Forced Helium Dehydration (FHD) System may be 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 7.1.6 and circulated through the duration given in Table 7.1.6 to ensure that the cask cavity is suitably dry.

10. Optionally, 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 and time limits are necessary to ensure the vacuum drying criteria is met. Users shall refer to Table 7.1.6 and Table 7.1.7 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 7.1.6 for the duration given in Table 7.1.6, with the valve closed, it shall be considered dry.
11. The cask cavity is backfilled to the requirements in Table 7.1.8 and the port caps/plugs are closed.
12. With the inner closure lid inter-seal test port plug 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 to the required acceptance criteria provided in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals. Note that 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.
13. The sealing surfaces and mating surfaces of the inner closure lid port covers are inspected for signs of damage. Any damage that would prevent a seal is remedied and any old seals are removed. The space beneath the port covers are filled to the requirements in Table 7.1.8. The port cover bolts are torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.3 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 acceptance criteria provided in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

7.1.8 Cask Closure (Bare Basket)[3]

1. The test port plugs on the inter-seal test ports of the inner closure lid and inner closure lid port covers are installed and torqued. The containment closure flange outer sealing surface protective cover is removed. The sealing surfaces for the outer closure lid are inspected for signs of damage or particulate matter that might affect the seal performance. Any particulate matter or sealing surface damage that would prevent a seal is remedied. The user ensures that the inner or outer closure lid inter-seal test port plug(s) are installed. The outer closure lid is installed using new seals. The outer closure lid bolts are installed and torqued. Bolt torque requirements and recommended

[3] The material presented in this section was adopted from the previously approved HI-STAR 180D SAR [7.1.5] with minor editorial changes

tightening procedure are provided in Table 7.1.3 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 7.1.8.
3. The outer closure lid access port plug is closed.
4. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested to the required acceptance criteria in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

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 and torqued.

7.1.9 Preparation for Transport (Bare Basket)[4]

1. If more than twelve months have elapsed since the performance of the leakage tests described in Subsection 7.1.8, a periodic leakage test shall be performed as follows:

   a. If installed, the outer closure lid is removed and the inner closure lid inter-seal test port plug(s) and inner closure lid port cover inter-seal test port plugs are removed. The inner closure lid inner seal and vent and drain port cover plate inner seals are leak tested to the required acceptance criteria listed in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

   b. The inner closure lid inter-seal test port plug(s) and inner closure lid port cover inter-seal test port plugs are installed with new seals.

   c. The sealing surfaces for the outer closure lid are inspected for signs of damage or particulate matter that might affect the seal performance. Any particulate matter or sealing surface damage that would prevent a seal is remedied. 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 are provided in Table 7.1.3 and Figure 7.1.1, respectively. The user may attach security seals to the outer closure lid bolts at this time.

   d. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.8.

   e. The outer closure lid access port plug, fitted with a new seal, is torqued to the requirements in Table 7.1.3. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested to the required acceptance criteria in chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

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[4] The material presented in this section was adopted from the previously approved HI-STAR 180D SAR [7.1.5] with minor editorial changes

f. 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.

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 should be installed promptly. Personnel should remain clear and exercise other appropriate ALARA controls when working around the bottom end of the cask.

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. If required, the cask trunnions are removed and the trunnion hole plugs are installed. The 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 7.1.3 and Figure 7.1.1, respectively.

7. 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.

8. Final radiation surveys of the package surfaces per 10CFR71.47 [7.1.3] and 49CFR173.443 [7.1.1] are performed and if necessary, the HI-STAR 100MB Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents.

9. The surface temperatures of the accessible areas of the package are measured if required.

10. 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.

11. 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 [7.1.4].

    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 transport.

Table 7.1.1

HI-STAR 100MB Package Torque Requirements - MPC

Fastener (See Note 1)	**Recommended Torque (N-m), τ** (See Note 2)	**Minimum Total Bolt Preload** kN (See Note 7)	**Comments**
Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	13,500	Intermediate pass is final pass for empty but previously used packages
Closure Lid Port Cover Bolts	See Note 3	68.2	None
Top Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Bottom Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Test Port Plugs	"Snug Tight"	N/A	None

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 from 0.12 (extremely effective lubricant such as Bowman Anti-Sieze) to 0.18 (commercial lubricant). The above formula is derived from Shigley, et. al. [7.1.6]. The above torque values assume a high quality lubricant (K=0.12). A higher value may be used based on the lubricant supplier's recommendation.

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 referenced in the CoC.

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

Type XL Cask XL with MPC Backfill Requirements

Cask Space	**Reference Pressure or Pressure Range**
MPC	See Table 7.1.4
Cask Annulus (Notes 1 and 2)	6 psig to 15 psig
Closure Lid Port Space	Atmospheric
Backfill Gas	
Type	Helium
Reference Purity	99.9 % Nom.

Notes:

1. The reference pressure is based on a reference cask space bulk temperature of ≥ 21.1°C (70°F)
2. Following cask drying operations, the gas temperature inside the annulus 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 annulus pressure is within the specified range is sufficient.

Table 7.1.3
HI-STAR 100MB PACKAGE TORQUE REQUIREMENTS -Bare Basket

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	13,500	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	13,500	Intermediate pass is final pass for empty but previously used packages
Inner/ Outer Closure Lids Port Cover Bolts	See Note 3	68.2	None
Outer Closure Lid Access Port Plug	"Snug Tight"	N/A	Alternate torque may be permitted with Holtec approval
Inner/ Outer Lids and Port Cover Test Plugs	"Snug Tight"	N/A	None
Top Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Bottom Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None

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 from 0.12 (extremely effective lubricant such as Bowman Anti-Sieze) to 0.18 (commercial lubricant). The above formula is derived from Shigley, et. al. [7.1.6]. The above torque values assume a high quality lubricant (K=0.12). A higher value may be used based on the lubricant supplier's recommendation.

   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 referenced in the CoC.
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 7.1.4

MPC BACKFILL PRESSURE REQUIREMENTS

MPC Type	Pressure Range (Note 1)
MPC-32M	$\geq$ 2.9 psig and $\leq$ 31.8 psig
Note 1: Helium used for backfill of MPC shall have a purity of $\geq$ 99.995%. The pressure range is based on a reference temperature of 21.1^{o}C (70^{o}F).	

TABLE 7.1.5

TYPE XL CASK CAVITY WITH MPC DRYING LIMITS FOR "LOAD-AND-GO" MPCs-Please Review for Applicability (NOTE 1)

MPC Type	Fuel Burnup (MWd/mtU) (Note 4)	MPC Heat Load (kW)	Method of Moisture Removal (Notes 2 and 3)
MPC-32M	All burnups up to maximum in Table 7.7.1	See Table 7.7.5	VDS or FHD

NOTES:

1. The limits presented in this table are applicable only for "load-and-go" MPCs where the contents are loaded and dried under this certificate.

2. VDS means a vacuum drying system operated continuously or in cyclic mode in compliance with ISG-11, Rev. 3 requirements. The acceptance criterion when using a VDS is the MPC cavity pressure shall be ≤ 3 torr for ≥ 30 minutes while the MPC is isolated from the vacuum pump. Vacuum drying of the MPC must be performed with the annular gap between the MPC and the CASK filled with water.

3. FHD means a forced helium dehydration system. The acceptance criterion when using an FHD system is the gas temperature exiting the demoisturizer shall be ≤ 21^{o}F for ≥ 30 minutes or the gas dew point exiting the MPC shall be ≤ 22.9^{o}F for ≥ 30 minutes.

Table 7.1.6

TYPE SL CASK WITH BARE BASKET DRYING LIMITS AND CRITERIA

Fuel Burnup (MWd/mtU)	**Heat Load (kW)**	**Method of Moisture Removal**
All Fuel Assembly Burnups	See Table 7.7.5	Forced Helium Dehydration
		Vacuum Drying
Dryness Criteria		
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

Table 7.1.7

CLADDING TEMPERATURE LIMITS UNDER 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

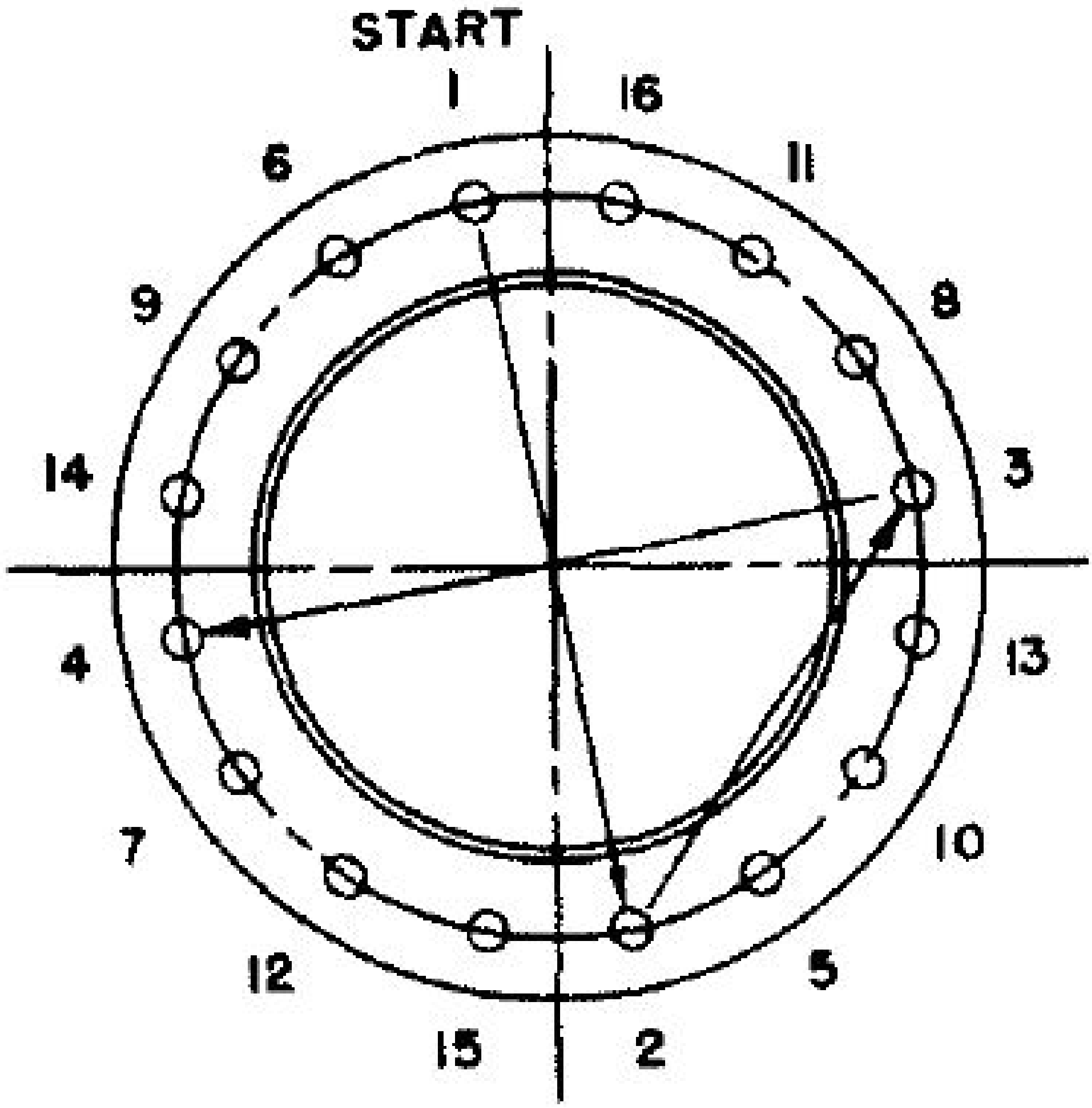
Table 7.1.8

TYPE SL CASK WITH BARE BASKET BACKFILL REQUIREMENTS

Cask Space	**Reference Pressure or Pressure Range**
Cask Cavity Space (Notes 1 and 2)	F-32M: 2.9 psig to 21.8 psig F-24M: 2.9 psig to 21.8 psig
Cask Inter-Lid Space (Notes 1 and 3)	0 psig to 2.5 psig
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.



Note: It is important that all bolted joints be tightened uniformly and in a diametrically staggered pattern as illustrated above. Due to the large diameter of the 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 the Certificate Holder.

FIGURE 7.1.1

SCEMATIC DIAGRAM OF THE RECOMMENDED BOLT TIGHTENING PROCEDURE

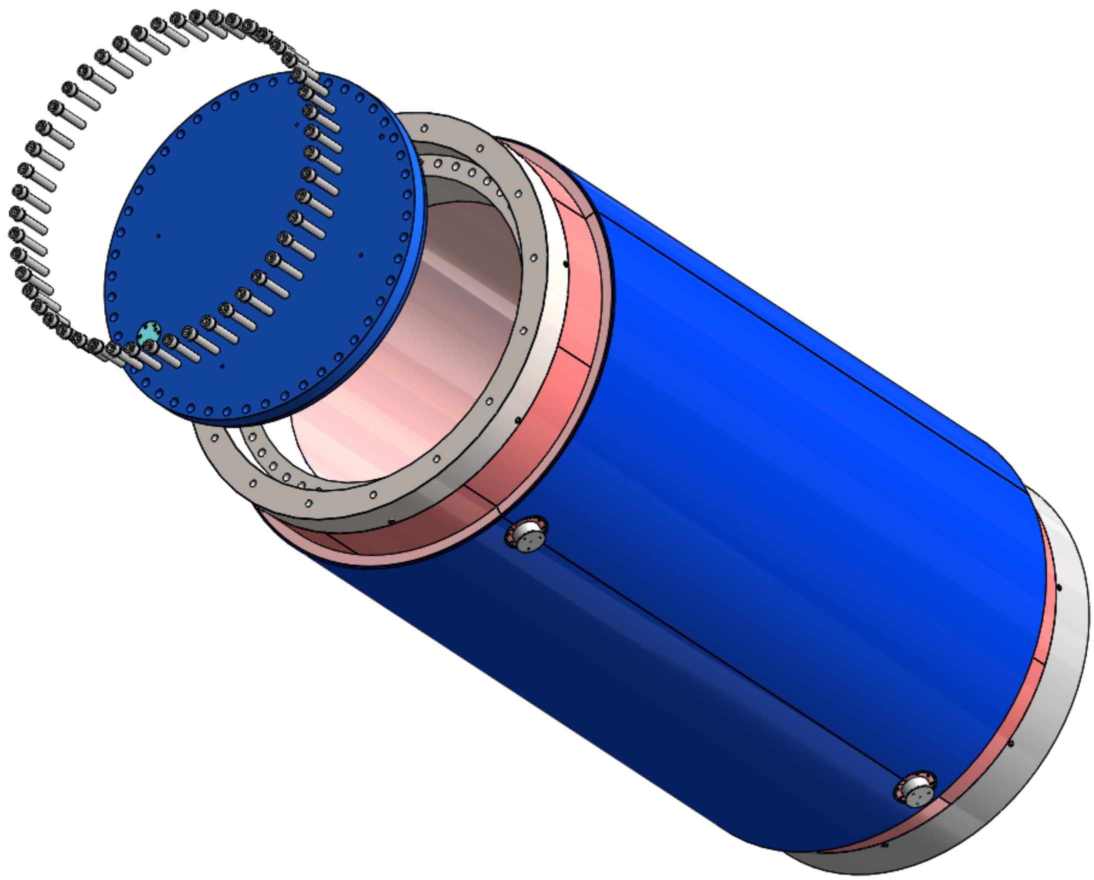
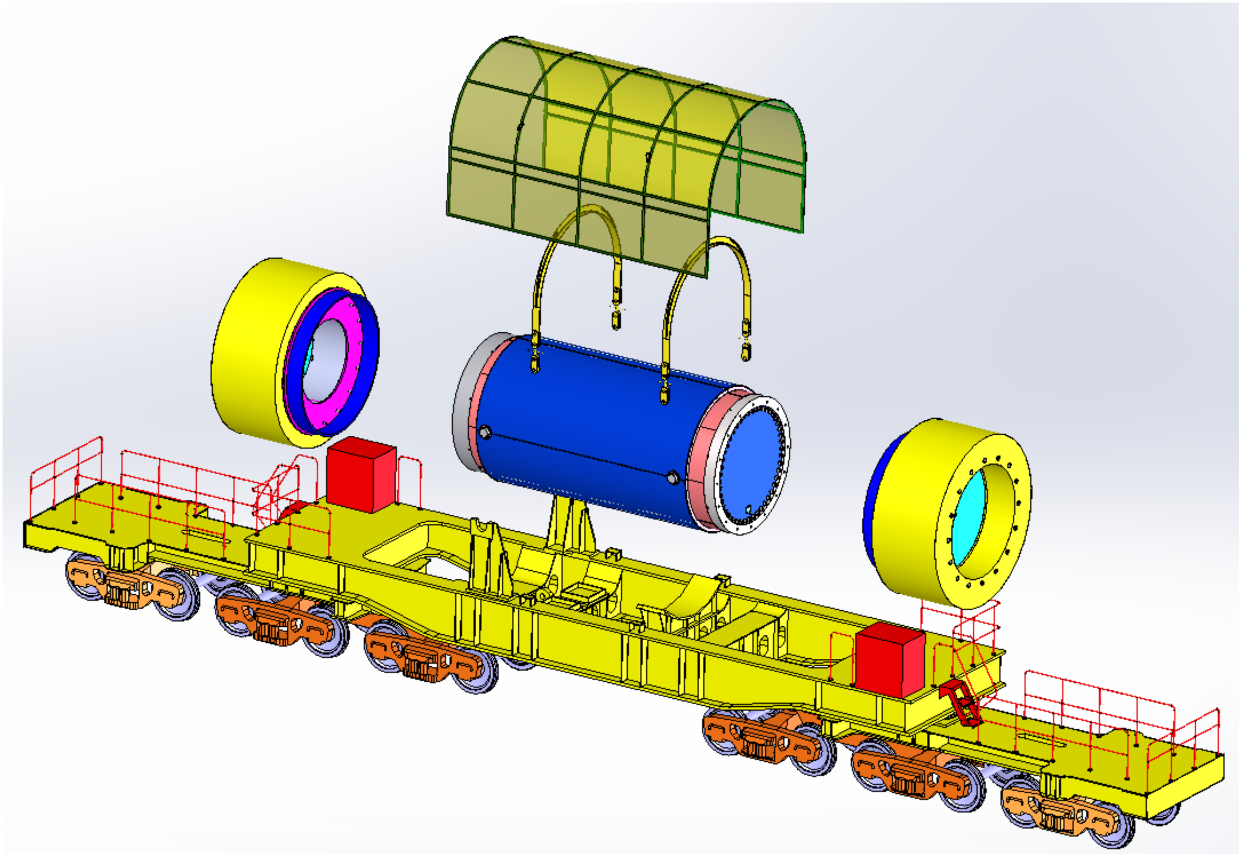


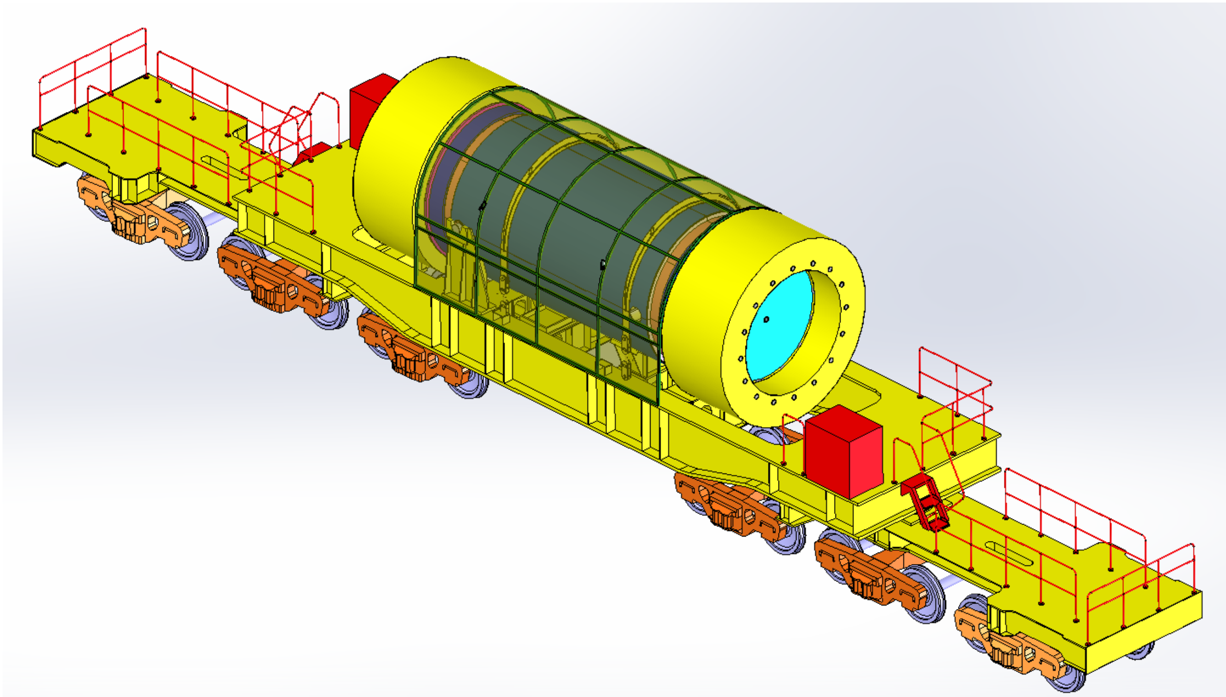
FIGURE 7.1.2: HI-STAR 100MB CLOSURE LID, BOLTS



NOTE: LONGITUDINAL STOPS (AXIAL RESTRAINTS) NOT SHOWN.

FIGURE 7.1.3: GENERAL ARRANGEMENT OF THE HI-STAR 100MB ON A TRANSPORT VEHICLE WITH IMPACT LIMITER, AND TIE-DOWNS ATTACHED. PERSONNEL BARRIER INSTALLED

(SHOWN FOR ILLUSTRATION ONLY)



Note: Longitudinal Stops (axial restraints) not shown. The bottom trunnions are shown engaged by retractable downending device; however, all trunnions must be disengaged and rendered inoperable.

FIGURE 7.1.4: HI-STAR 100MB TRANSPORT ASSEMBLY ON RAIL CAR (SHOWN FOR ILLUSTRATION ONLY)

7.2 PACKAGE UNLOADING[1]

In the event that the HI-STAR 100MB Package needs to be unloaded, the essential elements required to prepare the package for MPC unloading are described below.

7.2.1 Receipt of Package from Carrier

1. The HI-STAR 100MB 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 [7.1.1] and 10CFR20.1906 [7.1.2]. If necessary, the HI-STAR 100MB 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. The location of measurements shall correspond to the same locations recorded for the radiation survey prior to shipping. 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. The location of measurements shall correspond to the same locations recorded for shipping. 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 bottom end of the HI-STAR 100MB 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 material presented in this section was adopted from the previously approved HI-STAR 190 SAR [7.2.1] with minor editorial changes

5. The impact limiters 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.

7. The cask lifting appurtenance is 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 MPC

1. The outer lid access port cover is removed and a gas sample is drawn from the cask cavity space to determine radiological conditions.
2. The cask cavity gas is handled in accordance with Radiation Protection directions and the closure lid is removed.
3. Position the HI-STAR 100MB at the designated MPC transfer location.
4. Remove any road dirt with water. Remove any foreign objects from cavity locations.
5. Transfer the HI-TRAC to the MPC transfer location.
6. Install the mating device on top of the HI-STAR 100MB.
7. Position HI-TRAC above HI-STAR 100MB.
8. Remove any plugs from the MPC bolt holes.
9. Attach the MPC to the MPC lifting device in accordance with the site-approved rigging procedures.
10. Align HI-TRAC over HI-STAR 100MB and mate the components.
11. Remove the HI-TRAC bottom lid using the mating device.

ALARA Warning:
Personnel should remain clear (to the maximum extent practicable) of the mating device open end during MPC raising due to radiation streaming. The mating device may be used to supplement shielding during removal of the MPC lift rigging.

12. Attach the overhead lifting device and raise the MPC into HI-TRAC.
13. Install the HI-TRAC bottom lid using the mating device.
14. Lower the MPC onto the HI-TRAC bottom lid.
15. Disconnect the MPC lifting slings from the lifting device.
16. Remove HI-TRAC from on top of HI-STAR 100MB.

17. Remove the mating device from on top of HI-STAR 100MB.

7. 2.3 Removal of Contents from MPC

1. The HI-TRAC annulus is filled with water. Water addition should be performed in a slow and controlled manner until water steam generation has ceased.
2. The MPC closure ring above the vent and drain ports and the vent and drain port cover plates are core-drilled and removed to access the vent and drain ports.
3. A temporary attachment is connected to the vent port to open the vent port and collect a gas sample from inside the MPC. A gas sample analysis is performed to assess the condition of the fuel assembly cladding.
4. The MPC is cooled as necessary to reduce the MPC internal temperature. This allows water flooding without thermally shocking the fuel assemblies or over-pressurizing the MPC from the formation of steam. The MPC is then filled with water.
5. Appropriate monitoring for combustible gas shall be performed prior to, and during MPC lid welding operations. The space below the MPC lid shall be vented/exhausted or purged with inert gas prior to, and during MPC lid cutting operations to provide additional assurance that flammable gas concentrations will not develop in this space. Purging is the recommended method to mitigate flammable gas accumulation.
6. The MPC lid to MPC shell weld is removed using an automated weld removal system or other suitable equipment. The weld removal equipment is removed with the MPC lid left in place.
7. The top surfaces of the MPC and HI-TRAC are cleared of metal shavings.
8. The inflatable annulus seal is installed.
9. The MPC lid slings are attached, and the lift yoke is engaged to the HI-TRAC lifting blocks.
10. The HI-TRAC is placed in the spent fuel pool or other appropriate unloading area and the MPC lid is removed.
11. The spent fuel assemblies are removed from the MPC using applicable site procedures.
12. The HI-TRAC and MPC are returned to the designated preparation area where any water in the MPC is pumped back into the spent fuel pool, liquid radwaste system, or other approved location as necessary.
13. The annulus water is drained and the MPC and overpack are decontaminated.

7. 2.4 Removal of Contents from Bare Basket Cask[2]

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.

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[2]The material presented in this section was adopted from the previously approved HI-STAR 180D SAR [7.1.5] with minor editorial changes

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 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 OF EMPTY PACKAGE FOR TRANSPORT[1]

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 [7.1.1] and 10CFR71.87(i) [7.1.3] 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 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 gram U-235 in accordance with 49 CFR 173.453(b)

3. The closure lid is installed and the bolts are torqued. See Table 7.1.1 or Table 7.1.3 for torque requirements.

4. The closure lid port covers are installed if necessary.

5. The cask is downended and positioned on the transport equipment.

6. 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(b) and (c). Any issues are identified to site management and the cask is decontaminated as directed by site radiation protection.

[1] The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [7.2.1] with minor editorial changes

- 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.

7. Final radiation surveys of the empty package surfaces are performed per 49CFR173.428(a).

8. If desired, the personnel barrier and personnel barrier locks are installed and the personnel barrier keys are transferred to the carrier.

9. 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 [7.1.4] have been removed, obliterated, or covered and the "Empty" label prescribed in 49CFR172.450 [7.1.4] 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.

10. The empty package is then released for transport.

7. 4 OTHER OPERATIONS

There are no other operations for the HI-STAR 100MB 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.

7.5 ADDITIONAL REQUIREMENTS FOR THE TRANSPORT OF HBF[1]

The MPC Enclosure Vessel is credited as an inner containment boundary for high burnup fuel (HBF). The acceptance criteria and supplemental requirements for crediting the MPC Enclosure Vessel are contained in chapter 8. These requirements include the performance of the pre-shipment MPC leakage test included in subsection 7.1.4.

The user of MPCs containing HBF and stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72 shall confirm that the general licensee implementing the approved HBF Aging Management Program has not concluded that the analyzed configuration of the HBF has been compromised during the period of extended storage.

MPCs containing high burn-up fuel and stored under the provisions of 10CFR 72 shall undergo an MPC enclosure vessel shell surface defect inspection prior to shipment as specified in subsection 8.1.6.

[1] The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [7.2.1] with minor editorial changes

7.6 BURNUP VERIFICATION CONDITIONS OF THE HI-STAR 100MB PACKAGE[1]

For those spent fuel assemblies that need to meet the burnup requirements specified in Table 7.7.3 or Table 7.7.7, a burnup verification shall be performed in accordance with either Method A or Method B described below.

Method A: Burnup Verification Through Quantitative Burnup Measurement

For each assembly in the F-32M or MPC-32M where burnup credit is required, the minimum burnup is determined from the burnup requirement applicable to the configuration chosen for the cask (see Table 7.7.3(a)). A measurement is then performed that confirms that the fuel assembly burnup exceeds this minimum burnup. The measurement technique may be calibrated to the reactor records for a representative set of assemblies. The assembly burnup value to be compared with the minimum required burnup should be the measured burnup value as adjusted by reducing the value by a combination of the uncertainties in the calibration method and the measurement itself.

Method B: Burnup Verification Through an Administrative Procedure and Qualitative Measurements

Depending on the location in the basket, assemblies loaded into a specific F-32M basket or MPC-32M can either be fresh, or have to meet a single minimum burnup value. The assembly burnup value to be compared with the minimum required burnup should be the reactor record burnup value as adjusted by reducing the value by the uncertainties in the reactor record value. An administrative procedure shall be established that prescribes the following steps, which shall be performed for each cask loading:

- Based on a review of the reactor records, all assemblies in the spent fuel pool that have a burnup that is below the minimum required burnup of the loading curve for the cask to be loaded are identified.
- After the cask loading, but before the release for shipment of the cask, the presence and location of all those identified assemblies is verified, except for those assemblies that have been loaded as fresh assemblies into the cask.

Additionally, for all assemblies to be loaded that are required to meet a minimum burnup, a visual check or gross measurement shall be performed that verifies that the assembly is not a fresh assembly. This measurement is not applicable if reactor records show that at the time of fuel loading, no fresh fuel assemblies were present in the spent fuel pool.

[1] The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [7.2.1] with minor editorial changes

7.7 PERMISSIBLE CONTENT CONDITIONS IN THE HI-STAR 100MB PACKAGE

The following tables and figures provide the content conditions for the HI-STAR 100MB.

Table/Figure	Description
Table 7.7.1	Fuel Assembly Limits
Table 7.7.2	PWR Fuel Assembly Characteristics
Table 7.7.3(a)	Fuel Assembly Minimum Burnup Requirement for MPC-32M/ F-32M
Table 7.7.3(b)	Fuel Assembly Maximum Enrichment for F-24M
Table 7.7.4	Incore Operating Requirements for MPC-32M/ F-32M
Table 7.7.5	Decay Heat Load Limits
Table 7.7.6(a)	Fuel Specifications for the F-24M
Table 7.7.6(b)	Fuel Specifications for the F-32M
Table 7.7.6(c)	Fuel Specifications for the MPC-32M
Table 7.7.7	Adjustments of Burnup for Calculation of Assembly Decay Heat
Table 7.7.8	Loading Configurations for MPC-32M and F-32M
Table 7.7.9	Loading Configurations for F-24M

Table 7.7.1 (Page 1 of 2)

FUEL ASSEMBLY LIMITS

I. BASKET MODEL: MPC-32M, F-32M

A. Allowable Contents

1. Uranium oxide, PWR undamaged fuel assemblies, meeting the criteria in Table 7.7.2, without irradiated non-fuel hardware and meeting the following specifications:

a. Fuel Rod Cladding Material, Guide Tubes Material and Instrument Tubes Material:	ZR (Note 1)
b. Maximum initial enrichment, minimum burnup per assembly:	≤5 wt.% U-235 See Table 7.7.3(a)
c. Post-irradiation cooling time, average burnup per assembly:	See Table 7.7.6(b) (F-32M) See Table 7.7.6(c) (MPC-32M)
d. Decay heat per assembly	See Table 7.7.5
e. Fuel assembly length: (includes NFH)	≤ 161.8 inches (nominal) for F-32M ≤ 176.8 inches (nominal) for MPC-32M
f. Fuel assembly width: (includes NFH)	≤ 8.54 inches (nominal design)
g. Fuel assembly weight: (includes NFH)	≤ 1,680 lbs
h. Maximum Initial Uranium Loading:	0.495 MTU (MPC-32M) 0.469 MTU (F-32M)
i. Non-Fuel hardware	ITTR/ GTA (Note 2)

B. Quantity per basket: Up to 32 fuel assemblies can be stored in MPC-32M or F-32M.

Notes:
1. Zircaloy 2, Zircaloy 4, ZIRLO or M5 material is permitted.
2. Irradiated non-fuel hardware is not permitted.

Table 7.7.1 (Page 2 of 2)

FUEL ASSEMBLY LIMITS

II. BASKET MODEL: F-24M

A. Allowable Contents

1. Uranium oxide, PWR undamaged fuel assemblies, meeting the criteria in Table 7.7.2, without irradiated non-fuel hardware and meeting the following specifications:

a. Fuel Rod Cladding Material, Guide Tubes Material and Instrument Tubes Material:	ZR (Note 1)
b. Maximum initial enrichment, minimum burnup per assembly:	See Table 7.7.3(b) for enrichments, No minimum burnup requirement
c. Post-irradiation cooling time, average burnup per assembly:	See Table 7.7.6(a) (F-24M)
e. Decay heat per assembly	See Table 7.7.5
e. Fuel assembly length: (includes NFH)	≤ 161.8 inches (nominal design)
f. Fuel assembly width: (includes NFH)	≤ 8.54 inches (nominal design)
g. Fuel assembly weight: (includes NFH)	≤ 1,680 lbs
h. Maximum Initial Uranium Loading:	0.469 MTU
i. Non-Fuel hardware	ITTR/ GTA (Note 2)

B. Quantity per basket: Up to 24 fuel assemblies can be stored in F-24M.

Notes:
1. Zircaloy 2, Zircaloy 4, ZIRLO or M5 material is permitted.
2. Irradiated non-fuel hardware is not permitted.

Table 7.7.2 (Page 1 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (NOTE 1)

Fuel Assembly Array/ Class	14x14 A	14x14 B	14x14 C
Clad Material	ZR	ZR	ZR
No. of Fuel Rod Locations	179	179	176
Fuel Clad O.D. (in.)	≥ 0.400	≥ 0.417	≥ 0.440
Fuel Clad I.D. (in.)	≤ 0.3514	≤ 0.3734	≤ 0.3880
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3444	≤ 0.3659	≤ 0.3805
Fuel Rod Pitch (in.)	≤ 0.556	≤ 0.556	≤ 0.580
Active Fuel Length (in.) (Note 5)	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	17	17	5 (Note 2)
Guide/Instrument Tube Thickness (in.)	≥ 0.017	≥ 0.017	≥ 0.038

Table 7.7.2 (Page 2 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (NOTE 1)

Fuel Assembly Array/Class	**15x15 A**	**15x15 B**	**15x15 C**	**15x15 D**	**15x15 E**	**15x15 F**
Clad Material	ZR	ZR	ZR	ZR	ZR	ZR
No. of Fuel Rod Locations	204	204	204	208	208	208
Fuel Clad O.D. (in.)	≥ 0.418	≥ 0.420	≥ 0.417	≥ 0.430	≥ 0.428	≥ 0.428
Fuel Clad I.D. (in.)	≤ 0.3660	≤ 0.3736	≤ 0.3640	≤ 0.3800	≤ 0.3790	≤ 0.3820
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3580	≤ 0.3671	≤ 0.3570	≤ 0.3735	≤ 0.3707	≤ 0.3742
Fuel Rod Pitch (in.)	≤ 0.550	≤ 0.563	≤ 0.563	≤ 0.568	≤ 0.568	≤ 0.568
Active Fuel Length (in.) (Note 5)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	21	21	21	17	17	17
Guide/Instrument Tube Thickness (in.)	≥ 0.0165	≥ 0.015	≥ 0.0165	≥ 0.0150	≥ 0.0140	≥ 0.0140

Table 7.7.2 (Page 3 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (NOTE 1)

Fuel Assembly Array/Class	**15x15H**	**15x15I**	**16x16 A**	**16x16B**	**16x16C**
Clad Material	ZR	ZR	ZR	ZR	ZR
No. of Fuel Rod Locations	208	216	236	236	235
Fuel Clad O.D. (in.)	≥ 0.414	≥ 0.413	≥ 0.382	≥ 0.374	≥ 0.374
Fuel Clad I.D. (in.)	≤ 0.3700	≤ 0.367	≤ 0.3350	≤ 0.3290	≤ 0.3290
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3622	≤ 0.360	≤ 0.3255	≤ 0.3225	≤ 0.3225
Fuel Rod Pitch (in.)	≤ 0.568	≤ 0.550	≤ 0.506	≤ 0.506	≤ 0.485
Active Fuel length (in.) (Note 5)	≤ 150	≤ 150	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	17	9 (Note 4)	5 (Note 2)	5 (Note 2)	21
Guide/Instrument Tube Thickness (in.)	≥ 0.0140	≥ 0.0140	≥ 0.0350	≥ 0.0400	≥ 0.0157

Table 7.7.2 (Page 4 of 4)

PWR FUEL ASSEMBLY CHARACTERISTICS (NOTE 1)

Fuel Assembly Array/Class	**17x17A**	**17x17 B**	**17x17 C**
Clad Material	ZR	ZR	ZR
No. of Fuel Rod Locations	264	264	264
Fuel Clad O.D. (in.)	≥ 0.360	≥ 0.372	≥ 0.377
Fuel Clad I.D. (in.)	≤ 0.3150	≤ 0.3310	≤ 0.3330
Fuel Pellet Dia. (in.) (Note 3)	≤ 0.3088	≤ 0.3232	≤ 0.3252
Fuel Rod Pitch (in.)	≤ 0.496	≤ 0.496	≤ 0.502
Active Fuel length (in.) (Note 5)	≤ 150	≤ 150	≤ 150
No. of Guide and/or Instrument Tubes	25	25	25
Guide/Instrument Tube Thickness (in.)	≥ 0.016	≥ 0.014	≥ 0.020

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/class.
2. Each guide tube replaces four fuel rods.
3. Annular fuel pellets are allowed in the top and bottom 8” of the active fuel length.
4. One Instrument Tube and eight Guide Bars (Solid Zr).
5. Fuel assemblies with axial fuel blankets are allowed for loading.

Table 7.7.3(a)

FUEL ASSEMBLY MINIMUM BURNUP REQUIREMENTS FOR TRANSPORTATION IN MPC-32M/ F-32M

Assembly Classes	Minimum Cooling Time (years)	Minimum Burnup (B) (GWd/mtU) as a Function of the Initial Enrichment (E) (Notes 1, 2) (wt% ^{235}U)
15x15B, C, D, E, F, H, I and 17x17A, B, C	3.0	$B = (-0.079224)*E^3 - (0.76419)*E^2 + (22.411)*E - 41.183$
16x16A, B, C (Note 3)	3.0	$B = (-1.0361)*E^3 + (11.386)*E^2 - (29.174)*E + 20.85$

Table 7.7.3(b)

FUEL ASSEMBLY MAXIMUM INITIAL ENRICHMENT REQUIREMENTS FOR TRANSPORTATION IN F-24M

Assembly Classes	Maximum Initial Enrichment (E) (Notes 1, 2) (wt% ^{235}U)
15x15B, C, D, E, F, H	4.50
17x17A	4.70
17x17B, C	4.95
14x14A, C, D 15x15A, I 16x16A, B, C	5.00

Notes:
1. E = Initial enrichment (e.g., for 4.50 wt.%, E = 4.50).
2. Loading configurations for MPC-32M/F-32M are provided in Table 7.7.8, and for F-24M in Table 7.7.9.
3. 0 GWD/MTU burnup required for enrichments 2.25% or less.

Table 7.7.4

IN-CORE OPERATING REQUIREMENTS FOR FUEL ASSEMBLIES WITH MINIMUM BURNUP REQUIREMENTS FOR TRANSPORTATION IN MPC-32M/F-32M

Assembly Type	Specific Power (MW/mtU)	Moderator Temperature (K)	Fuel Temperature (K)	Soluble Boron (ppm)
Upper Bound Values (for Design Basis Calculations)				
15x15D, E, F, H	47.36	604	1169	1000
15x15B, C, I 16x16C	52.33	620	1219	1000
16x16A, B	51.90	608	1113	1000
17x17A, B, C	61.61	620	1181	1000

Table 7.7.5

DECAY HEAT LOAD LIMITS

Fuel Package	Maximum Decay Heat Load per Assembly (kW)	Total Heat Load (kW)
MPC-32M	0.906	29
F-32M	1.0	32
F-24M	1.33	32

Notes:

1. Uniform heat loading pattern.
2. Regionalized loading pattern permitted to store hot fuel under the following restrictions:
   (a) Heat load in each quadrant limited to 0.25Q.
   (b) Heat load q at a radial location closer to centerline may be reduced by δ and decay heat increased by an equal amount δ at a location farther from centerline.
   (c) Hot fuel heat load limited to 120% of the maximum per cell decay heat under uniform loading tabulated herein.

Table 7.7.6(a)

FUEL SPECIFICATION FOR THE F-24M

Minimum Initial U-235 Enrichment (wt.%)	**Maximum Burnup (MWd/mtU)**				
	25000	35000	45000	50000	55000
	Minimum Cooling Time (Years)				
0.7	5	N/A	N/A	N/A	N/A
1.7	4	5.5	N/A	N/A	N/A
2.7	4	4.5	6	N/A	N/A
3.5	3.5	4.5	5.5	7	10
4.1	3.5	4	5	6	7
4.4	3.5	4	5	5.5	6
4.7	3.5	4	5	5.5	6

Table 7.7.6(b)

FUEL SPECIFICATION FOR THE F-32M

Minimum Initial U-235 Enrichment (wt.%)	**Maximum Burnup (MWd/mtU)**				
	25000	35000	45000	50000	55000
	Minimum Cooling Time (Years)				
0.7	7	N/A	N/A	N/A	N/A
1.7	5.5	9	N/A	N/A	N/A
2.7	5.5	6.5	12	N/A	N/A
3.5	5	6	9	13	18
4.1	5	5.5	8	11	13
4.4	5	5.5	7	10	11
4.7	5	5.5	6.5	9	10

Table 7.7.6(c)

FUEL SPECIFICATION FOR THE MPC-32M

Minimum Initial U-235 Enrichment (wt.%)	**Maximum Burnup (MWd/mtU)**				
	25000	35000	45000	50000	55000
	Minimum Cooling Time (Years)				
0.7	6	N/A	N/A	N/A	N/A
1.7	5	8	N/A	N/A	N/A
2.7	5	6	10	N/A	N/A
3.5	4.5	5.5	8	11	19
4.1	4.5	5.5	7	9	13
4.4	4.5	5.5	7	8	11
4.7	4.5	5.5	6.5	8	10

Table 7.7.7

ADJUSTMENTS OF BURNUP FOR CALCULATION OF ASSEMBLY DECAY HEAT

- PWR Assemblies
  - With blankets: No adjustment
  - With exposure to APSRs
    - Up to 15 GWd/mtU: add 2 GWd/mtU
    - Up to 30 GWd/mtU: add 1 GWd/mtU
    - Above 30 GWd/mtU: no adjustment needed
  - All other
    - Up to 15 GWd/mtU: add 1 GWd/mtU
    - Up to 30 GWd/mtU: add 0.5 GWd/mtU
    - Above 30 GWd/mtU: no adjustment needed

Table 7.7.8

LOADING CONFIGURATIONS FOR MPC-32M and F-32M

Configuration	**Assembly Specifications**
Uniform Loading	• All fuel assemblies must be undamaged. • Minimum burnup requirement in Table 7.7.3(a) applies to all applicable fuel assemblies (Note 1).

Notes:

1. For undamaged fuel assemblies that need to meet the minimum burnup requirements specified in Table 7.7.3(a), verification is required that during full power operation control rod bank insertion did not exceed 8 inches from the top of the active fuel. Number of these assemblies is limited by the full capacity of the MPC-32M and F-32M.

Table 7.7.9

LOADING CONFIGURATIONS FOR F-24M

Configuration	Assembly Specifications
Uniform Loading	• All assemblies undamaged.

7.8 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 text or table.

[7.1.1] U.S. Code of Federal Regulations, Title 49 “Transportation”, Part 173, "Shippers – General Requirements for Shipments and Packagings."

[7.1.2] U.S. Code of Federal Regulations, Title 10, “Energy”, Part 20 "Standards for Protection against Radiation".

[7.1.3] U.S. Code of Federal Regulations, Title 10, “Energy”, Part 71 "Packaging and Transportation of Radioactive Material".

[7.1.4] 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."

[7.1.5] “Final Safety Analysis Report for the HI-STAR 180D transport package”, Holtec Report HI-2125175. Docket #71-9367 (USNRC).

[7.1.6] Shigley J.D. and Mischke C.R., “Mechanical Engineering Design”, 5th Edition, pp 346-347, McGraw Hill (1989)

[7.2.1] “Final Safety Analysis Report for the HI-STAR 190 transport package”, Holtec Report HI-2146214. Docket #71-9373 (USNRC).

CHAPTER: ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 INTRODUCTION[1]

This chapter identifies the acceptance tests and maintenance program for the HI-STAR 100MB 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 document, all applicable regulatory requirements, and the Certificate of Compliance (CoC). The acceptance criteria and maintenance program described in this chapter are in full compliance with the requirements of 10CFR Part 71 Subpart G [8.0.1].

The HI-STORM 100MB package, as discussed in this safety analysis, may have two distinct type of Fuel Packages, namely;

1. "Bare Basket Fuel Package" wherein the used fuel resides in helium atmosphere inside the cask's internal cavity equipped with a qualified Fuel Basket held in place by the so-called Basket Shims.
2. "MPC Type Fuel Package" which is loaded and maintained in accordance with its host storage system FSAR and CoC.

This chapter independently specifies an MPC acceptance tests and maintenance program to cover all the requirements necessary for the eligibility of the MPC as a Fuel Package in HI-STAR 100MB under a Part 71 license. An MPC Transportability Checklist provided in this chapter includes the MPC supplemental requirements that must be met prior to transportation of any MPC in HI-STAR 100MB.

1 The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [8.0.2] with minor editorial changes

8.1 INSPECTIONS AND ACCEPTANCE TESTS[2]

In this section the inspections and acceptance tests to be performed on the HI-STAR 100MB Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR 100MB 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. *Acceptance tests specified in this chapter are called out as mandatory requirements in the CoC.*

8.1.1 Visual Inspections and Measurements

The HI-STAR 100MB Packaging (including the fuel package) shall be assembled in accordance with the drawing package referenced in chapter 1. Dimensional tolerances that define the limits on the dimensions critical to the licensing basis analysis are included in these drawings. A fabrication sampling plan shall be made and controls shall be exercised to ensure that the packaging conforms to the dimensions and tolerances specified in the Licensing 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 by a manufacturing deviation during its fabrication. Any *important-to-safety* component found to be under the minimum thickness requirement shall be repaired or replaced, as appropriate.
- Visual inspections shall be made to verify that neutron absorber panels and basket shims are present as required by the design of the fuel package.
- 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 100MB Packaging shall become part of the final quality 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

2 The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [8.0.2] with minor editorial changes

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 100MB Packaging welds shall be performed in accordance with the drawing package referenced in in the CoC and the applicable codes and standards in this subsection. Weld examinations and repairs shall be performed as specified below. All code weld inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [8.1.1]. All required inspections, examinations, and tests shall become part of the final quality documentation package.

The following specific weld requirements shall be followed in order to verify fabrication in accordance with the drawings.

1. Cask 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 insure 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. geometric conformance, workmanship etc.).

2. Code welds in the cask, and primary load bearing members in the impact limiter 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 welds (e.g. seal welds) on the cask, impact limiters and other ancillaries.

3. Code welds in the MPC Enclosure Vessel shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB NF, and NG (Articles NB-5300, NF-5300 and NG-5300) as applicable.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, Articles NB-4450, NF-4450, and NG-4450, as applicable, and examined after repair in the same manner as the original weld. 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.).

4. The MPC lid-to-shell weld shall be examined using a progressive multi-layer liquid penetrant (PT) examination during welding. The multi-layer PT must, at a minimum, include the root and final weld layers and one intermediate PT after each approximately 3/8 inch weld depth has been completed.

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

6. Non-code welds shall be examined and repaired in accordance with written and approved Holtec standard procedures (HSPs).

8.1.3 Structural and Pressure Tests

The cask containment boundary will be examined and tested by a combination of methods (including helium leak test, pressure test, MT, and/or PT, as specified in the licensing drawing package) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging. MPC containment boundary (or pressure boundary as applicable) will be examined and tested by a combination of methods (including helium leak test, pressure test, RT, 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 its confinement effectiveness.

8.1.3.1 Lifting Attachments

Two top trunnions are provided for vertical lifting and handling of the loaded or empty cask. The top trunnions are required to be designed, tested and inspected in accordance with ANSI N14.6 [8.1.2]. Two bottom trunnions are provided for rotation of the loaded or empty cask for downending/upending operations.

The top 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 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 (the cantilevered portion 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/load test 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 shall be provided. Test results shall be documented and shall become part of the final quality documentation package.

The requirements in the preceding paragraph do not apply to the bottom trunnions since the bottom trunnions are not used for cask lifting.

8.1.3.2 Pressure Testing

Pressure testing of the HI-STAR 100MB cask containment boundary (cavity space) is required. The cask cavity shall be pressure tested in accordance with ASME Section III, Subsection NB, NB-6000 at a test pressure of not less than 150% of cask cavity *maximum normal operating pressure* per 10CFR71.85 (b) or at a test pressure of 125% of the cask cavity design internal pressure; whichever is greater. Pressure testing may be performed using a single temporary test seal on the lid.

Pressure testing of the MPC containment boundary (or pressure boundary as applicable) is required to verify the lid-to-shell field weld in accordance with the requirements of the ASME Code Section III, Subsection NB, Article NB-6000 and applicable sub-articles, when field welding of the MPC lid-to-shell weld is completed. If hydrostatic testing is used, the MPC shall be pressure tested to 125% of design pressure. If pneumatic testing is used, the MPC shall be pressure tested to 120% of design pressure.

All pressure testing shall be performed in accordance with approved procedures written by qualified personnel in accordance with Holtec QA program. The written and approved test procedure shall clearly define the test equipment arrangement. 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 final quality documentation package.

8.1.4 Leakage Tests

Leakage rate tests on the HI-STAR 100MB cask containment system and MPC containment boundary shall be performed per written and approved procedures in accordance with the requirements of chapter 7 and the requirements of ANSI N14.5 [8.1.3] specified herein. 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, pre-shipment, periodic and maintenance leakage rate tests.

A pre-shipment leakage rate test of cask containment seals is performed following each loading of the Fuel Package into the HI-STAR 100MB cask. This pre-shipment leakage rate test is valid for 1 year as long as the seals are not unloaded by removing closure fasteners.

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.

Leakage rate testing procedures shall be approved by an ASNT Level III specialist. 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 [8.1.1]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

The fabrication leakage rate test results shall become part of the final quality documentation package. The pre-shipment leakage rate test shall be documented in accordance with the user's quality assurance program.

8.1.5 Component and Material Tests

8.1.5.1 Seals

Cask closure seals, specified in the drawing package referenced in the CoC 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 the cask's containment boundary welds made of ferritic materials, are specified in Table 8.1.5.

Non-containment boundary ferritic materials, such as dose blocker parts, shall meet the Charpy impact testing requirement set forth for ASME Subsection NF Class 3 structures.

Test results shall become part of the final quality 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 may be performed by Holtec, the crush material supplier, or third party testing facility in accordance with approved procedures. Impact limiter material crush strength is specified in the drawing package in the CoC.

The certified test results shall be retained by Holtec International as archive record for each batch of impact limiter crush material used. Test results shall be documented and shall become part of the final quality documentation package.

8.1.5.4 Neutron Shielding Material Testing

Each manufactured lot of the Holtite™ neutron shield material shall be tested to verify that boron carbide content, hydrogen concentration (density) and bulk material density meet the requiremed critical characteristics. Boron carbide content shall be verified by spectro-chemical 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 final quality documentation package.

8.1.5.5 Metamic–HT 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 [8.1.4]. The material properties and characteristics have been tested and documented in Ref. [8.1.5]. The manufactured Metamic-HT is subject to all quality assurance requirements under Holtec International's NRC approved quality program. Production testing requirements including acceptance criteria for Metamic-HT are provided in Table 8.1.3.

Metamic-HT panels will be manufactured to Holtec's purchase specification [8.1.6] that incorporates the 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 its specified 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 inthe 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 the used fuel assemblies to be safely inserted.

(iv) 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 [8.1.7]:
    - 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.

    All welding by FSW process shall meet applicable requirements of ASME Section IX, 2013 Edition [8.1.7].

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, radiography and 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 5632 with any additional requirements per Holtec approved written procedure. In addition, at least one welded coupon from the population of Metamic-HT production panels used for manufacturing a fuel basket type must pass the criteria provided herein and shall be so documented in the Documentation Package of the manufactured fuel baskets.

8.1.5.6 Non- Code parts

Non-code parts such as coatings used to protect the inside and outside surfaces of the cask, basket shims, etc., shall be tested using applicable Holtec Standard procedures.

8.1.5.7 Shielding Tests

A shielding effectiveness test of each fabricated cask must be performed after loading with approved contents and prior to the first shipment as specified in the following paragraph.

A shielding effectiveness test shall be performed of the cask assembled as a package to verify the effectiveness of the shielding using written and approved procedures. 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 final quality documentation package.

8.1.5.8 Thermal Tests

The first fabricated HI-STAR 100MB cask shall be tested to confirm its heat dissipation capability.

A thermal test performed for a similar cask design may be used as proof of heat transfer capability in lieu of thermal testing of HI-STAR 100MB. In case of a proof based on a similar cask, an engineering evaluation between HI-STAR 100MB and the previously-tested cask shall be documented and become part of the final quality documentation package.

The test shall be conducted after fabrication is essentially 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 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 heat-up 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 quality records documentation package for the HI-STAR 100MB 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 100MB 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 100MB cask shall not be accepted until the root cause is determined, appropriate corrective actions are completed, and the cask 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 [8.1.8].

8.1.6 MPC Enclosure Vessel Shell Surface Defect Inspection

MPC's containing high burn-up fuel and stored for a duration greater than 5 years under the provisions of 10CFR 72 shall undergo an MPC enclosure vessel shell surface defect inspection prior to shipment according to chapter 7. Inspections or tests outlined below are intended to ensure that existing defects and flaws do not develop into cracks during the hypothetical accident conditions of transport.

The entire surface of the MPC shell shall be subject to VT using a remotely actuated camera. In addition, an eddy current testing (ECT) process that is capable of identifying surface defects that are sufficiently deep to reduce the net wall thickness below that required to meet the local membrane stress limit corresponding to the Design Pressure for the canister's Enclosure Vessel, conservatively set at 0.25 inch in this safety analysis. Any flaw detected on the MPC's surface by ECT that indicates compliance with the above minimum required wall shall be deemed to be acceptable. Any flaw that exceeds the maximum allowable flaw depth will disqualify the canister for transport until further investigation is performed and the NRC accepts, under the exemption process or other appropriate licensing action, the owner-provided evidence that the affected canister will survive a HAC. .

Not every MPC at a given ISFSI requires ECT. A user may elect to conduct ECT of every MPC to be shipped or elect to conduct ECT on the population of MPCs at an ISFSI using a lot-based statistical tier system for MPC selection specified in Table 8.1.6. The statistical approach for the selection of MPCs maximizes ALARA and minimizes lifting and handling of the loaded canisters. The statical approach for the selection of MPCs to be ECT'd adopts the same tiering system used for selection of coupons for the production coupon testing program of Metamic-HT neutron absorber for ensuring Minimum Guaranteed Values are met. The same tiering system is approved in the HI-STAR 190 docket [71-9373].

Shipment restriction: MPCs approved for transport must be shipped within 5 years of transport approval.

8.1.6.1 Miscellaneous Acceptance Tests

8.1.6.2 Post-Shipment HBF 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. Three measurements are taken from each side of the package below the cask axial centerline (below the top cask trunnion, at the middle of the cask (below the cask centerline) and below the bottom cask trunnion). The user may select measurement locations within the areas defined by the zones shown in Figure 8.1. The post-shipment measurement locations shall correspond to the pre-shipment measurement locations for proper comparison.

The post-shipment surface temperature measurements should not exceed the pre-shipment surface temperature measurements by more than 5 degrees C when adjusted under the same ambient conditions. 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 exceed the pre-shipment surface dose rate measurements by more than 10%.

Failed tests shall be reported to USNRC within one month of the post-shipment measurement and shall include a description of the package contents, any available engineering justification for failed test(s), and if applicable any special precautions that will be implemented prior to unloading the contents of the package.

8.1.6.3 10CFR72 AMP Based HBF Integrity Acceptance Test

For packages containing HBF, the integrity of the HBF shall be confirmed as specified in section 7.5. Although fuel reconfiguration and significant fuel cladding damage is not expected to occur during extended storage periods, for MPCs stored for more than 20 years prior to shipment, an Aging Management Program shall be implemented to ensure HBF integrity prior to transport with reasonable assurance.

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 (Leaktight as defined by ANSI N14.5 [8.1.3])
Leakage Rate Test Sensitivity	$5x10^{-8}$ ref-cm^3/s air (½ of the leakage rate acceptance criterion per ANSI N14.5 [8.1.3])

Notes:

1. For helium as the tracer gas, the Leakage Rate Acceptance Criterion and Test Sensitivity are multiplied by a factor of 2.
2. Per ANSI N14.5 [8.1.3] (para. 7.6.4), an alternative pre-shipment leakage rate acceptance criterion that may be used in lieu of the reference air leakage rate $L_{R,}$ is "No Detected Leakage" when tested using a test method with a sensitivity of at least $1x10^{-3}$ ref-cm^3/s. The following conditions apply to the testing of gasketed joints:
   a. The joint gasket must be reusable (e.g. elastomeric seals).
   b. The gasket was previously installed and the gasketed joint qualified to a leak rate not more than the reference air leakage rate L_R as specified in the table above. (i.e. the prequalified gasket was never replaced).

Table 8.1.2 (Sheet 1 of 3)
Leakage Rate Tests For HI-STAR 100MB and MPC Containment Systems

Leakage Test	System Tested	Components Tested	Type of Leakage Rate Test (from ANSI N14.5 [8.1.3], App. A)	Allowable Leakage Rate
Fabrication Leakage Rate Test (Note 4)	HI-STAR 100MB Cask	• Containment Shell • Containment Bottom Forging • Containment Top Forging • Closure Lid • Closure Lid Port Cover Plate • Containment Shell Welds • Containment Shell to Containment Bottom Forging Weld • Containment Shell to Containment Top Forging Weld	A.5.3	Table 8.1.1
		• Closure Lid Inner Seal	A.5.4	Table 8.1.1
		• Closure Lid Port Cover Inner Seal	A.5.4	Table 8.1.1
Pre-Shipment Leakage Rate Test (Note 4)	HI-STAR 1100MB Cask	• Closure Lid Inner Seal • Closure Lid Port Cover Inner Seal	A.5.4 or Per Note 3	Table 8.1.1
	MPC (Note 4)	• Shell • Baseplate • Top closure assembly (consisting of lid, closure ring and vent and drain port cover plats) • Shell Welds • Shell to Baseplate Weld • Top closure assembly welds (consisting of Lid-to-shell weld, closure ring weld and vent and drain port cover plate welds)	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 2 of 3)
Leakage Rate Tests For HI-STAR 100MB and MPC Containment Systems

Leakage Test	System Tested	Components Tested	Type of Leakage Rate Test (from ANSI N14.5 [8.1.3], App. A)	Allowable Leakage Rate (Note 1)
Maintenance Leakage Rate Test (Note 2)	HI-STAR 100MB Cask	• Containment Shell • Containment Bottom Forging • Containment Top Forging • Closure Lid • Closure Lid Port Cover Plate • Containment Shell Welds • Containment Shell to Containment Bottom Forging Weld • Containment Shell to Containment Top Forging Weld	A.5.3	Table 8.1.1
		• Closure Lid Inner Seal	A.5.4	Table 8.1.1
		• Closure Lid Port Cover Inner Seal	A.5.4	Table 8.1.1
Periodic Leakage Rate Test (Note 2)	HI-STAR 100MB Cask	• Closure Lid Inner Seal • Closure Lid Port Cover Inner Seal	A.5.4	Table 8.1.1
	MPC (Note 4)	• Shell • Baseplate • Top closure assembly (consisting of lid, closure ring and vent and drain port cover plats) • Shell Welds • Shell to Baseplate Weld • Top closure assembly welds (consisting of Lid-to-shell weld, closure ring weld and vent and drain port cover plate welds)	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 3 of 3)
Leakage Rate Tests For HI-STAR 100MB and MPC Containment Systems

Notes:

1. For a Leakage Rate Acceptance Criterion of "Leak-tight as defined by ANSI N14.5" [8.1.3], the summation of individual component leakage rates of the containment boundary of a package is not required.
2. Purpose of Leakage Rate Tests per ANSI N14.5 [8.1.3]:
    a. Fabrication Leakage Rate Test: To demonstrate that the containment system, as fabricated, will provide the required level of containment.
    b. Pre-shipment Leakage Rate Test: To confirm that the containment system is properly assembled for shipment.
    c. Maintenance Leakage Rate Test: To confirm that any maintenance, repair, or replacement of components has not degraded the containment system.
    d. Periodic Leakage Rate Test: To confirm that the containment capabilities of the packaging built to an approved design have not deteriorated during the period of use.
3. For a pre-shipment test implementing the alternative pre-shipment leakage rate acceptance criterion specified in Note 2 of Table 8.1.1, alternative types of leak rate tests may be used as supported by ANSI N14.5.
4. The leakage testing of an MPC is required if it contains HBF. Leakage testing is performed according to the procedure(s) provided in chapter 7 of this safety analysis.

Table 8.1.3 (Sheet 1 of 2)
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 [8.1.6]
		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 [8.1.6]
		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 (Sheet 2 of 2)

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 [8.1.6]
		Mechanical Properties (see Note 3)	Per Sampling Plan Table 8.1.4 (see note 2)	To ensure structural performance	Per Holtec's Purchasing Specification [8.1.6]
		B_4C content by areal density measurements (neutron attenuation method)	One coupon 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. Sampling Plan is included in the Metamic-HT Manufacturing Manual [8.1.4].
3. 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.	Number of Extrusions Tested as a Percent of Number of Extrusions in the Lot	Number of Continuous Lots that Must Pass to Drop Down to the Next Tier
1	20	5
2	12.5	5
3	5	10
4	1	N/A

Note 1: 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. 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.

Note 2: Testing shall be moved up to the next tier if any MGV property fails in two consecutive lots.

Note 3: Tiering defined on the basis of sample size. Higher tier testing requires greater percentage of sample testing (i.e. moving up the table).

Table 8.1.5: Fracture Toughness Test Criteria: HI-STAR 100MB Cask Containment System

(Sheet 1 of 3)

Item	Material	Thickness in. (mm)	Qualification to LST of -29°C (-20°F) (Note 3)		Qualification to LST of -40°C (-40°F) (Note 3)	
			Charpy V-Notch Temperature	Drop Test Temperature (Note 1)	Charpy V-Notch Temperature	Drop Test Temperature (Note 1)
Weld Metal for NB Welds	As required	NA	$T_{NDT} \leq$ -62°C (-80°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	$T_{NDT} \leq$ -62°C (-80°F) based on containment shell thickness	$T_{NDT} \leq$ -73°C (-100°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	$T_{NDT} \leq$ -73°C (-100°F) based on containment shell thickness
Containment Shell	SA-203 E/ SA-350 LF3	1.5(38)	$T_{NDT} \leq$ -62°C (-80°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -62°C (-80°F) per R.G. 7.11	$T_{NDT} \leq$ -73°C (-100°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -73°C (-100°F) per R.G. 7.11
Containment Top Flange	SA-350 LF3	8.375 (213)	$T_{NDT} \leq$ -69°C (-92°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -69°C (-92°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)	$T_{NDT} \leq$ -80°C (-112°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -80°C (-11°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)
Containment Bottom Flange	SA-350 LF3	5(127)	$T_{NDT} \leq$ -88°C (-12-6°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -88°C (-12-6°F) per R.G 7.12.	$T_{NDT} \leq$ -99°C (-146°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -99°C (-146°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)

Table 8.1.5: Fracture Toughness Test Criteria: HI-STAR 100MB Cask Containment System (Sheet 2 of 3)

Item	Material	Thickness in. (mm)	Qualification to LST of -29°C (-20°F) (Note 3)		Qualification to LST of -40°C (-40°F) (Note 3)	
			Charpy V-Notch Temperature	Drop Test Temperature (Note 1)	Charpy V-Notch Temperature	Drop Test Temperature (Note 1)
Inner Closure Lid	SA-350 LF3	5.75 (146)	$T_{NDT} \leq$ -89°C (-128°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -89°C (-128°F) per R.G. 7.12	$T_{NDT} \leq$ -101°C (-148°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -101°C (-149°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)
Outer Closure Lid	SA-350 LF3	11 (179)	$T_{NDT} \leq$ -73°C (-100°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -73°C (-100°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)	$T_{NDT} \leq$ -84°C (-120°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -84°C (-120°F) per fracture initiation criteria developed in the NUREG-CR-3826 (Notes 4 and 5)
Inner/Outer Closure Lid Bolts	SA-564 630 / SA-705- 630	1 1/2" (38)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -29°C	No requirements (per Table NB-2333-1)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 2) Min. test temperature = -40°C	No requirements (per Table NB-2333-1)

Table 8.1.5: Fracture Toughness Test Criteria: HI-STAR 100MB Cask Containment System (Sheet 3 of 3)

Notes:

1. Materials to be tested in accordance with ASTM E208-87a.
2. An additional Charpy absorbed energy requirement of 5 ft-lb at -29ºC (-20ºF) or at -40^{0}C (-40^{0}F), depending on the desired cask LST qualification, is imposed on the closure lid bolts.
3. 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).
4. 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.
5. In lieu of qualification per NUREG/CR-3826, qualification per Reg Guide 7.12 [8.1.9] may be applied.
6. Containment System components with exemption from brittle fracture testing in accordance with ASME Section III, Subsection NB-2300 may not be listed in this table.

Table 8.1.6: Tier System for MPC Selection for ECT

Tier No.	Number of MPCs Tested as a Percent of Number of MPCs in the Lot	Number of Continuous Lots that Must Pass to Drop Down to the Next Tier
1	20	5
2	12.5	5
3	5	10
4	1	N/A

Note 1: If an MPC fails with respect to the ECT acceptance criterion, then every MPC to be shipped (within the Lot) must undergo ECT.

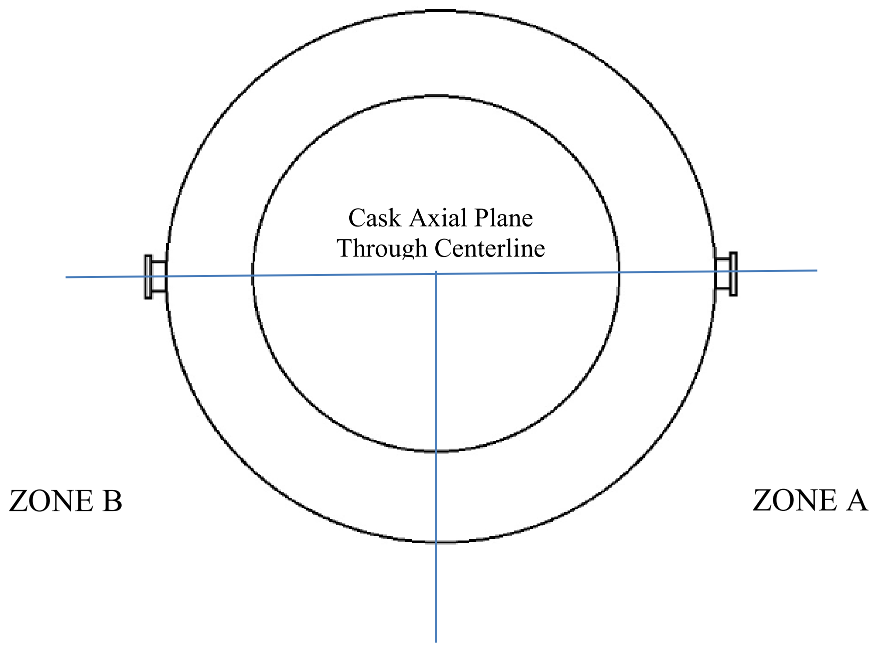
Note 2: Testing shall be moved up to the next tier for the next Lot to be qualified for transport if any MPC fails with respect to the ECT acceptance criterion.

Note 3: Tiering defined on the basis of sample size. Higher tier testing requires greater percentage of sample testing (i.e. moving up the table).

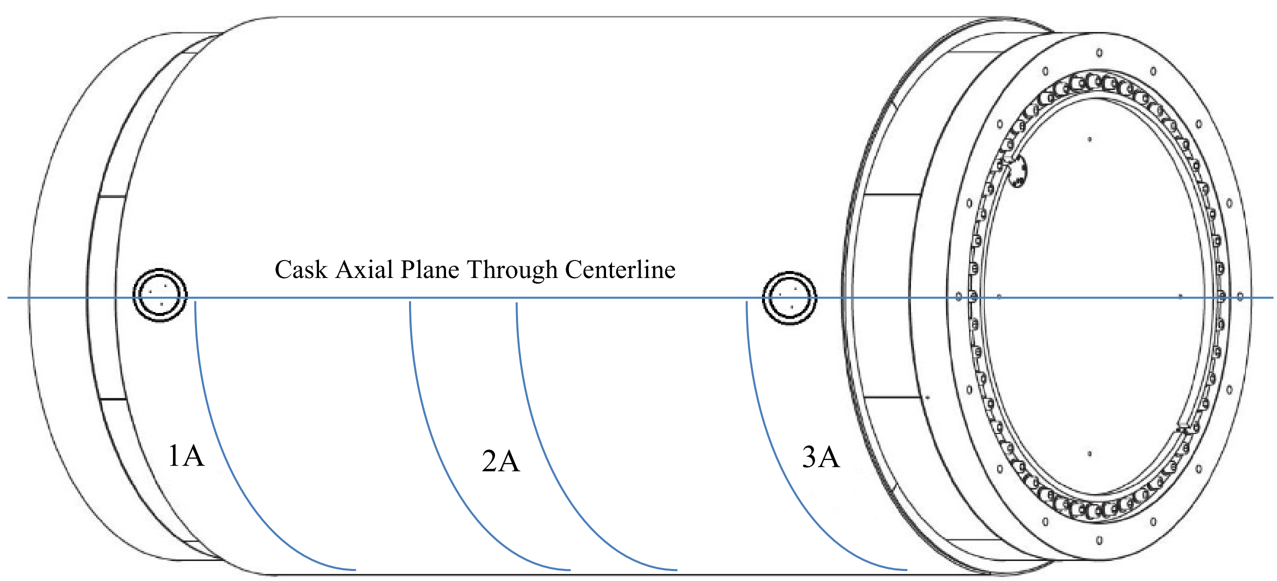
Note 4: A Lot is defined as a population of MPCs at an ISFSI identified by the user of the ISFSI. A Lot may comprise of one or more MPCs and may comprise of a subset of the ISFSI or the entire ISFSI. Only the MPCs within the Lot are eligible to be qualified for transport by the ECT statistical approach.

Note 5: The value for the calculated number of MPCs to be tested shall be rounded up to the nearest whole number. Example No. 1: The number of MPCs to be tested per Tier No. 2 for a Lot of 20 MPCs shall be 3 MPCs. Example No. 2: The number of MPCs to be tested per Tier No. 4 for a Lot of 2 MPCs shall be 1 MPC.

Note 6: See Subsection 8.1.6 of this SAR for additional information and requirements relevant to qualification of MPCs by ECT.



CASK BOTTOM END VIEW (SHOWN WITHOUT IMPACT LIMITERS)



NOTE: There are three subzones within "ZONE A" and "ZONE B" on opposing sides of the cask. The subzones of "ZONE B" mirror the subzones of "ZONE A". The width of the subzones is 2 feet nominal.

HORIZONTAL CASK (SHOWN WITHOUT IMPACT LIMITERS)

Figure 8.1: Measurements Zones for the Post Shipment HBF Fuel Integrity Acceptance Test

8.2 MAINTENANCE PROGRAM[3]

An ongoing maintenance program for the HI-STAR 100MB Cask, impact limiter and Fuel Package will be prepared and issued prior to the delivery and first use of the HI-STAR 100MB 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 100MB Package in accordance with 10CFR71 [8.0.1] regulations, conditions in the Certificate of Compliance, and the design requirements and criteria contained in this safety analysis.

The HI-STAR 100MB 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 (for casks that don't have a stainless steel exterior), seal replacement, and leak testing following seal replacement. Such maintenance requires methods and procedures that are configured to be aligned with those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR 100MB 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.

As defense-in-depth, the MPC maintenance program shall include an aging managmenet program for any storage durations longer than the intial 20 year license period under the provisions of 10CFR72 and verification that the MPC pressure boundary is free of cracks, pinholes, uncontrolled voids or other defects that cound significantly reduce the effectiveness of the packaging. Acceptance criteria established under the part 72 aging management program shall be considered acceptable.

8.2.1.1 Leakage Tests

Leakage rate tests on the HI-STAR 100MB cask containment system and MPC containment boundary shall be performed per written and approved procedures in accordance with the requirements of chapter 7 and the requirements of ANSI N14.5 [8.1.3] specified herein. Tables 8.1.1 and 8.1.2 specify the allowable leakage rate and test

3 The material presented in this section was adopted from the previously approved HI-STAR 190 SAR [8.0.2] with minor editorial changes

sensitivity as well as components to be tested for fabrication, pre-shipment, periodic, and maintenance leakage rate tests.

If the pre-shipment leakage rate test expires (section 8.1.4), a periodic leakage rate test of the containment seals and MPC must be performed prior to transport. This periodic leakage rate test is valid for 1 year. Also see Table 8.2.1.

Maintenance leakage rate testing shall be performed prior to returning a cask to service following maintenance, repair (such as a weld repair), or replacement of containment system components (such as closure lid or port cover plate). Only that portion of the containment system that is affected by the maintenance, repair or component replacement needs to be leak tested.

Leakage rate testing procedures shall be approved by an ASNT Level III specialist. 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 [8.1.1]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

The periodic and maintenance leakage rate tests shall be documented in accordance with the user's quality assurance program.

8.2.2 Component and Material Tests

8.2.2.1 Relief Devices

The neutron shield relief devices on the cask shall be visually inspected for damage or indications of excessive corrosion prior to each transport of the HI-STAR 100MB package. If the inspection determines an unacceptable condition, the neutron shield relief devices shall be replaced. The neutron shield relief devices shall be replaced periodically while the cask is in service if recommended by the manufacturer's O&M manual.

8.2.2.2 Periodic Neutron Shield Test

Periodic verification of the cask neutron shield integrity shall be performed within 5 years prior to shipment. The periodic verification shall be performed by radiation measurements with either loaded contents or a check source. 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, burn-up, cooling time, etc.) or the particular check source used for the measurements.

The test shall be documented and maintained in accordance with the user's quality assurance program.

8.2.2.3 Packaging Surfaces

Accessible external surfaces of the cask and impact limiters shall be visually inspected for damage prior to each fuel loading 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.

8.2.2.4 Packaging Fasteners

Cask closure fasteners and impact limiter fasteners shall be visually inspected for damage such as excessive wear, galling, or indentations on the threaded surfaces prior to installation. 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 internal threads may be repaired per standard industry practice (e.g. threaded inserts). 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 the original applicable code.

Bolting of the closure lid and port cover plate, shall be replaced as guided by fatigue analysis per the provisions of ASME Code Section III. 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 Top Flange internal threads for closure 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. One bolting cycle is the complete sequence of torquing and removal of bolts.

8.2.2.5 Cask Trunnions

Cask trunnions shall be inspected prior to each fuel loading. 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. Following any replacements and/or repair, the load testing shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria.

8.2.2.6 Closure Seals

The HI-STAR 100MB Cask is equipped with elastomeric seals on the closure lid and port cover. 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 and closure lid or port cover plate may require the seals to be visually inspected to ensure they remain free of debris, they do not exhibit damage (i.e. no tears or gouges), and they do not exhibit excessive compression set (i.e. the seal projects past the plane of the top seating surface of the seal groove). If seals are deemed acceptable they may be re-used. Closure seals are specified for long-term use and do not require in-service maintenance if not disturbed. Reused elastomeric seals are subject to replacement based on seal design life as recommended by the seal manufacturer.

8.2.3 Confirmatory Thermal Tests

A periodic verification of adequate rate of heat dissipation from the cask to the environs shall be performed on HI-STAR 100MB cask upon first loading and subsequently within 5 years prior to shipment. Acceptable performance under test conditions ensures that design basis fuel cladding temperature limits to which the HI-STAR 100MB Package is qualified under design basis heat loads will not be exceeded during transport. Thermal performance of HI-STAR 100MB cask shall be verified by measuring the surface temperature on the cask's lateral surface as illustrated in Figure 8.2.1.

8.2.4 Miscellaneous Tests

No additional tests are required for the HI-STAR 100MB Packaging, packaging components, or packaging materials.

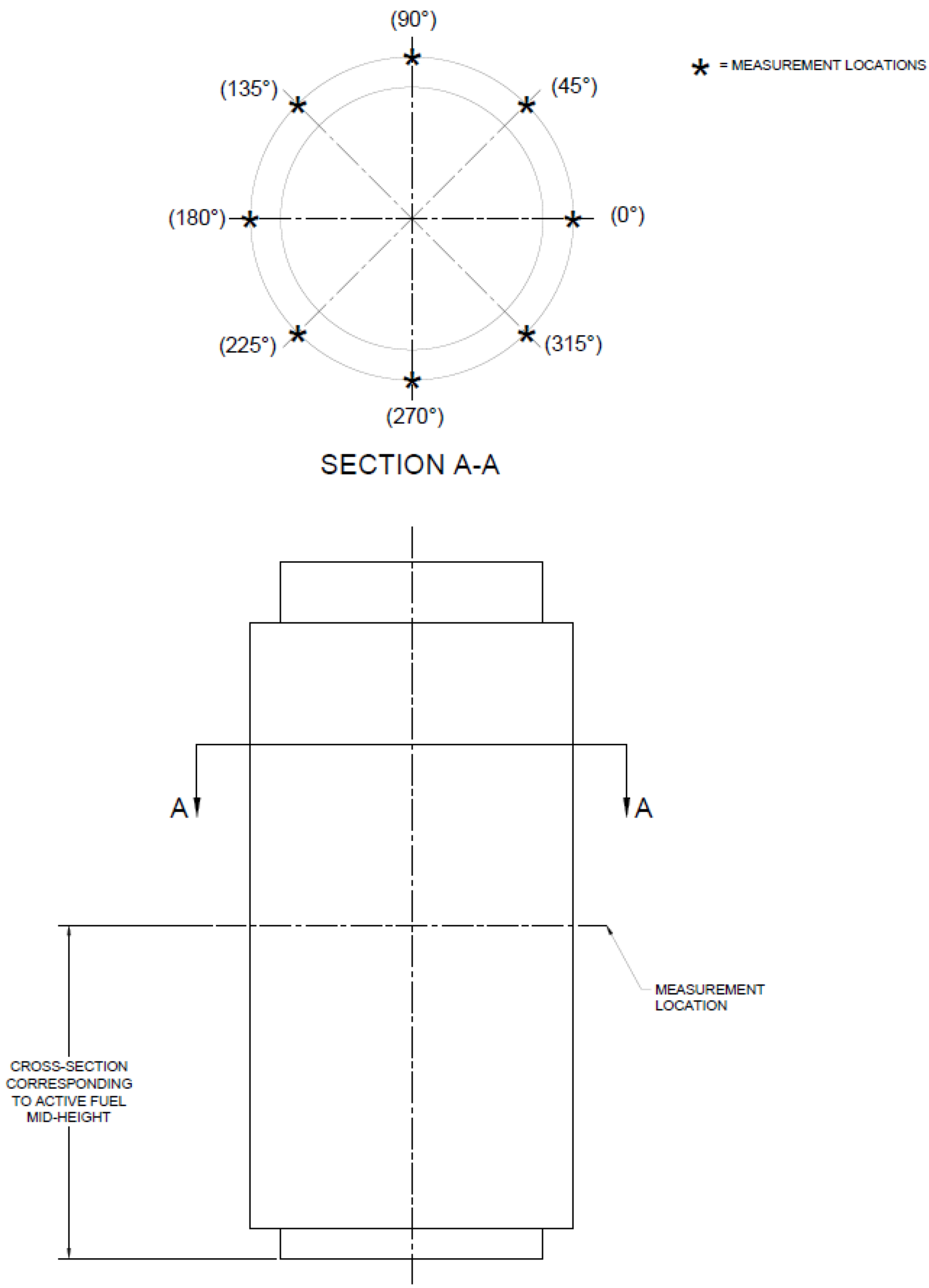
Table 8.2.1 (Sheet 1 of 2)

Maintenance Inspections and Tests Program Schedule

Task	Schedule
Cask and impact limiter surface visual inspection. (See Paragraph 8.2.2)	Prior to loading the loaded MPC into the cask or prior to loading/unloading bare basket.
Cask closure fasteners/bolts visual inspection (See Paragraph 8.2.2)	Prior to installation and/or prior to transport.
Cask trunnion visual inspection (See Paragraph 8.2.2)	Prior to loading the sealed MPC into the cask or prior to loading/unloading bare basket.
Impact limiter and impact limiters fasteners visual inspection (See Paragraph 8.2.2)	Prior to installation and/or prior to transport
Neutron shield relief device visual inspection (See Paragraph 8.2.2)	Prior to package transport
Pre-shipment leakage rate test of cask containment system seals (See Subsection 8.2.1)	Prior to package transport following each MPC or bare basket loading of the cask.
Pre-shipment leakage rate test of MPC containment boundary for MPC's containing HBF (See Subsection 8.2.1)	Prior to package transport following each MPC loaded into the cask
Periodic leakage rate test of cask containment system seals (See Subsection 8.2.1)	Prior to package transport if period from last test exceeds 1 year.
Periodic leakage rate test of MPC containment boundary for MPC's containing HBF (See Subsection 8.2.1)	Prior to package transport if period from last test exceeds 1 year.
Maintenance Leakage Rate Test of Cask containment boundary (See Subsection 8.2.1)	Following maintenance, repair or replacement of containment system components
Seal replacement for Closure Lid and/or Port Cover Plate (See Paragraph 8.2.2)	Following removal of closure bolting if the seal is not reusable or if the reusable seal is found to be damaged, is not free of debris, exhibits excessive compression set or does not meet the maintenance leakage rate test or pre-shipment test OR if required based on seal design life limitations

Table 8.2.1 (Sheet 2 of 2)
Maintenance Inspections and Tests Program Schedule

Task	Schedule
Bolt replacement (*Service Life*) for Closure Lid (See subsection 8.2.2)	Every 225 bolting cycles for SA-564/705 630 Every 256 bolting cycles for SB-637
Bolt replacement (*Service Life*) for port Cover Plate Bolts (See subsection 8.2.2)	558 bolting cycles for the bolt specified in drawing package referenced in the CoC.
Containment Top Forging closure bolt thread *Service Life* (See subsection 8.2.2)	1000 bolting cycles for the bolt specified in drawing package referenced in the CoC.
Neutron shield relief device replacement (See paragraph 8.2.2)	As required by the manufacturer's O&M manual
Periodic Neutron Shield Test (See subsection 8.2.2)	Within 5 years prior to shipment
Confirmatory Thermal Test (See subsection 8.2.3)	Within 5 years prior to shipment
MPC Enclosure Vessel pressure boundary structural integrity as confirmed by MPC aging management program for MPCs stored beyond the duration of the initial 20 year license period under the provisions of 10CFR 72 (See subsection 8.2.1).	Prior to package transport following each MPC loading of HBF into the cask
MPC Enclosure Vessel Shell Surface Defect Inspection for MPCs containing HBF and stored beyond 5 years under the provisions of 10CFR 72. MPCs passing inspection (approved for transport) must be shipped within 5 years). (See subsection 8.1.6)	Prior to transport. This test may be conducted based on a statistical testing approach as indicated in Subsection 8.1.6 and Table 8.1.6. The statistical approach may result in inspection of every MPC or the user may elect not to follow the statistical approach and instead inspect every MPC.
Post-Shipment Fuel Integrity Acceptance Test. (See subsection 8.1.6) (For HBF)	Prior to package transport following each MPC loading into the cask (pre-shipment) and post-shipment, as applicable.
10CFR72 AMP Based HBF Integrity Acceptance Test. (See subsection 8.1.6)	Prior to package transport



Note: For casks loaded with mixed fuel types, use a best estimate of assembly count weighted active fuel mid-height for measurement location.

Figure 8.2.1: Temperature Measurement Locations for the Periodic Thermal Test

8.3 MPC TRANSPORTABILITY CRITERIA[4]

Table 8.3.1 provides a checklist of transportability requirements an MPC must meet prior to transport in HI-STAR 100MB. The requirements include MPC acceptance criteria, design features, design criteria, aging management program, and other requirements that, unless otherwise noted, provide defense-in-depth as well as consistency to the safety approach of HI-STAR 100MB. Table 8.3.1 features an applicability column to distinguish whether requirements are applicable to MPCs loaded with MBF (where only the MPC pressure boundary structural integrity is essential to the safety approach as defense-in-depth) or to MPCs loaded with HBF (where in addition to the MPC pressure boundary structural integrity, the MPC containment boundary leak-tightness and containment boundary integrity under hypothetical accident conditions of transport are essential to the safety approach to ensure moderator exclusion under hypothetical accident conditions of transport).

4 The material presented in this section was adopted from the previously approved HI-STAR 190 FSAR with minor editorial changes

Table 8.3.1
MPC Transportability Checklist
(Sheet 1 of 2)

Requirement	Applicability	
	MPC loaded with MBF	MPC loaded with HBF
MPC Acceptance Tests and Inspections (Primary Safety Case)		
Visual Inspection and Measurements (Subsection 8.1.1)	✓	✓
Weld Examination (Subsection 8.1.2)	✓	✓
Structural and Pressure Tests (Paragraph 8.1.3.2)	✓	✓
Containment Boundary Leakage Tests (Subsection 8.1.4)		✓
Metamic-HT Tests (Paragraph 8.1.5.5)	✓	✓
Containment Boundary Integrity Confirmation by Enclosure Vessel Shell Surface Defect Inspection (See Subsection 8.1.6)		✓
MPC Structural Design Criteria (Primary Safety Case)		
The MPC's Enclosure Vessel must meet the stress intensity limits of ASME Section III Subsection NB under all applicable NCT and HAC of transport	✓	✓
The MPC is structurally qualified to remain "leaktight as defined by ANSI 14.5 [8.1.3]" under all normal and accident conditions of transport		✓
MPC Pressure Requirements		
The pressure inside the MPC remains < 100 psig (10CFR71.4) when prepared for transport in HI-STAR 100MB	✓	✓
MPC Design Features (Defense-in-Depth)		
The MPC must be all-welded, i.e., no reliance on mechanical seals or gaskets for radiological confinement	✓	✓
The MPC's Enclosure Vessel must be made of a corrosion resistant alloy	✓	✓
No pressure relief or pressure protection features or other form of breachable penetrations through the MPC pressure or containment boundary	✓	✓
Vent, drain or other penetrations must have a welded closure	✓	✓

Table 8.3.1
MPC Transportability Checklist
(Sheet 2 of 2)

Requirement	Applicability	
	MPC loaded with MBF	MPC loaded with HBF
MPC Inspections During Fabrication (Defense-in-Depth)		
All pressure boundary components in the MPC's Enclosure Vessel must be volumetrically tested	✓	✓
All butt welds in the MPC pressure boundary must be 100% radiographed.	✓	✓
The MPC top lid-to-shell weld joint must be progressively liquid penetrant (L.P.) tested	✓	✓
MPC Aging Management Program[5] (Defense-in-Depth)		
Enclosure vessel pressure boundary structural integrity confirmation (See Section 7.5.)		✓
MPC Maintenance Program (Primary Safety Case)		
The MPC has not suffered a handling accident that could significantly reduce the effectiveness of the packaging	✓	✓

5. The Aging Management Program is only applicable for storage durations longer than the initial 20 year license period under the provisions of 10CFR72.

8.4 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. References strictly consultative; the commitment in the SAR or the CoC may not be aligned with a cited reference. 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.”

[8.0.2] “Final Safety Analysis Report on the HI-STAR 190 Storage System”, Holtec Report HI-2146214, Latest Revision, Docket No. 71-9373

[8.1.1] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, 2006.

[8.1.2] 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.

[8.1.3] 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.

[8.1.4] “Metamic-HT Manufacturing Manual”, Latest Revision, Holtec International (Proprietary)

[8.1.5] “Metamic-HT Qualification Sourcebook”, HI-2084122, Latest Revision, Holtec International (Privileged Intellectual Property)

[8.1.6] Metamic-HT Purchasing Specification”, Holtec Document ID PS-11, Latest Revision, Holtec International (Proprietary)

[8.1.7] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2007 Edition, 2008 Addenda. (except 2007 Edition for MPCs and 2013 of Section IX for FSW)

[8.1.8] Holtec International Document DOC-5014-03, “Acceptance Testing of First HI-STAR Overpack (Thermal and He Leak Tests)”, September 2006

[8.1.9] 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.