NON-PROPRIETARY VERSION

SAFETY ANALYSIS REPORT
on
THE HI-STAR 180 PACKAGE

(Proposed Revision 7.A)

by

Holtec International
Krishna P. Singh Technology Campus
1 Holtec Boulevard
Camden, NJ 08104
(holtecinternational.com)

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* The safety designation is pursuant to Holtec International's Quality Assurance Program.

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GLOSSARY AND NOTATION

GLOSSARY

AFR is an acronym for Away From Reactor.

ALARA is an acronym for As Low As Reasonably Achievable.

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

Basket Shims are aluminum alloy 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.

C.G. 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.

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 safety 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 safety 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 is the computed heat rejection capacity of the HI-STAR package with a specific fuel basket with CSF stored in uniform storage with the ambient at the normal temperature and the peak cladding temperature (PCT) at 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 180 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 180 package.

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

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

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

Expanded Containment Boundary means a second barrier against leakage 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.

FAT is an acronym for factory acceptance test.

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 Impact Attenuator (FIA) is the deformable metallic compression element that may be used to close the gap between a stored fuel assembly and the closure lid to eliminate axial rattling of fuel during transport. An FIA is a type of fuel spacer. Also see fuel shim.

Fuel Package means the fuel along with the fuel basket and fuel basket related packaging such as basket shims and secondary containers. Also see Waste Package.

Fuel Shim is a metallic compression element that may be used to minimize the gap between a stored fuel assembly and the closure lid to mitigate axial rattling of fuel during transport. A fuel shim is a type of fuel spacer. Also see fuel impact attenuator.

GTCC is an acronym for Greater Than Class C waste.

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

HI-STAR is a generic term used to denote the family of metal casks consisting of HI-STAR 60, HI-STAR 63, HI-STAR 80, HI-STAR ATB-1T, HI-STAR 100, HI-STAR 100Z, HI-STAR 180, HI-STAR 180D, HI-STAR 180L and HI-STAR HB.

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

HI-STAR 180 Packaging consists of the HI-STAR 180 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).

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

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.

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

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

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

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

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

Metamic™ 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).

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

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

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

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

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 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), primary and secondary neutron source assemblies (NSAs), water displacement guide tube plugs, orifice rod assemblies, and vibration suppressor inserts.

Non-Fuel Waste (NFW) means radioactive waste other than spent nuclear fuel. NFW is used in this SAR as an alternative term to Radioactive Waste.

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

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

ORNL is an acronym for Oak Ridge National Laboratory

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

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

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

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

Pressure Relief Device means a mechanical component specifically designed to relieve excess internal pressure upon reaching or exceeding a design set point. In this SAR, the term pressure relief device refers to commercial poppet valves, commercial rupture disks or similar devices.

PWR is an acronym for Pressurized Water Reactor.

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

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

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

SAR is an acronym for Safety Analysis Report.

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

Short-term Operations means those normal operational evolutions necessary to support 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).

STP is Standard Temperature (298ºK) 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).

Waste Package means the radioactive waste along with the radioactive waste basket or radioactive waste supporting structure internal to the cask. A waste package may be a fuel package or a non-fuel waste package. Also see Fuel Package and NFW.

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

ZPA is an acronym for Zero Period Acceleration.

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

NOTATION

α Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})

d_{max}: Maximum predicted crush of the impact limiters in a package free drop event.

e: Elongation in percent (i.e., maximum tensile strain expressed in percentage at which the ASME Code test specimen will fail)

E Young's Modulus, MPa x 10^4 (psi x 10^6)

f: Factor-of-Safety (dimensionless)

m: Metric for bolted joint leakage (Table 2.6.1)

P_b Primary bending stress intensity

P_e Expansion stress

$P_L + P_b$ Either primary or local membrane plus primary bending

P_L Local membrane stress intensity

P_m Primary membrane stress intensity

Q Secondary stress

S_u Ultimate Stress, MPa (ksi)

S_y Yield Stress, MPa (ksi)

S_m Stress intensity values per ASME Code

T_c: Allowable fuel cladding temperature

T_p: Peak computed fuel cladding temperature

α_{max}: Maximum value measured or computed deceleration from a package drop event. α_{max} can be parallel or lateral to the centerline of the cask.

β: Weight percent of boron carbide in the neutron shield

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

Γ: Total gasket spring back in the unloading cycle

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

δ: Lateral (global) deflection of the basket panel

δ_g: Maximum permissible gasket relaxation to maintain leak tightness

δ_{max}: Maximum value of δ

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

ξ: Weight percent of hydrogen in the neutron shield material

ρ: Density

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

ψ: Thermal conductivity

θ Orientation of free drop (see Section 2.7.1)

CHAPTER 1: GENERAL INFORMATION

1.0 OVERVIEW

This Safety Analysis Report (SAR)* for the HI-STAR 180 Package is a compilation of information and analyses in the format suggested in Reg. Guide 7.9 [1.0.1] to support a United States Nuclear Regulatory Commission (USNRC) licensing review for certification as a spent nuclear fuel transportation package pursuant to the provisions of 10CFR71 Subpart D [1.0.2] and 49CFR173 [1.0.3].

HI-STAR 180 is the model name of a transport cask engineered to serve as a type B(U)F-96 packaging for transporting radioactive material (including but not limited to commercial spent fuel (CSF) and low to high level non-fuel waste (NFW) which can encompass reactor-related GTCC waste) under exclusive use shipment pursuant to 10CFR71.47. This SAR considers only CSF as the package contents.

Figures 1.0.1 and 1.0.2 provide pictorials of the exterior of the HI-STAR 180 Cask and HI-STAR 180 Packaging, respectively. The licensing drawing package in Section 1.3 provides the essential details of the package design that are necessary to define its interface dimensions and its physical characteristics needed to perform the required safety evaluations. For the reader's convenience and clarity, additional pictorials of the cask and packaging components are provided throughout this SAR.

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

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

* See Glossary for definition and abbreviation of terms used throughout this SAR.

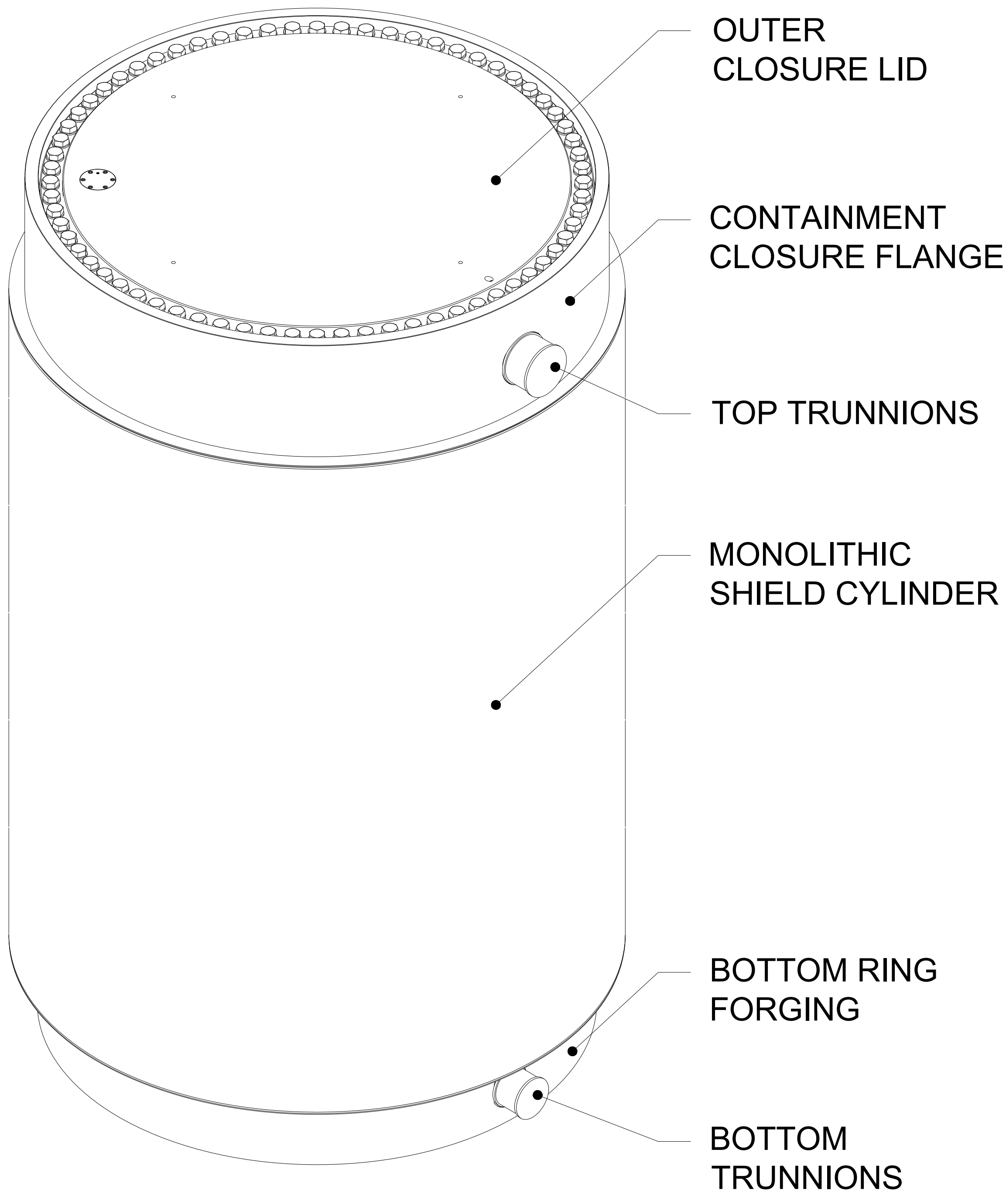
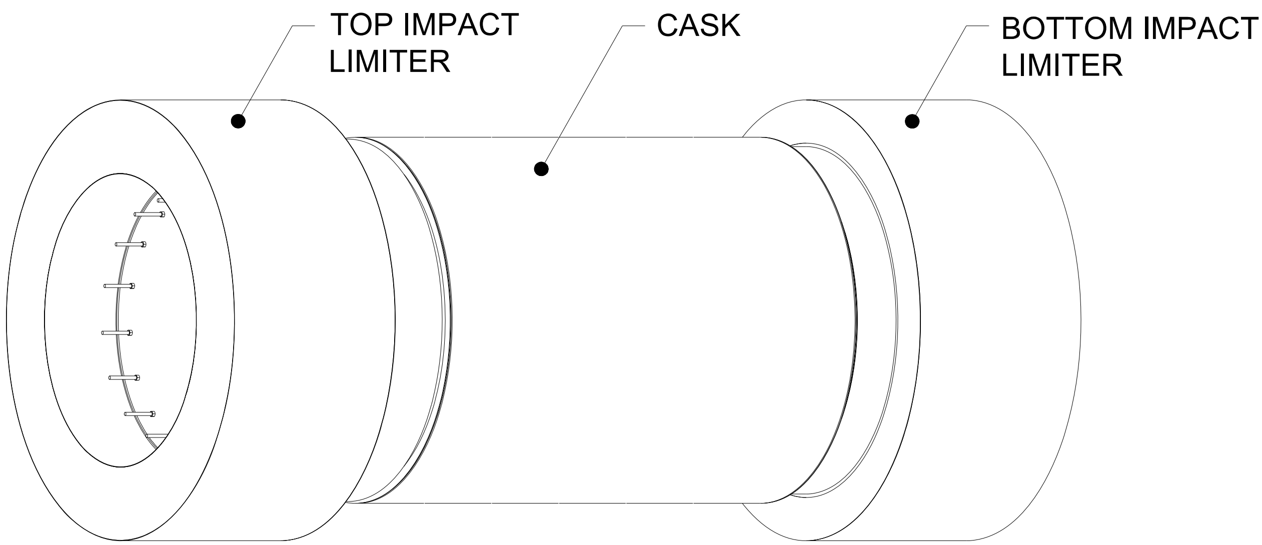


FIGURE 1.0.1 – EXTERIOR PICTORIAL VIEW OF THE HI-STAR 180 CASK

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



Note: Personnel Barrier Not Shown.

FIGURE 1.0.2 – EXTERIOR PICTORIAL VIEW OF HI-STAR 180 PACKAGING

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

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1.1 INTRODUCTION TO THE HI-STAR 180 PACKAGE

The HI-STAR 180 Package is a cylindrical metal cask with impact limiters qualified to carry CSF and engineered to be shipped by rail, road and seagoing vessel. Several key design concepts of the HI-STAR 180 Package are directly adapted from or reflected in Holtec's various licensed transport packages (see Table 1.1.1). 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.

The HI-STAR 180 Cask containment system is engineered to parallel the anatomical design and construction of the containment system of HI-STAR 100 Package certified for transport under Docket No. 71-9261 [1.0.4] and for storage under Docket No. 72-1008 [1.0.5]. More specifically, the containment system materials of construction, welding joint details, NDE requirements, seal joint type, and Code of construction for the HI-STAR 180 Packaging, are identical or similar to those of the HI-STAR 100 Packaging (certified by the USNRC and deployed at nuclear plants since the late 1990s).

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Finally, the design embodiment, construction, and materials for the HI-STAR 180 Package impact limiters are identical to those used in the HI-STAR 100 Package (Docket No. 71-9261) [1.0.4] and are fully described in this SAR.

Table 1.1.3 provides general dimensional and weight data on the HI-STAR package. Safety analysis is performed to dimensional data in the drawing package and to weight data in Chapter 2 unless otherwise specified in this SAR.

The HI-STAR 180 Package complies with all of the requirements of 10CFR71 for a Type B(U)F-96 package. In particular, the prescribed maximum normal operating pressure (MNOP) of 700 kPa (100 lb/in^2) for a type B(U) package is observed. No pressure relief device or feature intended to allow continuous venting during transport is provided on the HI-STAR 180 containment boundary (10CFR71.43(e) and 10CFR71.43(h)). Therefore, there is no pressure relief device or other feature that may permit release of radioactive material under the tests specified in 10CFR71.73. Analyses that demonstrate the compliance of the HI-STAR 180 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 180 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 180 Packaging with design basis fuel contents (Section 5.0 provides the determination of the TI). Therefore, the HI-STAR 180 Package must be transported by exclusive use shipment (10CFR71.47) for any shipment of spent nuclear fuel. An empty but previously loaded HI-STAR 180 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 180 Packaging is designed to ensure safe transport of SNF. Some of the key features of the HI-STAR 180 Packaging that enhance its effectiveness are:

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Withheld in Accordance with 10 CFR 2.390

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This SAR supports a licensed life of the HI-STAR 180 package of 5 years, after which a renewal by the USNRC is based upon an affirmative safety assessment to support such renewal. Even though the safety analysis is not required to address more than 5 years, all safety evaluations are based on a design or service life of at least 40 years to provide a suitable degree of conservatism.

This is accomplished by using materials of construction that have been exhaustively tested and determined capable of withstanding HI-STAR 180's operating environments without degradation and with negligible reduction if any, in their capability to render their intended function (materials of construction and testing are discussed in Section 1.2 and Section 2.2 of this SAR). A maintenance program, as specified in Chapter 8, is implemented to ensure the HI-STAR 180 Package will meet its Design Life of 40 years. The technical considerations that assure the HI-STAR 180 performs its design functions throughout its Design Life include all areas germane to the long-term integrity of the system, such as:

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

Table 1.1.1
HI-STAR Family of Transport Packages
(USNRC Docketed Only)

Model No.	USNRC Docket and SAR Reference	Year First Certified	Content (Fuel Type or NFW)	Approx. Cask Cavity Length (mm [inch])	Approx. Cask ID (mm [inch])	Fuel Package Type: Bare Basket (B) or Canisterized (M)
HI-STAR 100 (Classic)	71-9261 [1.0.4]	1998	BWR & PWR	4855 [191 1/8]	1747 [68 3/4]	M
HI-STAR 100 Version HB		2009	BWR	2929 [115 5/16]	1747 [68 3/4]	M
HI-STAR 100 Version HB GTCC		2018	NFW	2931 [115 3/8]	1747 [68 3/4]	N/A
HI-STAR 100MB	71-9378 [1.1.6]	2019	PWR	4201 [165 3/8 (SL)] 4855 [191 1/8 (XL)]	1747 [68 3/4]	M & B
HI-STAR 60	71-9336 [1.1.5]	2009	PWR	3547 [139 5/8]	1080 [42 1/2]	B
HI-STAR 180	71-9325 [this SAR]	2009	PWR	3572 [140 5/8]	1850 [72 7/8]	B
HI-STAR 180D	71-9367 [1.1.1]	2014	PWR	2944 [115 7/8]	1850 [72 7/8]	B
HI-STAR 180L	71-9381 [1.1.7]	Foreseen 2020	BWR	4543 [178 7/8]	1689 [66 1/2]	B
HI-STAR 190	71-9373 [1.1.2]	2017	BWR & PWR	4845 [190 3/4 (SL)] 5417 [213 1/4 (XL)]	1931 [76]	M
HI-STAR 80	71-9374 [1.1.3]	2018	BWR & PWR & NFW	4579 [180 1/4]	1242 [48 7/8]	B
HI-STAR ATB-1T	71-9375 [1.1.4]	Foreseen 2019	NFW	N/A	N/A	N/A
Note: Dimensions are taken from respective licensing drawing packages approved at the time of this writing. Dimensions are nominal and may be rounded. N/A stands for Not Applicable.						

Table 1.1.2

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

Waste Package Model No. (Notes 3 and 4)	Waste Package Type (Fuel Package or NFW Package)	Content Type	Canisterized or Bare Basket	Basket Structural Material and Neutron Absorber	Damaged Fuel Container or Other Secondary Packaging
F-32	Fuel Package	PWR	Bare Basket	Metamic-HT	Quivers (Notes 5)
F-37	Fuel Package	PWR	Bare Basket	Metamic-HT	Quivers (Notes 5)

Notes

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

Table 1.1.3 [Withheld in Accordance with 10 CFR 2.390]

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1.2 DESCRIPTION OF PACKAGING COMPONENTS AND THEIR DESIGN AND OPERATIONAL FEATURES

1.2.1 Packaging

1.2.1.1 Major Packaging Components and Packaging Supports and Restraints

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

a. Cask

The HI-STAR 180 Cask is a cylindrical metal cask designed and qualified to hold SNF in a subcritical “fuel package” configuration featuring a highly thermally conductive Metamic-HT fuel basket. The containment of the radiological contents is provided by a cryogenic nickel steel shell (the Containment Shell) welded to a nickel steel baseplate (the Containment Baseplate) at the bottom and a suitably machined nickel steel forging (the Containment Closure Flange) at the top. The Containment Closure Flange is equipped with machined surfaces to fasten two independent cryogenic steel closure lids, each equipped with concentric metallic seals. The fully cryogenic steel weldment and the cryogenic steel closure lid define the “Containment System Boundary” for the cask. The Containment System Boundary, including both closure lids, is designed and manufactured to ASME Section III Division 1, Subsection NB [1.2.1] as clarified in this SAR. Cask design details are shown in the drawing package in Section 1.3.

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

1) The Cask Containment Shell (CCS): The innermost cylindrical member of the cask containment system made from cryogenic nickel steel forging or plate.
2) Cask Bottom Region (CBR): The CBR consists of a thick cryogenic nickel steel forging, namely the Containment Baseplate, featuring neutron and gamma shielding material for additional dose reduction. The CBR includes a massive bottom ring steel forging and bottom trunnions used for cask rotation that are rendered inoperable during package transport.
3) Cask Top Region (CTR): The CTR consists of a massive cryogenic nickel steel forging, namely the Containment Closure Flange. The CTR includes top trunnions (cask’s interfacing lift points) which are rendered inoperable during package transport
4) Double Closure Lid System (DCLS): The DCLS consists of two specially shaped lids, the Inner and Outer Closure Lids, with two machined concentric grooves in each lid to provide containment protection. The bolted lid joints are “controlled compression” joints engineered to meet the leak-tight criterion of ANSI N14.5 [8.1.6] under the normal and hypothetical accident conditions of transport. See SAR Appendix 1.B for information on Moderator Exclusion applicable only to Fuel Packages containing HBF.

The inner closure lid features neutron shielding material and additional gamma shielding material for ALARA.

5) Gamma Capture Space (GCS): The GCS refers to the monolithic shield cylinders which renders the principal function of blocking gamma radiation.
6) Neutron Capture Space (NCS): The NCS refers to the sector pockets within the monolithic shield cylinders that are filled with neutron shield material and whose principal function is to block the neutrons accreted by the contained waste package. This space itself is non-structural. The sector pockets are provided with pressure relief protection (as shown in the drawing package in Section 1.3) to prevent the over-pressurization of its enclosure (the monolithic shield cylinder weldment) in the case of off-gassing of the shield material.

The above description of the constituent parts is summarized in Table 1.2.17 for ease of reference.

As with the previously licensed HI-STAR 100 Cask, all materials used in the HI-STAR 180 Cask containment system boundary are widely used in low temperature applications and regardless of their product form, are of compatible metallurgical genre and thus are readily weldable to each other. While the HI-STAR 180 Cask containment system boundary renders the function of a high integrity pressure vessel by providing multiple highly reliable leakage barriers in its double lid closure, it does not possess the necessary shielding in the radial direction to attenuate the radiation dose sufficiently to meet the limits mandated in 10CFR71. Therefore, for shielding purposes, it is necessary to surround the containment shell with additional material optimized to reduce levels of gamma and neutron radiation. This additional shielding is achieved with a monolithic cylinder equipped with longitudinal through holes in the form of "sector pockets" near their outer boundary that provide the enclosure space for Holtite. The monolithic cylinder is made of alloy steel with excellent impact resistant properties at low temperatures. As shown in the drawing package in Section 1.3, the monolithic shield cylinder is configured from several short annular monolithic shield cylinders stacked on top of each other to provide full-length gamma and neutron shielding around the containment shell and active fuel region. Because of their complex geometry and large mass, it is necessary to produce the monolith cylinders using the casting process. The casting technology to produce the low temperature alloy steel that yields the requisite properties (density, tensile strength, and impact strength at low temperatures) is well established in the U.S. Standards [1.2.2, 1.2.16].

Use of alloy steels with excellent conductivity and impact strength properties helps render the HI-STAR 180 cask body into an efficient heat dissipater. [

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sufficiently small to prevent any inelastic effects, yet they help enhance the axial buckling strength of the containment shell under impactive axial loadings. However, this buckling capacity increase is conservatively not accounted for in the structural analyses of the Containment Shell in this SAR.

Further, because the monolithic shield cylinders are not integral to the containment shell, a crack in the body of a monolithic shield cylinder will not radially propagate into the containment shell and in this manner the crack-arrest characteristic in HI-STAR 180 is similar to that in the previously licensed HI-STAR 100.

The monolithic shield cylinders are equipped with "sector pockets" that hold the Holtite-B neutron shielding material. The sector pockets contain pressure relief protection (as shown in the drawing package in Section 1.3) to prevent their overpressurization from off-gassing of the neutron shield material.

Finally, like the HI-STAR 100 Cask, the HI-STAR 180 Cask features two removable top trunnions secured to the Containment Closure Flange for lifting and handling. In addition, the HI-STAR 180 Cask is equipped with two removable bottom trunnions secured to the Containment Baseplate. The bottom trunnions may be used as turning trunnion or may be used as lifting trunnions for horizontal lifting and handling in unison with the top trunnions.

b. Waste Packaging

Waste packages qualified for use with HI-STAR 180 are listed in Table 1.1.2. Waste packages may take various forms such as fuel packages or non-fuel waste (NFW) packages. Waste packages are also identified as either canisterized, where the waste package is sealed in a separate canister, or not canisterized (also referred to as a bare waste-package). Therefore, the waste packaging discussed herein is dependent on the waste package type. The F-32 and F-37 are bare-basket PWR fuel packages currently available for the HI-STAR 180 Package. Quivers and dummy fuel assemblies are discussed in Subsection 1.2.2.

The F-32 and F-37 fuel baskets are major components of the F-32 and F-37 fuel packages, respectively. Their design details, illustrated in the drawing package in Section 1.3, show that they are both of a honeycomb construction and feature 32 and 37 storage cavities accordingly.

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c. Impact Limiters:

Two impact limiters (also referred to as AL-STAR 180) are installed at the two extremities of the HI-STAR 180 Cask and 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 HI-STAR 180 impact limiters are of the same design genre as the AL-STAR 100 used in the HI-STAR 100 Package (Docket No. 71-9261). The following key design features typify the HI-STAR 180 impact limiters:
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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.

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d. Personnel Barrier:

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

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

Dose calculations in this SAR conservatively consider an open (flat-bed) conveyance and do not rely on conveyances that are "closed" or with "enclosures". Moreover, it is conservatively shown, with the exception of the transport index, that the package design complies with the external surface radiation limits for a non-exclusive use shipment in accordance with 10CFR71.47(a). Thus for the purpose of dose calculations/measurements that ensure compliance with regulatory radiation limits, the jurisdictional boundary of the HI-STAR 180 Packaging is the outer most external surfaces of the impact limiters and the cask. However, due to exceedance of the transport index (exclusive use shipment applies), the package is also shown to comply with the radiation limit at 2 meters from the vertical planes projected from the outer edges of the vehicle (excluding the top and underside of the vehicle) in accordance with 10CFR71.47(b)(3). See SAR Chapter 5 for complete acceptance criteria on radiation limits.

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

e. Packaging Supports and Restraints:

The HI-STAR 180 Package lends itself to a horizontal packaging assembly for transport as shown in the drawing packaging in Section 1.3 and is engineered for shipment by seagoing vessel, railroads and roadways using appropriate supports and restraints. An illustrative example of packaging supports and restraints for rail transport is provided in Figure 1.3.2. The arrangement of packaging supports and restraints may vary as long as the package is properly secured and qualified for the specific mode of transport. Tapered wedge shims that close the gap between the impact limiters and the axial restraints (longitudinal stops) of the transport vehicle are examples of auxiliary equipment that may be used to restrain the package against axial movement. Non-integral appurtenances to the cask, such as the transport cradle, longitudinal stops, support saddles, tie down system and wedge shims are not structural parts of the HI-STAR 180 Package and, as such, are not designated as packaging components.

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

In the HI-STAR 180 transport package configuration, the cask trunnions are not qualified to be used to lift the HI-STAR 180 Package (i.e., loaded cask with impact limiters) and in fact are replaced by steel trunnion (shielding) plugs which are then covered by the impact limiters. Therefore, in the package transport configuration, there are no lifting attachments remaining that are a structural package and there is no structural part of the package that must be rendered inoperable for lifting the package per 10CFR71.45(a).

1.2.1.2 Overall Packaging Dimensions and Weight

An overview of approximate general dimensions and weights are provided in Table 1.1.3. Packaging dimensions are provided in the drawing package in Section 1.3.

The nominal weights for the HI-STAR 180 Package main components, nominal weight of the cask and package at maximum capacity with design basis SNF are provided in Section 2.1 (and Table 2.1.11) for safety analysis purposes. The weight of the package contents is discussed in Subsection 1.2.2 below.

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

1.2.1.3 Containment Features

The Containment System forms an internal cylindrical cavity for housing the waste packages listed in Table 1.1.2. A schematic of containment system components is shown in the drawing package in Section 1.3 and also in Figures 4.1.1, 4.1.2, and 4.1.3 (all components with the primary function of containment are shown in these schematics). As shown in these schematics, the massive inner closure lid system defines the containment boundary. The outer closure lid system along with the inter-lid space also meets the design and manufacturing criteria to be merged with the inner containment space to define an expanded containment boundary. The expanded containment boundary will play its role only in the unlikely event that the boundary defined by the inner lid fails to hold.

Both closure lids have been engineered to perform the containment function with final qualification by leak testing according to ANSI N14.5 [8.1.6] as specified in Chapter 8, Table 8.1.2 and to the leakage acceptance criterion specified in Chapter 8, Table 8.1.1. Each closure lid joint features equally proficient seals, one seal serving as a back-up to the other seal.

1.2.1.4 High Burnup Fuel Transportation and Moderator Exclusion Features

The HI-STAR 180 packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF). To address concerns with the structural integrity of HBF under accident conditions, and its potential impact on criticality safety, the design of HI-STAR 180 provides utmost assurance of water exclusion under a postulated 10CFR 71.73 accident scenario. The principal approach consists of assurance of moderator exclusion under accident conditions, following the intent of and performance objectives of ISG-19 [1.2.15].Details of the design measures and technical confirmation to meet the intent and performance objectives of ISG-19 are described in Appendix 1.B, where additional defense-in-depth measures to ensure sub-criticality compliance are also discussed.

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1.2.1.5 Neutron and Gamma Shielding Features

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

The initial attenuation of gamma and neutron radiation emitted by the radioactive spent fuel is provided by the fuel basket and the fuel basket shims. However, most of the shielding in the transport package is contained in the body of the cask and consists of neutron shielding (by steel and Holtite) and gamma shielding (by steel in radial direction, and by steel and lead in axial directions).

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

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1.2.1.5.1 Holtite™ Neutron Shielding Material

(a) Qualification of the Holtite™ Neutron Shielding Material

The shielding against neutron radiation in HI-STAR 180 Packaging is provided by Holtite-B. Holtite™ is a hydrogen rich, radiation resistant, polymeric material impregnated with boron carbide. Holtite-A is the predecessor of Holtite-B which was developed by Holtec International in the early 90s as a part of the company's HI-STAR 100 design development program.

Holtite-A was subjected to extensive studies of its critical characteristics (viz., radiation resistance, physical stability at service temperature and homogeneity) during its evaluation and validation program [1.2.4, 1.2.5], which led to its regulatory approval in the HI-STAR 100 Docket (71-9261) and subsequent use in the manufactured HI-STAR 100 overpacks. Holtite B is an improved version of Holtite-A in respect of its stability at higher temperatures.

Like Holtite-A, Holtite-B is a relatively poor conductor of heat and possesses limited gamma attenuation capability. Its main function is to provide neutron shielding which is enabled by a hydrogen rich polymeric matrix and spatially distributed particles of Boron Carbide. Holtite-B may also contain spatially distributed particles of copper to enhance thermal conductivity and/or gamma shielding. Boron carbide and copper content of the Holtite-B for the HI-STAR 180 are specified in this SAR as critical characteristics.

Holtite-B has been subjected to the same battery of tests to establish its radiation resistance, physical stability at service temperature and homogeneity as Holtite-A [1.2.17]. In contrast to Holtite-A which is qualified to operate under 149°C (300°F) temperature, Holtite-B is capable of operating at 204°C (400°F) in sustained use without a significant weight loss. Critical Characteristics of the Holtite-B neutron shielding material used in the safety analyses are provided in Table 1.2.16.

1.2.1.6 Criticality Control Features

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

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

1.2.1.6.1 Qualification of Metamic-HT

Metamic-HT is a composite of nano-particles of aluminum oxide (alumina) and finely ground boron carbide particles dispersed in the metal matrix of pure aluminum. Metamic-HT is the constituent material of the HI-STAR 180 fuel baskets. Metamic-HT neutron absorber is a successor to the Metamic (classic) product widely used in dry storage fuel baskets [1.2.7] and spent fuel storage racks [1.2.8, 1.2.9]. Metamic-HT is engineered to possess the necessary mechanical characteristics for structural application in spent nuclear fuel casks. The mechanical properties of Metamic-HT are derived from the strengthening of its aluminum matrix with ultra-fine-grained (nano-particle size) alumina (Al_2O_3) particles that anchor the grain boundaries for high temperature strength (the "HT" designation is derived from this characteristic) and creep resistance. The specific Metamic-HT composition utilized in this SAR is defined in Table 1.2.15. In what follows, Metamic-HT refers to the alumina strengthened aluminum with homogeneously dispersed boron carbide particles manufactured to the weight loading specifications of this Table.

METAMIC-HT was first certified by the USNRC in 2009 in this HI-STAR 180 transport application 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 used in HI-STORM FW (Docket No. 72-1032), HI-STORM UMAX (Docket No. 72-1040) and HI-STORM 180D (Docket No. 71-9367) utilize METAMIC-HT for neutron absorbing and structural functions.

(i) Thermo-physical Properties of Metamic-HT

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(iv) Welding of Metamic-HT

Because METAMIC-HT is an aluminum-based nano-spheroid reinforced metal matrix composite (MMC) and a non-code material, the Sourcebook [1.2.27] documents the tensile strength of the Metamic-HT welds as determined by the tensile testing protocol specified in Section IX (2007 Edition) of the ASME Code. The tensile strength criterion of FSW welds is provided in the drawing package in Section 1.3. As is generally true of metal matrix composites, Friction Stir Welding (FSW) is known to provide predictable and stronger joint strength on a repeatable basis compared to classical welding methods such as metal inert gas or tungsten inert

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gas welding. Accordingly, the FSW process is used for joining Metamic-HT panels with the requirements specified in SAR Paragraph 8.1.5.4 to qualify the welding procedure and welder operator. The procedure qualification and welder operator qualification protocol, provided in the Metamic-HT Manufacturing Manual [1.2.25], has been established to accord with the unique bonding characteristics of Metamic-HT and to ensure that the required minimum joint strength is realized with full assurance in the production of the fuel baskets. Sections 2.3 and 8.1 of this SAR respectively provide additional information on the reference ASME code, design & fabrication aspects and testing / inspection requirements for Metamic-HT basket welding.

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1.2.1.7 Lifting and Tie-Down Devices

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

Lifting trunnions are manufactured from a high strength alloy and designed in accordance with 10CFR71.45 and NUREG 0612 (per Chapter 2) with load testing performed in accordance with ANSI N14.6 [8.1.3] (per Chapter 8).

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

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

1.2.1.8 Heat Transfer Features

The HI-STAR 180 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 [1.2.13]. 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 180 Package are conduction and thermal radiation.

The free volume of the space under the inner closure lid (storage cavity) and the cask inter-lid space are filled with high purity helium gas (see Chapter 7 of this SAR) during fuel loading operations. Besides providing an inert dry atmosphere for the fuel cladding, the helium gas also provides conductive heat transfer between each assembly and the surrounding basket walls and across any gaps between the metal surfaces inside the containment system. Metal conduction transfers the heat throughout the fuel basket, through the containment system boundary, and finally through the monolithic shield cylinder and other exterior cask components. The cask storage cavity and inter-lid spaces are backfilled with helium to pressures specified in Tables 1.2.1 and 1.2.2.

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

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1.2.1.9 Internal Support Features

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

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1.2.1.10 Anti-Rotation Devices

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

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1.2.1.11 Packaging Markings

Each HI-STAR 180 Packaging shall have a unique identification plate with appropriate markings per 10CFR71.85(c). The identification plate shall not be installed until each HI-STAR 180 Packaging component has completed the fabrication acceptance test program and been accepted by authorized Holtec International personnel.

1.2.2 Contents of Package

The HI-STAR 180 Package is classified as a Category I Type B package since the maximum activity of the contents to be transported in the HI-STAR 180 Package is above limits shown in Table 1 of Regulatory Guide 7.11 [1.2.3].

The allowable radioactive waste (i.e. allowable content) corresponding to each qualified waste package identified in Table 1.1.2 is specified in this Subsection.

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

- Lower burnup fuel with long cooling times from earlier cycles of the plant; and
- High burnup fuel with intermediate cooling times from current plant operations; and
- High and moderate burnup fuel with short cooling times to be transported after plant shutdown; and
- UO_2 fuel with a large initial enrichment range; and
- MOX fuel from recycling, with a wide range of isotopic compositions.

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Table 1.2.3a lists allowable contents for the H-STAR 180 Package with references to several other tables that further define the allowable contents. Table 1.2.3b lists the acceptable physical characteristics of the fuel assemblies qualified for transportation in the HI-STAR 180 package. UO_2 assemblies are limited to an initial enrichment of less than or equal to 5 wt% ^{235}U. For MOX assemblies, four sets of limits are specified in Table 1.2.4, and three sets are specified in Table 1.2.5. A MOX assembly meeting the limits in one of the sets in each table is acceptable for transport.

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The maximum mass of fissile material permitted for transport in the HI-STAR 180 Package is also shown in Table 1.2.3c.

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The radioactive and fissile material is in the form of solid fuel pellets with a maximum fuel density shown in Table 1.2.3c. There are no moderating material or neutron absorbers in the contents, nor any other material that would create a chemical, galvanic or other reaction leading to the release of combustible gases.

The maximum weight of the radioactive materials and the payload are shown in Table 1.2.3.

Figures 1.2.3 and 1.2.4 provide cross sectional views of the F-32 and F-37 baskets storage cell layouts. The storage cells are numbered and basket quadrants are specified as shown in these figures to facilitate fuel loading under regionalized storage. With regionalized loading there are eight regions defined for each basket. The storage cell numbers for each region and the storage cell numbers for each quadrant are listed in Tables 1.2.6a and 1.2.6b, and also noted in Figures 1.2.3 and 1.2.4. Table 1.2.7a specifies loading curves (minimum burnup as a function of initial enrichment) for UO_2 fuel in certain regions in the F-37 basket for ten different configurations.

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Corresponding core operating requirements are listed in Table 1.2.14. There are no minimum burnup requirements for the F-32 basket. Table 1.2.7b specifies maximum enrichment limits for fresh fuel in certain regions in the F-32 basket for two different configurations. The two configurations allow different numbers and locations of fresh fuel assemblies and fuel debris in quivers. Tables 1.2.8 and 1.2.9 list the specific minimum enrichment, maximum decay heat, maximum burnup and minimum cooling time limits for six loading patterns for the F-32 and for four loading patterns for the F-37 fuel basket.

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1.2.2.1 Core Operating Parameters†

For assemblies that need to meet the burnup requirements listed in Table 1.2.7a, certain operating limits during in-core depletion must be satisfied. These limits are listed in Table 1.2.14. For each assembly, the parameters Soluble Boron Concentration (SBC), Specific Power (SP), and Moderator Temperature (MT) must be calculated using the following equations. In these equations, and the symbols used therein, the subscript i denotes the cycle. The summation ($\sum$) in these equation is to be performed over all cycles i that the assembly was in the core.

Given

B_i	Assembly-average burnup for cycle i
BC_i	Core-average burnup for cycle i
SB_i	Average In-Core Soluble Boron Concentration for cycle i
T_i	Length of Cycle
CITi	Core Inlet Temperature
COT_i	Core Outlet temperature

the values to be compared to the limits in Table 1.2.14 are to be calculated as follows:

Soluble Boron:

$$SB = \sum (SB_i * B_i) / \sum B_i$$

Assembly Average Specific Power:

$$SP = \sum B_i / \sum T_i$$

Assembly Average Moderator Temperature:

$CFC_i = B_i/BC_i$ Correction Factor; if $CFC_i<1$ then set $CFC_i = 1$

$$MT = \sum (B_i*(CIT_i + CFC_i * (COT_i-CIT_i))) / \sum B_i$$

Additionally, the presence of NFH in fuel assemblies during depletion is permitted under the following conditions:

- Fuel assemblies with NFH inserted no more than 38 cm into the active region during full power operation are permitted without any further limitations
- Fuel assemblies where NFH was inserted more than 38 cm, up to full length insertion, must have a minimum cooling time of 20 years.

† This SAR paragraph is included by reference into the CoC.

1.2.3 Special Requirements for Plutonium

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

1.2.4 Operational Features

The HI-STAR 180 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). There are no complex operational features that required a detailed exposition. Similar to the MPC closure lids loaded in HI-STAR 100 and HI-STORM 100 overpacks, the HI-STAR 180 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 180 Packaging is a completely passive system once loaded and sealed in accordance with 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.

Typical Loading Operations

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 [1.2.7] 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 Chapter 3 and procedures in Chapter 7 of this SAR.

Following the fuel drying operations, the cask cavity is backfilled with helium gas and the vent/drain ports are sealed (quantity of helium is specified in Table 1.2.1). The inner Containment Boundary seals are then leak tested to the leakage acceptance criteria specified in Chapter 8 of this SAR.

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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 (quantity of helium is specified in Table 1.2.2). The outer lid (expanded) containment boundary seals are then also leak tested to the leakage acceptance criteria specified in Chapter 8 of this SAR.

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 180 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 Section 8 in this SAR.

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Table 1.2.1
HI-STAR 180 Cask Cavity Helium Backfill Pressure Limits

See Table 7.1.4 of this SAR.

Table 1.2.2
HI-STAR 180 Inter-Lid Space Helium Backfill Pressure Limits

See Table 7.1.4 of this SAR.

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Table 1.2.3a [Withheld in Accordance with 10 CFR 2.390]

Table 1.2.3b
Fuel Assembly Characteristics

Item	Reference Data
Fuel Assembly Type	14x14
No. of Fuel Rod Locations	179
Design Initial Heavy Metal Mass (kg)	341 Max.
Fuel Rod Clad O.D. (mm)	≥10.72 Nom.
Fuel Rod Clad I.D. (mm)	≤9.61 Nom.
Fuel Pellet Dia. (mm)	≤9.31 Nom.
Fuel Rod Pitch (mm)	≤14.224 Nom.
Active Fuel Length (mm)	≤3070 Nom.
No. of Guide and/or Instrument Tubes	17
Guide/Instrument Tube Thickness (mm)	≥0.285 Nom.

Note 1: Parameter values noted as nominal are intended to fix the general description of the allowable content. The maximum fuel assembly length in this table is set to the nominal length of the longest fuel assembly intended to be loaded. The supporting safety analyses consider tolerances as appropriate to the specific evaluation to achieve overall bounding conditions.

Table 1.2.3c [Withheld in Accordance with 10 CFR 2.390]

Table 1.2.4
Isotopic Characteristics of MOX Fuel For Use in Shielding Analysis

	Isotopic Composition (g/assembly)			
Criteria / Isotope	1	2	3	4
Pu238	≤ 700	≤ 202	≤ 202	≤ 202
Pu239	≥ 12808	≥ 11000	≥ 7438	≥ 8000
Pu240	≥ 5726	≥ 3800	≥ 1700	≥ 1700
Pu241	≤ 2300	≤ 1600	≤ 1250	≤ 1600
Pu242	≤ 1900	≤ 751	≤ 700	≤ 751
U235	≥ 724	≥ 720	≥ 2100	≥ 720
U238	≤ 298007	≤ 320200	≤ 326000	≤ 326000

Note: Each MOX assembly selected for loading must meet criteria 1, 2, 3 or 4.

Table 1.2.5
Isotopic Characteristics of MOX Fuel For Use in Criticality Analysis

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

Note: Each MOX assembly selected for loading must meet criteria 1, 2 or 3.

Table 1.2.6a

Regions for Regionalized Loading

Region Number	Cell Numbers	
	F-32 (see Figure 1.2.3)	F-37 (see Figure 1.2.4)
1	3,11,22,30	2,16,22,36
2	8,12,21,25	6,17,21,32
3	13,14,19,20	12,18,20,26
4	4,5,28,29	19
5	6,9,24,27	1,3,9,15,23,29,35,37
6	7,15,18,26	5,7,10,14,24,28,31,33
7	1,10,23,32	11,13,25,27
8	2,16,17,31	4,8,30,34

Table 1.2.6b

Quadrants for Regionalized Loading

Quadrant Number	Cell Numbers	
	F-32 (see note 1)	**F-37** (See note 2)
1	3, 4, 8, 9, 10, 14, 15, 16	2, 3, 6, 7, 8, 12, 13, 14, 15, 19, 20, 21, 22
2	20, 21, 22, 26, 27, 28, 31, 32,	19, 20, 21, 22, 26, 27, 28, 29, 32, 33, 34, 36, 37
3	17, 18, 19, 23, 24, 25, 29, 30	16, 17, 18, 19, 23, 24, 25, 26, 30, 31, 32, 35, 36
4	1, 2, 5, 6, 7, 11, 12, 13	1, 2, 4, 5, 6, 9, 10, 11, 12, 16, 17, 18, 19

Notes:

1. F-32 Quadrants are defined in Figure 1.2.3. The total additive heat load in each quadrant shall not exceed the quadrant heat load limit specified in Table 1.2.3a.
2. F-37 Quadrants are defined in Figure 1.2.4. The total additive heat load in each quadrant shall not exceed the quadrant heat load limit specified in Table 1.2.3a. Because the F-37 quadrants share storage cell locations, the following equations are specified to ensure total heat load per quadrant is not exceeded.

- Quadrant No. 1: Actual quadrant heat load = (1/2)2 + 3 + (1/2)6 + 7 + 8 + (1/2)12 + 13 + 14 + 15 + (1/4)19 + (1/2)20 + (1/2)21 + (1/2)22
- Quadrant No. 2: Actual quadrant heat load = (1/4)19 + (1/2)20 + (1/2)21 + (1/2)22 + (1/2)26 + 27 + 28 + 29 + (1/2)32 + 33+ 34 + (1/2)36 + 37
- Quadrant No. 3: Actual quadrant heat load = (1/2)16 +(1/2)17 + (1/2)18 + (1/4)19 + 23 + 24 + 25 + (1/2)26 + 30 + 31 +(1/2)32 + 35 + (1/2)36
- Quadrant No. 4: Actual quadrant heat load = 1 + (1/2)2 + 4 + 5 + (1/2)6 + 9 + 10 + 11 + (1/2)12 + (1/2)16 + (1/2)17 + (1/2)18 + (1/4)19

Where values in fractions denote the quadrant's share of specific storage cell heat loads. Whole numbers in the above equations denote the decay heat in that cell number.

Table 1.2.7a

Loading Curves for UO_2 Fuel in Specific Regions of the F-37 Basket

Configuration	Regions (Figure 1.2.4)	Maximum Initial Enrichment for Fresh UO_2 Fuel Assemblies (wt% ^{235}U)	Minimum Assembly Burnup for UO_2 Assemblies with an Initial Enrichment up to 5.0 wt% ^{235}U. (GWd/mtU)
1	1,2,3,4,6,7,8	2.80	22
2	1,3,6,7,8	2.73	25
3	2,3,6,7,8	2.73	25
4	2,4,6,7,8	2.55	27
5	2,4,5,6,7	2.55	27
6	2,3,4,6,7	2.42	31
7	2,4,6,7	2.38	34
8	1,2,3,4,5,7,8	2.31	35
9	1,3,4,6,7	2.38	34
10	1,2,3,4,5,6,7,8	2.55	29

Notes :

1. All regions not listed above for a given Configuration can be loaded with fresh MOX fuel meeting the requirements in Table 1.2.4 and Table 1.2.5 or loaded with fresh UO_2 fuel with an enrichment of up to 5 wt% ^{235}U. The loading curves are not applicable to quiver contents.
2. Minimum Burnup Requirements at intermediate enrichments can be determined by linear interpolation.
3. See Appendix 7.B for burnup verification requirements.

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Table 1.2.7b

Maximum Initial Enrichment Limits for UO_2 Fuel in Specific Regions of the F-32 Basket

Configuration	Regions (see Figure 1.2.3)	Maximum Initial Enrichment for Fresh UO_2 Fuel Assemblies (wt% ^{235}U)
1	1,2,3,4,5,6,7,8	5.00
2	1,2,3,4,5,6,7,8	4.70

Notes:

1. All regions listed above for a given Configuration can be loaded with fresh MOX fuel meeting the requirements in Table 1.2.4 and Table 1.2.5. The limits in this table are not applicable to quiver contents.

Table 1.2.8: Loading Patterns for the F-32 Basket

(Sheet 1 of 3)

Loading Pattern A for the F-32 Basket					
Region	Maximum Heat Load per Assembly[2] (kW)	Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt%) or MOX	Minimum Cooling Time (years)	Alternative Fuel Specification (Table 1.2.10)
1	2.1	61.5	MOX	11	A-6, C-1
2	1.2	51	4.5	3	A-1
3	1.0	60	4.5	9	A-1
4	1.2	66	4.5	14	A-2
5	1.5	54	4.5	4	A-3
6	1.5	66	4.5	3	A-6
7	1.2	66	4.5	11	A-4
8	1.2	15	4.5	3	A-5
Loading Pattern B for the F-32 Basket					
1	2.1	66	4.5	3	A-6
2	1.2	51	4.5	3	A-1
3	1.0	60	4.5	9	A-1
4	1.2	66	4.5	14	A-2
5	1.5	48	MOX	17	A-6
6	1.5	66	4.5	3	A-6
7	1.2	66	4.5	11	A-4
8	1.2	15	4.5	3	A-5

[2] Maximum overall cask heat load and maximum heat load per basket quadrant specified in Table 1.2.3a must not be exceeded. Refer to Figure 1.2.3.

Table 1.2.8: Loading Patterns for the F-32 Basket

(Sheet 2 of 3)

Loading Pattern C for the F-32 Basket					
Region	Maximum Heat Load per Assembly[2] (kW)	Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt%) or MOX	Minimum Cooling Time (years)	Alternative Fuel Specification (Table 1.2.10)
1	1.8	63	4.5	3.5	A-7
2	1.2	51	4.5	3	A-1
3	1.0	60	4.5	9	A-1
4	1.2	66	4.5	14	A-2
5	1.7	60	MOX	15	A-6
6	1.6	66	4.5	3	A-6
7	1.2	66	4.5	11	A-4
8	1.2	15	4.5	3	A-5
Loading Pattern D for the F-32 Basket					
1	1.8	63	4.5	4	A-8
2	1.2	48	MOX	17	A-6
3	1.0	60	4.5	9	A-1
4	1.2	66	4.5	14	A-2
5	1.7	48	MOX	17	A-7
6	1.6	66	4.5	4	A-9
7	1.2	66	4.5	11	A-4
8	1.2	39	MOX	17	A-5

[2] Maximum overall cask heat load and maximum heat load per basket quadrant specified in Table 1.2.3a must not be exceeded. Refer to Figure 1.2.3.

Table 1.2.8: Loading Patterns for the F-32 Basket (Sheet 3 of 3)

Loading Pattern E for the F-32 Basket					
Region	Maximum Heat Load per Assembly[2] (kW)	Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt%) or MOX	Minimum Cooling Time (years)	Alternative Fuel Specification (Table 1.2.10)
1 through 8	1	66	4.5	7	n/a
Loading Pattern F for the F-32 Basket					
1	1.8	63	4.5	3.5	A-7
2	1.2	63	4.5	4	A-10
3	1.0	60	4.5	9	A-1
4	1.2	66	4.5	14	A-2
5	1.7	63	4.5	5	A-3
6	1.6	66	4.5	4	A-9
7	1.2	66	4.5	11	A-4
8	1.2	51	MOX	17	A-8

[2] Maximum overall cask heat load and maximum heat load per basket quadrant specified in Table 1.2.3a must not be exceeded. Refer to Figure 1.2.3.

Table 1.2.9: Loading Patterns for the F-37 Basket

(Sheet 1 of 2)

Loading Pattern A for the F-37 Basket					
Region	Maximum Heat Load per Assembly[2] (kW)	Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt%) or MOX	Minimum Cooling Time (years)	Alternative Fuel Specification (Table 1.2.10)
1	2.1	61.5	MOX	11	B-9, C-1
2	1.2	51	4.5	4	B-1
3	0.8	60	4.5	9	B-2
4	0.5	66	4.5	14	B-3
5	1.2	66	4.5	14	B-4
6	1.5	66	4.5	4	B-10
7	1.0	66	4.5	11	B-5
8	1.2	15	4.5	4	B-6
Loading Pattern B for the F-37 Basket					
1	2.1	66	4.5	4	B-10
2	1.2	51	4.5	4	B-1
3	0.8	60	4.5	9	B-2
4	0.5	66	4.5	14	B-3
5	1.2	66	4.5	14	B-4
6	1.5	48	MOX	17	B-9
7	1.0	66	4.5	11	B-5
8	1.2	15	4.5	4	B-7

[2] Maximum overall cask heat load and maximum heat load per basket quadrant specified in Table 1.2.3a must not be exceeded. Refer to Figure 1.2.4.

Table 1.2.9: Loading Patterns for the F-37 Basket

(Sheet 2 of 2)

Loading Pattern C for the F-37 Basket					
Region	Maximum Heat Load per Assembly[2] (kW)	Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt%) or MOX	Minimum Cooling Time (years)	Alternative Fuel Specification (Table 1.2.10)
1	1.7	63	4.5	14	B-8
2	1.2	48	MOX	17	B-9
3	0.8	60	4.5	9	B-2
4	0.5	66	4.5	14	B-3
5	1.2	45	MOX	17	B-4
6	1.7	63	4.5	5	B-11
7	1.0	63	4.5	11	B-2
8	1.2	15	4.5	4	B-6
Loading Pattern D for the F-37 Basket					
1 through 8	0.865	66	4.5	8	n/a

[2] Maximum overall cask heat load and maximum heat load per basket quadrant specified in Table 1.2.3a must not be exceeded. Refer to Figure 1.2.4.

Table 1.2.10: Alternative Fuel Specifications
(Sheet 1 of 5)

Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt% ^{235}U)	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10
		Minimum Cooling Time (Years)									
66	4.5	20	14	7	11	20	3	4	4.5	4	7
66	3.95	26	20	13	17	26	8	4.5	6	7	11
63	4.5	16	14	6	10	14	3	3.5	4	3	4
63	3.95	22	18	8	12	20	3.5	4	5	4.5	8
60	4.5	11	11	5	9	12	3	3.5	4	2.5	3
60	3.95	16	14	6	10	14	3	4	4.5	3	4.5
57	4.5	7	10	4.5	8	9	3	3.5	3.5	2	2.5
57	3.95	12	11	5	9	12	3	3.5	4	2.5	3
54	4.5	4.5	9	4	7	8	3	3	3.5	2	2
54	3.95	8	10	4.5	8	9	3	3.5	3.5	2	2.5
54	3.15	16	12	6	9	14	3	3.5	4	3	4
51	4.5	3	8	4	7	7	2.5	3	4	2	2
51	3.95	4.5	9	4	7	8	2.5	3	3.5	2	2
51	3.15	10	10	5	8	11	3	3.5	4	2.5	3
48	4.5	3	7	3.5	6	6	2.5	3	3	2	2
48	3.95	3	8	4	7	7	2.5	3	3	2	2
48	3.15	6	9	4.5	7	8	3	3	3.5	2.5	2
45	4.5	2.5	7	3.5	6	5	2.5	3	3	2	2
45	3.95	3	7	3.5	6	6	2.5	3	3	2	2
45	3.15	4	8	4	7	7	2.5	3	3.5	2.5	2
42	4.5	2.5	6	3.5	6	5	2.5	2.5	3	2	2
42	3.95	2.5	6	3.5	6	5	2.5	3	3	2	2
42	3.15	3	7	3.5	6	6	2.5	3	3	2.5	2
39	4.5	2	6	3	5	4.5	2.5	2.5	3	2	2
39	3.95	2.5	6	3.5	5	5	2.5	2.5	3	2	2
39	3.15	2.5	6	3.5	6	5	2.5	3	3	2.5	2
36	4.5	2	7	3	5	4.5	2.5	2.5	2.5	2	2
36	3.95	2	6	3	5	4.5	2.5	2.5	2.5	2	2
36	3.15	2.5	6	3.5	5	5	2.5	2.5	3	2.5	2
33	4.5	2	5	3	4.5	4	2	2.5	2.5	2	2
33	3.95	2	5	3	4.5	4.5	2.5	2.5	2.5	2	2
33	3.15	2	6	3	5	4.5	2.5	2.5	2.5	2.5	2

Table 1.2.10: Alternative Fuel Specifications
(Sheet 2 of 5)

Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt% ^{235}U)	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10
		Minimum Cooling Time (Years)									
30	3.95	2	5	3	4.5	4	2	2.5	2.5	2	2
30	3.15	2	5	3	4.5	4	2	2.5	2.5	2.5	2
27	4.5	2	4.5	3	4	4	2	2.5	2.5	2	2
27	3.95	2	4.5	3	4.5	4	2	2.5	2.5	2	2
24	4.5	2	4.5	2.5	4	3.5	2	2.5	2.5	2	2
24	3.95	2	4.5	2.5	4	3.5	2	2.5	2.5	2	2
24	3.15	2	4.5	2.5	4	4	2	2.5	2.5	2.5	2
21	4.5	2	4	2.5	4	3.5	2	2	2.5	2	2
21	3.95	2	4.5	2.5	4	3.5	2	2	2.5	2	2
21	3.15	2	4.5	2.5	4	3.5	2	2	2.5	2.5	2
18	4.5	2	4	2.5	3.5	4	2	2	2	2	2
18	3.95	2	4	2.5	4	3.5	2	2	2	2	2
18	3.15	2	4	2.5	4	3.5	2	2	2	2.5	2
15	4.5	2	4	2.5	3.5	3	2	2	2	2	2
15	3.95	2	4	2.5	3.5	3.5	2	2	2	2	2
15	3.15	2	4	2.5	3.5	3.5	2	2	2	2.5	2

Table 1.2.10: Alternative Fuel Specifications
(Sheet 3 of 5)

Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt% ^{235}U)	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11
		Minimum Cooling Time (Years)										
66	4.5	20	18	14	14	11	28	30	20	4	4	6
66	3.95	26	24	20	20	16	**	**	24	4	6	8
63	4.5	16	14	10	14	8	26	26	14	4	4	5
63	3.95	22	20	16	18	12	28	30	20	4	4.5	6
60	4.5	12	9	6	11	4.5	22	24	12	4	4	4.5
60	3.95	18	16	11	14	8	26	26	18	4	4	5.5
57	4.5	8	5.5	4	10	4	20	20	9	4	4	4.5
57	3.95	12	10	7	11	5	22	24	12	4	4	4.5
54	4.5	5.5	4	4	8	4	14	18	8	4	4	4
54	3.95	8	5.5	4	9	4	20	20	9	4	4	4.5
54	3.15	16	14	10	12	7	24	26	14	4	4	5
51	4.5	4	4	4	8	4	12	12	6	4	4	4
51	3.95	5.5	4	4	8	4	14	18	7	4	4	4
51	3.15	11	9	5	10	4	22	22	11	4	4	4.5
48	4.5	4	4	4	7	4	10	10	5.5	4	4	4
48	3.95	4	4	4	7	4	12	12	6	4	4	4
48	3.15	7	4.5	4	9	4	20	20	8	4	4	4
45	4.5	4	4	4	6	4	9	9	5	4	4	4
45	3.95	4	4	4	7	4	10	10	5.5	4	4	4
45	3.15	4.5	4	4	8	4	14	14	7	4	4	4
42	4.5	4	4	4	6	4	8	8	4.5	4	4	4
42	3.95	4	4	4	6	4	8	8	5	4	4	4
42	3.15	4	4	4	7	4	10	10	5.5	4	4	4
39	4.5	4	4	4	5.5	4	7	7	4.5	4	4	4
39	3.95	4	4	4	5.5	4	7	7	4.5	4	4	4
39	3.15	4	4	4	6	4	9	9	5	4	4	4
36	4.5	4	4	4	5.5	4	6	6	4.5	4	4	4
36	3.15	4	4	4	6	4	7	8	5	4	4	4
33	3.95	4	4	4	5.5	4	6	6	4.5	4	4	4
33	3.15	4	4	4	6	4	7	7	5	4	4	4

**- Not permitted for loading

Table 1.2.10: Alternative Fuel Specifications
(Sheet 4 of 5)

Maximum Burnup (GWd/mtU)	Minimum Enrichment (wt% ^{235}U)	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11
		Minimum Cooling Time (Years)										
30	4.5	4	4	4	5.5	4	5.5	5.5	4.5	4	4	4
30	3.95	4	4	4	5.5	4	5.5	5.5	4.5	4	4	4
30	3.15	4	4	4	6	4	6	6	5	4	4	4
27	4.5	4	4	4	5.5	4	5	5	4.5	4	4	4
27	3.15	4	4	4	6	4	5.5	5.5	5	4	4	4
24	3.95	4	4	4	5.5	4	5	5	4.5	4	4	4
24	3.15	4	4	4	6	4	5	5	5	4	4	4
21	4.5	4	4	4	5.5	4	4.5	4.5	4.5	4	4	4
21	3.95	4	4	4	5.5	4	5	4.5	4.5	4	4	4
18	3.95	4	4	4	5.5	4	4.5	4.5	4.5	4	4	4
18	3.15	4	4	4	6	4	4.5	4.5	5	4	4	4
15	4.5	4	4	4	5.5	4	4	4	4.5	4	4	4

**- Not permitted for loading

Table 1.2.10: Alternative Fuel Specifications
(Sheet 5 of 5)

Maximum Burnup (GWd/mtU)	Fuel Type	C-1
		Minimum Cooling Time (Years)
60	MOX	10.5
58.5	MOX	9.5
57	MOX	9
55.5	MOX	8
54	MOX	7.5

Table 1.2.11: Not Used

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Table 1.2.12a: [Withheld in Accordance with 10 CFR 2.390]

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Table 1.2.12b: [Withheld in Accordance with 10 CFR 2.390]

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Table 1.2.13: Not Used

Table 1.2.14: Core Operating Requirements for Assemblies that need to meet the Burnup Requirements in Table 1.2.7a

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

Table 1.2.15: [Withheld in Accordance with 10 CFR 2.390]

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Table 1.2.16: General Characteristics of Holtite-B

Property (Note 1)	Property Value
Minimum Bulk Density, g/cm^3	1.248
Minimum Hydrogen Density, g/cm^3	0.1068
Minimum Boron Carbide Content, wt%	2
Minimum Copper Content, wt. %	10
Minimum Effective Thermal Conductivity, W/m-K (Btu/ft-hr-°F) (including contribution from conductivity enhancers)	0.4 (0.23) at design temperature
Design Temperature, °C (°F)	204 (400)

Note 1: All properties are critical characteristics with the exception of copper content. The bulk density, hydrogen density and boron carbide content are shielding function critical characteristics and a condition of the CoC.

Table 1.2.17

Major Constituent Parts of the HI-STAR 180 Cask

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

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Table 1.2.18 [Withheld in Accordance with 10 CFR 2.390]

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Figure 1.2.1: [Withheld in Accordance with 10 CFR 2.390]

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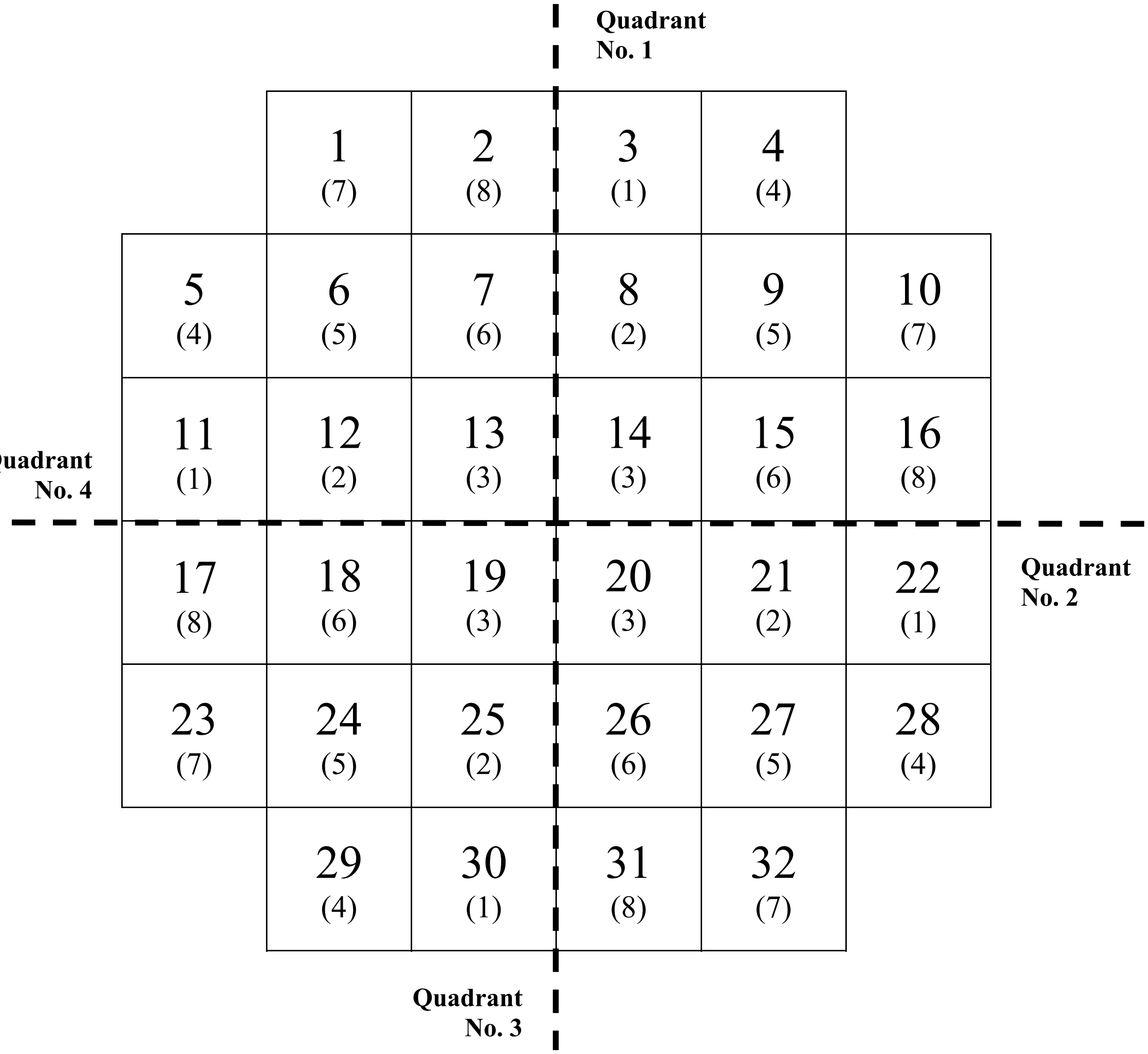
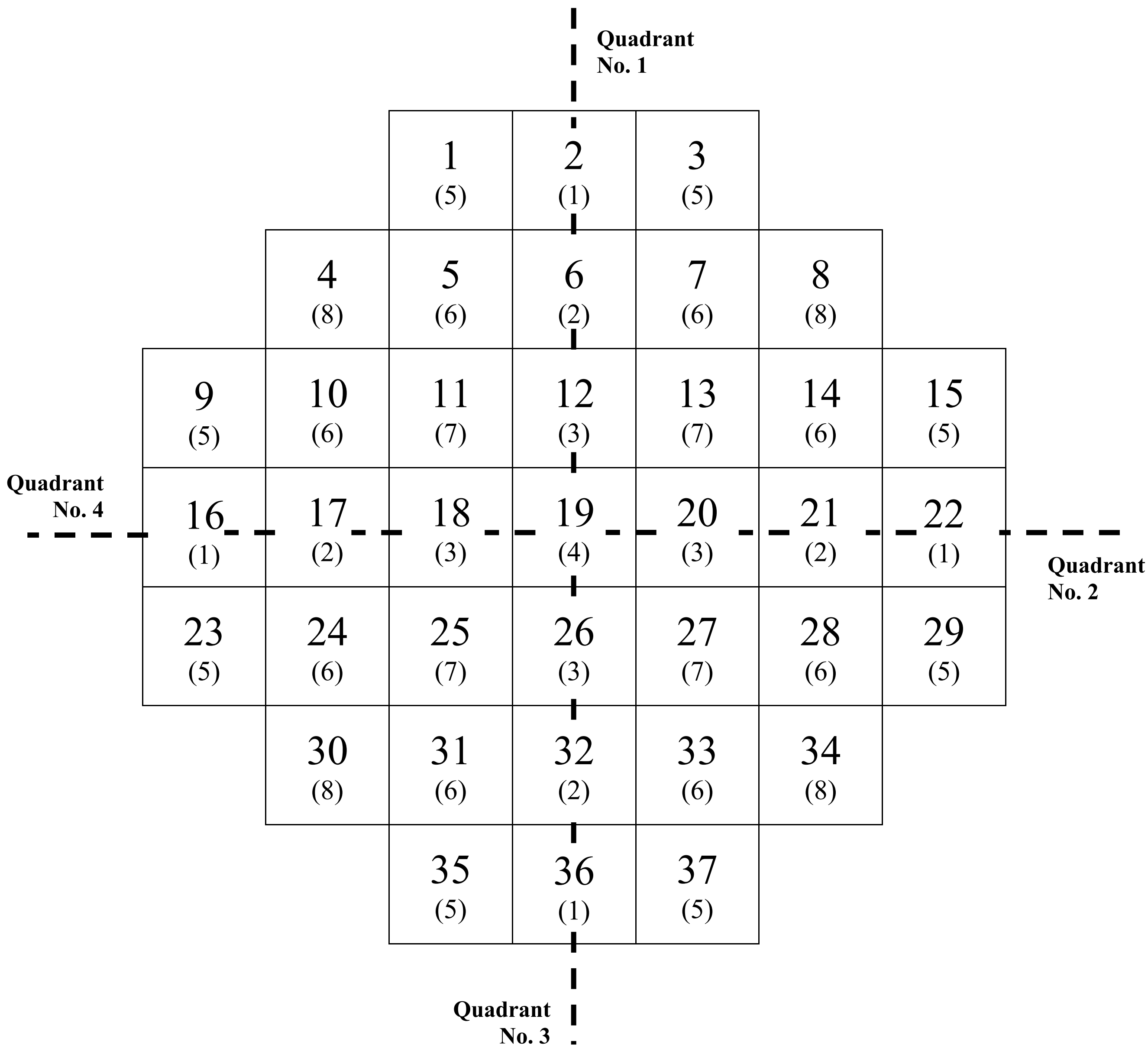
Figure 1.2.2: [Withheld in Accordance with 10 CFR 2.390]



Notes:
1. Numbers in parenthesis denote region number.
2. All quadrants are rotationally symmetric by region number.
3. Heat loads by cask, basket quadrant, and storage cell are specified in Table 1.2.3a and Table 1.2.8.
4. See Table 1.2.6a and 1.2.6b for more information.
5. Up to two quivers are allowed. Quivers are allowed in cells 1 and 32 or 10 and 23. Maximum allowable heat load for quiver locations is specified in Table 1.2.3a.

FIGURE 1.2.3: F-32 FUEL BASKET STORAGE CELL NUMBERING AND BASKET QUADRANT IDENTIFICATION



Notes:
1. Numbers in parenthesis denote region number.
2. All quadrants are symmetric by region number.
3. Heat loads by cask, basket quadrant, and storage cell are specified in Table 1.2.3a and Table 1.2.9.
4. See Table 1.2.6a and 1.2.6b for more information.
5. Up to two quivers are allowed. Quivers are allowed in cells 4 and 34 or 8 and 30. Maximum allowable heat load for quiver locations is specified in Table 1.2.3a.

FIGURE 1.2.4: F-37 FUEL BASKET STORAGE CELLS NUMBERING AND BASKET QUADRANT IDENTIFICATION

Figure 1.2.5: [Withheld in Accordance with 10 CFR 2.390]

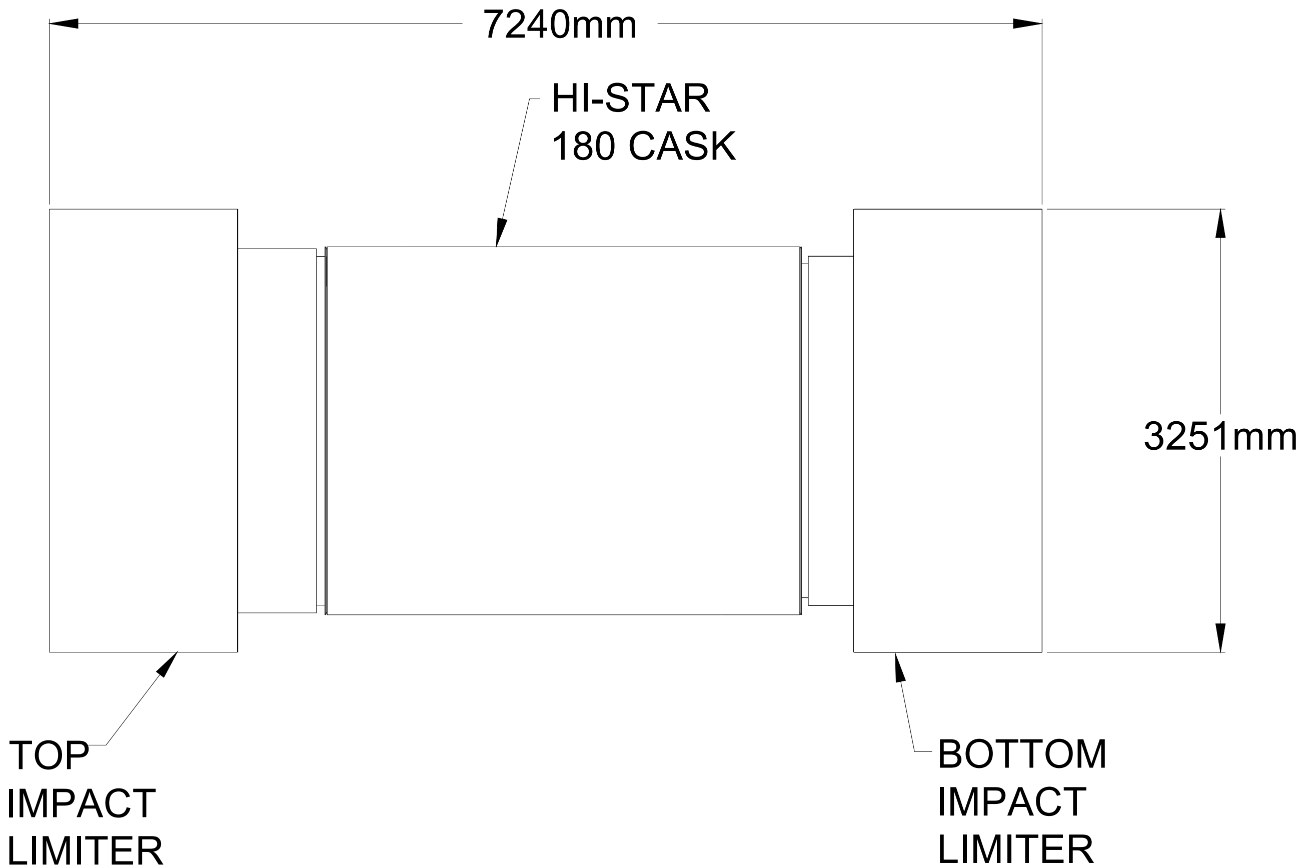
1.3 ENGINEERING DRAWINGS

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

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

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

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



Note: Dimensions are nominal.

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

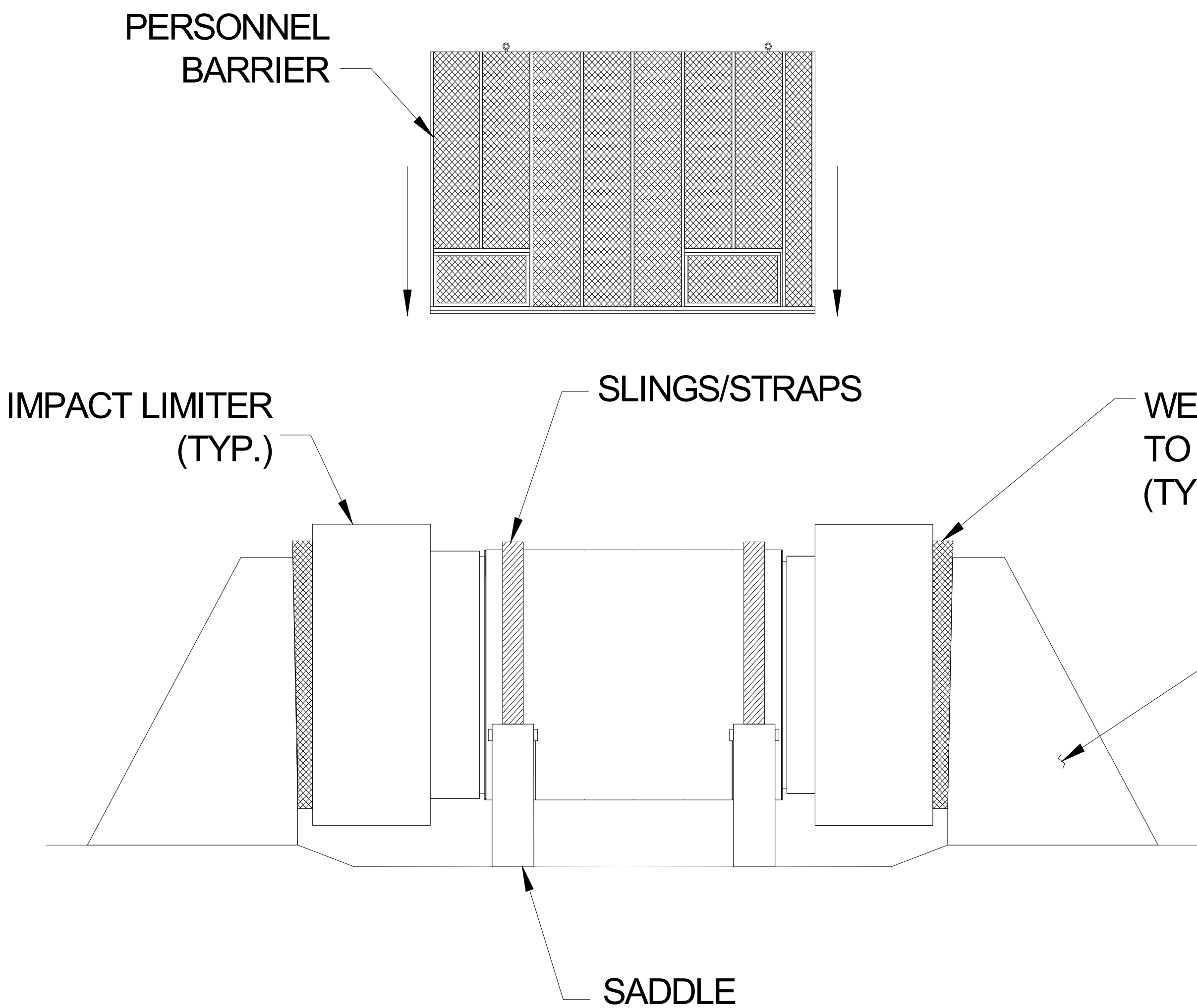


FIGURE 1.3.2: ILLUSTRATION OF HI-STAR 180 TYPICAL RAILCAR TRANSPORT CONFIGURATION

Licensing Drawings 4845, 4847, 4848 & 5062 [Withheld in Accordance with 10 CFR 2.390]

1.4 SUMMARY OF COMPLIANCE WITH 10CFR71 REQUIREMENTS

The HI-STAR 180 Package complies with the requirements of 10CFR71 for a Type B(U)F-96 package. Analyses which demonstrate that the HI-STAR 180 Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR. The HI-STAR 180 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 180 Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR 180 Package to meet the requirements of 10CFR71, Paragraphs 71.45, 71.51, and 71.55. 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 180 Package is shown to be within the permissible limits set forth in 10CFR71, Paragraphs 71.51, and 71.55.

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

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

- The HI-STAR 180 Packaging description including the drawing package provided in Section 1.3 provides an adequate basis for evaluation of the HI-STAR 180 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 180 packaging has been identified.

- The applicable codes and standards for the HI-STAR 180 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 180 Packaging are specified (in Section 1.2).

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1.5 LOCATION OF PROPERTIES OF SPECIAL PURPOSE MATERIALS

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

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Table 1.5.1: [Withheld in Accordance with 10 CFR 2.390]

1.6 QUALITY ASSURANCE AND DESIGN CONTROL

1.6.1 Quality Assurance Program:

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

1.6.2 Package Design Control:

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

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CHAPTER 1 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as "latest revision". Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company's Configuration Control system. Supporting documents submitted to the USNRC with the HI-STAR 180 LAR 9325-2 have been italicized.

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

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

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

[1.0.4] "Safety Analysis Report for the HI-STAR 100 Package", Holtec Report HI-951251, latest revision, Docket No. 71-9261.

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

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

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

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

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

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

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

[1.1.7] "Safety Analysis Report for the HI-STAR 180L Package", Holtec Report HI-2177805, latest revision, USNRC Docket No. 71-9381.

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

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

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

[1.2.2] American Society for Testing and Materials, ASTM A-352-93, "Ferritic and Martensitic Steel Castings for Pressure-Containing Parts Suitable for Low-Temperature Service"

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

[1.2.4] Holtite-A: Development History and Thermal Performance Data, Holtec Report HI-2002396, 2002, Docket No. 72-1014. (Holtec Proprietary)

[1.2.5] Holtite-A: Results of Pre-and Post-Irradiation Tests and Measurements, Holtec Report HI-2002420, 2003, Docket No. 72-1014. (Holtec Proprietary)

[1.2.6] "Qualification of METAMIC for Spent Fuel Storage Applications", Report 1003137, EPRI, Palo Alto, CA, October 2001.

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

[1.2.8] USNRC Docket No. 72-1004 SER on NUHOMS 61BT (2002).

[1.2.9] "Safety Evaluation by the Office of Nuclear Reactor Regulation Related to Holtec International Report HI-2022871 Regarding Use of Metamic in Fuel Pool Applications," Facility Operating License Nos. DPR-51 and NPF-6, Entergy Operations, Inc., docket No. 50-313 and 50-368, USNRC, June 2003.

[1.2.10] “Sourcebook for Metamic Performance Assessment”, by Dr. Stanley Turner, Holtec Report HI-2043215, Rev. 2, Docket No. 71-9261 (TAC L24029). (Holtec Proprietary)

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

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

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

[1.2.14] NUREG-1617, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, U.S. Nuclear Regulatory Commission, Washington, D.C., 2000.

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[1.2.16] ASME Boiler & Pressure Vessel Code, Section II, Part A, SA-352-LCC American Society of Mechanical Engineers, 2007.

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[1.2.17] *“Holtite-B Sourcebook”, Holtec Report HI-2167314, Latest Revision. (Holtec Proprietary)*

[1.2.18] “Handbook of Aluminum - Alloy Production and Materials Manufacturing”, Vol. 2, Edited by G.E. Totten and D.S. Mackenzie, CRC (Taylor and Francis Group), 2003.

[1.2.19] “Oxide Dispersion Strengthening” by Ansell et. als, ASME Convergence, Vol. 47, Gordon and Breach, NY (1966).

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[1.2.21] “Metals Handbook”, Vol. 7, 9th Edition

[1.2.22] NUREG-2224, Dry Storage and Transportation of High Burnup Spent Nuclear Fuel, U.S. Nuclear Regulatory Commission, Washington, D.C., Draft Document for Review, July 2018.

[1.2.23] Turner, S.E., “Reactivity Effects of Streaming Between Discrete Boron Carbide Particles in Neutron Absorber Panels for Storage or Transport of Spent Nuclear Fuel,” Nuclear Science and Engineering, Vol. 151, Nov. 2005, pp. 344-347.

[1.2.24] Natrella, M.G., “Experimental Statistics, “National Bureau of Standards Handbook 91, National Bureau of Standards, Washington, DC, 1963.

[1.2.25] “Metamic-HT Manufacturing Manual”, Latest Revision, Holtec International (Holtec Proprietary).

[1.2.26] “Metamic-HT Purchasing Specification”, Holtec Document ID PS-11, Latest Revision (Holtec Proprietary).

[1.2.27] *“Metamic-HT Qualification Sourcebook”, Holtec Report No. HI-2084122, Latest Revision, (Holtec Proprietary).*

[1.2.28] “Application of Time-Temperature-Stress Parameters to High Temperature Performance of Aluminum Alloys”, by J.G. Kaufman, Z. Long and S. Ningileri, Minerals, Metals & Materials Society, 2007.

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

[1.2.30] “Dynamic Mechanical Response and Microstructural Evolution of High Strength Aluminum-Scandium (Al-Sc) Alloy”, by W.S. Lee and T.H. Chen, Materials Transactions, Vol. 47, No. 2(2006), pp 355-363, Japan Institute for metals.

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

[1.2.32] NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick."

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

[1.2.34] “Design Specification of 14x14 LTS PWR Quiver”, Report NRT 18-186, Latest Revision (Westinghouse Electric Sweden AB Proprietary)

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

APPENDIX 1.A (Not Used)

APPENDIX 1.B: [Withheld in Accordance with 10 CFR 2.390]

CHAPTER 2: STRUCTURAL EVALUATION

2.0 INTRODUCTION

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

In particular, the objectives of this chapter are twofold:

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

Among the topical areas addressed in this chapter are:

i. Structural characterization of the cask and its appurtenances.
ii. Identification of the materials used in the package and their *critical characteristics*.
iii. Identification of the loads applied on the package during handling, normal conditions of transport and accident conditions. Definition of miscellaneous bounding conditions for design such as a fire and immersion in water.
iv. Derivation of acceptance criteria for the package's performance under the aforementioned various conditions of service from the ASME B&PV Codes and other reference standards.
v. Analyses of the package using appropriate methodologies to establish the margins of safety under each condition of service. In addition to the typical evaluations for normal and accident conditions, these analyses include:
   - Evaluation of the physical integrity of the spent fuel (including fuel rods in precisely designed prismatic boxes referred as "Quivers", which is discussed in detail in Section 1.2.2) under the postulated impactive loading events.
   - A demonstration of the adequacy of the minimum acceptable Charpy impact values specified for the parts subject to potential impact loadings. This is based on a methodology that determines the fracture strength of a material using the Charpy impact strength data.

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

To facilitate regulatory review, throughout this chapter, the assumptions and conservatism inherent in the analyses are identified along with a complete description of the analytical methods, models, and acceptance criteria. A summary of other considerations germane to satisfactory structural performance, such as protection against corrosion, creep (in the Metamic-HT fuel basket), and brittle fracture, is also provided. Finally, the methodology to determine the fracture strength of a material using the Charpy impact strength data, used by Holtec International to set down the required Charpy strength in load bearing members in lifting and handling equipment, is presented. This methodology is used to demonstrate the adequacy of the minimum acceptable Charpy impact values specified for the parts of the HI-STAR 180 Package that are potentially subject to a direct impact impulse.

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2.1 STRUCTURAL DESIGN

2.1.1 Discussion

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

2.1.1.1 Cask

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

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

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

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

The containment space (or space within the containment boundary as identified in the drawing package in Section 1.3 and described in Paragraph 1.2.1.3 and Section 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].

[

Withheld in Accordance with 10 CFR 2.390

]

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

Withheld in Accordance with 10 CFR 2.390

]

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

[

Withheld in Accordance with 10 CFR 2.390

]

2.1.1.2 Fuel Basket and Fuel Basket Support

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

2.1.1.3 Impact Limiters

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

Withheld in Accordance with 10 CFR 2.390

]

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

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

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

2.1.2 Design Criteria

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

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

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

- The shield cylinders are required to remain in place and functional after all Normal and Hypothetical Accident Conditions of Transport.

- The fuel basket is required to maintain its shape so as to ensure reactivity control after all Normal and Hypothetical Accident Conditions of Transport.

- The fuel basket supports are required to maintain global positioning of the fuel basket after all Normal and Hypothetical Accident Conditions of Transport.

- The impact limiters are required to have an appropriate shape and energy absorption capacity to ensure that impacts, resulting from hypothetical accident events, do not cause any of the containment and shielding components to fail to meet their specified requirements. The impact limiters are also designed to limit the accelerations in order to protect the Spent Nuclear Fuel cladding integrity and the structural performance of the Quivers.

2.1.2.1 Loading and Load Combinations

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

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

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

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

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

Finally, the interface load produced between the shield cylinder and containment shell due to the method of assembly, causes the shield cylinder to add structural support to the containment shell. The beneficial effect of the interface load between the shield cylinder and the containment shell is conservatively neglected in the structural analyses.

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 180 Package, the Design Internal Pressure and Design Temperatures, set down in Table 2.1.1, accordingly bound all service condition values.

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

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

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

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

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

Table 2.1.1 provides the above values of design basis internal and external pressures. Because the HI-STAR 180 cask operates under a sub-atmospheric pressure under normal condition of transport, the Design Internal Pressure could be set at zero psig, but is conservatively set higher in Table 2.1.1 to cover all essential operations described in Chapter 7 of this SAR.

The most adverse possible internal pressure state occurs under the simultaneous effect of fire and 100% rod rupture. This pressure (provided in Table 3.1.4) 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 of specified in Table 2.1.1.

3. Handling Loads

The lifting devices in the HI-STAR 180 cask are subject to the specific stress limits set forth by NUREG-0612 [2.1.5], 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 1/6 of the material yield strength while subject to the lifted load that includes an appropriate dynamic load amplifier. These limits apply to the cask lifting trunnions and to the threaded holes in the lids. An associated requirement is an evaluation of the stress intensity state in the cask baseplate when the package is being lifted. Baseplate loads considered are the self-weight of the baseplate plus attached shielding, the fuel, the fuel basket, and the fuel basket supports. A 15% load amplifier is applied (as discussed in Subsection 2.5.1) and Level A stress intensity limits of the ASME Code, Section III, Subsection NB are used to evaluate acceptance.

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

4. Normal Conditions of Transport Loads (§71.71)

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

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

External pressure loads ((a) and (b) above) are clearly enveloped by the design external pressure set by a deep submersion of the package (10CFR71.61). This condition is evaluated in Section 2.7. The normal operating conditions (e) are evaluated to demonstrate that the containment meets requirements of the ASME Code to be designated as a “pressure vessel”. The “1-foot drop event” (c) evaluation in this section is the “Side Drop”. The HI-STAR 180 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 180 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.

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

- Load Combination N1:

Bolt pre-load plus Design Internal pressure and normal operating temperature plus defense-in-depth loading from FIAs (see Subsection 2.1.1.1)

- Load Combination N2:
  Free drop from 1 foot plus bolt pre-load

5. Hypothetical Accident Condition Loads (§71.73)

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

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

a. Free Drop

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

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

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

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

- Bottom Center-of-Gravity Over-the-Corner Drop: In this drop scenario, the HI-STAR 180 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 outer closure lid. Because of the proximity of the bolted joints, this case is considered limiting for an end puncture.

The above loading events may occur under the so-called "hot" (maximum ambient temperature) or "cold" condition at -29ºC (-20ºF). In the latter thermal state, the effects of brittle fracture must also be evaluated.

Because the HI-STAR 180 Package operates at a relatively low internal pressure or even sub-atmospheric conditions, the impact and puncture loadings under service conditions are orders of magnitude greater than pressure loadings. Therefore, the pressure loads are neglected in the drop and puncture analyses.

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). Based on the temperature changes established in Chapter 3, an evaluation is performed to demonstrate that the land compression load at the lid/flange joint does not degrade to an unacceptable value.

d. Immersion

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

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

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

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

2.1.2.2 Acceptance Criteria

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2.1.3 Weights and Centers of Gravity

Table 2.1.11 provides the weights of the individual HI-STAR 180 components as well as the total Transport Package weights, and the weight of the heaviest loaded HI-STAR 180 Cask.

Table 2.1.12 provides the location of the calculated center of gravity (CG) for the package. The CG is assumed to be located on the cask centerline since the non-axisymmetric effects of the cask plus contents are negligible.

2.1.4 Identification of Codes and Standards for Package Design

The design of the HI-STAR 180 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 180 Package.

Table 2.1.13 lists each major structure, system, and component (SSC) of the HI-STAR 180 Packaging, along with its function, and applicable code or standard. The Bill of Materials for each drawing set 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 2.1.14 lists some alternatives to the ASME Code where appropriate. Table 2.1.15 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 180 cask are procured to ASTM Specifications, except for the fuel basket (made of Metamic-HT) and the neutron absorber (a Holtec custom-engineered product made from boron carbide uniformly dispersed into a hydrogen rich material, which are specialty materials, not sufficiently used to merit an ASTM Standard. These special purpose materials have been tested and characterized under Holtec’s QA Program).

The *critical characteristics* of all materials set down in this SAR establish the minimum requirements that must be met by the material. The applicable *critical characteristics* for each part in the HI-STAR 180 cask are listed in Table 2.1.16 with the required limiting values, as applicable.

2.1.5 Partially Loaded Package

The maximum allowable empty basket cells in a partially loaded package shall not be greater than 12. Additionally, the loading of the basket should be symmetrical as described in Table 1.2.3. These requirements ensure that the maximum decelerations of the HI-STAR 100 package used to structurally qualify the package are not exceeded for normal and hypothetical drop events. The detailed evaluation is are documented in [2.1.12].

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

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

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

Notes:

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

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

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

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

Notes:

1. Stress limits for Level A loading ensure that bolt remains elastic.
2. Limit set on primary tension plus primary bending for Level D loading is based on an elastic stress evaluation; however, the overriding acceptability of the joint design is performance based on an assured absence of leakage.

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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.

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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.

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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. Table 2.2.2 contains other mechanical and thermal properties of the bolting material.
3. Sources for design stress intensity values are Tables 4 and 2A of ASME Section II, Part D.
4. Values for SA-564 630 are conservatively based on age hardening at 1075ºF (H1075).

Table 2.1.9

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Table 2.1.10: [Withheld in Accordance with 10 CFR 2.390] (Sheet 1 of 4)

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Table 2.1.10: [Withheld in Accordance with 10 CFR 2.390] (Sheet 2 of 4)

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Table 2.1.10: [Withheld in Accordance with 10 CFR 2.390] (Sheet 3 of 4)

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Table 2.1.10: [Withheld in Accordance with 10 CFR 2.390] (Sheet 4 of 4)

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

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Table 2.1.11: [Withheld in Accordance with 10 CFR 2.390]

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

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Table 2.1.13: Applicable Codes and Standards for the Materials Used in the HI-STAR 180 Packaging

	Item	Principal Function	Applicable Codes and Reference Standard
1.	Containment Baseplate	Containment Boundary	ASME Code Section III Subsection NB
2.	Containment Shell	Containment Boundary	ASME Code Section III Subsection NB
3.	Containment Closure Flange	Containment Boundary	ASME Code Section III Subsection NB
4.	Inner Closure Lid	Containment Boundary	ASME Code Section III Subsection NB
5.	Outer Closure Lid	Containment Boundary	ASME Code Section III Subsection NB
6.	Inner Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
7.	Outer Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
8.	Vent and Drain Port Plugs	Containment Boundary	ASME Code Section II
9.	Seals and Gaskets	Containment Boundary	Non-Code (Manufacturer’s Catalog and Test Data)
10.	Fuel Basket (Metamic-HT)	Positioning of Fuel Assemblies and Quivers for Criticality Control	Non-Code (Manufacturer’s Test Data [1.2.27])
11.	Monolithic Shield Cylinders	Gamma Shielding	ASME Code Section II
12.	Holtite-B	Neutron Shielding	Non-Code (Manufacturer’s Test Data [1.2.17])
13.	Trunnions	Lifting and Handling	ASME Code Section II and NUREG-0612
14.	Monolithic Shield Cylinder Top Cap	Holtite Cavity Space Enclosure (non-structural)	ASME Code Section II
15.	Monolithic Shield Cylinder Bottom Cap	Holtite Cavity Space Enclosure (non-structural)	ASME Code Section II

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Table 2.1.13: Applicable Codes and Standards for the Materials Used in the HI-STAR 180 Packaging (Continued)

	Item	Principal Function	Applicable Codes and Reference Standard
16.	Basket Shims	Positioning of Basket in the Containment Cavity	ASTM B221
17.	Impact Limiter Backbone Plate Material	Structural Support of Impact Limiter	ASME Code Section II
18.	Impact Limiter Attachment Rods and Nuts	Structural Support of Impact Limiter	ASME Code Section II
19.	Impact Limiter Crush Material	Impact Energy Absorption	Non-Code (Manufacturer's Catalog and Test Data)
20.	Impact Limiter Insulation Board	Thermal Protection Against Fire Damage	Non-Code (Manufacturer's Catalog and Test Data)
21.	Impact Limiter Fastener Strain Limiter	Protection of Impact Limiter Fasteners Against Excessive Stress/Strain	Non-Code (Manufacturer's Catalog and Test Data)
22.	Fuel Impact Attenuators	Impact Energy Absorption	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 2.1.14: ASME Code Requirements and Alternatives for the HI-STAR 180 Package

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

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Table 2.1.14: ASME Code Requirements and Alternatives for the HI-STAR 180 Package (Continued)

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

Table 2.1.14: ASME Code Requirements and Alternatives for the HI-STAR 180 Package (Continued)

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

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Table 2.1.15: ASME Code Boiler & Pressure Vessel Code and Other ANSI and Holtec Standards Applicable to HI-STAR 180

1.	Sub-Component ID	Material Procurement	Design Criteria	Stress and Deformation Analysis	Welding	Inspection	Testing
2.	Containment System (includes closure lids and applicable subcomponents, 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	ASME Code Section III Subsection NB-5000	ASME Code Section III Subsection NB-6000
3.	Fuel Basket	Holtec Manufacturing Manual	Chapter 2 of this SAR	Chapter 2 of this SAR	Holtec Manufacturing Manual (Note 1)	Holtec Manufacturing Manual	Holtec Manufacturing Manual
4.	Lifting Trunnions	ASME Code Section II	10CFR71.45 and NUREG-0612	10CFR71.45 and NUREG-0612	ASME Code Section III Subsection NF	Chapter 8 of this SAR	Chapter 8 of this SAR
5.	Monolithic Shield Cylinders	ASME Code Section II Part A	Chapter 2 of this SAR	Chapter 2 of this SAR	ASME Code Section IX	ASME Code Section V	Chapter 2 of this SAR
6.	Basket Shims	ASTM B211	Chapter 2 of this SAR	Chapter 2 of this SAR	Not Applicable	Not Applicable	Not Applicable
7.	Neutron Shielding	Holtec Manufacturing Manual	Reference [1.2.17]	Not Applicable	Not Applicable	Holtec Manufacturing Manual	Holtec Manufacturing Manual and Chapter 8 of this SAR

Note 1: Holtec Manufacturing Manuals contain detailed instructions for manufacturing of the subassemblies and the complete component in accordance with the applicable SAR, Codes, Standards, and for special products, such as Metamic, the supplier's specifications. The Holtec Manufacturing Manual is a compilation of procedures, travelers, weld maps, specifications, Standards, etc, to ensure the manufacturing of the HI-STAR components in full accord with this SAR. The manufacturing manuals are prepared, reviewed, and approved by use by the Holtec Manufacturing Division and Nuclear Division, and the latest issue maintained in the company's network under Holtec's configuration control system.

Table 2.1.15: ASME Code Boiler & Pressure Vessel Code and Other ANSI and Holtec Standards Applicable to HI-STAR 180 (Continued)

8.	**Sub-Component ID**	**Material Procurement**	**Design Criteria**	**Stress and Deformation Analysis**	**Welding**	**Inspection**	**Testing**
9.	Bottom Steel Cover Plate	ASME Code Section II Part A	Chapter 2 of this SAR	Chapter 2 of this SAR	ASME Code Section IX	ASME Code Section V	Not Applicable
10.	Impact Limiter Backbone Structure	ASME Code Section II Part A	Chapter 2 of this SAR	Chapter 2 of this SAR	ASME Code Section IX	ASME Code Section V	Not Applicable

Note: ITS Components not listed above shall be procured, designed, fabricated, inspected, and tested in accordance with ASME, ASTM, AWS, or other applicable industrial codes as specified in Holtec International's manufacturing documents.

Table 2.1.16: [Withheld in Accordance with 10 CFR 2.390]

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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 180 packaging are SA-203E and SA-350 LF3, respectively. The material properties (used in structural evaluations) of SA-203 E and SA-350 LF3 are given in Table 2.2.1.

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

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

2.2.1.1.2 Bolting and Trunnion Materials

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

2.2.1.1.3 Fuel Basket

The Fuel Basket is made of Metamic-HT.

Metamic-HT, a high strength, nanotechnology-based counterpart of the classic Metamic neutron absorber material, is extensively characterized in the Metamic-HT Source Book [1.2.27]. Minimum guaranteed values (MGVs) of Metamic-HT are provided in Table 1.2.12a.

2.2.1.1.4 Weld Material

All weld filler materials utilized in the welding of the Code components, which excludes the Metamic-HT fuel basket, will comply with the provisions of the appropriate ASME Code

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

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

2.2.1.1.5 AL-STAR Impact Limiter

The AL-STAR impact limiter for the HI-STAR 180 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, an insulating board that protects the impact limiter crush material from the relatively high temperature in the cask, and attachment bolts. The energy absorbing material is positioned in the impact limiter to realize adequate crush modulus in all potential impact modes. The external surface of the impact limiter consists of a stainless steel skin to provide long-term protection against weather and inclement environmental conditions. Attachment bolts are also made of stainless steel, which imparts a high fracture toughness and high ductility in the entire temperature range of service.

Rail transport considerations limit the maximum diameter of the impact limiter. The axial dimension of the impact limiter is limited by the considerations of maximum permissible packaging weight for rail transport. Within the limitations of space and weight, the impact limiter should possess sufficient energy absorption capacity so as to meet the structural demands on the package under all postulated drop orientations. The sizing of the impact limiter internal structure is principally guided by the above considerations. For example, in order to ensure that a sufficient portion of the energy absorbing material participates in lateral impacts, a thick high strength steel shell, buttressed with gussets, provides a hard backing surface for the 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 stainless steel impact limiter attachment bolts are provided in Table 2.2.6.

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

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

Table 2.2.10 also contains the required *critical characteristics* of [

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2.2.1.1.6 Closure Lid Seals

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

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

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The load required to "seat" the gaskets is a small percentage of the total applied bolt preload force; hence the required "seating load" (an ASME Boiler & Pressure Vessel code term) is not an important parameter. The size of the gasket in relation to the size of the groove, on the other hand, is a critical dimension that is based on the gasket supplier's test data and which must be controlled through the gasket Procurement Specification. The critical sealing dimensions consistent with seal manufacturers' data are provided in Appendix 4.A. Other critical characteristics of the HI-STAR 180 gasket that must be controlled to ensure a robust joint performance are listed in Table 2.2.12. The gaskets will be procured as an *Important-to-Safety* part.

Using the above criteria, the closure seals have been conservatively specified to provide a high degree of assurance of leak tightness under normal and accident conditions of transport so that package service conditions at normal or accident pressures under high and low temperatures will not challenge the capabilities of cask closure seals. Creep of the cask closure seals, even under long term use in a loaded cask (40 years), is not credible due to its materials of construction and nickel alloy seal spring. The specifications for the closure lid seals are provided below:

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Table 2.2.12 provides the data on the bolted joint loads, including the load needed to "seat" the closure plate gaskets.

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2.2.1.2 Nonstructural Materials

2.2.1.2.1 Monolithic Shield Cylinder

The monolithic shield cylinder is not in the primary load path of the HI-STAR 180 cask during a lifting operation since it has no connection to the upper trunnions. The monolithic shield cylinders do, however, girdle the containment shell and thus may act in concert with the containment shell during Hypothetical Accident Conditions of Transport. Necessary structural properties for the monolithic shield, for analysis purposes, are the yield and ultimate strength; a representative set of properties is tabulated in Table 2.2.7, and *critical characteristics* are provided in Table 2.1.16.

2.2.1.2.2 Holtite Neutron Shielding Material

The non-structural properties of the neutron shielding material are provided in Section 1.2. Holtite B does not serve a structural function in the HI-STAR 180D package; however, since the Holtite is included in the structural analysis model, the mechanical properties used as input to the analysis model are listed in Table 2.2.8.

2.2.1.2.3 Fuel Basket Supports

The fuel basket supports (basket shims), made of an aluminum alloy 2219-T8511, provide the heat transfer bridge between the basket and the cask inside surface, and serve to position the fuel basket. Representative mechanical properties for the basket supports are tabulated in Table 2.2.9.

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2.2.1.2.4 Cask Coating

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

2.2.1.2.5 Cask Liner

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

a) Conventional Surface Preservative

The HI-STAR 180 cask interior steel surfaces are coated with Thermaline® 450 (see www.carboline.com for product data sheet) or equivalent surface preservative. Conventional surface preservatives refer to sprayed/rolled on and cured “paints”. Although interior cask surfaces are not accessible for routine liner repair during loaded cask operation, the dry helium environment protects cask contents and internals, including cask liners from long-term degradation. Conventional surface preservatives shall be applied in accordance with the manufacturer’s recommendation and to the recommended dry film thickness. Conventional surface preservatives shall not result in significant chemical reaction with borated water.

Thermaline® 450 is the product name at the time of this SAR writing. Chemically identical products with different names are permitted. The following critical characteristics are specified conservatively for conventional surface preservatives and in order of importance to guide the in the selection of equivalent surface preservatives:

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b) Aluminum Oxide

Aluminum oxide provides excellent corrosion resistance and is compatible with the cask aluminum basket supports. [

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Aluminum oxide may be applied by the commonly used thermal spray method along the cask inner surfaces. Approved procedures will be developed for performing the operation taking into consideration or fully applying available guidance from recognized standards. The following standards are available for developing procedures and for qualifying thermal spray contractors or operators.

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

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

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

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

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

International.

2.2.1.2.6 Lead

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

2.2.2 Chemical, Galvanic or Other Reactions

There is no credible mechanism for significant chemical or galvanic reactions in the packaging during loading operations or in the package during transport.

Similar to the HI-STAR 100 packaging, the HI-STAR 180 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 gasses. Metamic-HT plate has high corrosion resistance, and anodizing to meet the required emissivity further enhances its corrosion resistance. Therefore, chemical, galvanic or other reactions involving the cask materials are unlikely and are not expected.

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

2.2.3 Effects of Radiation on Materials

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

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

The HI-STAR 180 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 40-year gamma fluence (assuming design basis fuel for 40 years without radioactive decay) from the spent nuclear fuel transported in the HI-STAR 180 Package is on the order of 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 [2.2.3, 2.2.4, 2.2.5], which is far greater than the 40-year neutron fluence from spent nuclear fuel transported in the HI-STAR 180 Package, which is on the order of 10^{16} n/cm^2 assuming design basis fuel for 40 years without radioactive decay. Also, as indicated in reference [2.2.3], "The effects listed in the table above are generally less significant at elevated temperatures for a given fluence and some defects can be removed by heating (annealing)."

As discussed in Section 1.2 and its references, the Metamic-HT neutron absorber and Holtite have been tested extensively to prove that it will not degrade over the cask design life of 40 years. With the high nickel content in its spring, the cask closure seal materials are also most resistant to radiation. No adhesives are used in the cask packaging and packaging coatings (especially cask liners) are selected for the high radiation environment.

Table 2.2.1: Containment Boundary – Mechanical Properties

Temperature ºC (ºF)	SA-350 LF3/SA-203 E					
	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-ºC x 10^{-6} (in./in. per degree F x 10^{-6})
E = Young's Modulus MPa x 10^4 (ksi x 10^3)

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

Table 2.2.2: Outer Closure Lid Bolt – Mechanical Properties

SA-193 Grade B7 and SA-320 L7 [less than 64 mm (2.5 in) diameter]					
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)

Definitions:

S_y = Yield Stress, MPa (ksi)

α = Mean Coefficient of thermal expansion, cm/cm-ºC x 10^{-6} (in/in-ºF x 10^{-6})

S_u = Ultimate Stress, MPa (ksi)

E = Young's Modulus, MPa x 10^4 (psi x 10^6)

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6] for ferrous materials.
2. Source for S_u values is Table U of [2.1.6] for ferrous materials, or from Section II, Part A. Where ultimate strength is unavailable, values above 300 deg. F are based on 100 deg.F value multiplied by ratio of yield strength at room temperature to yield strength at desired temperature.
3. Source for α values is Tables TE-1 and TE-4 of [2.1.6] for ferrous materials.
4. SA-705/564 630 (H1025) and SB-637 N07118 per Table 2.2.3 are optional material for Outer Closure Lid Bolts.

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

SA-705 630, SA-564 630 (H1025 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	999.5 (145.0)	1068 (155)	19.7 (28.5)	11.16 (6.2)
93.3 (200)	924.4 (134.1)	1068 (155)	19.1 (27.8)	11.34 (6.3)
149 (300)	885.1 (128.4)	1068 (155)	18.8 (27.2)	11.52 (6.4)
204 (400)	854.1 (123.9)	913.0 (132.4)	18.4 (26.7)	11.70 (6.5)
260 (500)	827.9 (120.1)	885.1 (128.4)	18. (26.1)	11.70 (6.5)
288 (550)	816.2 (118.4)	872.7 (126.6)	17.8 (25.8)	11.88 (6.6)
SB-637 N07718* (less than or equal to 6 inches diameter) (*If used as trunnion material, Table 2.1.16 must be satisfied instead)				
38 (100)	1034 (150.0)	1276 (185.0)	19.83 (28.76)	12.9 (7.1)
93.3 (200)	992.8 (144.0)	1225 (177.6)	19.51 (28.3)	13.0 (7.2)
149 (300)	970.1 (140.7)	1196 (173.5)	19.24 (27.9)	13.2 (7.3)
204 (400)	953.5 (138.3)	1176 (170.6)	18.96 (27.5)	13.4 (7.5)
260 (500)	943.2 (136.8)	1163 (168.7)	18.75 (27.2)	13.6 (7.6)
316 (600)	932.9 (135.3)	1151 (166.9)	18.48 (26.8)	13.9 (7.7)

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 or ratioing the material design stress intensity values for SB-637 N07718.
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 desired temperature to yield strength at room temperature. For SB-637 N07118, the ratio of the ultimate strength to yield strength at 100 deg. F is used.
3. Source for α values is Tables TE-1 and TE-4 of [2.1.6], as applicable. Values for α are for H1075 condition in lieu of H1025 condition.
4. SA-705 630 and SA-564 630 (both UNS No. S17400) have the same chemistry requirements and are considered equivalent for the intended application.

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

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

Definitions:

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

Notes:

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

Table 2.2.5: Miscellaneous Steel – Mechanical Properties

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

Temperature ºC (ºF)	**SA-516 Grade 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)

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Table 2.2.5 (Continued): Miscellaneous Steel – Mechanical Properties

Definitions:

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

Notes:

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

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

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

Note: Source for stress is Table 3 of [2.1.6].

Table 2.2.7: Monolithic Shield Cylinder – Mechanical Properties

SA-352 LCC / A352-93 LCC				
Temp. ºC (ºF)	**S_y**	**S_u**	**E**	**α**
37.8 (100)	275.8 (40.0)	482.6 (70.0)	20.2 (29.3)	11.7 (6.5)
93.33 (200)	251.7 (36.5)	482.6 (70.0)	19.86 (28.8)	12.06 (6.7)
148.89 (300)	244.8 (35.5)	482.6 (70.0)	19.51 (28.3)	12.42 (6.9)
204.2 (400)	234.4 (34)	482.6 (70.0)	19.24 (27.9)	12.78 (7.1)
260 (500)	223.4 (32.4)	482.6 (70.0)	18.82 (27.3)	13.14 (7.3)

Definitions:

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

Notes:

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

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Table 2.2.8: [Withheld in Accordance with 10 CFR 2.390]

Table 2.2.9: Basket Shims - Mechanical Properties

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

Definitions:

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

Notes:

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

Table 2.2.10[2]: [Withheld in Accordance with 10 CFR 2.390]

[2] This table is referenced in Chapter 8 and hence cannot be altered without a license amendment.

Table 2.2.11: Mechanical Properties of Lead

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

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

Table 2.2.12: [Withheld in Accordance with 10 CFR 2.390]

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

Table 2.2.14: [Withheld in Accordance with 10 CFR 2.390]

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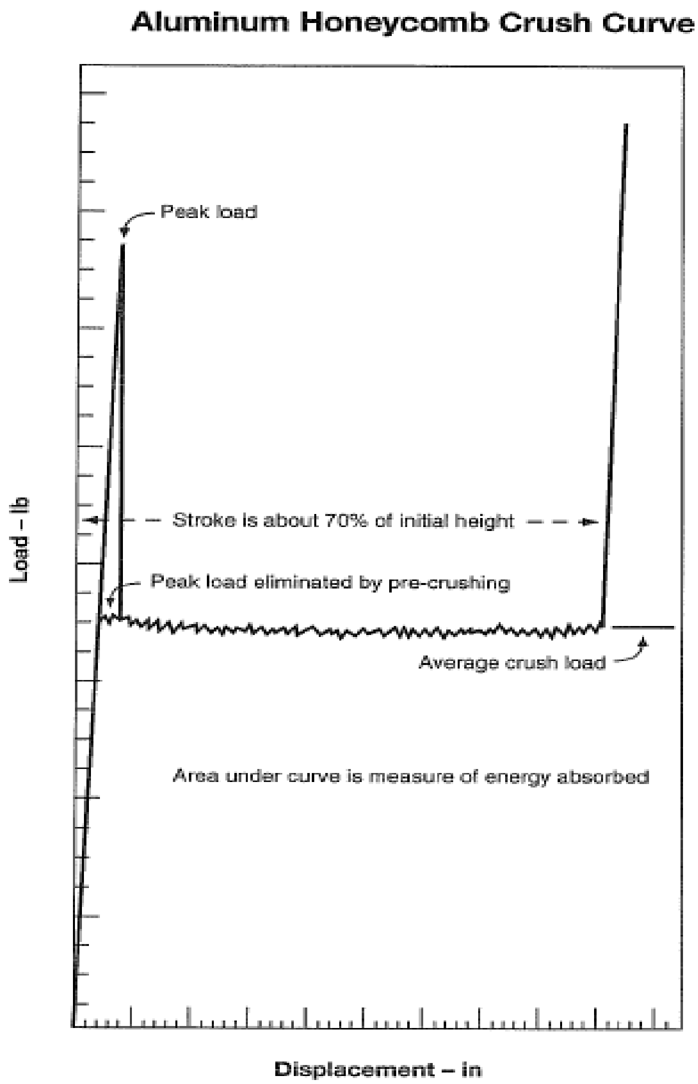

Figure 2.2.1: Aluminum Honeycomb Load vs. Crush Curve (Typical, reproduced from Ref. [2.1.1])

2.3 FABRICATION AND EXAMINATIONS

2.3.1 Fabrication

Consideration of the manufacturing process of a cask must be an integral part of its design evolution to ensure that the as-engineered cask can be manufactured to meet the intents of the design. For HI-STAR 180, 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 180. Of course, there are several candidate manufacturing sequences that will meet the above criteria. In the following, an overview of one such acceptable fabrication sequence for the HI-STAR 180 is presented to illustrate its fabricability while meeting the above objectives. Other sequences may be used provided they meet the above criteria for quality fabrication

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As shown in the basket drawings in the licensing drawing package in Section 1.3, certain peripheral junctions in the fuel basket grid work are welded to provide additional dimensional fixity to the basket. Strictly speaking, these welds are not required for the basket to render its structural function.

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Nevertheless, they are incorporated in the basket's design, included in the structural finite element evaluations, and specified as structural welds in the drawing package in Section 1.3 of the SAR. Extensive comparative evaluation of candidate welding processes has shown that the "Friction Stir welding" (FSW) provides at least 30% greater joint strength than classical welding methods in Metamic-HT joints. Accordingly, FSW has been specified as the mandatory welding process for basket weld joints. As can be deduced from the licensing drawing package, the weld configuration in the fuel basket welds is of Category C, Type III (by virtue of being corner joint with essentially a thru-thickness "stir zone") per Section III Subsection NG. In the evaluation of the joint's structural strength, the weld joint is considered to emulate a full penetration weld with its thickness defined by the depth of the friction stir zone. Actual weld qualification testing on representative coupons prepared in accordance with the provisions of Section IX show section tensile strength of the FSW weld to be consistently in the range of the tensile strength of the base metal which provides the assurance that the weld joints internal to the fuel basket will have significant strength reserve compared to the structural demand placed on them. The bending and shear strength of the welded joints are computed using the weld tensile strength and weld depth determined from the coupon tests with the strength penalty factor applied in conformance with Table NG-3352-1.

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

2.3.2 Examinations

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

1. Materials of construction specified for the HI-STAR 180 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, unless it involves Metamic-HT, shall be performed using welders and weld procedures that have been qualified in accordance with ASME Code Section IX and the applicable ASME Section III Subsections. Welding of welds identified as NITS welds may be performed as described above for code welds or using welders and weld procedures that have been qualified in accordance with AWS D1.1 or AWS D1.2 as applicable. The weld requirements for Metamic-HT are summarized below in item 14.

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

4. The HI-STAR 180 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 volumetric examination per Subsection NB of the ASME Code.

5. Grinding and machining operations of the HI-STAR 180 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 180 shall be performed in accordance with

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written and approved procedures in order to verify compliance to design drawings and fit-up of individual components. All inspections of critical dimensions and functional fit-up tests shall be documented.

7. Lifting trunnions are provided for lifting and handling of the HI-STAR 180. The trunnions are designed in accordance with 10CFR71.45 and NUREG-0612, and inspected and tested following guidance of ANSI N14.6. A carefully engineered design to eliminate local stress risers in the highly-stressed regions of the trunnion during lift operations and excellent stress margins ensure that the lifting trunnions will work reliably. Further, pursuant to the defense-in-depth approach of NUREG-0612, acceptance criteria for the lifting trunnions have been established in conjunction with other considerations applicable to heavy load handling.

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

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

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

9. The majority of materials used in the HI-STAR 180 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 180 containment boundary are carried out in accordance with Table 2.1.10. Weld material used in welding the containment boundary is also tested as specified in Table 2.1.10.

   Non-containment portions of the HI-STAR 180, as required, shall be impact tested in accordance with Table 2.1.10A. Test results shall be documented and shall become

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part of the final quality documentation record package.

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

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

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

13. A completed quality documentation record package shall be prepared and maintained during fabrication of each HI-STAR 180 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 180 has been fabricated and inspected in accordance with the governing Certificate-of- Compliance.

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

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

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

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

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

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

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

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

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

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

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

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

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2.4 GENERAL REQUIREMENTS

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

2.4.1 Minimum Package Size

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

2.4.2 Tamper-Indicating Feature

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

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

2.4.3 Positive Closure

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

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2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Lifting Devices

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

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

The evaluation of the adequacy of the lifting devices entails careful consideration of the applied loading and associated stress limits. The load combination D+H, where H is the "handling load", is the generic case for all lifting adequacy assessments. The term D denotes the dead load. Quite obviously, D must be taken as the bounding value of the dead load of the component being lifted. Table 2.1.11 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 [2.5.5], Section 3.3, which stipulates a dynamic factor equal to 0.15 for slowly executed lifts. Thus, the "apparent dead load" of the component for stress analysis purposes is $D^* = 1.15D$. Unless otherwise stated, all lifting analyses in this chapter use the "apparent dead load", D^*, in the lifting analysis.

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

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

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

It should be emphasized that in the results for the trunnion stress levels, the safety factor, SF represents the additional margin that is over and beyond the margin built into NUREG 0612 (e.g., a factor of 10 on ultimate strength or 3 on yield strength).

2.5.1.1 Cask Trunnion Analysis

The lifting trunnion for the HI-STAR 180 cask is presented in the drawing package provided in Section 1.3. The two lifting trunnions for HI-STAR 180 are circumferentially spaced at 180-degrees. The trunnions are designed for a two-point lift and are sized to satisfy the aforementioned NUREG-0612 criteria. The trunnion material is identified in the drawing package shown in Section 1.3, which also specifies the trunnion threaded connection details in a note. There are also two (optional) trunnions at the base of the cask. These trunnions may be used as rotation supports when changing package orientation from vertical to horizontal (or vice- versa), or may be used to support 50% of the loaded cask when it is carried 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, but the maximum lifted load is 50% of the total load.

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2.5.1.2 Cask Closure Lids and Baseplate During Lifting

2.5.1.2.1 Closure Lid Lifting Holes

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

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

2.5.1.2.2 Baseplate

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

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

2.5.1.3 Failure of Lifting Devices

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

2.5.2 Tie-Down Devices

There are no tie-down devices that are a structural part of the package. Therefore, 10CFR71.45(b) is not applicable to the HI-STAR 180 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 180 package. The loads used to design these components are determined using the load amplifiers given by the American Association of Railroads (AAR) Field Manual, Rule 88 [2.5.4].

2.5.3 Safety Evaluation of Lifting and Tie-Down Devices

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

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

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

Item	Calculated Value	Safety Factor
Upper Trunnions		
Bending stress (Comparison with Yield Strength in Tension) (ksi)	10.815	4.0
Shear stress (Comparison with Yield Strength in Shear) (ksi)	3.190	8.14
Bearing Stress on Top Forging (Comparison with Yield Strength in Compression) (ksi)	9.456	1.18
Bending Moment (Comparison with Ultimate Moment) (kip-in)	798	2.03
Shear Force (Comparison with Ultimate Shear Force) (kip)	159	3.78
Lower Trunnions		
Bending stress (Comparison with Yield Stress) (ksi)	11.440	3.78
Shear stress (Comparison with Yield Strength in Shear) (ksi)	2.680	9.69
Bearing Stress on Bottom Forging (Comparison with Yield Strength in Compression) (ksi)	8.175	1.36
Bending Moment (Comparison with Ultimate Moment) (kip-in)	399	1.92
Shear Force (Comparison with Ultimate Shear Force) (kip)	79.35	4.44

Note: The tabulated results are conservatively based on a bounding cask weight of 125.2 metric tons (276,000 lbf), which exceeds the maximum value in Table 2.1.11.

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

Item	Value, kg (lb.)	Capacity, kg (lb.)	Minimum Safety Factor
Inner Closure Lid Direct Load	8,744 (19,260)	30,550 (67,290)	3.49

Note: Safety Factor in this table represents the margin above the mandated value of 3 on yield strength and 5 on ultimate strength per ANSI N14.6 [2.5.1].

Table 2.5.3: Top End Lift – Safety Factors

Item	Value- MPa (ksi)	Allowable- MPa (ksi)	Safety Factor
Containment Shell	< 20.68 (3.0)	143.8 (20.85)	> 6.95
Baseplate (Center)	< 58.6 (8.5)	215.6 (31.27)	> 3.68
Baseplate (Joint with Shell)	< 58.6 (8.5)	215.6 (31.27)	> 3.68

Note: This table is constructed from an analysis with zero internal pressure, simulating a case where the internal pressure is less than atmospheric.

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

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

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2.6 NORMAL CONDITIONS OF TRANSPORT

In this section, the HI-STAR 180 package, consisting of the cask and the AL-STAR impact limiter, when subjected to the normal conditions of transport specified in 10CFR71.71, is shown to meet the design criteria in Subsection 2.1.2 (which are derived from the stipulations in 10CFR71.43 and 10CFR71.51). The vehicle utilized for the stress/deformation analysis is a comprehensive 3-D finite element simulation of the package on Q.A.-validated codes (see Appendix 2.A). 3-D finite element models of the cask, the fuel basket, and the two impact limiters have been prepared and assembled into a complete system to evaluate all of the Normal and Accident Conditions of Transport that involve an impact event. The stress analysis of the cask containment boundary is carried out using a 3-D finite element model or a simplified plate-and-shell theory solution, as appropriate. The stress intensity limits applicable to the containment boundary, as summarized below, are the central focus of the required qualifications.

i. The containment boundary must meet ASME Code Level A stress intensity limits under the design internal pressure and under operating internal pressure plus temperature appropriate to the normal condition of transport. For conservatism, only the containment boundary is considered, i.e., the strengthening effect of the Dose Blocker parts that girdle the containment shell is neglected.

ii. The containment boundary must also meet the same Level A stress limits when subject to a 0.3-meter side drop with impact limiters in place. For this dynamic analysis, the entire package is modeled and a comprehensive 3-D finite element simulation of the package drop performed using a public domain, QA validated computer code (Appendix 2.A). For this purpose, 3-D finite element models of the cask, the fuel basket, and the two AL-STAR impact limiters have been prepared.

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

For the HI-STAR 180, the simulation of the package drop event is carried out using two independent approaches that are referred to as the (i) Classical Dynamics Approach and (ii) the numerical dynamics approach implemented in LS-DYNA.

The Classical Dynamics Approach methodology uses a simplified two-dimensional characterization of AL-STAR impact limiter calibrated and validated by static and scale model test data on the HI-STAR 100 docket (Docket No. 71-9261). The extensive body of material in the HI-STAR 100 on the dynamic simulation has been organized and condensed in [2.6.5]. The methodology described in this report is used to obtain the peak g-loads, α_{max}, and impact material crush, d_{max}, for the wide variety of impact scenarios considered in this safety analysis effort. These g-loads and crush data provide an independent means to assess the structural adequacy of the package.

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

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

2.6.1 Heat

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

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

2.6.1.1 Summary of Pressures and Temperatures

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 180 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 180 fuel baskets, the fuel basket supports, and the cask are discussed in Chapter 3, for the Normal Conditions of Transport under hot conditions. Conservative estimates of free thermal expansion of the components in the HI-STAR 180 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 Subsection 3.4.4. Table 3.4.2 documents the radial and axial expansions prior to and after heat-up.

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2.6.1.3 Stress Calculations

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

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

The Package is analyzed for the Load Combinations N1 and N2 listed in Subsection 2.1.2 using the finite element codes ANSYS [2.5.2] and LS-DYNA [2.5.3], and the models described in Subsection 2.7.1 and in the Holtec Proprietary calculation packages [2.1.12] and [2.6.1]. For the simulation of the normal operating condition (Load Combination N1 consisting of design pressure and temperature), the package orientation is not significant. For the 1-foot free drop condition (Load Combination N2), the package is oriented at a 0-degree angle with respect to the horizontal rigid target, and the package has an initial downward vertical velocity given by

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

so that V = 96.3 inch/sec. (37.9 cm/sec.)

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

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

2.6.1.3.2 Fatigue Considerations

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

- Cask Fatigue Considerations

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

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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). [

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Using Figure I-9.4 (NB, loc. cit), the permissible number of cycles is 225; this sets a limit on the number of permitted loadings if SA-564/705 630 (H1025 is used for closure lid bolts.

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Using Figure I-9.4, the permissible number of cycles is 250; this sets a limit on the number of permitted loadings if SB-637 N07718 material is used for the closure lid bolts.

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

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

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Using Figure I-9.1 (of NB, loc. cit), the allowable number of cycles is approximately equal to 1500.

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

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

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2.6.1.3.3 Stability of the Metamic Fuel Basket Plates

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

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

2.6.1.3.4 Closure Lid Flanged Joint

The closure lid-to-flange joint in all HI-STAR family of casks is engineered to be a "controlled compression joint" (see Figure 2.6.1) widely used in the pressure vessel industry (see [2.7.7, Chapter

3, pp 144-51]). [

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2.6.1.4 Comparison with Allowable Stresses

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

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

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

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

2.6.1.4.1 Results for Pressure Boundary Stress Intensity

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

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

2.6.1.4.2 Result Summary for Normal Heat Condition for Transport

- Maximum Cask Deceleration from Load Combination N2

Table 2.6.4 lists the maximum cask deceleration calculated for the 0.3-meter side drop using the LS-DYNA model. Table 2.6.4 also defines the bounding value for β_{max}, which is used as input for the static stress analysis.

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

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

- Status of Lid Bolts and Seals

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The inner closure lid port cover seals are analyzed using classical methods to demonstrate that the torque requirement for the inner closure lid port cover bolts (Table 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 Section 2.6.1.3.4.

ii. The closure lid seals, including port cover seals, do not unload beyond the minimum “useful” springback (per Table 2.2.12) required to maintain leak tightness under Load Combinations N1 and N2; therefore, the seals continue to perform their function under Normal Conditions of Transport.

- ASME Pressure Test Condition

See Paragraph 8.1.3.2 for pressure test specifications.

- Performance of Non-Containment Components of Package

The Holtec Proprietary calculation package documenting all of the finite element solutions [2.6.1] contains graphical visualizations of the stress intensity and deformation for every component in the HI-STORM 180 package. In particular, the fuel basket and the monolithic shield surrounding the containment shell are surveyed to evaluate their performance and compare with the acceptance criteria in Section 2.1. Table 2.6.7 summarizes the acceptance criteria for performance of the non-containment components of the HI-STAR 180. 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 180 for the Normal Heat Condition of Transport.

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

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

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

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

iv. The containment boundary seals, which includes the closure lid seals and the vent and drain port cover seals, do not unload beyond the minimum springback required to maintain leak tightness (per Table 2.2.12).

Therefore, the HI-STAR 180 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 subsection 2.1.2.2.

The value of the ambient temperature has two principal effects on the HI-STAR 180 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 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. However, since the bolt preloads may be altered by a change in the environmental temperature, the effect of bolt temperature changes on the level of preload, subsequent to the initial application of preload, must be considered and is evaluated in the Holtec Proprietary calculation package [2.1.12]. The methodology used is based on the closure bolt analysis in the HI-STAR 100 Docket. The analysis accounts for the maximum possible internal pressure and the relative growth (or shrinkage) of a preloaded bolt connecting the lid to the flange. The results from that calculation are summarized below:

Evaluation of Environmental Temperature Changes on the Level of Preload	
Item	**Value (ksi)**
Initial Bolt Prestress -Heat (Inner/Outer Lids)	76/55
% Change (Heat to Cold)	-1.5/+2.0

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

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

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

2.6.2.1 Differential Thermal Expansion

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

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

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

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

2.6.3 Reduced External Pressure

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

2.6.4 Increased External Pressure

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

2.6.5 Vibration

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

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

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

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

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2.6.6 Water Spray

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

2.6.7 Free Drop

The structural analysis of a 0.3-meter (1-foot) free drop under the heat condition is documented in Subsection 2.6.1.4. As demonstrated in Subsection 2.6.1.4 safety factors are well over 1.0 (see Tables 2.6.4 and 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 180 Package per [2.1.3].

2.6.9 Compression

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

2.6.10 Penetration

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

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

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

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

ITEM	LEVEL A†	LEVEL D†	TEMPERATURE
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	228.6 (33.2)	506.8 (73.5)	135°C (275 °F)
Outer Closure Lid – Primary Bending Stress Intensity – Mpa (ksi)	228.6 (33.2)	506.8 (73.5)	135°C (275 °F)
Containment Shell – Primary Membrane Stress Intensity – Mpa (ksi)	145.66 (21.125)	337.86 (49.0)	218°C (425 °F)
Containment Shell – Primary + Secondary Stress Intensity – Mpa (ksi)	436.97 (63.375)	NA	218°C (425 °F)
Baseplate – Primary Membrane + Bending Stress Intensity – Mpa (ksi)	230.98 (33.5)	506.78 (73.5)	135°C (275 °F)
Baseplate – Primary + Secondary Stress Intensity – Mpa (ksi)	461.28 (66.9)	NA	135°C (275 °F)
Inner Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	666.0 (96.6)	895.11 (129.825)	135°C (275 °F)
Outer Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	437.14 (63.4)	655.54 (95.075)	135°C (275 °F)
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	999.1 (144.9) ††	1068.7 (155.0)	135°C (275 °F)
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	655.54 (95.075) ††	861.88 (125.0)	135°C (275 °F)
Monolithic Shield Cylinder – Ultimate Strength – MPa (ksi)	NA	482.6 (70.0)	204.4°C (400 °F)

† Obtained from Section 2.1.
†† Lesser of 3Sm and S_y is used for conservatism.

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

Method	α_{max} (g's)
Numerical (LS-DYNA) Solution	22.96*
The value of β_{max} for static analysis chosen to bound the above is 25 g's.	

*Upper Bound Crush Strength

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

Location and Stress Intensity Component	Calculated Value
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	29.82 (4.325) SF=7.23
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	91.15 (13.22) SF=2.37
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	19.67 (2.853) SF=7.31
Containment Shell – Primary + Secondary Stress Intensity – MPa (ksi)	86.58 (12.557) SF=4.98
Baseplate – Primary Membrane + Bending Stress Intensity at Center – MPa (ksi)	57.90 (8.398) SF=3.72
Baseplate – Primary + Secondary Bending Stress Intensity at Periphery – MPa (ksi)	SF > 4.98

Note: “SF” means Safety Factor.

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Table 2.6.6: Results for 1-Ft Drop Static Analysis

Item	Allowable from Table 2.6.5 of [1]	Side Drop
Primary Membrane stress intensity in the containment shell – MPa (ksi)	145.66 (21.125)	52.26 (7.58) † SF = 2.79
Primary + Secondary stress intensity in the containment shell – MPa (ksi)	436.97 (63.375)	116.87 (16.95) SF = 3.74

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

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

Criterion	Load Combination N1	Load Combination N2
Stress Intensity in Monolithic Shield – Primary Stress Intensity Below Ultimate Strength	-	Yes
Fuel Basket Deformation – Maximum Total Deflection < 1mm	Yes	Yes

Table 2.6.8

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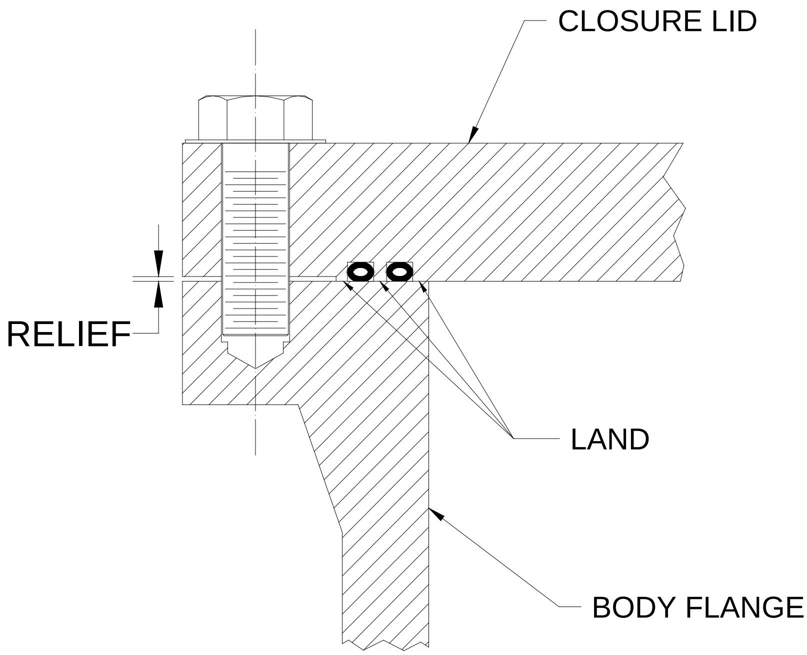

Note:
The sealing grooves may be located in the flange or the cover.

FIGURE 2.6.1: ESSENTIAL ELEMENTS OF A CLASSICAL "CONTROLLED COMPRESSION JOINT"

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

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

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

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

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

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

The hypothetical accident conditions, as defined in 10CFR71.73 and explained in Regulatory Guide 7.9, are applied to the HI-STAR 180 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 inch) diameter mild steel pin (of length sufficient to impart the impact of energy to the cask structure through penetrant action). In the third step, the package is subject to a 1475°F temperature fire environment for 30 minutes. Finally the package is subject to water immersion.

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

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2.7.1 9-meter Free Drop

2.7.1.1 Problem Description and Dynamic Model

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

The central purpose of the impact limiter, defined as an essential package appurtenance in Section 1.2, is to limit the package maximum deceleration, α_{max}. The HI-STAR package, consisting of the loaded cask and top and bottom impact limiters, is essentially a cylindrical body with a very rigid interior (namely, the cask) surrounded by a pair of relatively soft crushable structures. The crushable structure (impact limiter) should deform and absorb the kinetic energy of impact without detaching itself from the cask, disintegrating, or otherwise malfunctioning. A falling cylindrical body may theoretically impact the target surface in an infinite number of orientations; the impact limiter must limit decelerations to insure that stress intensity and performance limits, as described in Section 2.1, are satisfied, and to ensure that the impact limiter does not detach from the cask, regardless of the impact orientation. In general, a drop event orientation is defined by the angle of the HI-STAR 180 longitudinal axis, "θ", with the impact surface. In this notation, θ = 0° means a side drop and θ = 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. To limit the temperature range experienced by the impact limiter during transport, an insulation board (see drawing package in Section 1.3) is incorporated in the impact limiter. Thus, the temperature of the crush material in the impact limiter is only marginally influenced by the heat load of the contents. The minimum acceptable value of the insulation board's thermal resistance is provided in Table 2.2.10.

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

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

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

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The remaining design objectives, namely, limiting of the maximum rigid body deceleration under the 9-meter drop event and preventing contact of the cask with the unyielding surface, are demonstrated by the Classical Dynamics Method and the LS-DYNA [2.5.3] finite element code, as discussed earlier. LS-DYNA has been benchmarked extensively by others [2.7.5, 2.7.6] and by Holtec using the test data from the static tests of the crush material and, more importantly, from the quarter-scale model 9-meter drop experiments carried out at the Oak Ridge National Laboratory in support of HI-STAR 100 Part 71 certification in the late 90s [2.7.4] (see Appendix 2.B). The Classical Dynamics Method has also been benchmarked against the HI-STAR 100 ¼-scale drop tests [2.6.5]. As discussed in Appendix 2.B, the LS-DYNA simulation model for the family of Al-STAR impact limiters is a credible and reliable vehicle for determining the HI-STAR 180 Package’s impact performance *with respect to the extent of crush and the peak g-load.* LS-DYNA has been used by Holtec International in a wide variety of impact scenarios in dry storage projects [2.7.10].

Regulatory Guide 7.9 calls for evaluation of the response of the containment component in terms of stress intensity, and includes investigation of structural stability as well as the consequences of the combined effects of temperature gradients, pressure, and other loads. The work effort to fulfill the above Reg. Guide 7.9 recommendation is carried out using the static analysis approach, as discussed in the foregoing.

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

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2.7.1.2 Simulation of Drop Events

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

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

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

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

The various drop orientations analyzed using LS-DYNA and the Classical Dynamics Method to identify the most damaging scenario with reasonable assurance are summarized in Tables 2.7.3A and 2.73B, respectively. Of these, the slap-down event warrants special mention because it often produces the bounding decelerations in transport packages and has two candidate orientations in an axially nonsymmetrical package, namely:

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

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

As can be seen from Table 2.7.3A, upper and lower bound properties of the crush material are also analyzed in LS-DYNA to ensure that the largest value of α_{max} and maximum crush, d_{max}, have been identified. Based on the LS-DYNA results, the slap-down orientation that produced the largest value of α_{max} is then analyzed using the Classical Dynamics Method.

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 2.7.3A summarizes the maximum values of α_{max} for the axial and lateral direction from all of the drop scenarios simulated on LS-DYNA. Table 2.7.3B contains the α_{max} and maximum crush data obtained from the Classical Dynamics Method.

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

i. The secondary slap down impact is always more severe than the primary impact: The maximum deceleration and impact limiter crush occur in the region of the secondary impact.

ii. All body bolt stresses remain below the yield point, i.e., there is no risk of failure of any bolt fastened to the top forging.

iii. The bolts joining the impact limiters to the cask remain essentially undeformed in all cases (i.e., their stresses do not reach the material plastic limit).

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

The governing values of α_{max} (axial and lateral) culled from Tables 2.7.3A and 2.7.3B, and rounded up by a modest amount (for conservatism), henceforth referred to as "Design Basis" decelerations, β_{max}, are provided in Table 2.7.4. These design basis decelerations are used in the "static analyses" to determine the margins-of-safety in the different constituent parts of the package.

Evidently, the axial and lateral β_{max} values respectively challenge the top and bottom plate components, and the fuel basket panels in bending. Thus, β_{max} (axial) determines the margin-of-safety in the baseplate and inner closure lid (the outer closure lid does not experience the direct impact of the contents). The β_{max} (lateral) governs the lateral loading on and deflection of the fuel basket walls.

The axial deceleration, β_{max}, can be cast as a pressure loading on the inner closure lid (or the baseplate, depending on the assumed sense of action of the inertia load). The pressure p_{max} corresponding to β_{max} is given by

$$p_{\max} = 4\, W_c \,\frac{\beta_{\max}}{(\pi D^2)}$$

where W_c is the weight of the cask contents (basket and basket shims plus fuel) and D is the inside diameter of the containment closure flange.

In the "static analysis" procedure, p_{max} is applied as a pressure loading on the inner lid and the baseplate. Table 2.7.5 summarizes the value of p_{max} and identifies the most vulnerable locations and parts in the package that must be evaluated.

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

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

For convenience, the allowable stress limits necessary for the safety evaluation of each part are compiled in Table 2.6.3. The corresponding results from the ANSYS static analyses are listed in Table 2.7.6. In addition, Table 2.7.10 provides a comparison between the maximum component stresses calculated using ANSYS and LS-DYNA. Overall the stress results obtained from ANSYS are more conservative than the LS-DYNA results.

Based on the tabular results presented in Tables 2.7.6, 2.7.9, and 2.7.10, 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 remain in the elastic stress range and the gaskets remain under a compressed state at the conclusion of the event. Therefore, continued bolted joint effectiveness in the wake of the 9-meter free drop event is assured.

- The monolithic shield surrounding the containment shell remains intact.

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

- The small quantity of lead, used for shielding in the HI-STAR 180, is included in the LS-DYNA model. The lead is characterized by the properties given in Table 2.2.11. A review of all drop and puncture simulation results leads to the conclusion that there is no lead slump.

- Since the ability to accurately include and evaluate large displacements is included within the LS-DYNA algorithm, the effect of any instability is automatically included. 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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Using the approach described above, the potential fracture of the closure lid bolts and the monolithic shield cylinder under cold conditions at -40 degrees F is investigated. By simulating the standard Charpy V-notch impact test using the minimum Charpy energy specified in Subsection 2.1, the failure strains of the SA-193 B7 and SA-564 630 bolting materials and SA-352 LCC shield cylinder material are calibrated.

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

2.7.2 Crush

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

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

Two independent methods are used to analyze the hypothetical puncture event. The first method uses the LS-DYNA simulation model to examine the puncture accidents. For the top end puncture, the impact limiter is conservatively ignored. A mild steel bar, having the appropriate dimensions, is added to the model, placed in the proper orientation, and fixed to the ground. The package is then assumed to have a known initial velocity at contact with the bar. For conservatism, the side puncture model only credits the solid portion of monolithic shield, which is inboard from the neutron shield cavities. Further details of the simulation model and the results (all output figures) for the top end puncture and side puncture are provided in the Holtec Proprietary calculation packages [2.6.1] and [2.1.12], respectively.

The second method uses energy principles and strength of materials formula to determine the primary stress intensities in the containment boundary. In particular, local penetration is examined by comparing the potential energy of the falling cask with the strain energy required to shear a circular plug of material from an otherwise rigid plate. For the top end puncture, the Impact Limiter is conservatively ignored. The primary stress intensity in the containment shell due to the side puncture is calculated assuming that the shell deflects like a cantilever beam, which is fixed at the shell cross-section through the cask centroid. The stress in the closure lid away from the immediate vicinity of the impact is calculated by considering a simply supported circular plate under a concentrated load at its center. Details of the analysis and the results from each puncture accident are provided in the Holtec Proprietary calculation package [2.1.12]. The key results of the puncture analysis are summarized in Table 2.7.7.

The results from the puncture analyses yield the following conclusions:

i. The bolted joint maintains its integrity; the margin-against-leakage parameter, m, (defined in paragraph 2.6.1.4) remains at the maximum possible value of 10.

ii. No thru-wall penetration of the containment boundary or dose blocker parts (shield cylinder) is indicated. The total depth of local indentation is a fraction of the available material thickness in the path of the penetrant. Although the outer region of the monolithic shield (where the neutron shield cavities are located) is not credited in the model, the steel bar is expected to penetrate this region in the case of a side puncture event (see Figure 2.7.14).

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

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

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

2.7.4 Thermal

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

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

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

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

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

Table 2.7.8 provides a summary of the key results obtained from the continued sealing analysis under the fire accident; the details of the solution are documented in the Holtec Proprietary calculation package [2.1.12]. The analysis methodology used here is based on the methodology previously used for the HI-STAR 100 licensing effort. The primary loading is the temperature change of the bolted connection from the fire. Because of the similarities in coefficient of thermal expansion between the lid and flange and the bolts, the bolt loads do not change significantly from their starting value. As a result, the change in the compression on the lands is also insignificant. Therefore, the fire transient, 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 transient.

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 transient. It is concluded in that section that:

1. The containment boundary, protected by the monolithic shield, 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 computes to experience temperature in excess of its design limit, leading to a certain modest loss in the cask’s neutron shielding capacity.

2.7.4.2 Differential Thermal Expansion

Differential thermal expansions under the limiting conditions of the fire transient 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.

iii. The temperature of the Holtite material exceeds its recommended operating limit for a very short duration; hence, a certain amount of loss of neutron shielding will occur.

2.7.5 Immersion - Fissile Material

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

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

2.7.6 Immersion - All packages

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

2.7.7 Deep Water Immersion Test

The HI-STAR 180 containment boundary is subject to an all-around external pressure of 2.0 MPa (290 psi) after applying initial bolt preload. Code Case N-284 is used to evaluate the propensity for containment shell instability assuming the monolithic shielding does not prevent the 290 psi pressure from acting directly on the outer surface of the containment shell. The Holtec Proprietary calculation package [2.1.12] contains the supporting details; it is demonstrated there that there is no yielding of the vessel and that there is no elastic or plastic instability of the containment shell. Since the external pressure acts in a direction to add additional pressure to the lands of the lids, seal opening is not a concern for this accident. The primary stress intensity in the lids, assuming that the lids are subject to 290 psi and are conservatively considered as simply supported plates at the bolt circle, meet the Level D ASME Code limits (this is easily demonstrated by examining the results for the N1 normal load condition summarized in Section 2.6). In-leakage of water through the containment system boundary seals is confirmed to be non-credible to satisfy the intent of ISG-19 [2.7.3]. 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 180 Package meets the requirements of 10CFR71.61 and 10CFR71.73. All (plausibly) vulnerable orientations of free drop have been analyzed. Two puncture events have also been considered and reported in the tables in Section 2.7. All safety factors are greater than 1.0 for the hypothetical accident conditions of transport, and the sealing function is maintained at the end of each event and at the end of the sequence. The fuel basket does not experience any primary plastic strain after any of the accidents simulated in this safety analysis effort. Therefore, the HI-STAR 180 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 180 containment space will remain inaccessible to the moderator under the immersion event of §71.73, which follows free drop, puncture, and fire.

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

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

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

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

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

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

Case No.	Drop Scenario	θ	Maximum Computed Deceleration in g's α_{max}		Maximum Crush Inch		Reference Figure	Comments
			Axial	Lateral	Allowable * Value	Computed Value		
1.	End drop – bottom down (UB**)	90	85.03	-	15.12	7.56	2.7.1	
2.	End drop – top down (UB)	90	68.25 (78.08***)	-	15.12	7.27	2.7.1	
3.	Side drop (UB)	0	-	73.83	10.85	9.95	2.7.3	
4.	C.G.-over-corner drop – top down (UB)	65.6	39.87	18.09	30.44	23.28	2.7.2	
5.	Oblique drop (slap down) – primary impact at the top end (UB)	6	-	79.26	10.85	9.48	2.7.4	Bounding results of the primary and secondary impacts are reported
6.	Oblique drop (slap down) – primary impact at the bottom end (UB)	6	-	72.26	10.85	9.48	2.7.4	Bounding results of the primary and secondary impacts are reported
7.	Side drop (LB)	0	-	67.48	10.85	10.63	2.7.3	

* Allowable crush based on distance to closest point on steel backbone, except for end drop where allowable crush is 63% of the distance to closest point.
** "UB" indicates Upper Bound crush strength values are used in drop simulation; "LB" indicates Lower Bound crush strength values are used in drop simulation.
*** For the case where FIAs are not used.

Table 2.7.3B: Nine-Meter Free Drop Simulations Results Using the "Classical Dynamics" Method

Case No. ***	Drop Scenario	θ	Maximum Computed Deceleration in g's α_{max}		Maximum Crush Inch		Reference Figure	Comments
			Axial	Lateral	Allowable* Value	Computed Value		
1.	Top End drop (UB**)	90	59.8	-	15.12	7.33	2.7.1	
3.	Side drop (UB)	0	-	53.0	10.85	8.45	2.7.3	
4.	C.G.-over-corner drop – top down (UB)	65.6	31.42	14.25	30.44	16.7	2.7.2	
5.	Oblique drop (slap down) – primary impact at the top end (UB)	6	-	82.86	10.85	9.98	2.7.4	Bounding results of the primary and secondary impacts are reported

* Allowable crush based on distance to closest point on steel backbone, except for end drop where allowable crush is 63% of the distance to closest point.
** "UB" indicates Upper Bound crush strength values are used in drop simulation.
***

Table 2.7.4: Design Basis Decelerations*, β_{max} , for "Static Analysis" of 9-Meter Free Drop

Direction		Deceleration (in g's)	Controlling Drop Scenario
Axial	Top End	82	Top End Drop
	Bottom End	90	Bottom End Drop
Lateral		95	Oblique Drop

* Design Basis Deceleration in each direction is set down to be greater than the largest value of α_{max} from Table 2.7.3 in that direction by a modest percentage (for conservatism).

Table 2.7.5: Equivalent Load from the Design Basis Decelerations, β_{max}

Direction		β_{max} (in g's)	Equivalent Load	Type of Stress and Location of Maximum Stress
Axial	Top End	82	1,118 psi	Flexure of baseplate, flexure of inner and outer lids, unloading of gasket seals, possible overstressing of bolts, axial in-plane compression of Metamic-HT panels in the fuel basket.
	Bottom End	90	1,220 psi	
Lateral		95	746 lb/inch per panel	Flexure of Metamic-HT panels, in-plane compression of Metamic-HT panels, flexure of containment shell, monolithic shield cylinder strength.

Table 2.7.6: - Results from 30-Ft Drop Simulations Using ANSYS Static Analysis

Item	ALLOWABLE STRESS†	TOP END DROP	BOTTOM END DROP	SIDE DROP
Inner or Outer Closure Lid Top – Primary Bending Stress Intensity – MPa (ksi)	506.8 (73.5)	263.17 (38.17) SF = 1.93	NA	NA
Containment Shell – Primary Membrane Stress Intensity – Mpa (ksi)	337.86 (49.0)	58.47 (8.48) SF = 5.78	200.15 (29.03) SF = 1.69	199.05 (28.87) SF = 1.7
Baseplate – Primary Membrane + Bending Stress Intensity – Mpa (ksi)	506.78 (73.5)	NA	317.85 (46.1) †† SF = 1.59	NA
Fuel Basket Panel Lateral Deformation – Maximum Total Deflection < 1 mm?	NA	NA†††	NA†††	Yes (0.3 mm)
Inner Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	895.11 (129.825)	758.97 (110.08) SF = 1.18	NA	NA
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	1068.7 (155.0)	866.53 (125.68) SF = 1.23	NA	NA
Outer Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	655.54 (95.075)	518.21 (75.16) SF = 1.26	NA	NA
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	861.88 (125.0)	772.7 (112.07) SF = 1.12	NA	NA
Lid Seals Remain Sufficiently Compressed?	NA	Yes	NA	NA
Monolithic Shield Cylinder – Primary Effective Stress (Compared to Ultimate Strength) – MPa (ksi)	482.6 (70.0)	107.56 (15.6) SF = 4.49	94.94 (13.77) SF = 5.08	334.26 (48.48) SF = 1.44

Note: "SF" means Safety Factor. "NA" means Not Applicable or Not Bounding.

† See also Table 2.6.3.

†† As an example, the stress distribution in the baseplate under 30-ft bottom end drop is shown in Figure 2.7.12.

††† During an end drop, the lateral pressure exerted on the fuel basket panels is negligibly small, and therefore the panel deformations are bounded by the side drop results.

Table 2.7.7: Minimum Safety Factors for Containment Boundary Components Due to Puncture Event

ITEM	CALCULATED VALUE, MPa (ksi)	ALLOWABLE LIMIT, MPa (ksi)	SAFETY FACTOR
Side Puncture – Primary Membrane Stress Intensity in Containment Shell	29.7 (4.31)	337.3 (48.9)	11.3
Top End Puncture – Primary Membrane Plus Bending Stress Intensity in Outer Closure Lid	351.3 (51.0)	506.8 (73.5)	1.44

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Table 2.7.8: Bolted Joint Performance Under the Fire Transient Event

ITEM	AT PEAK OF FIRE	BEFORE AND AFTER FIRE
Inner Closure Lid Bolt – Average Service Stress MPa (ksi)	496.4 (72.0)	494.4 (71.7)
Outer Closure Lid Bolt – Average Service Stress MPa (ksi)	351.6 (51.0)	352.3 (51.1)

Table 2.7.9: Key Performance Objectives for Non-Containment Components of the HI-STAR 180

Criterion	Result
Effective Stress in Monolithic Shield – Primary Effective Stress Below Ultimate Strength	Yes
Fuel Basket Deformation – Maximum Total Deflection < 1 mm	Yes

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

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

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIALS FOR AIR TRANSPORT

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

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2.10 SPECIAL FORM

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

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2.11 FUEL RODS

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

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

[

Withheld in Accordance with 10 CFR 2.390

]

Table 2.11.1

Intentionally Deleted

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

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

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Table 2.11.4: [Withheld in Accordance with 10 CFR 2.390]

Table 2.11.5: [Withheld in Accordance with 10 CFR 2.390]

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

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

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

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

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

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

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Figure 2.11.7: **[Withheld in Accordance with 10 CFR 2.390]**

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Figure 2.11.8: **[Withheld in Accordance with 10 CFR 2.390]**

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Figure 2.11.9: **[Withheld in Accordance with 10 CFR 2.390]**

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Figure 2.11.10: **[Withheld in Accordance with 10 CFR 2.390]**

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CHAPTER 2 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. Supporting documents submitted to the USNRC with the HI-STAR 180 LAR 9325-2 have been italicized.

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

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

ANSYS Mechanical

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

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

LS-DYNA

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

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

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

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

CHAPTER 3: THERMAL EVALUATION

3.0 INTRODUCTION

In this chapter, compliance of the HI-STAR 180 Package to 10CFR Part 71 [1.0.2] and ISG-11, Rev. 3 [3.3.3] thermal requirements is evaluated for normal transport and hypothetical accident conditions of transport. The analysis considers passive rejection of decay heat from the Spent Nuclear Fuel (SNF) to a 10CFR71-mandated environment for normal transport and hypothetical fire accident conditions.

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

1. A package must be designed, constructed, and prepared for shipment so that in still air at 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 -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 180 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 180 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.

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3.1 DESCRIPTION OF THERMAL DESIGN

3.1.1 Design Features

Design details of the HI-STAR 180 Package are presented in Chapter 1 and structural and mechanical features are described in Chapters 1 and 2. The HI-STAR 180 Package geometry is detailed in Holtec drawings included in Section 1.3. All materials of construction are itemized in the drawings. The assembled packaging with impact limiters installed is shown in Figure 1.3.2. As shown in this figure, the HI-STAR 180 Package is equipped with a personnel barrier to prevent access to hot cask surfaces. The package consists of a Metamic-HT fuel basket inside a thick steel cask with twin (inner and outer) bolted closure lids. Two basket designs, the F-32 and F-37 baskets are available for storing upto 32 and 37 PWR fuel assemblies. The fuel basket is a honeycomb structure engineered with square-shaped compartments to store PWR fuel. Prior to lid closure, the cask cavity is backfilled with helium. This provides a stable and inert environment for the transport of the SNF. Heat is transferred from the cask to the environment by passive heat transport mechanisms only.

The HI-STAR 180 Package is designed to safely dissipate heat under passive conditions (no wind). During transport, the HI-STAR 180 Package is placed in a horizontal position with impact limiters installed at both ends of the cask. Under normal transport conditions, the cask contents (fuel basket, fuel and basket shims) rest on solid surfaces. Direct contact between the cask and its contents enhance heat dissipation. Prior to cask closure the cask cavity is backfilled with sub-atmospheric pressure helium to eliminate leakage of radioactive gases to the environment. A double-lid design is engineered to eliminate air in-leakage during transport and to prevent water ingress under a hypothetical water immersion accident. Presence of a substantially more conductive medium (helium) relative to air in the cavity spaces aids heat transfer by minimizing gap resistances and dissipating heat by natural convection in the cavity peripheral spaces.

The fuel basket is a matrix of square-shaped fuel compartments sized to store PWR Spent Nuclear Fuel (SNF). The basket is formed by a honeycomb structure of thick Metamic-HT plates. The fuel basket is surrounded by an array of shaped Aluminum spacers (basket shims) inserted in the cask cavity peripheral spaces. Cross-sectional views of the two fuel basket designs are provided in Chapter 1. Heat is dissipated in the fuel basket principally by conduction of heat in the highly conductive Metamic-HT plates arrayed in two orthogonal directions. Heat dissipation in the fuel basket peripheral spaces is by a combination of contact heat transfer, helium conduction and radiation across narrow peripheral spacer gaps and by conduction through the Aluminum basket shims. The fuel basket and the Aluminum basket shims reside in a containment boundary formed by the containment shell, baseplate and two closure lids. The containment shell is enclosed in a shrink fitted thick-section cask body engineered with neutron shield pockets. The HI-STAR 180 cask body is engineered with low profile fins to enhance heat transfer area and concomitant dissipation of heat. In the interest of conservatism dissipation of heat by fins is ignored.

The helium backfill gas is an integral part of the HI-STAR 180 thermal design. The helium fills all the spaces between solid components and provides an improved conduction medium (compared to air) for dissipating decay heat. Additionally, helium in the spaces between the fuel basket and the cask cavity is heated differentially and dissipates heat by the so-called "Rayleigh" convection. To ensure that the helium gas is retained and not diluted by lower conductivity air, the cask containment boundary is designed as an ASME Section III pressure vessel equipped with high integrity double seals in *both* the inner and outer closure lids. This ensures the presence of helium during transport. The helium gas is therefore retained in an undiluted state, and may be credited in the thermal analyses.

An important thermal design criterion imposed on the HI-STAR 180 Package is to ensure that the peak fuel cladding temperatures are below regulatory limits. An equally important design criterion is to minimize temperature gradients within the fuel basket to minimize thermal stresses. In order to meet these design objectives, the HI-STAR 180 fuel basket is designed to possess certain distinctive characteristics, which are summarized in the following.

The cask design minimizes resistance to heat transfer within the basket and basket periphery regions. This is ensured by designing the fuel basket with highly conductive Metamic-HT plates. In the fuel basket peripheral spaces thick Aluminum basket shims are inserted to facilitate basket-to-cask heat transfer. The cask design incorporates top and bottom plenums with interconnected downcomer paths to facilitate heat dissipation by internal helium circulation. This mode of heat transfer is active when the cask is tilted a few degrees from horizontal orientation. The top and bottom plenums are formed between the cask ends and fuel basket lateral flow holes in the top and bottom sections of each fuel cell wall. The fuel basket is designed to minimize structural discontinuities (i.e., gaps), which can introduce large thermal resistances to heat flow. Consequently, temperature gradients are minimized in this design, which results in lower thermal stresses within the basket. Low thermal stresses are also ensured by provisions in the cask design that permit unrestrained axial and radial thermal growth of the basket.

The HI-STAR 180 Package is designed to transport PWR spent fuel assemblies. As explained next, thermal analysis of the HI-STAR 180 Package considers all three fundamental modes of heat transfer: conduction, natural convection and thermal radiation. On the outside surface of the cask, heat is dissipated to the environment by buoyancy induced convective air-flow (natural convection) and thermal radiation. Within the cask body, heat dissipation is principally by heat conduction. Inside the cask cavity heat dissipation is conservatively limited to conduction and radiation. Between surfaces (e.g., between neighboring fuel rods) heat is transported by a combination of conduction through a gaseous medium (helium) and thermal radiation. Finally buoyancy-induced convective heat transport occurs within the open spaces of the cask cavity. Heat transfer between the fuel basket external surface and enclosure shell inside wall is enhanced by the so-called "Rayleigh" effect in differentially heated cavities [3.1.1]. In the interest of conservatism convective heat transfer in the cavity spaces is neglected.

In Section 3.2 the thermal criteria for ensuring Spent Nuclear Fuel (SNF) integrity and cask effectiveness are provided. To ensure SNF integrity, the ISG-11 recommended cladding temperature limits [3.3.3] are adopted (Table 3.2.11). To ensure cask effectiveness the cask materials and components are required to be below the pressure and temperature limits for creep, yield, decomposition and melting (Tables 2.1.1, 3.2.10 and 3.2.12).

3.1.2 Contents Decay Heat

The HI-STAR 180 Package decay heat limits are conservatively understated to limit radiation dose from hot (short cooled) fuel. This is ensured by requiring fuel loading to comply with both the decay heat and burnup limits in Tables 1.2.8 and 1.2.9. The HI-STAR 180 Package is designed to allow fuel loading under uniform and regionalized loadings. The cask and assembly design heat loads are defined in Chapter 1, Tables 1.2.8 and 1.2.9. These tables define the permissible heat load patterns for the F-32 and F-37 baskets. The aggregate cask heat load, Q_d, and quadrant heat load under all storage configurations is limited as defined in Table 1.2.3a.

3.1.3 Summary Table of Temperatures

The HI-STAR 180 Package temperatures are analyzed for normal transport condition and hypothetical fire accident event. The analytical modeling is discussed in Sections 3.3 and 3.4. The analysis results are provided in Tables 3.1.1 and 3.1.3. The HI-STAR 180 normal transport and hypothetical accident temperatures comply with the normal and accident temperature limits specified in Tables 3.2.10, 3.2.11 and 3.2.12.

3.1.4 Summary Table of Maximum Pressures

The HI-STAR 180 Package containment boundary pressures are computed for normal transport condition and hypothetical fire accident event. The analytical modeling is discussed in Sections 3.3 and 3.4. The analysis results are provided in Tables 3.1.2 and 3.1.4. The HI-STAR 180 normal transport and hypothetical accident containment pressures comply with the pressure limits specified in Chapter 2, Table 2.1.1.

3.1.5 Cask Surface Temperature Evaluation

In accordance with the regulatory requirement specified in 10CFR71 (§71.43(g)), the cask surface temperature is computed in still air at 38°C (100°F) and in the shade. Under this scenario the maximum computed cask surface temperature, 105°C (221°F) is above the allowable surface temperature limit of 85°C (185°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 bounding personnel barrier is defined and evaluated.

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Table 3.1.1: HI-STAR 180 Normal Transport Maximum Temperatures

Material/Component	Temperature °C (°F)
Fuel Cladding	314 (597)
Fuel Basket	275 (527)
Containment Shell	182 (360)
Monolithic Shield Cylinder Neutron Shield	165 (329)
Cask Surface	118 (244)
Inner Closure Lid Neutron Shield Bottom Neutron Shield	113 (235) 127 (261)
Impact Limiter Exposed Surface	80 (176)
Inner Closure Lid[1]	119 (246)
Outer Closure Lid[1]	101 (214)
Containment Baseplate[1]	131 (268)
Inner Closure Lid Seals[Note 1] Inner Closure Lid Inner Seal Vent/Drain Port Cover Plate Inner Seal	 114 (237) 114 (237)
Outer Closure Lid Seals[Note 1] Outer Closure Lid Inner Seal Access Port Plug Seal	 101 (214) 91 (196)
Aluminum Basket Shims	224 (435)
Impact Limiter Type 1 Crush Material Bottom • Bulk • Maximum Top • Bulk • Maximum	 76 (169) 83 (181) 76 (169) 99 (210)
Impact Limiter Type 2 Crush Material Bottom • Bulk • Maximum Top • Bulk • Maximum	 70 (158) 74 (165) 70 (158) 74 (165)
Note 1: The temperatures of lid seals relied upon for containment function are reported herein. The containment boundary seals are defined in Chapter 4, Tables 4.1.2 and 4.1.3.	

[1] In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported.

Table 3.1.2: HI-STAR 180 Maximum Operating Pressures

Condition	Absolute Pressure[1] kPa (psia)	Bulk Temperature °C (°F)
Fuel Storage Cavity MNOP [2] Initial Backfill (at 21.1°C (70°F)) Normal Condition With 3% Rods Rupture(Note 1)	 40 (5.8)[3] 67.6 (9.8) 89.6 (13.0)	 224 (435)
Inter-Lid Space	163.4 (23.7)	103 (217)

Note 1: In accordance with NUREG-1617 [3.1.3], 3% of the rods are assumed to be breached releasing 100% fill gas and 30% fission gas to containment.

1 The coincident gage pressure defined as pressure above 1 atm ambient pressure is below the gage pressure limit under normal transport specified in Table 2.1.1.

2 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.

3 The HI-STAR 180 helium backfill pressure limits are specified in Chapter 1. For a bounding evaluation the upperbound limit is used in the pressure calculations.

Table 3.1.3: Hypothetical Fire Accident Maximum HI-STAR 180 Temperatures

Material/Component	Initial Condition °C (°F)	During Fire °C (°F)	Post Fire Cooldown °C (°F)
Fuel Cladding	314 (597)	314 (597)	352 (666)
Fuel Basket	275 (527)	275 (527)	320 (608)
Containment Shell	182 (360)	183 (361)	228 (442)
Monolithic Shield Cylinder Neutron Shield	165 (329)	666 (1231)	666 (1231)
Cask Surface	118 (244)	687 (1269)	687 (1269)
Inner Closure Lid Neutron Shield Bottom Neutron Shield	113 (235) 127 (261)	268 (514) 168 (334)	268 (514) 280 (536)
Impact Limiter Exposed Surface	80 (176)	782 (1440)	782 (1440)
Inner Closure Lid*	119 (246)	125 (257)	191 (376)
Outer Closure Lid*	101 (214)	398 (748)	398 (748)
Containment Baseplate*	131 (268)	148 (298)	211 (412)
Inner Closure Lid Seals Inner Closure Lid Inner Seal Vent/Drain Port Cover Plate Inner Seal	 114 (237) 114 (237)	 133 (271) Note 1 117 (243)	 193 (379) Note 1 189 (372)
Outer Closure Lid Seals Outer Closure Lid Inner Seal Access Port Plug Seal	 101 (214) 91 (196)	 196 (385) Note 2 144 (291)	 233 (451) Note 2 261 (502)
Aluminum Basket Shims	224 (435)	224 (435)	270 (518)
Impact Limiter Type 1 Crush Material Bottom • Bulk • Maximum Top • Bulk • Maximum	 76 (169) 83 (181) 76 (169) 99 (210)	 495 (923) 713 (1315) 491 (916) 712 (1314)	 495 (923) 713 (1315) 491 (916) 712 (1314)
Impact Limiter Type 2 Crush Material Bottom • Bulk • Maximum Top • Bulk • Maximum	 70 (158) 74 (165) 70 (158) 74 (165)	 696 (1285) 782 (1440) 693 (1279) 782 (1440)	 696 (1285) 782 (1440) 693 (1279) 782 (1440)
Note 1: Bounding inner closure lid outer seal temperature conservatively tabulated. Note 2: Bounding outer closure lid outer seal temperature conservatively tabulated.			

* In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported.

Table 3.1.4: Maximum HI-STAR 180 Hypothetical Fire Accident Pressures

Condition	Absolute Pressure[1] kPa (psia)	Cask Cavity Bulk Temperature °C (°F)
No fuel rods rupture	73.8 (10.7)	270 (518)
With assumed 100% fuel rods rupture[2]	883.7 (128.2)[Note 1]	
Note 1: The HI-STAR 180 fuel cavity accident pressure bounds the inter-lid pressure.		

1 The coincident gage pressure defined as pressure above 1 atm ambient pressure is below the accident condition fuel cavity and inter-lid space gage pressure limits specified in Table 2.1.1.

2 Pressure analysis is based on NUREG 1617 [3.1.3] requirements: Release of 100% of the rods fill gas and 30% of the significant radioactive gases from ruptured rods.

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3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

3.2.1 Material Properties

Materials present in the HI-STAR 180 Packaging include structural steels, aluminum, lead, insulation, neutron shielding material (Holtite-B), neutron absorber (Metamic-HT), impact limiter crush material and helium. In Table 3.2.1, a summary of references used to obtain cask material properties for performing all thermal analyses is presented.

Thermal conductivity data of cask structural steels, neutron shielding materials, impact limiters, lead, insulation and helium are provided in Table 3.2.2. Thermal conductivities of fuel, aluminum basket shims and fuel basket (Metamic-HT) are provided in Tables 3.2.3, 3.2.4 and 3.2.5.

Surface emissivity data for key materials of construction are provided in Table 3.2.6. The emissivity properties of painted surfaces are generally excellent. Kern [3.2.5] reports an emissivity range of 0.8 to 0.98 for a wide variety of paints. In the HI-STAR 180 Package thermal analysis, an emissivity of 0.85[†] is applied to exterior painted surfaces. A theoretical bounding solar absorbtivity coefficient is applied to all exposed cask surfaces.

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

The HI-STAR 180 Package exposed surfaces heat transfer coefficient is calculated by accounting for both natural convection heat transfer and radiation. Natural convection from a heated horizontal cylinder depends upon the product of the Grashof (Gr) and Prandtl (Pr) numbers. Following the approach developed by Jakob and Hawkins [3.2.8], GrPr is expressed as $L^3 \Delta T\ Z$, where L is the diameter of the cask, ΔT is the cask surface-to-ambient temperature differential and Z is a parameter which is a function of air properties evaluated at the average film temperature. The temperature dependence of Z for air is provided in Table 3.2.9.

The long-term thermal stability and radiation resistance of Holtite-B has been confirmed through qualification testing and is archived in Reference [1.2.17]. The qualification test conditions exceed the Holtite-B thermal and radiation environment (gamma and neutron fluence) in the HI-STAR 180 cask. The Holtite-B thermal stability test temperature is the same as the design temperature reported in Table 1.2.16, is above the maximum operating temperature of Holtite-B (See Table 3.1.1). The Holtite-B radiation test exposures exceed the HI-STAR 180 5-year licensed life fluence under transport by a large factor (See Table 3.2.13). The qualification testing confirms that Holtite-B does not degrade at elevated temperatures and Holtite-B is unaffected by high neutron fluence and megarad gamma doses. Qualification testing shows cumulative weight loss is limited to 5 wt% for a minimum service life of 40 years.

[†] This is conservative with respect to prior cask industry practice, which has historically accepted higher emissivities. For example, the TN-32 TSAR (Docket 72-1021) uses 0.95 emissivity and HI-STAR SAR (Dockets 72-1008 and 71-9261) uses 0.85 emissivity for painted surfaces.

3.2.2 Component Specifications

The HI-STAR 180 Package materials and components which are required to be maintained below maximum pressure and temperature limits for safe operation, to ensure their intended functions, are summarized in Chapter 2 (Table 2.1.1) and Chapter 3 (Tables 3.2.10, 3.2.11 and 3.2.12). These materials and components do not degrade under exposure to extreme low temperatures. As defined by transport regulations, the HI-STAR 180 Package cold service temperature is conservatively limited to –40°C (-40°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 metallic seals ensure leak tightness of the closure plates if the manufacturer's recommended design temperature limits are not exceeded. Integrity of SNF during transport requires demonstration of HI-STAR 180 Package fuel cladding temperatures below regulatory limits for Moderate Burnup Fuel (MBF) and High Burnup Fuel (HBF). In the HI-STAR 180 thermal evaluation, the cladding temperature limits of ISG-11, Rev. 3 [3.3.3] 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) 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 Package's thermal performance under hypothetical accident conditions, lowerbound material temperature limits for short-duration events are defined in Tables 3.2.10, 3.2.11 and 3.2.12.

[†] Neutron absorber materials are manufactured using B_4C and aluminum. B_4C is a refractory material that is unaffected by high temperatures and aluminum is solid at temperatures in excess of 538°C (1000°F).

Table 3.2.1: Summary of HI-STAR Packaging Materials Thermal Property References

Material	Emissivity	Conductivity	Density	Heat Capacity
Helium	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Zircaloy Cladding	EPRI [3.2.3]	NUREG [3.2.6]	Rust [3.2.4]	Rust [3.2.4]
UO_2	Not Used	NUREG [3.2.6]	Rust [3.2.4]	Rust [3.2.4]
Carbon Steel	Kern [3.2.5]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Aluminum Basket Shims	Test Data [1.2.27]	ASM [3.2.14]	ASM [3.2.14]	ASM [3.2.14]
Holtite-B	Not Used	Table 1.2.16 (Note 2)		Polymer Handbook [3.2.15]
Metamic-HT	Test Data [1.2.27]	Test Data [1.2.27]	Test Data [1.2.27]	Test Data [1.2.27]
Impact Limiter Crush Material	NA	Note 1	Table 2.2.10	ASME [3.2.7]
Air	NA	Incropera [3.2.11]	Ideal Gas Law	Incropera [3.2.11]
Lead	NA	Handbook [3.2.2]	Handbook [3.2.2]	Handbook [3.2.2]
Insulation	Table 2.2.10			

Note 1: Nominal values of thermal conductivity are specified in Table 3.2.2.
Note 2: Thermo-physical properties supported by Holtite-B Sourcebook [1.2.17] defined in cited table.

Table 3.2.2: Thermal Conductivity of HI-STAR 180 Cask Materials

Material	@ 93.3ºC (200°F) W/m-ºK (Btu/ft-hr-°F)	@ 232.2ºC (450°F) W/m-ºK (Btu/ft-hr-°F)	@ 371.1ºC (700°F) W/m-ºK (Btu/ft-hr-°F)
Helium	0.1686 (0.0976)	0.2227 (0.1289)	0.2722 (0.1575)
Carbon Steel	47.7 (27.6)	45.5 (26.3)	41.5 (24)
Cryogenic Steel	41.1 (23.8)	41.0 (23.7)	38.5 (22.3)
Impact Limiters[1]	[Withheld in Accordance with 10CFR 2.390]		
Holtite-B[1]	Table 1.2.16		
[Withheld in Accordance with 10CFR 2.390]	[Withheld in Accordance with 10CFR 2.390]		
Lead	30 (17.3)		
Air	0.03 W/m-ºK@350ºK 0.0373 W/m-ºK@450ºK 0.0439 W/m-ºK@550ºK 0.0497 W/m-ºK@650ºK		
Note 1: Sensitivity studies show that fuel, containment seals and containment boundary temperatures are insensitive to wide band thermal conductivity variations of impact limiter crush material [3.4.1]. Accordingly nominal properties are defined and adopted in the SAR.			

[1] Reasonably bounding values under normal and fire accident conditions are tabulated herein. During post-fire cooldown conductivity is understated (See Table 3.4.1).

Table 3.2.3: Thermal Conductivity of Fuel Assembly Materials

Fuel Cladding		Fuel (UO_2)	
Temperature ºC (°F)	Conductivity W/m-ºK (Btu/ft-hr-°F)	Temperature ºC (°F)	Conductivity W/m-ºK (Btu/ft-hr-°F)
200 (392)	14.3 (8.28)	37.8 (100)	6.02 (3.48)
300 (572)	15.1 (8.76)	231.1 (448)	6.02 (3.48)
400 (752)	16.6 (9.60)	298.9 (570)	5.60 (3.24)
500 (932)	18.06 (10.44)	422.8 (793)	3.94 (2.28)

Table 3.2.4: Thermal Conductivity of Aluminum (Basket Shims Material)

Material	Conductivity W/m-ºK (Btu/ft-hr-°F)
[Withheld in Accordance with 10CFR 2.390]	120 (69.3)

Table 3.2.5: [Withheld in Accordance with 10CFR 2.390]

Table 3.2.6: [Withheld in Accordance with 10CFR 2.390]

Table 3.2.7: [Withheld in Accordance with 10CFR 2.390]

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Table 3.2.8: Helium and Air Viscosity Variation with Temperature[1]

Helium	
Temperature (°F)	Viscosity (Micropoise)
167.4	220.5
200.3	228.2
297.4	250.6
346.9	261.8
463.0	288.7
537.8	299.8
737.6	338.8
Air	
171	208.2
351	250.7
531	288.4
711	322.5

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

Table 3.2.9: Variation of Natural Convection Properties Parameter "Z" for Air with Temperature[1]

Temperature (°F)	Z (ft^{-3} $°F^{-1}$)
40	2.1×10^6
140	9.0×10^5
240	4.6×10^5
340	2.6×10^5
440	1.5×10^5

[1] Obtained from Jakob and Hawkins [3.2.8].

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Table 3.2.10: HI-STAR 180 Structural Materials Temperature Limits

	Material	Normal Condition Temperature Limits[a] °C (°F)	Short Term Operations & Accident Temperature Limits[a] °C (°F)
Fuel Basket	Metamic-HT	400 (752)[b]	500 (932)[b]
Basket Shims	Aluminum Alloy	260 (500)[f]	371 (700)[e]
Containment Shell	Cryogenic Steel	204 (400)[c]	371 (700)[d]
Baseplate and Closure Flange	Cryogenic Steel	204 (400)[c]	371 (700)[d] (Structural Accidents) 420 (788) (Fire Accident)[e]
Inner and Outer Closure Lids	Cryogenic Steel	204 (400)[c]	371 (700) (Structural Accidents)[d] 420 (788) (Fire Accident)[e]
Monolithic Shield Surface	Carbon Steel	204 (400)[c]	371 (700) (Structural accidents)[d] 788 (1450) (Fire accident)[e]

Notes

(a) The ASME Code requires that the vessel design temperature be established with appropriate consideration of internal or external heat generation. In accordance with ASME Section III Code, Para. NCA-2142 the design temperature is set at or above the structural members' section temperature defined as the maximum through thickness mean metal temperature of the part under consideration. The section temperatures of the structural members shall not exceed the temperatures limits tabulated herein.
(b) The temperature limits of Metamic-HT are bounded by the maximum material qualification test temperatures [1.2.27].
(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 and Aluminum Alloys.
(f) Bounded by Table 2.2.9.

Table 3.2.11: Fuel Cladding Temperature Limits

Component	Material	Normal Condition Temperature Limits ºC (ºF)	Short Term Operations & Accident Temperature Limits ºC (ºF)
Fuel Cladding (Moderate Burnup Fuel)	See Note 1	400 (752)	570 (1058)
Fuel Cladding (High Burnup Fuel)	See Note 1	400 (752)	400 (752) (Short Term Operations) 570 (1058) (Accident)

Notes

1. Fuel cladding temperature limits are applicable to all cladding materials approved for power generation [3.3.3].

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Table 3.2.12: HI-STAR 180 Component Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Short Term Operations & Accident Temperature Limits °C (°F)
Inner and Outer Closure Lid Seals	Note 1	200 (392)	371 (700)
Closure Lids Port Cover and Port Plug Seals	Note 1	200 (392)	371 (700)
Neutron Shield	Holtite-B	[Withheld in Accordance with 10CFR 2.390]	Note 2
Impact Limiter Bulk	[Withheld in Accordance with 10CFR 2.390]	Table 2.2.10	NA[Note 3]
Gamma Shield	Lead	316 (600)	316 (600)[Note 4]

Notes

[Withheld in Accordance with 10CFR 2.390]

Table 3.2.13: [Withheld in Accordance with 10CFR 2.390]

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3.3 THERMAL EVALUATION UNDER NORMAL CONDITIONS OF TRANSPORT

The HI-STAR 180 Package is designed to safely dissipate heat under passive conditions (no wind). Under normal transport conditions, the cask contents (fuel basket, fuel and Aluminum basket shims) rest on solid surfaces. Direct contact between the cask and its contents enhances heat dissipation. Nevertheless to engineer a robust measure of conservatism a hypothetical bounding configuration (levitating fuel basket) is assumed. Under this assumption, the fuel, fuel basket, basket shims and cask are in concentric alignment (i.e. they do not make physical contact).

The HI-STAR 180 Package consists of two distinct fuel basket geometries, the F-32 and F-37 designs engineered to hold 32 and 37 PWR fuel assemblies. The cask is rated for the same heat load for both basket types. Apart from their storage capacity, the two fuel basket designs are similar with respect to the basket material (Metamic-HT), basket construction (interlocking honeycomb panels) and thickness of the Metamic-HT plates. From a thermal-hydraulic standpoint both the two fuel baskets give similar cask and fuel temperatures. However as somewhat higher temperatures are reached in the F-32 basket (See Table 3.3.4) an F-32 equipped HI-STAR 180 Package is evaluated for compliance with transport regulations.

The HI-STAR 180 Package thermal analysis is performed using the FLUENT CFD code [3.3.2]. FLUENT is a well-benchmarked CFD code validated by the code developer with an array of theoretical and experimental works from technical journals. Additionally, Holtec has Q.A. validated FLUENT within the company's quality assurance program and confirmed the code's capability to reliably predict temperature fields in dry storage [3.3.4] using independent full-scale test data from a loaded cask [3.2.3]. The code has a long history of usage for obtaining NRC approval of fuel storage in transport and storage casks. A list of dockets wherein USNRC relied on FLUENT thermal models for cask certification is given in Table 3.3.3.

The HI-STAR 180 cask is designed to allow fuel loading under uniform and regionalized loading conditions. The aggregate cask decay heat under uniform or regionalized storage is limited to 32 kW. Under uniform loading, every storage cell is loaded with fuel emitting heat at the maximum permissible level. Under regionalized loading, the fuel storage cells (Figures 1.2.3 and 1.2.4) are grouped in eight regions (Tables 1.2.6a and 1.2.6b) and regionalized fuel decay heat limits are defined in Tables 1.2.8 and 1.2.9 under an array of fuel loading patterns A through F (F-32 basket) and A through D (F-37 basket). As explained next, the fuel loading patterns optimize shielding and thermal design of the HI-STAR 180 Package. The fuel decay heat limits are defined to permit High Heat High Gamma dose (HHHG) UO_2 fuel storage in the shielded interior storage locations and High Heat Low Gamma dose (HHLG) MOX fuel (upto 4 fuel assemblies) in the peripheral Region 1 basket locations. To define a limiting pattern, an array of bounding fuel storage configurations is analyzed using 3D thermal models of the F-32 and F-37 baskets. The maximum permissible cask heat load (Tables 1.2.3, 1.2.8 and 1.2.9) is assumed in the pattern screening analyses. The bounding configurations are constructed by conservatively assuming the interior cells are populated with HHHG fuel and the Region 1 peripheral fuel storage locations are populated with HHLG fuel. The balance of cask decay heat is uniformly distributed in the remaining peripheral cells. The results of pattern screening evaluation are presented in Table 3.3.4. As highlighted in Table 3.3.4 the highest cladding temperatures are reached in regionalized heat load distribution corresponding to F-32 fuel loading patterns A and B[10]. For the HI-STAR 180 thermal evaluation, the heat distribution of one bounding pattern A in the F-32 fuel basket is analyzed in detail. Modeling details of the principal thermal transport mechanisms are provided in the following.

Fuel Region Effective Planar Conductivity

In the HI-STAR 180 thermal modeling, the cross section bounded by the inside of a storage cell is replaced with an "equivalent" square section characterized by an effective thermal conductivity in the planar and axial directions. 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 equivalent planar conductivity of the storage cell space is obtained using a 2D conduction-radiation model of [Withheld in Accordance with 10CFR 2.390]. The fuel geometry is constructed using the ANSYS code [3.3.1]. The finite-element model, consisting of an array of fuel rods with helium gaps between them residing in a storage cell is illustrated in Figure 3.3.2. In the axial direction, an area-weighted average of the cladding and helium conductivities is computed.

The fuel region effective conductivity is defined as the calculated equivalent conductivity of the fuel storage cell by including conduction and radiation heat transfer. Because radiation is proportional to the fourth power of absolute temperature, the effective conductivity is a strong function of temperature. The ANSYS finite element model is used to characterize fuel resistance at several representative storage cell temperatures and the effective thermal conductivity as a function of temperature obtained and presented in Table 3.3.1.

Heat Rejection from Cask and Impact Limiter Surfaces

The exposed surfaces of the HI-STAR 180 Package dissipate heat by radiation and external natural convection heat transfer. [

[Withheld in Accordance with 10CFR 2.390]

[10] The heat load distribution in fuel loading patterns A and B are identical.

[Withheld in Accordance with 10CFR 2.390]

]

Determination of Solar Heat Input

The intensity of solar radiation incident on exposed surfaces depends on a number of time varying parameters. The solar heat flux strongly depends upon the time of the day as well as on latitude and day of the year. Also, the presence of clouds and other atmospheric conditions (dust, haze, etc.) can significantly attenuate solar intensity levels. In the interest of conservatism, the solar attenuation effects of dust, haze, angle of incidence and latitude are neglected.

The insolation energy absorbed by the HI-STAR 180 Package is the product of incident insolation and the package absorbtivity. For conservatism theoretical bounding absorbtivity equal to unity is assumed for the cask surfaces. For polished surfaces solar absorbtivity obtained from robust sources is applied (See Table 3.2.6). The HI-STAR 180 Package thermal analysis is based on 12-hour daytime insolation specified in 10CFR71. During normal transport conditions, the HI-STAR Package is cyclically subjected to solar heating during the 12-hour daytime period followed by cooling during the 12-hour nighttime. However, due to the large mass of metal and the size of the Package, the dynamic time lag exceeds the 12-hour heating period. Accordingly, the HI-STAR Package model includes insolation at exposed surfaces averaged over a 24-hour time period. The 10CFR71 12-hour insolation is summarized in Table 3.3.2.

[Withheld in Accordance with 10CFR 2.390]

[Withheld in Accordance with 10CFR 2.390]

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The HI-STAR 180 Package thermal analysis is based on a 3D thermal model of the HI-STAR 180 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.

[Withheld in Accordance with 10CFR 2.390]

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[Withheld in Accordance with 10CFR 2.390]]
Sectional and isometric views of the HI-STAR 180 thermal model are presented in Figures 3.3.3 and 3.3.4, respectively.

[Withheld in Accordance with 10CFR 2.390]

]

To this model insolation heat (Table 3.3.2) is applied on all external surfaces of the HI-STAR 180 Package assuming 100% absorption. Natural convection and radiation from exposed surfaces is enabled to model heat dissipation to ambient air. Using this model, steady state HI-STAR 180 Package temperatures in still air for the limiting decay heat distribution defined in Section 3.3 are computed and evaluated in the next section.

3.3.1 Heat and Cold

3.3.1.1 Maximum Temperatures

As required by transport regulations the HI-STAR 180 Package is evaluated under hot ambient conditions defined in 10CFR71. These conditions are 38°C (100°F) ambient temperature, still air and insolation (Table 3.3.2). To ensure a bounding evaluation, design heat load and a limiting heat load distribution (See Section 3.1.2) are assumed. Under this array of adverse conditions, the maximum steady state temperature of the cask structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3 and results reported in Subsection 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature is well within the ISG-11, Rev. 3 temperature limit (Table 3.2.11).

- The maximum temperature of fuel basket is well within the design temperatures (Table 3.2.10).

- The maximum temperatures of the containment boundary and lid seals (Table 3.1.1) are well below the design temperatures (Tables 3.2.10 and 3.2.12, respectively).

- The maximum temperatures of the aluminum basket shims (Table 3.1.1) are well below the design temperature limits (Table 3.2.10).

- The neutron shielding material (Holtite-B) temperature (Table 3.1.1) is well within its design limit (Table 3.2.12).

The temperatures of the HI-STAR 180 Package during normal transport are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The above observations lead us to conclude that the temperature field in the HI-STAR 180 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 180 Package is conducive to safe transport of spent nuclear fuel.

3.3.1.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR 180 Package is evaluated for a cold environment at -40°C (-40°F). The HI-STAR Package design does not require minimum decay heat load restrictions for transport. Therefore zero decay heat load and no solar input are bounding conditions for cold evaluation. Under these conditions, the temperature distribution in the HI-STAR 180 Package uniformly approaches the cold ambient temperature. All HI-STAR 180 Package materials of construction satisfactorily perform their intended function in the transport mode at this minimum postulated temperature condition. Evaluations in Chapter 2 demonstrate the acceptable structural performance of the cask materials at low temperature. The HI-STAR 180 shielding and criticality materials (Holtite-B and Metamic-HT) are unaffected by exposure to cold temperatures.

3.3.1.3 Personnel Barrier Evaluation

As defined in Chapter 1, personnel barrier is an open lattice cage placed around the HI-STAR 180 cask to prevent access to the hot surfaces (See Figure 1.3.2). The open structure ensures that movement of ambient air is not unduly restricted and the cask temperatures are not impacted. To provide an additional layer of assurance a thermal calculation was performed assuming bounding personnel barrier characteristics defined in Table 3.3.7. The thermal calculation deployed the same 3D HI-STAR 180 thermal model articulated in this section except for the inclusion of an enveloping porous cylinder having the flow resistance characteristics of the personnel barrier defined in Table 3.3.7. The cask temperatures with and without the personnel barrier are tabulated in Table 3.3.8. The results show that the cask temperatures are essentially unchanged by the deployment of the personnel barrier.

3.3.1.4 Basket Shims Gap Sensitivity Evaluation

[Withheld in Accordance with 10CFR 2.390]

3.3.1.5 Basket Shims Creep Evaluation

Basket shims creep is evaluated in Structural Evaluation Chapter 2, Section 2.2.

3.3.2 Maximum Normal Operating Pressure (MNOP)

The HI-STAR 180 cavity is de-moisturized and backfilled with dry helium after fuel loading and prior to lid closures. The MNOP evaluation considers the following source of gases:

<u>Initial Backfill:</u>
The HI-STAR 180 cavity is assumed to be backfilled to the maximum permissible pressure limit (Table 1.2.1).

<u>Water Vapor:</u>
The HI-STAR 180 cavity and its stored fuel are de-moisturized to a very low vapor pressure (less than 3 torr). As this pressure is dwarfed by the helium backfill pressure it is neglected in the MNOP calculations.

<u>Helium from radioactive decay:</u>
The helium from radioactive decay is dwarfed by the generation of fission products during power generation. These products are assumed to be released into the HI-STAR 180 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 180 Package uses non-reactive materials of construction. Generation of flammable gases is not credible.

<u>Fuel Rod Failures:</u>
In accordance with NUREG 1617 [3.1.3], 3% of the fuel rods are assumed to be breached.

During normal transport conditions, the gas temperature within the cavity rises to its maximum operating temperature as determined by the thermal evaluation described earlier. The gas pressure inside the cavity increases monotonically with rising temperature. The pressure rise is determined using the Ideal Gas Law.

The HI-STAR 180 Maximum Normal Operating Pressure (MNOP) is calculated for the §71.71(c)(1) heat condition (38ºC (100ºF) 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 MNOP is computed and reported in Subsection 3.1.4. The HI-STAR 180 cavity pressures presented in Table 3.1.2 show that the MNOP is well below the design pressure of the containment boundary (Table 2.1.1).

The evaluation of pressures and temperatures reached during transport provides reasonable assurance of safe transport of spent nuclear fuel packaged in a HI-STAR 180 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.

3.3.3 <u>Time-to-Boil Limits</u>

In accordance with NUREG-1536 [3.1.2], water inside the HI-STAR 180 cavity is not permitted to boil during fuel loading operations. In this manner operational concerns due to vapor formation and two-phase conditions are avoided. To meet this requirement time limits are defined herein for completion of wet operations upon removal of a loaded HI-STAR 180 cask from the pool.

When the HI-STAR 180 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 180. To ensure a bounding heat-up rate determination, the thermal model assumes the following:

i. Design heat input from the fuel assemblies is applied to the cask.
ii. Heat dissipation to air by natural convection and radiation from the cask is neglected.
iii. Water mass in the cask cavity is 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) (Table 1.2.3)
C_h = thermal inertia of the loaded cask, J/^{o}C (Btu/°F)
T = cask temperature, ^{o}C (°F)
t = time after loaded cask is removed from the pool, 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^{o}C (212^{o}F) at the water surface)
$T_{initial}$ = initial cask temperature (pool temperature during in-pool fuel loading operations)

Table 3.3.5 provides a summary of t_{max} at several representative $T_{initial}$ temperatures.

3.3.3.1 <u>Additional Measures During Extended Duration Operations</u>

In the unlikely event that the maximum allowable time provided in Table 3.3.5 is found to be insufficient to complete wet transfer operations, forced water circulation must be provided to remove the decay heat from the cask cavity. During forced circulation relatively cooler water enters the inner closure lid drain port connection and heated water exits from the vent port. The minimum water flow rate required to maintain the water temperature below boiling is determined as follows:

$$M_W = \frac{Q_c}{C_{pW}(T_{max} - T_{in})}$$

where:

Q_c = cask decay heat, W (Btu/hr)
M_W = minimum water flow rate, kg/s (lb/hr)
C_{pw} = water heat capacity, J/kg-°C (Btu/lb-°F)
T_{max} = cask user selected maximum cavity water temperature, °C (°F) (must be less than 100°C (212°F))
T_{in} = water supply temperature, °C (°F)

3.3.4 Fuel Temperatures During Moisture Removal Operations

The initial loading of SNF in the HI-STAR 180 requires that the water within the cask cavity be drained and replaced with helium. This operation may be carried out using the conventional vacuum drying approach or optionally forced helium dehydration. Vacuum drying is evaluated in Subsection 3.3.4.1 wherein removal of bulk and residual moisture from the HI-STAR 180 is accomplished by evacuating the cavity after draining the cask. Fuel drying by forced flow helium drying process is articulated in Subsection 3.3.4.2.

3.3.4.1 Vacuum Drying

Prior to the start of the HI-STAR 180 draining operation, both the cask cavity is flooded with water. The presence of water in the cask cavity ensures that the fuel cladding temperatures are lower than design basis limits by large margins. As the heat generating active fuel length is uncovered during the draining operation, the fuel and basket mass undergo a gradual heat up from the initially cold conditions when the heated surfaces were submerged under water. Following the draining operation the HI-STAR 180 cavity is lined up to vacuum pump and the cavity pressure substantially lowered to facilitate fuel drying. To bound the fuel temperatures during vacuum drying a thermal model is conservatively articulated with the following assumptions:

1) Design heat load and a bounding decay heat distribution pattern defined in Section 3.3 are assumed.
2) The cask and the loaded fuel are assumed to have reached asymptotic steady state temperatures.
3) The cask bottom is assumed to be insulated.
4) The cask is assumed to be placed in still air and hot (38°C (100°F)) ambient temperature.

The results of thermal evaluation excerpted from supporting HI-STAR 180 Calculation Package [3.4.1] are presented in Table 3.3.6. The results show that the maximum fuel cladding temperature is below the ISG 11 mandated temperature limits of moderate burnup fuel with robust margins. The result supports vacuum drying of moderate burnup fuel without time limits. Vacuum drying of high burnup fuel requires evaluation of suitable time limits as articulated in Section 3.3.5.

3.3.4.2 Forced Helium Dehydration

Demoisturization of the HI-STAR 180 cask loaded with high burnup fuel is conducted by the Forced Helium Dehydration (FHD) system. The FHD is a conventional, closed loop dehumidification system consisting of a condenser, a demoisturizer, a compressor, and a pre-heater. The FHD is utilized to extract moisture from the HI-STAR 180 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 the peak cladding temperatures 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 180 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. As a result, the peak fuel cladding temperatures will approximate the values reached during normal transport as described elsewhere in this chapter.

3.3.5 Cyclic Vacuum Drying

[Withheld in Accordance with 10CFR 2.390]

[Withheld in Accordance with 10CFR 2.390]

]

3.3.6 Quiver Evaluation

[

[Withheld in Accordance with 10CFR 2.390]

]

3.3.7 Partial Cask Loading and Dummy Fuel

HI-STAR 180 fuel baskets as specified in Table 1.2.3a are permitted for loading with empty fuel storage locations. These may be optionally loaded with dummy fuel[11] to meet weight requirements. Partially loaded casks are thermally bounded by full cask under design basis thermal payloads as empty cells do not generate heat and in this manner do not add to the thermal burden of the fuel basket.

11 Dummy Fuel refers to weight ancillary that emulates the weight and exterior dimensions of a fuel assembly and made of stainless steel.

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Table 3.3.1: [Withheld in Accordance with 10CFR 2.390] **Fuel Effective Conductivities**

Temperature °C (°F)	Conductivity W/m-°C (Btu/ft-hr-°F)
Planar Conductivity	
93 (200)	0.443 (0.256)
232 (450)	0.758 (0.438)
371 (700)	1.198 (0.692)
Axial Conductivity	
93 (200)	1.187 (0.686)
232 (450)	1.325 (0.765)
371 (700)	1.494 (0.863)

Table 3.3.2: 10CFR71 Insolation Data

Surface Type	12-Hour Insolation	
	(g-cal/cm^2)	(W/m^2)
Horizontally Transported Flat Surfaces		
- Base	None	None
- Other Surfaces	800	774.0
Non-Horizontal Flat Surfaces	200	193.5
Curved Surfaces	400	387.0

Table 3.3.3: History of FLUENT for Securing Transport and Storage Cask Certifications

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

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Table 3.3.4: [Withheld in Accordance with 10CFR 2.390]

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Table 3.3.5: [Withheld in Accordance with 10CFR 2.390]

Table 3.3.6: Maximum Cladding Temperature Under Vacuum Drying Operation

Temperature, ^{o}C (^{o}F)	Temperature Limit, ^{o}C (^{o}F)**Note 1**
485 (905)Note 2	570 (1058)

Notes:
(1) ISG 11, Rev. 3 temperature limits of Moderate Burnup Fuel under vacuum drying operations is tabulated herein.
(2) Computed cladding temperature exceeds ISG 11, Rev. 3 mandated High Burnup Fuel temperature limits. Demoisturization requires following the Cyclic Vacuum Drying method articulated in Section 3.3.5 or optionally using Forced Helium Dehydration. See Section 3.3.4.2.

Table 3.3.7: [Withheld in Accordance with 10CFR 2.390]

Table 3.3.8: [Withheld in Accordance with 10CFR 2.390]

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Table 3.3.9: [Withheld in Accordance with 10CFR 2.390]

Table 3.3.10: [Withheld in Accordance with 10CFR 2.390]

Table 3.3.11: [Withheld in Accordance with 10CFR 2.390]

Table 3.3.12: [Withheld in Accordance with 10CFR 2.390]

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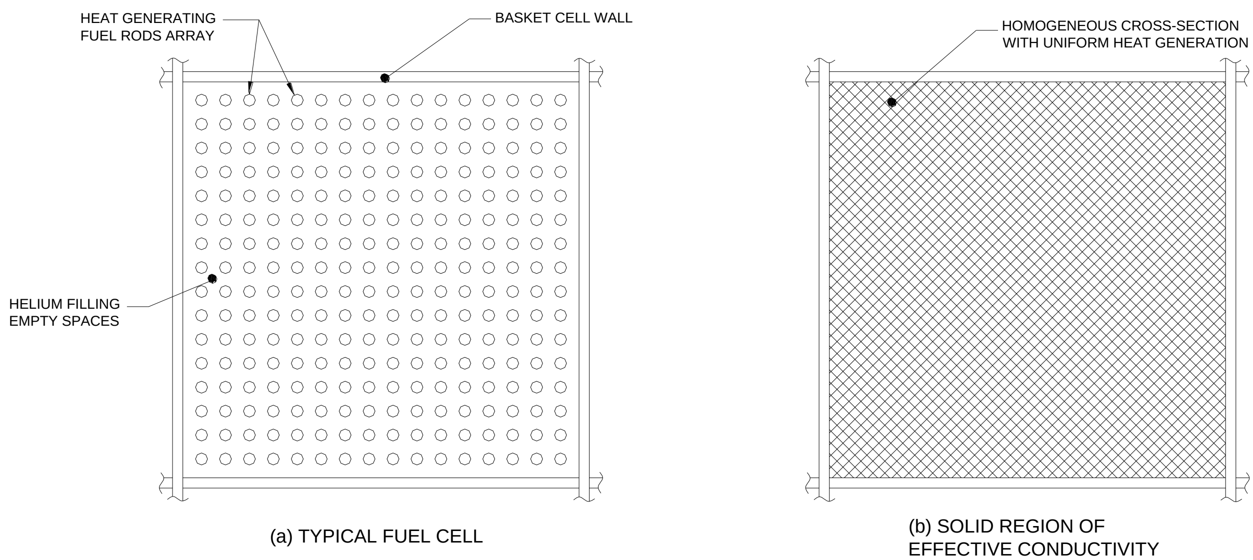

FIGURE 3.3.1: HOMOGENIZATION OF THE STORAGE CELL CROSS-SECTION

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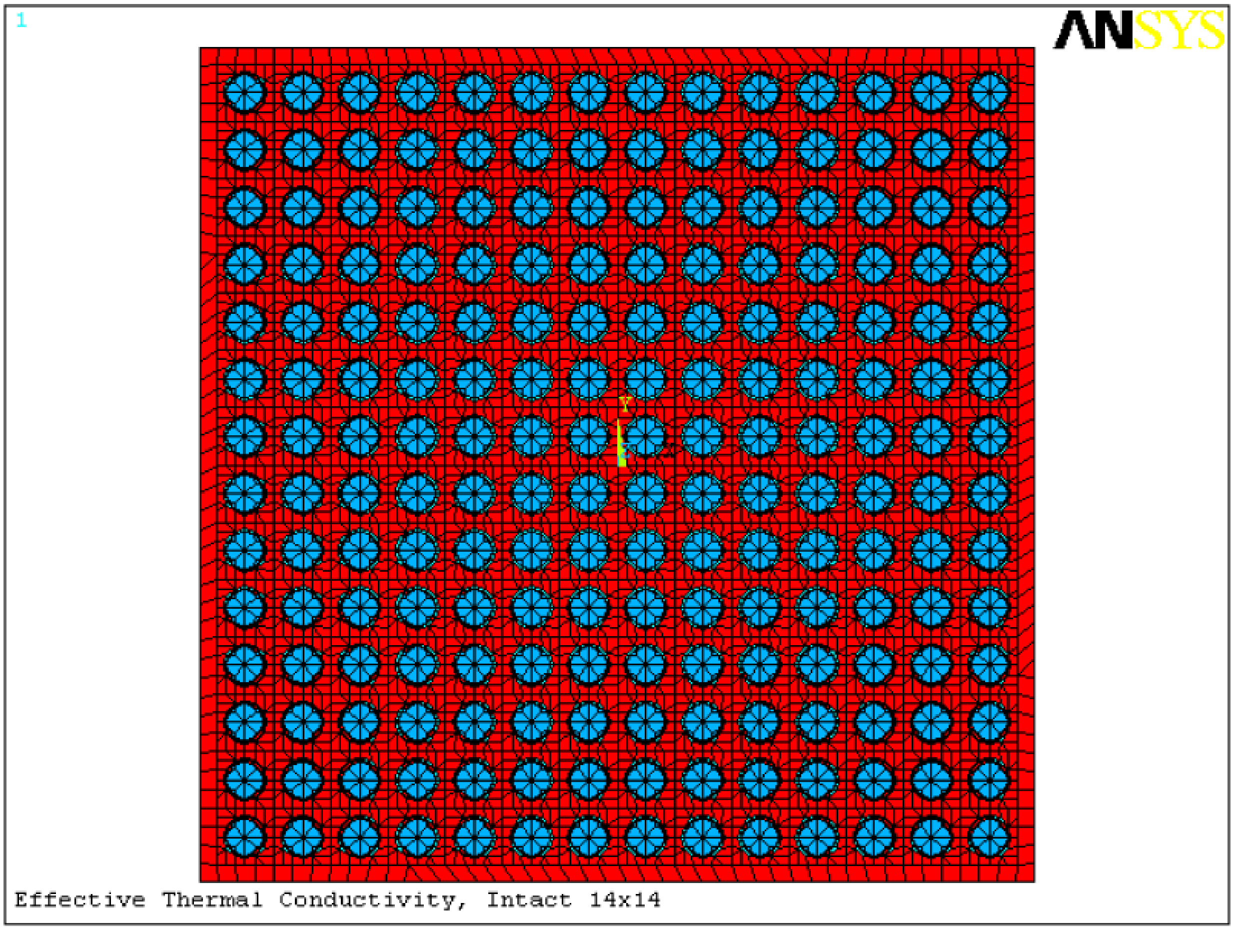

FIGURE 3.3.2: FINITE ELEMENT MODEL OF THE PWR 14x14 FUEL ASSEMBLY

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FIGURE 3.3.3: [Withheld in Accordance with 10CFR 2.390]

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FIGURE 3.3.4: [Withheld in Accordance with 10CFR 2.390]

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3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT

As mandated by 10 CFR Part 71 requirements, the HI-STAR 180 Package under the limiting F-32 fuel basket thermal loading is subjected to a sequence of hypothetical accidents. The objective is to determine and assess the cumulative damage sustained by the package. The accident scenarios specified in order are: (1) a 9 m (30 foot) free drop onto an unyielding surface; (2) a 1 m (40-inch) drop onto a mild steel bar; (3) exposure to a 30-minute fire at 802ºC (1475°F) and (4) immersion under a 0.9 m (3 ft) head of water. The initial conditions for the fire accident specify steady state at an ambient temperature between -40^{0}C (-40^{0}F) and 38ºC (100°F). In the HI-STAR 180 Package hypothetical fire accident evaluation, insolation with a theoretical bounding absorbtivity equal to unity is applied before and after fire. During fire, insolation is neglected because insolation flux is grossly bounded by the fire heat flux and the cask is assumed to be engulfed by the fire which will block much of the solar radiation. The effects of the accidents (1), (2) and (4) are evaluated in Chapter 2. In this section, the effects of accident (3) are evaluated. The initial condition prior to fire accident is the hot ambient environment for normal transport and design heat load (See Section 3.3). The fire accident evaluation is performed assuming an adverse combination of factors that overestimate heat input during fire followed by an underestimation of heat rejection to the environment after the fire.

During drop and puncture accidents some neutron shield [Withheld in Accordance with 10CFR 2.390] can rupture thereby reducing the ability of the package to reject heat after the fire. To bound this hypothetical accident condition, the neutron shield thermal conductivity is assumed during fire to maximize heat input and thermal conductivity of air is applied to the neutron shield pockets during post-fire cooldown to minimize post-fire cooling. During drop events the honeycomb 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. Because of these reasons the global thermal performance of the HI-STAR 180 cask is unaffected by the drop events.

During fire some portions of the neutron shield will be exposed to high temperatures. In computing the heat input to the package during fire the undegraded neutron shield thermal conductivity is assumed. During the post-fire cooldown phase, thermal conductivity of air is applied to the neutron shield [Withheld in Accordance with 10CFR 2.390] to minimize heat dissipation and thermal inertia properties of undegraded neutron shield material is assumed to maximize fire accumulated thermal energy. During fire a 10 CFR Part 71 mandated cask surface absorbtivity is assumed to maximize radiant heat input to the cask.

During fire the resin bonding the impact limiter's corrugated aluminum honeycomb layers is destroyed thus severely degrading the normal-to-layers direction conductivity. In the interest of conservatism the undegraded honeycomb conductivity is assumed during fire to maximize heat input and an opposite assumption is used to minimize post-fire heat dissipation by applying air conductivity for the normal-to-layers direction (see Table 3.4.1).

The temperature history of the HI-STAR Package is monitored during the 30-minute fire and during post-fire cooldown for a sufficient length of time for the cask and fuel to reach maximum temperatures. The impact of transient temperature excursions on HI-STAR 180 Package materials is evaluated.

3.4.1 Initial Conditions

In accordance with transport regulations the HI-STAR 180 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 180 bounding steady state temperature distribution under hot ambient conditions reported in Section 3.1.3 is adopted as the initial condition for fire accident evaluation.

3.4.2 Fire Conditions

As required by transport regulations the HI-STAR 180 Package is evaluated under an all-engulfing fire at 802°C (1475°F) lasting for 30 minutes (§10CFR71.73(c)(4)). The regulations specify a minimum fire emissivity (0.9) and lowerbound package absorbtivity (0.8) for hypothetical accident evaluation. In the HI-STAR 180 fire accident evaluation, the minimum specified emissivity and conservatively postulated absorbtivity are adopted.

Heat input to the HI-STAR 180 Package while engulfed in a fire is from a combination of radiation and forced convection heat transfer. This can be expressed by the following equation:

$$q_F = h_{fc}\,(T_F - T_s) + \sigma\alpha\,\varepsilon\,[T_F^4 - T_s^4]$$

where:

- q_F = fire heat input, W/m^2 (Btu/ft^2-hr)
- T_F = fire condition temperature 1075°K (1935°R)
- T_S = package surface temperature °K (°R)
- h_{fc} = forced convection heat transfer coefficient W/m^2-°K [Btu/ft^2-hr-°F] (See Table 3.4.3)
- ε = flame emissivity (0.9 (min.) in accordance with transport regulations)
- α = package absorbtivity (0.8 (min.) in accordance with transport regulations)
- σ = Stefan-Boltzmann Constant 5.67x10^{-8} W/m^2-°K^4 (0.1714×10^{-8} Btu/ft^2-hr-°R^4)

For conservatism, the reported Sandia large pool fires forced convection heat transfer coefficient (See Table 3.4.3) is adopted. In Table 3.4.1 the principal fire accident assumptions are summarized.

The HI-STAR 180 package fire accident analysis is based on a 3D thermal model that properly accounts for radiation, conduction and natural convection modes of heat transfer. The thermal model incorporates several conservative assumptions listed below.

1. The undegraded neutron shield conductivity is assumed during fire to maximize heat input to the cask body.
2. To maximize initial temperatures, the limiting decay heat pattern defined in Section 3.3 and bounding (steady state) temperatures are assumed.
3. To maximize the rate of heat input from the ends during fire the undegraded conductivity

of impact limiters aluminum honeycomb material is assumed (See Table 3.4.1).
4. To maximize fire heating of the cask, an all-engulfing fire, a high flame emissivity (ε = 0.9) and a theoretically bounding package absorbtivity are assumed.
5. To minimize heat dissipation from the cask during post fire cooldown, the thermal conductivity of air is applied to the neutron shield [Withheld in Accordance with 10CFR 2.390] is assumed.
6. The Sandia laboratories reported forced convection heat transfer during large pool fires (See Table 3.4.3) is adopted.
7. To maximize fire accumulated thermal energy the thermal inertia properties of undegraded neutron shield and Aluminum honeycomb materials are assumed during post fire cooldown.

Using this model, the transient heat up of the cask and it's internals during the 30-minute fire is computed. At the end of the fire the hot ambient condition is restored and a post fire cooldown of the cask for a period of 22 hrs is computed. As shown in Figure 3.4.1, this period is sufficient for the cask internals (principally the SNF) to reach their maximum temperatures and begin to recede. The results of the analysis are evaluated in the next section.

3.4.3 Maximum Temperatures and Pressures

3.4.3.1 Maximum Temperatures

The HI-STAR 180 Package is evaluated under a hypothetical fire accident at 802^{o}C (1475^{o}F) lasting for 30 minutes. To ensure a bounding evaluation, the limiting decay heat pattern (See Subsection 3.1.2) and hot initial conditions are assumed. Under this array of adverse conditions, the maximum temperatures reached in the cask structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3, applying the fire accident thermal loads and computing the time-dependent response of the package to the 30-minute fire followed by a post fire cooldown for a sufficient duration to allow the cask and its contents to reach their maximum temperatures. The results of the critical components (cladding, basket, seals and containment shell) are graphed in Figure 3.4.1 and maximum temperatures reached during fire and post-fire cooldown are reported in Subsection 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature (Table 3.1.3) is well within the ISG-11, Rev. 3 accident temperature limit (Table 3.2.11).
- The maximum temperature of fuel basket is well within its accident design temperature (Table 3.2.10).
- The maximum temperatures of the containment boundary and lid seals (Table 3.1.3) are well below the ASME Code limits (Tables 3.2.10 and 3.2.12, respectively).
- The maximum temperatures of the aluminum basket shims (Table 3.1.3) are well below the accident temperature limits (Table 3.2.10).

- The maximum temperatures of the lid seals (Table 3.1.3) are well below the accident temperature limit (Table 3.2.12).

The HI-STAR 180 Package fire accident temperatures are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The thermal evaluation provides reasonable assurance of safety in the event of a fire. This conclusion is based on the technical data and analyses presented in this chapter in conjunction with provisions of 10 CFR Part 71, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

3.4.3.2 Maximum Pressures

The HI-STAR 180 containment pressure is computed based on the maximum temperatures of the cask contents (fuel basket and fuel) reached during the fire accident. The calculations use an array of conservative assumptions listed below:

i) Maximum initial fill pressure (See Table 1.2.1)
ii) 100% rods rupture
iii) 100% release of rods fills gas and 30% release of fission gases
iv) Lowerbound cavity free volume

The maximum containment pressures are tabulated in Subsection 3.1.4. The results show that the pressures are well below the containment boundary design pressure (Table 2.1.1).

3.4.4 Maximum Thermal Stresses

The HI-STAR 180 Package is designed to ensure a low state of thermal stress in the structural members. This is ensured by using high conductivity materials (Metamic- HT and low alloy steels) to minimize temperature gradients and large fit-up gaps to allow unrestrained thermal expansion of the cask internals (fuel basket) during normal transport. The differential thermal expansion of the fuel basket during normal transport is calculated in Reference [3.4.1] and results provided in Table 3.4.2. The normal transport gaps are bounding during fire because of the expansion of the cask body under direct fire heating. As thermal interference is precluded during fire a low state of thermal stress prevails in the cask.

3.4.5 Accident Condition for Fissile Material Package for Air Transport

Not applicable as transport of package by air is not requested.

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Table 3.4.1: Hypothetical Fire Accident Assumptions

	Initial Condition	30-minute Fire	Post-Fire Equilibrium
1. Neutron shield conduction	Yes (Understated Conductivity)	Yes (Undegraded material Conductivity)	No (Air conductivity applied to the neutron shield pockets)
2. Insolation	Yes	No	Yes
3. Surface Convection	Natural	Forced	Natural
4. Impact limiter conduction[Note A]			
Parallel to Aluminum Layers	Table 3.2.2	Table 3.2.2	Table 3.2.2
Normal to Aluminum Layers	Table 3.2.2	Table 3.2.2	Air conductivity
5. Cask Surface Solar Absorbtivity	1.0	NA	1.0
6. Emissivity			
Cask surface	0.85	0.9 (fire emissivity)	0.66
Polished Surfaces (impact limiter)	Table 3.2.6	0.9 (fire emissivity)	Table 3.2.6
Note A: [Withheld in Accordance with 10CFR 2.390]			

Table 3.4.2: [Withheld in Accordance with 10CFR 2.390]

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Table 3.4.3: Sandia Pool Fire Test Data[12]

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)

[12] From Sandia large pool fires report [3.4.2], Page 41.

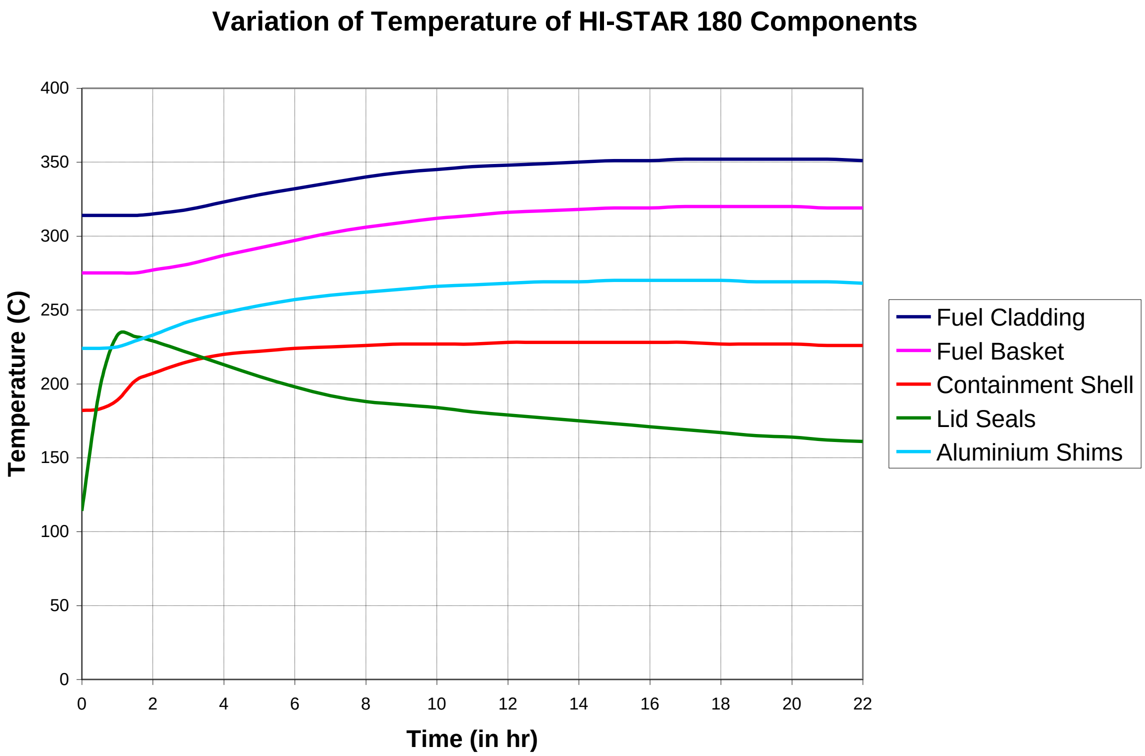

FIGURE 3.4.1: HI-STAR 180 FIRE AND POST FIRE COOLDOWN TEMPERATURE HISTORY

CHAPTER 3 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system. Supporting documents submitted to the USNRC with the HI-STAR 180 LAR 9325-2 have been italicized.

[3.1.1] Gebhart, B., Jaluria, Y., Mahajan, R.L. and Sammakia, B., “Buoyancy Induced Flows and Transport”, Hemisphere Publishing Corporation, NY, (1988).

[3.1.2] NUREG-1536, “Standard Review Plan for Dry Cask Storage Systems,” USNRC, (January 1997).

[3.1.3] NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel", USNRC, March 2000.

[3.2.1] Baumeister, T., Avallone, E.A. and Baumeister III, T., “Marks’ Standard Handbook for Mechanical Engineers”, 8th Edition, McGraw Hill Book Company, 1978.

[3.2.2] Rohsenow, W.M. and Hartnett, J.P., “Handbook of Heat Transfer,” McGraw Hill Book Company, New York, 1973.

[3.2.3] Greer et al., “The TN-24P Spent Fuel Storage Cask: Testing and Analyses,” EPRI NP-5128, PNL-6054, UC-85, (April 1987).

[3.2.4] Rust, J.H., “Nuclear Power Plant Engineering,” Haralson Publishing Company, (1979).

[3.2.5] Kern, D.Q., “Process Heat Transfer,” McGraw Hill Kogakusha, (1950).

[3.2.6] "A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior", NUREG/CR-0497, (August 1981).

[3.2.7] ASME Boiler and Pressure Vessel Code, Section II, Part D, (2007).

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

[3.2.9] Not Used.

[3.2.10] Kauder, L., "Spacecraft Thermal Control Coatings References," NASA Technical Procedure, NASA/TP-2005-212792, NASA/Goddard Space Flight Center, Greenbelt, MD, July 2005.

[3.2.11] "Fundamentals of Heat and Mass Transfer", 4th Edition, F.P. Incropera and D.P. DeWitt, John Wiley & Sons, Inc., New York, 1996.

[3.2.12] Not Used.

[3.2.13] Not Used.

[3.2.14] Aluminum Alloy 2219 Material Data Sheet, ASM Aerospace Specification Metals, Inc., Pompano Beach, FL.

[3.2.15] "Physical Properties of Polymers Handbook", James E. Mark, 2nd Edition.

[3.2.16] Metamic Report Number HTA06911, High Temperature Metamic Metal Matrix Composite for Structural Applications and Criticality Control, Revision 2.

[3.3.1] ANSYS Finite Element Modeling Package, Swanson Analysis Systems, Inc., Houston, PA, 1993.

[3.3.2] FLUENT Computational Fluid Dynamics Software (Fluent, Inc., Centerra Resource Park, 10 Cavendish Court, Lebanon, NH 03766).

[3.3.3] "Cladding Considerations for the Transportation and Storage of Spent Fuel", Interim Staff Guidance – 11, Rev. 3, (11/17/03).

[3.3.4] "Topical Report on the HI-STAR/HI-STORM Thermal Model and its Benchmarking with Full-Size Cask Test Data," Holtec Report HI-992252, Rev. 1, Holtec International, Marlton, NJ, 08053. (Holtec Proprietary).[13]

[3.4.1] "Thermal Analyses of the HI-STAR 180", Holtec Report HI-2073649, Latest Revision, (Holtec Proprietary).[14]

[3.4.2] "Thermal Measurements in a Series of Large Pool Fires", Sandia Report SAND85 – 0196 TTC – 0659 UC 71, (August 1971).

13 Supporting document previously submitted with the HI-STAR 180 initial License Application (Docket 71-9325).
14 Supporting document submitted with HI-STAR 180 LAR 9325-2.

CHAPTER 4: CONTAINMENT

4.0 INTRODUCTION

This chapter demonstrates the HI-STAR 180 cask containment system compliance with the permitted activity release limits specified in 10CFR71 for both normal and hypothetical accident conditions of transport [4.0.1]. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the loaded HI-STAR 180 cask will not exceed the allowable radionuclide release rates.

The containment system for the HI-STAR 180 cask consists of the components, seals and welds identified in the drawing package in Section 1.3 and also in Figures 4.1.1, 4.1.2, and 4.1.3. Both the inner and outer closure lids are containment system components whose closure joints must be tested prior to shipment.

Chapter 2 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and **[Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Chapter 3 of this SAR shows that the peak containment system component temperatures and pressures are within the design basis limits for all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Since both the containment system is shown to remain intact and the temperature and pressure design bases are not exceeded, the design basis leakage rates are not exceeded during normal or hypothetical accident conditions of transport.

The HI-STAR 180 cask is subjected to a fabrication leakage rate test before the first loading. The fabrication leakage rate test is performed at the factory in accordance with ANSI N14.5-2014 [4.0.2] as part of the HI-STAR 180 cask acceptance testing. The HI-STAR 180 cask is also subjected to a pre-shipment leakage rate test after each cask loading and closure. The pre-shipment leakage rate test is performed in accordance with ANSI N14.5-2014 by the user as final acceptance testing of the HI-STAR 180 cask containment system. The **[Withheld in Accordance with 10 CFR 2.390]** seals of the HI-STAR 180 cask are to be replaced and retested for each cask loading and closure.

Additional requirements and clarification are provided in Section 4.4 and Chapter 8.

4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

The containment system for the HI-STAR 180 cask consists of the containment shell, the containment base plate, the containment closure flange, the inner closure lid, the outer closure lid, inner and outer closure lid bolts, the inner closure lid port covers, the outer closure lid access port plug, and their respective **[Withheld in Accordance with 10 CFR 2.390]** seals and welds as specified in the drawing package in Section 1.3. The containment boundary and containment system components are shown in Figure 4.1.1 with additional detail on the inner and outer closure lids provided in Figures 4.1.2 and 4.1.3, respectively.

The containment system components for the HI-STAR 180 system are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NB [4.1.1], to the maximum extent practicable as clarified in Chapter 2 of this SAR. Chapter 1 specifies design criteria for the containment system. Section 2.1 provides the applicable Code requirements. Exceptions to specific Code requirements with complete justifications are presented in Table 2.1.14.

4.1.1 Containment Vessel

The cask containment vessel consists of components which form the inner containment space and expanded containment inter-lid space. The inner containment space is used to house the internal basket designs which hold spent nuclear fuel. The containment vessel is represented by the containment shell, containment base plate, containment closure flange, and inner and outer closure lids. These are the main containment system components that create an enclosed cylindrical cavity for the containment of the enclosed radiological contents. The materials of construction for the containment vessel are specified in the drawing package in Section 1.3. No valve or pressure relief device is specified on the HI-STAR 180 containment system.

4.1.2 Containment Penetrations

The cask containment system penetrations include the inner closure lid vent and drain ports, and the outer closure lid access port. Each penetration has redundant **[Withheld in Accordance with 10 CFR 2.390]** seals. The containment penetrations are designed and tested to ensure that the radionuclide release rates specified in 10CFR71.51 will not be exceeded.

4.1.3 Seals and Welds

The cask uses a combination of seals and welds designed and tested to provide containment during normal transport conditions, and during and after hypothetical accident conditions of transport. Seals and welds are individually discussed below.

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

4.1.3.1 Containment Seals

The containment system seals are designed and fabricated to meet the design requirements of the HI-STAR 180 cask specified in subparagraph 2.2.1.1.6 and in accordance with the manufacturer's recommendations. Chapter 7 describes the operating procedures required for proper seal function. Seal and closure details are provided in the drawing package in Section 1.3.

4.1.3.1.1 Inner Closure Lid

[

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]

4.1.3.1.2 Outer Closure Lid

[

Withheld in Accordance with 10 CFR 2.390

]

4.1.3.2 Containment Welds

The cask containment system welds consist of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment closure flange, and the full penetration weld connecting the containment base plate to the containment shell. All containment system boundary welds are fabricated and inspected in accordance with ASME Code Section III, Subsection NB. The weld details and examinations are shown in the drawing package in Section 1.3.

4.1.4 Closure Lids

[

Withheld in Accordance with 10 CFR 2.390

]

Bolt torquing patterns, lubrication requirements, and torque values are provided in Table 7.1.1. The torque values are established to maintain leaktight containment during normal and accident conditions of transport. Torque values for the inner and outer closure lid bolts preclude separation of the closure lids from the containment closure flange as clarified in Chapter 2. The closure lid bolts cannot be opened unintentionally or by a pressure that may arise within the package.

Figure 4.1.1: **[Withheld in Accordance with 10 CFR 2.390]**

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Figure 4.1.2: **[Withheld in Accordance with 10 CFR 2.390]**

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Figure 4.1.3: **[Withheld in Accordance with 10 CFR 2.390]**

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4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

Section 2.6 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and the **[Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all normal conditions of transport as defined in 10CFR71.71. Section 3.1 of this SAR shows that all containment system components are maintained within their peak temperature and pressure limits for all normal conditions of transport as defined in 10CFR71.71. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (see Table 8.1.1) will not be exceeded during normal conditions of transport.

4.2.1 Containment Criteria

The leaktight criteria as defined by ANSI N14.5-2014 shall be used for all containment system leakage tests. Compliance with the leaktight criteria of ANSI N14.5 precludes any significant release of radioactive materials and ensures that the radionuclide release rates specified in 10CFR71.51(a)(1) will not be exceeded during normal conditions of transport. Therefore, no containment analyses are performed for normal conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Table 8.1.1 and Table 8.1.2.

4.2.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5 (also see Table 8.1.1).

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4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Section 2.7 of this SAR shows that all containment system components are maintained within their code-allowable stress limits and the **[Withheld in Accordance with 10 CFR 2.390]** seals remain compressed during all hypothetical accident conditions of transport as defined in 10CFR71.73. Section 3.1 of this SAR shows that all containment system components are maintained within their peak temperature and pressure limits for all hypothetical accident conditions of transport as defined in 10CFR71.73. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (see Table 8.1.1) will not be exceeded during hypothetical accident conditions of transport.

4.3.1 Containment Criteria

The leaktight criteria as defined by ANSI N14.5-2014 shall be used for all containment system leakage tests. Compliance with the leaktight criteria of ANSI N14.5 precludes any significant release of radioactive materials and ensures that the radionuclide release rates specified in 10CFR71.51(a)(2) will not be exceeded during hypothetical accident conditions of transport. Therefore, no containment analyses are performed for hypothetical accident conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Table 8.1.1 and Table 8.1.2.

4.3.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5 (also see Table 8.1.1).

4.4 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

All leakage rate testing of the cask containment system shall be performed in accordance with the guidance in ANSI N14.5-2014. Table 8.1.2 provides the containment system components to be tested and the type of leakage test to be performed for post-fabrication, pre-shipment, periodic, and maintenance qualification.

4.4.1 Fabrication Leakage Rate Test

The fabrication leakage rate test demonstrates that the containment system, as fabricated, provides the required level of containment. The fabrication leakage test for the HI-STAR 180 package is performed at the fabrication facility to ensure that the welded enclosure vessel will maintain its containment function.

Additionally, after fabrication of all components, the inner and outer closure lids are installed and the **[Withheld in Accordance with 10 CFR 2.390]** are tested to ensure that the fit-up of the inner and outer closure lids with the containment flange will meet the leakage rate acceptance criteria after fuel loading.

4.4.2 Pre-Shipment Leakage Rate Test

The pre-shipment leakage rate test demonstrates that the containment system closure has been properly performed. The initial pre-shipment leakage rate test is performed by the user before shipment, after the contents are loaded and the containment system is assembled. The pre-shipment leakage rate test remains valid for 1 year.

4.4.3 Periodic Leakage Rate Test

The periodic leakage rate test demonstrates that the containment system closure capabilities have not deteriorated over an extended period of use. A periodic leakage rate test is only required if the most current leakage rate test occurred more than twelve months prior to package transport. Periodic leakage rate testing is performed by the user before each shipment if the previous leakage rate test has expired. The periodic leakage rate test remains valid for 1 year.

4.4.4 Maintenance Leakage Rate Test

The maintenance leakage rate test demonstrates that the containment system provides the required level of containment after undergoing maintenance, repair and or containment component replacement; and shall be performed prior to returning a package to service.

CHAPTER 4 REFERENCES

The following generic industry and Holtec-produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. 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.

[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.

[4.0.2] ANSI N14.5-2014. "American National Standard for Radioactive Materials- Leakage Tests on Packages for Shipment."

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

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Appendix 4.A: [Withheld in Accordance with 10 CFR 2.390]

CHAPTER 5 - SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR 180 Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter. The HI-STAR 180 is designed to accommodate either the F-32 basket or the F-37 basket, containing up to 32 and 37 PWR fuel assemblies, respectively.

In order to offer the user flexibility in fuel loading, the HI-STAR 180 offers several different loading patterns, where different positions in the basket are qualified for different burnup/cooling time/enrichment combinations. Both the F-32 and the F-37 can be loaded with UO_2 fuel only or a mixture of UO_2 and MOX fuel. The patterns are described in Subsection 1.2.2. All loading patterns have been analyzed and found to be acceptable compared to the regulatory limits.

In addition to storing undamaged PWR fuel assemblies, the HI-STAR 180 system is designed to transport PWR fuel rods which may be leaking, broken, or fragmented (as explained in Table 1.2.3a). PWR fuel rods which are leaking, broken, or fragmented, are required to be loaded into quivers prior to loading in the HI-STAR 180. Subsection 5.4.7 provides more detail on quivers.

The transport index in 10CFR71 is defined as the number determined by multiplying the radiation level in milliSievert per hour (mSv/h) at one meter from the external surface of the package by 100. Since the HI-STAR 180 has been designed to meet a dose rate limit of 0.1 mSv/h at 2 meters from the surface of the vehicle, the dose rate at 1 meter from the package could be greater than 0.1 mSv/h and the transport index could exceed 10. Therefore, the HI-STAR 180 loaded with design basis fuel must be shipped by exclusive use shipment as discussed in Section 1.1.

The shielding analyses were performed with MCNP-4A [5.1.1] developed by Los Alamos National Laboratory (LANL). The source terms for the design basis fuels were calculated with the SAS2H [5.1.2] and ORIGEN-S [5.1.3] sequences from the SCALE 4.4 system. These are principally the same codes that were used in Holtec's approved Storage and Transportation FSARs and SAR under separate docket numbers [5.1.4]. Detailed descriptions of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

This chapter contains the following information:

- A description of the shielding features of the HI-STAR 180.
- A description of the source terms.
- A general description of the shielding analysis methodology.
- A description of the analysis assumptions and results for the HI-STAR 180.

- Analyses for the HI-STAR 180's content and results to show that the 10CFR71.47 dose rate limits are met during normal conditions of transport and that the 10CFR71.51 dose rate limit is not exceeded following hypothetical accident conditions.

5.1 DESCRIPTION OF SHIELDING DESIGN

5.1.1 Design Features

The principal design features of the HI-STAR 180 packaging with respect to radiation shielding consist of the fuel basket and basket support structures, the cask including the two lids, and certain parts of the impact limiters. The main shielding is provided by the cask body. The cask body steel and the lids provide the main gamma shielding, while the neutron shielding is provided by the Holtite neutron absorber embedded in the cask body and inner lid. In the radial direction, the neutron absorber is located in two overlapping rows of pockets near the outer surface of the cask. In the axial direction, neutron absorber is present in the bottom section of the cask, and in the inner lid. Additional gamma shielding in axial direction is provided by a lead layer in the inner lid and the bottom section of the cask. The fuel basket and the basket supports maintain the fuel assemblies in a fixed position within the package, and also provide additional gamma shielding. For the impact limiters, only the central steel structures are credited in the analysis as additional gamma shielding in the axial direction. Additionally, the Holtite in the impact limiters is credited. Any shielding effect of the crushable impact limiter material and its surrounding steel skin is neglected. The dimensions of the shielding components are shown in the drawing package in Section 1.3. Main dimensions used in the shielding analyses are also shown in Figure 5.3.3 through 5.3.7. The shielding material densities are listed in Table 5.3.2 and Table 5.3.3.

5.1.2 Summary of Maximum Radiation Levels

The burnup and cooling time combinations specified in Subsection 1.2.2 were determined strictly based on the shielding analysis in this chapter. Each combination was independently analyzed and it was verified that the calculated dose rates were less than the regulatory limits (more discussion provided in Section 5.4). In this subsection, only the results for each basket that produce the highest dose rates at the surface and at 2 m under normal conditions, and at 1 m under accident conditions are presented. Dose rates for additional configurations are presented in Section 5.4.

The dose rates listed in the tables in this subsection are maximum values, considering axial, radial and azimuthal variations as applicable. This is achieved by specifying a reasonably fine grid of dose locations around the cask and selecting the highest values. For details on dose locations see Subsection 5.3.3.

The dose rates listed in this subsection are based on a number of conservative assumptions. However, they do not account for any uncertainties except for the inherent uncertainties of the Monte Carlo calculations, which are listed in the results tables. In Subsection 5.4.6, additional calculations are performed using a best estimate approach instead of the conservative assumptions, and then adding the effect of the major uncertainties. These calculations result in dose rates that are equivalent to or less than those listed in this subsection. This provides further assurance that the dose rates listed here are reasonable and conservative.

5.1.2.1 Normal Conditions

As discussed in Section 1.1, HI-STAR 180 will be transported by exclusive use shipment and complies with 10CFR71.47(b).

Dose rates are calculated on the cask surface, at locations shown in Figure 5.1.1. Results are presented in Tables 5.1.1 and 5.1.2 for the F-32 and F-37 basket, respectively.

All values are below 2 mSv/h, therefore showing that the HI-STAR 180 complies with 10CFR71.47(b)(1). Note that the additional conditions stated in 10CFR71.47(b)(1)(i) through (iii) (closed vehicle; fixed position; no loading/unloading) do not have to be met by the HI-STAR 180, since the surface dose rate do not exceed 2 mSv/h.

The calculated dose rates on the surface of the cask are below 2 mSv/h. Therefore, dose rates at any point on the outer surface of the vehicle will also be below 2 mSv/h. The HI-STAR 180 therefore complies with 10CFR71.47(b)(2).

The maximum dose rates for the HI-STAR 180 have been calculated at a distance of 2 m from the cask and impact limiter surfaces, for the locations shown in Figure 5.1.1. Results are presented in Tables 5.1.3 and 5.1.4 for the F-32 and F-37 basket, respectively, showing that all dose rates at that distance are below 0.1 mSv/h. Consequently, the dose rates 2 m from the outer edges of the vehicle will also be below 0.1 mSv/h. The HI-STAR 180 therefore complies with 10CFR71.47(b)(3).

Dose rates have been calculated to determine the distance necessary to comply with the 0.02 mSv/hr requirement specified in 10CFR71.47(b)(4) for any normally occupied space. The results presented in Tables 5.1.5 and 5.1.6 for the F-32 and F-37 basket, respectively, identify the distances necessary from Dose Locations 4 and 5 (the top and bottom of the HI-STAR 180, see Figure 5.1.1) for which exposed personnel of private carriers must maintain in order meet the 0.02 mSv/h requirement. Therefore, if the normally occupied space of the vehicle is at a distance less than the values specified in 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 180's compliance with the 10CFR71.47(b) limits.

5.1.2.2 Hypothetical Accident Conditions

The hypothetical accident conditions of transport presented in Section 2.7 have two bounding consequences that affect the shielding materials. These are the damage to the neutron shield as a result of the design basis fire, and damage to the impact limiters as a result of the 9-meter (30 foot) drop. Conservatively, the shielding analysis of the hypothetical accident condition assumes the neutron shield is completely destroyed and replaced by a void and the impact limiters are no longer present. This is a highly conservative assumption since some portion of the neutron shield would be expected to remain after the fire, and the impact limiters have been shown through the calculations in Chapter 2 to remain attached following impact.

Throughout the hypothetical accident condition the axial location of the fuel will remain practically fixed within the baskets (see Subsection 5.3.1.2). Chapter 2 shows that the HI-STAR 180 cask remains 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 1 meter from the surface for the conditions of the HI-STAR 180 Package after the postulated accident. Corresponding maximum dose rates are listed in Tables 5.1.7 and 5.1.8 for the F-32 and F-37 basket, respectively. All values in these tables are below the regulatory limit of 10 mSv/h.

Analyses summarized in this section demonstrate the HI-STAR 180 Package's compliance with the 10CFR71.51 radiation dose limit.

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TABLE 5.1.1

[Withheld in Accordance with 10 CFR 2.390]

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TABLE 5.1.2

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.1.3

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.1.4

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TABLE 5.1.5

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TABLE 5.1.6

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TABLE 5.1.7

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.1.8

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FIGURE 5.1.1 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.1.2 : **[Withheld in Accordance with 10 CFR 2.390]**

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5.2 SOURCE SPECIFICATION

The principal sources of radiation in the HI-STAR 180 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 SAS2H [5.1.2] and ORIGEN-S [5.1.3] modules of the SCALE 4.4 system using the 44-group library.

The assemblies to be qualified for transportation in the HI-STAR 180 contain both UO_2 and MOX assemblies. A description of the design basis fuel assemblies for the source term calculations is provided in Tables 5.2.1 through Tables 5.2.3 for both the UO_2 and MOX fuel.**[**

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Subsection 1.2.2 specifies the bounding burnup, cooling time and enrichment combinations for spent nuclear fuel that were analyzed for transport in the HI-STAR 180. **[**

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The source term calculations also determine the radionuclide composition of the spent fuel for the various conditions. **[**

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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 5.2.3 discusses the uncertainties associated with the SAS2H/ORIGEN-S calculations related to reactor input parameters, decay heat generation, and source term calculations.

5.2.1 Gamma Source

Table 5.2.4 provides the gamma source in MeV/s and photons/s as calculated with SAS2H and ORIGEN-S for bounding burnup and cooling time combinations for UO_2 and MOX fuel, and for the burnup and cooling time combinations specified in the uniform loading cases in subsection 1.2.2.

NUREG-1617 [5.2.1] states that "In general, only gammas from approximately 0.8 MeV-2.5 MeV will contribute significantly to the external radiation levels." **[**

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ORIGEN-S was used to calculate a ^{60}Co activity level for the desired burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.2] and is described here.

1. The activity of the ^{60}Co from ^{59}Co, steel and inconel is calculated using ORIGEN-S. 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 5.2.5. These scaling factors were taken from Reference [5.2.2].

Table 5.2.6 provides the ^{60}Co activity utilized in the shielding calculations in the non-fuel regions of the assemblies for the bounding burnup and cooling time combinations, and for the burnup and cooling time combinations specified in the uniform loading cases in Subsection 1.2.2.

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5.2.2 Neutron Source

It is well known that the neutron source strength for a UO_2 assembly increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel that increases the inventory of other transuranium nuclides such as Cm. The gamma source also varies with enrichment, although only slightly. **[**

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The neutron sources calculated for the UO_2 and MOX fuel are listed in Table 5.2.7 in neutrons/s for the bounding burnup and cooling times, and for the burnup and cooling time combinations specified in the uniform loading cases in Subsection 1.2.2. **[**

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5.2.3 Uncertainties in Depletion Calculations

There are various uncertainties associated with the SAS2H/ORIGEN-S calculations. Some uncertainties are inherent to the code, e.g., physics data, while other uncertainties are associated with input data. This subsection provides estimates of those uncertainties. Specifically, the variations in the gamma and neutron source terms from variations in the input parameters, and the variations in heat loads, gamma and neutron source terms resulting from the uncertainty in the isotope calculations are determined. In all cases, the variations or uncertainties in the amount of relevant isotopes are taken from published references. The depletion calculations performed for the HI-STAR 180 are then used to determine how much the heat load, gamma and neutron source terms are expected to change as a result of the changes in the isotope amounts.

5.2.3.1 Uncertainties in Source Term Input Reactor Operating Parameters

In [5.1.5], studies were performed to determine what effect changes in the relevant input parameters to SAS2H and ORIGEN-S have on the calculated concentration for a range of important isotopes. The results of the studies are presented as functions in the form of power laws for each input parameter, and each selected isotope. For a single nuclide and input parameter, the function has the form

$$S_i \propto x_j^{p_{i,j}}$$

where,

S_i = Relative Change in Mass or Source Term for Isotope i
x_j = Relative Change in Input Parameter j
$p_{i,j}$ = Power Coefficient for Input Parameter j's impact on Source Term from Isotope i

For all input parameters, the effect on isotope i is then

$$S_i \propto \prod_j x_j^{p_{i,j}}$$

In Table B.2 in [5.1.5], a matrix is presented with power coefficient for various input parameters and isotopes. The isotopes include Cm-244, which dominates the neutron source in the fuel, and several fission products that dominate the gamma source. **[**

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5.2.3.2 Uncertainties in Decay Heat Calculations

The estimation in the uncertainty of the decay heat values is performed with the same methodology that was previously used for the HI-STORM to determine decay heat uncertainty for high burnup fuel (see Section 5.2.5.3 of [1.2.7]). **[**

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It is noted that the uncertainty coefficients from [5.2.3] are based on measured fuel samples with burnup values varying from approximately 11.5 GWd/MTU to 31.5 GWd/MTU, which is less than the maximum burnup for the HI-STAR 180. However, the comparisons of the measured-to-computed percentage differences presented in [5.2.3] indicate no increasing difference as a function of increasing burnup. **[**

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The calculated temperatures reported in Chapter 3 show significant margin against all temperature limits. It is therefore not considered necessary to apply any uncertainty to the calculated heat load values before comparing them to the allowable limits listed in Section 1.2.

5.2.3.3 Uncertainties in Source Term Generation

Estimating the uncertainties in the source term values is performed using the same approach as discussed before for the decay heat, **[**

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TABLE 5.2.1

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TABLE 5.2.2

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.2.3

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TABLE 5.2.4

CALCULATED GAMMA SOURCE PER ASSEMBLY
FOR SELECTED BURNUP AND COOLING TIMES

Lower Energy	**Upper Energy**	**UO_2 Fuel 66,000 MWd/MTU 3 Year Cooling 4.5 wt% ^{235}U**		**MOX Fuel 61,500 MWd/MTU 11 Year Cooling MV-1**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)	(MeV/s)	(Photons/s)
0.45	0.7	2.84E15	4.93E15	1.07E15	1.87E15
0.7	1.0	1.35E15	1.58E15	1.23E14	1.45E14
1.0	1.5	2.72E14	2.18E14	8.57E13	6.85E13
1.5	2.0	1.98E13	1.13E13	4.34E12	2.48E12
2.0	2.5	1.91E13	8.50E12	4.40E10	1.96E10
2.5	3.0	7.16E11	2.60E11	6.06E09	2.21E09
Total		4.50E15	6.75E15	1.29E15	2.08E15

Lower Energy	**Upper Energy**	**UO_2 Fuel 66,000 MWd/MTU 7 Year Cooling 4.5 wt% ^{235}U**		**UO_2 Fuel 66,000 MWd/MTU 8 Year Cooling 4.5 wt% ^{235}U**	
(MeV)	(MeV)	(MeV/s)	(Photons/s)	(MeV/s)	(Photons/s)
0.45	0.7	1.59E15	2.76E15	1.46E15	2.54E15
0.7	1.0	3.80E14	4.47E14	2.83E14	3.33E14
1.0	1.5	1.10E14	8.76E13	9.35E13	7.48E13
1.5	2.0	5.00E12	2.86E12	4.31E12	2.46E12
2.0	2.5	7.31E11	3.25E11	3.36E11	1.49E11
2.5	3.0	4.76E10	1.73E10	2.47E10	8.99E09
Total		2.09E15	3.30E15	1.84E15	2.95E15

TABLE 5.2.5

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TABLE 5.2.6

CALCULATED ^{60}Co SOURCE PER ASSEMBLY
FOR SELECTED BURNUP AND COOLING TIMES

Location	**UO_2 Fuel** **66,000 MWd/MTU** **3 Year Cooling** **4.5 wt% ^{235}U** **(Photons/s)**	**MOX Fuel** **61,500 MWd/MTU** **11 Year Cooling** **MV-1** **(Photons/s)**
Bottom nozzle	2.49E13	5.91E12
Active fuel zone	2.70E13	6.30E12
Upper portion of fuel rods w/o grid spacer	6.59E12	1.55E12
Upper portion of fuel rods with grid spacer	2.96E12	6.92E11
Top nozzle	2.51E12	4.39E12

Location	**UO_2 Fuel** **66,000 MWd/MTU** **7 Year Cooling** **4.5 wt% ^{235}U** **(Photons/s)**	**UO_2 Fuel** **66,000 MWd/MTU** **8 Year Cooling** **4.5 wt% ^{235}U** **(Photons/s)**
Bottom nozzle	1.37E13	1.20E13
Active fuel zone	1.47E13	1.29E13
Upper portion of fuel rods w/o grid spacer	3.62E12	3.17E12
Upper portion of fuel rods with grid spacer	1.62E12	1.42E12
Top nozzle	1.32E12	1.16E12

TABLE 5.2.7

CALCULATED NEUTRON SOURCE PER ASSEMBLY
FOR BOUNDING BURNUPS AND COOLING TIMES

Lower Energy (MeV)	Upper Energy (MeV)	UO_2 Fuel 66,000 MWd/MTU 3 Year Cooling 4.5 wt% ^{235}U (Neutrons/s)	MOX Fuel 61,500 MWd/MTU 11 Year Cooling MV-1 (Neutrons/s)
1.0E-01	4.0E-01	3.71E7	7.41E07
4.0E-01	9.0E-01	1.89E8	8.33E08
9.0E-01	1.4	1.73E8	9.14E08
1.4	1.85	1.27E8	5.19E08
1.85	3.0	2.24E8	7.06E08
3.0	6.43	2.04E8	7.72E08
6.43	20.0	1.82E7	1.51E08
Totals		9.74E8	3.97E09

Lower Energy (MeV)	Upper Energy (MeV)	UO_2 Fuel 66,000 MWd/MTU 7 Year Cooling 4.5 wt% ^{235}U (Neutrons/s)	UO_2 Fuel 66,000 MWd/MTU 8 Year Cooling 4.5 wt% ^{235}U (Neutrons/s)
1.0E-01	4.0E-01	3.13E7	3.00E7
4.0E-01	9.0E-01	1.60E8	1.53E8
9.0E-01	1.4	1.46E8	1.40E8
1.4	1.85	1.08E8	1.03E8
1.85	3.0	1.89E8	1.82E8
3.0	6.43	1.72E8	1.66E8
6.43	20.0	1.53E7	1.47E7
Totals		8.22E8	7.90E8

TABLE 5.2.8

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TABLE 5.2.9

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5.3 SHIELDING MODEL

The shielding analysis of the HI-STAR 180 was performed with MCNP-4A [5.1.1]. MCNP is a Monte Carlo transport code that offers a full three-dimensional combinatorial geometry modeling capability including such complex surfaces as cones and tori. This means that no gross approximations were required to represent the HI-STAR 180 in the shielding analysis. MCNP-4A is the same code that is used for the shielding calculations of Holtec's other approved dry storage and transportation systems under separate dockets.

The MCNP model of the HI-STAR 180 Package for normal conditions has the neutron shield and impact limiters in place. The MCNP model for the hypothetical accident condition replaces the neutron shield with void and removes the impact limiters as discussed in Subsection 5.1.2.2. The shielding effect of the aluminum honeycomb in the impact limiters was conservatively neglected in all MCNP models. However, credit was taken for the outer dimensions of the impact limiters in axial direction under normal conditions, i.e. the axial dose locations are based on the distance from the skin around the crush material.

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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 180 Packaging. These drawings were used to create the MCNP models used in the radiation transport calculations. The drawing package also illustrates the HI-STAR 180 on a typical transport vehicle with a personnel barrier installed. The vehicle and barrier were not considered in the MCNP model, i.e. the outer dimensions of the vehicle are conservatively assumed to be identical to the outer dimensions of the package as modeled for normal conditions. Figures 5.3.1 and 5.3.2 show the cross-sectional views of the HI-STAR 180 cask and F-37 and F-32 baskets respectively, as they were modeled in MCNP. The figures were created with the MCNP plotter and are drawn to scale. **[Withheld in Accordance with 10 CFR 2.390]** Figure 5.3.3 shows the MCNP model of the F-32 and F-37 baskets including the as modeled dimensions. Figure 5.3.4 shows a cross sectional view of the HI-STAR 180 cask with the as-modeled thickness of the various materials. Figure 5.3.5 is an axial representation of the HI-STAR 180 cask with the various as-modeled dimensions indicated. Figures 5.3.6 and 5.3.7 provide the as-modeled dimensions of the impact limiters during normal conditions. The aluminum honeycomb material in the impact limiter is not shown in Figure 5.3.6 because it was conservatively neglected in the MCNP calculations.

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The conditions and tests specified in 10CFR 71.71 for normal conditions have no effect on the configuration of the cask. Therefore, no additional considerations are necessary for these conditions and tests.

During the MCNP modeling process a few modeling simplifications were made. The simplifications between model and drawings are listed and discussed here.

F-32 and F-37 Basket Modeling Simplifications

1. The flow holes in the top and bottom 6.0 cm of the basket walls are not explicitly modeled. Rather, a reduced density is used over the region defined by the height of the holes. **[Withheld in Accordance with 10 CFR 2.390]**

2. The holes in the basket shims are modeled with squared rather than rounded corners. This is conservative since it neglects a small amount of material in the analyses.

HI-STAR Modeling Simplifications

1. **[Withheld in Accordance with 10 CFR 2.390]** This localized reduction in the thickness of the bottom of the cask was not modeled. Since there is significant shielding in this area of the HI-STAR, this localized reduction in shielding will not affect the calculated dose rates.

2. The annular monolithic cylinders are modeled as one casting rather than multiple castings stacked on top of one another. This is acceptable since the gap between the castings is small, and the castings overlap to prevent any significant streaming.

3. In the modeling of the impact limiters, only the neutron shield (Holtite) and the steel, shown in Figure 5.1.1, were represented. Conservatively, the aluminum honeycomb of the impact limiters was not modeled.

4. The trunnions are removed during transportation and are therefore not explicitly modeled. The resulting void is modeled as a solid material due to the insertion of trunnion "plugs".

5. The bolts utilized for closure of the inner and outer lid are not modeled, but rather the bolt hole locations are modeled as a solid material.

6. Penetrations in the two lids were not modeled. This is acceptable since these penetrations are not aligned and are covered by the port covers, and additionally by the steel structure of the impact limiter. Any streaming through these penetrations would therefore have a negligible effect.

7. 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.

Note that for some dose locations for dose points #1 and #3 at 1 or 2 m (see Figures 5.1.1 and 5.1.2), the dose locations are placed at 1 or 2 m from the monolithic shield cylinder (dose point #2), which places them at distances slightly larger than 1 or 2 m from the corresponding surface dose locations. This is acceptable and does not affect the determination of the maximum dose rates, since the maximum radial dose rates at 1 and 2 m distance occur at the center of the cask (dose location #2).

In the radial direction, the model is conservatively based on the minimum outer diameter of the cask, and the Holtite pocket thickness of 75 mm (while the nominal dimension is 78 mm).

5.3.1.2 Fuel and Source Configuration

In the model homogenized regions represent the fuel. Calculations on a similar cask design were performed to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it was concluded that it was acceptable to homogenize the fuel assembly without loss of accuracy. **[**

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In the model for the F-32, the fuel is modeled as fresh UO_2 fuel with an enrichment of 5 wt% ^{235}U. In the model for the F-37, the fuel is modeled as fresh UO_2 fuel with an enrichment of 3.5 wt%. This enrichment results in a reactivity that is equivalent to the various loading combinations of fresh and burned fuel, as shown in Chapter 6, and is therefore appropriate for the shielding analysis.

5.3.1.3 Streaming Through Radial Steel Ribs

The HI-STAR 180 cask utilizes Holtite as a neutron absorber in radial and axial directions. **[**

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5.3.2 Material Properties

Composition and densities of the various materials used in the HI-STAR 180 shielding analyses are given in Table 5.3.2 and Table 5.3.3. See Subsections 1.2.1.5.1 and 1.2.1.6 for further information on the Holtite and Metamic neutron absorber, respectively. All of the materials and their actual geometries are represented in the MCNP model. All steel in the cask was modeled as carbon steel.

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To account for the thermal expansion of Holtite at operating temperatures, the material is installed with suitable gaps in cold conditions, which would close when the cask is fully loaded at operating conditions. Additionally, Holtite may experience some minor long-term weight loss from exposure to the temperatures. All this is considered in the model by utilizing a reduced density for the material, and a composition that is adjusted for the weight loss.

[

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Section 3.4 demonstrates that all materials used in the HI-STAR 180 remain at or below their design temperatures during all normal conditions. Therefore, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

During normal operations, the depletion of B-10 in the Metamic and the Holtite neutron shield is negligible. Based on calculations prepared for a similar cask model, the fraction of B-10 atoms that are depleted in 50 years is less than 1E-6 in both the Metamic and Holtite. Therefore, the shielding analysis does not need to address any changes in the composition of the Metamic or Holtite as a result of neutron absorption.

5.3.3 Tally Specifications

The dose rate values listed in Tables 5.1.1 through 5.1.8, with corresponding dose point locations illustrated in Figure 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 2 cm each at the surface, at 1 m and at 2 m from the surface. In axial direction they are cylindrical disks with a thickness of 2 cm at various distances from the cask. Further details are discussed below.

Radial Tallies

- Dose Location 2
  This dose location captures the maximum dose rate around the radial shield cylinder, **[**

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- Dose Locations 1 and 3
  These are the dose locations adjacent to the impact limiter skirt surrounding the upper and lower forgings of the cask. **[Withheld in Accordance with 10 CFR 2.390]**

Axial Tallies

The tally volumes located on the top and bottom surfaces, 1 meter and 2 meter positions of the cask were composed the following way:

- Dose Locations 4 and 5
  In axial direction, the tally volumes are circular disks that are divided into radial sections, each about 23 cm wide.

The dose locations for both radial and axial tallies are also described in Section 5.4.4.

TABLE 5.3.1

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TABLE 5.3.2

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.3.3

[Withheld in Accordance with 10 CFR 2.390]

FIGURE 5.3.1 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.3.2 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.3.3 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.3.4 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.3.5 : **[Withheld in Accordance with 10 CFR 2.390]**

FIGURE 5.3.6: **[Withheld in Accordance with 10 CFR 2.390]**

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FIGURE 5.3.7: **[Withheld in Accordance with 10 CFR 2.390]**

5.4 SHIELDING EVALUATION

5.4.1 Methods

A significant number of conservative assumptions are applied throughout the shielding calculations. These assumptions will assure that the actual dose rates will always be below the calculated dose rates, and below the regulatory limits. **[**

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The MCNP-4A code [5.1.1] was used for all of the shielding analyses. MCNP is a continuous energy, three-dimensional, coupled neutron-photon-electron Monte Carlo transport code. Continuous energy cross-section data is represented with sufficient energy points to permit linear-linear interpolation between these points. The individual cross section libraries used for each nuclide are those recommended by the MCNP manual. All of these data are based on ENDF/B-V data. The large user community has extensively benchmarked MCNP against experimental data. References [5.4.2], [5.4.3], and [5.4.4] are three examples of the benchmarking that has been performed. Note also that the principal approach in the shielding analysis here is identical to the approach in licensing applications previously reviewed and approved by the USNRC.

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5.4.2 Input and Output Data

[**Withheld in Accordance with 10 CFR 2.390**]The principal input data is therefore the dimensions shown in the drawings in Chapter 1, the fuel specifications, and the material compositions listed in Subsection 5.3. Sample input files for MCNP are provided in Appendices 5.A and 5.B.

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] The output of the postprocessing 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 on the surface of the package during normal transport conditions for the HI-STAR 180 with design basis fuel. Tables 5.1.3 and 5.1.4 list the maximum dose rate 2 m from the edge of the transport vehicle during normal conditions. The burnup and cooling time combinations chosen for the tables in that section were the combinations that resulted in maximum dose rates for the normal operation on the surface and at 2 m from the surface, as specified in the regulatory requirements. These combinations may not be all from the same loading condition but show the highest dose rate at each individual dose location.

Figure 5.1.1 shows the dose locations on the surface and the condition of the HI-STAR 180 Package during normal transport. Each of these dose locations has a corresponding location at 2 m from the surface. The impact limiters are intact and outlined on the figure, but the crushable material is neglected. Dose point locations correspond to results in Tables 5.1.1 through 5.1.4 and are maximum values. The azimuthal dose values are taken from the dose point locations that are shown in Figure 5.3.4. [
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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 is comprised of axial segments **[Withheld in Accordance with 10 CFR 2.390]**. The highest dose rate of these axial segments was chosen as the value for dose location 2. Dose location 1 corresponds to the axial extension of the lower impact limiter that spans between the bottom of the **[Withheld in Accordance with 10 CFR 2.390]**. Dose location 3 corresponds to the axial extension of the upper impact limiter that spans **[Withheld in Accordance with 10 CFR 2.390]**. Dose location 4 corresponds to the surface location directly above the **[Withheld in Accordance**

with 10 CFR 2.390] in the top impact limiter, and dose location 5 corresponds to the location directly below the radial rib plates in the bottom impact limiter. As mentioned above, the radial extension of the impact limiters beyond the cask surface is neglected for the radial 2 m dose locations, i.e. these dose rates are determined conservatively at a distance of 2 m from the cask surface.

Detailed results are listed in Tables 5.4.2 through 5.4.5. These tables show the highest total dose rates at each dose location for each pattern in each basket. Note that dose rates listed for a single pattern are not necessarily from the same case, since it is unlikely that a single loading condition results in maximum dose rates at all 5 dose locations.

Table 5.4.2 shows that the maximum dose rate on the surface of the cask during normal conditions, with either basket, is at dose location #1. This result is reasonable because this location is on the lower cask skirt where there is less shielding, as can be seen in Figure 5.1.1.

Table 5.4.3 shows that the maximum dose rates at 2 m from the surface of the cask during normal conditions, with either basket, occur at either dose location #2 or dose location #5, depending on the loading plan. At 2 m from the surface, it is expected that the highest dose rates would occur at the midpoints of the cask, either axially (location #2) or radially (location #5). Dose location #4 has additional shielding in the cask lid, which accounts for the dose rate differences in locations 4 & 5. Additionally, localized dose rate peaks would be minimized further from the cask surface, as can be seen by the uniformity of the dose rate results.

Table 5.4.5 shows that the maximum dose rates at 1 m from the surface of the cask during hypothetical accident conditions, with either basket, occur at either dose location #2 or dose location #5, depending on the loading plan. This result is reasonable because of the loss of the neutron shielding.

To support the manufacturing of the Holtite pockets, an analysis was performed for the minimum Holtite pocket thickness of 70 mm. The results showed that the effect of the minimum Holtite pocket thickness of 70 mm on the dose rates is insignificant, and all the dose rates are below the regulatory limits. Since the bounding dose rate is at 2 meters from the cask, small and local fluctuation in the Holtite pocket thickness does not have a significant effect. Therefore, locally, the Holtite pocket thickness may be less than 70 mm, as long as the average Holtite thickness of a pocket is 70 mm or more.

5.4.5 Fuel Reconfiguration

The structural analyses of fuel rods in Subsection 2.11 show that the fuel is expected to remain essentially undamaged during the hypothetical accident conditions. The design basis calculations for the hypothetical accident conditions therefore use the same model to represent fuel as the calculations for normal conditions. The current subsection presents additional calculations to show that even if some fuel reconfigurations should occur, the dose rates would still be expected to remain below the regulatory limits.

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The results show that the design basis dose rates are bounding in most dose locations. Further, all analyzed fuel reconfiguration scenarios meet the dose rate regulatory requirements. It can therefore be concluded that any fuel reconfiguration during hypothetical accident conditions will not result in dose rates that exceed the regulatory limits and will in most cases even result in a reduction of dose rates compared to undamaged fuel.

5.4.6 Effect of Uncertainties

The design basis calculations presented in Section 5.1 and Subsection 5.4.4 are based on a range of conservative assumptions, but do not explicitly account for uncertainties in the methodologies, codes and input parameters, that is, it is assumed that the effect of uncertainties is small compared to the numerous conservatisms in the analyses. To show that this assumption is valid, this section presents calculations and results based on a different approach, where calculations are performed as "best estimate" calculations, and then estimated uncertainties are added. The results based on this approach are then compared to results in Subsection 5.4.4.

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Results are presented in Tables 5.4.9 through 5.4.12. The tables show the calculated dose rates, the individual and combined uncertainties, and total dose rates with and without uncertainties. For comparison purposes, the tables also show the dose rates of the design basis calculations. In all cases, the total dose rates, including uncertainties, are comparable to or lower than the corresponding values from the design basis calculations. This provides further confirmation that the design basis calculations are reasonable and conservative.

5.4.7 PWR Fuel Rods in Quivers

Quivers allow for the storage of PWR fuel rods as explained in Table 1.2.3a. Quivers can accommodate a smaller amount of PWR fuel rods than an undamaged PWR fuel assembly. The magnitude of the source term from a quiver will be less than a design basis undamaged PWR. Therefore, it is expected that the dose rates from a HI-STAR 180 system loaded with quivers (as specified in Table 1.2.3a) will be less than the dose rates of the cask loaded with design basis undamaged fuel assemblies.

TABLE 5.4.1 (a)

TYPICAL AXIAL BURNUP PROFILE

Axial Section (1 = Top)	Burnup (GWd/MTU)	
	UO_2	MOX
1	31.08	27.44
2	40.97	36.12
3	48.91	44.62
4	53.6	50.07
5	56.45	53.58
6	58.21	55.94
7	59.08	57.29
8	59.62	58.01
9	59.96	58.53
10	60.06	58.90
11	60.11	59.01
12	60.19	59.12
13	60.17	59.26
14	60.1	59.23
15	60.15	59.24
16	60.14	59.34
17	60.03	59.30
18	60.09	59.27
19	60.09	59.34
20	59.98	59.33
21	60.03	59.26
22	60.02	59.26
23	59.89	59.19
24	59.83	58.95
25	59.65	58.64
26	59.25	58.18
27	58.61	57.14
28	57.16	55.14
29	54.75	52.09
30	50.54	47.00
31	42.74	38.37
32	32.43	28.71

TABLE 5.4.1 (b)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Gamma Energy (MeV)	**(mSv/h)/ (photon/cm^2-s)** †
0.01	3.96E-05
0.03	5.82E-06
0.05	2.90E-06
0.07	2.58E-06
0.1	2.83E-06
0.15	3.79E-06
0.2	5.01E-06
0.25	6.31E-06
0.3	7.59E-06
0.35	8.78E-06
0.4	9.85E-06
0.45	1.08E-05
0.5	1.17E-05
0.55	1.27E-05
0.6	1.36E-05
0.65	1.44E-05
0.7	1.52E-05
0.8	1.68E-05
1.0	1.98E-05
1.4	2.51E-05
1.8	2.99E-05
2.2	3.42E-05

† Values have been multiplied by 10 to convert mrem, as given in [5.4.1], to mSv

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TABLE 5.4.1 (b) (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Gamma Energy (MeV)	**(mSv/h)/ (photon/cm^2-s)** †
2.6	3.82E-05
2.8	4.01E-05
3.25	4.41E-05
3.75	4.83E-05
4.25	5.23E-05
4.75	5.60E-05
5.0	5.80E-05
5.25	6.01E-05
5.75	6.37E-05
6.25	6.74E-05
6.75	7.11E-05
7.5	7.66E-05
9.0	8.77E-05
11.0	1.03E-04
13.0	1.18E-04
15.0	1.33E-04

† Values have been multiplied by 10 to convert mrem, as given in [5.4.1], to mSv

TABLE 5.4.1 (b) (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Neutron Energy (MeV)	Quality Factor	(mSv/h)/(n/cm^2-s) †, ††
2.5E-8	2.0	3.67E-05
1.0E-7	2.0	3.67E-05
1.0E-6	2.0	4.46E-05
1.0E-5	2.0	4.54E-05
1.0E-4	2.0	4.18E-05
1.0E-3	2.0	3.76E-05
1.0E-2	2.5	3.56E-05
0.1	7.5	2.17E-04
0.5	11.0	9.26E-04
1.0	11.0	1.32E-03
2.5	9.0	1.25E-03
5.0	8.0	1.56E-03
7.0	7.0	1.47E-03
10.0	6.5	1.47E-03
14.0	7.5	2.08E-03
20.0	8.0	2.27E-03

† Values have been multiplied by 10 to convert mrem, as given in [5.4.1], to mSv

†† Includes the Quality Factor

TABLE 5.4.2

TOTAL DOSE RATES ON THE
SURFACE OF THE HI-STAR 180 PACKAGE FOR NORMAL CONDITIONS
WITH THE F-32 AND F-37 Basket

Dose Point[††] Location	Total Dose Rate (mSv/h)					
	Loading Pattern, F-32					
	A	B	C	D	E	F
1	0.8645	0.6887	0.7863	0.9027	0.6702	0.7693
2	0.4112	0.3699	0.3966	0.4026	0.3643	0.3499
3	0.6165	0.5009	0.5835	0.6691	0.4830	0.5437
4	0.3294	0.2683	0.3119	0.3711	0.2556	0.2939
5	0.4290	0.3710	0.4119	0.4702	0.3788	0.4184
	Loading Pattern, F-37					
	A	B	C	D		
1	0.8220	0.7831	0.9041	0.6974		
2	0.4924	0.4071	0.4509	0.3414		
3	0.5625	0.5901	0.6561	0.4999		
4	0.2959	0.3075	0.3314	0.2563		
5	0.4194	0.3822	0.4120	0.3764		
10CFR71.47 Limit (mSv/h)	2	2	2	2	2	

[††] Refer to Figure 5.1.1.

TABLE 5.4.3

TOTAL DOSE RATES AT
TWO METERS FROM THE HI-STAR 180 PACKAGE FOR NORMAL CONDITIONS
WITH THE F-32 AND F-37 BASKET

Dose Point[††] Location	**Total Dose Rate (mSv/h)**					
	Loading Pattern, F-32					
	A	**B**	**C**	**D**	**E**	**F**
1	0.0602	0.0549	0.0582	0.0639	0.0540	0.0581
2	0.0826	0.0813	0.0826	0.0860	0.0815	0.0811
3	0.0699	0.0603	0.0651	0.0715	0.0628	0.0648
4	0.0570	0.0450	0.0525	0.0619	0.0426	0.0490
5	0.0932	0.0862	0.0900	0.0926	0.0870	0.0927
	Loading Pattern, F-37					
	A	**B**	**C**	**D**		
1	0.0636	0.0587	0.0627	0.0565		
2	0.0906	0.0870	0.0909	0.0812		
3	0.0703	0.0692	0.0699	0.0635		
4	0.0510	0.0529	0.0584	0.0442		
5	0.0901	0.0837	0.0863	0.0850		
10CFR71.47 Limit (mSv/h)	0.1	0.1	0.1	0.1	0.1	

†† Refer to Figure 5.1.1.

TABLE 5.4.4

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TABLE 5.4.5

TOTAL DOSE RATES AT
ONE METER FROM THE HI-STAR 180 PACKAGE FOR ACCIDENT CONDITIONS
WITH THE F-32 AND F-37 BASKET

Dose Point[††] Location	**Dose Rate (mSv/h)**					
	Loading Pattern, F-32					
	A	**B**	**C**	**D**	**E**	**F**
1	4.122	3.173	3.672	4.119	3.022	3.565
2	9.049	7.039	8.164	9.026	6.663	7.816
3	3.850	2.984	3.449	3.882	2.852	3.383
4	1.791	1.486	1.728	2.041	1.420	1.615
5	7.703	6.880	7.601	8.638	7.035	7.730
	Loading Pattern, F-37					
	A	**B**	**C**	**D**		
1	4.259	3.560	4.352	3.060		
2	9.329	7.432	9.423	6.551		
3	3.907	3.157	3.984	2.788		
4	0.958	0.945	1.019	0.808		
5	5.205	4.708	4.803	4.545		
10CFR71.51 Limit (mSv/h)	10	10	10	10	10	

[††] Refer to Figure 5.1.2.

TABLE 5.4.6

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TABLE 5.4.7

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.4.8

[Withheld in Accordance with 10 CFR 2.390]

TABLE 5.4.9

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Table 5.4.10

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Table 5.4.11

[Withheld in Accordance with 10 CFR 2.390]

Table 5.4.12

[Withheld in Accordance with 10 CFR 2.390]

Table 5.4.13

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CHAPTER 5 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system. Supporting documents submitted to the USNRC with the HI-STAR 180 LAR 9325-2 have been italicized.

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[5.2.3] M. D. DeHart and O. W. Hermann, “An Extension of the Validation of SCALE (SAS2H) Isotopic Predictions for PWR Spent Fuel,” ORNL/TM-13317, Oak Ridge National Laboratory, September 1996.

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National Laboratory, September 1994.

[5.4.1] "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", ANSI/ANS-6.1.1-1977.

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[5.4.4] J. C. Wagner, et al., "MCNP: Criticality Safety Benchmark Problems," LA-12415, Los Alamos National Laboratory, October 1992.

[5.4.5] *Holtec International Report HI-2073653, "Source Term Analysis for the HI-STAR 180", Rev. 4 (Holtec Proprietary)*

[5.4.6] *Holtec International Report HI-2073655, "Shielding Analysis for the HI-STAR 180", Rev. 13 (Holtec Proprietary)*

[5.4.7] ORNL/M-5503, 'The Radioactive Materials Packaging Handbook", Oak Ridge National Laboratory, 1998.

Appendix 5.A

[Withheld in Accordance with 10 CFR 2.390]

Appendix 5.B

[Withheld in Accordance with 10 CFR 2.390]

Appendix 5.C

[Withheld in Accordance with 10 CFR 2.390]

CHAPTER 6 CRITICALITY EVALUATION

6.0 INTRODUCTION

This chapter documents the criticality evaluation of the HI-STAR 180 Cask for the packaging and transportation of radioactive materials (spent nuclear fuel) in accordance with 10CFR71. The results of this evaluation demonstrate that an infinite number of HI-STAR 180 Packages with variations in internal and external moderation remain subcritical with a margin of subcriticality greater than 0.05Δk. This corresponds to a criticality safety index (CSI) of zero (0.0) and demonstrates compliance with criticality requirements in 10 CFR 71.55 and 10 CFR 71.59 for normal and hypothetical accident conditions of transport.

In addition to demonstrating that the criticality safety acceptance criteria are satisfied, this chapter describes the HI-STAR 180 design structures and components important to criticality safety. It also provides limiting fuel characteristics. With the cask and fuel description, this chapter gives data in sufficient detail to allow the criticality evaluation of the package.

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

The containment system of the HI-STAR 180 is a cylindrical shell with a flat bottom and flat bolted lids at the top. Inside the containment system, fuel assemblies are placed in a basket structure to maintain their location.

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For general details of these baskets see the description and drawings in Section 1.3. Sketches showing the basket details that are important for criticality safety are shown in Section 6.3.1 of this chapter.

Criticality safety of the HI-STAR 180 depends on the following principal design features:

- The inherent geometry of the fuel basket design within the cask. [**Withheld in Accordance with 10 CFR 2.390]**

- The incorporation of permanent fixed neutron-absorbing material in the fuel basket structure. [**Withheld in Accordance with 10 CFR 2.390]**

- Administrative limits on the maximum enrichment (F-32 and F-37) and minimum average assembly burnup (F-37). [**Withheld in Accordance with 10 CFR 2.390]**

- The ability of the cask to prevent water inleakage under accident conditions. As a result [**Withheld in Accordance with 10 CFR 2.390]**

- The cask is equipped with a double lid system. [**Withheld in Accordance with 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 8 (ISG-8), Revision 2, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks".

- USNRC Interim Staff Guidance 19 (ISG-19), Revision 0, "Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)".

6.1.2 Summary Table of Criticality Evaluations

The principal calculational results address the following conditions:

- A single package, under the conditions of 10 CFR 71.55(b), (d), and (e);
- An array of undamaged packages, under the conditions of 10 CFR 71.59(a)(1); and
- An array of damaged packages, under the conditions of 10 CFR 71.59(a)(2)

Results are summarized in Table 6.1.1 for the most reactive configurations and fuel condition. The table contains the maximum k_{eff}, and the uncertainty for each case. The results are conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For package arrays, an infinite number of packages are analyzed. The maximum k_{eff} value for all cases is below the regulatory limit of 0.95. The results therefore demonstrate that the HI-STAR 180 Package is in full compliance with 10CFR71 (71.55(b), (d), and (e) and 71.59(a)(1) and (a)(2)). Table 6.1.2 presents the loading curves for the F-37 basket for the different loading configurations. Figure 1.2.4 in Section 1.2 shows basket locations in the F-37 basket referenced in Table 6.1.2. Table 6.1.3 presents the maximum initial enrichments of the fresh undamaged PWR UO_2 fuel for the different loading configurations. Figure 1.2.3 in Section 1.2 shows basket locations in the F-32 basket referenced in Table 6.1.3.

To assure the true reactivity will always be less than the calculated reactivity, the following conservative assumptions were made:

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6.1.3 Criticality Safety Index

The calculations for package arrays are performed for infinite arrays of HI-STAR 180 Packages under flooded conditions and results are below the regulatory limit, i.e. N is infinite. Therefore, the criticality safety index (CSI) is zero (0.0).

Table 6.1.1

SUMMARY OF THE CRITICALITY RESULTS
TO DEMONSTRATE COMPLIANCE WITH 10CFR71.55 AND 10CFR71.59

F-32				
Configuration	% Internal Moderation	% External Moderation	Applicable Requirement	Maximum[1] k_{eff}
Single Package, unreflected	100%	0%	n/a	0.9419
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	0.9429
Containment, fully reflected	100%	100%		0.9420
Single Package, Damaged	0%	100%	10CFR71.55 (e)	0.3800
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	0.4080
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	0.4025

F-37				
Configuration	% Internal Moderation	% External Moderation	Applicable Requirement	Maximum[1] k_{eff}
Single Package, unreflected	100%	0%	n/a	0.9483
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	0.9487
Containment, fully reflected	100%	100%		0.9463
Single Package, Damaged	0%	100%	10CFR71.55 (e)	0.3716
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	0.3961
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	0.3891

1 The maximum k_{eff} is equal to the sum of the calculated k_{eff}, two standard deviations, the code bias, and the uncertainty in the code bias. For all cases, the standard deviation ranges from 0.0003 to 0.0007. The combined bias and bias uncertainty is 0.0027 for the F-32, and 0.0107 for the F-37.

Table 6.1.2

Burnup Requirements for UO_2 fuel the F-37 Basket

Configuration	Fresh UO_2† and MOX†† Fuel	Fuel Debris† in Quiver	Spent UO_2† Fuel		
	Region (see Figure 1.2.4)	Region (see Figure 1.2.4)	Region (see Figure 1.2.4)	Loading Curve†††	
				Maximum Initial Enrichment for Fresh UO_2 Fuel Assemblies (wt% ^{235}U)	Minimum Assembly Burnup for UO_2 Assemblies with an Initial Enrichment of 5.0 wt% ^{235}U. (GWd/mtU)
1	5	-	1,2,3,4,6,7,8	2.80	22
2	2, 4, 5	-	1,3,6,7,8	2.73	25
3	1, 4, 5	-	2,3,6,7,8	2.73	25
4	1, 3, 5	-	2,4,6,7,8	2.55	27
5	1,3,8	-	2,4,5,6,7	2.55	27
6	1,5,8	-	2,3,4,6,7	2.42	31
7	1,3,5,8	-	2,4,6,7	2.38	34
8	6	-	1,2,3,4,5,7,8	2.31	35
9	2,5,8	-	1,3,4,6,7	2.38	34
10	-	Cells 8 and 30 of Region 8 OR Cells 4 and 34 of Region 8	1,2,3,4,5,6,7, the remaining Cells of Region 8 which do not contain fuel debris in quivers	2.55	29

† Maximum Initial Enrichment of UO_2 Fuel and Fuel Debris is 5.0 wt% ^{235}U.
†† For the bounding composition of MOX fuel see Section 6.2
††† Intermediate Burnup values can be determined by linear interpolation

Table 6.1.3

Loading Configurations for the F-32 Basket

Configuration	Fresh UO_2 and MOX† Fuel	Fuel Debris†† in Quiver	Maximum Initial Enrichment for Fresh UO_2 Fuel Assemblies (wt% ^{235}U)
	Region (see Figure 1.2.3)	Region (see Figure 1.2.3)	
1	1,2,3,4,5,6,7,8	-	5.00
2	1,2,3,4,5,6,8, the remaining Cells of Region 7 which do not contain fuel debris in quivers	Cells 10 and 23 of Region 7 OR Cells 1 and 32 of Region 7	4.70

† For the bounding composition of MOX fuel see Section 6.2.
†† Maximum Initial Enrichment of UO_2 Fuel Debris is 5.0 wt% ^{235}U.

6.2 FISSILE MATERIAL CONTENT

6.2.1 General

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6.2.2 Fuel Parameters

The various fuel assemblies to be qualified all have similar principal characteristics, such as array size and number of fuel rods and guide tubes, which are listed in Table 6.2.1. However, they differ in some of the details, such as fuel rod and guide tube dimensions. Previous studies [6.2.1] have shown that the bounding conditions correspond to:
[

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6.2.3 MOX Assemblies

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6.2.4 Damaged Fuel Assemblies and Fuel Debris

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TABLE 6.2.1: [Withheld in Accordance with 10 CFR 2.390]

TABLE 6.2.2: [Withheld in Accordance with 10 CFR 2.390]

TABLE 6.2.3: [Withheld in Accordance with 10 CFR 2.390]

TABLE 6.2.4: [Withheld in Accordance with 10 CFR 2.390]

FIGURE 6.2.1: [Withheld in Accordance with 10 CFR 2.390]

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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 180 in sufficient detail to identify the package accurately and provide a sufficient basis for the evaluation of the package.

6.3.1 Model Configuration

Figures 6.3.1 through 6.3.4 show representative cross sections of the criticality models for the two baskets. Figure 6.3.1 shows a single cell from the basket. The cells are identical for both baskets, except for the width of the flux trap. Figures 6.3.2 and 6.3.3 show the entire F-32 and F-37 basket, respectively. Figure 6.3.4 shows a sketch of the calculational model in the axial direction.

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The basket geometry can vary due to manufacturing tolerances and due to potential deflections of basket walls as the result of accident conditions. The basket tolerances are defined on the drawings in Chapter 1. [**Withheld in Accordance with 10 CFR 2.390]**

Based on the calculations, the conservative dimensional assumptions listed in Table 6.3.2 were determined for the basket designs. Because the reactivity effect (positive or negative) of the manufacturing tolerances is not assembly dependent, these dimensional assumptions were employed for all criticality analyses.

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Variations of other parameters, namely fuel density and water temperature in the cask, were analyzed using CASMO-4. The results are presented in Table 6.3.3, 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 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 and external reflections. The effect of these conditions is discussed in Section 6.3.4.

Additionally, studies are performed to evaluate the potential effect of fuel reconfiguration during accident conditions. These are presented in Section 6.3.5.

6.3.2 Material Properties

Composition of the various components of the principal designs of the HI-STAR 180 Package is listed in Table 6.3.4. In this table only the composition of fresh fuel is listed. For a discussion on the composition of spent fuel for burnup credit see Appendix 6.B.

The HI-STAR 180 is designed such that the fixed neutron absorber will remain effective for a period greater than 60 years, and there are no credible means to lose it. A detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of the fixed neutron absorber are provided in Subsection 1.2.1.6.

The continued efficacy of the fixed neutron absorber is assured by acceptance testing, documented in Subsection 8.1.5.4, to validate the ^{10}B (poison) concentration in the fixed neutron absorber. To demonstrate that the neutron flux from the irradiated fuel results in a negligible depletion of the poison material, a conservative calculation of the number of neutrons absorbed in the ^{10}B was performed (see [5.4.6], Appendix F). The calculation shows that the fraction of ^{10}B atoms destroyed during the service life in the fixed neutron absorber by neutron absorption is negligible (less than 10^{-6}). 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

The criticality analyses use the same codes, MCNP4a and CASMO-4, that were used for Holtec's dry storage and transportation systems reviewed and approved by the NRC under separate dockets.

The principal code for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP4a [6.3.1] developed at the Los Alamos National Laboratory. MCNP4a was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP4a design basis calculations used continuous energy cross-section data, based on ENDF/B-V, as distributed with the code.

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CASMO-4 [6.3.2 – 6.3.4] was used for determining some incremental reactivity effects (see Section 6.3.1). Although CASMO has been extensively benchmarked, these calculations are used only to establish direction of reactivity. This allows the MCNP4a calculational model to use the worst combination of tolerances. Additionally, CASMO-4 was used to determine the isotopic composition of spent fuel for burnup credit in the HI-STAR 180 (see Appendix 6.B).

6.3.4 Demonstration of Maximum Reactivity

6.3.4.1 Internal and External Moderation

The regulations in 10CFR71.55 include the requirement that the package remains subcritical when assuming moderation to the most reactive credible extent. The regulations in 10CFR71.59 require subcriticality for package arrays under different moderation conditions. Subsections 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. [6.3.5] has demonstrated that the phenomenon of a peak in reactivity at low moderator densities does not occur when strong neutron absorbing material is present or in the absence of large water spaces between fuel assemblies. Nevertheless, calculations for a single reflected cask and for infinite arrays of casks were made to confirm that the phenomenon does not occur with low density water inside or outside the HI-STAR 180.

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6.3.4.1.1 Single Package Evaluation

The calculational model for a single package consists of the HI-STAR Cask surrounded by a hexagonal box filled with water. The neutron absorber on the outside of the HI-STAR is neglected, since it might be damaged under accident conditions, and since it is conservative to replace the neutron absorber (Holtite) with a neutron reflector (water). The minimum water thickness on each side of the cask is 30 cm, which effectively represents full water reflection. The outer surfaces of the surrounding box are conservatively set to be fully reflective, which effectively models a three dimensional array of casks with a minimum surface to surface distance of 60 cm. The calculations with internal and external moderators of various densities are shown in Table 6.3.6. For comparison purposes, a calculation for a single, unreflected cask (Case 1) is also included in Table 6.3.6. At 100% external moderator density, Case 2 corresponds to a single, fully-flooded cask, fully reflected by water. Figure 6.3.5 plots calculated k_{eff} values as a function of internal moderator density for 100% external moderator density (i.e., full water reflection).

Results listed in Table 6.3.6 and plotted in Figure 6.3.5 support the following conclusions:

- The calculated k_{eff} for a fully-flooded cask is independent of the external moderator (the small variations in the listed values are due to statistical uncertainties which are inherent to the calculational method (Monte Carlo)); and

- Reducing the internal moderation results in a monotonic reduction in reactivity, with no evidence of any optimum moderation. Thus, the fully flooded condition corresponds to the highest reactivity, and the phenomenon of optimum low-density moderation does not occur and is not applicable to the HI-STAR 180.

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 180 Packages under hypothetical accident conditions (i.e, internal and external moderation by water to the most reactive credible extent and no neutron shield present).

In accordance with 10CFR71.59 requirements, calculations were performed to simulate an infinite three-dimensional square array of internally fully-flooded (highest reactivity) casks with varying cask spacing and external moderation density. The maximum k_{eff} results of these calculations are listed in Table 6.3.7 and confirm that the individual casks in a square-pitched array are independent of external moderation and cask spacing.

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The calculations demonstrate that the thick steel wall of the overpack is more than sufficient to preclude neutron coupling between casks, consistent with the findings of Cano, et al [6.3.5]. Neglecting the Holtite neutron shielding in the calculational model provides further assurance of conservatism in the calculations.

6.3.4.2 Partial Flooding

To demonstrate that the HI-STAR 180 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 the HI-STAR 180 and demonstrate that the fully flooded condition is the most reactive.

The reactivity changes during the flooding process were evaluated for the F-32 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 (0.002 g/cm^3). Results of these calculations are shown in Table 6.3.11.

Additional calculations are performed for the F-37, with burned fuel in the cask, and the cask in the vertical orientation. [**Withheld in Accordance with 10 CFR 2.390]**
The results are presented in Table 6.3.16. The table also shows the reference case with the fully flooded cask.

In all cases, for both the F-32 and F-37, 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 Clad Gap Flooding

The reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated. Table 6.3.12 presents maximum k_{eff} values that demonstrate the positive reactivity effect associated with flooding the pellet-to-clad gap regions. These results confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. For all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded.

6.3.4.4 Preferential Flooding

Preferential flooding of the baskets is not possible [**Withheld in Accordance with 10 CFR 2.390]**

6.3.4.5 Eccentric Positioning of Assemblies in Fuel Storage Cells

In this subsection, studies are presented to determine the reactivity effect of eccentric positioning of fuel assemblies in the fuel storage cells, and the conditions with the highest maximum k_{eff} are identified.

To conservatively account for eccentric fuel positioning in the fuel storage cells, three different configurations are analyzed, and the results are compared to determine the bounding configuration:

- Cell Center Configuration: All assemblies centered in their fuel storage cell;
- Basket Center Configuration: All assemblies in the basket are moved as closely to the center of the basket as permitted by the basket geometry; 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.

The results are presented in Table 6.3.5. The table shows the maximum k_{eff} value for centered and the two eccentric configurations for each condition, and the difference in k_{eff} between the centered and eccentric positioning. The results and conclusions are summarized as follows:

- For both the F-32 and F-37 basket, the cell centered configuration results in the highest reactivity.

Therefore, all further calculations, including those that demonstrate compliance with 10CFR71 requirements, are performed with assemblies centered in the basket cells.

6.3.5 Potential Fuel Reconfiguration under Accident Conditions

The cask is designed to remain internally dry under any accident conditions. Therefore, any fuel reconfiguration under accident conditions would be of no consequences. Nevertheless, as a defense-in-depth, analyses are performed assuming coinciding fuel reconfiguration and flooding of the cask.

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In summary, these results show that credible damage of the fuel assemblies from transport accident conditions will not have a significant effect on the reactivity of the package.

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 location are not occupied with fuel, the amount of fissile material is obviously reduced. Also, under the bounding condition of a fully flooded cask, the amount of water is increased. This will result in an increased moderation of neutrons in the empty cell locations. This increased moderation will increase the effectiveness of the surrounding thermal neutron absorber. Described differently, the now empty cell locations will act as additional flux traps. Therefore, due to the reduced amount of fissile material, and the increased neutron absorption, the reactivity of the package under partial loading conditions will be reduced, and will always be bound by the fully loaded conditions. No further evaluations of this condition are therefore necessary.

In addition, it is acceptable to load dummy assemblies at any basket cell location. The dummy fuel assemblies may displace a volume of water that is either smaller or larger than that displaced by the original fuel assemblies, thus either increase or decrease neutron absorption. However, the reactivity effect due to change in moderation is small, and the impact of reduction in fissile material is dominant. The reactivity of the cask with dummy assemblies will be reduced and bounded by the cask with fuel assemblies in all basket cell locations. No further evaluations are therefore necessary.

Table 6.3.1: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.2: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.3

CASMO-4 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Change in Nominal Parameter	Δk Maximum Tolerance F-32	Action/Modeling Assumption
Increase UO_2 Density to Maximum	0.0013 max. = 10.52 g/cc nom. = 10.42 g/cc	Assume max UO_2 density
Increase in Temperature 20°C 40°C 70°C 100°C	 Ref. -0.0034 -0.0103 -0.0190	Assume 20°C
10% Void in Moderator 20°C with no void 20°C 100°C	 Ref. -0.0472 -0.0657	Assume no void

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Table 6.3.4: [Withheld in Accordance with 10 CFR 2.390]

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Table 6.3.5: [Withheld in Accordance with 10 CFR 2.390]

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Table 6.3.6

MAXIMUM REACTIVITIES WITH REDUCED WATER DENSITIES FOR CASK ARRAYS†

Case Number	Water Density		MCNP4a Results		
	Internal	External	HI-STAR 180		
			Max. k_{eff}††	1 σ	EALF (eV)
1	100%	single cask	0.9419	0.0006	0.3781
2	100%	100%	0.9429	0.0005	0.3802
3	100%	70%	0.9429	0.0005	0.3788
4	100%	50%	0.9434	0.0006	0.378
5	100%	20%	0.9431	0.0007	0.3792
6	100%	10%	0.9442	0.0006	0.3785
7	100%	5%	0.9435	0.0006	0.3779
8	100%	0%	0.9430	0.0005	0.3772
9	70%	0%	0.8211	0.0006	0.9142
10	50%	0%	0.7179	0.0005	2.6428
11	20%	0%	0.5293	0.0004	100.69
12	10%	0%	0.4753	0.0003	1086.9
13	5%	0%	0.4550	0.0002	5195.3
14	10%	100%	0.4705	0.0003	1158.3

† For an infinite hexagonal array of casks with 60 cm spacing between cask surfaces.

†† Maximum k_{eff} includes the bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.

Table 6.3.7: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.8: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.9

REACTIVITY EFFECTS OF SPACING AND EXTERNAL MODERATOR DENSITY FOR HEXAGONAL (TRIANGULAR-PITCHED) ARRAYS OF HI-STAR 180 CASKS INTERNALLY FLOODED WITH WATER OF 10% FULL DENSITY

Cask-to-Cask External Spacing (cm)					
External Moderator Density (%)	2	10	20	40	60
10	0.4714	0.4714	0.4709	0.4704	0.4701
100	0.4698	0.4700	0.4704	0.4705	0.4705

Note:

1. All values are maximum k_{eff} which include the bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.
2. The standard deviation (σ) of the calculations is about 0.0004.

Table 6.3.10: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.11: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.12: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.13: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.14: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.15: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.15a: [Withheld in Accordance with 10 CFR 2.390]

Table 6.3.16

REACTIVITY EFFECTS OF PARTIAL CASK FLOODING FOR HI-STAR 180 WITH THE F-37 BASKET

HI-STAR 180, F-37 BASKET	
Flooded Condition (Number of axial sections flooded at the bottom)	Vertical Orientation
1	0.6104
2	0.7552
3	0.8239
4	0.8620
5	0.8854
6	0.8996
7	0.9081
8	0.9154
9	0.9205
10	0.9233
11	0.9256
12	0.9284
13	0.9298
14	0.9327
15	0.9332
16	0.9334
32 (ALL)	0.9409

Notes:

1. All values are maximum k_{eff} which include bias, uncertainties, and calculational statistics, evaluated for the worst case combination of manufacturing tolerances.
2. The standard deviation (σ) of the calculations ranges between 0.0004 and 0.0007.

FIGURE 6.3.1: [Withheld in Accordance with 10 CFR 2.390]

FIGURE 6.3.2: [Withheld in Accordance with 10 CFR 2.390]

FIGURE 6.3.3: [Withheld in Accordance with 10 CFR 2.390]

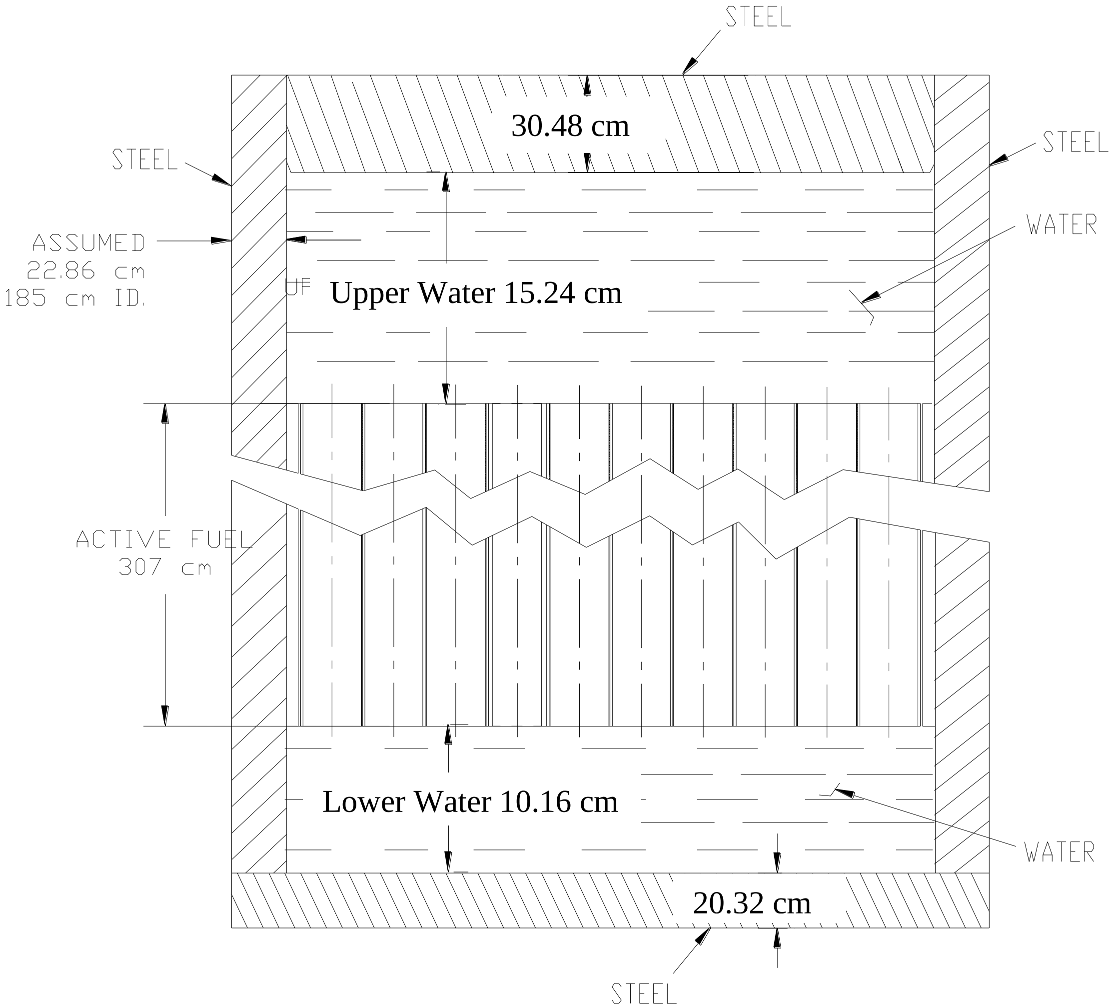

FIGURE 6.3.4 SKETCH OF THE CALCULATIONAL MODEL IN THE AXIAL DIRECTION

FIGURE 6.3.5: [Withheld in Accordance with 10 CFR 2.390]

6.4 SINGLE PACKAGE EVALUATION

6.4.1 Configuration

The calculations in this section demonstrate that a single HI-STAR 180 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 6.3.3 are used
- The assemblies are centered in the cell locations, which results in the highest k_{eff} as demonstrated in Section 6.3.4.5
- The pellet to clad gap is assumed to be flooded (see Section 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 sections 6.3.4.1 through 6.3.4.4 demonstrate that the moderation by water to the most reactive credible extent corresponds to the internally fully flooded condition of the basket, with the pellet-to-clad gap in the fuel rods also flooded with water. The external moderation has a statistically negligible effect.

Under normal condition, water is assumed to leak into the package, consistent with 10 CFR 71.55. Flooding with full density water is assumed, since this is the bounding condition as shown in Section 6.3.4.

To demonstrate compliance with 10CFR71.55 under normal conditions, the following calculations are performed for the HI-STAR 180 design:

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To satisfy the requirements of 10CFR71.55 (b)(1), the calculations are performed

[

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The maximum k_{eff} values for all these cases, calculated with 95% probability at the 95% confidence level, are listed in Table 6.4.1 for the F-32 basket and in Table 6.4.2 for the F-37 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 conditions of transport.

Additional calculations (CASMO-4) at elevated temperatures confirm that the temperature coefficients of reactivity are negative as shown in Table 6.3.3. 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.

The HI-STAR 180 is designed for high burnup fuel (HBF), i.e. for fuel with burnups larger than 45 GWd/mtU. For fuel of this burnup, there are concerns that the fuel cladding could be damaged under accident conditions, with a potential effect on reactivity. Chapter 2 demonstrates that the cask remains leaktight under all credible accident conditions. **[Withheld in Accordance with 10 CFR 2.390]**

In summary, the hypothetical transport accidents have no adverse effect on the geometric form of the package contents important to criticality safety, and thus, are limited to the effects on internal and external moderation evaluated in Subsection 6.3.4.1.

To demonstrate compliance with 10CFR71.55 under accident conditions, the following calculations are performed for the HI-STAR 180 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. Fuel is modeled as undamaged, since any small rearrangements of fuel as a result of the accident would have a negligible effect, compared to the safety margin for this condition. The external neutron moderator is conservatively neglected in the model. This case addresses the requirement of 10CFR71.55 (e).

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6.4.2 Results

In calculating the maximum reactivity, the analysis uses the following equation:

[Withheld in Accordance with 10 CFR 2.390]

Appendix 6.A presents the critical experiment benchmarking for fresh UO_2 and MOX fuel and the derivation of the corresponding bias and standard error of the bias (95% probability at the 95% confidence level).

See Appendix 6.B, Section 6.B.3, for the critical experiment benchmarking for spent fuel.

The results are listed in Table 6.4.1 for the F-32 basket and in Table 6.4.2 for the F-37 basket. For the F-37 basket, all 10 configurations defined in Table 6.1.2 are analyzed for an internally flooded, unreflected cask. Configuration 2 shows the highest reactivity. This configuration is therefore the only configuration analyzed to show compliance with 10CFR71.55, and for the evaluations of package arrays in the following sections 6.5 and 6.6.

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Table 6.4.1

HI-STAR 180 SINGLE PACKAGE WITH F-32 BASKET

Configuration	% Internal Moderation	% External Moderation	Max.‡ k_{eff}	1 σ	EALF (eV)
Single Package, Unreflected:					
Configuration 1, 5.0 wt% ^{235}U	100%	0%	0.9419	0.0006	0.3781
Configuration 2, 4.7 wt% ^{235}U	100%	0%	0.9417	0.0006	0.3574
Configuration 1, 5.0 wt% ^{235}U					
Single Package, fully reflected	100%	100%	0.9429	0.0005	0.3802
Containment, fully reflected	100%	100%	0.9420	0.0006	0.3784
Single Package, Damaged	0%	100%	0.3800	0.0004	183570

‡ The maximum k_{eff} is equal to the sum of the calculated k_{eff}, two standard deviations, the code bias, and the uncertainty in the code bias.

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Table 6.4.2

HI-STAR 180 SINGLE PACKAGE WITH F-37 BASKET

Configuration	% Internal Moderation	% External Moderation	Max.‡ k_{eff}	1 σ	EALF (eV)
Single Package, Unreflected:					
Configuration 1, 22 GWd/mtU	100%	0%	0.9443	0.0006	0.3821
Configuration 2, 25 GWd/mtU	100%	0%	0.9483	0.0006	0.3781
Configuration 3, 25 GWd/mtU	100%	0%	0.9448	0.0005	0.3773
Configuration 4, 27 GWd/mtU	100%	0%	0.9473	0.0006	0.3758
Configuration 5, 27 GWd/mtU	100%	0%	0.9458	0.0006	0.3761
Configuration 6, 31 GWd/mtU	100%	0%	0.9462	0.0005	0.3743
Configuration 7, 34 GWd/mtU	100%	0%	0.9474	0.0007	0.3727
Configuration 8, 35 GWd/mtU	100%	0%	0.9441	0.0006	0.3692
Configuration 9, 34 GWd/mtU	100%	0%	0.9438	0.0006	0.3739
Configuration 10, 29 GWd/mtU	100%	0%	0.9468	0.0007	0.1877
Configuration 2, 25 GWd/mtU:					
Single Package, fully reflected	100%	100%	0.9487	0.0006	0.3781
Containment, fully reflected	100%	100%	0.9463	0.0005	0.3795
Single Package, Damaged	0%	100%	0.3716	0.0004	237409

‡ The maximum k_{eff} is equal to the sum of the calculated k_{eff}, two standard deviations, the code bias, and the uncertainty in the code bias.

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

6.5.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator density have a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under normal conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally and externally dry, is modeled. All other modeling assumptions are identical to the modeling assumptions for the single package under normal conditions. The analyses are performed for both baskets. For both the F-32 and F-37 baskets, only the most reactive loading configuration is modeled. Due to the large margins to the regulatory limit, this is sufficient to show regulatory compliance. 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 are presented in Table 6.5.1, and show that the maximum k_{eff} is well below the regulatory limit 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 180 PACKAGE ARRAYS UNDER NORMAL CONDITIONS

Configuration	% Internal Moderation	% External Moderation	Max.‡ k_{eff}	1 σ	EALF† (eV)
F-32, Configuration 1	0%	0%	0.4080	0.0004	127540
F-37, Configuration 2	0%	0%	0.3961	0.0003	168954

‡ The maximum k_{eff} is equal to the sum of the calculated k_{eff}, two standard deviations, the code bias, and the uncertainty in the code bias.
† EALF = Energy of the Average Lethargy of Fission, a measure of the thermalization of the fission process.

6.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6.6.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator density have a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under accident conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally dry with full external water reflection, is modeled. This model is consistent with the model for the single cask under accident condition, and recognizes the fact that water intrusion under accident condition is not considered credible. This calculation addresses the requirement of 10CFR71.59 (a)(2)

6.6.2 Results

The results are presented in Table 6.6.1, and show that the maximum k_{eff} is well below the regulatory limit 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 6.6.1

HI-STAR 180 PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS

Configuration	% Internal Moderation	% External Moderation	Max.‡ k_{eff}	1 σ	EALF (eV)
F-32, Configuration 1	0%	100%	0.4025	0.0004	138620
F-37, Configuration 2	0%	100%	0.3891	0.0004	182738

‡ The maximum k_{eff} is equal to the sum of the calculated k_{eff}, two standard deviations, the code bias, and the uncertainty in the code bias.

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Not Applicable. The HI-STAR 180 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. No significant trends were evident in the benchmark calculations or the derived bias. Detailed benchmark calculations are presented in Appendix 6.A. These are the same benchmark calculations that were used in Holtec's previously approved storage and transportation FSARs and SAR.

The benchmark calculations were performed with the same computer codes and cross-section data, described in Section 6.3, that were used to calculate the k_{eff} values for the cask. Further, all calculations were performed on the same computer hardware, specifically, personal computers under Microsoft Windows.

Additional benchmark calculations performed for the burnup methodology for the HI-STAR 180 are presented in Appendix 6.B.

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. Supporting documents submitted to the USNRC with the HI-STAR 180 LAR 9325-2 have been italicized.

[6.2.1] Holtec International Report HI-951251, Safety Analysis Report HI-STAR 100 Cask System, USNRC Docket 71-9261, Revision 16.

[6.2.2] Holtec International Report HI-2002444, Final Safety Analysis Report on the HI-STORM 100 System, USNRC Docket 72-1014, Revision 14.

[6.3.1] J.F. Briesmeister, Ed., "MCNP - A General Monte Carlo N-Particle Transport Code, Version 4A," Los Alamos National Laboratory, LA-12625-M (1993).

[6.3.2] "CASMO-4 Methodology", Studsvik/SOA-95/2, Rev. 0, 1995.

[6.3.3] "CASMO-4 A Fuel Assembly Burnup Program, Users Manual," SSP-01/400, Rev. 1, Studsvik Scandpower, Inc., 2001.

[6.3.4] "CASMO-4 Benchmark Against Critical Experiments", Studsvik/SOA-94/13, Studsvik of America, 1995.

[6.3.5] J.M. Cano, R. Caro, and J.M Martinez-Val, "Supercriticality Through Optimum Moderation in Nuclear Fuel Storage*," Nucl. Technol.*, 48, 251-260, (1980).

[6.4.1] M.G. Natrella, "Experimental Statistics", National Bureau of Standards, Handbook 91, August 1963.

[6.4.2] *Holtec International Report HI-2073654, "Criticality Analysis for the HI-STAR 180", Revision 8. (Holtec Proprietary)*

Appendix 6.A: [Withheld in Accordance with 10 CFR 2.390]

Appendix 6.B: [Withheld in Accordance with 10 CFR 2.390]

Appendix 6.C: [Withheld in Accordance with 10 CFR 2.390]

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Appendix 6.D: [Withheld in Accordance with 10 CFR 2.390]

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Appendix 6.E: [Withheld in Accordance with 10 CFR 2.390]

Appendix 6.F: [Withheld in Accordance with 10 CFR 2.390]

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CHAPTER 7: PACKAGE OPERATIONS

The text matter and data presented in this chapter in **bold** font (or as otherwise noted) are an integral part of the Certificate of Compliance (CoC) of the package and cannot be altered without NRC's approval through a license amendment. Moreover, essential elements and criteria in Section 7.0 through Section 7.3 and Appendix 7.B have been identified as conditions of the CoC.

7.0 INTRODUCTION

This chapter provides a summary description of the essential elements and minimum requirements necessary to prepare the package for shipment and to ensure that it operates in a safe and reliable manner under normal and accident conditions of transport pursuant to the provisions of 10CFR71 [7.1.4], as described in this SAR. The information presented in this chapter along with the technical basis of the package design described in Chapters 2 through 6 will be used by Holtec International's Site Services organization to develop more detailed generic procedures for users of the HI-STAR 180 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 180 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 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.**
- **The procedures are in conformance with this SAR and the NRC issued CoC.**
- **The operational steps are ALARA**
- **The procedures contain provisions for documenting successful execution of all safety significant steps for archival reference.**
- **Holtec's lessons learned database has been consulted to incorporate all applicable lessons learned from prior cask handling and loading evolutions.**
- **Procedures contain provisions for classroom and hands-on training and for a Holtec approved personnel qualification process to 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 the fuel will be loaded into or unloaded from the HI-STAR cask submerged in a spent fuel pool. With some modifications, the information presented herein can be used to develop site-specific procedures for loading or unloading fuel into the system within a hot cell or other remote handling facility.

US Department of Transportation (USDOT) transportation regulations in 49CFR parts 172 [7.1.1] and 173 [7.1.2] applicable to the transport of the HI-STAR 180 package as well as USNRC regulations in 10CFR20 [7.1.3], are only addressed in this chapter to the extent required to ensure compliance with 10CFR71 regulations and to provide a more complete package operation description. Applicable 49CFR and 10CFR20 regulations, including those explicitly called out in 10CFR 71.5, shall be complied with for package use in the US and/or for US package export and import. For transport outside US territory and under the approval 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 180. Written procedures are required and will be developed or modified to account for such items as handling and storage of systems, structures and components identified as *important-to-safety*, heavy load handling, specialized instrument calibration, special nuclear material accountability, fuel handling procedures, training, equipment and process qualifications. Users shall implement controls to ensure that the lifted weights do not exceed the cask lifting trunnion design limit. Users shall implement controls to monitor the time limit for the removal of the cask from the spent fuel pool to the commencement of cask draining to prevent boiling. Users shall also implement controls to ensure that the cask cannot be subjected to a fire event in excess of design limits during loading operations.

For the determination of cyclic vacuum drying time limits, thermal evaluations may implement Fluent 3D models that are the same or consistent with the models used for safety analysis. Alternatively, other demonstrably conservative and appropriately benchmarked models may be utilized.

The procedures in this chapter contain generic ALARA notes and warnings to alert users to radiological issues. Actions identified with these notes and warnings are not mandatory and shall be implemented based on a determination by radiation protection.

The operations covered in this safety analysis address the following areas:

1. Preparation for loading a cask
2. Loading of cask contents
3. Preparation for shipment of a loaded cask
4. Package unloading
5. Preparation for shipment of an empty cask

Appendix A of this chapter (Appendix 7.A) provides figures of the HI-STAR 180 Package during its various loading states during typical operations/evolutions.

Appendix 7.B provides burnup verification conditions of the HI-STAR 180 Package.

Control of the package operation shall be performed in accordance with the user's Quality Assurance (QA) program to ensure critical steps are not overlooked and that the cask has been confirmed to meet all requirements of the Part 71 CoC before being released for shipment.

Table 7.1.1 provides the HI-STAR 180 Package bolt torque and sequencing requirements.

Fuel assembly selection and verification shall be performed by the user in accordance with written, approved procedures that ensure that only SNF assemblies authorized in the CoC are loaded into the HI-STAR 180 cask. Fuel assembly selection, and some aspects of assembly verification, are typically performed well in advance of the actual loading date, specifically with respect to the selection and verification of the assemblies to meet the definition of undamaged fuel in the CoC. A typical approach to show compliance with the CoC definition of undamaged fuel may include the following steps:

- **During reactor operation, the water chemistry is monitored. If no indication of fuel leakage is detected, all assemblies unloaded from the core are considered undamaged.**

- **If indication of leakage is found in the water during reactor operation, the population of the assemblies in the core that may have the leak may be narrowed down by a more detailed evaluation of the leaked isotopes, or by manipulating control blades in a BWR core.**

- **Once unloaded, further examination, such as sipping, may be performed to clearly identifying the leaking assembly or assemblies, out of the population identified.**

- **Once leaking assemblies are identified, they may simply be considered not meeting the CoC requirements and excluded from the selection, or further tests are performed to identify the extent of cladding damage.**

Fuel handling shall be performed in accordance with written site-specific procedures.

The following specific SAR information and Holtec documents (Holtec references) are incorporated by reference in this Chapter. All other references to the SAR and Holtec documents are for completeness of information.

Holtec Document/SAR	**Specific Information Incorporated by Reference**
SAR Section 3.3.3 and Table 3.3.5	**Methodology to calculate Time-To-Boil Limits and Generic TTB Limits in the Table.**

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7.1 PACKAGE LOADING

Note: This section, including tables and figures, is an integral part of the Certificate of Compliance (CoC) of the package.

The HI-STAR 180 Package is used to load and transport spent fuel. The essential elements required to prepare the HI-STAR 180 Package for fuel loading, to load the fuel, to ready the cask for transport and to ship the HI-STAR 180 Package as a Transport Package are described below.

7.1.1 Preparation for Loading a Cask

1. If the HI-STAR 180 Packaging has previously been used to transport spent fuel, the HI-STAR 180 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 180 Packaging is visually receipt inspected to verify that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. Any issues are identified to site management. Any road dirt is washed off and any foreign material is removed.
3. Radiological surveys are performed in accordance with 49CFR173.443 and 10CFR20.1906. If necessary, the HI-STAR 180 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 trunnion hole plugs, if installed, are removed and the cask trunnions are installed. The cask is upended and the neutron shield pressure relief devices are inspected to confirm that they are installed, intact, and not covered by tape or any other covering.
6. The cask lids are removed and used seals are removed and discarded. If equipped, the neutron shield pressure relief device(s) on the inner closure lid is inspected to confirm it is installed, intact, and not covered by tape or any other covering.
7. The containment closure flange inner and outer lid seal 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 seal surface is weld repaired, the seal surfaces are faced with corrosion resistant veneers.
8. The inner and outer closure lid bolts are inspected for distortion and damaged threads and any suspect bolts are replaced.
9. Any foreign material is removed from inside the cask and the basket panels are visually checked to verify they are not damaged.

7.1.2 Loading of Cask Contents

7.1.2.1 Fuel Loading Operations

ALARA Note:
A bottom protective cover may be attached to the cask bottom or placed in the designated preparation area or spent fuel pool. This will help prevent embedding contaminated particles in the cask bottom surface and ease the decontamination effort. Waterproof tape placed over empty bolt holes and bolt plugs may also reduce the time required for decontamination. Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

1. The cask containment closure flange seal surfaces are covered with a protective cover or a protective funnel. Caps or plugs are installed on the neutron shielding enclosure pressure relief devices. The user ensures that the proper fuel spacers (fuel shims or Fuel Impact Attenuators (FIAs)) are positioned in the bottom of basket cell locations where a fuel spacer is determined to be required based on the specific fuel assembly to be loaded there and the as-built cask cavity length. 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. (In what follows, cask cavity and fuel pool are used synonymously).

2. If used, dummy fuel assemblies are installed at this time or during fuel loading. Removal and reinstallation are allowed during fuel loading if necessary.

3. Prior to loading the fuel, the user identifies the fuel to be loaded and the fuel is independently verified that it meets the conditions of the CoC and this Chapter. Users performing burnup verification shall refer to Appendix 7.B.

4. Quivers may be loaded with contents, dried, backfilled and leak tested prior to loading into the cask. Prior to loading the quiver with spent fuel rods, the user identifies the fuel rods (or fuel debris) to be loaded and the content is independently verified that it meets the conditions of the CoC and this Chapter.

5. Prior to loading quivers into the cask, the user identifies the quivers to be loaded and the quivers are independently verified that they meet the conditions of the CoC and the operational requirements in Table 7.1.5.

6. The pre-selected assemblies, dummy fuel assemblies and quivers (as applicable) are loaded into the cask and a visual verification of the assembly identification is performed. Any additional information required to be documented by the CoC or this Chapter for the shipping manifest must be recorded.

7. If equipped, the neutron shield pressure relief device(s) on the inner closure lid is verified to be undamaged prior to fuel loading or prior to becoming inaccessible by the outer closure lid installation. Caps or plugs are installed on the neutron shielding enclosure pressure relief devices.

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Caution:
The inner closure lid bolts are installed at any time after the inner closure lid is installed but before the cask is dried. When installing inner closure lid bolts, the bolts must remain loose until the inner closure lid vent port (and any connected vent line) is opened to prevent pressure build-up in the cask. If installing inner closure lid bolts underwater, then the inner closure lid vent port must be open.

8. While still underwater, the containment closure flange seal protection device is removed. The containment closure flange sealing surfaces for the inner closure lid are inspected to verify they are free of particulate matter or damage that might affect the seal performance. Any particulate matter or damage that would prevent a seal is remedied. Prior to placing the inner lid in the water its sealing surfaces are inspected to verify they are free of particulate matter or damage that might affect seal performance. Any particulate matter or damage that would prevent a seal is remedied. New seals are installed in the inner closure lid and the lid is then lowered into the water and installed on the cask. The lid is visually inspected to confirm it is properly seated. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to the start of draining operations. Bounding time limits for design basis fuel are shown in Table 3.3.5 using the methodology in Section 3.3.3. Users may use these bounding limits or calculate their own time limits using the methodology of Section 3.3.3. If it appears that the Time-to-Boil limit will be exceeded prior to draining operations, the user shall take appropriate action to either replace the water in the cask cavity with an inert gas, circulate water through the cask cavity to reset the Time-to-Boil clock, or return the cask to the spent fuel pool and remove the lid to allow for natural water circulation. If the inner closure lid vent port is open, the inner closure lid bolts may be installed at this time.

ALARA Note:
Activated debris may have settled on flat surfaces of the cask during fuel loading. Cask surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce decontamination time, the cask surfaces should be kept wet until decontamination begins.

9. 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.

10. The accessible areas of bottom of the cask and the cask bottom protective cover, if used, are decontaminated, the cask is placed in the designated preparation area and the lift attachment is removed. The top surfaces and accessible areas of the cask are decontaminated. Caps or plugs are removed from the neutron shielding enclosure pressure relief devices.

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11. At the discretion of Radiation Protection, dose rates are measured at the inner closure lid and around the cask body to confirm appropriate radiological control. The inner closure lid vent port is opened and temporary shielding (if used) is installed.

12. Any standing water is removed from the inner and outer closure lid bolt holes in the closure flange. The inner closure lid bolts are installed and torqued after the vent port is opened and before the cask cavity is either drained or dried. Bolt torque values and patterns are provided in Table 7.1.1 and Figure 7.1.1, respectively. If desired, the user may attach security seals to the inner closure lid bolts at this time.

ALARA Warning:
Personnel should remain clear of the drain lines any time water is being pumped or purged from the cask. Radiological crud, suspended in the water, may create a radiation hazard to workers. Dose rates will rise as water is drained from the cask. Continuous dose rate monitoring is recommended.
Caution:
An inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during loading operations.

13. For drying with forced helium, the Forced Helium Dehydration (FHD) System is connected to the cask and used to remove moisture from the cask cavity. There is no time limit on FHD drying. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. After the bulk water has been removed, the helium exiting the FHD demoisturizer is cooled to a temperature or dew point given in Table 7.1.2 and circulated through the duration given in Table 7.1.2 to ensure that the cask cavity is suitably dry.

14. For drying with vacuum, a vacuum drying system is connected to the cask and used to remove moisture from the cask cavity. The user performs a site-specific evaluation to determine whether cyclic vacuum drying and time limits are necessary to ensure the vacuum drying criteria is met. Users shall refer to Table 7.1.2 and Table 7.1.3 for vacuum drying criteria. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. The cask cavity is vacuum dried. Once it is demonstrated that the cask cavity pressure meets the pressure criterion given in Table 7.1.2 for the duration given in Table 7.1.2, with the valve closed, it shall be considered dry.

15. The cask cavity is backfilled to the requirements in Table 7.1.4 and the port caps/plugs are closed.

16. With the inner closure lid inter-seal test port plug (that will be located beneath the outer closure lid access port) removed, the inner closure lid inter-seal space is dried. The inner closure lid inner seal is helium leak tested through its respective inter-seal test ports in

accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting of the seals. The leak testing of the inner closure lid main seal may be performed immediately after the lid bolts are installed and torqued such that if a leak is detected, the cask does not need to be reflooded.

17. The sealing surfaces of the inner closure lid port covers and its respective mating surfaces on the inner closure lid are inspected for signs of damage. Any damage that would prevent a seal is remedied and new seals are installed. The space beneath the port covers are backfilled to the requirements in Table 7.1.4. The port cover bolts are torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The vent and drain port cover plate inner seals are leak tested through their respective inter-seal test port in accordance with test requirements and acceptance criteria provided in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting of the seals. Following the leakage test, the vent and drain port cover plate inter-seal test port plugs are left removed.

7.1.2.2 Cask Closure

1. The inter-seal test port plug(s) of the inner closure lid are installed with new seals and torqued. The containment closure flange outer seal surface protective cover is removed. The containment closure flange sealing surfaces for the outer closure lid are inspected to verify they are free of particulate matter or damage that might affect the seal performance. Any particulate matter or damage that would prevent a seal is remedied. 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. Verification is made that the port cover inter-seal test plugs on the vent port cover plate and the drain port cover plate are both removed and left removed. The outer closure lid is installed using new seals and with the outer closure lid access port positioned directly above one of the inner closure lid inter-seal test ports. The outer closure lid bolts are 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. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4.

3. The outer closure lid access port plug is fitted with a new seal and torqued to the requirements in Table 7.1.1.

4. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested in accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting of the seals.

5. The outer closure lid access port cover is installed with a seal and port cover bolts are torqued. The outer closure lid inter-seal test port plug(s) is installed with new seal and torqued.

7.1.3. <u>Preparation for Shipment of a Loaded Cask</u>

1. If more than twelve months have elapsed since the performance of the leakage tests described in Section 7.1.2.2, a periodic leakage test shall be performed as follows:

   a. The outer closure lid access port plug and the inner closure lid inter-seal test port plug are removed.

   b. The inner closure lid inner seal and vent and drain port cover plate inner seals are leak tested through the inter-lid space in accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting of the seals.

   c. The inner closure lid inter-seal test port plug(s) is installed with a new seal.

   d. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4.

   e. The outer closure lid access port plug is fitted with a new seal and torqued to the requirements in Table 7.1.1. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested in accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates may require cleaning or repair of the seal surfaces and replacement of the seals prior to retesting of the seals.

   f. The outer closure lid access port cover and outer closure lid inter-seal test port plug(s) are installed with new seals and torqued.

2. The cask neutron shield pressure relief devices are visually verified to be undamaged.

ALARA Warning:
Dose rates around the 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.
Note: If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

3. The cask is moved to the transport location, downended, and placed on the transport vehicle.
4. A visual inspection for signs of impaired condition is performed. Any non-satisfactory conditions are remedied.
5. Contamination surveys are performed per 49CFR173.443. If necessary, the cask is further decontaminated to meet the survey requirements.
6. The cask trunnions are removed and the trunnion hole plugs are installed. The impact limiters are installed on the cask and the bolts/nuts are torqued in accordance with Table 7.1.1.
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 [7.1.4] and 49CFR173.443 [7.1.2] are performed and if necessary, the HI-STAR 180 Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents.
9. The surface temperature of the accessible areas of the package are measured to confirm temperatures are within 10CFR71.43 requirements, if the personnel barrier will not be used.
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 [7.1.1].

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 including information required by the references from this chapter to other chapters.

Following the above checks, the Transport Package is released for transport.

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Table 7.1.1

HI-STAR 180 Package Torque Requirements (See Note 6)
(Sheet 1 of 2)

Fastener (See Note 1)	**Recommended Torque (N-m), τ** (See Note 2)	**Minimum Total Bolt Preload** kN (lbf) (See Note 7)	**Comments**
Inner Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	39,985 ($8.989x10^6$)	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Outer Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	28,940 ($6.506x10^6$)	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Inner Closure Lid Port Cover Bolts	See Note 3	171 ($3.844x10^4$)	None
Outer Closure Lid Access Port Plug	See Note 3	40 ($8.992x10^3$)	None
Top and Bottom Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Top and Bottom Impact Limiter Adapters Bolts/Nuts	"Snug Tight"	N/A	None

Table 7.1.1

HI-STAR 180 Package Torque Requirements
(Sheet 2 of 2)

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 (derived from Shigley, et. al.*),

   $\tau = (P_B)(K)(d)$

   where, K = Torque coefficient

   The torque coefficient, K, varies depending on bolt lubricant used (e.g. extremely effective lubricants such as Bowman Anti-Sieze have a K value = 0.12).

   P_B = Minimum Bolt Preload.

   d = Nominal bolt diameter (soft conversion between metric and US units is permitted)

   Fastener sizes are provided in the drawing package 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.

* Shigley J. D. and Mischke C. R., "Mechanical Engineering Design", 5th Edition, pp 346-347, Mc Graw Hill (1989).

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Table 7.1.2

Cask Drying Method and Dryness Criteria

Fuel Burnup (MWD/MTU)	**Heat Load (kW)**	**Method of Moisture Removal (Note 1)**
All Fuel Assembly Burnups	Up to maximum cask heat load in Table 1.2.3a Q_{DB}	Forced Helium Dehydration
		Vacuum Drying (continuous and cyclic) (Note 2)
Recommended Dryness Criteria (Note 1)		
Forced Helium Dehydration	Temperature or dew point of gas exiting the FHD demoisturizer, T_{FHD}	≤ -5.0°C (22.9°F)
	Duration of gas circulation at T_{FHD}	≥ 30 minutes
Vacuum Drying (continuous and cyclic)	Cask cavity vacuum pressure, P_{VAC}	≤ 0.4 kPa (3 Torr)
	Duration of isolated cask cavity at P_{VAC}	≥ 30 minutes

Notes:
1. Users shall refer to Table 7.1.3 for criteria applicable to cask drying operations.
2. Time limits may be applicable.
3.

Table 7.1.3

Criteria Applicable to Cask Drying Operations

Criterion	Specification
Fuel Cladding Temperature Limit	400ºC (752ºF) (High Burnup Fuel)
	570°C (1058°F) (Moderate Burnup Fuel)
Fuel Cladding Temperature Excursion During Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision
Thermal Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision

Table 7.1.4

Cask Backfill Requirements

Cask Space	**Reference Pressure or Pressure Range**
Cask Cavity Space (Notes 1 and 2)	20 kPa (2.9 psia) to 40 kPa (5.8 psia) absolute pressure
Cask Inter-Lid Space (Notes 1 and 3)	0 kPa (0 psig) to 17.2 kPa (2.5 psig) gauge pressure
Inner Closure Lid Port Space	atmospheric
Recommended Backfill Gas	
Type	Helium
Reference Purity	99.99% Nom.

Notes:

1. The reference pressure is based on a reference cask space bulk temperature of ≥ 21.1ºC (70ºF)
2. Following cask drying operations, the gas temperature inside the cask cavity will be higher than 21.1ºC (70ºF); 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 21.1ºC (70ºF), the gas temperature in the inter-lid cavity will be higher than 21.1ºC (70ºF); 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 21.1ºC (70ºF), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1ºC (70ºF) 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.

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Table 7.1.5

Quiver Operational Requirements

Criterion	Specification
Condition of Fuel Rods	Either broken fuel rods or fuel debris or otherwise punctured fuel rods with nominal 3 mm or larger opening
Dryness	≤ 0.4 kPa (3 Torr)
Backfill Pressure (Notes 1 and 2)	20 kPa (2.9 psig) to 40 kPa (5.8 psig) gauge pressure
Backfill Gas	99% Nom. purity Helium
Leaktightness	≤ $1x10^{-7}$ ref-cm^3/s air ($1x10^{-8}$ Pa-m^3/s air)

Notes:

1. The reference pressure is based on a reference quiver space bulk temperature of ≥ 21.1ºC (70ºF).
2. For ambient temperatures above 21.1ºC (70ºF), the gas temperature in the quiver cavity will be higher than 21.1ºC (70ºF); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the quiver cavity pressure is sufficient to establish the proper backfill conditions. For ambient temperatures below 21.1ºC (70ºF), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1ºC (70ºF) using the ideal gas law. Use of pressure gauges to confirm that the quiver cavity pressure is between the adjusted limits is sufficient to establish the proper backfill conditions.

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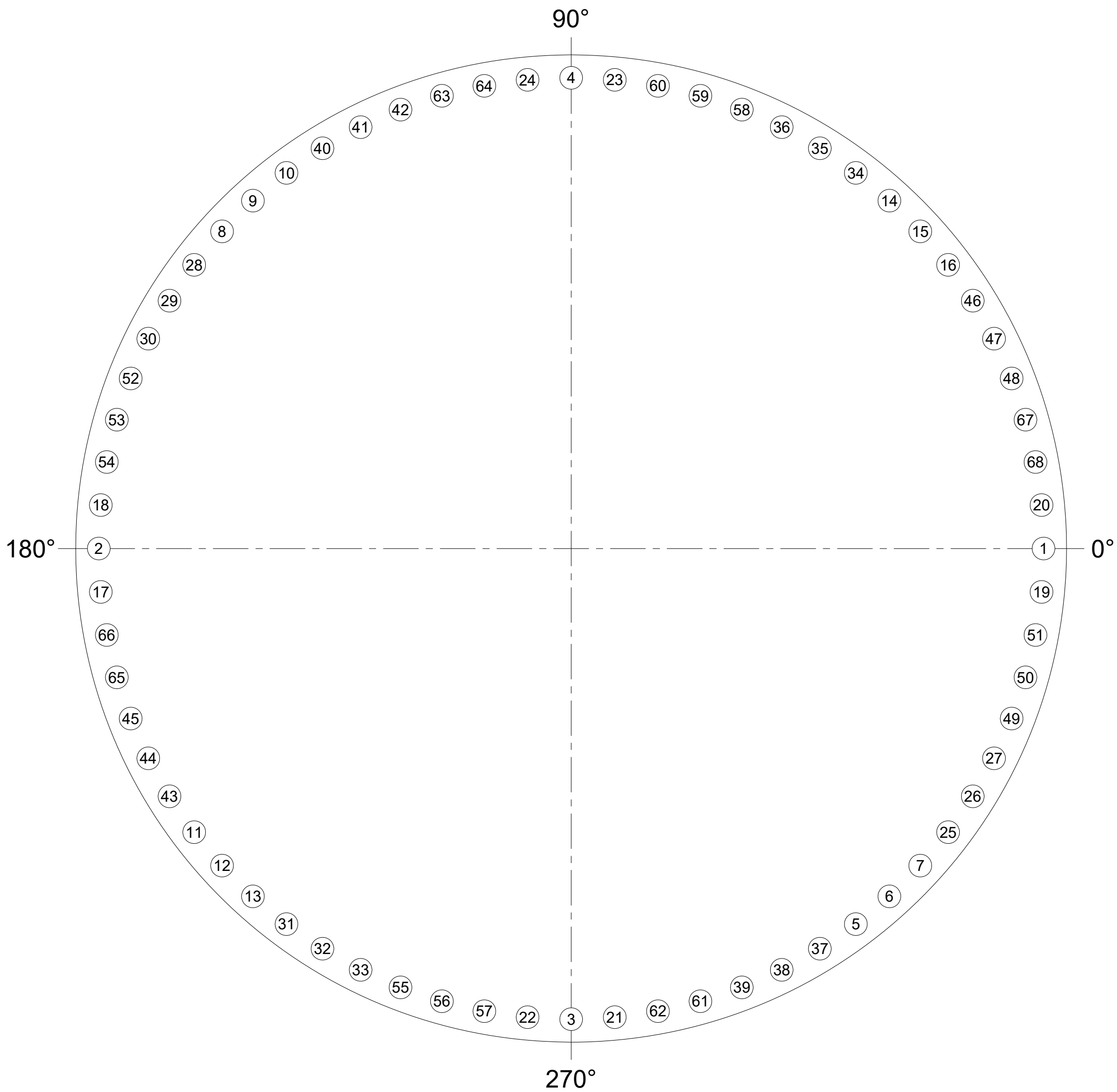

Note: Closure lid bolts are to be tightened uniformly. Due to the large diameter of the closure lids and other factors, the standard star pattern with added flexibility is permitted. The tightening sequence in this example pattern shows that after bolts 1 thru 4 are tightened, the remaining bolts may be tightened in groups of up to three (e.g. bolts 5, 6 and 7) before moving to diametrically opposed bolts (e.g. 8, 9 and 10). Tools designed to torque more than one bolt at a time (e.g. bolts 1 and 2 simultaneously) may be implemented and are recommended as good ALARA practice. Alternate patterns shall be approved by Holtec.

FIGURE 7.1.1

EXAMPLE BOLT TORQUE PATTERN FOR 68 BOLT CLOSURE LIDS

7.2 PACKAGE UNLOADING

Note: This section is an integral part of the Certificate of Compliance (CoC) of the package.

In the event that the HI-STAR 180 Package needs to be unloaded, the essential elements required to prepare the package for fuel unloading, to cool the stored fuel assemblies in the cask, to flood the internal cavity, to remove the lids and bolts, to unload the spent fuel assemblies, and to recover the cask are described below.

7.2.1 Receipt of Package from Carrier

1. The HI-STAR 180 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 installed, 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 [7.1.2] and 10CFR20.1906 [7.1.3]. If necessary, the HI-STAR 180 Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties.

ALARA Warning:
Dose rates around the bottom end of the HI-STAR 180 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.

4. The impact limiters and tie-down system are removed.
5. The cask is visually inspected to verify there are no outward visual indications of impaired physical conditions and a radiation survey and a removable contamination survey are performed to establish appropriate radiological controls. Any issues are identified to site management.

Note:
If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

6. The trunnion hole plugs are removed and the cask trunnions are installed. The cask is upended and returned to the fuel building or other unloading area.
7. The cask is placed in the designated preparation area.

7.2.2 Removal of Contents

1. The outer lid access port cover is removed and a gas sample is drawn from the inter-lid space to determine radiological conditions.

2. The inter-lid space gas is handled in accordance with Radiation Protection directions and the outer closure lid is removed.

3. The inner closure lid port covers are removed to access the vent and drain ports.

ALARA Warning:
Gas sampling is performed to assess the condition of the fuel cladding. If a leak is discovered in the fuel cladding, the user's Radiation Control organization may require special actions to vent the cask cavity.
Caution:
An inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during unloading operations.

4. A temporary attachment is connected to the vent port to open the vent port tube cap/plug and a gas sample from inside the cask cavity is collected. A gas sample analysis is performed to assess the condition of the fuel assembly cladding. As necessary during preparation for lid removal, the gas inside the cask cavity is handled/vented to an approved location. Depending on cask cavity pressure, the cavity may require additional backfill or venting to equalize its pressure to atmospheric.

5. If the cask is to be unloaded under water, the cask is filled with water at a controlled rate to minimize thermal shock to the fuel assemblies and to avoid over-pressurizing the cask from the formation of steam. The effluent is directed to the spent fuel pool or other approved discharge point.

6. If the cask is not immediately moved to the spent fuel pool, water is circulated through the cask to cool the contents and allow for establishment of a Time-To-Boil time limit. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to placement of the cask in the spent fuel pool. If it appears that the Time-to-Boil limit will be exceeded prior to placement of the cask in the spent fuel pool, the user shall take appropriate action to circulate water through the cask cavity to reset the Time-to-Boil clock.

7. The inner closure lid bolts may be removed at any time from after the internal cavity pressure is equalized until the time the inner closure lid is to be removed. In addition, the inner closure lid bolts are removed either before the cask is placed in the spent fuel pool or other fuel unloading area or after placement of the cask in one of these areas.

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

8. The lift attachment is engaged to the lifting trunnions and the cask is placed in the spent fuel pool or other appropriate unloading area. The inner closure lid is removed.

9. All fuel assemblies are returned to the spent fuel storage racks and the cask fuel cells are vacuumed to remove any assembly debris and crud.

10. The fuel cells are inspected for any remaining items to be removed as appropriate.

ALARA Warning:
Activated debris may have settled on flat surfaces of the cask during fuel unloading. Surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce contamination of the cask, the surfaces of the cask and lift yoke should be kept wet until decontamination can begin.

11. The cask is returned to the designated preparation area and any water is pumped back into the spent fuel pool, liquid radwaste system or other approved location as necessary.

12. The cask is decontaminated as directed by site Radiation Protection personnel. Outer surfaces of the cask are decontaminated to remove surface contamination to the level necessary to allow for proper cask transport, loading, or storage as applicable.

7.3 PREPARATION FOR SHIPMENT OF AN EMPTY CASK

Note: This section is an integral part of the Certificate of Compliance (CoC) of the package.

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 [7.1.2] and 10CFR71.87(i) [7.1.4] are met. At the user's discretion, impact limiters and/or personnel barrier are installed. The procedures provided herein describe the installation of the impact limiters and personnel barrier. These steps may be omitted, as appropriate.

7.3.2 Preparation for Empty Package Shipment

1. The containment closure flange inner closure lid seal surface protector is removed from the cask, if necessary.

2. The cask is surveyed for contamination and verified to be empty and contain less than 15 gm U-235 in accordance with 49CFR173.421(a)(5).

3. The inner closure lid is installed and the bolts are torqued. See Table 7.1.1 for torque requirements.

4. The inner closure lid port covers are installed if necessary.

5. The containment flange outer closure lid seal surface protector is removed, if necessary, the outer closure lid is installed, and the bolts are torqued. See Table 7.1.1 for torque requirements. If desired, a security seal may be attached to the outer closure lid bolts.

6. The outer closure lid access port plug and access port cover are installed if necessary.

Note:
If the cask is to be lifted horizontally using the trunnions, the lifting equipment shall be designed to ensure that the load on the bottom trunnions is evenly distributed between the two trunnions.

7. The cask is downended and positioned on the transport equipment.

8. A final inspection of the cask is performed and includes the following:

   - A final survey for removable contamination on the accessible external surfaces of the cask in accordance with 49CFR173.443(a). If necessary, the cask is decontaminated to meet the survey requirements.

   - A radiation survey of the cask to confirm that the radiation levels on any external surface of the cask do not exceed the levels required by 49CFR173.421(a)(2). Any issues are identified to site management and the cask is decontaminated as directed by site radiation protection.

   - A visual inspection of the cask to verify that there are no outward visual indications of impaired physical condition except for superficial marks and dents and that the empty package is securely closed in accordance with 49CFR173.428(b).

   - Verification that the cask neutron shield pressure relief devices are installed, are intact and are not covered by tape or other covering.

9. If necessary, the cask trunnions are removed, the trunnion hole plugs are installed, the impact limiters are installed and the impact limiter bolts/nuts are torqued. (See Table 7.1.1 for torque requirements.)

10. If desired, a security seal is installed on the top impact limiter.

11. Final radiation surveys of the empty package surfaces are performed per 10CFR71.47, and 49CFR173.428(a).

12. If desired, the personnel barrier and personnel barrier locks are installed and the personnel barrier keys are transferred to the carrier.

13. A final check to ensure that the empty package is ready for release is performed and includes the following checks:

    - Verification that the receiver has been notified of the impending shipment.

    - Verification that any labels previously applied in conformance with Subpart E of 49CFR172 [7.1.1] have been removed, obliterated, or covered and the "Empty" label prescribed in 49CFR172.450 is affixed to the packaging in accordance with 49CFR173.428(e).

    - Verification that the empty package for shipment is prepared in accordance with 49CFR173.422.

    - Verification that all required information is recorded on the shipping documentation.

14. The empty package is then released for transport.

7.4 OTHER OPERATIONS

There are no other operations for the HI-STAR 180 Package with regard to provisions for any special operational controls (e.g., route, weather, shipping time restrictions, etc.). Essential operations and controls are detailed in Chapter 7 of this SAR.

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CHAPTER 7 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table.

[7.1.1] U.S. Code of Federal Regulations, Title 49 “Transportation”, Part 172 "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements, and Security Plans."

[7.1.2] U.S. Code of Federal Regulations, Title 49 “Transportation”, Part 173, "Shippers – General Requirements for Shipments and Packages,"

[7.1.3] U.S. Code of Federal Regulations, Title 10, “Energy”, Part 20 "Standards for Protection against Radiation".

[7.1.4] U.S. Code of Federal Regulations, Title 10, “Energy”, Part 71 "Packaging and Transportation of Radioactive Material".

APPENDIX 7.A: SUPPLEMENTARY INFORMATION

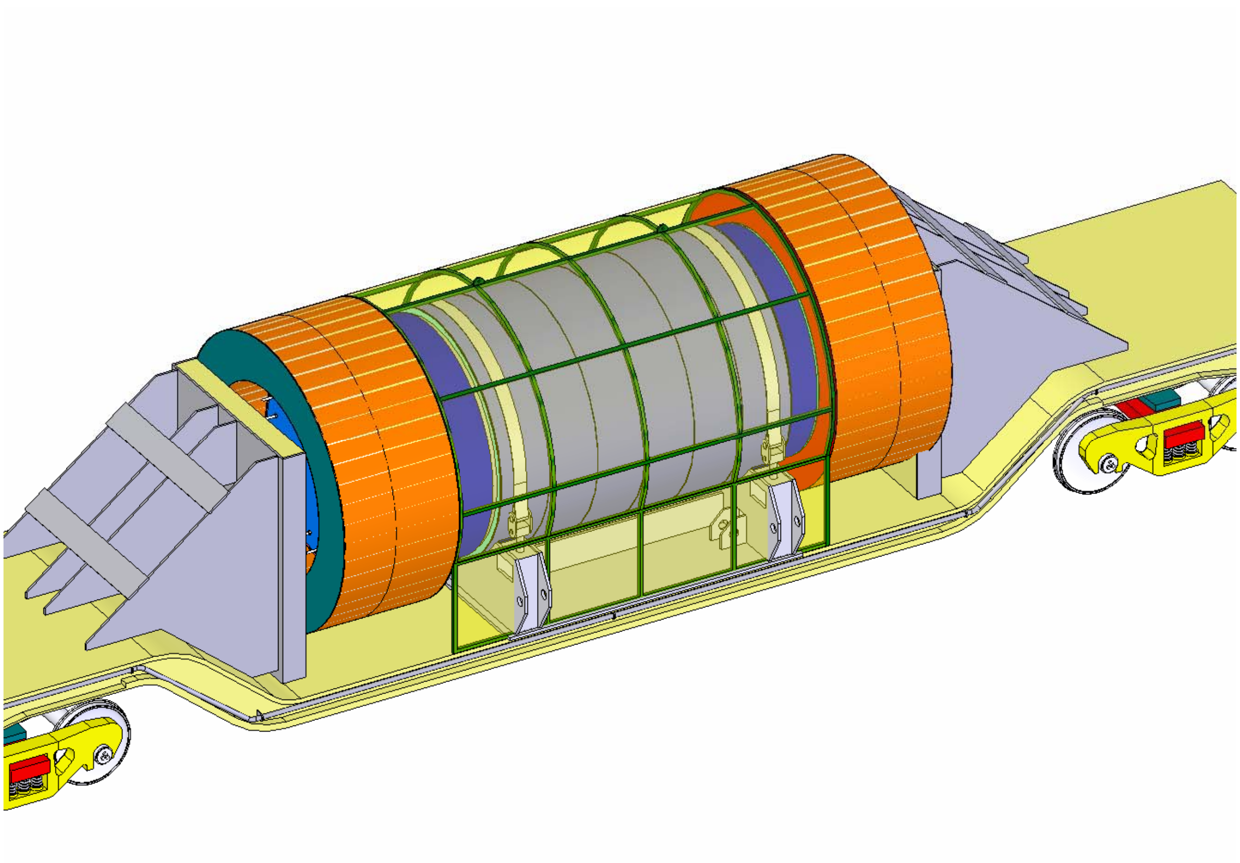

FIGURE 7.A.1: GENERAL ARRANGEMENT OF THE HI-STAR 180 ON A RAIL CAR WITH IMPACT LIMITER, TIE-DOWNS AND PERSONNEL BARRIER ATTACHED (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

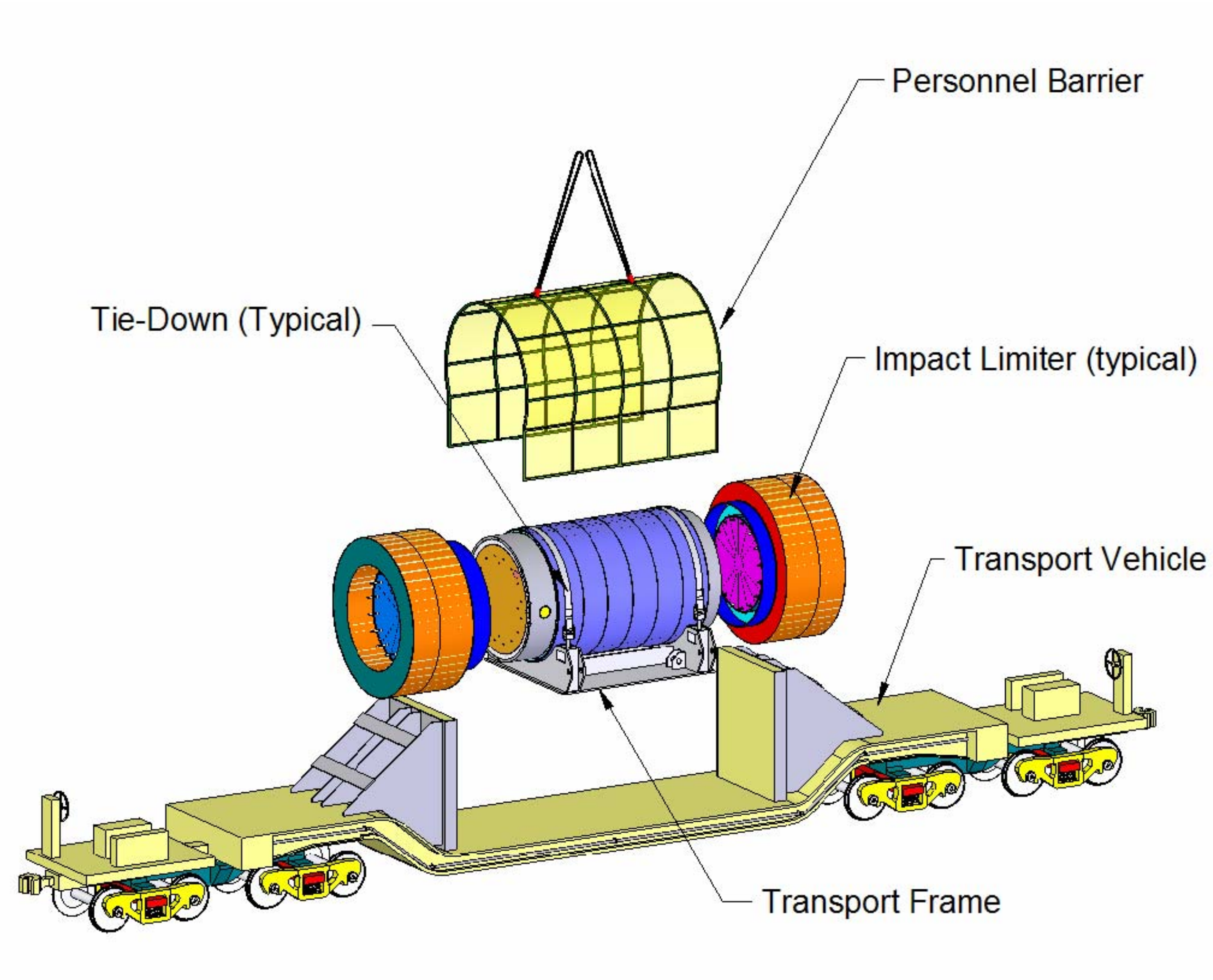

FIGURE 7.A.2: HI-STAR 180 TRANSPORT ASSEMBLY
(EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

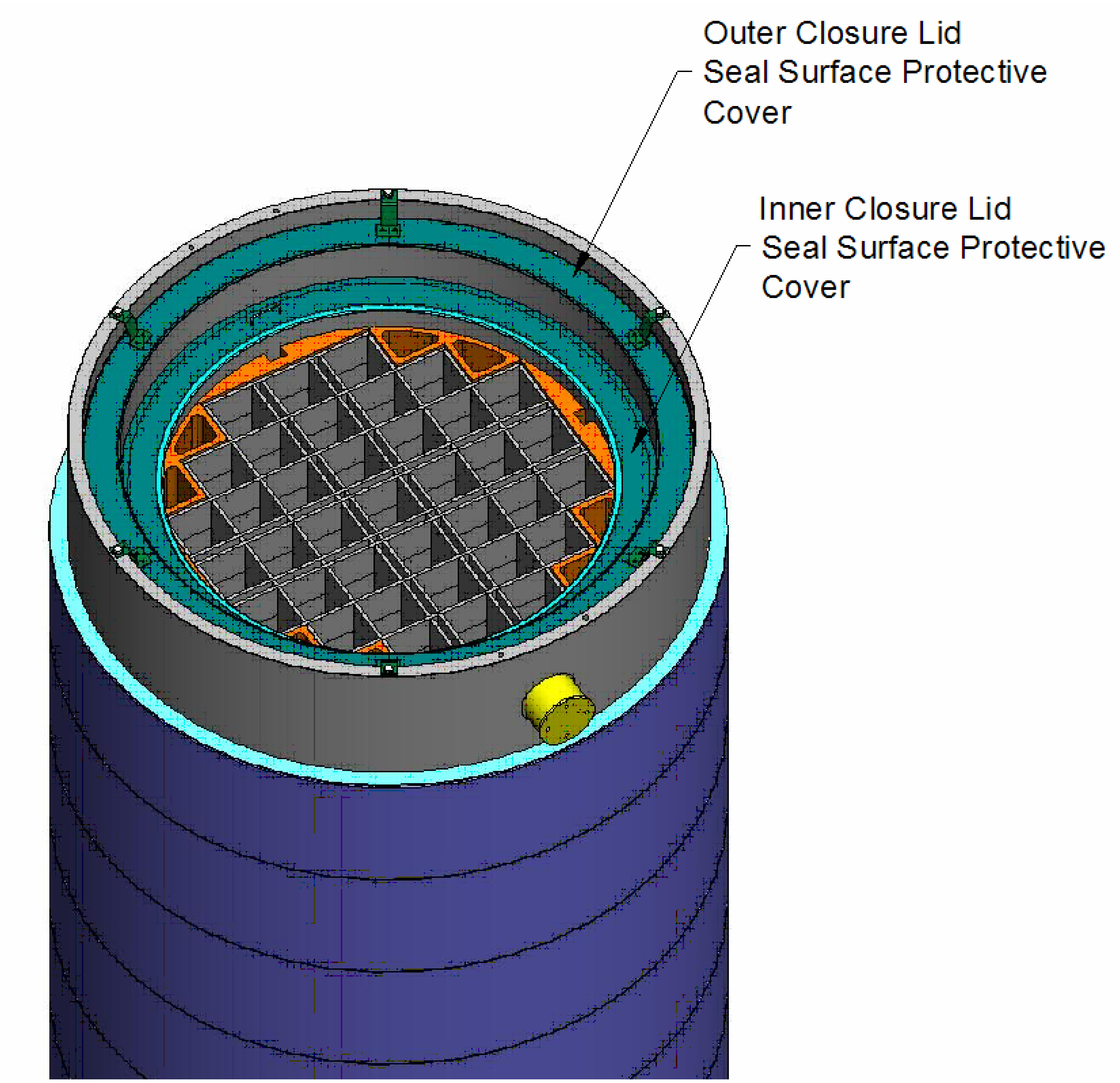

FIGURE 7.A.3: HI-STAR 180 SHOWN WITH INNER AND OUTER CLOSURE LIDS REMOVED AND SEAL SURFACE PROTECTIVE COVERS INSTALLED ON THE CONTAINMENT CLOSURE FLANGE (SEAL SURFACE PROTECTORS SHOWN FOR EXAMPLE ONLY AND MAY VARY IN ACTUAL CONFIGURATION DETAILS)

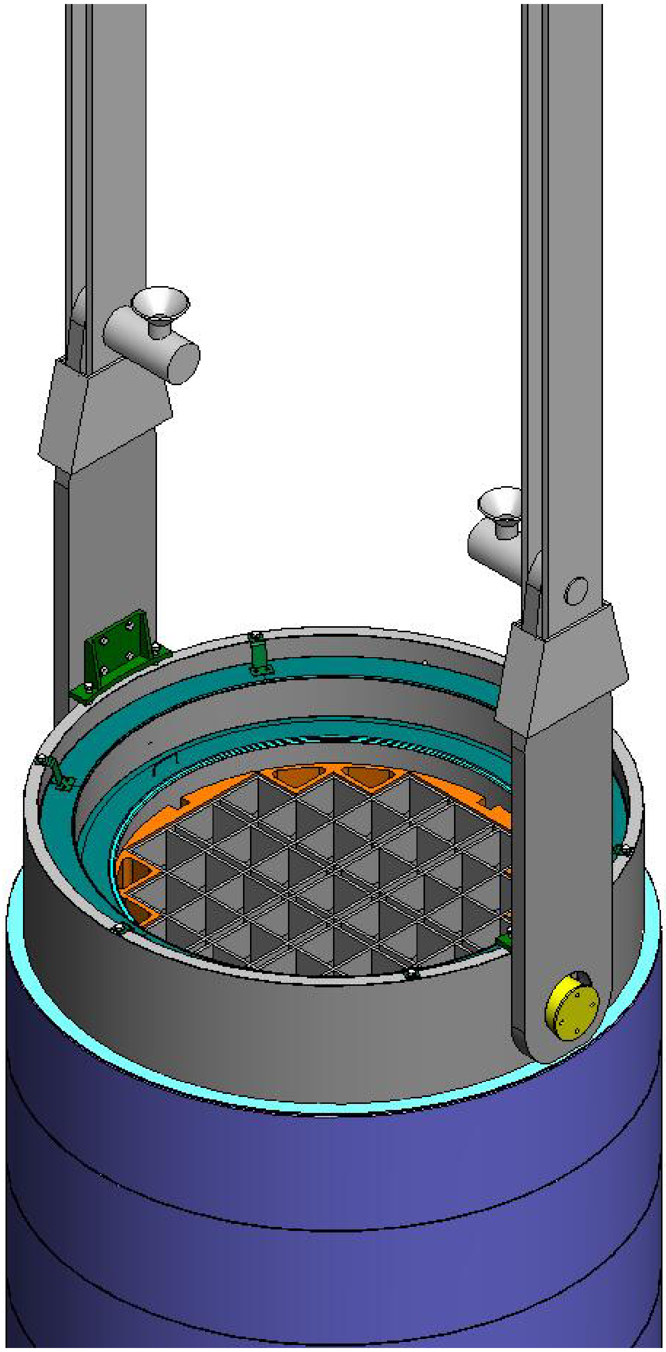

FIGURE 7.A.4: HI-STAR 180 SHOWN BEING LOADED INTO THE SPENT FUEL POOL (LIFTING ATTACHMENTS ARE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, FINAL CONFIGURATION OF LIFT ATTACHMENTS WILL BE DETERMINED BASED ON PLANT SYSTEMS)

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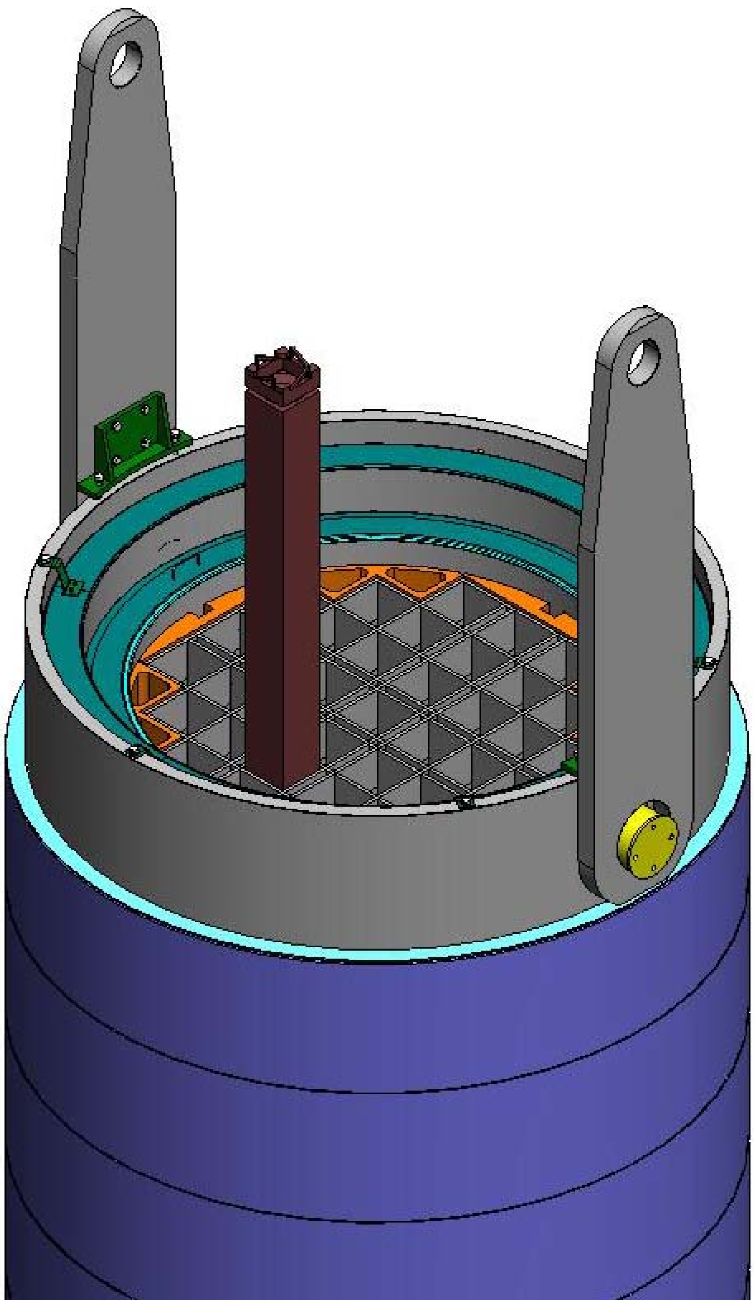

FIGURE 7.A.5: SPENT FUEL ASSEMBLY LOADING IN THE HI-STAR 180 (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

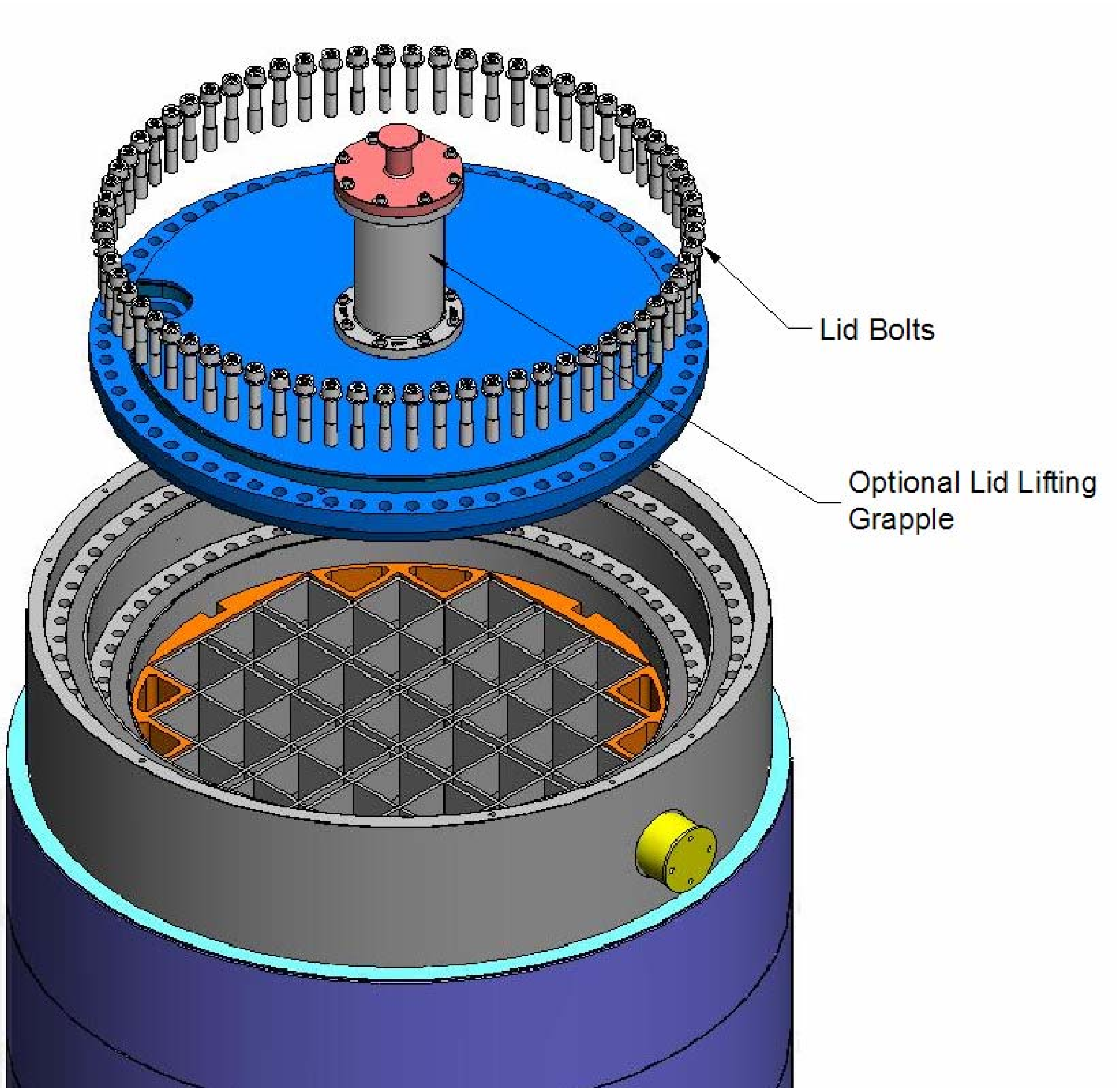

FIGURE 7.A.6: HI-STAR 180 INNER CLOSURE LID, BOLTS AND OPTIONAL LID LIFTING GRAPPLE ASSEMBLY (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

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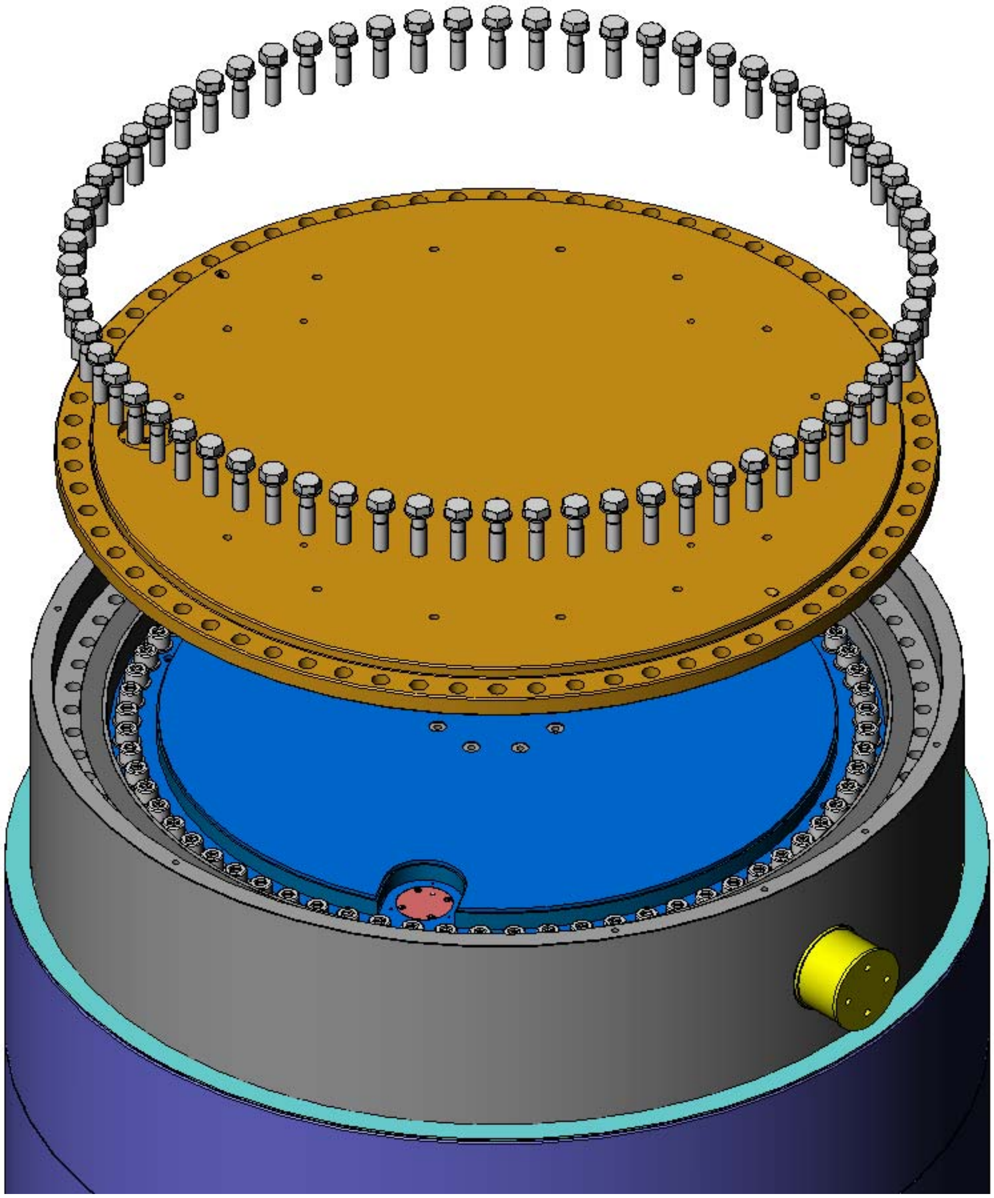

FIGURE 7.A.7: HI-STAR 180 OUTER CLOSURE LID EXPLODED VIEW (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

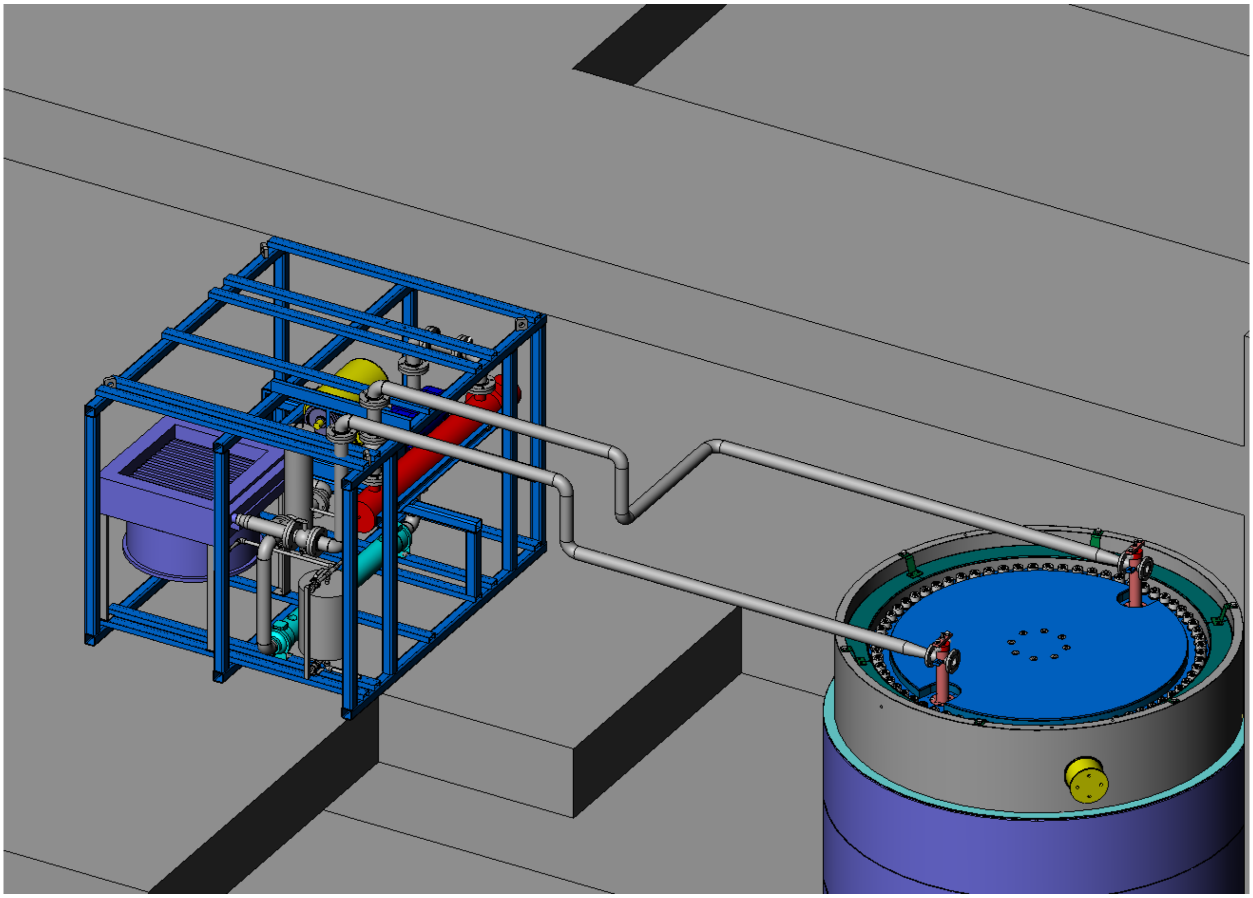

FIGURE 7.A.8: HI-STAR 180 SHOWN DURING DEWATERING, DRYING AND BACKFILL OPERATIONS (EXAMPLE CONFIGURATION FOR ILLUSTRATION ONLY, ACTUAL CONFIGURATION IS DEPENDENT UPON PLANT SYSTEMS)

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APPENDIX 7.B

BURNUP VERIFICATION CONDITIONS OF THE HI-STAR 180 PACKAGE

Note: This Appendix is an integral part of the Certificate of Compliance (CoC) of the package.

For those spent fuel assemblies that need to meet the burnup requirements specified in Table 1.2.7a, 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-37 where burnup credit is required, the minimum burnup is determined from the burnup requirement applicable to the configuration chosen for the cask (see Table 1.2.7a). 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-37 basket 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 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.

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CHAPTER 8: ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The text matter and data presented in this chapter in bold font (or as otherwise noted) are an integral part of the Certificate of Compliance (CoC) of the package and cannot be altered without NRC's approval through a license amendment. Moreover, essential elements of the acceptance tests in Section 8.1, the maintenance program in Section 8.2 and containment boundary seal data in Appendix 8.A have been identified as conditions of the CoC.

8.0 INTRODUCTION

This chapter identifies the acceptance tests and maintenance program to be conducted on the HI-STAR 180 Package to verify that the structures, systems and components (SSCs) classified as *important-to-safety* have been fabricated, assembled, inspected, tested, accepted, and maintained in accordance with the requirements set forth in this Safety Analysis Report (SAR), all applicable regulatory requirements, and the Certificate of Compliance (CoC). The acceptance criteria and maintenance program described in this chapter is in full compliance with the requirements of 10CFR Part 71 Subpart G [8.0.1].

The following specific SAR information is incorporated by reference in this Chapter. All other references to the SAR and Holtec documents are for completeness of information.

Reference Source	Specific Information Incorporated by Reference
SAR Table 2.2.12	• Maximum Total Load Needed to Compress Seals • Minimum "Useful" Springback to Maintain Leaktightness
SAR Table 2.1.14	All Code Alternatives
SAR Table 2.1.10	All Fracture Toughness Test Criteria

8.1 ACCEPTANCE TESTS

In this section the inspections and acceptance tests to be performed on the HI-STAR 180 Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR 180 Package has been fabricated, assembled and accepted for use and loading under the conditions specified in this SAR and the USNRC issued CoC in accordance with the requirements of 10CFR Part 71.

8.1.1 Visual Inspections and Measurements

The HI-STAR 180 Package shall be assembled in accordance with the licensing drawing package in the CoC. Dimensional tolerances that define the limits on the dimensions critical to the licensing basis analysis are included in these drawings. Fabrication drawings provide additional dimensional tolerances necessary to ensure fit-up of parts as well as compliance with the design conditions. A fabrication sampling plan shall be made and controls shall be exercised to ensure that the packaging conforms to the dimensions and tolerances specified on the licensing and fabrication drawings. These dimensions are subject to independent confirmation and documentation in accordance with the Holtec QA program approved in NRC Docket No. 71-0784.

The following shall be verified as part of visual inspections and measurements:

- **Visual inspections and measurements shall be made to ensure that the packaging effectiveness is not significantly reduced. Any *important-to-safety* component found to be under the minimum thickness requirement shall be repaired or replaced as required.**
- **Thread dimensions on important to safety SSC's shall be checked using calibrated thread gauges or may be accepted via a torque test as described in Paragraph 8.2.3.4.**
- **Visual inspections shall be made to verify that neutron absorber panels, basket shims and anti-rotation bars are present as required by cask and basket design.**
- **Visual Inspections shall be made to verify that fuel spacers (Fuel Impact Attenuators (FIAs), fuel shims or similar devices) are present as required by the cask design.**
- **The packaging shall be visually inspected to ensure it is conspicuously and durably marked with the proper markings/labels in accordance with 10CFR71.85(c).**
- **The packaging shall be inspected for cleanliness and preparation for shipping in accordance with written and approved procedures.**

The visual inspection and measurement results for the HI-STAR 180 Package shall become part of the equipment documentation package.

8.1.2 Weld Examination

The examination of HI-STAR 180 Package welds shall be performed in accordance with the drawing package referenced in the CoC, applicable codes and standards, and applicable code alternatives. Weld examinations and repairs shall be performed as specified below. **All code weld inspections and Metamic-HT weld inspections (excluding NITS welds and non-structural welds) shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [8.1.2].** All required inspections, examinations, and tests shall become part of the equipment documentation package.

The following specific weld requirements shall be followed in order to verify fabrication in accordance with the drawings.

1. **Containment boundary welds including any attachment welds (and temporary welds to the containment boundary) shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. Examinations, Visual (VT), Radiographic (RT), and Liquid Penetrant (PT) or Magnetic Particle (MT), apply to these welds as defined by the code. These welds shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450 and examined after repair in the same manner as the original weld. Weld overlays for cask sealing surfaces shall be VT and PT examined to 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. proper geometry, workmanship etc.).**

2. **NF welds on the cask (other than containment boundary welds) and on primary load bearing members of 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 (non-code) welds (e.g. seal welds).**

3. **Basket welds connecting Metamic-HT panels shall be examined and repaired in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for welding Metamic-HT with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition). The basket welds, made by the Friction Stir Weld process, are classified as Category 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 or as Non-Structural on the drawing package referenced in the CoC.**

4. **NITS (non-code) welds shall be examined and repaired in accordance with written and approved procedures**

8.1.3 Structural and Pressure Tests

The cask containment boundary will be tested by combination of methods (including helium leak test, pressure test, and NDE, as specified in this Chapter and the drawing package referenced in the CoC) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

8.1.3.1 Lifting Trunnions

Two top trunnions are provided for vertical lifting and handling of the loaded cask. The top trunnions are required to be tested and inspected in accordance with ANSI N14.6 [8.1.3]. Two bottom trunnions are provided for rotation of the loaded cask and may be used for horizontal cask lifting and handling. **If the bottom trunnions are to be used for lifting and handling of the loaded cask they must be tested and inspected in accordance with ANSI N14.6. Otherwise, the bottom trunnions may be tested and inspected in accordance to commercial specifications and requirements acceptable for similar nuclear applications and as clarified further below.** Both top and bottom trunnions are rendered inoperable in the transport package configuration.

The top lifting trunnions shall be tested in accordance with ANSI N14.6 at 300% of the maximum design (service) lifting load (the full weight of the loaded cask at a minimum). Load tests may be performed in excess of the maximum design (service) lifting load provided an engineering evaluation is performed to ensure trunnions or other cask components will not be damaged by the load test. The test load shall be applied for a minimum of 10 minutes. The accessible parts of the top trunnions (areas outside the cask), and the local cask areas shall then be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and top trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require replacement of the trunnion and/or repair of the cask. Following any replacements and/or major repair, as defined in ANSI N14.6, the load testing shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria. Testing shall be performed in accordance with written and approved procedures. Certified material test reports verifying trunnion material mechanical properties meet ASME Code Section II requirements provide further verification of the trunnion load capabilities. Test results shall be documented and shall become part of the equipment documentation package.

The requirements for ANSI N14.6 regarding the testing and inspection in the preceding paragraph for the top trunnions also apply to the bottom trunnions if they are to be used for horizontal lifting. The maximum rated load of the bottom trunnions shall be greater than or equal to one half the rated load of the top trunnions times a factor of 1.15. The 1.15 multiplier ensures a trunnion rating that conservatively accounts for offset in the cask center of gravity (C.G.). Even if the bottom trunnions are not used for lifting of the cask, they must be load tested to 200% the rated load for a minimum of 10 minutes and inspected in the same manner described in the foregoing.

8.1.3.2 Pressure Testing

Pressure testing of the HI-STAR 180 containment boundary (cavity space) and expanded containment boundary (inter-lid space) is required.

The cask cavity space shall be hydrostatically or pneumatically pressure tested at the required multiple of the design internal pressure in accordance with the provisions of the ASME Code Section III, Subsection NB, Article NB-6000. In addition, the cask cavity test pressure shall not be less than 150% of cask cavity maximum normal operating pressure per 10CFR71.85(b) and shall not be less than 100 psig.

The inter-lid space shall be hydrostatically or pneumatically pressure tested at the required multiple of the maximum operating pressure in accordance with ASME Section III, Subsection NB, NB-6000. In addition, the cask inter-lid space test pressure shall not be less than the test pressure used to qualify the cask cavity space.

The pressure test may be performed at any time during cask fabrication after containment boundary fabrication is completed. Pressure testing may be performed in various cask closure configurations as needed to ensure each containment boundary closure is pressure tested at least once; however, containment seals do not require pressure testing. Containment boundary closures may be tested with single temporary test seal.

All pressure testing shall be performed in accordance with written and approved procedures written by qualified personnel in accordance with the Holtec QA program. The written and approved test procedure shall clearly define the test equipment arrangement. SNT-TC-1A is not applicable to this test; however, for quality assurance, trained and qualified personnel shall perform the test and the leakage verification in accordance with written procedures and document the results. The leakage verification shall be performed in accordance with written quality assurance program.

Test results shall be documented and shall become part of the equipment documentation package.

8.1.4 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5 [8.1.6] as specified in this Chapter. Tables 8.1.1 and 8.1.2 specify the allowable leakage rate and test sensitivity in terms of helium leaktightness as well as components to be tested for fabrication and pre-shipment leakage rate tests.

A pre-shipment leakage rate test of cask containment seals is performed following loading of authorized contents into the cask. This pre-shipment leakage rate test is valid for 1 year

or until the tested component(s) is opened or respective containment fasteners are untorqued.

Leakage rate testing procedures shall be approved by an ASNT Level III specialist. The written and approved test procedures shall clearly define the test equipment arrangement. Leakage rate testing shall be performed by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A. Leakage rate testing shall be performed in accordance with a written quality assurance program.

In case of an unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

Fabrication leakage rate test results shall become part of the equipment documentation package. Pre-shipment leakage rate tests shall be documented in accordance with the user's quality assurance program.

8.1.5 Component and Material Tests

8.1.5.1 Seals

Cask closure seals are conservatively specified in the drawing package referenced in the CoC and in Appendix 4.A to provide a high degree of assurance of leak tightness under normal and accident conditions of transport. Seal tests under the most severe package service conditions including performance at pressure under high and low temperatures will not challenge the capabilities of these seals and thus are not required. Seal specifications are in accordance with the manufacturer recommendation.

8.1.5.2 Impact Testing

To provide protection against brittle fracture under cold conditions, fracture toughness test criteria of cask ferritic containment boundary components, including containment boundary welds, are specified in Table 2.1.10. Non-containment boundary ferritic steel package components are tested for fracture toughness in accordance with Table 2.1.10A. Exemption from fracture toughness testing as allowed by ASME Code Section III, Subsections NB and NF may apply. Code alternatives listed in Table 2.1.14 may apply.

Test results shall become part of the equipment documentation package.

8.1.5.3 Impact Limiter Crush Material Testing

Verification of the transport impact limiter crush material crush strength is accomplished by performance of a crush test of sample blocks. The verification tests are performed by the crush material supplier or third-party testing facility in accordance with Holtec

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approved procedures. Impact limiter material crush strength is specified in the drawing package referenced in the CoC.

The certified test results shall be retained by Holtec International as archive record for each batch of impact limiter crush material manufactured and used. Test results shall be documented and shall become part of the equipment documentation package.

8.1.5.4 Neutron Shielding Material

Each manufactured lot of Holtite-B neutron shield material shall be tested to verify boron carbide content, hydrogen density and bulk Holtite material density. 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.

Manufacturing of Holtite neutron shielding material shall be conducted according to approved written procedures that shall ensure mix ratios and mixing methods are controlled in order to achieve proper material composition and distribution, and that emplacement is properly controlled.

Test results for each manufactured lot of neutron shield material shall become part of the equipment documentation package.

8.1.5.5 Neutron Absorber Material

The manufacturing of Metamic-HT is governed by a set of quality validated standard procedures contained in the Metamic-HT Manufacturing Manual [1.2.25]. The material properties and characteristics have been tested and documented in the Metamic-HT Sourcebook [1.2.27]. **Production testing requirements including acceptance criteria are provided in Table 8.1.3.**

Metamic-HT panels will be manufactured to Holtec's purchase specification [1.2.26] that incorporates all requirements set forth in this chapter, the drawing package referenced in the CoC and the fabrication drawings. The supplier of raw materials must be qualified under Holtec's quality program for important to safety materials and components or alternatively each lot of raw material shall be tested in accordance with Table 8.1.3 requirements. The manufacturing of Metamic-HT is subject to all quality assurance requirements under Holtec International's NRC approved quality program.

The tests conducted on Metamic-HT to establish the compliance of the manufactured panels with Holtec's Purchasing Specification are intended to ensure that *critical characteristics* of the final product will meet the minimum guaranteed values (MGVs). Tests are performed at both the raw material and manufactured panels stages of production with the former serving as the insurer of the properties in the final product and the latter serving the confirmatory function.

The testing is conducted for each lot of raw material and finished panels as prescribed in Table 8.1.3. A lot is defined as follows:

> "Lot" means a population of an item that shares identical attributes that are central to defining a critical performance or operational characteristic required of it. Thus, a lot of boron carbide powder procured to a certified Purchasing Specification used in the manufacturing of Metamic-HT is the bulk quantity of the powder that has the same particle size distribution. A lot of finished panels drawn from a powder mix and manufactured in an extrusion run have identical aluminum and boron carbide characteristics and the same extrusion conditions.

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 the Metamic-HT Manufacturing Manual.**
- **Homogenized mixtures of Al powder(s) and boron carbide powder(s) from traceable lots, prepared for sintering and billet forming operations, shall have the minimum boron carbide wt% verified by wet chemistry testing of one sample from each lot of blended powders. The mixing/blending of the batch shall be controlled via approved procedures.**

(ii) Testing of finished panels

The number of panels subject to testing shall be governed by Table 8.1.4. The panels that need to be tested per the statistical protocol of Table 8.1.4, hereafter referred to as test panels, shall be subject to the following evaluations:

- **The Metamic-HT panels shall be tested for all mechanical properties in accordance with Table 8.1.4 sampling plan.**
- **The thickness of each panel will be measured using the procedure set down in the Metamic-HT Manufacturing Manual. The average measured value must meet the minimum basket wall requirements specified in the Drawing Package referenced in the CoC.**
- **One coupon from the test panel shall be subject to neutron attenuation testing to quantify the boron carbide content for compliance with the minimum requirement in Table 1.2.15 using written procedures.**

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(iii) Testing of Basket

- **Metamic-HT basket cells shall be tested by a dummy gage to insure that they are large enough to permit contents to be safely inserted.**

FSW Procedure Qualification, Welder Operator Qualification and Welded Coupon Test:

A. **Procedure qualification and welder operator qualification of the Friction Stir Welding (FSW) process shall meet the following requirements from ASME Section IX, 2013 Edition [8.1.1]:**
   - **The Procedure Qualification Record (PQR) shall meet the essential variable requirements of QW-267.**
   - **The Weld Procedure Specification (WPS) shall meet the essential variable requirements of QW-267, QW-361.1(e) and QW-361.2.**
   - **Welder operator performance qualifications shall meet the essential variable requirements of QW-361.2.**
   - **Welder operator may be qualified by volumetric NDE of a test coupon; or a coupon from their initial production welding within the limitations of QW-304 and QW-305; or by bend tests taken from a test coupon.**

B. **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 5362 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.

Visual Inspection of Metamic-HT Panels:

Each plate of neutron absorber shall be visually inspected for damage such as scratches, cracks, burrs, foreign material embedded in the surfaces, voids, and delaminations. Panels are also visually inspected for contamination on the surface as specified in the Manufacturing Manual [1.2.25]. Panels not meeting the acceptance criteria will be reworked or rejected. Unless basket is fabricated at the same factory manufacturing Metamic-HT, all panels shall be inspected before being shipped to the cask manufacturing facility where they may be subject to receipt inspection prior to installation.

8.1.6 Shielding Tests

A shielding effectiveness test of each fabricated cask must be performed after loading with approved contents but prior to the first shipment as specified in the following paragraph.

A shielding effectiveness test shall be performed to verify the effectiveness of the shielding using written and approved procedures. **The test may be performed with the loaded cask in the vertical or horizontal configurations (no impact limiters) or in the horizontal orientation with impact limiters, as long as the configuration is appropriately taken into account. Calibrated radiation detection equipment shall be used to take measurements at the surface of the HI-STAR package. Measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the shielding. The calculated values shall be representative of the loaded contents (e.g. fuel type, enrichment, burnup, cooling time, etc.).** Measurements shall be documented and become part of the equipment documentation package.

8.1.7 Thermal Tests

The first fabricated HI-STAR cask shall be tested to confirm its heat transfer capability through the containment shell and monolithic shielding cylinders.

A thermal test performed for a similar cask design (e.g. HI-STAR 180D USNRC Docket 71-9367 or HI-STAR 180L USNRC Docket 71-9381) may be used as proof of heat transfer capability in lieu of thermal testing of the HI-STAR 180. **In case of a proof with similar cask, an engineering evaluation between HI-STAR 180 and the previously-tested cask shall be documented** and become part of the equipment documentation package.

The test shall be conducted after fabrication is complete. A test cover plate shall be used to seal the cask cavity. The cavity will be heated with steam.

Twelve (12) calibrated thermocouples shall be installed on the external walls of the cask using four thermocouples, equally spaced circumferentially, at three different elevations. Three calibrated thermocouples shall be installed on the internal walls of the cask in locations to be determined by procedure. Additional temperature sensors shall be used to monitor ambient temperature, steam supply temperature, and condensate drain temperature. The thermocouples shall be attached to strip chart recorders or other similar mechanism to allow for continuous monitoring and recording of temperatures during the test. Instrumentation shall be installed to monitor cask cavity internal pressure.

After the thermocouples have been installed, dry steam will be introduced through an opening in the test cover plate previously installed on the cask and the test initiated. Temperatures of the thermocouples, plus ambient, steam supply, and condensate drain temperature shall be recorded at hourly intervals until thermal equilibrium is reached. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of potential ambient test conditions and incorporated into the test procedure. In general, thermal equilibrium is expected approximately 12 hours after the start of steam heating. Air will be purged from the cask cavity via venting during the heatup cycle. During the test, the steam condensate flowing out of the cask drain shall be collected and the mass of the condensate measured with a precision weighing instrument.

Once thermal equilibrium is established, the final ambient, steam supply, and condensate drain temperatures and temperatures at each of the thermocouples shall be recorded. The strip charts, hand-written logs, or other similar readout shall be marked to show the point when thermal equilibrium was established and final test measurements were recorded. The final test readings along with the hourly data inputs and strip charts (or other similar mechanism) shall become part of the quality records documentation package for the HI-STAR 180 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 (J/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 180 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 180 Package shall not be accepted until the root cause is determined, appropriate corrective actions are completed, and the package is re-tested with acceptable results.

Testing shall be performed in accordance with written and approved procedures similar to the Holtec standard procedure used for the test performed on the HI-STAR 100 overpack and documented in Holtec Document DOC-5014-03 [8.1.7].

8.1.8 Miscellaneous Tests

No additional tests are required prior to using the packaging.

Table 8.1.1
Containment System Performance Specifications

Design Attribute	Design Rating
Leakage Rate Acceptance Criterion	$1x10^{-7}$ ref-cm^3/s air ($1x10^{-8}$ Pa-m^3/s air) (Leaktight as defined by ANSI N14.5)
Leakage Rate Test Sensitivity	$5x10^{-8}$ ref-cm^3/s air ($5x10^{-9}$ Pa-m^3/s air) (½ of the leakage rate acceptance criterion per ANSI N14.5)

Notes:

1. During leakage rate tests appropriate conversion factors will be employed using written and approved procedures to account for actual backfill/tracer gas. For helium as the tracer gas, the Leakage Rate Acceptance Criterion and Test Sensitivity are multiplied by a factor of 1.86.
2. "Leaktight" criteria specified herein is applicable to Fabrication, Maintenance, Pre-shipment and Periodic leakage tests.
3. This table is a condition of the CoC.

Table 8.1.2
Leakage Rate Tests For The HI-STAR 180 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5, App. A)	Allowable Leakage Rate
Fabrication Leakage Rate Test	• Containment Shell • Containment Baseplate • Containment Closure Flange • Inner Closure Lid • Outer Closure Lid • Inner Closure Lid Vent and Drain Port Cover Plates • Containment Shell Welds • Containment Shell to Containment Baseplate Weld • Containment Shell to Containment Closure Flange Weld	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1
Pre-Shipment Leakage Rate Test	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1

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Table 8.1.2 (Continued)
Leakage Rate Tests For The HI-STAR 180 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5, App. A)	Allowable Leakage Rate
Maintenance Leakage Rate Test	• Containment Shell • Containment Baseplate • Containment Closure Flange • Inner Closure Lid • Outer Closure Lid • Inner Closure Lid Vent and Drain Port Cover Plates • Containment Shell Welds • Containment Shell to Containment Baseplate Weld • Containment Shell to Containment Closure Flange Weld	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1
Periodic Leakage Rate Test	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Vent/Drain Port Cover Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Access Port Plug Seal	A.5.4	Table 8.1.1

Notes:
1. For a Leakage Rate Acceptance Criterion specified in Table 8.1.1 as “Leaktight as defined by ANSI N14.5”, the summation of individual component leakage rates of the containment boundary of a package is not required.
2. This table is a condition of the CoC.

Table 8.1.3
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
i.	B_4C powder (raw material) (see note 1)	Particle size distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchase Specification [1.2.26]
		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 Purchase Specification [1.2.26]
		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 specified in Table 1.2.15.

Table 8.1.3 (Continued)
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
iv.	Finished Metamic-HT panel	Thickness and width, straightness, camber and bow	Holtec QA Program Sampling Plan	To ensure fabricability of the basket	Per Holtec's Purchasing Specification [1.2.26]
		Mechanical & Structural MGV Properties (see Note 2)	Per Sampling Plan Table 8.1.4	To ensure structural performance.	MGVs Per Holtec's Purchasing Specification [1.2.26]
		B_4C content by areal density measurements (neutron attenuation method)	One sample from a panel from each Metamic-HT manufactured lot	To ensure criticality safety	The B_4C content must meet the minimum wt% specification in Table 1.2.15

Notes:
1. The B_4C testing requirements apply if the raw material supplier is not in Holtec's Approved Vendor List.
2. All properties shall be measured at room temperature on extruded coupons.
3. This table is a condition of the CoC.

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).

Note 4: This table is a condition of the CoC.

Table 8.1.5: Intentionally Deleted

8.2 MAINTENANCE PROGRAM

An ongoing maintenance program for the HI-STAR 180 Package will be prepared and issued prior to the delivery and first use of the HI-STAR 180 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 180 Package in accordance with 10CFR71 regulations, conditions in the Certificate of Compliance, and the design requirements and criteria contained in this Safety Analysis Report (SAR).

The HI-STAR 180 package is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions. As a result, only minimal maintenance will be required over its lifetime, and this maintenance would primarily result from weathering effects, and pre- and post-usage requirements for transportation. Typical of such maintenance would be the reapplication of corrosion inhibiting materials on accessible external surfaces, seal replacement, and leak testing following seal replacement. Such maintenance requires methods and procedures no more demanding than those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR 180 Package is provided in Table 8.2.1.

8.2.1 Structural and Pressure Tests

No periodic structural or pressure tests on the packaging following the initial acceptance tests are required to verify continuing performance.

8.2.2 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5 [8.1.6] as specified in this Chapter. Tables 8.1.1 and 8.1.2 specify the allowable leakage rates and test sensitivity as well as components to be tested for maintenance and periodic leakage rate tests.

If the pre-shipment leakage rate test (Section 8.1.4) expires, a periodic leakage rate test of the containment seals must be performed prior to transport. This periodic leakage rate test shall be performed at the frequency indicated in Table 8.2.1.
Maintenance leakage rate testing shall be performed prior to returning a package to service following maintenance, repair (such as a weld repair), or replacement of containment system components (such as containment seals replacement and/or removal of closure bolts/plugs). Only that portion of the containment system that is affected by the maintenance, repair or component replacement needs to be leak tested. In case of unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

Periodic and maintenance leakage rate test results shall be documented and maintained in accordance with the user's quality assurance program.

Leakage rate testing procedures shall be approved by an 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. Leakage rate testing shall be performed in accordance with a written quality assurance program.

8.2.3 Component and Material Tests

8.2.3.1 Relief Devices

The neutron shield relief devices shall be visually inspected for damage or indications of excessive corrosion **at the frequency indicated in Table 8.2.1**. If the inspection determines an unacceptable condition, the neutron shield relief devices shall be replaced. Additionally, the neutron shield relief devices shall be replaced periodically while the cask is in service if required by the manufacturer's O&M manual.

8.2.3.2 Shielding Materials

Periodic verification of the neutron shield integrity shall be performed at the frequency indicated in Table 8.2.1 using written and approved procedures. Calibrated radiation detection equipment shall be used to take measurements (with either loaded contents or a check source) at the surface of the package. At a minimum, measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the neutron shield. The calculated values shall be representative of the loaded contents (i.e., fuel type, enrichment, burnup, cooling time, etc.) or the particular check source used for the measurements.

8.2.3.3 Packaging Surfaces

Accessible external surfaces of the packaging (including impact limiters) shall be visually inspected for damage at the frequency indicated in Table 8.2.1 to ensure that the packaging effectiveness is not significantly reduced. Visual inspections of the cask and impact limiters shall be performed for external surface coating and component damage including surface denting, surface penetrations, weld cracking, chipped or missing coating. Where necessary, cask coatings shall be reapplied. **Damage shall be evaluated for impact on packaging safety and shall be repaired or replaced accordingly. Wear and tear from normal use will not impact cask safety. Repairs or replacement in accordance with written and approved procedures, as set down in the O&M manual, shall be required if unacceptable conditions are identified.**

Prior to installation or replacement of a closure seal, the cask sealing surface shall be cleaned and visually inspected for scratches, pitting or roughness, and affected surface areas shall be polished smooth or repaired as necessary in accordance with written and approved procedures.

8.2.3.4 Packaging Fasteners

Cask and impact limiter fasteners shall be visually inspected for damage such as excessive wear, galling, or indentations on the threaded surfaces **at the frequency indicated in Table 8.2.1**. **Threaded fasteners shall be examined in accordance with paragraph NB-2582, ASME Section III, Subsection NB. Fasteners without sufficient usable thread length meeting the requirements of NB-2582 shall be replaced. Threaded fasteners of important to safety SSC's with minor thread damage (up to 2 missing/damaged threads or threads found out of tolerance) may be accepted via a torque test. For fasteners directly loaded in the load path for lifting components designed per ANSI N14.6, the torque required for the test shall develop a tensile load in the fastener equivalent to the tensile load developed during the 300% load test. For fasteners not directly loaded in the load path for lifting components designed per ANSI N14.6 and for other important to safety fastener connections, the torque required for the test shall be equal to 125% of the torque required by the fastener in service.**

Damaged fasteners with external threads shall be replaced accordingly. Damaged fasteners with internal threads (including bushings, welded/helical inserts and other threaded components) may be repaired per standard industry practice. The use of threaded bolt hole inserts for thread repairs is permitted as specified in the drawing package referenced in the CoC. Any repair shall be evaluated to ensure ASME Code stress limits applicable to bolted closure joints are met. Any required material or manufacturing process testing would also be performed in accordance with ASME Section III, Subsection NB or Subsection NF as applicable.

Bolting of both Inner and Outer Closure Lids, including Inner Closure Lid Port Covers, shall be replaced as guided by the fatigue analysis per the provisions of Section III of the ASME Code. The maintenance program in Table 8.2.1 provides a bolt change out schedule to insure that the cumulative damage factor accumulated by a bolt shall be less than 1.0 with sufficient margin. One bolting cycle is the complete sequence torquing and removal of bolts.

Containment Closure Flange internal threads for closure bolts and Inner Closure Lid internal thread for Port Cover Bolts have a maximum service life limit based on bolting cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. The bolting cycles specified in Table 8.2.1 shall not be exceeded. Inserts, plugs and bushings used in containment components have a maximum service life limit based on bolting or torqueing/loosening cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. One bolting cycle is the complete sequence torquing and removal of bolts.

Maintenance of important to safety fasteners including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.5 Cask Trunnions and Trunnion Replacement Plugs

Cask trunnions shall be inspected at the frequency indicated in Table 8.2.1. The accessible parts of the trunnions (areas outside the cask), and the local cask areas shall be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require repair or replacement of the trunnion and/or repair of the cask. The repair process shall involve removal of the trunnion from the cask and inspection of all surfaces of the trunnion for further defects that may require repair.

Cask trunnion replacement plugs shall be inspected at the frequency indicated in Table 8.2.1. Cask trunnion replacement plugs shall be visually examined for deformation, distortion, or cracking has occurred of threads to the extent necessary to ensure smooth installation and removal.

Following any replacements and/or repair, the load testing (Subsection 8.1.3) shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.6 Closure Seals

The HI-STAR 180 Packaging is equipped with metallic closure seals on the inner and outer closure lids and other penetration closure joints as specified in the drawing package referenced in the CoC. The closure seals are shipped from the factory pre-inspected and carefully packaged. Once installed and compressed, the seals should not be disturbed by removal of closure fasteners. **Removal of closure fasteners requires replacement of closure seals and performance of a Maintenance Leakage Rate Test for closure seals classified as containment boundary seals.** Closure seals are specified for long-term use and do not require additional maintenance.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.7 Fuel Basket

No additional tests are required for the HI-STAR 180 fuel basket.

8.2.3.8 Fuel Spacer

Fuel shims, FIA's or similar devices as required by the cask design shall be visually inspected for damage at the frequency indicated in Table 8.2.1. If inspection determines an unacceptable condition, the device shall be replaced in accordance with written and approved procedures.

Maintenance of important to safety components including repair or replacement shall be documented and maintained in accordance with the user's quality assurance program.

8.2.4 Thermal Tests

Periodic thermal performance test shall be performed in accordance with written and approved procedures at the frequency indicated in Table 8.2.1 to demonstrate that the thermal capabilities of the cask remain within its design basis.

This test shall be performed immediately after a HI-STAR 180 Package is loaded with spent nuclear fuel. **The in-service test is performed to verify a continued adequate rate of heat dissipation from the cask to the environment.** Acceptable performance under test conditions ensures that design basis fuel cladding temperature limits to which the HI-STAR 180 Package is qualified under design basis heat loads will not be exceeded during transport.

Prior to performing the test, thermal equilibrium of the HI-STAR 180 Package shall be verified by measuring the temperature at a defined point near the mid-plane of the HI-STAR 180 Package at one-hour intervals using a calibrated thermocouple or surface pyrometer. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of ambient test conditions and incorporated into the test procedure.

After thermal equilibrium is established, **temperatures shall be measured and recorded using a calibrated thermocouple or surface pyrometer at four equally spaced circumferential locations at the mid height of the active fuel.** The decay heat load and fuel cycle history of the fuel assemblies loaded in the HI-STAR 180 Package shall also be recorded. These records shall become part of the maintenance program quality records for the HI-STAR 180 Package.

The HI-STAR 180 Package is considered acceptable if the average measured surface to ambient temperature differential indicated in the procedure, when adjusted for environmental conditions, is not exceeded.

The test results shall be documented and maintained in accordance with the user's quality assurance program.

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8.2.5 Miscellaneous Tests

No additional tests are required for the HI-STAR 180 Packaging, packaging components, or packaging materials.

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Table 8.2.1 (Sheet 1 of 2)
Maintenance Inspections and Tests Program Schedule

Task	Schedule
Cask surface visual inspection. (See Paragraph 8.2.3.3)	Prior to each fuel loading
Packaging external surface visual inspection. (See Paragraph 8.2.3.3)	• Prior to fuel loading • Prior to each transport
Cask closure fasteners/bolts visual inspection (See Paragraph 8.2.3.4)	• Prior to installation • Prior to each transport if damage is suspected
Cask trunnion visual inspection (See Paragraph 8.2.3.5.)	• Prior to fuel loading • Prior to transport if period from last visual inspection exceeds 1 year
Cask Trunnion Replacement Plug visual inspection (See Paragraph 8.2.3.5.)	Prior to transport
Impact limiter and fasteners visual inspection (See Paragraph 8.2.3.4)	• Prior to installation • Prior to each transport if damage is suspected
Neutron shield relief device visual inspection (See Paragraph 8.2.3.1)	• Prior to each transport • Prior to each transport
Periodic leakage rate test of containment system seals (See Subsection 8.2.2)	Prior to transport if period from last test exceeds 1 year.
Seal replacement for Inner and Outer Closure Lids (See Paragraph 8.2.3.6)	Following removal of closure bolting
Bolt replacement (*Service Life*) for Inner Closure Lid (See Paragraph 8.2.3.4)	Every 225 bolting cycles for SA 564/705 630 Every 277 bolting cycles for SB-637
Bolt replacement (*Service Life*) for Outer Closure Lid (See Paragraph 8.2.3.4)	Every 588 bolting cycles for SA 193-B7 Every 588 bolting cycles for SA SA320-L7 Every 225 bolting cycles for SA 564/705 630 Every 250 bolting cycles for SB-637

Table 8.2.1 (Sheet 2 of 2)
Maintenance Inspections and Tests Program Schedule

Bolt replacement (*Service Life*) for Inner Closure Lid Port Cover Bolts (See Paragraph 8.2.3.4)	250 bolting cycles
Containment Closure Flange internal thread (*Service Life) for threaded bolt holes for inner and outer closure lids* (See Paragraph 8.2.3.4)	1500 bolting cycles
Access Port Plug replacement (Service Life)	5000 bolting cycles based on a conservative effective alternating stress intensity of 63.384 ksi
Seal replacement for Outer Closure Lid Access Port Plug (See Paragraph 8.2.3.6)	Following removal of access port plug
Seal replacement for Inner Closure Lid Port Covers (See Paragraph 8.2.3.6)	Following removal of port cover fasteners
Neutron shield relief device replacement (See Paragraph 8.2.3.1)	If required by the manufacturer's O&M manual
Shielding Test (See Paragraph 8.2.3.2)	• Within 5 years of the last shielding effective test or last periodic shielding verification prior to shipment. • Prior to shipment following major repairs and maintenance activities.
Thermal Test (See Subsection 8.2.4)	Within 5 years prior to shipment
Maintenance Leakage Rate Test (See Subsection 8.2.2)	Following maintenance, repair or replacement of containment system components
Fuel Spacers (Fuel Shims, FIAs or similar devices) Inspection (See Paragraph 8.2.3.8)	Prior to loading into cask.

This table is a condition of the CoC.

CHAPTER 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 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.

[8.0.1] U.S. Code of Federal Regulations, Title 10, "Energy", Part 71, "Packaging and Transportation of Radioactive Materials."

[8.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2007 (Section IX, 2013 for FSW only unless otherwise indicated).

[8.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, 2006.

[8.1.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

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

[8.1.5] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1m) But Not Exceeding 12 Inches (0.3m)," Regulatory Guide 7.12, June 1991.

[8.1.6] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials Leakage Tests on Packages for Shipment", ANSI N14.5, 2014.

[8.1.7] Holtec International Document DOC-5014-03, "Acceptance Testing of First HI-STAR Overpack (Thermal and He Leak Tests)", September 2006.