NONPROPRIETARY VERSION

SAFETY ANALYSIS REPORT

on

THE HI-STAR 330 Non-Fuel Waste Transport System

By

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- ☒ Technical Report (Per HQP 3.2)(Such as a Licensing Report)
- ☐ Design Criterion Document (Per HQP 3.4)
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ABOUT THIS SAR

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

REVISION STATUS AND CONFIGURATION CONTROL

SAR review and verification are controlled at the chapter level and changes are annotated at the section level. Chapters include chapter sections, chapter appendices and chapter supplements (as applicable). The revision of this SAR is the same as the latest revision of any chapter in this SAR. Licensing drawings are controlled individually within the Holtec drawing configuration control system.

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REVISION SUMMARY

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

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GLOSSARY AND NOTATION

GLOSSARY

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

Base Plate means the base steel plate which supports the walls of the cask and the Liner Tank.

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

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

C.G.O.C is an acronym for Center of Gravity Over Corner during a free drop.

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

CoC is an acronym for Certificate of Compliance.

COF is an acronym for Coefficient of Friction.

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

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

Cooling Time (or post-irradiation decay time, PCDT) for segmented reactor internals radioactive materials is the time between removal of the internals from the shutdown reactor and the time the segmented reactor internals are loaded into the cask. Cooling Time is also referred to as the "age" of the reactor internals radioactive materials.

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

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

Design Heat Load is the permitted heat rejection rate from the HI-STAR package.

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 330 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 330 package.

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

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.

FAT is an acronym for factory acceptance test.

Fissile Material means the radionuclides uranium-233, uranium-235, plutonium-239, and plutonium-241, or any combination of these radionuclides. Fissile material means the fissile nuclides themselves, not material containing fissile nuclides. Unirradiated natural uranium and depleted uranium and natural uranium or depleted uranium, that has been irradiated in thermal reactors only, are no included in this definition. Certain exclusions from fissile material controls are provided in §71.15. This SAR may specify specific exclusions.

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.

HAC is an acronym for Hypothetical Accident Conditions as defined in the applicable regulations.

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

HI-STAR 330 Cask or cask means the cask that receives and contains the radioactive materials. It provides the containment system boundary for radioactive materials and fulfills all requirements of 10CFR71 to merit certification as a Type B(U)-96 package.

HI-STAR 330 Package consists of the HI-STAR 330 cask, Liner Tank, Liner Tank Cassette (LTC), and the licensed radioactive contents loaded for transport.

HI-STAR 330 Packaging consists of the HI-STAR 330 Package without the licensed radioactive contents loaded.

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

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

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

Liner Tank Cassette (LTC) are painted carbon steel rectangular structure consisting of a baseplate, tie rods at each corner and the lid. Liner Tank Cassettes serve as a mechanism for transferring the radioactive materials to the Liner Tanks situated in the HI-STAR 330 cask.

Liner Tanks are painted carbon steel rectangular tanks defined by a rectangular shell, baseplate and lid with associated welds and bolts.

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.

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

NDE is an acronym for Non-Destructive Examination.

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.

NFW is an acronym for non-fuel waste. 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.

Owner is the entity who has title (ownership) to the cask.

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

Radioactive Materials/Wastes are non-fissile reactor-related wastes in solid form.

Routine Conditions of Transportation (RCT) is define as incident free transport conditions, which may include the effects of acceleration, vibration or vibration resonance without any deterioration in the effectiveness of the package as a whole.

SAR is an acronym for Safety Analysis Report.

Secondary Container is the term used for the various Liner Tank types.

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

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

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

Single Waste Item means any non-divisible waste item under accident conditions. If an item could potentially break into pieces during an accident, then the maximum permissible specific activity limits apply to any volume of that waste item that could potentially be fragmented and become a separate single piece.

Special Nuclear Material (SNM) is defined by Title I of the Atomic Energy Act of 1954 as plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235. The definition includes any other material that the Commission determines to be special nuclear material, but does not include source material. As of this writing, the NRC has not declared any other material as SNM.

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

SSC is an acronym for Structures, Systems and Components.

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

Tertiary Waste Container is the term used for a container that provides a shielding function to loaded radioactive contents with higher specific activity waste. Tertiary containers along with the radioactive contents they contain, are loaded within a secondary container.

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

Top Flange means the machined region of the containment walls that interfaces with the closure lid (sealing surface and the lid bolts), and effects sealing of the Containment Boundary through one or more gaskets.

Transport Frame is a structure that is fitted to a transport vehicle and used to support the cask during transport.

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

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

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

User is the entity tasked with operating the cask. May be the Owner or someone else contracted to render the services.

Verification in this SAR means confirmation of compliance of a characteristic that is not specified by the Code invoked in this SAR or called out as requiring inspection therein or determined by

Certificate Holder's licensing organization to not be of significant safety consequence. A Verification can be performed by a person trained under the Certificate holder's quality organization program to establish compliance with a provision of minor safety import in the SAR. Verification covers the whole gamut of activities that don't lie within the purview of Inspection or testing.

Waste Package is the generic term to denote the assemblage of the Liner Tank loaded with the Liner Tank Cassette (LTC) containing radioactive materials.

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 leak-tightness ranges from 1 x 10^{-2} std cm^3/s air to 1 x 10^{-4} std cm^3/s air in accordance with ASTM E1003-05 "Standard Test Method for Hydrostatic Leak Testing."

Wet Hood shields and transfers a Liner Tank Cassette (LTC) to and from the Liner Tank.

Wrench tight is achieved by further tightening from hand tight with a standard size box or open-end wrench until significant resistance is felt in the bolt. The amount of torque applied is limited to the force that may be applied using one hand without extending the length of the wrench using "cheater bars" or other torque multipliers. Wrench tight is intended to ensure that the fastener is loading in tension and not necessarily to close all gaps between components that may be present due to local distortion.

NOTATION

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)

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

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_{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).

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

ρ: Density

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

ψ: Thermal conductivity

θ Orientation of free drop

CHAPTER 1: GENERAL INFORMATION

1.0 Overview

The HI-STAR 330 transport cask is engineered to serve as a Type B(U)-96 packaging for transporting radioactive Non-Fuel Waste (NFW) including reactor-related waste and hardware pursuant to 10CFR71. This Safety Analysis Report (SAR)[1] for the HI-STAR 330 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 non-fissile radioactive material transportation package pursuant to the provisions of 10CFR71 Subpart D [1.0.2] and 49CFR173 [1.0.3].

The Licensing drawing package in Section 1.3 of this chapter provides the essential details of the package design that are necessary to define its interface dimensions and its physical, structural, containment, thermal and shielding characteristics needed to perform the required safety evaluations. For the reader's convenience and clarity, additional pictorials of the cask and packaging components are provided in this SAR.

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 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 unless otherwise noted, the information can be amended subject to the stipulations of 71.107(c).

The HI-STAR 330 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), Docket No. 71-0784.

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

a. A chapter is identified by a whole numeral, say *m* (i.e., *m*=3 means Chapter 3).
b. A section is identified by one decimal separating two numerals. Thus, Section 3.1 is a section in Chapter 3.

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

c. A subsection has three numerals separated by two decimals. Thus, Subsection 3.2.1 is a subsection in Section 3.2.
d. A paragraph is denoted by four numerals separated by three decimals. Thus, Paragraph 3.2.1.1 is a paragraph in Subsection 3.2.1.
e. A subparagraph has five numerals separated by four decimals. Thus, Subparagraph 3.2.1.1.1 is a part of Paragraph 3.2.1.1.

Tables and figures associated with a section are placed after the text narrative. Complete sections are replaced if any material in the section is changed. The specific changes are appropriately annotated. Drawing packages are controlled separately within the Holtec QA program and have individual revision numbers. If a drawing is revised in support of the current SAR revision, that drawing is included in Section 1.3 at its latest revision level. All changes to the SAR including the drawings are subject to a rigorous configuration control under Holtec's QA program approved by the USNRC under Docket No. 71-0784.

1.1 Introduction to the HI-STAR 330 Package

The HI-STAR 330 System consists of the primary cask and the waste package types as specified in Table 1.2.1 and Table 7.1.2.

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

The Liner Tank is engineered to fit the containment space of the cask with appropriate clearance to support operational activities. The Liner Tank is a metallic structure with metal walls intended to provide shielding protection as well as the necessary structural strength for handling purposes. Two Liner Tank types are evaluated in this SAR, with their side wall shielding thicknesses being their principal defining characteristic. The external dimensions of the Liner Tanks are identical to allow the use of a single cask design for transport.

The Liner Tank may be loaded using an LTC or by direct placement of material into the tank. In either case, the loaded non-fuel wastes shall meet the specifications in Subsection 1.2.2. The LTC is designed to fit the internal cavity of the Liner Tank with appropriate clearance to support operational activities. Appropriate steps are taken during the loading process to ensure external surfaces of the Liner Tank are not contaminated, or are appropriately decontaminated, prior to transferring the tanks into the HI-STAR 330 Cask.

The internal heat generation of the material in the Liner Tanks is low and easily dissipated to the environment through natural convection and radiation heat transfer. The Liner Tanks and its contents are dried after loading to remove water, thus preventing a significant increase in cask cavity pressure due to vaporization and/or gas generation from radiolysis of water.

The HI-STAR 330 Package complies with all of the requirements of 10CFR71 for a Type B(U)-96 package. In particular, because the internal heat generation rate for the package is minimal, the maximum normal operating pressure (MNOP) in the cask under the worst combination of heat generation and insolation is a fraction of the allowable MNOP for a Type B(U) package. No pressure relief device or feature intended to allow continuous venting during transport is provided on the HI-STAR 330 containment boundary (10CFR71.43(e) and 10CFR71.43(h)). Therefore, there is no pressure relief device or feature that may permit release of radioactive material under the tests specified in 10CFR71.73. Analyses that demonstrate the compliance of the HI-STAR 330 Package with the requirements of Subparts E and F of 10CFR71 are provided in this SAR.

[

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The cask closure lid and inner elastomeric closure lid gasket are engineered to prevent leakage in excess of the limits in 10 CFR 71.51 under routine, normal and accident conditions of transport. An outer elastomeric cask closure lid gasket is included in the design to support leak testing of the primary inner seal. This gasket also provides a non-credited, but redundant barrier against leakage from the Containment Boundary during routine and normal transport conditions.

Table 1.1.1 provides dimensional and weight data on the HI-STAR package utilized in the various safety analyses summarized in this SAR.

The Criticality Safety Index (CSI) for HI-STAR 330 is zero, since an unlimited number of packages are subcritical under the procedures specified in 10 CFR 71.59(a). The Transport Index (TI) is below 10 for HI-STAR 330 with design basis contents (Section 5.0 provides the determination of the TI). However, the maximum temperature of accessible surfaces in still air at 38°C (100°F) without insolation is in excess of 50°C (122°F), and less than 85°C (185°F); therefore, pursuant to 10CFR 71.43(g), the HI-STAR 330 packaging must be transported by exclusive use shipment. An empty but previously loaded HI-STAR 330 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 330 Packaging is designed to ensure safe transport of non-fuel waste.
[

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This SAR supports a licensed life of the HI-STAR 330 Package of 5 years, after which a renewal by the USNRC will be 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 330's operating environments without degradation and maintain their essential capability to render their intended function. A maintenance program, as specified in Chapter 8, is implemented to ensure the HI-STAR 330 Package will meet its Design Life of 40 years. The technical considerations that assure the HI-STAR 330 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

In this SAR, US customary units are the official units of measure unless otherwise specified (values in SI units, if provided, are for information only when accompanied by the equivalent US customary unit value).

TABLE 1.1.1
OVERALL DIMENSIONS AND WEIGHTS OF HI-STAR 330

Item	Value	
Inside dimensions of the HI-STAR Cask cavity, in. (Note 1)	Length	132
	Width	53
	Height	92
Outside dimensions of the HI-STAR Cask with impact absorbers installed, in. (Note 1)	Length	200
	Width	111
	Height	155
Maximum gross weight of the loaded HI-STAR 330 package	Table 7.1.1	
Nominal weight of the empty HI-STAR 330 cask (no waste package), lb	Table 7.1.1	
Maximum permissible weight of the cask contents (waste package), lb	Table 7.1.1	

Notes:
1. Dimensions are approximate and for information only. Design basis safety analyses use dimensions provided in the drawing package and/or elsewhere in this SAR. Upper or lower bound dimensions may be used in design basis safety analysis, as appropriate, to ensure conservatism.

1.2 Description of Packaging Components and Their Design & Operational Features

1.2.1 Packaging

1.2.1.1 Major Packaging Components and Packaging Supports and Restraints

The HI-STAR 330 Packaging typically consists of four major components (Cask, secondary container, waste basket, and impact absorbers) as discussed in subparagraphs (a) through (d) below. If necessary for transport of material with higher specific activity, a tertiary container as discussed in Subsection 1.2.2 may be included to provide the additional shielding necessary to meet the 10CFR71 radiation dose limits. Auxiliary equipment, such as packaging supports or restraints typically necessary for package transport, is described in subparagraph (e) below.

a. Cask

As illustrated in the licensing drawing package, HI-STAR 330 is of a rectangular parallelepiped configuration with an inset heavy closure lid which provides sole access to its contents. The closure lid is secured to the cask using suitably pre-loaded bolts that thread into the upper flange at the top of the main body of the cask. The interfacing surfaces of the lid and the flange are machined to seat two concentric elastomeric gaskets forming a compression joint, which has been used in the entire family of HI-STAR transport packages and which provides maximum protection of the Containment boundary against leakage in the aftermath of a severe impactive event such as the free drop accident envisaged under 10CFR71.73. The HI-STAR package is lifted using trunnions located on the side walls designed with structural safety margins required under NUREG-0612 [1.2.3]. Additional lifting attachments, only used for lifting of the closure lid, are welded to the Closure Lid containment plate.

With the exception of the elastomeric closure lid inner gasket, the Containment Boundary of HI-STAR 330 consists of a weldment of alloy steel components that consists of a baseplate, four containment walls, a top flange, a closure lid and associated containment boundary welds. The baseplate and walls of the Containment Boundary weldment are buttressed by a thick steel enveloping plate structure termed the “Dose Blocker Structure” or DBS. As its name implies, the DBS provides additional shielding under normal service conditions such that the cask complies with the radiation dose limits set forth in 10CFR71[

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]. The Containment Boundary weldment is joined to the DBS structure by welding along the periphery of the cask where its upper flange and DBS plates meet near the upper edge of the cask. The Licensing drawing package shows the welds of the Containment Boundary and DBS.

The governing Code for the Containment Boundary of HI-STAR 330 is ASME Code Subsection NB [1.2.1] which has well-articulated rules for plate & shell type structures operating under ambient conditions. The Code guides the cask’s design with respect to stress limits, testing requirements for raw materials, welding specifications & weld inspections and factory acceptance testing.

The material for the DBS is selected to be an ASTM pressure vessel grade steel with welding performed to Section IX. All DBS external welds are subject to visual examination by production staff qualified for such examination. The structural acceptance criteria for the HI-STAR 330 packaging parts are guided by the goal of providing large margins under all performance modes.

Unless otherwise specified, cask surfaces may be coated for surface preservation purposes, including corrosion prevention. Coating shall be chosen based on expected service conditions and shall be appropriate for exposure to radiation as well as environmental exposure. The coating material and performance requirements are described in Chapter 2 of this SAR.

The free drop event postulated in 10CFR71.73 is an uncontrolled lowering of the package from 9 meters onto an essentially unyielding surface in the orientation expected to result in the maximum damage. **[**

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

b. Secondary Containers

The Liner Tank is defined as the rectangular vessel that conforms to the internal dimensions of the cask as illustrated in the licensing drawings. The Liner Tank is designed to provide an environmentally sequestered enclosure for radioactive NFW during transportation. Four waste packages (Types A, B, C, and D) are analyzed for the HI-STAR 330 Package. Each waste package type is qualified to a certain total maximum activity and specific activity level. The design details, illustrated in the drawing package in Section 1.3, indicate that all Liner Tanks are of similar construction and geometry. The distinguishing feature of each type of Liner Tank is the thickness of its walls. Each type of Liner Tank is designed to either accommodate the dimensions of a specific type of LTC used for loading its radioactive contents, or be used without an LTC but with increased shielding thickness of its top cover and bottom plates. The steel plate construction of the Liner Tanks provides shielding of gamma radiation, with greater plate thicknesses coinciding with better shielding for contents with higher specific activities.

The Liner Tanks are rectangular steel weldments with a steel lid. The walls, top cover and bottom of the Liner Tanks are orthogonal with each other and are manufactured to dimensions with controlled tolerances. The rectangular geometry provides stability during transport conditions and the steel provides structural strength and rigidity. These attributes render the Liner Tanks structurally rugged under the routine and normal conditions of transportation in 10 CFR 71.71, including short-term loading/unloading conditions.

The Liner Tank's exterior dimensions and the Cask's interior dimensions are designed such that the potential for significant movement of the Liner Tank within the Cask is eliminated. The clearance is sufficient to allow for the minor difference in thermal expansion between the components while still maintaining adequate heat transfer. The design of the Liner Tank types are similar, varying mainly due to handling requirements at the loading facilities. A pictorial view of a typical Liner Tank is provided in Figure 1.2.1.

The welded metallic construction of the walls and base plate of the Liner Tanks, together with the bolted metallic top cover enable an uninterrupted heat transmission path, making the Liner Tanks effective heat rejection devices.

The interior and exterior surfaces of the Liner Tanks (steel weldment and top cover) are coated for surface preservation purposes. Coating materials are chosen based on expected service conditions. The coatings are appropriate for possible exposure to the pool water, as well as radiation and environmental exposure. Lubricants are used on the Liner Tanks for lubrication of bolts and screws. The lubricating materials are selected for satisfactory performance under the operating conditions. Coating materials, adhesives and lubricants for the Liner Tanks are described in Chapter 2.

The top covers of the Liner Tanks are equipped with metallic seals as indicated in the drawing package in Section 1.3. The seals serve a "cleanliness" function and are not *important-to-safety.*

c. Waste Baskets

The Liner Tank Cassettes (LTCs) are designed to accommodate loading and transfer of radioactive waste from the storage pool to the Liner Tank. There are two types of LTCs that are currently available for the HI-STAR 330 Package. Each type of LTC accommodates contents of a given mass and activity, and are by design assigned to be compatible with a specific type of Liner Tank. The LTCs consist of rectangular bottom plates and top plates, joined by structurally robust tubes in the corners. The rectangular geometry provides stability during transport conditions and the steel construction provides structural strength and rigidity. The LTC's exterior dimensions and the Liner Tank's interior dimensions are designed such that the potential for significant movement of the LTC is eliminated. The clearance is sufficient to allow for the minor difference in thermal expansion between the components while still maintaining adequate heat transfer. A pictorial view of a typical LTC is provided in Figure 1.2.2. LTCs are illustrated in the drawing package in Section 1.3.

Of the steel construction of the LTCs, only the lid and base plate are credited in shielding of gamma radiation from the waste contents. The metallic construction of the corner tubes, top plate and bottom plate of the LTCs enable an uninterrupted heat transmission path, making the LTCs effective heat rejection devices.

The surfaces of the LTCs are coated for surface preservation purposes. The coating material is chosen based on expected service conditions. The coating material is appropriate for pool operations and can withstand radiation from the contents as well as environmental conditions.

Adhesives and lubricants are employed in the LTCs for lubrication of gliding surfaces and for locking and sealing of threaded fasteners. The lubricating materials are selected for satisfactory performance under the operating conditions. Coating materials, adhesives and lubricants for the LTCs are provided in Chapter 2.

d. Impact Absorbers

The HI-STAR 330 package has external impact absorbers (crushable attachments) constructed from solid aluminum, which serve the same impact forces reduction function as impact limiters for fuel bearing transport casks during the critical free drop events pursuant to 10 CFR 71.73. The impact absorbers are arranged to ensure that during drop events stresses are mitigated or evenly distributed across the impacted surfaces of the package thereby limiting the stresses in the containment boundary components below the acceptable limits. The impact absorbers are mounted to the cask exterior as depicted in the drawing package in Section 1.3.

An insulation board is used in the top impact absorber strongback frame to ensure the sealing gasket performance is not compromised during accident conditions due to high temperatures. The insulation board material is suitable to resist temperatures in excess of the bounding temperatures for normal and accident conditions of transport. Specifications for the insulation board are shown in the licensing drawing and Appendix 1.A of this chapter,

e. Packaging Supports, Restraints, and Tie-Down Devices

The HI-STAR 330 transport cask is engineered for shipment by road, railroad and sea using appropriate non-integral supports and restraints, such as the tie-down system and transport frame. Non-integral supports and restraints are not structural parts of the HI-STAR 330 Package and, as such, are not designated as packaging components.

Packaging supports, restraints and tie-down devices shall be designed as appropriate for road, railroad and sea 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 (land or sea transportation) standards. More specifically, 10CFR71.45(a) and (b) requirements must be complied with.

During transportation all structural components that could be used to lift the package are rendered inoperable in accordance with 10CFR71.45(a). The Cask trunnions are used to secure the Cask to the Transport Frame, rendering the trunnions inoperable during transport.

1.2.1.2 Overall Packaging Dimensions and Weight

The overall dimensions and component weights on the HI-STAR 330 Package are summarized in Tables 1.1.1 and 7.1.1. The weight of the HI-STAR 330 Package will differ depending on the weight of packaging components (i.e. LTC type, Liner Tank type) and the contents. The maximum gross weight is set according to the heaviest allowable waste package, as discussed in Subsection

1.2.2 below. The maximum gross transport weight of the HI-STAR 330 Package, including the top impact absorber assembly, is to be marked on the packaging nameplate.

1.2.1.3 Containment Features

As discussed in Subsection 1.2.1 and shown in the Licensing drawing package, the HI-STAR 330 Containment boundary is defined by a thick steel alloy weldment of a rectangular box profile with a gasketed heavy walled Closure Lid with a bolted design to provide convenient installation and retrieval of the waste package stored in it. The Containment Boundary is designed to maintain its structural integrity under all routine, normal and hypothetical accident conditions. In particular, the gasketed joint is designed to ensure protection against leakage of radioactive materials in the aftermath of the Design Basis events postulated in this SAR.

Leakage testing of the Closure Lid (containment) inner seal and the gasketed joint shall be in accordance with ANSI N14.5 [8.1.4] as specified in Chapter 8 of this SAR.

1.2.1.4 Gamma Shielding Features

The principal function of the HI-STAR 330 cask package is to ensure that it attenuates the radiation emitted by the Liner Tank's contents to the levels required under the part 71 regulations. The HI-STAR 330 Package is equipped with appropriate shielding to minimize personnel exposure. The HI-STAR 330 Packaging ensures the external radiation standards of 10CFR71.47 under exclusive shipment are met when loaded with the Liner Tank and contents whose radiation emission rate is at or below that analyzed in this SAR. The attenuation of gamma radiation occurs through three sequential metal masses in the body of the HI-STAR package for waste package Types A through D:

1. The initial attenuation of the gamma radiation emitted by the contents is provided primarily by the steel mass of the Liner Tanks, LTCs (top and bottom plates, if LTCs are used), tertiary containers (if required), self-shielding of the metallic waste.

2. The Containment Boundary, a high integrity alloy steel weldment, provides the second gamma attenuation barrier in the package. The Containment Boundary is designed to withstand all design basis events postulated in the SAR without suffering any degradation in its gamma shielding function.

3. The Dose Blocker Structure (DBS), as shown in the Licensing drawing, is a steel weldment that envelopes the Containment Boundary and provides the last stage in attenuation of the radiation emitted by the cask's contents. The DBS is designed to ensure that it will not detach from the cask body under any postulated Design Basis accident events and that the physical damage sustained from design basis impact events postulated in the SAR will be minimal and confined to the local region of impact.

The drawing package in Section 1.3 provides additional information on the configuration of gamma shielding features.

1.2.1.5 Criticality Control Features

There are no criticality control features in the HI-STAR 330 Package. The limited quantities of fissile materials in the package contents in Table 7.1.2 qualifies the HI-STAR 330 for exemption from classification as a fissile material package per 10 CFR 71.15. Chapter 6 contains additional details.

1.2.1.6 Lifting and Tie-Down Devices

As shown in the Licensing drawing in Section 1.3, permanently imbedded trunnions on opposite sides of the cask body provide the means for a symmetrical lift of the package. Trunnions are conservatively qualified with increased stress margins for lifting and handling of critical loads in compliance with NUREG-0612 as specified in Chapter 8. Lifting trunnions are designed in accordance with 10CFR71.45 and NUREG-0612. Testing of trunnions is in accordance with ANSI N14.6 [1.2.2]. As is evident from the Licensing drawing, the trunnion must project out sufficiently to provide sufficient shoulder for the lift rigging to engage it.

Lifting of the HI-STAR 330 Package requires the use of external handling devices. Standard rigging (e.g., slings) are typically utilized when the cask is to be lifted and handled in its upright orientation. There are no transport or loading operations that require tilting or other manipulation of the cask’s orientation. The cask user shall ensure that all lifting equipment as well as its appurtenances used to lift and handle the HI-STAR 330 meet appropriate specifications.

Figure 1.3.1 provides an example illustration of a package in a transport configuration. The cask trunnions are used as attachment points for tie-down on two sides of the cask body, which along with the buttressed supports on the sides and ends of the transport frame prevent excessive vertical or lateral movement of the cask during normal transportation.

1.2.1.7 Heat Transfer Features

The HI-STAR 330 Package provides effective heat dissipation for safe transport of the Liner Tank described in Subsection 1.2.1. The radioactive materials decay heat is passively dissipated without any mechanical or forced cooling. The temperature of the contents is dependent on the decay heat and the heat dissipation capabilities of the cask.

The heat transfer mechanisms in the HI-STAR 330 Package are conduction, convection and thermal radiation. Heat is transferred by conduction in areas of the cask where the Liner Tank outer surface comes into contact with the inner surface of the cask containment boundary. The clearance between the Liner Tank and the cask is small, thereby reducing the thermal resistance through the gaps. Air in the free volume of the cask outside the Liner Tank contributes to conductive heat transfer across gaps between the metal surfaces of the Liner Tank and the internal surfaces of the containment system. Metal conduction transfers the heat throughout the LTC, through the Liner

Tank, containment system boundary, and finally through the DBS and other exterior cask components.

The all-metallic (steel) construction of the LTC, Liner Tank and HI-STAR 330 cask enables the HI-STAR 330 Package to dissipate heat efficiently. Collectively the heat transfer features of HI-STAR 330 maintain wastes and packaging components temperatures at or below the allowable limits in Chapter 3.

For protection of the elastomeric gaskets during a fire accident, the package is equipped with an insulation board **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** . The insulation board ensures **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** does not exceed its maximum operating temperature during the fire accident.

1.2.1.8 Security Seal

The HI-STAR 330 Package provides a security seal that while intact provides evidence that the Package has not been opened by unauthorized persons, as shown in the drawing package in Section 1.3. When installed, the security seal prevents the removal of an Top Impact Absorber attachment bolt, preventing the removal of the Top Impact Absorber. This, in turn, prevents removal of the Cask Lid, as the steel strongback plates of the installed Top Impact Absorber prevent access to the Cask Lid bolts. The security seal is a *not important-to-safety* (NITS) feature. This seal satisfies the requirements of 10 CFR 71.43(b).

1.2.1.9 Packaging Markings

Each HI-STAR 330 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 330 cask has completed the final factory acceptance test (FAT) and verification.

1.2.2 Contents of Package

The HI-STAR 330 Package is classified as a Category I Type B package since the maximum activity of the contents to be transported in the HI-STAR 330 Package is above limits shown in Table 1 of Regulatory Guide 7.11 [1.2.4]. It is specifically designed for transportation of NFW from a nuclear power plant over the plant's entire life cycle, including transport after the plant shutdown.

The contents for each type of waste package, while generally similar in physical description and chemistry, varies in total activity and specific activity. The NFW and package payload physical characteristics are provided in this subsection. The required loading specifications are provided in Chapter 7 of this SAR. The authorized contents permitted for shipment in the HI-STAR 330, including general waste type, radioactive material limits, heat load, waste location requirements, weight limitations and other applicable requirements, are summarized in Table 1.1.1, Table 1.2.1 and Table 7.1.2.

The radioactive waste contents consist of radiation-activated or surface-contaminated materials such as the following:

- Segmented and non-segmented solid reactor internals including, but not limited to, Top Guides/Core Grids, Core Shrouds, Core Shroud Heads, Lower Core Shrouds, Steam Separator Units, Core Spray Sparger Assemblies, Steam Dryers, and Feed Water Spargers. The material is typically in the form of neutron activated metals (e.g. stainless steel and Inconel) and metal oxides in solid form. Surface contamination is expected and may include contaminants from pool water exposure, crud from reactor operations and fine chips from cutting operations. Any contents not made from stainless steel or Inconel (like ceramic mesh screens) do not contain induced activity, i.e. have not been subject to a neutron flux from the reactor core, and only contain CRUD and surface contamination.
- Secondary waste (e.g. debris/chips) generated by the mechanical cutting process, contaminated material processing tools (e.g. spent saw blades), chip drums (stainless steel) with surface contamination or induced activity, and metallic waste filters (stainless steel, ceramic or glass mesh screens) which may be loaded in chip drums. If needed, the chip drums design allows water to drain by gravity, prevents pooling of residual water and facilitates moisture removal during vacuum drying process.
- High activity waste enclosed in Tertiary Containers, used in conjunction with Liner Tanks and LTCs for the transport of material that requires the presence of additional shielding materials to achieve the radiation dose limits set forth in 10CFR71. The Containers may be designed as robust box-like structures or in other configurations as appropriate for the shape and size of the contained material, and shall be made of steel or higher density material to achieve sufficient shielding thickness. The structural elements (welds, closure system, etc.) of the Tertiary Containers are important to safety and shall be designed in accordance with ASME Section III Subsection NF requirements. The Tertiary Containers are designed to be placed in Liner Tanks along with other NFW hardware without additional constraints, and shall remain intact (that is, maintain their shielding configuration) during the critical free drop events prescribed in 10 CFR 71.73.

The waste components are typically cut by mechanical cutting techniques and segmented with the objective to provide good packing density. Generally, LTCs will not be loaded with segments of exactly the same geometry. Segments are not stabilized in the LTC, and will move if the Liner Tank is upset.

Payload will vary from shipment to shipment; however, the design basis parameters specified in Table 1.2.1 and Table 7.1.2 for the contents and the HI-STAR 330 must be met to ensure compliance with regulatory and safety analysis requirements.

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

<u>Radioactive Waste Specification</u>

To ensure that all contents which are geometrically admissible in the cask are authorized for transportation, it is necessary to determine the governing radioactive waste specifications for each analysis criteria as necessary (structural, containment, shielding, thermal-hydraulic, and criticality). Tables 1.2.1 and 7.1.2 lists the key characteristics of the contents, which were evaluated to determine the governing design criteria for the radioactive waste. Substantiating results of analyses for qualification of the contents listed in Table 1.2.1 and 7.1.2 are presented in the respective chapters dealing with the specific qualification topic.

1.2.3 Special Requirements for Plutonium

The contents of the package, provided in Section 1.2.2 and to be transported in the HI-STAR 330 Package may contain plutonium in solid form.

1.2.4 Operational Features

The HI-STAR 330 Packaging has been developed to facilitate loading and unloading of radioactive wastes with ALARA protection against handling accidents and a minimum number of handling evolutions (i.e., simplicity of handling). **[**

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<u>Typical Loading Operations</u>

Loading of Liner Tank, using an LTC (See Figure 7.1.2)

The Liner Tank (without Top Cover) is staged at a designated loading area within a shielded Dry Box. The LTC (without Top Plate) is lowered into the pool and loaded with preselected waste segments and/or chip drums. While still underwater, the LTC Top Plate is installed. A Wet Hood (an ancillary that provides temporary shielding during transfer operations) is lowered into the pool to engage the loaded LTC. The LTC is removed from the pool in the Wet Hood and placed into the open Liner Tank. A drying system is used to remove all bulk water from the Liner Tank and its contents, in accordance with Chapter 7 of this SAR. Following the drying operations, the Liner Tank cavity containing the LTC is restored to ambient pressure and the Liner Tank Top Cover is installed and bolted in place.

Loading of Liner Tank, without the use of an LTC (See Figure 7.1.3)

As an alternative to using an LTC, dry waste may be directly placed into a Liner Tank. To accomplish this, the Liner Tank (without Top Cover) is staged at a designated loading area within a shielded Dry Box. The Liner Tank is then loaded with preselected waste segments and/or chip drums. The Liner Tank Top Cover is then installed and bolted in place.

Installation of a loaded Liner Tank into Cask (See Figure 7.1.4)

Prior to installation into the HI-STAR 330 Cask, a loaded Liner Tank is confirmed to have been loaded in accordance with Chapter 7 of this SAR. The Cask may be loaded while attached to its transport frame, or may be removed from its transport frame. With the Cask Closure Lid removed, the Liner Tank is lowered into the Cask. The Cask Closure Lid is then installed, and its bolts are installed and torqued to compress the elastomeric seals. The cask is sealed closed with the (unpressurized) ambient air.

Preparation for Transport (See Figure 1.2.3)

The Top Impact Absorber is installed, a security seal (tamper device) is attached, and tie-down devices are employed to secure the package to the transport frame. If not already in place, the cask is then placed on the transport frame using an appropriate lift fixture and/or rigging. The HI-STAR 330 Package is then ready for transport. The inspections, verifications, and tests (acceptance criteria and maintenance program requirements) required to prepare the package for shipment are specified in Chapter 8 of this SAR.

TABLE 1.2.1
PACKAGE DESIGN BASIS HEAT LOAD AND NORMAL DESIGN PRESSURE

Waste Package Type	**B**	**C**
Maximum calculated waste package heat load, kW (Note 1)	0.99	0.13
Package Design Basis Heat Load, kW (Note 2)	Table 7.1.2	
Normal Design Pressure, psig	5	

Notes:

1. The maximum calculated waste package heat loads are consistent with the maximum allowable Co-60 activities specified in Table 7.1.2 and therefore not required to be specified separately as permissible heat loads.
2. The design basis heat load for the HI-STAR 330 Package is set to bound the maximum calculated heat load of all waste packages. The package design basis heat load is defined as the maximum permissible heat load in Table 7.1.2.

[Figure 1.2.1 Withheld in Accordance with 10 CFR 2.390]

[Figure 1.2.2 Withheld in Accordance with 10 CFR 2.390]

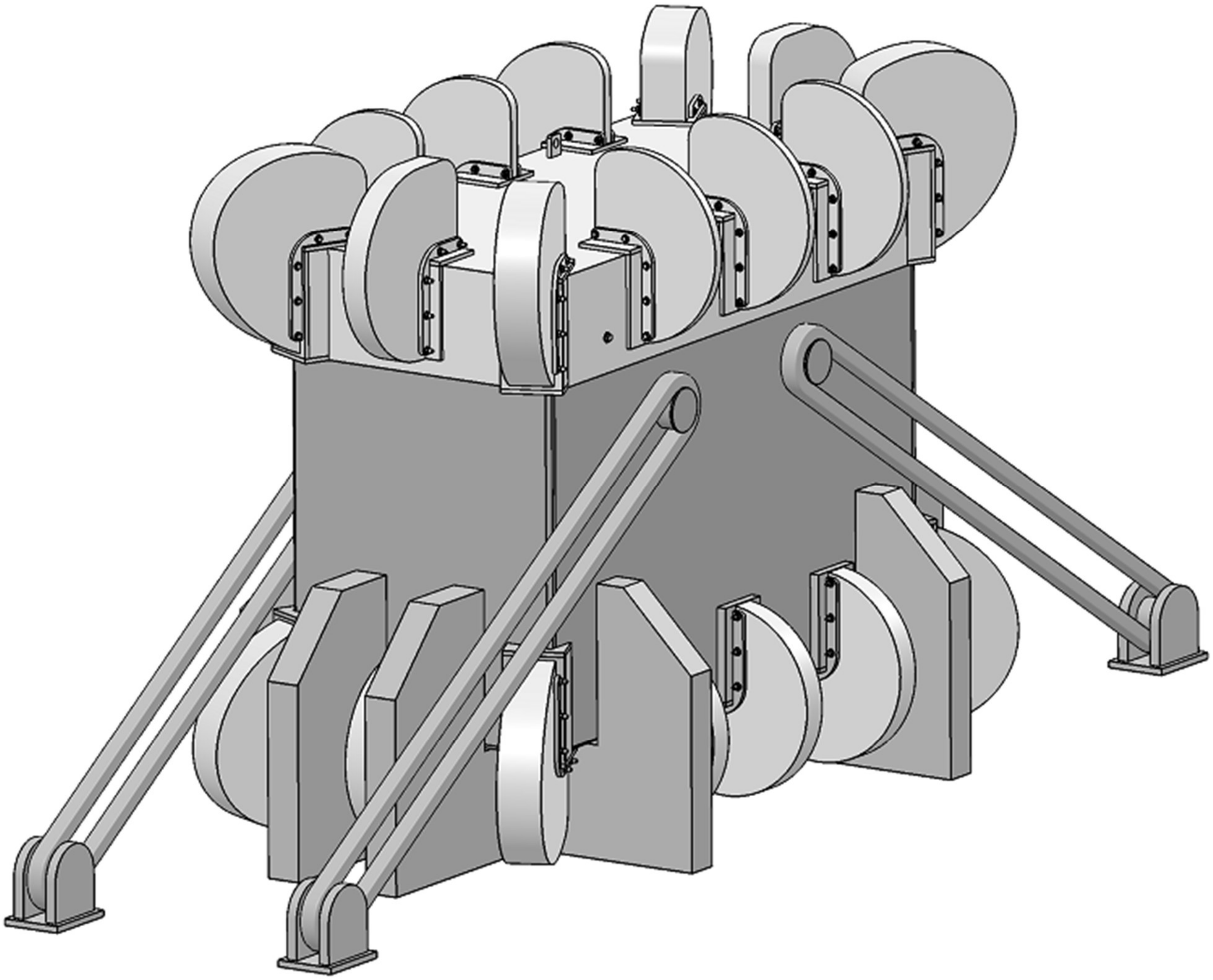


FIGURE 1.2.3
EXAMPLE ILLUSTRATION OF HI-STAR 330 PACKAGE IN CONCEPTUAL TRANSPORT CONFIGURATION

1.3 Engineering Drawings

This section contains a HI-STAR 330 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.

The manufacturing of the HI-STAR 330 components is required to be in strict compliance with the Drawing Package in this section.

The following HI-STAR 330 System Licensing Drawings are provided in this section:

Drawing Number	Description	Rev.
12482	HI-STAR 330 Type B/C Waste Transport Cask	5
12596	Liner Tanks and Cassettes	1

[Drawings Withheld in Accordance with 10 CFR 2.390]

1.4 Summary of Compliance with 10CFR71 Requirements

The HI-STAR 330 Package is designed to comply with the requirements of 10CFR71 for a Type B(U)-96 package. Analyses which demonstrate that the HI-STAR 330 Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR.

The HI-STAR 330 Package meets the structural, thermal, containment, and shielding and criticality requirements of 10CFR71, as described in Chapters 2 through 6. In Chapter 2, the compliance of the HI-STAR 330 Package with the general standards for all packages- 10CFR71.43- is demonstrated. Under the tests specified in 10CFR71.71 (routine and normal conditions of transport) the HI-STAR 330 Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR 330 Package to meet the requirements of 10CFR71, Paragraphs 71.45 and 71.51. Under the tests specified in 10CFR71.73 (hypothetical accident conditions), the damage sustained by the HI-STAR 330 Package is shown to be within the permissible limits set forth in 10CFR71, Paragraphs 71.51.

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 ensuring compliance with 10CFR71:

- The HI-STAR 330 Packaging has been described in sufficient detail to provide an adequate basis for its evaluation.

- The drawing package provided in Section 1.3 provides an adequate basis for evaluation of the HI-STAR 330 Packaging against the 10CFR71 requirements. 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 330 packaging has been identified.

- The applicable codes and standards for the HI-STAR 330 Packaging design, fabrication, assembly, and testing have been identified in the drawing package in Section 1.3.

- The HI-STAR 330 Package meets the general requirements of 10 CFR 71.43(a) and 10 CFR 71.43(b), as demonstrated by the drawings provided in Section 1.3 and the discussion provided in Subparagraph 1.2.1.9.

- Allowable contents in the HI-STAR 330 Packaging are specified in Subsection 1.2.2.

- The only special purpose material, namely the gasket used to seal the Containment Boundary, is identified in the Licensing drawing in Section 1.3, and critical characteristics are provided in Table 2.2.6 of this SAR.

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.

[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.

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

[1.2.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code", Section III, Div. 1, Subsection NB (2013)

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

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

[1.2.4] 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.

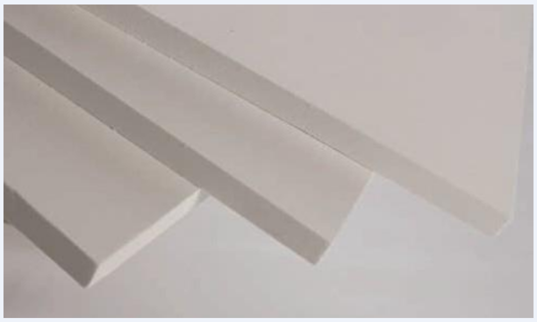
APPENDIX 1.A: KAOWOOL MILLBOARD SPECIFICATIONS

Morgan Advanced Materials

Thermal Ceramics

Kaowool® Millboards

Datasheet Code US: 5-14-702



Features

- Asbestos replacement millboard
- Thin durable insulation
- Thickness tolerance of ± 1/32" (0.8 mm)
- Easy to saw or die cut
- Excellent backup insulation
- 2000°F to 2700°F (1093°C to 1482°C) use limits

Product Description

Kaowool Millboard products are processed from a slurry consisting of Kaowool ceramic fibers, fillers and binders. The fiber raw material is kaolin, a naturally occurring high-purity alumina-silica fireclay. Kaowool Millboard products are strong, thin, durable ceramic fiber based boards having a variety of high-temperature applications. Although these products were formulated and designed to replace asbestos millboard, their potential use extends into more conventional refractory fiber applications. Their use should be considered whenever there is a need for a thin, durable board with excellent insulating characteristics.

Kaowool 822 Millboard is a high density, strong board with many applications including fire protection, thermal barriers, and backup insulation.

Kaowool 830 Millboard was specifically designed for use in the iron and steel industry as a molten contact product. It has proven to be excellent for use as a one shot casting mold liner for both stools and ingot molds because of the unique combination of organic and inorganic binders. This 40 pcf (641 kg/m^3), 0.16" (4 mm) product produces an exceptionally smooth surface finish on cast metal pieces when compared to those surfaces produced by sand casting or cast using other board products.

Kaowool 1401 Millboard is a strong, thin, dense board product with excellent compression resistance and insulating characteristics. It is produced from Kaowool ceramic fibers, clay, inert fillers, and a small amount of both organic and inorganic binders for increased handling strength. It maintains its integrity throughout a wide temperature range and is easily fabricated and die cut.

Applications

- High-temperature gaskets (all grades)
- High-temperature roll covering (grade 822)
- Fire protection (grade 822)
- Thermal barrier (grades 822 and 1401)
- Backup insulation (grades 822 and 1401)
- One-shot casting mold liner for stools and ingot molds (grade 830)
- Molten metal contact applications in the iron and steel industries (grade 830)
- Molten metal contact applications in the non-ferrous industries (grade 830)
- Heat and flame shields (grade 1401)
- Parting media (grade 1401)

Chemical Properties

Kaowool Millboard provides excellent resistance to chemical attack. Exceptions include hydrofluoric acid, phosphoric acid, and strong alkalis. A small amount of combustible organic binder will burn out at approximately 300°F (149°C). **Caution should be exercised during the initial heating. Adequate ventilation should be provided to avoid potential flash ignition of the binder out-gassing and to avoid air entry while at elevated temperature.**

Morgan Advanced Materials

Thermal Ceramics

Kaowool® Millboards

Boards and Shapes - Vacuum Formed Product Name	Kaowool Millboard 822	Kaowool Millboard 830	Kaowool Millboard 1401
Fiber Class	RCF	RCF	RCF
Physical Properties			
Color	white	tan	white
Continuous Use Temperature, °F	2000	2000	2000
Continuous Use Temperature, °C	1093	1093	1093
Classification Temperature, °F	2300	2700 one time	2300
Classification Temperature, °C	1260	1482 one time	1260
Melting Temperature, °F	3200	3200	3200
Melting Temperature, °C	1760	1760	1760
Density, pcf	55	40	35-40
Denisty, kg/m^3	881	641	560-641
Compressive strength @ 5% deformation, psi	50-75	-	10-20
Compressive strength @ 5% deformation, Mpa	0.34-0.51	-	0.06-0.14
Compressive strength @ 10% deformation, psi	100-125	-	55-70
Compressive strength @ 10% deformation, Mpa	0.69-0.86	-	0.38-0.48
Compressive strength @ 15% deformation, psi	250-300	-	175-200
Compressive strength @ 15% deformation, Mpa	1.72-2.06	-	1.20-1.38
Chemical Analysis, % weight basis after firing			
Alumina, Al_2O_3	35	35	36
Silica, SiO_2	63	65	60
Other	2	-	4
Loss of Ignition, LOI	5-7	12-15	9-11
Thermal Conductivity, BTU•in/hr•ft^2, per ASTM C201			
500°F	0.8	0.53	0.61
1000°F	0.89	0.71	0.81
1500°F	0.98	0.91	1.04
2000°F	1.08	1.15	1.33
Thermal Conductivity, W/m•K, per ASTM C201			
260°C	0.11	0.08	0.08
538°C	0.13	0.1	0.12
816°C	0.14	0.13	0.15
1093°C	0.16	0.16	0.19

Morgan Advanced Materials

Thermal Ceramics

Kaowool® Millboards

Standard Sizes				
Grade	Thickness in (mm)	Sheet Size in (cm)	Sq. Ft/Sheet (Sq. M/Sheet)	Weight/Sheet lbs (kg)
822	1/8 (3.18)	27½ x 27½ (70 x 70)	5.25 (0.49)	3.1 (1.4)
	1/8 (3.18)	55 x 55 (140 x 140)	21 (1.95)	12.4 (5.6)
	1/4 (6.35)	55 x 55 (140 x 140)	21 (1.95)	24.8 (11.2)
830	0.160 (4.06)	55 x 55 (140 x 140)	21 (1.95)	11.4 (5.2)
1401	1/16 (1.59)	55 x 55 (140 x 140)	21 (1.95)	4.2 (1.9)
	1/8 (3.18)	55 x 55 (140 x 140)	21 (1.95)	8.3 (3.8)
	3/16 (4.76)	55 x 55 (140 x 140)	21 (1.95)	12.5 (5.7)
	1/4 (6.35)	55 x 55 (140 x 140)	21 (1.95)	16.7 (7.6)
	3/8 (9.53)	55 x 55 (140 x 140)	21 (1.95)	25.0 (11.3)
	1/2 (12.70)	55 x 55 (140 x 140)	21 (1.95)	33.3 (15.1)

CHAPTER 2: STRUCTURAL EVALUATION

2.0 Introduction

This chapter presents a synopsis of the Analysis Methodology and Design Criteria relevant to the mechanical and structural characteristics of the HI-STAR 330 package that ensure compliance with the performance requirements of 10CFR71 [1.0.2].

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.
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. The appropriate methodologies used to analyze the HI-STAR 330 package.

Appendix 2.A provides introductory information on the principal codes used in the structural analysis (ANSYS and LS-DYNA).

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 and brittle fracture, is also provided.

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 330 package. These members are the containment system components together with those parts that render the radiation shielding function in the cask to protect the package in the event of a hypothetical accident condition (HAC) set forth in (§71.73).

2.1.1.1 Cask

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

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

The containment space (or space within the containment boundary as identified in the drawing package in Section 1.3 and described in Section 1.2) is the heart of the package.

ASME Section III, Division 1, Subsection NB is used as the reference Code for the design and construction of the HI-STAR 330 containment system.

2.1.1.2 Liner Tank

Liner Tank provides secondary packaging for the contents and is fitted into the HI-STAR 330 cask. The Liner Tank walls, including the top and bottom plates, serve as dose blocker parts.

The specific structural requirements of the Liner Tank, germane to its function as the waste container, are further discussed in this SAR chapter.

2.1.1.3 Liner Tank Cassettes

Liner Tank Cassettes (LTC) are loaded into the Liner Tanks. Only the top and bottom plates of the LTC are classified as dose blocker parts. The specific structural requirements of the LTC are further discussed in this SAR chapter.

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

2.1.2 Design Criteria

The HI-STAR 330 Transport package is characterized by the following attributes that differentiate it from casks used to transport the spent nuclear fuel:

(i) The package is fissile-exempt (i.e., little fissile material) and therefore criticality control is not relevant to the Cask's design criteria.

(ii) The internal heat generation in the package is negligible; therefore, there is little elevation of the metal temperature of the Containment Boundary above the ambient.

(iii) Because the contents are metallic waste, there is no safety imperative to use an inert gas atmosphere around the waste (plain air suffices).

(iv) Because there is no risk of a criticality event, internal deformations inside the cask are not a concern. Therefore, there is no safety imperative to employ traditional impact limiters to deal with the accident scenarios of 10CFR71.73.

ASME Code Section III, Subsection NB, which is espoused in Regulatory Guide 7.6 [2.1.1], is the reference Code for structural qualification of the package under Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC). The structural qualification of the trunnions for normal handling follows the provisions in NUREG-0612 [1.2.3] and Subsection NF of the Code for material specifications.

The various ASME Code Sections invoked in this SAR for stress analysis and material properties data are listed in reference [2.1.2] through [2.1.5]. Loading conditions and load combinations for transport are defined in Regulatory Guide 7.8 [2.1.6]. 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 330 package possesses sufficient structural capability to maintain the integrity of the Containment Boundary under both normal and hypothetical accident conditions of transport articulated in 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. The table below lists the guidance from Reg. Guide 7.6 and HI-STAR 330's compliance/alternatives thereto.

Conformance with Reg. Guide 7.6 Provisions on the structural requirements for HI-STAR 330 Containment Boundary	
1. Material properties, design stress intensities, and fatigue curves are obtained from the ASME Code.	As there are no significant cyclic loads on the HI-STAR 330 package, fatigue curves of the ASME Code are not utilized.
2. Under NCT, 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.	This guidance is fully complied with; see Table 2.1.1.

Conformance with Reg. Guide 7.6 Provisions on the structural requirements for HI-STAR 330 Containment Boundary	
3. Perform fatigue analysis for NCT using ASME Code Section III methodology (NB) and appropriate fatigue curves.	There are no significant cyclic loads; hence a fatigue analysis is not warranted.
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.	This guidance is fully complied with; see Table 2.1.1.
5. Buckling of the containment vessel should not occur under normal or accident conditions.	This guidance is fully complied with; inelastic material model used in the comprehensive FE model is capable of predicting buckling behavior.
6. Under HAC, 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.	This guidance is fully complied with; see Table 2.1.1.
7. The extreme total stress intensity range should be less than $2S_a$ at 10 cycles as given by the appropriate fatigue curves.	This guidance is fully complied with.

2.1.2.1 Loading and Load Combinations

In addition to handling loads, 10CFR71 and Regulatory Guide 7.6 define two loading conditions that must be considered for qualification of a transport package. These are defined as “Normal Conditions of Transport” (NCT) and “Hypothetical Accident Conditions” (HAC).

1. Handling Loads

The lifting trunnions in the HI-STAR 330 cask are subject to specific limits set forth in NUREG-0612 [1.2.3]. More specifically, only four trunnions (one load path) shall meet the factor of safety of 5 against ultimate, as required by NUREG-0612 while subject to the lifted load that includes an appropriate dynamic load amplifier.

2. 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 (20 psia).
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).
f. Water spray test
g. Penetration test
h. Compression test

Since the normal internal pressure loading for the HI-STAR 330 is less than 5 psig (35 kPa), the small reduced external pressure (internal overpressure) loading noted in (a) will not influence the structural integrity of the HI-STAR 330 package.

To envelope loading ((b) above), a bounding external pressure analysis is performed and is labeled as Load Case E in Table 2.1.1. Further, the analyzed external pressure loading on the cask bounds the loading due to the cask immersion under the water head of 15 m (50 ft) applicable for the HAC loads.

The normal operating conditions (e) is bounded by the Design Pressure in Table 1.2.1 which indicates that the Package does not merit designation as a “pressure vessel”. The “1-foot drop event” (c) is labeled as Load Case B in Table 2.1.1. Vibratory loads (d) transmitted to the HI-STAR 330 package by the transport vehicle will produce negligibly small stresses in comparison with stresses that will be produced by the accident condition loadings described previously. Fatigue considerations due to mechanical vibrations are further discussed in Section 2.6.

Water spray test and penetration test ((f) and (g) above) are not applicable to the HI-STAR 330 package. The water spray test, which simulates exposure to rainfall of approximately 5 cm per hour for at least 1 hour, is not structurally significant to the HI-STAR 330 cask. This is because the HI-STAR 330 package is quite massive, and therefore it has a large thermal inertia. As a result, the package will have a slow thermal response to external temperature changes, such as the water spray test. Since the water spray test will not cause a sudden change in temperature leading to large thermal strains, it poses no significant risk to the containment boundary system or the shielding capabilities of the HI-STAR 330 package. The minimum thickness of material between the outside surface of the package and the nearest point on the containment boundary system is at least 2 inches and hence the penetration test does not pose any threat to the package.

Lastly, a compression test (h) using a load equal to the greater of the following two conditions is considered for the HI-STAR 330 analysis:

(i) The equivalent of 5 times the weight of the package; or
(ii) The equivalent of 13 kPa (2 lbf/in^2) multiplied by the vertically projected area of the package.

3. <u>Hypothetical Accident Condition Loads (§71.73)</u>

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

a. Free Drop of 9-m (30 ft)
b. Puncture

c. Engulfing fire @ 800ºC (1475ºF)
d. Immersion in 15-m (50 ft) head of water.

a. Free Drop

Labeled as Load Case C in Table 2.1.1, the free drop accident consists of a free fall of the loaded package from a height of 9 meters on to an essentially unyielding surface in any credible orientation that would inflict maximum damage to the package. Six such candidate adverse orientations have been selected and listed in Table 2.1.1 as those requiring safety analyses.

b. Puncture

Denoted as Load Case D in Table 2.1.1, this event consists of a 1-m (40-in) free drop onto a stationary and vertical mild steel bar of 15 cm (6 in) diameter. The bar is assumed to be of such a length as to cause maximum damage to the cask. The package is assumed to drop in the worst-case orientation(s) with the penetrant force being applied at the location that can cause maximum damage to the cask.

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. Based on the temperature changes established in Chapter 3, an evaluation is performed to demonstrate that the fire event does not compromise the structural integrity of the containment boundary. This case is labeled as Load Case F in Table 2.1.1.

d. Immersion

The bounding external pressure loading, in support of the normal conditions of transport, is considered to envelope the pressure corresponding to the cask immersion under 15-m (50 ft.) water head. This case is labeled Load Case E in Table 2.1.1. The external pressure evaluation for the containment boundary is extremely conservative due to the fact that the normal service Level A stress limits are imposed for this loading condition.

Based on the above considerations, the Load Combinations that are considered in Section 2.7 are:

Hypothetical Accident Load Cases	
Event	**Load Case in Table 2.1.1**
9-m Free Drops	Load Case C
1-m Puncture Drops	Load Case D
15-m (50-ft) Immersion into Water	Load Case E
Fire	Load Case F

e. Deep Water Submergence

Since the HI-STAR 330 package has radioactive contents with activity less than $10^5 A_2$, the package is exempted from the enhanced water immersion test.

2.1.2.2 Acceptance Criteria

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e. Applicable minimum allowable stress intensity limits for the containment system, including cask lid locking system, are obtained from the ASME Code, Section III, Division 1, Subsection NB [2.1.1]. The limiting allowable stress intensity values are given in Tables 2.1.3 through 2.1.6.

Allowable stresses and stress intensities are calculated using the data provided in the ASME Code, Section II, Part D [2.1.6] and Tables 2.1.2A and 2.1.2B. Tables 2.1.3 through 2.1.6 provide numerical values of stress intensities, as a function of temperature, for the cask containment system materials.

Throughout this chapter, the term "S_m" and "S_u" denote the design stress intensity and ultimate strength, respectively. Property values at intermediate temperatures that are not reported in the tables are obtained by linear interpolation as allowed by paragraph NB-3229 of the ASME Code.

Terms relevant to the analyses are extracted from the ASME Code (Figure NB-3222-1) as follows.

Symbol	Description	Notes
P_m	Average primary stress across a solid section.	Excludes effects of discontinuities and concentrations. Produced by pressure and mechanical loads.
P_L	Average stress across any solid section.	Considers effects of discontinuities but not concentrations. Produced by pressure and mechanical loads, including inertia earthquake effects.
P_b	Primary bending stress.	Component of primary stress proportional to the distance from the centroid of a solid section. Excludes the effects of discontinuities and concentrations. Produced by pressure and mechanical loads, including inertia earthquake effects.
P_e	Secondary expansion stress.	Stresses, which result from the constraint of free-end displacement. Considers effects of discontinuities but not local stress concentration. (Not applicable to casks.)
Q	Secondary membrane plus bending stress.	Self-equilibrating stress necessary to satisfy continuity of structure. Occurs at structural discontinuities. Can be caused by pressure, mechanical loads, or differential thermal expansion.

Summarizing the previous discussions, in accordance with Regulatory Guide 7.6 and ASME Code Section III, Subsection NB, the allowable stress limits for the cask containment system are based on design stress intensities (S_m), yield strengths (S_y), and ultimate strengths (S_u). These limits govern the design of the containment baseplate, the containment side walls, the containment end walls, the closure lid, and the cask closure lid bolting and are given in Tables 2.1.3 through 2.1.6 for normal and hypothetical conditions of transport as a function of temperature. As the ASME Code sections governing the containment system are stress based, there is no explicit maximum strain limit set down in this SAR for the containment system.

Certain parts of the HI-STAR 330 containment system are composed of ferritic steel materials, which may be subject to impact loading in a cold environment and, therefore, must be evaluated and/or subjected to impact testing in accordance with the ASME Code to ensure protection against brittle fracture.

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(ii) Dose Blocker Structure (DBS)

[

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]

(iii) Liner Tank

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

(iv) Liner Tank Cassette (LTC)

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

(v) Cask Impact Absorbers (Crushable Attachments)

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

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2.1.3 Weights

Section 1.1 provides the overall weights of the HI-STAR 330 Transport package and its constituent components.

2.1.4 Identification of Codes and Standards for Package Design

The design of the HI-STAR 330 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) [2.1.5] that are cited herein are used for the design of the containment system of the HI-STAR 330 Package.

Table 2.1.8 lists each major structure, system, and component (SSC) of the HI-STAR 330 Packaging, along with its function, and applicable code or standard. The drawing package in Section 1.3 identifies whether items are “Important to Safety” (ITS) or “Not Important to Safety” (NITS); the identification is carried out using the guidance of NUREG/CR-6407, “Classification of Transportation Packaging and Dry Spent Fuel Storage System Components”. Table 8.1.3 lists some alternatives to the ASME Code where appropriate. Table 8.1.2 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 [2.1.9].

All materials and sub-components that do not constitute the containment system in the HI-STAR 330 cask are procured to a recognized national consensus standard.

TABLE 2.1.1
STRUCTURAL LOADING EVENTS AND ASSOCIATED ACCEPTANCE CRITERIA FOR HI-STAR 330

#	Loading Case	Loading	Constituent Part	Stress/Strength Limit	Comment
1	A	Lifting and handling of Cask	Cask Lifting Trunnions	Factor of safety of 5 against ultimate strength per NUREG-0612 when considering redundant load path	Minimum strength values from the drawing package in Section 1.3 are used.
2	A	Lifting and handling of Cask	Containment System	The primary membrane plus bending stress intensity shall be less than 1.5 times the ASME code stress intensity	Per Subsection NB
3	A	Lifting and handling of Closure lid	Closure Lid Lift Points	Same as #1 above	Per NUREG-0612
4	A	Lifting and handling of Closure Lid	Closure Lid Plate	Same as # 2 above	Same as #2 above
5	B	Free drop from 0.3 meters	Cask body & lid, depending on the orientation of drop	1. Containment system must meet Level A stress intensity limits per Subsection NB. 2. Closure Lid Bolting: The Closure lid bolting must meet the acceptance criteria per Table 2.1.2B. 3. The DBS components must not detach from the cask or suffer substantial loss of material causing the Part 71 normal condition dose limits to be exceeded.	This loading condition corresponds to the Part 71 normal condition. [**Proprietary Information Withheld in Accordance with 10 CFR 2.390**]

#	Loading Case	Loading	Constituent Part	Stress/Strength Limit	Comment
6	C	Free drop from 9 meters	Cask body & lid, depending on the orientation of drop	1. Containment system must meet Level D stress intensity limits per Subsection NB. 2. Closure Lid Bolting: The Closure lid bolting must meet the acceptance criteria per Table 2.1.2B. 3. DBS: Must not detach from the cask causing the Part 71 post-accident dose limits to be exceeded.	This loading corresponds to the Part 71 hypothetical accident condition. The critical HAC drop events are: **[** **Proprietary Information Withheld in Accordance with 10 CFR 2.390** **]**
7	D	Puncture	Most vulnerable part of the cask to a local penetrant load.	Same as # 6 above	Drop of the loaded cask from 1 meter on to a steel bar. See Sub-section 2.7.2 for specific drop conditions. Containment boundary must remain intact (i.e., no breach).
8	E	15m (50 ft.) Water immersion	Cask body & lid	Containment boundary must meet Level A stress intensity limits per Subsection NB	Containment boundary must not buckle under external pressure load corresponding to immersion accident.
9	F	Fire	Closure Lid Connection (Sealing)	Effectiveness of the containment seals must be evaluated	**[** **Proprietary Information Withheld in Accordance with 10 CFR 2.390]**

TABLE 2.1.2A: 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 2.1.2B: 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 the bolt remains elastic.
2. Limit set on primary tension plus primary bending for Level D loading is based on an elastic stress evaluation; however, the overriding acceptability of the joint design is performance based on an assured absence of leakage.
3. The closure lid bolt joints are friction type joints due to the large preload stress; they are not subjected to shear per ASME Code, Section III, Division 1, Subsection NF, NF-3324.6(a)(3)(b). Therefore, there is no need to include the shear and combined tensile and shear stress allowables in this table.

TABLE 2.1.3: 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)

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 2.1.2A.

TABLE 2.1.4: 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)

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 2.1.2A.
4. See Table 2.1.3 for stress classification definitions.

TABLE 2.1.5: 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)

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 2.1.2A.
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 2.1.3 for stress classification definitions.

TABLE 2.1.6: 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)

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 2.1.2A.
4. See Table 2.1.3 for stress classification definitions.

TABLE 2.1.7: DESIGN STRESS INTENSITY – BOLTING MATERIAL

Code: ASME NB (Bolt < 2.5-inch diameter)
Material: SA-564/705 630 (H1025)
Item: Stress Intensity

Temperature **ºC (ºF)**	**Design Stress Intensity** **MPa (ksi)**
-29 to 38 (-20 to 100)	333.0 (48.3)
93.3 (200)	333.0 (48.3)

Notes:

1. Level A and D limits per Table 2.1.2B.
2. Table 2.2.2 contains other mechanical and thermal properties of the bolting material.
3. Sources for design stress intensity values for SA-564/705 630 material, is Table 2A of ASME Section II, Part D.
4. Values for SA-564/705 630 are conservatively based on age hardening at 1075ºF (H1075).

TABLE 2.1.8: APPLICABLE CODES AND STANDARDS FOR THE MATERIALS USED IN THE HI-STAR 330 PACKAGING

	Item	Principal Function	Applicable Codes and Reference Standard
1.	Containment Baseplate	Containment Boundary	ASME Code Section III Subsection NB[1]
2.	Containment Side Walls	Containment Boundary	ASME Code Section III Subsection NB[1]
3.	Containment End Walls	Containment Boundary	ASME Code Section III Subsection NB[1]
4.	Closure Lid Bolting	Containment Boundary	ASME Code Section III Subsection NB[1]
5.	Seals and Gaskets	Containment Boundary	Non-Code (Manufacturer's Catalog and Test Data)
6.	Trunnions	Lifting and Handling	Refer to Table 8.1.2

Note:
[1] The applicable codes listed in here are specific for the component procurement and fabrication. The analysis and acceptance criteria for the containment boundary are specifically discussed in section 2.1.1.

2.2 Materials

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

2.2.1 Structural Materials

2.2.1.1 <u>Containment System</u>

The nickel alloy and low-alloy steels used in the HI-STAR 330 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.

The cask closure lid bolting is made from precipitation hardened (PH) steel, namely SA-564/705 630 (H1025). The material properties used for structural evaluations are given in Table 2.2.2.

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

2.2.1.2 <u>Trunnion Materials</u>

The HI-STAR 330 cask has a total of four lifting trunnions, as shown in the licensing drawings in Section 1.3. Each trunnion is comprised of a solid steel shaft embedded into the cask side walls comprising dose blocker structure. The governing material properties for the trunnion material are listed in Table 2.2.3.

2.2.1.3 <u>Dose Blocker Structure</u>

The DBS is made of carbon steel components. The DBS girdles the containment system, and it is designed to provide gamma shielding and physical protection to the transport package. The necessary structural properties for the DBS are provided in Table 2.2.4.

2.2.1.4 <u>Weld Material</u>

All weld filler materials utilized in performing Containment Boundary welds (as defined in the licensing drawings), 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 Dose Blocker Structure welds will be made using weld procedures that meet the requirements of ASME Section IX. 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.

2.2.1.5 Closure Lid Seals

The containment integrity of the HI-STAR 330 package relies on a closure lid system with elastomeric seals, as shown in the licensing drawings in Section 1.3.

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2.2.1.6 Impact Absorber Components (Crushable Attachments)

The impact absorbers (crushable attachments) are made of aluminum bars or plates to comply with minimum characteristics summarized in Table 8.1.5, which are strategically connected to the cask exterior (see Figure 2.3.6). The primary function of these impact absorbers is to deform and absorb the impact energy during the critical drop events. They also serve to mitigate the impact severity and limit the g-load on the cask and its contents. The necessary structural properties for the impact absorbers are provided in Tables 2.2.4 and 2.2.5.

2.2.2 Nonstructural Materials

2.2.2.1 Insulation Board

As shown in the licensing drawings in Section 1.3, a thin layer of thermal insulation board is incorporated in the cask closure lid and at strategic locations in the cask body to protect the closure lid seals against high temperatures during the design basis fire accident. The insulation board is pre-heated prior to installation as needed to remove any residual, combustible organic binders. The thermal properties of the insulation board are given in Section 3.2. The structural evaluations for the HI-STAR 330 package do not take any credit for the insulation board as a load bearing member, and therefore its strength properties are not important to safety.

2.2.3 Effects of Radiation on HI-STAR 330 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 [2.2.1].

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

The HI-STAR 330 containment boundary is composed primarily of nickel/low alloy steel, which has a proven history of use in the nuclear industry. The contents of HI-STAR 330 are classified as fissile-exempt, and therefore the cask's materials will not be subject to appreciable neutron fluence. Gamma radiation damage to stainless steel does not occur until the fluence level reaches 10^{18} rads or more. The 50-year gamma fluence (assuming design basis for 50 years without radioactive decay) from the waste transported in the HI-STAR 330 package reduces significantly as it penetrates through cask components. Therefore, there is no risk of degradation of the containment system due to gamma fluence from the cask's waste package.

2.2.4 Packaging Coatings and Consumable Chemical Products

The information provided in this section identifies paints/coatings, lubricants and adhesives that may be applied to the HI-STAR 330 Package. Products identified in this section may be substituted by equivalent products meeting the specified acceptance criteria established in the table below.

The coatings, lubricants and adhesives identified are commercially available products with years of proven performance. Chemically identical products with different names are permitted. Alternative products may be determined to be equivalent with consideration of manufacturer recommendation. Products that have had proven performance in similar applications, environments and/or operating conditions may also be permitted. Products shall be applied in accordance with the manufacturer's recommendation or as approved by Holtec. The following critical characteristics are ranked in order of importance to guide in the selection of equivalent products:

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2.2.5 Liner Tank and Liner Tank Cassette

The Liner Tank and LTC shall be made from structural steel material with minimum strength properties per the licensing drawings listed in Section 1.3.

In addition, the materials used to construct the Liner Tanks and the Liner Tank Cassettes, which are loaded inside the HI-STAR 330 transport cask, do not require fracture toughness testing for the following reasons:

i) The Liner Tanks and LTC's are not relied upon as containment barriers or pressure retaining vessels. Therefore, there is no concern that a thru-wall crack in either component would lead to a radioactive release or a loss of cavity pressure.

ii) The side walls and the top and bottom plates of the Liner Tanks, as well as the top and bottom plates of the Liner Tank Cassettes, are only credited in the shielding evaluation to mitigate dose rates external to the HI-STAR 330 package.

iii) Excluding the normal (NCT) and HAC drop events, the Liner Tanks and the Liner Tank Cassettes, while inside the HI-STAR 330 cask, only need to support their own self-weight, and therefore the stress levels in these components are quite small and generally compressive in nature. Only the top plates, which are subject to bending during the top end drop, develop tensile stresses; however, the maximum tensile stress is less than 1 ksi, which is small fraction of the material yield strength.

iv) During a hypothetical drop accident, the HI-STAR 330 containment boundary provides a solid backing surface for the side walls and top/bottom plate that are adjacent to the point of impact. Only the side walls and top/bottom plate of the Liner Tank and LTC that are away from the point of impact can develop significant tensile stresses due to flexure, which could have the potential to cause a brittle fracture. However, as discussed in Section 5.3.1.1.2, the geometry of the Liner Tanks is such that, even if a thru-thickness crack were to develop, a significant dislocation of a side wall or top/bottom plate is not credible. A relocation of the top or bottom plates of the Liner Tank Cassette, on the other hand, cannot be entirely ruled out based on geometric considerations. Therefore, as described in Section 5.3.1.1.2, the shielding accident conditions model considers external dose rates at 1-meter from the cask surface assuming that the LTC top and bottom plates are conservatively removed from the analytical model. As shown in Table 5.1.3, the calculated dose for this extremely conservative geometry is less than the regulatory limit.

v) Finally, the shielding evaluation performed in Chapter 5 conservatively assumes that all corner welds on the Liner Tank fail under Hypothetical Accident Conditions resulting in a 20 mm wide separation gap along all corner edges of the Liner Tank. In addition, the shielding evaluation further assumes that the most activated Type A waste bypasses the LTC top plate and occupies the gap between the Liner Tank walls (see Figure 5.3.4), leaving only the side wall of the HI-STAR 330 cask to provide gamma shielding. This conservative shielding model bounds the potential dose consequences of any thru-wall cracks that may develop elsewhere in Liner Tank due to brittle fracture.

In summary, in light of their performance requirements, geometry, and dose rate evaluations performed in Chapter 5, fracture toughness testing of the Liner Tank and LTC materials are not required.

TABLE 2.2.1: MECHANICAL PROPERTIES OF CONTAINMENT COMPONENTS

Temperature ºC (ºF)	**SA-350 LF3/SA-203 E for Cask Containment Boundary**					
	S_y	S_u	E	α	S_y	S_u
-73.30 (-100)	258.6 (37.5)	482.6 (70.0)	19.72 (28.6)	-	275.8 (40.0)	482.6 (70.0)
37.78 (100)	258.6 (37.5)	482.6 (70.0)	19.03 (27.6)	11.7 (6.5)	275.8 (40.0)	482.6 (70.0)
93.33 (200)	235.8 (34.3)	482.6 (70.0)	18.68 (27.1)	12.06 (6.7)	252.3 (36.6)	482.6 (70.0)

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 [2.1.4].
2. Source for S_u values is Table U of [2.1.4].
3. Source for α values is material group 1 in Table TE-1 of [2.1.4].
4. Source for E values is material group C in Table TM-1 of [2.1.4].

TABLE 2.2.2: MECHANICAL PROPERTIES OF CLOSURE LID BOLT MATERIAL

SA-564/705 630 (H1025 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	999.5 (145.0)	1068.7 (155)	19.5 (28.3)	11.16 (6.2)
93.3 (200)	924.4 (134.1)	1068.7 (155)	19.1 (27.8)	11.34 (6.3)

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [2.1.4].
2. Source for S_u values is Table U of [2.1.4].
3. Source for α values is Table TE-1 of [2.1.4]. Values for α are for H1075 condition in lieu of H1025 condition.
4. Source for E values is Table TM-1 of [2.1.4].
5. SA-705 630 and SA-564 630 (both UNS No. S17400) have the same chemistry requirements and are considered equivalent for the intended application.

TABLE 2.2.3: MECHANICAL PROPERTIES OF TRUNNION MATERIAL

Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	344.74 (50.0)	620.5 (90)	17.65 (25.6)	15.5 (8.6)
66 (150)	293.72 (42.6)	620.5 (90)	17.5 (25.4)	15.8 (8.8)
93 (200)	267.5 (38.8)	620.5 (90)	17.3 (25.1)	16.2 (8.9)

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 [2.1.4].
2. Since the S_u values for SA479 S21800 are not listed in Table U of [2.1.4], an equivalent alloy design. S31803 is used to obtain the ultimate strengths from this Table. Note that the ultimate strength values reported above are more limiting than the values reported in the critical characteristics Table 8.1.5.
3. Source for α values is material group 3 in Table TE-1 of [2.1.4].
4. Source for E values is material group I in Table TM-1 of [2.1.4].

TABLE 2.2.4: MECHANICAL PROPERTIES DOSE BLOCKER STRUCTURE

Temperature °C (°F)	SA-516 Grade 70 or A516 Gr 70			
	S_y	S_u	α	E
38 (100)	262.0 (38.0)	482.6 (70.0)	11.7 (6.5)	20.17 (29.26)
93.3 (200)	239.9 (34.8)	482.6 (70.0)	12.06 (6.7)	19.86 (28.8)

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [2.1.4].
2. Source for S_u values is Table U of [2.1.4].
3. Source for α values is material group 1 in Table TE-1 of [2.1.4].
4. Source for E values is "Carbon steels with C less than or equal to 0.30%" in Table TM-1 of [2.1.4].

TABLE 2.2.5: MECHANICAL PROPERTIES OF ALUMINUM (IMPACT ABSORBERS)

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	241.3 (35.0)	289.6 (42.0)	6.90 (10.0)	22.3 (12.4)
66 (150)	238.6 (34.6)	289.6 (42.0)	--	22.9 (12.7)
93 (200)	232.4 (33.7)	289.6 (42.0)	6.6 (9.6)	23.4 (13.0)

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 [2.1.4].
2. Source for S_u values is Table 1B of [2.1.4]; for temperatures above 38°C (100°F), S_u values are ratioed based on value of S at corresponding temperature.
3. Source for α values is Table TE-2 of [2.1.4].
4. Source for E values is Table TM-2 of [2.1.4].

TABLE 2.2.6: PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390

TABLE 2.2.6 PROPRIETARY INFORMATION WITHHELD IN ACCORDANCE WITH 10 CFR 2.390

2.3 Fabrication and Examinations

The HI-STAR 330 non-fuel waste transport cask, as shown in the licensing drawings in Section 1.3, is a stainless steel and alloy steel weldment of rectangular cross section. The inner walls and baseplate of the cask are fabricated of alloy steel (SA-517/A514) qualified to Subsection NB of the ASME code. The closure lid is a monolithic plate made of the same material and also procured to ASME Section III Subsection NB specifications. The inner walls, inner baseplate, and closure lid constitute the Containment Boundary of the cask. The cask outer walls and bottom plates, as well as the closure lid outer plate, constitute the Dose Blocker Structure (DBS), which is made from austenitic stainless steel (Type 304). The DBS components provide a prophylactic envelope around the containment system to protect it from environmental hazards as well as direct impact during an accident event. The DBS materials are procured to ASME Section II specifications.

As can be seen from manufacturing sequence of the cask pictorially illustrated in Figures 2.3.1 through 2.3.3, the fabrication steps are straight forward. The major manufacturing steps necessary to complete the cask's fabrication are outlined below. The sequence of steps may be altered to improve fabricability or manufacturing efficiency. Welding and NDE requirements are specified on the licensing drawings in Section 1.3. A change in the raw material product form may also necessitate alteration in the steps:

i. Flatten and cut all plate sections and check mating parts for fit up.
ii. Assemble and weld the intermediate dose blocker walls.
iii. Assemble and weld the containment walls, using the dose blocker walls as a constraint to control weld distortion.
iv. Assemble and weld the containment and dose blocker base plates, and closure flange.
v. Apply high strength weld overlay to the closure flange sealing surfaces, and machine seal grooves.
vi. Install and weld the lifting trunnions to the dose blocker walls.
vii. Assemble and install the machined closure lid, with sealing surface weld overlay applied.
viii. [Proprietary Information Withheld in Accordance with 10 CFR 2.390]
ix. Perform leak test.

The following additional steps to insure high quality welds are employed in the manufacturing of HI-STAR 330 cask:

i. The guidance of Reg Guide 1.31 [2.3.1] is followed to insure that there is sufficient quantity of delta-ferrite phase in the weld metal to protect against crack propagation.
ii. All weld procedures are qualified to Section IX of the ASME code. In-process inspection of finished welds is provided in Chapter 8.

FIGURE 2.3.1: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.3.2: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.3.3: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

2.4 General Requirements

As can be seen from the external dimensions of the packaging in Section 1.3, the HI-STAR 330 Packaging meets the requirements of Part 71.

2.5 Lifting and Tie-down Standards

2.5.1 Lifting Devices

This subsection presents analysis methodologies and acceptance criteria for all lifting operations applicable to the transport of a HI-STAR 330 package to demonstrate compliance with requirements of 10CFR 71.45 [1.0.2] and NUREG-0612 [1.2.3].

In terms of the structural acceptance criteria, NUREG-0612 [1.2.3] is determined to be more stringent than the 10CFR 71.45. NUREG-0612 is therefore considered for the analysis of lifting points (or attachments) that are part of the HI-STAR 330 transport package in this SAR.

Accordingly, the lifting attachments that are part of the cask must meet the following stress criteria to comply with NUREG-0612 stress limits:

(1) Redundant Lift: A lifting member or lift point (lifting interface on the cask) is considered as load-path redundant if an alternative load path is determined to exist to prevent uncontrolled lowering of the equipment (or accidental drops). Lift points should have a design safety factor of five (5) times with respect to the material ultimate strength considering a single load path (i.e. only half the total number of lift points must be considered).

(2) Non-Redundant Lift: A lifting member or lift point (lifting interface on the cask) is considered as non-redundant if its failure would result in an uncontrolled lowering of the equipment (or accidental drops) is considered a Non-Redundant Lift. Lift points should have a design safety factor of ten (10) times with respect to the material ultimate strength considering both the load paths (i.e. all the lift points must be considered).

The aforementioned criteria ensure a safe handling of heavy loads in critical regions within nuclear power plants.

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. 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. 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.

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)

The analysis details are presented in [2.6.4].

2.5.1.1 Cask Trunnion Analysis

The HI-STAR 330 package is provided with four Lifting Trunnions on the cask side walls to perform vertical lifting of the cask. The licensing drawings in Section 1.3 shows the location of the Lifting Trunnions. It is further noted that all four trunnions shall be used for vertical lifting of the transport package at any time. As discussed in Section 8.1.2.4, all four trunnions are considered in the lifting analysis.

The trunnion material is identified in the licensing drawings in Section 1.3. The embedded trunnion is analyzed as a cantilever beam subjected to a line load applied at the centerline of the interfacing lifting device. A strength of materials approach is used to represent the trunnion as a cantilever beam with a circular cross section. The bending moment and shear force at the root of the trunnion cantilever is compared against allowable stress limit. The contact region between the trunnion and the surrounding package wall plate material is also evaluated to demonstrate satisfaction of ASME Level A stress limits [2.1.5].

Minimum safety factors are summarized in Table 2.5.1.

2.5.1.2 Baseplate During Lifting

During lifting of a loaded HI-STAR 330 the containment baseplate is subject to amplified dead load, D*, from the Liner Tank and its internals. To analyze this condition, the baseplate and a portion of the containment shell is modeled using the ANSYS finite element code [2.6.2] and a static lifting analysis is performed. The weight of the closure lid is included in the FE model. The load case considers the loads from the fully loaded Liner Tank and the self-weight of the baseplate. In this load case, the 15% amplifier is applied to the lifted load.

The results from the analysis of the top-end lift are summarized in Table 2.5.2, where the minimum safety factors for components in the load path are computed using the ASME Level A allowable stress intensities from Table 2.1.3.

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 330 cask; therefore, the requirement imposed by 10CFR71.45(a) is satisfied.

2.5.2 Tie-Down Devices

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2.5.3 Safety Evaluation of Lifting and Tie-Down Devices

Cask lifting and tie-down devices have been considered in Subsections 2.5.1 and 2.5.2, respectively. More importantly their designs have been shown to satisfy the requirements of 10CFR71.45. All calculated safety factors for the cask lifting and tie-down devices are greater than 1.0.

TABLE 2.5.1: RESULTS FOR CASK TRUNNION ANALYSIS

Item	Calculated Value	Safety Factor
Bending Moment in Trunnion – kip-in (kN-m)	373.75 (42.23)	1.25
Shear Force in Trunnion – kip (kN)	74.75 (332.5)	3.75
Bearing Stress in Trunnion hollow Shaft (Comparison with Yield Strength in Compression) – ksi (MPa)	14.23 (98.14)	2.39
Note: Safety factors for the trunnions reported in this table are computed based on the requirements of NUREG-0612 [1.2.3]. The bearing stress safety factor is based on 3 times the lifted load and compared against the material yield strength.		

TABLE 2.5.2: RESULTS FOR BASEPLATE LIFTING

Item	Value, psi (MPa)	Limit, psi (MPa)†	Minimum Safety Factor
Base Plate, Membrane† Bending Stress	508 (3.503)	34,950 (240.9)	68.8
†The stress limit is established in Table 2.1.3.			

2.6 Routine and Normal Conditions of Transport

In this section, the HI-STAR 330 package, when subjected to the normal conditions of transport (listed as load case B in Table 2.1.1) are analyzed. A comprehensive 3-D finite element analysis of the package, using Q.A.-validated codes (see Appendix 2.A), is utilized for its structural qualification. A 3-D finite element model of the HI-STAR 330 cask along the Liner Tank and Liner Tank Cassette has been prepared and assembled into a package system to analyze both the Normal and Hypothetical Accident Conditions of Transport drops.

The loading cases listed in Table 2.1.1 include both static and dynamic conditions. For static loading conditions, the cask is analyzed using simplified yet conservative strength of material based approach. A more rigorous finite element (FE) analysis is conducted using computer code ANSYS [2.6.2] when necessitated. For dynamic loading scenarios involving impacts (transport package drops pursuant to 10CFR71), the state of the art numerical analysis code LS-DYNA is used. Appendices 2A and 2B provides the QA validation of the LS-DYNA code for evaluating the drop events.

2.6.1 Description of the Finite Element Model

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2.6.2 External Pressure Loading

As identified in Table 2.1.1, Loading Case E, the cask exterior surface is subject to bounding external pressure loading. The applied pressure corresponds to a bounding 15 m (50 ft.) immersion into water. Service Level A Stress intensity limits from ASME Code Section III Subsection NB are used to determine safety for containment. The results of this evaluation are summarized in Table 2.6.1. The induced stress intensity results for this loading condition are shown in Figure 2.6.8.

It is clearly demonstrated that the cask containment boundary components have substantial safety factor under the external pressure loading.

2.6.3 NCT Drop Analysis Results

As identified in Table 2.1.1, the governing drop orientations deemed critical for the Normal Condition of transport are considered for the safety evaluation. Applicable stress intensity limits from ASME Code Section III Subsection NB are used to demonstrate the safety compliance of the containment boundary components. For the Dose Blocker System (DBS), it is necessary to ensure that there will be no significant reduction in the shielding capacity of the HI-STAR 330 package. The DBS is considered effective in shielding as long it can be demonstrated that there is no separation and gross yielding (substantial loss of material) subsequent to the free drop loading. The results of this analysis are summarized in Table 2.6.2. Figures 2.6.9 through 2.6.12 show the maximum shear stress induced in the cask containment components. The induced primary and secondary stress intensities are then conservatively estimated based on the visual examination of the stress contours from these maximum shear stress plots. The stress results are carefully examined to classify them as primary or secondary nature following the guidance from ASME Subsection NB [2.1.5] and are over-estimated to render conservative results. Correspondingly, the safety factors for the critical cask containment components are computed.

The summary results presented in Table 2.6.2 demonstrate that the cask meets the required acceptance stress intensity limits from the ASME Code Section III Subsection NB, as specified in Table 2.1.1, for the containment boundary components under the NCT drops.

The seal seating surfaces on the closure lid and the top containment walls and the bars provided for the structural support to the thermal insulation board are demonstrated to be not critical under the 1-ft. drop accidents. The results for these critical components govern for the 30-ft (9-m) drop accidents and are evaluated in Section 2.7.

Lastly, the Liner Tanks and the LTC's are demonstrated to meet the specified acceptance criteria. Specifically, the Liner Tank and LTC are evaluated in calculation package [2.6.4] and shown to meet the following criteria:

a) The Liner Tank walls are not subject to gross deformation under the top and bottom end drops.
b) The Liner Tank top lid and baseplate remain connected to the tank walls when subject to critical side drop accidents. In other words, the evaluations demonstrate the base welds and the top closure bolts remain structurally adequate.
c) The LTC corner tie-rods are shown not to buckle under the NCT drops. The LTC top and bottom plates remain in place under the critical NCT limiting end drops.

It is therefore demonstrated that the Liner Tanks and LTC's remain functional following the NCT drops.

2.6.4 Compression

As discussed in Subsection 2.1.2, an evaluation is performed for the compression test. The HI-STAR 330 cask is subjected to a load corresponding to the compression test and an FE based analysis is performed to determine the corresponding stresses in the cask containment components. The results of this evaluation are summarized in Table 2.6.3. It is clearly demonstrated that large safety factors exist in the cask containment boundary components under the compression loading.

2.6.5 Fatigue Considerations

Regulatory Guide 7.9 [2.6.5] suggests consideration of fatigue due to cyclic loading under normal conditions of transport.

The extent of fatigue expenditure in the HI-STAR 330 Transport Package due to vibration of the package during transport will be negligible because of the large section modulus of the cask structure and small inertia loads associated with transportation. The structural stiffness of the HI-STAR 330 Transport Package, 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 cask structural members and its welds.

Fatigue Analysis of the Cask Containment Walls

To provide quantitative evidence, the induced stress in the containment shell (at its minimum cross section) under the dead weight of the HI-STAR 330 cask is compared against the endurance limit of SA-203 steel. Table 2.6.5 addresses the fatigue assessment for the containment walls under normal conditions of transport.

Fatigue Analysis of the Cask Closure Lid, Closure Lid Bolts and the Conning Flange Internal Threads

The cask closure lid for the HI-STAR 330 package is not subject to significant load fluctuations under normal operations. During HI-STAR 330 package normal transportation, however, the closure lid may be subject to some inertial loads. The inertial loads on the closure lid are significantly lower than the loads representative of the free drops analyzed in Sections 2.6 and 2.7.

On the other hand, the bolts securing the closure lid to the top flange is subject to pre-loading (pre-stress). The maximum tensile stress range, developed in the cask closure bolts during normal operating conditions, occurs during the bolt preloading operation. As a result of bolt preloading, the cask containment flange internal threads are also subject to stresses which warrants a fatigue assessment. The fatigue assessment of the closure lid bolting and the corresponding internal threads in the containment flange is documented in [2.6.4].

The summary results for the fatigue assessment of the containment wall, the closure lid bolts and the containment flange are presented in Table 2.6.5.

2.6.6 Vibration

During transportation vibratory motions may result in low-level stress cycles in the package due to beam-like or plate-type deformation modes. 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 based calculations are performed to establish that vibrations are not an issue in transport of the HI-STAR 330.

When in a horizontal position, the HI-STAR 330 cask is supported over a considerable length of the DBS. Conservatively considering the HI-STAR 330 as a uniform beam with both ends free, and assuming the total mass of the internals 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 [2.6.4]).

The “drum mode” frequency of the containment boundary side wall, assuming that it acts as a rectangular plate with simply supported edges, is also in the rigid range based on calculations performed in [2.6.4].

Based on these frequency calculations, it is concluded that vibration effects are inconsequential to the structural integrity of the HI-STAR 330 package.

TABLE 2.6.1
SUMMARY RESULTS FOR THE CASK EXTERNAL PRESSURE LOADING

Component	Stress Type	Allowable Stress Intensity – ksi/MPa	Induced Stress Intensity- ksi/MPa	Safety Factor
Closure Lid	Primary Membrane plus Primary Bending	34.95/240.97	5.19/35.8	6.73
Containments Wall Plate	Primary Membrane plus Primary Bending	34.95/240.97	25.09/173.0	1.34
Base Plate	Primary Membrane plus Primary Bending	34.95/240.97	10.87/74.95	3.22

TABLE 2.6.2
SUMMARY RESULTS FOR THE CONTAINMENT BOUNDARY COMPONENTS – GOVERNING NCT DROPS

Simulation	Component	Stress Category	Induced Stress MPa/ksi	Allowable Stress MPa/ksi	Safety Factor	Reference
Top End Drop	Closure Lid Bolts	Primary Membrane Stress Intensity	430.9 (62.5)	666 (96.6)	1.55	[2.6.3]
		Primary Bending Stress Intensity	632.2 (91.7)	999 (144.9)	1.58	
	Containment Wall + Baseplate + Top Flange+ Closure Lid	Primary Membrane Stress Intensity	110.3 (16)	157.9 (22.9)	1.43	
		Primary Membrane + Bending Stress Intensity	212.4 (30.8)	237.2 (34.4)	1.12	
		Secondary Stress Intensity	417.8 (60.6)	473.7 (68.7)	1.13	
Bottom Drop	Closure Lid Bolts	Primary Membrane Stress Intensity	393 (57)	666 (96.6)	1.69	
		Primary Bending Stress Intensity	434.4 (63)	999 (144.9)	2.30	
	Containment Wall + Baseplate + Top Flange+ Closure Lid	Primary Membrane Stress Intensity	117 (17)	157.9 (22.9)	1.35	
		Primary Membrane + Bending Stress Intensity	186.2 (27)	237.2 (34.4)	1.27	
		Secondary Stress Intensity	433.7 (62.9)	473.7 (68.7)	1.09	
Side Drop (Long Side)	Closure Lid Bolts	Primary Membrane Stress Intensity	413.7 (60)	666 (96.6)	1.61	
		Primary Bending Stress Intensity	461.9 (67)	999 (144.9)	2.16	
	Containment Wall + Baseplate + Top Flange+ Closure Lid	Primary Membrane Stress Intensity	117 (17)	157.9 (22.9)	1.35	
		Primary Membrane + Bending Stress Intensity	151.7 (22)	237.2 (34.4)	1.56	
		Secondary Stress Intensity	410.2 (59.5)	473.7 (68.7)	1.15	

TABLE 2.6.2 (CONTINUED)
SUMMARY RESULTS FOR THE CONTAINMENT BOUNDARY COMPONENTS – GOVERNING NCT DROPS

Simulation	Component	Stress Category	Induced Stress MPa/ksi	Allowable Stress MPa/ksi	Safety Factor	Reference
Side Drop (Short Side)	Closure Lid Bolts	Primary Membrane Stress Intensity	372.3 (54)	666 (96.6)	1.79	[2.6.3]
		Primary Bending Stress Intensity	461.9 (67)	999 (144.9)	2.16	
	Containment Wall + Baseplate + Top Flange+ Closure Lid	Primary Membrane Stress Intensity	131 (19)	157.9 (22.9)	1.21	
		Primary Membrane + Bending Stress Intensity	165.5 (24)	237.2 (34.4)	1.43	
		Secondary Stress Intensity	413.7 (60)	473.7 (68.7)	1.15	

TABLE 2.6.3: RESULTS FOR COMPRESSION TEST

Loading	Component	Stress Type	Allowable Stress ksi (MPa)[1]	Stress intensity ksi (MPa)	Safety Factor
Uniform Pressure on top lid, 160 psi	Closure Lid	Primary Membrane plus Primary Bending	34.95 (240.97)	5.28 (36.40)	6.62
	Containments Wall Plate	Primary Membrane plus Primary Bending	34.95 (240.97)	4.00 (27.59)	8.74
	Base Plate	Primary Membrane plus Primary Bending	34.95 (240.97)	1.52 (10.47)	23.0

[1] The stress limits are established in Table 2.1.3.

TABLE 2.6.4: KEY FE MODEL DATA

Item	Value
Weight of the Cask Contents (Loaded Waste Package)	Refer to Table 1.1.1 of this SAR
Cask Inside Dimensions	
Cask Outside Dimensions	
Total Number of Elements (including Liner Target)	>1,340,000
Total Number of Nodes	>1,650,000

TABLE 2.6.5: RESULTS FOR FATIGUE ASSESSMENT

Component	Effective Stress Intensity Amplitude ksi (MPa)	Number of Cycles
Closure Lid Bolt	172.6 (1,190)	250
Containments Wall Plates	8.86 (61.1)	$> 1x10^8$
Closure Flange Internal Threads	19.68 (135.7)	$> 1x10^5$

FIGURE 2.6.1: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

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

FIGURE 2.6.3: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.4: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.5: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.6: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.7: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.8: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.9: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.10: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.11: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.12: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.13: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.14A: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.6.14B: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

2.7 Hypothetical Accident Conditions

The hypothetical accident conditions of transport (HAC), pursuant to the 10CFR71 HAC conditions, are considered for the HI-STAR 330 package as a sequence of loading events. The package is first subject to a 9-meter (30 ft.) drop. To identify the damage to the package components all orientations as discussed in Table 2.1.1 are considered. The package is then subject to a 1-meter (40-inch) drop onto the solid cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar is 15 cm (6.0 inch) diameter mild steel pin. The bar length is selected so as to cause maximum damage to the cask. In the third step, the package is subject to a 800°C (1475°F) temperature fire environment for 30 minutes. Finally, the package is subject to 15 m (50 ft.) water immersion. The water immersion loading is discussed in Section 2.6.

2.7.1 9-meter Free Drop (HAC Drops)

This is the Load Case C from Table 2.1.1. The finite element model, as described in the Subsection 2.6.1, is used for this analysis. All the FE model attributes discussed in Section 2.6 are carried forward for the HAC conditions. As noted in Section 2.6, the base simulations are all performed using the minimum ASME material properties for the cask containment and the DBS parts. Since the lower bound material properties for the cask containment and the DBS parts imply lower stress allowable limits, using lower strength properties lends conservatism to the safety assessment for the package. On the other hand, the upper bound stiffness and strength properties of the impact absorber imparts higher impact loads (g-loads) on the cask and its internals (Liner Tank and LTC as applicable). Therefore, all base HAC drop simulations of the HI-STAR 330 Package are performed based on the lower bound material properties for the cask components with exception to the impact absorbers.

To rule out any uncertainty and to demonstrate the safety results for the package containment are not adversely affected, additional sensitivity simulation is performed using the lower bound material flow curve for the impact absorber components externally attached to the cask. The sensitivity simulation considers lower bound material strength properties for the impact absorber summarized in Table 8.1.5 of this SAR.

To induce maximum damage to the Package components all plausible orientations of the transport package, with respect to the impact target, are considered. The following hypothetical drop accidents are considered governing in terms of imparting maximum damage to the critical cask containment components viz. threatening the closure lid joint, challenging the package containment corner welds, and the DBS components.

Drop Orientations for the 9 m (30 ft.) Free Drop	
1. Top End Drop	The package drops vertically and hits the ground at the top end.
2. Bottom End Drop	The package drops vertically and hits the ground with the bottom end.

3. Long Side Drop	The package drops with its longitudinal axis vertically orientated. The primary impact is considered on the larger package surface in order to maximize the bending in the containment wall.
4. Short Side Drop	The package drops with its longitudinal axis horizontally orientated. The primary impact is considered on the short surface to maximize the loading on the sealing zone and bolts.
5. C.G.O.C. (Primary Impact with Top End Corner)	The center-of-gravity of the package is directly above and aligned with the initial contact point at the cask top end.
6. C.G.O.C. (Primary Impact with Bottom End Corner)	The center-of-gravity of the package is directly above and aligned with the initial contact point at the cask bottom end.
7. Oblique Drop on Top Lid (a.k.a. Slapdown)	The package orientation w.r.t the impact target corresponds to the quarter-scale package oblique top-down drop [2.6.6]
8. Sensitivity Simulation	Same as Drop orientation 1 with lower bound material strength properties for the impact absorbers per Table 8.1.5.

As discussed earlier, the structural integrity of the HI-STAR 330 containment boundary components under the HAC drops is evaluated using the component stress intensity (i.e., two times maximum shear stress) results obtained from the analyzed drop events. Figures 2.7.1 through 2.7.11 show the typical stress results for the HAC drop simulations. Table 2.7.1 summarizes the key results for all the critical 30-ft (9-m) HAC drop conditions.

Figures 2.7.4 and 2.7.5 show the extent of local deformation in the cask DBS for the limiting CGOC top and bottom end drop accidents, respectively. It can be seen from the simulation results, that the deformation of the cask is minimal due to the provision of the impact absorber material. The simulation results also demonstrate that there is no gross failure or separation of the dose blocker components from the cask body.

Figure 2.7.11 shows that the opening between the closure lid and the top flange subsequent to the governing top end drop accident. Since the opening, subsequent to the critical drop accident, is less than the useful springback of the seals, the joint is demonstrated to be leaktight.

In addition, the Liner Tank is evaluated to meet the specified acceptance criteria, as documented in the calculation [2.6.4]. Specifically, it is demonstrated that:

a) the Liner Tank walls are not subject to gross failure under the top and bottom end drops;
b) the Liner Tank top lid and baseplate remain connected to the tank walls when subject to the critical side drop accidents.

It is therefore demonstrated that the Liner Tank satisfies the structural acceptance criteria for the HAC drops.

As previously noted, the top and bottom plate of the LTC's are also credited for shielding under accident conditions. However, a relocation of those plates is considered in the shielding analyses, i.e. no credit is taken any more for the corner tie-rods. Therefore, no structural acceptance criterion for the LTC during the hypothetical accident conditions (HAC) is applied.

Lastly, the key results for the sensitivity simulation are summarized in Table 2.7.3. It is shown that the upper bound material strength properties considered for the impact absorber material in the sensitivity simulation have negligible effect on the results. The summary table also indicates that the strength of the connections between the impact absorber components and the cask exterior have minimal influence (second order effect) on the cask containment safety results. More importantly, the overall conclusion reached from the base simulations remains unchanged.

The materials used for the cask exterior impact absorber components must meet the strength limits summarized in Table 8.1.5 of this SAR. If the strength properties for these impact absorbing (or energy absorbing) components exceed the limits specified in the Table 8.1.5, the package must be qualified by re-analysis using the same licensing basis FE model and methodology presented in this Chapter.

2.7.2 Puncture

This is the Load Case D in Table 2.1.1. The effects of the puncture drop will, quite ostensibly, be most severe when the steel bar is perpendicular to the impact surface. Therefore, the puncture analysis assumes that the bar is perpendicular to the impact surface and is aligned with the center of gravity of the package as applicable.

Four limiting transport package orientations are considered for the 1-meter (40-inches) puncture drop events viz., the top end puncture onto the closure center, the top end puncture onto the closure lid edge aligned with the seals, the puncture bar aligned with the seals onto the cask short side and the puncture bar aligned with the seals onto the cask long side. Specific details of the 40-inches puncture are discussed below:

i. *Top End Puncture Drop:* This particular drop event is considered critical since it could challenge the closure lid and potentially open up the sealed joint contributing to loss of the gasket sealing function. The top end drop puncture model is identical to the 9-m (30-ft.) top end drop model except for the impact target which is replaced by a 6" diameter vertical steel bar fixed at its base. The puncture bar essentially impacts on the closure lid long edge aligned with the seals to maximize the potential damage to the seal seating surfaces. Another top end puncture drop event is considered with the puncture bar impacting the center of the closure lid which maximizes bending in the closure lid.

ii. *Short Side Puncture Drop Near Sealing Region :* The short side puncture drop model is identical to the corresponding 9-m side drop model with exception that the impact target is replaced by a 6" diameter vertical steel bar fixed at its base. To render conservative results, the puncture bar is assumed to impact the HI-STAR 330 package onto the outer side dose blocker plate aligned with the seal seating region to maximize the potential damage to the seal seating surfaces

iii. *Long Side Puncture Drop Near Sealing Region :* The long side puncture drop model is identical to the corresponding 9-m side drop model with except that the impact target is replaced by a 6" diameter vertical steel bar fixed at its base. The impact target is placed near the center of the long side in plane of the sealing region to maximize the potential damage to the seal seating surfaces.

Figure 2.7.5 shows that there is superficial damage to the DBS after the 30 ft. (9-m) CGOC drop events. Hence, a sequential puncture drop event after the CGOC drop event is unwarranted as separate puncture analyses are already to maximize the potential damage to the seal seating surfaces. Targeted puncture drops onto the package top and side drops aligned with the sealing region is further justified due to the closer proximity of the sealing region from the cask exterior from the cask top and sides in comparison to cask corner.

A mild steel bar used for the puncture simulations is placed in the proper orientation to maximize the damage to the cask. Its bottom nodes are applied a fixed constraint. The package is then assumed to have a known initial velocity at contact with the bar. The governing results from this evaluation are summarized in Table 2.7.2. Figures 2.7.7 through 2.7.10 show the key results in the containment boundary components.

The results from the puncture analyses yield the following conclusions:

i. No thru-wall penetration of the containment boundary is indicated. The total depth of local indentation is a fraction of the available material thickness in the path of the penetrant.

ii. The primary stresses in the closure lid, the containment shell, and the baseplate remain below their respective limits.

iii. The opening between the closure lid to top flange in the seal region, resulting from the governing HAC, is shown to be less than the seal useful springback. It is therefore demonstrated that the land area (i.e. closure lid/top flange joint interface region) remains sealed subsequent to the critical HAC drop events.

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

v. The thermal performance of the package remains unaffected by the puncture drops.

The above results confirm the structural adequacy of the package under the "puncture" event.

2.7.3 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.

During NCT, thermal stresses have no effect on the behavior of the closure lid sealed joint. This is due to the low design basis heat load of the cask (see Table 7.1.2) and the fact that the maximum metal temperatures of the containment top flange and the closure lid are nearly equal under NCT (see Table 3.1.1).

The more significant risk to the closure lid sealed joint and the effectiveness of the containment boundary is associated with the fire event during HAC. The worst-case scenario is a top-down drop with the cask coming to rest on the closure lid followed by a 30-minute enveloping fire per 10CFR71 requirements. Since the closure lid is directly exposed to the flame, it heats up more than the closure lid bolts and causes differential thermal growth between these two components. The risk is that, with the cask oriented upside down, the differential thermal growth would allow the lid to displace downward and unload the sealed joint between the closure lid and the compression land on the top flange.

To evaluate this risk, the maximum differential thermal growth between the closure lid and the closure lid bolts has been calculated for the fire event and compared with the minimum useful springback of the seals specified in Table 2.2.6. Since the calculated differential thermal growth is much less than the useful springback, the seals will remain functional and the containment boundary will not be compromised. The differential thermal growth calculation is documented in [2.6.4].

The 30-minute fire event also results in an increased cask cavity pressure, as reported in Table 3.1.3. The induced stress in the containment boundary due to the maximum cask cavity pressure is less than the material yield strength corresponding to the peak metal temperature, as shown in [2.6.4]. This means that the fire accident event does not result in any permanent deformation of the containment boundary components. More importantly, it allows the evaluation of the drop and puncture events to be decoupled from the fire accident event since the latter does not produce any inelastic strains.

TABLE 2.7.1: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

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TABLE 2.7.1: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

TABLE 2.7.2: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

TABLE 2.7.3: [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.1 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.2 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.3 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.4 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.5 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.6 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.7 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.8 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.9 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.10 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

FIGURE 2.7.11 [Proprietary Information Withheld in Accordance with 10 CFR 2.390]

2.8 Safety Conclusions

The structural analyses reported in this chapter show that:

(i) The stresses in the Package containment boundary components under normal lifting and handling conditions meet the limits in Section III subsection NB of the ASME Code for Level A condition. The stresses in the lifting trunnions meet the more stringent limits of NUREG-0612.

(ii) The materials used in manufacturing the cask are qualified to provide assurance against brittle fracture under "cold" service conditions.

(iii) The stress intensity limits of Subsection NB for Level A service condition are satisfied by the package's containment boundary under the normal condition of transport (Load Case B in Table 2.1.1).

(iv) The stress intensity limits of Subsection NB for the Level A condition are satisfied by the cask's containment boundary for Load Case E (15 m water immersion).

(v) The stress intensity limits of Subsection NB for Level D service condition are satisfied by the package's containment boundary under hypothetical accident conditions (Load Cases C and D in Table 2.1.1).

(vi) Under all loading conditions, the Dose Blocker Structure (DBS) remains attached to the cask with its shielding capability essentially unimpaired.

(vii) The shielding and thermal performance of the package is maintained subsequent to the critical drop events.

(viii) The Liner Tanks and LTC's meet the required acceptance criteria under the NCT and HAC drops.

Therefore, it is concluded that the HI-STAR 330 package can withstand all stipulated loadings under 10CFR71 and meet the applicable acceptance criteria with positive safety margins.

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.

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[2.1.2] ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, American Society of Mechanical Engineers, 2013 Edition.

[2.1.3] ASME Boiler & Pressure Vessel Code, Section III, Subsection WB, American Society of Mechanical Engineers, 2013 Edition.

[2.1.4] ASME Boiler & Pressure Vessel Code, Section II, Parts A and D, American Society of Mechanical Engineers, 2013 Edition.

[2.1.5] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, American Society of Mechanical Engineers, 2013 Edition.

[2.1.6] Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material", Revision 1, March, 1989, U.S. Nuclear Regulatory Commission.

[2.1.7] Deleted.

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[2.2.1] DOE-HDBK – 1017/2-93, DOE Fundamentals Handbook, Material Science, Vol. 2 of 2.

[2.3.1] Reg Guide 1.31, “Control of Ferrite Content in Weld Metal”, October 2013, Rev 4.

[2.6.1] LS-DYNA, Version 971, LSTC Software, 2006.

[2.6.2] ANSYS, Version 2020R2, Ansys Inc., Copyright 2020 SAS IP, Inc.

[2.6.3] Holtec Calculation HI-2240059, Revision 0, "HI-STAR 330 Package Drop Analysis".

[2.6.4] Holtec Calculation HI-2210998, Revision 0, "Structural Calculation Package for HI-STAR 330 Transport Package".

[2.6.5] Regulatory Guide 7.9, Standard Format and Content of Part 71 Applications for Approval of Packages for Radioactive Material

[2.6.6] HI-2167517, Revision 2, "HI-STAR ATB 1T Transport Package Quarter Scale Drop Simulations Using LS-DYNA Program".

[2.6.7] SAND2017-0404 "Holtec HI-STAR 330 Impact Test Program Report", Sandia National Laboratories, January 2017.

[2.6.8] HI-2210251, Revision 0, "Benchmarking of Material Stress-Strain Curves in LS-DYNA".

[2.7.1] Draft Guidance Document, Use of Explicit Finite element Analysis for the Evaluation of Nuclear Transport and Storage Packages in Energy-Limited Impact Events, 2015.

[2.7.2] Atlas of Stress-Strain Curves, Howard E. Boyer, American Society for Metals, 1987.

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, HI-STAR 180 and HI-STAR 180D SARs.

CHAPTER 3: THERMAL EVALUATION

3.0 Introduction

In this chapter, compliance of the HI-STAR 330 Package to 10CFR Part 71 [3.0.1] regulation thermal requirements are evaluated for normal transport and hypothetical accident conditions. The analysis considers passive rejection of the package's internally generated decay heat to the 10CFR71 mandated environment for normal transport and hypothetical fire accident conditions.

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

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

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

3. 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)].

4. 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)].

5. For hypothetical accident conditions, a thermal event consisting of a fully engulfing hydrocarbon fuel/air fire with an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 802ºC (1475°F) for a period of 30 minutes [§71.73(c)(4)].

Section 3.1 describes the thermal design features of the HI-STAR 330 Package. Section 3.2 lists the material properties data required to perform the thermal analyses and the applicable temperature limit criteria required to demonstrate the adequacy of the HI-STAR 330 Package design under normal and hypothetical accident conditions. Thermal analyses to evaluate the normal transport are described and presented in Section 3.3. Thermal analyses for hypothetical accident conditions are described and presented in Section 3.4.

3.1 Description of Thermal Design

3.1.1 Design Features

Design details of the HI-STAR 330 Package are presented in Chapter 1 with structural and mechanical features further described in Chapter 2. The HI-STAR 330 Package geometry is detailed in Section 1.3. The HI-STAR 330 Package consists of a Liner Tank inside a thick cask equipped with a removable closure lid. An insulation board is used in the top impact absorber strongback frame to ensure the sealing gasket performance is not compromised during accident conditions due to high temperatures. The Liner Tank contains a Liner Tank Cassette (LTC), and the stainless-steel segments cut from reactor internal components placed in the LTC. The Liner Tank cavity and the cask cavity (i.e. the open space between the Liner Tank external surface and the cask internal surface) are at atmospheric pressure, at time of its sealing. Prior to sealing the Liner Tank, the residual water inside the Liner Tank is removed by the method of vacuum drying.

The rejection of heat from the cask occurs from its external surfaces by natural convection and radiation.

3.1.2 Contents Decay Heat

The design basis heat load for the HI-STAR 330 Package is provided in Table 1.2.1.

3.1.3 Summary Table of Temperatures

The HI-STAR 330 Package temperatures are analyzed for the normal transport condition and under the design basis fire event in Sections 3.3 and 3.4, respectively. Tables 3.1.1 and 3.1.2 provide summary data on computed package temperatures under the normal transport condition and the design basis fire event.

3.1.4 Summary Table of Maximum Pressures

The HI-STAR 330 Package containment boundary pressure under normal transport condition is required to remain below the design pressure set down in Table 1.2.1. Internal pressures computed under the normal and design basis fire conditions are summarized in Table 3.1.3.

3.1.5 Cask Surface Temperature Evaluation

In accordance with the regulatory requirement specified in 10CFR71 (§71.43(g)), the cask accessible surface temperature is evaluated in still air at 38ºC (100ºF) and in shade. The calculated cask surface temperature tabulated in Table 3.1.4 is below the allowable surface temperature limit of 85ºC (185ºF).

[Table 3.1.1 Withheld in Accordance with 10 CFR 2.390]

[Table 3.1.2 Withheld in Accordance with 10 CFR 2.390]

[Table 3.1.3 Withheld in Accordance with 10 CFR 2.390]

Table 3.1.4

HI-STAR 330 NORMAL TRANSPORT SURFACE TEMPERATURE IN SHADE

Component	Temperature °C (°F)
Cask External Accessible Surface	51 (124)
Note 1: The computed surface temperature reported herein complies with the accessible surface temperature limit (85ºC (185ºF)).	

3.2 Material Properties and Components Specifications

3.2.1 Material Properties

Materials present in the HI-STAR 330 Packaging include structural steels, insulation, air and elastomeric gaskets at the containment boundary. In Table 3.2.1, a summary of references used to obtain package material properties for performing all thermal analyses is presented.

Thermal conductivity data of stainless steel, alloy steel, carbon steel and air are provided in Table 3.2.2. In Table 3.2.3, the specific heat and density data of package materials are presented. These properties are used in performing transient analyses (e.g. hypothetical fire accident condition). The air viscosity is provided in Table 3.2.4. Any material that satisfies the thermal properties of insulation board provided in Table 3.2.8 is permitted for use.

Surface emissivity data for key materials of construction are provided in Table 3.2.5. The emissivity of painted surfaces is generally high. Kern [3.2.3] reports an emissivity range of 0.8 to 0.98 for a wide variety of paints. In the HI-STAR 330 Package thermal analysis, an emissivity specified in Table 3.2.5[†] is applied to the exterior painted surfaces. A theoretical bounding solar absorptivity coefficient as specified in Table 3.2.5 is applied to all exposed cask surfaces.

The heat is dissipated from the HI-STAR 330 Package exposed surfaces by both natural convection heat transfer and radiation. Natural convection from a heated surface depends upon the product of the Grashof (Gr) and Prandtl (Pr) numbers. Following the approach developed by Jakob and Hawkins [3.2.7], GrPr is expressed as $L^3 \Delta T\ Z$, where L is the dimension 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 3.2.6.

3.2.2 Component Specifications

The HI-STAR 330 Package materials and components are required to be maintained below the maximum pressure and temperature limits for safe operation. To ensure their intended functions, the temperature limits are summarized in Table 3.2.7. These materials and components do not degrade under exposure to extreme low temperatures. As defined by transport regulations, the HI-STAR 330 Package cold service temperature is limited to –40°C (-40°F).

[†] 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.

TABLE 3.2.1
SUMMARY OF HI-STAR 330 PACKAGING MATERIAL THERMAL PROPERTY REFERENCES

Material	Emissivity	Conductivity	Density	Heat Capacity
Stainless Steel Plates	ORNL [3.2.5], [3.2.6]	ASME [3.2.4]	Marks' [3.2.1]	Marks' [3.2.1]
ASME Steel	Kern [3.2.3]	ASME [3.2.4]	Marks' [3.2.1]	Marks' [3.2.1]
Air	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Insulation Board	NA	Table 3.2.8		

TABLE 3.2.2
THERMAL CONDUCTIVITY OF HI-STAR 330 PACKAGE MATERIALS

FLUID			
Material	Air		
Temperature °C (°F)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)		
37.8 (100)	0.0265 (0.0153)		
93.3 (200)	0.0299 (0.0173)		
232.2 (450)	0.0389 (0.0225)		
371.1 (700)	0.047 (0.0272)		
537.8 (1000)	0.0582 (0.0336)		
800 (1472)	0.0699 (0.0404)		
SOLID			
Temperature °C (°F)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)		
Material	SA-240 Gr.304	SA-203 Gr. E/ SA-350 LF3	SA-516 Gr. 70
21 (70)	14.9 (8.6)	41.0 (23.7)	60.4 (34.9)
38 (100)	15.1 (8.7)	40.8 (23.6)	60.1 (34.7)
93 (200)	16.1 (9.3)	40.7 (23.5)	58.3 (33.7)
232 (450)	18.3 (10.6)	39.8 (23.0)	52.1 (30.1)
371 (700)	20.4 (11.8)	37.4 (21.6)	46.0 (26.6)
538 (1000)	22.7 (13.1)	34.1 (19.7)	38.8 (22.4)
677 (1250)	24.7 (14.3)	30.6 (17.7)	32.2 (18.6)
816 (1500)	26.5 (15.3)	26.1 (15.1)	26.8 (15.5)

TABLE 3.2.3
MATERIAL DENSITY AND SPECIFIC HEAT PROPERTIES

Materials	Density kg/m^3 (lbm/ft^3)	Specific Heat J/kg-K (Btu/lbm-°F)
SA-240 Gr. 304	8025 (501)	502 (0.12)
SA-516 Gr. 70	7835 (489)	418 (0.1)
SA-203 Gr. E	7835 (489)	418 (0.1)
Air	(Ideal Gas Law)	1006 (0.24)

TABLE 3.2.4
AIR VISCOSITY VARIATION WITH TEMPERATURE

Temperature °C (°F)	Air Viscosity 10^{-6} N-s/m^2 (Micropoise)
0 (32.0)	17.20 (172.0)
21.4 (70.5)	18.24 (182.4)
126.8 (260.3)	22.94 (229.4)
170.2 (338.4)	24.63 (246.3)
297.3 (567.1)	29.30 (293.0)
372.0 (701.6)	31.67 (316.7)
581.2 (1078.2)	37.76 (377.6)
709.3 (1309)	41.05 (410.5)
809.1 (1488)	43.65 (436.5)

TABLE 3.2.5
SUMMARY OF MATERIAL SURFACE EMISSIVITY DATA

Material	Emissivity
Stainless Steel Plates	0.587
Carbon steel (unpainted)	0.66
Painted surfaces	0.85
Note 1: Emissivity data obtained from [3.2.8]. Note 2: A bounding solar absorptivity coefficient of 1 is applied to all exposed cask surfaces.	

TABLE 3.2.6
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}
620	6.3×10^{4}
980	1.9×10^{4}
1520	5.1×10^{4}

[1] Obtained from Jakob and Hawkins [3.2.7].

TABLE 3.2.7
HI-STAR 330 PACKAGE COMPONENT TEMPERATURE LIMITS

Component	Material	Normal Condition Temperature Limits °C (°F)	Fire Accident Temperature Limits °C (°F)
Containment Wall Plate	SA-203 Gr. E	426 (800) Note-1	1000 (1832) Note-2
Containment Base Plate	SA-203 Gr. E	426 (800) Note-1	1000 (1832) Note-2
Closure Lid	SA-203 Gr. E/ SA-350 LF3	426 (800) Note-1	1000 (1832) Note-2
Dose Blocker Plate	Carbon Steel	426 (800) Note-1	1000 (1832) Note-2
Closure Lid Seals	Elastomeric	See Table 2.2.6	See Table 2.2.6
Insulation Board	Note 3	816 (1500)	816 (1500)

Notes:
1. The normal condition temperature limits are set to the maximum permissible metal temperature in Section II of the ASME Code.
2. The fire accident temperature limits are set to be well below the melting temperature for structural stability.
3. Any material that satisfies the thermal properties in Table 3.2.8 with material operating temperature limit in excess of 816°C (1500°F) is permitted.

TABLE 3.2.8
THERMAL PROPERTIES OF INSULATION BOARD

Property	Value
Density	Note 1
Specific Heat	Note 1
Thermal Conductivity (Note 2)	**[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**
Note 1: Density and specific heat of air conservatively adopted for transient evaluations. Note 2: Material with thermal conductivity values different from that cited herein can also be used as long as the thermal resistance (defined as a ratio of thickness to thermal conductivity) of the insulation board is either maintained or larger.	

3.3 Thermal Evaluation Under Routine and Normal Condition of Transport

3.3.1 Computer Code

The HI-STAR 330 Package is designed to safely dissipate heat under passive conditions (no wind). The thermal analyses of HI-STAR 330 Package are performed using the FLUENT CFD code [3.3.1]. FLUENT is a well-benchmarked CFD code validated within Holtec's quality assurance program. Fluent has a long history of usage in safety analysis of transport and storage casks. A list of dockets that rely on FLUENT for thermal analyses of casks is listed below in a tabular form.

USNRC Dockets on Holtec dry storage/transport systems that use Fluent	
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, Skull Valley, Utah
72-27	Humboldt Bay ISFSI, California
72-26	Diablo Canyon ISFSI (HI-STORM 100A)
72-17	Trojan ISFSI,Oregon
71-9325	HI-STAR 180 Transport
71-9336	HI-STAR 60 Transport
72-1032	HI-STORM FW MPC Storage system
72-1040	HI-STORM UMAX Canister Storage System
71- 9367	HI-STAR 180D transport system
71-9375	HI-STAR ATB-1T Transport Package

3.3.2 Maximum Waste Heat Generation Rate

The waste content (primarily stainless steel) is placed in a Liner Tank using an LTC or by direct placement of material into the tank. As specified in Table 1.2.1, the maximum calculated heat load of waste inside both type of Liner Tank is different but the design basis heat load is same. The maximum calculated volumetric heat generation rate inside both the Liner Tanks (T-100 and T-150) is same considering design basis heat load. This is because the amount of waste in a fully loaded Liner Tank is not only limited by the maximum waste weight but also the maximum permissible Co-60 activity. Table 7.1.2 provides the maximum permissible Co-60 activity of fully loaded Liner Tank and the maximum permissible Co-60 specific activity of any single waste item loaded into respective Liner Tank. For any single waste item, its volumetric heat generation rate is proportional to the Co-60 specific activity. It is considered that the waste with the maximum volumetric heat generation rate may yield the highest local maximum temperature under the same total decay heat load. The maximum volumetric heat generation rate of the waste in each Liner Tank is provided in Table 3.3.1. The maximum waste volumetric heat generation rate is essentially the same in both the tanks. Therefore, the temperature of the waste inside both the liner tanks is expected to be the same. However, to confirm the bounding liner tank, explicit thermal evaluation under normal transport condition is performed for both the tanks and results are presented in Table 3.3.3. Per Table 3.3.3, the temperature of the waste inside the Liner Tank T-150 is essentially higher than the Liner Tank T-100, and therefore Liner tank T-150 is considered to be the limiting Liner Tank.

The Liner Tank T-150 is adopted for thermal evaluation under the design basis heat load (as specified in Table 1.2.1).

3.3.3 Determination of Solar Heat Input

The intensity of solar radiation incident on exposed surfaces depends on the 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 12-hour insolation summarized in Table 3.3.2 is slightly higher than the value provided in 10CFR71. During normal transport conditions, the HI-STAR 330 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 330 Package model includes insolation on the top and side exposed surfaces of cask averaged over a 24-hour time period. The 24-hour insolation adopted in the evaluation is presented in Table 3.3.2. The insolation energy absorbed by the HI-STAR 330 Package is the product of the 24-hour average insolation and the package absorptivity.

3.3.4 Heat Rejection from Cask Surfaces

The exposed surfaces of the HI-STAR 330 Package dissipate heat by radiation and external natural convection heat transfer. Jakob and Hawkins [3.2.7] recommend the following correlations for natural convection heat transfer to air from heated vertical surfaces and horizontal plates:

Turbulent range:

$$h = 0.19\,(\Delta T)^{1/3}\ (\text{Vertical, GrPr} > 10^9)$$
$$h = 0.22\,(\Delta T)^{1/3}\ (\text{Heated Horizontal Plate Facing Upward, GrPr} > 2\text{x}10^7)$$
(in conventional U.S. units)

Laminar range:

$$h = 0.29\,\left(\frac{\Delta T}{L}\right)^{1/4}\ (\text{Vertical, GrPr} < 10^9)$$
$$h = 0.27\,\left(\frac{\Delta T}{L}\right)^{1/4}\ (\text{Heated Horizontal Plate Facing Upward, GrPr} < 2\text{x}10^7)$$
(in conventional U.S. units)

where ΔT is the temperature differential between the package exterior surface and ambient air and GrPr is the product of Grashof and Prandtl numbers. As described in Section 3.2, Gr×Pr can be expressed as $L^3\Delta TZ$, where Z (from Table 3.2.6) is larger than 9×10^5 for the cask external surface average temperature at about 60ºC (140°F), which corresponds to an average film temperature at 49ºC (120°F). The length scales L are the corresponding dimensions of each exterior surface of the package. It is thus apparent that the turbulent condition is always satisfied assuming a lowerbound L (~5 ft) and a small ΔT (~10ºF).

3.3.5 FLUENT Model for HI-STAR 330 Package

As noted in Section 1.1, there are different types of Liner Tank and LTC. The design details (illustrated in Section 1.3) indicate that Liner Tanks are all of the same construction and geometry. The distinguishing feature of each type of Liner Tank is the wall thickness. Each type of Liner Tank is designed to accommodate the dimensions of a type of LTC and its radioactive contents. As discussed in Section 3.3.2, the Liner Tank T-150 with the design basis heat load and the maximum waste volumetric heat generation rate is considered to be the limiting Liner Tank and is adopted as the license basis Liner Tank for the thermal evaluation.

To ensure an adequate representation of the cask, a geometrically accurate 3D model is constructed using the FLUENT CFD code pre-processor. All of the physical details of the cask are explicitly included in a half-symmetric model of the HI-STAR 330 Package. The three dimensional view of the HI-STAR 330 thermal model is presented in Figure 3.3.1. An overview of the principal features of the thermal model is provided in the following.

(i) **[Proprietary Information Withheld in Accordance with 10 CFR 2.390**

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(ii) **[Proprietary Information Withheld in Accordance with 10 CFR 2.390**

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(iii) To evaluate the hot transport condition, the cask is assumed to be in a 38°C (100°F) ambient air environment and subject to insolation (Table 3.3.2) on the external surfaces of the cask excluding the bottom surface.

(iv) The bottom surface of the cask is assumed to be supported by an insulating surface such that no rejection of heat from the bottom surface to the supporting structure can occur.

(v) The impact absorbers on the sides, bottom and top of the cask are conservatively ignored in the thermal analysis. This is conservative because modeling them increases heat rejection to the ambient during normal conditions due to larger exposed area. Further, they would reduce heat transfer into the cask during fire accident.

(vi) The gas in the plenum area inside the Liner Tank cavity and the cask cavity (i.e. between Liner Tank external surface and cask internal surface) can move freely. However, internal convection heat transfer inside the package (Rayleigh effect) is conservatively neglected. This maximizes the internal temperatures since heat transfer from the waste content to the cask walls due to air movement is completely ignored.

(vii) **[Proprietary Information Withheld in Accordance with 10 CFR 2.390**

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(viii) The waste content (primarily stainless-steel segments) is placed in a Liner Tank using a Liner Tank Cassette (LTC) or by direct placement of material into the Liner Tank. For the direct loading scenario, the volume of the stainless-steel box and the computed volumetric heat generation rate for the bounding heat load distribution scenario (i.e. concentrated heat load distribution) is the same when waste is placed inside the LTC. The thermal model of the cask under transport condition ignores natural convection by air movement inside the cask. Through the Liner Tank cavity empty space, the heat is dissipated by radiation and conduction. Since the cavity space of Liner Tank is primarily filled with a similar volume of air and concentrated waste box for both the scenarios (direct loading and loading to LTC), the thermal resistance and thermal inertia of the Liner Tank cavity under direct loading will essentially be the same as loading in the LTC. Therefore, heat dissipation inside the Liner Tank cavity will essentially be the same for both scenarios i.e. direct loading and loading in LTC. Therefore, thermal safety conclusions presented herein for loading using LTC are extended to the direct loading scenario as well.

3.3.6 Hypothetical Loading Distributions of Waste Content

The arrangement of the segments in each LTC is unique. To bound all the loading patterns of the waste content inside the LTC, two hypothetically limiting heat load distributions are evaluated as below.

(1) Concentrated Heat Load Distribution

It is considered that the temperature of the waste content is the highest if all the waste content is concentrated at the center of the LTC. For this concentrated heat load distribution, the waste content is modeled as a rectangular stainless steel box that locates at the center of the LTC cavity. The volume of the solid box is determined so that the total decay heat of the waste content is equal to the design basis decay heat load in Table 1.2.1. Under this hypothetical heat load distribution, the decay heat is concentrated in the central region of the LTC and the heat load per unit volume is conservatively maximized. In addition, the heat conduction by the direct contact between the waste content and the LTC is neglected. Therefore, this hypothetical heat load distribution overestimates the maximum temperature of the waste content.

(2) Uniform Heat Load Distribution

It is considered that the volume averaged temperature of the Liner Tank cavity is the highest if all the waste content is uniformly distributed inside the LTC. For this uniform heat load distribution, the LTC cavity space confined by the top, bottom and side plates is modeled a solid box with effective thermal properties of the waste content and the cavity air. The design basis decay heat load (Table 1.2.1) is applied as a uniform volumetric heat source on the solid box. **[**

Proprietary Information Withheld in Accordance with 10 CFR 2.390

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The above two hypothetical heat load distributions are evaluated for the Liner Tanks T-100 and T-150 with design basis heat load specified in Table 1.2.1. The results are reported in Table 3.3.3. The Liner Tank T-150 under the concentric heat load distribution described above is the limiting loading scenario and is adopted for the license basis model.

3.3.7 Grid Sensitivity Study

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

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3.3.8 Heat and Cold

3.3.8.1 Maximum Temperatures

As required by transport regulations, the HI-STAR 330 Package is evaluated under hot ambient conditions defined in 10CFR71. These conditions are 38ºC (100ºF) ambient temperature, still air and insolation (Table 3.3.2). Any acceleration, vibration or vibration resonance that may arise under routine conditions of transport enhances the heat dissipation of cask as compared to the still air condition analyzed in this section. The results of the steady state calculation are presented in Table 3.1.1, which shows a large thermal margin of safety in the HI-STAR 330 Package.

3.3.8.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR 330 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 330 Package uniformly approaches the cold ambient temperature. The inner closure lid seals and stainless-steel material of construction of HI-STAR 330, as discussed in Chapter 2, will perform satisfactorily in cold environmental conditions. Likewise, the HI-STAR 330 carbon steel material used for shielding function is unaffected by exposure to cold temperatures.

3.3.9 Maximum Normal Operating Pressure (MNOP)

The Maximum Normal Operating Pressure (MNOP) for the normal condition of transport is evaluated using Ideal Gas Law. Assuming the initial cavity bulk air temperature inside the HI-STAR 330 Package is equal to the ambient temperature of 21ºC (70ºF), the cavity pressure is calculated and reported in Table 3.1.3. The cask cavity pressure is below the design pressure limit for normal condition specified in Table 1.2.1. It is noted that the cavity air inside the HI-STAR 330 Package is heated by the waste before the cask is sealed. Thus, the initial cavity bulk air temperature inside the HI-STAR 330 Package is higher than the ambient temperature, and the cavity pressure reported in Table 3.1.3 is conservatively overestimated.

3.3.10 Acceptance Criteria for Liner Tank Vacuum Drying Operation

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Proprietary Information Withheld in Accordance with 10 CFR 2.390

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[Table 3.3.1 Withheld in Accordance with 10 CFR 2.390]

TABLE 3.3.2
INSOLATION DATA

Surface Type	12-Hour Insolation (Note-1)		24-Hour Insolation Adopted in Analysis	
	(g-cal/cm^2)	(W/m^2)	(g-cal/cm^2)	(W/m^2)
Horizontally Transported Flat Surfaces				
- Base	None	None	None	None
- Other Surfaces	826.2	800	413.1	400
Non-Horizontal Flat Surfaces	206.5	200	103.25	100
Curved Surfaces	413.1	400	206.55	200

Notes:

1. The 12-Hour Insolation is slightly higher than the value provided in 10CFR71.

[Table 3.3.3 Withheld in Accordance with 10 CFR 2.390]

[Figure 3.3.1 Withheld in Accordance with 10 CFR 2.390]

3.4 Thermal Evaluation Under Hypothetical Accident Conditions

As mandated by 10 CFR Part 71 requirements, the HI-STAR 330 Package is subjected to a sequence of hypothetical accidents. Amongst all the hypothetical accidents postulated in 10CFR71.73, the design basis fire in 71.73c(4) has a thermal consequence to the package. The objective of the evaluation summarized in this section is to determine the safety of the package under the fire condition that exposes the cask to a 30-minute enveloping fire at 802°C (1475°F).

The temperature history of the HI-STAR 330 Package is monitored during the 30-minute fire and during post-fire cooldown for a sufficient length of time for the cask containment boundary components to reach the maximum temperatures.

3.4.1 Initial Conditions

In accordance with transport regulations, the HI-STAR 330 Package fire accident is evaluated under hot ambient initial conditions (§10CFR71.71(c)(1) and §10CFR71.73(b)). These conditions are 38ºC (100ºF) ambient temperature, still air and insolation. The HI-STAR 330 steady state temperature distribution under normal condition of transport is used as the initial condition for fire accident evaluation.

As postulated in 10 CFR Part 71, the thermal model considers the fire accident post the drop and puncture accidents evaluated in Section 2.7. The following three bounding scenarios are considered by including the cumulative damage due to drop and puncture accidents to assess the thermal response of the cask to a 30-minute fire accident.

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[

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The containment boundary components must remain within its design temperature limits under fire accident. The containment boundary seal is most susceptible to reaching its limit under accident due to its proximity to fire flame. In order to protect the seal from reaching high temperatures, an insulation board as shown in drawings (Section 1.3) is designed and included in the thermal model. Under normal conditions of transport, the Liner Tank is placed on the containment base plate of the cask. After the drop accident, the position of the Liner Tank may change with the cask orientation. The position of the Liner Tank inside the cask is expected to have an insignificant impact on the cask temperature since the decay heat inside the cask is small as compared to heat from the fire. For the fire evaluation, the entire cask cavity is simplified into a solid volume with uniform heat generation and effective thermal properties. [

Proprietary Information Withheld in Accordance with 10 CFR 2.390

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This simplified cask model, and the results obtained under the normal conditions with this model are adopted as the initial conditions for the fire evaluation.

3.4.2 Fire Conditions

As required by transport regulations, the HI-STAR 330 Package is evaluated under an all-engulfing fire at 802ºC (1475ºF) lasting for 30 minutes (§10CFR71.73(c)(4)). The regulations specify a minimum fire emissivity (0.9) for hypothetical accident evaluation. In the HI-STAR 330 fire accident evaluation, the minimum specified emissivity (0.9) and absorptivity (0.8) are adopted.

In Table 3.4.1 the principal fire accident assumptions are summarized. For conservatism, the reported Sandia large pool fires forced convection heat transfer coefficient (See Table 3.4.2) is adopted.

The HI-STAR 330 Package fire accident analysis is based on a 3D thermal model that accounts for radiation, conduction and external forced convection modes of heat transfer. An all engulfing fire is conservatively assumed i.e. heat input into the cask from all sides of the cask. The transient heat up of the cask during the 30-minute fire is computed. At the end of the fire, the ambient condition is restored, and post fire cooldown of the package is continued for a sufficiently long period to obtain the maximum temperature of the package contents. Heat is dissipated from the cask by natural convection and radiation. Jakob and Hawkins [3.2.7] recommended correlations presented in Section 3.3.4 are adopted to compute the natural convection heat transfer coefficient during post-fire cooldown. The details of the modeling are presented in [3.4.2].

3.4.3 Maximum Temperatures and Pressures

3.4.3.1 Maximum Temperatures

The HI-STAR 330 Package is evaluated under a hypothetical fire accident at 802ºC (1475ºF) lasting for 30 minutes, followed by a post fire cooldown for a sufficient duration to allow the cask containment boundary components and the closure lid seals to reach the maximum temperatures. The temperature history of the cask containment boundary components and the closure lid seals is graphed in Figure 3.4.1. The maximum temperatures reached during fire and post-fire cooldown are reported in Table 3.1.2. The temperatures of the cask containment boundary components are below their respective safety limits.

When the seal temperature reaches its maximum, the total heat absorbed by the cask is sufficiently more than the decay heat released from the waste. Therefore, the decay heat of the waste has negligible impact on the temperature increase of the cask under the fire accident. The maximum temperature of the waste contents and Liner Tank inside the cask cavity will not exceed the fire temperature. The fire temperature is well below the melting temperature of carbon steel and stainless steel, and thus there is no safety concern due to the temperature rise of the waste contents and Liner Tank inside the cask cavity.

3.4.3.2 Maximum Pressure

Due to the uncertainty of the Liner Tank position and the waste position after the drop accident, the cask cavity is modeled as a solid volume with effective thermal properties as described in Section 3.4.1. The increase in the average temperature of the cask cavity is smaller than the increase in the average temperature of the cask containment boundary components since the heat from the fire is transferred from outside to inside. Based on the results presented in Table 3.1.2, the maximum increase in the average temperature of the cask containment boundary components is 156ºC (313ºF). The maximum cask cavity average temperature under the fire condition is conservatively overestimated by adding 160ºC (288ºF) to that under the normal condition of transport. Using Idea Gas Law, the maximum cavity pressure reached during the fire accident is evaluated and reported in Table 3.1.3.

3.4.4 Maximum Thermal Stresses

The potential of thermal interference between the cask and the Liner Tank during or after the fire event is considered. It is concluded that conditions to develop an interference do not exist because:

a. There is a gap between the Liner Tank and the cask under the as-installed condition to facilitate loading of the Liner Tank.
b. The gap will grow during the fire event because the heat-up of the Liner Tank will trail that of the cask and also because both are made of materials with the same thermal expansion rate.

Thus, it is concluded that the HI-STAR 330 Package has sufficient internal clearance to ensure against an internal interference during the design basis fire event and there is no risk of constraint to free expansion in the containment space.

TABLE 3.4.1
HYPOTHETICAL FIRE ACCIDENT ASSUMPTIONS

	Initial Condition	30-minute Fire	Post-Fire Equilibrium
Insolation	Yes	No	Yes
Surface Convection	Natural	Forced	Natural
Cask Surface Solar Absorptivity	Table 3.2.5	Note 1	Table 3.2.5
Emissivity of Cask Outer Surfaces	Painted Surfaces (Table 3.2.5)	0.9 (fire emissivity)	Unpainted Surface (Table 3.2.5)
Note 1: The surface absorptivity coefficient value used in the hypothetical fire thermal evaluation is 1, which is conservative as compared to absorptivity value mandated by the regulation [3.0.1].			

TABLE 3.4.2
SANDIA POOL FIRE TEST DATA [3.4.1]

Test equipment	3 m (10 ft) OD propane railcar
Fuel	JP-4
Pool Size	9 m x 9 m (30 ft x 30 ft)
Fire Temperature	649ºC to 1093ºC (843ºC avg.) 1200ºF to 2000ºF (1550ºF avg.)
Convective Coefficient	25.5 W/m^2-K (4.5 Btu/ft^2-hr-ºF)

[Figure 3.4.1 Withheld in Accordance with 10 CFR 2.390]

3.5 SAFETY CONCLUSIONS

The safety analyses performed in this chapter demonstrate that:

1. During normal condition of transport under the maximum specified ambient temperature, i.e. 38°C (100°F) and insolation, the maximum temperature of the containment boundary components is well below the ASME code limit, and the temperature of the seals is well below the manufacturer's recommended limit for long term operations. The cask cavity pressure is below the design pressure limit. The maximum surface temperature at any accessible location on the cask in shade is well below the 85°C (185°F) regulatory limit.

2. Under the design basis fire condition (10CFR 71.73c(4)), the maximum temperature of the containment boundary components is well below their respective limits for accident condition and the peak temperature of the closure lid seals (gasket) is below the manufacturer's recommended limit for short term operations.

3. Because permissible waste in the HI-STAR 330 Package is restricted to activated metals, there are no flammable materials inside the package to sustain a fire or cause an explosion.

Chapter 3 References

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[3.2.3] Kern, D.Q., "Process Heat Transfer," McGraw Hill Kogakusha, (1950).

[3.2.4] ASME Boiler and Pressure Vessel Code, Section II, Part D, 2023 Edition.

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[3.2.6] "Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year-Old PWR Spent Fuel", ORNL/CSD/TM-149 TTC-0316, (1983).

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[3.2.8] Henninger, J. H. "Solar Absorptance and Thermal Emittance of Some Common Spacecraft Thermal-Control Coatings," NASA Reference Publication 1121, April 1984.

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CHAPTER 4: CONTAINMENT

4.0 Introduction

This chapter demonstrates the HI-STAR 330 containment boundary compliance with the permitted activity release limits specified in 10CFR71, 71.51(a)(1) and 71.51(a)(2) for both normal and hypothetical accident conditions of transport [4.0.1]. The HI-STAR 330 package contents consist of segmented and non-segmented solid reactor internals (such as top guides/core grids, core shrouds, steam dryers etc.) and secondary waste such as debris and chips, generated by the mechanical cutting process. The containment criteria, expressed as the design basis leakage rate, ensure that the HI-STAR 330 package does not exceed the allowable radionuclide release rate specified in the NRC regulations. Leakage rates are determined in accordance with the recommendations of ANSI N14.5 [8.1.4], and using methodologies from NUREG/CR-6487, Containment Analysis for Type B Packages Used to Transport Various Contents [4.0.2], and Regulatory Guide 7.4, Leakage Tests on Packages for Shipment of Radioactive Materials [4.0.3].

The containment system boundary for the HI-STAR 330 packaging is specified on the drawing package in Section 1.3. The materials of construction for the packaging containment are specified in the Bill-of-Material in the drawing package in Section 1.3. All materials and construction assure that there will be no significant chemical, galvanic, or other reaction as required by 10CFR71.43(d). The containment boundary is securely closed by bolts. The closure of the containment boundary is sufficient to prevent unintentional opening or opening by pressure that may arise in the package as required by 10CFR71.43(c).

Chapter 2 of this SAR shows that all containment boundary components are maintained within their design limits 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 component temperatures and pressures are within the design basis limits for all normal conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Since the containment boundary 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 330 cask is subjected to containment system fabrication tests before the first use as described in Chapter 8. The containment system fabrication tests are performed at the factory as a part of the HI-STAR 330 acceptance testing. The welds of the containment boundary and the lid inner seal gasket of the closure lid are leakage tested in accordance with ANSI N14.5. Containment system periodic tests are described in Section 4.3. The condition of the elastomeric seal gaskets of HI-STAR 330 cask will be verified each time the HI-STAR 330 is loaded and if needed replaced as described in Chapter 7.

4.1 Containment Boundary

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4.1.1 Containment Vessel

The containment vessel for the HI-STAR 330 packaging consists of the cask components which form the inner cavity volume used to house a liner tank that can either contain a cassette loaded with radioactive waste or be directly loaded with radioactive waste. The liner tank and cassette do not provide containment function. The containment vessel components create an enclosed rectangular parallelepiped cavity sufficient for insertion and enclosure of the liner tank.

4.1.2 Containment Penetrations

HI-STAR 330 is designed without any containment boundary penetrations. The test port located in the closure lid does not penetrate the containment system boundary.

4.1.3 Seals and Welds

The HI-STAR 330 containment vessel uses a combination of seal gaskets and welds designed and tested to provide containment. Seal gaskets and welds are individually discussed below. The seal gaskets and welds provide a containment system, which is securely closed, cannot be opened unintentionally or by an internal pressure within the package as required in 10CFR71.43(c).

4.1.3.1 Containment Seal Gaskets

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4.1.3.2 Containment Welds

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Proprietary Information Withheld in Accordance with 10 CFR 2.390

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Full-penetration welds are specified for the plates that form the cask containment shell. The weld fabrication and inspection details are shown in the drawings in Section 1.3.

4.1.4 Closure

The cask closure lid is secured using multiple closure bolts around the perimeter. The number and position of the closure bolts are shown in the drawings in Section 1.3. Pre-tensioning of closure lid bolts compresses the concentric elastomeric seals between the closure lids and the containment closure flange forming the closure lid seal.

[Figure 4.1.1 Withheld in Accordance with 10 CFR 2.390]

4.2 Containment Under Normal And Hypothetical Accident Conditions Of Transport

Once the liner tank is transferred and sealed into the HI-STAR 330 package system there is no credible mechanism under normal and hypothetical accident conditions of transport, as defined in 10CFR71.71 and 10CFR71.73, for the containment boundary to be breached. Chapter 2 shows that all containment boundary components are maintained within their design limits during normal and hypothetical accident conditions of transport. Chapter 3 shows that the peak containment boundary component temperatures and pressures are within the design basis limits for normal and hypothetical accident conditions of transport. Since the containment vessel remains intact, the design temperatures and pressure are not exceeded, and significant leakage from the containment boundary as discussed in Section 4.1 is not credible; there can be no significant release of radioactive material during normal and hypothetical accident conditions of transport.

4.2.1 Pressurization of Containment Vessel

The HI-STAR 330 cask contains a liner tank. The only free space that remains within the cask is the space between the liner tank and the cask. Prior to loading the liner tank into the HI-STAR 330 cask, it is ensured that the HI-STAR 330 containment vessel cavity is dry. Therefore, a credible mechanism for any radiolytic decomposition that could cause an increase in the cavity internal pressure is absent. The potential for an explosive level of gases due to radiological decomposition in the containment vessel cavity is eliminated by excluding foreign materials in the package. The enclosed liner tank is drained and dried prior to its final closure; therefore, any liner tank leak would not introduce any explosive gases into the cask cavity. The interior of the liner tank contains metallic waste in air at relatively low temperatures. There is no possibility of chemical reaction that would produce gas or vapor to significantly affect the internal pressure of the containment vessel.

4.2.2 Containment Criteria

The allowable leakage rates presented in this chapter are determined in accordance with ANSI N14.5 [8.1.4] and shall be used for containment system fabrication verification and containment system periodic tests of the HI-STAR 330 containment boundary discussed in Chapter 8. Measured leakage rates shall not exceed the values presented in Table 8.1.1.

4.2.3 Leak Test Sensitivity

The sensitivity for the cask leakage test procedures is equal to one-half of the allowable leakage rate. The HI-STAR 330 containment packaging tests in Chapter 8 incorporate the appropriate leakage test procedure and sensitivity. The leakage rates for the HI-STAR 330 containment packaging with its corresponding sensitivity are presented in Table 8.1.1.

4.3 Leakage Rate Tests For Type B Packages

Compliance with Type B package containment requirements is demonstrated by conducting fabrication, pre-shipment, periodic and maintenances leakage rate tests according to ANSI N14.5 [8.1.4].

4.3.1 Fabrication Leakage Rate Test

Fabrication leakage rate testing shall be performed prior to first use of each packaging to demonstrate that as fabricated system will provide required level of containment. The HI-STAR 330 containment packaging tests in Chapter 8 incorporate the fabrication leakage test procedure and leakage rate sensitivity.

4.3.2 Pre-Shipment Leakage Rate Test

Pre-Shipment leakage rate testing shall be performed prior each shipment after the contents are loaded to confirm that the containment system is properly assembled for shipment. The HI-STAR 330 containment packaging tests in Chapter 8 incorporate the pre-shipment leakage test procedure and leakage rate sensitivity.

4.3.3 Periodic Leakage Rate Test

If the pre-shipment leakage rate test expires, periodic leakage rate testing shall be performed within 12 months prior to each shipment to demonstrate that containment capabilities have not deteriorated during a period of use. The HI-STAR 330 containment packaging tests in Chapter 8 incorporate the periodic leakage test procedure and leakage rate sensitivity.

4.3.4 Maintenance Leakage Rate Test

Maintenance leakage rate testing shall be performed prior to returning package to service following maintenance such as repair or replacement of components. The purpose of the test is to demonstrate that the system after maintenance will provide required level of containment. The HI-STAR 330 containment packaging tests in Chapter 8 incorporate the maintenance leakage test procedure and leakage rate sensitivity.

4.4 Containment Calculations

The HI-STAR 330 System is designed to meet the radioactive release limit requirements of 10CFR71.51. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the HI-STAR 330 package will not exceed the specified allowable radionuclide release rates. Leakage rates are determined in accordance with the recommendations of ANSI N14.5 [8.1.4], and using methodologies from NUREG/CR-6487, Containment Analysis for Type B Packages Used to Transport Various Contents [4.0.2], and Regulatory Guide 7.4, Leakage Tests on Packages for Shipment of Radioactive Materials [4.0.3].

4.4.1 Assumptions

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4.4.2 Methodology

The waste transported in HI-STAR 330 is limited to non-fissile reactor related waste irradiated at various NPPs. In accordance with NUREG/CR-6487 [4.0.2], the waste is considered non-dispersible. The specific guidance in NUREG/CR-6487, Chapter 4 "Solid Byproduct or Special Nuclear Materials" is followed in determining the appropriate source terms for waste transported in HI-STAR 330. More specifically, the guidance on non-dispersible solids that have releasable surface contamination is followed. According to NUREG/CR-6487, non-dispersible solids are structurally robust, will maintain their form when subject to transportation and/or loading-related forces, and contribute to the source term by spallation of surface contamination into the containment vessel fill gas to form a releasable aerosol. The containment analysis for the HI-STAR 330 assumed non-dispersible solids with no fines made of the bulk radioactive material.

4.4.2.1 Source Terms

The source-terms from releasable activity arise from surface activity of transported waste. Similar to the treatment of crud on the surface of irradiated nuclear fuel rods, the crud spallation fractions for normal and accident conditions are assumed. The majority of the activity associated with crud is due to ^{60}Co per NUREG/CR-6487. Specifically, Section 6.2 of NUREG/CR-6487 states, "The A_2 value used for the crud is dominated by the cobalt-60 in the crud. The effect of the cobalt-60 on the A_2 of the crud is so strong that the A_2 value used for the crud, for both PWR and BWR fuel rods, is the same as that of cobalt-60, which is 10.8 Ci (0.4 TBq)." [4.0.2]. Therefore all surface activity is assumed to be ^{60}Co with the amount provided in Table 4.4.2.

In transportation packages holding non-dispersible solids, the releasable material consists of fine particulates that spall-off the surface of the solids to create a powder aerosol inside the containment vessel. The activity concentration of the powder aerosol can be formulated as:

$$C_i = \frac{f_i \times A_S}{V_{tot}} \qquad \text{Equation 4.4.1}$$

where,

C_i is the activity concentration of the powder aerosol, with $i = N$ for normal conditions and $i = A$ for hypothetical accident conditions [Bq/cm^3; (Ci/cm^3)],

f_i is the activity fraction of the surface contamination that spalls-off the surface contaminated solids, where $i = N$ is for normal conditions and $i = A$ is for hypothetical accident conditions, shown in Table 4.4.1,

A_S is the surface activity [Bq; (Ci)]. $A_S = S_{AS} \times A_{SC}$, where S_{AS} is total surface area of the contaminated solids [cm^2] shown in Table 4.4.1, and A_{SC} is surface activity density of the contaminated solids [Bq/cm^2; (Ci/cm^2)] shown in Table 4.4.1,

V is the free volume inside the containment vessel [cm^3].

Calculated activity concentrations for normal and hypothetical accident conditions are provided in Table 4.4.4.

4.4.2.2 Releasable Activity

The releasable activity is the product of the activity concentration and free volume in containment boundary of HI-STAR 330 package.

$$RA_i = C_i \times V_{tot} \quad \text{Equation 4.4.2}$$

where,

RA_i is the releasable activity of the powder aerosol, with $i = N$ for normal conditions and $i = A$ for hypothetical accident conditions [Bq; (Ci)],

C_i is the activity concentration of the powder aerosol, with $i = N$ for normal conditions and $i = A$ for hypothetical accident conditions [Bq/cm^3; (Ci/cm^3)],

V is the free volume inside the containment vessel [cm^3].

4.4.2.3 Determination of A_2 Value

As described in Paragraph 4.4.2.1, source-terms from releasable activity arise from surface activity and all activity is assumed to be ^{60}Co. A_2 value for ^{60}Co is provided in 10CFR71, Appendix A and reproduced in Table 4.4.5.

4.4.2.4 Allowable Radionuclide Release Rates

The containment criterion for the HI-STAR 330 System under normal conditions of transport is given in 10CFR71.51(a)(1). This criterion requires that a package has a radioactive release rate less than A_2 x 10^{-6} in one hour, where A_2 is defined in Paragraph 4.4.2.3.

NUREG/CR-6487 and ANSI N14.5 provide the following equation for the allowable release rate for normal conditions of transport:

$$R_N = L_N \times C_N \leq A_2 \times 2.78 \times 10^{-10}/second \quad \text{Equation 4.4.3}$$

where,

R_N is the release rate for normal conditions of transport [Bq/s; (Ci/s)],

L_N is the volumetric gas leakage rate for normal conditions of transport [cm^3/s],

C_N is the total source term activity concentration for normal conditions of transport [Bq/cm^3; (Ci/cm^3)],

A_2 is the appropriate effective A_2 value [Bq; (Ci)].

The containment criterion for the HI-STAR 330 System under hypothetical accident conditions is given in 10CFR71.51(a)(2). This criterion requires that a package has a radioactive release rate less than A_2 in one week.

$$R_A = L_A \times C_A \leq A_2 \times 1.65 \times 10^{-6}/second \quad \text{Equation 4.4.4}$$

where,

R_A is the release rate for hypothetical accident conditions transport [Bq/s; (Ci/s)],

L_A is the volumetric gas leakage rate for hypothetical accident conditions transport [cm^3/s],

C_A is the total source term activity concentration for hypothetical accident conditions transport [Bq/cm^3; (Ci/cm^3)],

A_2 is the appropriate effective A_2 value [Bq; (Ci)].

Equations 4.4.3 and 4.4.4 are used to determine the allowable radionuclide release rates for each condition of transport with results provided in Table 4.4.6.

4.4.2.5 Allowable Leakage Rates at Operating Conditions

The allowable leakage rates at operating conditions are determined by dividing the allowable release rates by the appropriate source term activity concentration (modifying Equations 4.4.3 and 4.4.4).

$$L_N = \frac{R_N}{C_N} \text{ or } L_A = \frac{R_A}{C_A} \quad \text{Equation 4.4.5}$$

where,

L_N or L_A is the allowable leakage rate at the upstream pressure for normal (N) or accident (A) conditions [cm^3/s],

R_N or R_A is the allowable release rate for normal (N) or accident (A) conditions [Bq/s; (Ci/s)], and

C_N or C_A is the total source term activity concentration for normal (N) or accident (A) conditions [Bq/cm^3; (Ci/cm^3)].

The allowable leakage rates determined using Equation 4.4.5 are the allowable leakage rates at the upstream pressure. Table 4.4.6 summarizes the allowable leakage rates at the upstream pressures.

4.4.2.6 Leakage Rate Acceptance Criteria for Test Conditions

The leakage rates discussed thus far are determined at operating conditions. The following provides details of the methodology used to convert the allowable leakage rate at operating conditions to a leakage rate acceptance criterion at reference test conditions.

For conservatism, unchoked flow correlations are used since the unchoked flow correlations better approximate the true measured flow rate for the leakage rates associated with transportation packages. Using the equations for molecular and continuum flow provided in NUREG/CR-6487, the corresponding leak hole diameter is calculated by solving Equation 4.4.6 for D, the leak hole diameter.

$$L = \left[\frac{2.49 \times 10^6 D^4}{a\,\mu} + \frac{3.81 \times 10^3 D^3 \sqrt{\frac{T}{M}}}{a\,P_a}\right][P_u - P_d] \times \frac{P_a}{P_u}$$ Equation 4.4.6

where,

$L_{@P_u}$ is the allowable leakage rate at the upstream pressure for normal and accident conditions [cm^3/s],

a is the capillary length or seal gasket seating width [cm],

T is the temperature for normal and accident conditions [K],

M is the air molecular weight [g/mol] from ANSI N14.5, Table B1 [8.1.4],

u is the fluid viscosity for air [cP] from [4.4.3],

P_u is the upstream pressure for normal and accident conditions [atm],

D leak hole diameter [cm],

P_d is the downstream pressure for normal and accident conditions [atm], and

P_a is the average pressure; $P_a = (P_u + P_d)/2$ for normal and accident conditions [atm].

The actual leakage tests performed on the containment boundary welds are typically not performed under exactly the same conditions every time. Therefore, reference test conditions are specified to provide a consistent comparison of the measured leakage rate to the leakage rate acceptance criterion. The reference test conditions are specified in Table 4.4.7.

The bounding leak hole diameter at operating conditions is determined by solving Equation 4.4.6 for D where $L_{@P_u}$ is L_N and L_A in Table 4.4.6 for normal and hypothetical accident conditions of transport, respectively. Other parameters to solve Equation 4.4.6 are presented in Table 4.4.7.

Using this leak hole diameter and the temperature and pressure specified for reference test conditions provided in Table 4.4.7, Equation 4.4.6 is solved for the volumetric leakage rate at reference test conditions. Volumetric leakage rates for normal ($L_{u\text{-}N}$) and accident ($L_{u\text{-}A}$) conditions are specified in Table 4.4.8.

Equation B-1 of ANSI N14.5 [8.1.4] is used to express this volumetric leakage rate into a mass-like flow rate as follows:

$$Q_{u\text{-}i} = L_{u\text{-}i} \times P_{u\text{-}i}$$ Equation 4.4.7

where,

$Q_{u\text{-}i}$ is the mass-like leak rate [atm-cm^3/sec; (Pa-m^3/sec)], with $i = N$ for normal conditions and $i = A$ for accident conditions,

$L_{u\text{-}i}$ is the upstream volumetric leakage rate [cm^3/sec], with $i = N$ for normal conditions and $i = A$ for accident conditions, and

$P_{u\text{-}i}$ is the upstream pressure [atm; (Pa)], with $i = N$ for normal conditions and $i = A$ for accident conditions.

Using Equation 4.4.7, the volumetric flow rate is converted into a mass-like flow for both normal ($Q_{u\text{-}N}$) and accident ($Q_{u\text{-}A}$) conditions, with values presented in Table 4.4.8.

The most limiting mass-like flow value in Table 4.4.8 is conservatively selected as the basis for leakage rate acceptance criterion. The conservatively reduced value of leakage rate acceptance criterion is presented in Table 8.1.1.

[Table 4.4.1 Withheld in Accordance with 10 CFR 2.390]

Table 4.4.2: Isotope Inventory

Nuclide	Inventory
Gases	
N/A	N/A
Crud	
^{60}Co	597.8 Ci (2.212×10^{13} Bq)
Volatiles	
N/A	N/A
Fines	
N/A	N/A

[Table 4.4.3 Withheld in Accordance with 10 CFR 2.390]

[Table 4.4.4 Withheld in Accordance with 10 CFR 2.390]

Table 4.4.5: Total Source Term Effective A_2 for Normal and Hypothetical Accident Conditions

Equipment	Effective A_2
Normal Transport Conditions	
HI-STAR 330	10.8 Ci (0.4×10^{12} Bq)
Hypothetical Accident Conditions	
HI-STAR 330	10.8 Ci (0.4×10^{12} Bq)

Table 4.4.6 Allowable Release Rates and Leakage Rates at the Upstream Pressure

Equipment	Allowable Release Rate (R_N or R_A)	Allowable Volumetric Leakage Rate at P_u (L_N or L_A)
Normal Transport Conditions		
HI-STAR 330	3.0×10^{-9} Ci/s (111 Bq/s)	145×10^{-6} cm^3/s
Accident Conditions		
HI-STAR 330	17.85×10^{-6} Ci/s (660.5×10^3 Bq/s)	129×10^{-3} cm^3/s

Table 4.4.7: Parameters for Normal and Test Conditions

Parameter	Normal Conditions	Hypothetical Accident Conditions	Reference Air Test Conditions
Upstream Pressure (P_u)	NCT Liner Tank Cavity Pressure in Table 3.1.3	HAC Liner Tank Cavity Pressure in Table 3.1.3	1 atm (101.3 kPa)
Downstream Pressure (P_d)	1 atm (101.3kPa)	1 atm (101.3kPa)	0.01 atm (1 kPa)
Temperature (T)	NCT Liner Tank Cavity Bulk Temperature in Table 3.1.3	HAC Liner Tank Cavity Bulk Temperature in Table 3.1.3	25 °C (298 K)
Molecular Weight (M)	29 g/mol (air) Table B1 in [8.1.4]	29 g/mol (air) Table B1 in [8.1.4]	29 g/mol (air) Table B1 in [8.1.4]
Viscosity (u)	0.0219 cP (air) [4.4.3]	0.0281 cP (air) [4.4.3]	0.0184 cP (air) [4.4.3]
Seal Gasket Seating Width (a)	0.233 inch Conservatively assumed comparing to Table 2.2.6	0.233 inch Conservatively assumed comparing to Table 2.2.6	0.233 inch Conservatively assumed comparing to Table 2.2.6

Table 4.4.8: Calculated Allowable Leak Rates at Reference Conditions

Equipment	Volumetric Leakage Rate at Reference Conditions (L_{u-N} or L_{u-A})	Mass-like Flow Rate at Reference Conditions (Q_{u-N} or Q_{u-A})
Normal Transport Conditions		
HI-STAR 330	3.70×10^{-4} cm^3/s	3.70×10^{-4} atm-cm^3/s, Air (3.75×10^{-5} Pa-m^3/s, Air)
Accident Conditions		
HI-STAR 330	1.56×10^{-1} cm^3/s	1.56×10^{-1} atm-cm^3/s, Air (1.58×10^{-2} Pa-m^3/s, Air)

CHAPTER 4 REFERENCES

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CHAPTER 5 - SHIELDING EVALUATION

5.0 Introduction

The shielding analysis of the HI-STAR 330 Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter.

The HI-STAR 330 is designed to accommodate different types of Liner Tanks, with different wall thicknesses. The outer dimensions are the same for all types of Liner Tanks. The HI-STAR 330 cavity and outer dimensions are provided in the Engineering Drawings, Section 1.3. The Liner Tank (tank) and Liner Tank Cassette (LTC or cassette) dimensions are provided in the Engineering Drawings, Section 1.3. Additionally, the maximum Co-60 specific activity for each waste package type is listed in Table 7.1.2 and Table 7.1.3. Each maximum specific activity with the maximum waste weight has been analyzed and found to be acceptable compared to the regulatory limits.

The transport index in 10CFR71 is defined as the number determined by multiplying the radiation level in milliSievert per hour (mSv/h) at one meter from the external surface of the package by 100. Since HI-STAR 330 has met a dose rate of 0.1 mSv/h at a distance of 1 meter from the cask in all locations with design basis waste as shown in Table 5.1.5, the transport index is therefore below 10.

The shielding analyses were performed with MCNP-5 1.51 [5.1.1] developed by Los Alamos National Laboratory (LANL). MCNP-5 is principally the same code that was used in Holtec's approved Storage and Transportation FSARs and SAR under separate docket numbers [5.1.2]. Detailed descriptions of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter mirror those used in the SAR for HI-STAR 180 certified in Docket #71-9325 [5.1.2].

This chapter contains the following information:

- A description of the shielding features of HI-STAR 330
- A description of the source terms
- A general description of the shielding analysis methodology
- A description of the analysis assumptions and results for HI-STAR 330
- Analyses for the HI-STAR 330'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 330 packaging with respect to radiation shielding consist of the following steel components: base plate, top flange, containment wall plates, dose blocker plates, and closure lid. These various steel components provide the main gamma shielding. HI-STAR 330 is intended to serve as a transportation cask for transporting one loaded secondary container (per transport) containing irradiated and contaminated steel reactor internals. The secondary container steel tank and cassette plates provide additional gamma shielding. The dimensions of the shielding components of both the HI-STAR 330 cask and the secondary containers are shown in the drawing package in Section 1.3. The shielding material densities are listed in [

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]

[Table 5.3.1.

Tertiary containers may also be loaded within the secondary containers. The purpose of the tertiary containers allows unique higher specific activity material, like activated stellite, to be loaded within an additional steel box that provides additional shielding beyond what is required for the balance of the waste material loaded outside of the tertiary container but inside the secondary container. Dimensions and nomenclature of allowed tertiary containers and permissible maximum specific activity within tertiary container types are provided in Table 7.1.3.

5.1.2 Acceptance Criteria

The following shielding acceptance criteria for transportation casks for normal conditions, provided in 10CFR71.47 are applied:

- 2 mSv/h (200 mrem/h) on the external surface of the package; and
- 0.1 mSv/h (10 mrem/h) at any point 2 meters (80 in) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and
- 0.02 mSv/h (2 mrem/h) in any normally occupied space, except that this provision does not apply to private carriers, if exposed personnel under their control wear radiation dosimetry devices in conformance with 10 CFR 20.1502.

The shielding acceptance criteria for transportation casks for hypothetical accident conditions, provided in 10CFR71.51(a)(2) is the following:

- No external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in.) from the external surface of the package.

5.1.3 Summary of Maximum Radiation Levels

Each waste package, with its specific activity in Table 7.1.2 and Table 7.1.3 was independently analyzed and it was verified that the calculated dose rates were less than the regulatory limits. In this subsection, only the results for the bounding waste content for each of the waste package types with uniform waste content 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 cases are presented in Section 5.4.

The dose rates listed in the tables in this subsection are maximum values. This is achieved by specifying dose locations around the cask that may be dose rate maximums due to source configuration or minimum shielding thicknesses, and selecting the highest values.

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5.1.3.1 Normal Conditions

The shielding analysis confirms that the HI-STAR 330 complies with 10CFR71.47.

Table 5.1.1 presents the maximum surface dose rates resulting from the highest specific activity waste for all waste package types.

Dose rates are calculated on the cask surface, at locations shown in Figure 5.3.1 and Figure 5.3.2. Dose locations at the long side, short side, top, and bottom of the cask are used to determine the surface dose rates.

All values are below 2 mSv/h, therefore showing that the HI-STAR 330 complies with 10CFR71.47(b)(1). It should be noted that the additional conditions stated in 10CFR71.47(b)(1)(i) through (iii) (closed vehicle; fixed position; no loading/unloading) do not have to be analyzed for the HI-STAR 330, since the surface dose rates 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 330 therefore complies with 10CFR71.47(b)(2).

Table 5.1.2 presents the maximum 2 meter dose rates resulting from the highest specific activity waste for all waste package types.

The maximum dose rates for the HI-STAR 330 have been calculated at a distance of 2 m from the outer lateral surfaces of the cask, for the locations shown in Figure 5.3.1 and Figure 5.3.2. Results for the bounding 2 meter dose rates at 2 m distance are below 0.1 mSv/h. Consequently, the dose rates at 2 m from the outer edges of the vehicle will also be below 0.1 mSv/h. The HI-STAR 330 therefore complies with 10CFR71.47(b)(3).

Table 5.1.4 presents the calculated dose rates and distance necessary to comply with the 0.02 mSv/h requirement specified in 10CFR71.47(b)(4) for any normally occupied space. If the normally occupied space of the vehicle is at a distance less than the values specified for the 0.02 mSv/h requirement, radiation dosimetry is required for personnel to comply with 10CFR71.47(b)(4).

The analyses summarized in this section demonstrate HI-STAR 330's compliance with the 10CFR71.47(b) limits.

5.1.3.2 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 (possible weld failure) and deformation to the walls of the secondary containers, and damage (reduction in shielding thickness) to the impacted surface of the HI-STAR 330 cask as a result of the 9-meter (30 foot) drop.

Some indentation and localized thickness reduction of the HI-STAR 330 cask would be likely following the 9 meter drops presented in Section 2.7, which is taken into account by the modeled gaps (voided steel) in tank walls. Localized thickness reduction would also more likely occur at a corner or edge, which would have a limited effect on the highest dose rate that is typically located in the center of a wall (not near the corners or edges).

Chapter 2 shows that the HI-STAR 330 package remains significantly unaltered throughout the hypothetical accident conditions. Localized damage of the cask outer surface could be experienced during the pin puncture, and drop accidents. However, such localized deformations will have a negligible impact on the dose rate at 1 meter from the surface.

Section 5.3 considers and describes various accident conditions. Figure 5.3.3, Figure 5.3.4, and Figure 5.3.5 show the dose measurement locations at 1 meter from the surface of the HI-STAR 330 for postulated accident conditions.

The maximum dose rate 1-meter from the surface of the transport package considering shielding design basis hypothetical accident conditions, is presented in Table 5.1.3 and is below the regulatory limit of 10 mSv/h.

Analyses summarized in this section demonstrate the HI-STAR 330 Package's compliance with the 10CFR71.51(a)(2) hypothetical accident radiation dose rate limit.

Table 5.1.1: Maximum Surface Dose Rates for Maximum Specific Activity Waste Content (Uniform) Under Normal Conditions[1]

Normal Condition	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	Surface Dose Rates (mSv/hr)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	10 CFR 71.47 Limit (mSv/hr)
Entire cavity filled with a uniform source of maximum specific activity and maximum waste density		0.3531		2
		0.4658		
		0.0959		
		0.1634		

Table 5.1.2: Maximum 2-Meter Dose Rates for Maximum Specific Activity Waste Content (Uniform) Under Normal Conditions[1]

Normal Condition	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	2 meter Dose Rates (mSv/hr)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	10 CFR 71.47 Limit (mSv/hr)
Entire cavity filled with a uniform source of maximum specific activity and maximum waste density		0.0451		0.1
		0.0441		
		0.0399		
		0.0414		

[1] **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**

Table 5.1.3: Maximum 1-meter Dose Rates for Maximum Specific Activity Waste Content Under Accident Conditions[1]

Accident Condition, [Proprietary Information Withheld in Accordance with 10 CFR 2.390]	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	1 meter Dose Rates (mSv/hr)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	10 CFR 71.51 Limit (mSv/hr)
		3.15		10

Table 5.1.4: Distances for the 0.02 mSv/h Dose Rate Requirement for the HI-STAR 330 Under Normal Conditions[1]

Distance (meters)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	Dose Rate (mSv/hr)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	10 CFR 71.47 Limit (mSv/hr)
4		0.0191		0.02
4		0.0194		
4		0.0170		
4		0.0180		

[1] **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**

Table 5.1.5: Maximum 1-meter Dose Rates for Maximum Specific Activity Waste Content (Uniform) Under Normal Conditions[1]

Normal Condition	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	1 meter Dose Rates (mSv/hr)	[Proprietary Information Withheld in Accordance with 10 CFR 2.390]	HI-STAR 330 Transport Index
[Proprietary Information Withheld in Accordance with 10 CFR 2.390]		0.0674		6.8
		0.0668		
		0.0637		
		0.0654		

[1] **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**

5.2 Source Specification

The non-fuel waste content to be qualified for transportation in the HI-STAR 330 contains reactor internals as described in Subsection 1.2.2. A description of the design basis waste content for the source term calculations is provided in Table 7.1.2 and Table 7.1.3. Dimensions of the inner cavities and the thickness of the tank walls vary according to tank type. These variations are taken into account in assigning a density to the waste content and defining the dimensions of the source volume.

The principal sources of radiation in the HI-STAR 330 are:

- Gamma radiation originating from the following sources:

    1. Neutron induced activity in reactor internals

    2. Crud - surface contamination of activated corrosion products and actinides on stainless steel surfaces in contact with reactor coolant

- Neutron radiation – this source is negligible for activated steel components, however Table 7.1.2 provides a permissible waste material maximum neutron source per unit mass (n/s/kg). Table 5.4.5 from Reference [5.2.1] provides neutron dose calculations for similar waste content as in Table 7.1.2 and demonstrates that dose rates from neutron emitting radionuclides have negligible contribution to the total dose rates.

The primary source of activity in the waste content that contributes to external dose rates arises from the activation of ^{59}Co to ^{60}Co. The primary source of ^{59}Co in reactor internals is the impurities in the steel.

NUREG-2216 states that "In general, only gammas with energies from approximately 0.4 MeV-3.0 MeV will contribute significantly to the external radiation levels" [5.2.2]. Cobalt-60 is the most substantial high-activity gamma emitter in this gamma energy range. Co-60 is known to emit two high energy photons per disintegration at the discrete energies of 1.1732 and 1.3325 MeV [5.2.3], which are given equal weight in the MCNP source definition card. To include conservatism in the model, all of the remaining radioisotopes, including any radioisotopes that emit neutrons, in the waste content (excluding Co-60) are conservatively credited as an additional 10% Co-60 equivalent in the shielding calculations. Appendix 5.A in Reference [5.2.1] provides source term calculations showing that relative contribution of radionuclides other than Co-60 **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**.

5.3 Shielding Model

The shielding analysis of the HI-STAR 330 was performed with MCNP 5 [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 330 in the shielding analysis. MCNP 5 is essentially the same code that is used for the shielding calculations of Holtec's other approved dry storage and transportation systems under separate dockets.

The MCNP model of the HI-STAR 330 Package for normal conditions includes the tank and cassette top and bottom plates.

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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 330 Packaging. These drawings were used to create the MCNP models used in the radiation transport calculations.

The transport vehicle and frame were not considered in the MCNP model, i.e. the outer dimensions of the vehicle are conservatively assumed to be identical to the outer dimensions of the package as modeled for normal conditions. Figure 5.3.1 and Figure 5.3.2 show cross sectional views of the HI-STAR 330 cask under normal conditions as modeled in MCNP. Figure 5.3.3 shows a cross sectional view of the HI-STAR 330 cask under hypothetical accident conditions **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**.

5.3.1.1.1 Normal Conditions Modeling

The conditions and tests specified in 10CFR71 for norsmal conditions **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**.

5.3.1.1.2 Hypothetical Accident Conditions Modeling

Under the drop accident conditions the tank and cassette experience significant decelerations, which may result in a failure of the welds and lid bolts. It is therefore conservatively assumed that all welds and lid bolts of the tank fail. **[**

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For the cassette, the situation is different. Since the tie rods of the cassette are not strong enough, and assumed to fail under certain hypothetical accident conditions, a relocation of the top and bottom plates of the cassette is feasible. The T-150 contains waste with the highest specific activity and has the greatest top and bottom plate thickness, so the bounding case considers a relocation of the top and bottom plate of the cassette in the T-150 tank.

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5.3.1.2 Source Configuration

5.3.1.2.1 Normal Conditions Source Configuration

The waste source is conservatively modeled using the highest allowed specific activity (Bq/kg) for each waste package type as specified in Table 7.1.2 and Table 7.1.3. **[**

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5.3.1.2.2 Accident Conditions Source Configuration

The accident conditions shielding analyses follow the same source modeling approach as the normal conditions with the additional considerations:

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5.3.1.3 Material Properties

[

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[Table 5.3.1 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]

Figure 5.3.7 [Withheld in Accordance with 10 CFR 2.390]

5.4 Shielding Evaluation

5.4.1 Methods

A number of conservative assumptions are applied throughout the shielding calculations. These assumptions assure that the actual dose rates will always be below the calculated dose rates, and below the regulatory limits. Selected key assumptions are:

[

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The MCNP-5 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. Cross section libraries are based on ENDF/B-VI. These are the default libraries for the MCNP code version used for the shielding analyses. The large user community has extensively benchmarked MCNP against experimental data. References [5.4.2], [5.4.3], and [5.4.4] are three examples of the benchmarking that has been performed. MCNP-5 is essentially the same code that has been used as the shielding code in all of Holtec's dry storage and transportation analyses. Note also that the principal approach in the shielding analysis here is identical to the approach in licensing applications previously reviewed and approved by the USNRC.

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5.4.2 Input and output data

The advantage of using the Monte Carlo program MCNP is that the geometry can be modeled without making any significant simplifying assumptions. The principal input data is therefore the dimensions shown in the drawings in Section 1.3, the waste specifications, and the material compositions listed in Section 5.3.

[Proprietary Information Withheld in Accordance with 10 CFR 2.390] The output of the post-processing are the dose rates listed in this chapter.

5.4.3 Flux-to-dose-rate conversion

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]

5.4.4 External radiation levels

[

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Table 5.4.1: 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
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

† Values have been multiplied by 10 to convert rem, as given in [5.4.1], to mSv.

Gamma Energy (MeV)	**(mSv/h)/ (photon/cm^2-s)** †
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

[Table 5.4.2 Withheld in Accordance with 10 CFR 2.390]

[Table 5.4.3 Withheld in Accordance with 10 CFR 2.390]

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.

[5.1.1] X-5 Monte Carlo Team, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5," *LA-UR-03-1987*, Los Alamos National Laboratory (2003) (Revised 2/1/2008).

[5.1.2] HI-STAR 100 FSAR, Latest Revision (Docket 72-1008), and HI-STORM FSAR, Latest Revision (Docket 72-1014). HI-STAR 180, Latest Revision (Docket 71-9325); and HI-STAR 180D, Latest Revision (Docket 71-9367).

[5.1.3] HI-STAR 330 Shielding Calculation Package HI-2220506, Revision 0. Holtec International.

[5.2.1] HI-STAR ATB 1T SAR, HI-2146312 Latest Revision (Docket No. : 71-9375). Holtec International.

[5.2.2] NUREG-2216, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, USNRC, Washington, DC, August 2020.

[5.2.3] Nuclides and Isotopes: Chart of the Nuclides – 16th Edition. Lockheed Martin. Knolls Atomic Power Laboratory. 2002.

[5.4.1] "American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors", ANSI/ANS-6.1.1-1977.

[5.4.2] D. J. Whalen, et al., "MCNP: Photon Benchmark Problems," LA-12196, Los Alamos National Laboratory, September 1991.

[5.4.3] D. J. Whalen, et al., "MCNP: Neutron Benchmark Problems," LA-12212, Los Alamos National Laboratory, November 1991.

[5.4.4] J. C. Wagner, et al., "MCNP: Criticality Safety Benchmark Problems," LA-12415, Los Alamos National Laboratory, October 1992.

CHAPTER 6: CRITICALITY EVALUATION

6.0 Introduction

The HI-STAR 330 cask is designed to serve as a transportation cask for radioactive non-fuel waste material. The total weight of the fissile material to be transferred in HI-STAR 330 is less than the permissible quantity per package in Table 7.1.2. Since an individual package containing the maximum permissible quantity of fissile material in Table 7.1.2 or less is in compliance with 10 CFR 71.15 (a), it is exempt from the fissile material package standards of 10 CFR 71.55 and 71.59. Therefore, a specific criticality evaluation for the HI-STAR 330 containing the current radioactive material is not required.

CHAPTER 7: PACKAGE OPERATIONS

7.0 Introduction

This chapter provides a summary description of the essential elements and requirements necessary to prepare the HI-STAR 330 package for shipment to ensure that it operates in a safe and reliable manner under normal and accident conditions of transport pursuant to the provisions of 10CFR71 [7.1.1]. The information presented in this chapter shall be used by the User to establish operating procedures in the format and template of the Owner's organization consistent with the configuration of the nuclear plant site, conditions of the NRC issued Certificate of Compliance (CoC), and any applicable O&M manuals. 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 technical evaluation of all credible potential modes of *loss of load stability* has been performed;
- Procedures are in conformance with the essential elements and conditions of this Chapter and the CoC;
- The operational steps are ALARA;
- Procedures contain provisions for documenting successful execution of all safety significant steps for archival reference;
- Holtec's lessons learned database has been consulted to incorporate all applicable lessons learned from prior cask handling and loading evolutions;
- Procedures contain provisions for classroom and hands-on training and for a Holtec-approved personnel qualification process to 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.

US Department of Transportation (USDOT) transportation regulations in 49CFR [7.1.2] applicable to the transport of the HI-STAR 330 package are addressed in this chapter only to the extent required to ensure compliance with 10CFR71 regulations. Applicable 49CFR regulations, including those explicitly called out in 10CFR71.5, shall be complied with for package use in the US and/or for US package export and import. For transport outside US territory and under the approval or jurisdiction of one or more foreign competent authorities, other requirements such as the ADR, "Agreement Concerning the International Carriage of Dangerous Goods by Road" [7.1.3] and the RID, "Regulations Concerning the Carriage of Dangerous Goods by Rail" [7.1.4] may be utilized 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 operations of the HI-STAR 330. Written procedures shall 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, training, equipment and process qualifications. The User shall implement controls to ensure that the lifted weights do not exceed the cask lifting trunnion design limit. Lifting device interfaces shall meet the requirements of the licensing drawings. The User shall also implement controls to ensure that the cask cannot be subjected to a fire event in excess of the 10CFR71.73 design limits during loading operations.

Material selection and verification shall be performed by the user in accordance with written, approved procedures that ensure that only waste materials authorized in the CoC are loaded into the HI-STAR 330 cask.

Control of the package operations shall be performed in accordance with the Owner's Quality Assurance (QA) program to ensure critical steps are not overlooked and that the cask has been confirmed to meet all requirements of the CoC before being released for shipment.

7.1 Package Loading

The HI-STAR 330 Cask is used to transport non-fissile radioactive contents that have been loaded into secondary containers referred to as Liner Tanks, which may contain an optional waste basket referred to as a Liner Tank Cassette (LTC). Refer to the drawing package in Section 1.3 for details. In some cases, additional tertiary containers may be used to provide additional radiation shielding for highly activated waste material. These tertiary containers are placed within the secondary containers during loading operations along with other waste material.

For transport, the Cask is secured to a Transport Vehicle (truck, railcar, barge, etc.) either directly or indirectly via a Transport Frame. The cask may remain attached to the Transport Frame during loading and unloading operations, or be removed from the Transport Frame if necessary. Work platforms or other equipment required for access to the cask may be installed or removed at any stage during package loading/unloading, as required to facilitate operations.

The essential elements required to prepare and load the Cask and Liner Tanks are described below.

7.1.1 Preparation of a HI-STAR 330 Cask for Loading

7.1.1.1 <u>General Preparations</u>

1. The empty Cask is moved to a designated loading area using the Transport Frame and/or Transport Vehicle or other suitable device.

2. If installed, the Top Impact Absorber is removed by removing the attachment hardware, attaching rigging, and lifting the Top Impact Absorber from the Cask.

3. Visual examination of the empty Cask's exterior is performed to ensure that there are no indications of impaired physical conditions except for superficial marks and dents. Any road dirt is washed off and any foreign material is removed. If there are any indications of damage beyond superficial marks and dents, loading preparations will be stopped and site management will be notified. Conditions will be evaluated and repaired in accordance with Subsection 8.2.3(ii). Loading preparations will resume only after corrective actions and/or repairs have been completed.

4. If required for loading operations, the cask tie-downs are removed, the empty Cask is lifted from the Transport Frame by its Lifting Trunnions, and it is placed in a designated loading area. Temporary work platforms may be installed around the Cask to allow convenient access.

5. Radiological surveys are performed as directed by the designated radiation protection personnel. If necessary, the cask is decontaminated to meet survey requirements and/or the appropriate notification is served to the affected parties.

6. The Closure Lid Bolts and Washers are removed and the Closure Lid is removed from the Cask using an appropriate lift fixture and rigging.

7. The Lid Inner Seal and Outer Leak Test Gaskets are visually examined. If necessary, the gaskets are replaced per Table 8.2.1.

8. The Closure Lid and Cask Body sealing surfaces are visually examined. If necessary, the sealing surfaces are repaired to eliminate any potential leakage paths and tested per Subsection 8.2.3(v).

9. A Seal Gasket Protective Cover (SGPC) is installed on the Cask, to protect the Lid Inner Seal and Outer Leak Test Gaskets during loading operations. The SGPC may also include features to help guide the loaded Liner Tanks into the Cask. See Figure 7.1.4 for a typical SGPC design.

10. Any foreign material is removed from inside the Cask's containment space. Radiological surveys are performed as directed by the designated radiation protection personnel. If necessary, the cask is decontaminated to meet survey requirements and/or the appropriate notification is served to the affected parties.

11. A site-specific evaluation is used to determine if the maximum loaded weight, specific activity, and total activity of the contents to be loaded in the Waste Package complies with the limits in Tables 7.1.1, 7.1.2 and 7.1.3 (if tertiary containers are used).

Note:
The User shall verify prior to loading the cask that the specific activity of the waste components to be loaded have been pre-calculated (i.e. calculated prior to loading the cask) using a widely-recognized radiation-safety source-term computer code(s) that is accompanied by design control measures for ensuring the quality of computer programs. The "pre-calculation" is required to ensure the package decay heat and the package waste activity comply with the specified maximum values specified in this Chapter. Pre-calculated specific activity values for any single waste item shall ensure that the most activated portion of any single waste item is less than the required specific activity limit.

7.1.2 Liner Tank Loading

Liner Tanks may be loaded with or without an optional LTC, as described in Subsections 7.1.2.1 and 7.1.2.2. These loading operations, and the associated schematic of loading operations provided in Figures 7.1.2 and 7.1.3, include references to typical site-specific ancillary equipment designed to safely load the Liner Tanks while limiting the radiation exposure to personnel as low as reasonably achievable (ALARA).

7.1.2.1 Liner Tank Loading Using an LTC (See Figure 7.1.2)

1. A Liner Tank is staged inside a shielded Dry Box at a designated loading area, with its Top Cover and Bolts removed.

2. The LTC is loaded in the pool in accordance with a site-specific loading plan which includes procedures for cutting, weighing, measuring and marking waste component parts. After loading, the LTC top plate is installed.

ALARA Warning:
High radiation dose fields are to be expected when the loaded LTC is being transferred from the pool to the Dry Box. Temporary shielding, radiation monitoring and other procedural controls shall be utilized by the cask user to limit personnel dose ALARA.

3. The loaded LTC is lifted from the pool to the refueling area floor inside a radiation shielded Wet Hood.

4. The Wet Hood (with the LTC) is lifted over the Dry Box (with the Liner Tank installed), and lowered so that the LTC is seated within the Liner Tank.

ALARA Warning:
High radiation dose fields are to be expected when the Wet Hood is removed from the Dry Box. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA when the loaded Liner Tank is uncovered within the Dry Box.

5. The Wet Hood is disengaged from the LTC and removed.

6. The Dry Box Sealing Cover is installed,

7. The contents of the Dry Box (Liner Tank, LTC, waste contents) are dried using a drying system connected to the Dry Box. Drying is performed at parameters listed in Table 7.1.1 to remove bulk water from the Liner Tank and its contents.

8. The Drying Box Sealing Cover is removed.

9. The Liner Tank Top Cover is placed on the Liner Tank using an appropriate lift fixture and rigging. Additional radiation shielding may be installed on the tank to reduce personnel dose during this and subsequent activities.

10. The Liner Tank Top Cover bolts are installed and torqued to Wrench Tight.

ALARA Warning:
Dose rates near the open cask with a Liner Tank installed may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA. Remote verification or cleaning processes may be required.

11. The loaded Liner Tank is removed from the Dry Box using an appropriate lift fixture and transferred to a designated HI-STAR 330 Cask loading area, or a designated storage area for future shipment.

7.1.2.2 Liner Tank Loading Without the Use of an LTC (See Figure 7.1.3)

1. A Liner Tank (Type DL or MDL) is staged inside a shielded Dry Box at a designated loading area, with its Top Cover and Bolts removed.
2. The Liner Tank is loaded in accordance with a site-specific loading plan which includes procedures for cutting, weighing, measuring and marking waste component parts.
3. The Liner Tank Top Cover is placed on the Liner Tank using an appropriate lift fixture and rigging. Additional radiation shielding may be installed on the tank to reduce personnel dose during this and subsequent activities.
4. The Liner Tank Top Cover bolts are installed and torqued to Wrench Tight.
5. The loaded Liner Tank is removed from the Dry Box using an appropriate lift fixture and transferred to a designated HI-STAR 330 Cask loading area, or a designated storage area for future shipment.

7.1.3 Cask Loading

ALARA Warning:
Dose rates near the unshielded Liner Tank may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA.

1. Prior to installation into the Cask, the Liner Tank is certified to have been loaded in accordance with the procedure described in Section 7.1.2.1 or 7.1.2.2.
2. Verification of the loaded Liner Tank exterior cleanliness is performed. Any foreign material is removed from the outer surface of the Liner Tank.
3. The Liner Tank Top Cover bolts are verified to be installed.

ALARA Warning:
Dose rates above the uncovered cask after installation of the Liner Tank may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA.

4. The loaded Liner Tank is lifted and installed in the Cask using an appropriate lift fixture and rigging. After installation, the lift fixture and rigging are removed.

5. The SGPC is rigged and removed. A lift fixture with a quick disconnect system may be used to control radiation dose ALARA during SGPC removal operations.

7.1.4. Cask Closure

1. The Cask Closure Lid is lifted and installed on the Cask using an appropriate lift fixture and rigging. After installation, the lift fixture and rigging are removed.

2. The Cask Closure Lid Bolts and Washers are installed and torqued. Bolt torque requirements and a recommended tightening sequence are provided in Table 7.1.4 and Figure 7.1.1, respectively.

3. Leak testing of the sealed Cask is performed per Subsection 8.2.2.

4. If necessary, any temporary work platform(s) is removed from the work site.

7.1.5. Preparation for Transport

ALARA Warning:
Dose rates near the unshielded Liner Tank may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA.

1. If the pre-shipment leakage rate test has expired after one year (see Table 8.2.1 for leak test frequency requirements), a periodic leakage rate test of the containment seals must be performed per Subsection 8.2.2.

2. The Top Impact Absorber is lifted and installed on the Cask using an appropriate lift fixture and rigging.

3. The Top Impact Absorber attachment hardware is installed and torqued to Wrench Tight.

4. If necessary, the loaded Cask is lifted from its designated loading area by its Lifting Trunnions and placed on the Transport Frame.

5. If not already fastened, the cask is fastened to the Transport Frame using the cask Lifting Trunnions and tie-down bars. Fastening the cask to the Transport Frame renders the Lifting Trunnions inoperable for lifting the cask.

6. A visual inspection for signs of impaired condition is performed. Any non-satisfactory conditions are remedied.

7. Final radiation surveys of the cask surfaces per 10CFR71.47 and 49CFR173.443 are performed and, if necessary, the HI-STAR 330 Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents.

8. A security seal (tamper device) is attached to the Top Impact Absorber. The presence of the security seal prevents the unauthorized removal of the Top Impact Absorber and, subsequently, the unauthorized removal of the Cask Lid.

9. The loaded Cask is given a final examination according to user procedures to verify that all conditions for transport have been met. Final verification shall include the following:
   a) Final radiation survey(s) are complete and acceptable;
   b) Leakage testing is complete and acceptable, and has been performed within the required time period;
   c) Receiver has been notified of the impending shipment and has appropriate procedures and equipment available for receipt;
   d) Carrier has written instructions for transport and list of appropriate contacts;
   e) Package has appropriate labels and placards, in accordance with 49CFR172.403 and 49CFR172.500.
   f) All required information is included in the shipping documentation.

10. Following the above checks, the Transport Package is released for transport.

TABLE 7.1.1: PACKAGE CONTROL PARAMETERS & THEIR BASES

Item	Requirement	Basis
Maximum weight of the loaded HI-STAR 330 Package, lb	260,000	Estimates based on the materials of construction.
Nominal weight of the empty HI-STAR 330 cask (no waste package), lb	164,000	
Maximum permissible weight of the cask contents (waste package), lb	96,000 (Note 1)	Estimate based on the materials of construction of Liner Tank components and procedural limitations on weight of waste contents.
Waste package drying pressure and time (Note 2)	For material loaded wet from the pool, pressure to be established at or below the approximate vapor pressure of water at the package temperature, and held for a minimum of one hour.	Holding the Liner Tank waste contents at a pressure below the saturation pressure of water at the package temperature ensures rapid evaporation of the residual liquid water.

Notes

1. "Waste package" in this SAR is defined as the Liner Tank, LTC (if used), tertiary container (if used), other dunnage, and radioactive contents according to Tables 7.1.2 and 7.1.3 as applicable. Design basis safety analyses may use upper or lower bound weight values, as appropriate, to ensure conservatism.
2. Bulk water is drained from the LTC waste contents as the LTC is lifted from the pool. An additional drying process is used to remove residual water.

TABLE 7.1.2

CASK AND WASTE PACKAGE CONTROL PARAMETERS (SHEET 1 OF 2)

Waste Package Type	**B**		**C**	
Permissible Secondary Container Type (See Note 1)	T-150 Liner Tank	T-150DL or T-150MDL Liner Tank	T-100 Liner Tank	T-100DL or T-100MDL Liner Tank
Permissible Waste Basket Type	T-150 Liner Tank Cassette (LTC)	No LTC	T-100 Liner Tank Cassette (LTC)	No LTC
Representative Wall Thickness of the Secondary Container	6 inches (150 mm)		4 inches (100 mm)	
Tertiary Container Control Parameters	See Table 7.1.3		Not permitted	
Maximum permissible Co-60 specific activity of any single waste item loaded into Secondary Container	180 GBq/Kg (See Note 2)		23 GBq/Kg	
Maximum permissible specific activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of any single waste item loaded into Secondary Container	18 GBq/Kg (See Note 2)		2.3 GBq/Kg	
Maximum permissible Co-60 activity of fully loaded Secondary Container	2.16E+15 Bq (See Note 3)		2.76E+14 Bq	
Maximum permissible activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of fully loaded Secondary Container	2.16E+14 Bq (See Note 3)		2.76E+13 Bq	

TABLE 7.1.2

CASK AND WASTE PACKAGE CONTROL PARAMETERS (SHEET 2 OF 2)

Waste Package Type	All Waste Package Types
Maximum permissible Co-60 activity of non-fixed surface contamination	2.212E+13 Bq
Maximum permissible quantity of fissile material (including SNM)	2 grams
Minimum cooling time of waste	1.0 years
Maximum permissible heat load	1.75 kW
Maximum Permissible Waste Material Neutron Source per unit mass	20 n/s/kg

Notes:

1. Drawings describing the permissible secondary container types are listed in Section 1.3 of this SAR.
2. The maximum permissible specific activities of any single waste item loaded into the Secondary Container excludes materials loaded into tertiary containers, if used. See Table 7.1.3 for specific activity and total activity limits for waste loaded into Tertiary Containers.
3. See Table 7.1.3 for total maximum permissible activities of waste for packages loaded with Tertiary Containers.
4. Dose rate surveys shall be performed prior to shipment as specified in this Chapter to verify an acceptable loading of the cask in addition to demonstrating compliance with 10CFR71.47.
5. The limits for maximum specific activity of contents for each Waste Package Type in Table 7.1.2 have to be met by the most activated portion of any single waste item.

TABLE 7.1.3

WASTE PACKAGES WITH TERTIARY CONTAINERS - CONTROL PARAMETERS

Waste Package with Tertiary Container	**B-P75**	**B-P125**
Representative Wall Thickness of Tertiary Waste Container	3 inches (75 mm)	5 inches (125 mm)
Maximum permissible Co-60 specific activity of any single waste item loaded into Tertiary Container	3600 GBq/Kg	27000 GBq/Kg
Maximum permissible specific activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of any single waste item loaded into Tertiary Container	360 GBq/Kg	2700 GBq/Kg
Maximum permissible Co-60 activity of fully loaded waste package (Secondary + Tertiary Containers)	3.60E+15 Bq	
Maximum permissible activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of fully loaded waste package (Secondary + Tertiary Containers)	3.60E+14 Bq	

TABLE 7.1.4
WASTE PACKAGE TORQUE REQUIREMENTS

Fastener (See Note 1)	**Recommended Torque** (See Note 3)	**Minimum Total Bolt Preload** (kips)	**Comments** (See Notes 4 and 5)
Closure Lid Bolts	See Note 2 for calculation of final torque value 1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value	7,248	Intermediate pass is final pass for empty but previously used packages
Impact Limiter Strongback Attachment Hardware	"Wrench Tight"	N/A	None

Notes:

1. Fasteners shall be cleaned and inspected for damage or excessive wear (replaced if necessary) and coated with a light layer of lubricant, such as Loctite N-5000, Nuclear Grade Lubricant.
2. The nominal bolt torque, τ, is given by the semi-empirical formula:

   $\tau = (P_B)(K)(d)/N$

   where, P_B = Minimum total bolt preload.

   N = Number of bolts

   d = Nominal bolt diameter

   K = Torque coefficient

   The torque coefficient, K, varies depending on bolt lubricant used (extremely effective lubricants such as Bowman Anti-Seize have a K value = 0.12). The above formula is derived from Shigley, et. al. [7.1.5]. Bolt sizes are provided in the drawing package.
3. Values listed are for the minimum number of passes permitted. Additional intermediate passes are permitted.
4. For empty packages, alternate torque requirements may be used with Holtec approval.
5. 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.

FIGURE 7.1.1: RECOMMENDED BOLT TIGHTENING SEQUENCE

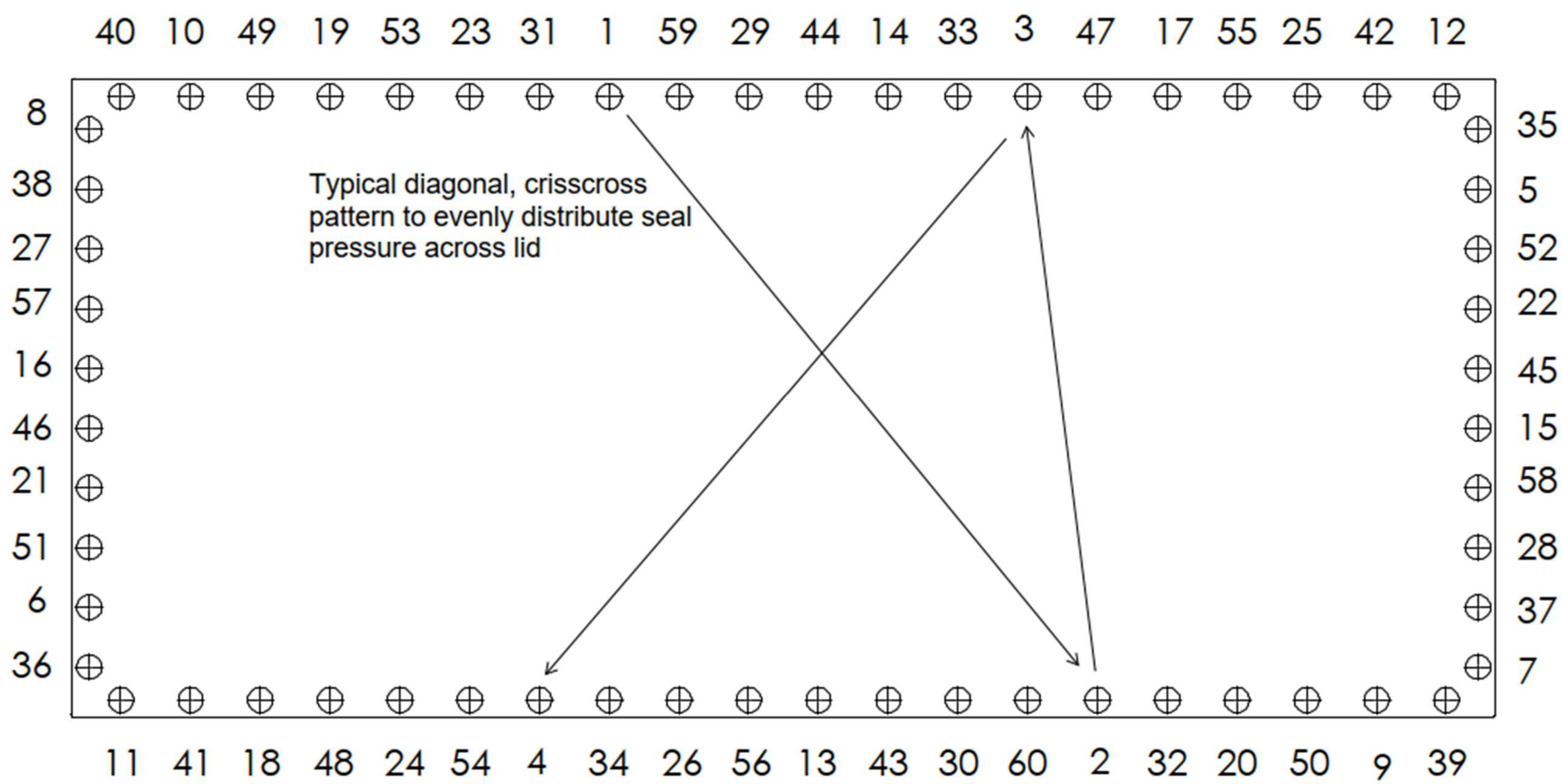
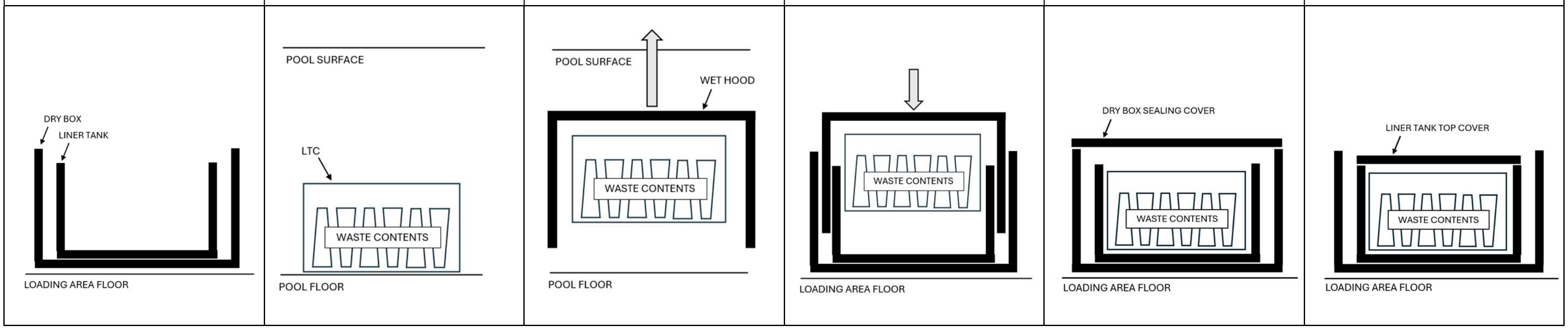


FIGURE 7.1.2: SCHEMATIC OF LINER TANK LOADING SEQUENCE USING AN LTC

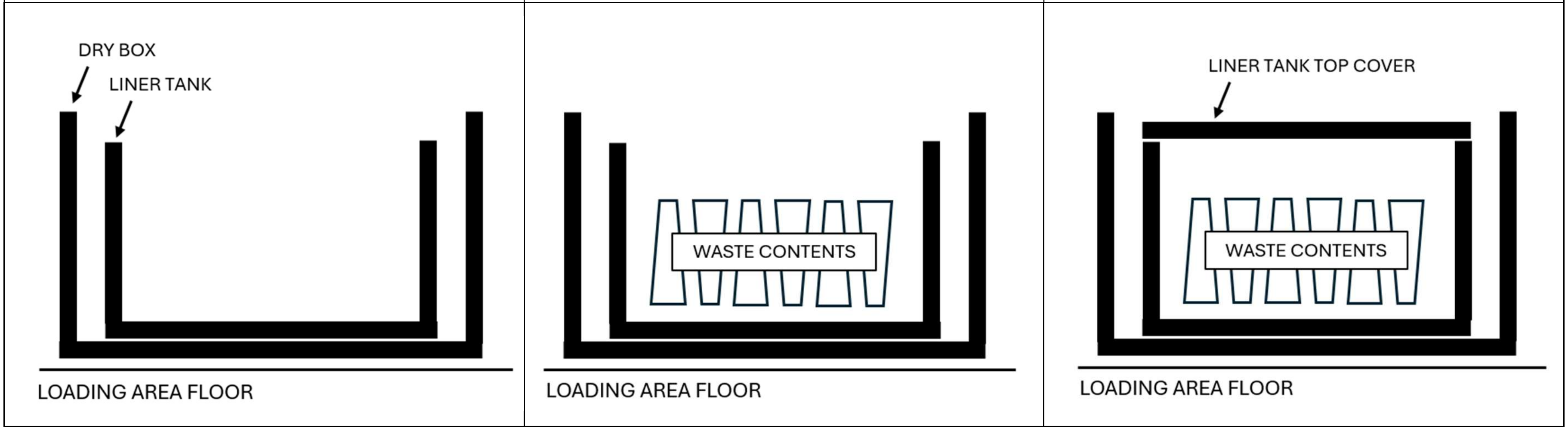
Liner Tank is staged within a shielded Dry Box* with its Top Cover and Bolts removed	LTC is loaded with waste material in the pool	LTC is lifted from the pool using a shielded Wet Hood*	Wet Hood* is lifted over the Dry Box* and the LTC is lowered into the Liner Tank	Wet Hood* is removed and a Dry Box Sealing Cover* is installed for drying	Dry Box Sealing Cover* is removed and the Liner Tank Top Cover is installed



* Dry Box, Wet Hood, and Dry Box Sealing Cover are ancillary devices that include additional shielding to limit dose rates during loading operations ALARA.

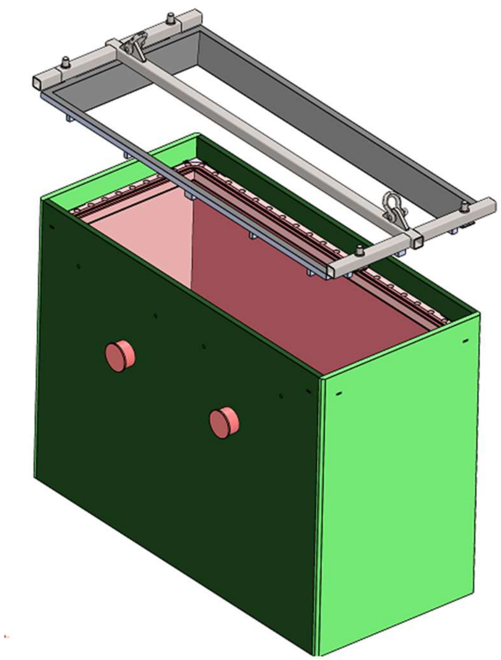
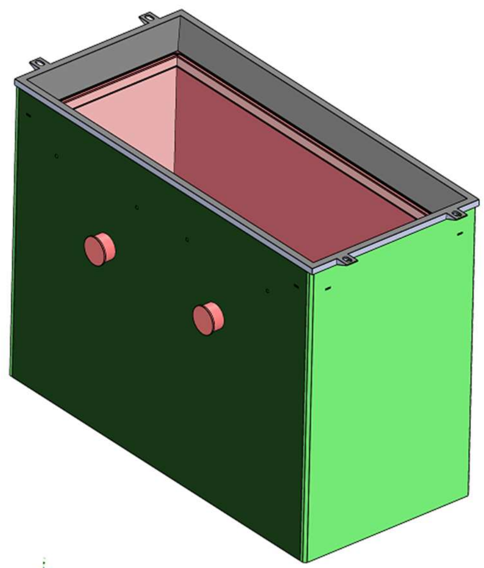
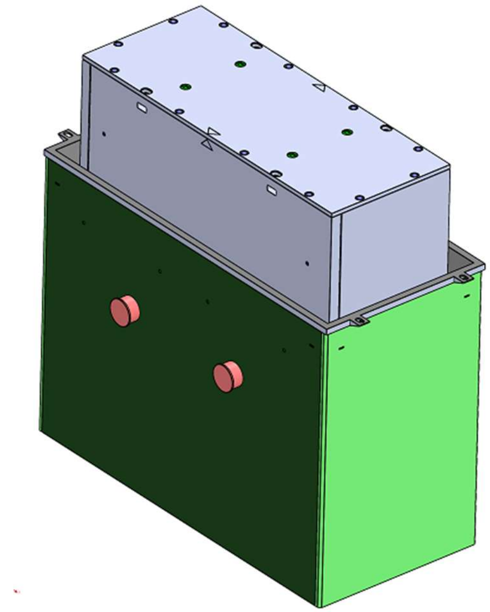
FIGURE 7.1.3: SCHEMATIC OF LINER TANK LOADING SEQUENCE WITHOUT THE USE OF AN LTC

Liner Tank is staged within a shielded Dry Box* with its Top Cover and Bolts removed.	**Liner Tank is loaded with waste material**	**Liner Tank Top Cover is installed**



* Dry Box is an ancillary device that includes additional shielding to limit dose rates during loading operations ALARA. For the loading of dry waste material into the Liner Tank, the function of the Dry Box is solely to provide personnel shielding during operations. Alternate shielding ancillaries may therefore be used in lieu of the Dry Box.

FIGURE 7.1.4: TYPICAL INSTALLATION OF THE SEAL GASKET PROTECTIVE COVER (SGPC)

SGPC lowered into place on Cask using lift fixture	SGPC in place on Cask for installation of Liner Tank	Installation of Liner Tank into Cask
		

7.2. Package Unloading

7.2.1 Receipt of Package from Carrier

1. The HI-STAR 330 Package is received from the carrier and it is verified that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. If there are any indications of damage beyond superficial marks and dents, unloading preparations will be stopped and the conditions will be reported to the Owner's management. Conditions will be evaluated and repaired in accordance with Subsection 8.2.3(ii). Unloading preparations will resume only after corrective actions and/or repairs have been completed.

2. Radiological surveys are performed as directed by the designated radiation protection personnel. If necessary, the HI-STAR 330 Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties.

3. The Cask (and Transport Frame if required) is placed in a designated preparation area.

4. The security seal is verified to be intact, to ensure that the package has not been opened by unauthorized persons. Following verification, the security seal is removed.

7.2.2 Removal of Contents

1. If required, the HI-STAR 330 Cask is unfastened from the Transport Frame.

2. If required, the HI-STAR 330 Cask is lifted from the Transport Frame by its Lifting Trunnions and placed in a designated unloading area. Temporary work platforms may be installed around the cask to allow convenient access.

3. The Top Impact Limiter attachment hardware is removed.

4. The Top Impact Limiter is rigged and removed from the cask.

5. The cask lid lifting device is installed on the Cask Lid.

6. The Closure Lid Bolts and Washers are removed.

ALARA Warning:
Dose rates near the open HI-STAR 330 Cask may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA.

7. The Cask Lid is removed and set in a designated area. Care is taken to prevent damage to the cask lid sealing surfaces and to maintain lid cleanliness.

8. The Liner Tank lifting device is installed and engaged, and the Liner Tank is lifted from the Cask and placed in a designated storage or unloading area.

9. The Cask and Cask Lid are decontaminated as directed by the designated Radiation Protection personnel. Outer surfaces of the Cask are decontaminated to remove surface contamination to the level necessary to allow for proper cask transport, loading, or storage as applicable.

7.3 Preparation of Empty Cask for Transport

7.3.1 Preparation of Empty Cask for Shipment

1. Verification that the cask lid o-ring gaskets and the cask o-ring sealing surface are free of any damage that may compromise the performance of the seal is performed. Any foreign material from inside the cask is removed.
2. The cask lid lifting device is installed and the Cask Lid is lifted and placed on the cask.
3. The Cask Lid lifting device is removed.
4. Closure Lid Bolts and Washers are installed and torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.4.
5. If necessary, the HI-STAR 330 Cask is lifted by its Lifting Trunnions and placed on the Transport Frame.
6. If not already fastened, the cask is fastened to the Transport Frame.
7. The Top Impact Absorber may be placed on the Cask for transport, with the Top Impact Absorber attachment hardware installed and torqued to Wrench Tight.
8. Final verification that the empty cask meets all conditions for transport is performed according to user procedures. Final verification shall include the following:

   a) Final radiation survey(s) are complete and acceptable;

   b) Receiver has been notified of the impending shipment and has appropriate procedures and equipment available for receipt;

   c) Prior shipping labels are removed, and new labels installed;

   d) Placarding is correct;

   e) Package is prepared in accordance with 49CFR173.428;

   f) All required information is included in the shipping documentation.
9. Following the above checks, the empty cask is released for transport.

7.4 Other Operations

There are no other operations for the HI-STAR 330 Package with regard to provisions for any special operational controls (e.g., route, weather, shipping time restrictions, etc.).

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 10, “Energy”, Part 71 "Packaging and Transportation of Radioactive Material".

[7.1.2] *U.S. Code of Federal Regulations,* Title 49, “Transportation”.

[7.1.3] Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR 2023).

[7.1.4] Regulations Concerning the Carriage of Dangerous Goods by Rail (RID), Appendix C to COTIF.

[7.1.5] Shigley J.D. and Mischke C.R., “Mechanical Engineering Design”, 5th Edition, pp 346-347, McGraw Hill (1989)

CHAPTER 8
ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 INTRODUCTION

This chapter identifies the acceptance tests and maintenance program to be conducted on the HI-STAR 330 Package to ensure 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 are in full compliance with the requirements of 10CFR Part 71 Subpart G [1.0.2].

8.1 ACCEPTANCE TESTS

In this section the inspections and acceptance tests to be performed on the HI-STAR 330 Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR 330 Package has been fabricated, assembled and accepted for use and loading under the conditions specified in Chapter 7 of this SAR and the USNRC issued CoC in accordance with the requirements of 10CFR Part 71.

8.1.1 Visual Inspections and Measurements

The HI-STAR 330 Packaging (including waste packaging with an *important-to-safety* shielding function) shall be assembled in accordance with the drawing package referenced in the CoC. Dimensional tolerances that define the limits on the dimensions critical to the licensing basis analysis are included in these drawings. Fabrication drawings provide additional dimensional tolerances necessary to ensure fit-up of parts as well as compliance with the design conditions. A shop *travelle*r including an inspection plan shall be prepared and controls shall be implemented to ensure that the packaging conforms to the dimensions and tolerances specified on the licensing drawings. These dimensions are subject to independent confirmation and documentation in accordance with the Holtec QA program approved in NRC Docket No. 71-0784.

The following shall be included as part of visual inspections and verifications:

- Visual inspections and measurements shall be made to ensure that the packaging effectiveness is not significantly reduced. Any *important-to-safety* component found to be under the minimum thickness requirement shall be repaired or replaced as required.
- Visual verification shall ensure the package is conspicuously and durably marked with the proper markings/labels in accordance with 10CFR71.85(c).
- The packaging shall be verified for cleanliness and preparation for shipping in accordance with written and approved procedures.

The visual inspection and measurement results for the HI-STAR 330 Packaging shall become part of the final quality documentation package.

8.1.2 Structural Testing of Components and Material

For materials required to be procured in accordance with ASTM or ASME specifications as listed in Table 8.1.2, material testing shall be performed and documented in accordance with Holtec's QA program to ensure compliance with the specifications. The critical characteristics of the dose blocker materials and other non-containment transport package component materials are defined in Table 8.1.5. All material test results shall be included in the final quality documentation package.

8.1.2.1 Containment Material

To provide protection against brittle fracture under cold conditions, fracture toughness test criteria for cask containment boundary ferritic components and associated welds are specified in Table 8.1.4. The welded cask containment boundary will be examined and tested by a combination of methods (including leakage rate test, MT, and/or PT, as specified in the licensing drawing and this Chapter) to ensure that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

8.1.2.2 Dose Blocker Material

To provide assurance against through-thickness cracks that could substantially affect the shielding effectiveness of the cask, the brittle fracture testing requirements of ASME Section III, Subsection NF [8.1.1] are invoked for all dose blocker materials and associated welds. Fracture toughness testing and acceptance criteria shall follow the guidance of NF-2300 (materials) and NF-2400 (welds). Brittle fracture testing of the Liner Tanks and LTCs is not required, as substantial reconfiguration of the component plates is not feasible due to their tight clearances within the loaded cask.

8.1.2.3 Impact Absorber Material

The structural strength and stiffness of the crushable aluminum Impact Absorber plates, which serve to absorb a significant portion of the energy from Package impact event, are crucial to maintaining the safety function of the package. Specifically, these components serve to protect the Cask containment boundary from excessive stresses and to maintain the Closure Lid sealing function during NCT and HAC drop events. Table 8.1.5 specifies the required range of strength properties for the aluminum Impact Absorber plates. The material shall be procured in accordance with an ASTM or ASME Section II specification, as indicated in Table 8.1.2. Further details regarding the numerical simulations used to establish the required ranges of critical properties are discussed in Chapter 2.

8.1.2.4 Trunnion Material

Four Lifting Trunnions embedded in the long sides of the Cask are provided for vertical lifting and handling of the Cask during loading and unloading operations. The trunnions are required to be designed in accordance with NUREG-0612 [1.2.3], and tested and inspected in accordance with ANSI N14.6 [1.2.2] at 300% of the maximum design-basis lifting load (Table 7.1.1) in the configuration matching the lifting equipment. The test load shall be applied for a minimum of 10 minutes. Load tests may be performed in excess of the test loads specified above provided an engineering evaluation is performed to ensure trunnions and other cask components will not be damaged by the load test. After the load test, a PT or MT examination shall be performed on all accessible parts of the trunnions in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. The accessible parts of the trunnions (areas visible outside the cask), and the local cask areas shall then be visually examined to ensure that no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between the lifting device and trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require replacement of the trunnion and/or repair of the cask.

Trunnion weld repair, if required, shall comply with the requirements of the ASME Code Section III, Article NF-4450. 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 ensuring trunnion material mechanical properties meet ASME Code Section II requirements provide further assurance of the trunnion load capabilities.

8.1.2.5 Containment Seals (Gaskets)

Cask containment seal materials are specified 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.

8.1.3 Weld Examination

The examination of HI-STAR 330 Package welds shall be performed in accordance with the drawing package referenced in the CoC and applicable codes and standards in Table 8.1.2, including alternatives as specified in Table 8.1.3. Weld examinations and repairs shall be performed as specified below. All inspections of structural code 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 specified in this chapter shall become part of the final quality documentation package.

The following specific weld requirements shall be followed to ensure 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 non-destructive weld examination and acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300 and code exceptions per Table 8.1.3 of this SAR. 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. 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. ITS welds for the cask DBS and Impact Absorber attachment structure 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.

3. Not *important-to-safety* (NITS) welds (e.g. seal welds) on the cask. shall be examined and repaired in accordance with written and approved procedures.

8.1.4 Pressure Testing

Pressure testing of the HI-STAR 330 package is not required. The Maximum Normal Operating Pressure (MNOP) for the HI-STAR 330 package does not exceed the 5 psig threshold in 10 CFR 71.85(b).

8.1.5 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per procedures written and approved in accordance with Chapter 7 of this SAR and the requirements of ANSI N14.5 [8.1.4], specified in this chapter. Table 8.1.1 specifies the leakage test method, allowable leakage rate and test sensitivity for fabrication and pre-shipment leakage rate tests. A pre-shipment leakage rate test of cask containment seals (gaskets) is performed for each loading prior to transport. This pre-shipment leakage rate test is valid for 1 year as long as the seal (gaskets) are not disturbed by removing the Cask closure lid, or as justified by the requirements in SAR Paragraph 8.2.4(v). In case of an unsatisfactory leakage rate, necessary repairs shall be performed and the Cask shall be retested using the same method as the original test until the test acceptance criterion is satisfied.

Leakage rate testing procedures shall be approved by an American Society for Nondestructive Testing (ASNT) Level III Specialist. The ASNT Level III Specialist approving leak testing procedures shall be qualified and certified in the nondestructive method of leak testing for which procedures are written. The written and approved test procedure shall clearly define the test equipment arrangement. Leakage rate testing shall be performed in accordance with a written quality assurance program by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A. Fabrication leakage rate test results shall become part of the final quality documentation package. The pre-shipment leakage rate test shall be documented in accordance with the user's quality assurance program.

8.1.6 Shielding Tests

A shielding effectiveness test shall be performed prior to the first shipment of each HI-STAR 330 package. Testing shall be performed using written and approved procedures. Calibrated radiation detection equipment shall be used to take measurements at the surface of the HI-STAR package. Measurements shall be taken at locations specified by the User's radiation protection program for comparison against calculated values for the specific loaded contents to assess the continued effectiveness of the shielding. If the measured dose rates are higher than the calculated values, then the cask shall not be shipped until the root cause is determined, appropriate corrective actions are completed, and the cask is re-tested with acceptable results.

Measurements shall be documented and become part of the final quality documentation package.

8.1.7 Thermal Tests

Thermal acceptance testing for the HI-STAR 330 is not required. Due to the low design basis heat load package components temperatures are maintained significantly below specified temperature limits.

8.1.8 Miscellaneous Tests

No additional tests are required prior to using the packaging.

TABLE 8.1.1 (SHEET 1 OF 2)
CONTAINMENT SYSTEM LEAK TEST SPECIFICATIONS

Leakage Test	**Components Tested**	**Leakage Test Method** **See Note 1**	**Leakage Rate Acceptance Criterion at Reference Conditions**	**Leak rate sensitivity** **(½ of leakage rate acceptance criterion per ANSI N14.5)**
Fabrication (Factory) Acceptance Test	• Containment Base Plate • Containment Wall Plates • Containment Top Flange • Closure Lid • Containment Boundary Welds	A.5.3	$1x10^{-4}$ atm-cm³/s, Air ($1x10^{-5}$ Pa-m³/s, Air)	$5x10^{-5}$ atm-cm³/s, Air ($5x10^{-6}$ Pa-m³/s, Air)
	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 or A.5.4		
Pre-Shipment Acceptance Test (Note 2)	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 or A.5.4		

TABLE 8.1.1 (SHEET 2 OF 2)
CONTAINMENT SYSTEM LEAK TEST SPECIFICATIONS

Leakage Test	Components Tested	Leakage Test Method See Note 1	Leakage Rate Acceptance Criterion at Reference Conditions	Leak rate sensitivity (½ of leakage rate acceptance criterion per ANSI N14.5)
Maintenance Acceptance Test	• Containment Base Plate • Containment Wall Plates • Containment Top Flange • Closure Lid • Containment Boundary Welds	A.5.3	$1x10^{-4}$ atm-cm^3/s, Air ($1x10^{-5}$ Pa-m^3/s, Air)	$5x10^{-5}$ atm-cm^3/s, Air ($5x10^{-6}$ Pa-m^3/s, Air)
	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 or A.5.4		
Periodic Leakage Acceptance Test	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 or A.5.4		

Notes:

1. Leakage test methods are from Appendix A of ANSI N14.5. For helium as the tracer gas, the Leakage Rate Acceptance Criterion and Test Sensitivity are multiplied by a factor of 1.85.
2. Per ANSI N14.5 (para. 7.6.4), pre-shipment acceptance testing of gaskets may be based on acceptance criteria of "No Leakage Detected" when tested to a sensitivity of $1x10^{-3}$ ref-cm^3/s under the following condition:
   a. Joint gasket has been previously installed and accepted based on testing to a leak rate not more than the reference air leakage rate specified in this Table;
   b. Joint gasket has not been replaced subsequent to acceptance testing;
   c. Joint gasket is reusable (e.g. elastomeric seal).
3. Purpose of Leakage Rate Tests per ANSI N14.5:
   a. Fabrication Leakage Rate Test: To demonstrate that the containment system, as fabricated, will provide the required level of containment.
   b. Pre-shipment Leakage Rate Test: To confirm that the containment system is properly assembled for shipment.
   c. Maintenance Leakage Rate Test: To confirm that any maintenance, repair, or replacement of components has not degraded the containment system.
   d. Periodic Leakage Rate Test: To confirm that the containment capabilities of the packaging built to an approved design have not deteriorated during a period of use.

TABLE 8.1.2

ASME CODE BOILER & PRESSURE VESSEL CODE AND OTHER STANDARDS APPLICABLE TO HI-STAR 330

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Criteria	Welding (Fabrication and Qualification)	Inspection	Testing
Cask Containment System (except closure seals)	ASME Code Section III Subsection NB-2000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-4000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-5000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-6000 and Chapter 8 of this SAR
Lifting Trunnions	ASME Code Section II	NUREG-0612	NUREG-0612	Not Applicable	Chapter 8 of this SAR	Chapter 8 of this SAR
Cask Dose Blocker Structure (DBS)	ASTM or ASME Code Section II	[**Proprietary Information Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V	Chapter 8 of this SAR
Crushable Impact Absorber Plates (Aluminum)	ASTM or ASME Section II	[**Proprietary Information Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	Not Applicable	Chapter 8 of this SAR	Not Applicable

Note 1: See drawing package referenced in the CoC for material requirements.

TABLE 8.1.3 (SHEET 1 OF 2)
ASME CODE REQUIREMENTS AND ALTERNATIVES FOR THE HI-STAR 330 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-2330	Establish T_{NDT} and test base metal, heat affected zone and weld metal at T_{NDT} +60°F.	Rather than testing to establish the RTNDT as defined in paragraph NB-2331, the guidance from Reg. Guide 7.11 [8.1.3] is used for materials less than 4 inches thick and Reg. Guide 7.12 [8.1.5] or NUREG/CR 3826 may be used for materials from greater than 4 up to 12 inches thick. Table 8.1.4 summarizes the specific impact testing requirements for the containment boundary components. The thickness of all containment boundary welds are equivalent to the nominal 2" thickness of the containment boundary base and side wall plates. Therefore, the highest acceptable TNDT for the containment welds is the same as that for the plates, as reflected in Table 8.1.4. Drop weight testing to determine the TNDT for containment boundary welds is therefore not required.

TABLE 8.1.3 (SHEET 2 OF 2)
ASME CODE REQUIREMENTS AND ALTERNATIVES FOR THE HI-STAR 330 PACKAGE

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Containment System	NB-4243	For Category C weld joints, either a butt welded joint or a full penetration corner joint as shown in Figure NB-4243-1 shall be used.	The cask containment welds will use a full-penetration weld joint design with optional permanent backing and no cover fillet. The structural acceptability of this weld joint for all normal and accident conditions has been demonstrated by analysis, and the presence of the backing does not interfere with the progressive liquid penetrant (PT) examination of the weld joint as discussed in this table.
Cask Containment System	NB-5231	Category C full penetration corner welded joints and similar welded joints in other components shall be ultrasonically or radiographically examined and either liquid penetrant or magnetic particle examined.	Progressive liquid penetrant (PT) examination is permitted in lieu of RT or UT examination for containment welds on the HI-STAR 330 cask, which is not a pressure vessel and therefore not subject to appreciable stress that could lead to defect propagation at the welded corner joints during normal operations. This multi-layer surface examination will include the root and final weld layers, and each 3/8" of weld depth (approximately), with the intent of providing a compensatory measure in lieu of RT/UT examination to ensure any weld defects cannot exceed the minimum increment depth. This increment is well-bounded by the 2/3" (one-third of weld thickness) acceptance standard for defect lengths detected by RT or UT examination (NB-5320 and NB-5331, respectively).
Cask Containment System	NB-7000	Vessels are required to have overpressure protection.	The cask is not a pressure vessel. No overpressure protection is provided.
Cask Containment System	NB-8000	States requirements for name, stamping and reports per NCA-8000.	HI-STAR 330 is to be marked and identified in accordance with 10CFR71. Code stamping is not required. QA data package prepared in accordance with Holtec's approved QA program.

TABLE 8.1.4: FRACTURE TOUGHNESS TEST CRITERIA: CONTAINMENT SYSTEM[1]

Item	Material	Material Thickness or Diameter (inches)	Maximum T_{NDT}[2] (°F)	Maximum Drop Weight Test Temperature (°F)	Maximum Charpy V-Notch Test Temperature (°F)	Testing and Acceptance Criteria
Containment Base Plate and Side Walls	SA-203 Grade E	2	LST - 73	T_{NDT}	T_{NDT} + 60	ASME Section III, Subsection NB, Article NB-2330
Containment Flange		3 ¾	LST - 100		T_{NDT} + 60	
Closure Lid		7 ¾	LST - 115		T_{NDT} + 60	
Closure Lid Bolts	SA-564 Type 630 H1100	2 ¼	N/A	Not Required	LST	ASME Section III, Subsection NB, Article NB-2333
Weld Metal for NB Welds	As required	2	LST - 73	Not Required[3]	T_{NDT} + 60	ASME Section III, Subsection NB, Article NB-2330 and Article NB-2430

Notes

1. The cask may be qualified to a Lowest Service Temperature (LST) of -20°F or -40°F.
2. For materials up to 4” thick, T_{NDT} is determined in accordance with the guidance of Reg. Guide 7.11 [8.1.3] for a Category I container and NUREG/CR 1815. For materials greater than 4” thick and up to 12” thick, T_{NDT} is determined in accordance with the guidance of Reg. Guide 7.12 [8.1.5]. In lieu of qualification per Reg. Guide 7.12, qualification per NUREG/CR-3826 may be applied to establish a higher T_{NDT} but with 100% volumetric examination to confirm the absence of flaws which exceed the critical values as defined in NUREG/CR-3826 Table 3. 100% volumetric re-examination is required for cask components qualified per NUREG-CR-3826 following cask operations which result in impactive or impulsive loadings in excess of those defined in the normal conditions of transport.
3. T_{NDT} has been specified in accordance with recognized guidelines consistent with the Code alternative to NB-2330 in Table 8.1.3 of this SAR; therefore, drop weight testing is not required.

TABLE 8.1.5 (SHEET 1 OF 3)
CRITICAL MATERIAL CHARACTERISTICS FOR NON-CONTAINMENT TRANSPORT PACKAGE COMPONENTS

Component	Material	Function	Applicable Critical Characteristics	Requirement[1]	Pre-Evaluated Material(s)[1]
Dose Blocker (Bottom, Side & End Plates)	Carbon Steel	Provides gamma radiation shielding, protection of the internal containment structure, and affects cask heat transfer	Yield strength (ksi)	34.8 min.	SA-516 Grade 70 or A516 Grade 70
			Ultimate strength (ksi)	70.0 min.	
			Thermal conductivity[2] (BTU/ft·hr·°F)	60.1	
			Specific heat[2] (BTU/lbm·°F)	0.11	
Cask Body and Lid Sealing Surfaces (Weld Overlay)	Austenitic Stainless Steel or Non-Ferrous Metal	Increased material strength to prevent inelastic strain in cask sealing region during drop events, and corrosion protection at sealing region.	Yield strength (ksi)	100 min.	AWS ER360
			Ultimate strength (ksi)	Minimum 125% of yield strength	
Lifting Trunnions and Tie-Down Bars	Austenitic Stainless Steel or Non-Ferrous Metal[3]	Means for lifting, handling, or tie-down of the cask	Yield strength (ksi)	38.8 min.	SA-479 S21800
			Ultimate strength (ksi)	90.0 min.	
Impact Absorbers (Corner and Side), Top Flange Corner Inserts, and Closure Lid Spacers	Aluminum[4]	Sacrificial material to protect containment and dose blocker	Yield strength (ksi)	18.0 min. 24.0 max.	ASTM B209 5083
			Ultimate strength (ksi)	42.0 min. 50.0 max.	
			Area reduction (%)[5]	42 min.	

TABLE 8.1.5 (SHEET 2 OF 3)
CRITICAL MATERIAL CHARACTERISTICS FOR NON-CONTAINMENT WASTE PACKAGE COMPONENTS

Component	Material	Function	Applicable Critical Characteristics	Requirement[1]	Pre-Evaluated Material(s)[1]
Top Impact Absorber Insulation Board	Insulation	Thermal protection to limit cask seal temperature during a fire	Thermal conductivity[6] (BTU·in/hr·ft^2·°F)	See Appendix 1.A	Kaowool Millboard 1401
Strongback Assembly and Side & Corner Attachment Assemblies (Top and Bottom)	Carbon Steel	Structural attachment of impact absorbers under normal transport conditions	Yield strength (ksi)	34 min.	SA-516 Grade 70 or A516 Grade 70
			Ultimate strength (ksi)	70 min.	
Strongback And Impact Absorber Attachment Bolts	Stainless Steel	Structural attachment of impact absorbers under normal transport conditions	Yield strength (ksi)	25 min.	SA-193 Grade 8
			Ultimate strength (ksi)	71 min.	
Liner Tank (Top, Bottom and Side Plates) & Liner Tank Cassette (Top and Bottom Plates)	Steel	Shielding during transport and structural support of materials during loading operations	Yield strength (ksi)	34 min.	SA-516 Grade 70 or A516 Grade 70
			Ultimate strength (ksi)	49 min.	
Liner Tank Cassette Corner Tubes	Steel	Maintain shielding configuration of LTC top and bottom plates	Yield strength (ksi)	72.5 min.	A513 Grade 1026 SRA or A519 Grade 1026 SRA
			Ultimate strength (ksi)	97 min.	

TABLE 8.1.5 (SHEET 3 OF 3)
CRITICAL MATERIAL CHARACTERISTICS FOR NON-CONTAINMENT TRANSPORT PACKAGE COMPONENTS

Notes

1. Pre-evaluated materials are those used as the basis for all critical characteristics used in the SAR's licensing basis evaluations. Unless otherwise specified, critical characteristic requirement shall be evaluated at 200°F or greater to bound the maximum normal operating temperature of the cask.
2. Listed thermal conductivity and specific heat capacity are values at 100°F used in the licensing-basis thermal analysis model, based on properties of SA-516 Grade 70 carbon steel. Because of the low internal heat load of the cask contents, the limiting heat transfer requirement is protection of the containment seal temperature during the fire accident. Therefore, for conservatism in bounding the thermal analysis model, alternative materials should have an equal or lesser nominal thermal conductivity and an equal or greater nominal specific heat value compared to SA-516 Grade 70 carbon steel over the entire analysis temperature range. As the thermal properties of carbon steel materials are well correlated with their material composition, confirmation of thermal properties by direct measurement is not required.
3. Material shall be austenitic stainless steel or non-ferrous material, in accordance with ASME Section III, Subsection NF-2311 for materials exempt from impact testing. Yield strength shall be less than 80% of ultimate strength, in accordance with ANSI N14.6.
4. Aluminum crush material properties are evaluated at ambient room temperature. Due to their large surface area at the periphery of the transport package, the temperature of the external impact absorbers is not affected by internal heat generation within the cask. Slight variation in the crush characteristics of the aluminum cask flange corner inserts and closure lid spacers due to elevated temperature does not significantly affect the safety function of the cask, as they are not the primary mechanism for cask deceleration after impact.
5. The minimum percentage area reduction is conservatively estimated based on the physical testing of aluminum material documented in [8.1.6]. Alternative aluminum materials shall be similarly tested to confirm the minimum percentage area reduction requirement is met. A larger percentage area reduction implies higher material ductility and energy absorption capacity, which will dissipate more energy during the impact event. Therefore, the upper bound (or maximum) percentage area reduction for these materials is not limiting for the safety determination.
6. Thermal conductivity values used in the licensing-basis thermal analysis model for the fire accident are based on nominal properties of commercially available Kaowool 1401 Millboard as specified in the manufacturer's datasheet (Appendix 1.A of this SAR). Alternative insulation material may be substituted, but must be qualified by re-analysis using the same licensing basis thermal models and methodology to ensure the containment seal temperature does not exceed allowable limits. Material acceptance shall be based upon the nominal thermal conductivity reported by the supplier, based on testing per ASTM C201 or other ASTM testing method.

8.2 MAINTENANCE PROGRAM

An ongoing maintenance program for the HI-STAR 330 Package will be prepared and issued prior to the delivery and first use of the 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 330 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 330 package is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions. The cask interior and exterior surfaces are coated for preservation, including corrosion resistance. As a result, only minimal maintenance will be required over its lifetime, primarily resulting from surface wear and weathering effects, and pre- and post-usage inspection requirements for transportation. Typical of such maintenance would be cask touch-up painting, seal replacement, and leak testing following seal replacement. Such maintenance activities are considered no more demanding than those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR 330 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 described in Subsection 8.1.3 of this SAR are required to ensure continuing performance.

8.2.2 Leakage Tests

Pre-shipment, periodic, and maintenance leakage rate tests on the cask containment system shall be performed per procedures written and approved in accordance with Chapter 7 of this SAR and the requirements of ANSI N14.5 [8.1.4] specified in this chapter. Table 8.1.1 specifies the leakage test method, allowable leakage rate and test sensitivity for periodic and maintenance leakage rate tests. Table 8.2.1 summarizes the schedule requirements for leak testing.

If the pre-shipment leakage rate test has expire prior to cask shipment (test is valid for one year), a periodic leakage rate test of the containment seals must be performed prior to transport.

Maintenance leakage rate testing shall be performed prior to returning a package to service following maintenance, repair (such as a weld repair, seal surface polishing etc.), or replacement of containment system components (such as containment seal gasket replacement). 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 an unsatisfactory leakage rate, necessary repairs shall be performed and the Cask shall be retested using the same method as the original test until the test acceptance criterion is satisfied.

Leakage rate testing procedures shall be approved by an American Society for Nondestructive Testing (ASNT) Level III Specialist. The ASNT Level III Specialist approving leak testing procedures shall be qualified and certified in the nondestructive method of leak testing for which procedures are written. The written and approved test procedure shall clearly define the test equipment arrangement. Leakage rate testing shall be performed in accordance with a written quality assurance program by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A [8.1.2]. The pre-shipment, periodic, and maintenance leakage rate test results shall be documented and maintained as required by the user's quality assurance program.

8.2.3 Component and Material Tests

(i) Shielding Materials

Radiation shielding in the HI-STAR 330 cask is provided entirely by the combined thickness of the steel plates that comprise the containment boundary, DBS, secondary container (Liner Tank, LTC), and tertiary containers (if used). As there is no physical mechanism for deterioration of the steel's shielding effectiveness over time other than gross damage, rearrangement, or loss of the material, visual inspection of the cask prior to each waste loading (as described in Section 8.2.3(ii)) is sufficient to ensure that the cask's shielding effectiveness is maintained. No periodic testing of the cask's shielding integrity is required.

(ii) Packaging Surfaces

Accessible surfaces of the Cask (internal and external) and Liner Tanks (external) shall be visually inspected prior to each waste loading to ensure that the packaging effectiveness is not significantly reduced. Inspections shall identify any surface coating and component damage, including conditions such as surface denting, surface penetrations, weld cracking, and chipped or missing coating. Where necessary, 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. Following repair or replacement of material that appreciably affects the cask's shielding integrity, a shielding test in accordance with Section 8.1.6 of this Chapter shall be re-performed.

Prior to installation or replacement of a closure seal, it shall be verified that the cask sealing surface is cleaned and surfaces affected by scratches, pitting or roughness shall be polished smooth or repaired as necessary in accordance with written and approved procedures.

(iii) Packaging Fasteners

Cask Closure Lid Bolts shall be examined in accordance with ASME Section III, Subsection NF-2582. Fasteners without sufficient usable thread length meeting the requirements of NF-2582 shall be replaced. Damaged internal threads may be repaired per standard industry practice (e.g. threaded inserts). Any repair shall be evaluated to ensure ASME Code stress limits applicable to bolted joints are met. Any required material or manufacturing process testing would also be performed in accordance with the original applicable code. Cask Closure Lid Bolts shall be replaced as guided by fatigue analysis per the provisions of ASME Code Section III. The maintenance program in Table 8.2.1 provides a bolt change out schedule to ensure that the cumulative damage factor accumulated by a bolt shall be less than 1.0 with sufficient margin. One bolting cycle is the complete sequence of torquing and removal of bolts.

The internal threads of the Containment Top Flange have a maximum service life limit based on bolting cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. The bolting cycles specified in Table 8.2.1 shall not be exceeded. One bolting cycle is the complete sequence of torquing and removal of bolts.

Cask Impact Absorber Bolts and Liner Tank Bolts shall require visual verification for indications of damaged or loose fasteners. Visual verification shall confirm wear on the threaded surfaces of loose fasteners prior to reinstallation or replacement. Liner Tank bolts shall be examined to ensure the requirements in the licensing drawing are met. Fasteners not meeting the requirements shall be replaced.

Bolting of the cask Impact Absorbers and Liner Tank Top Covers are foreseen to be one-time events. Unless replacement is necessary, impact absorbers will remain attached to the cask (bottom impact absorbers) or the strongback assembly (top impact absorbers) during loading, unloading and transport operations. Similarly, frequent installation and removal of Liner Tank Top Covers, following loading and closure of the Liner Tank, is not anticipated. Fatigue analysis for these bolts and internal threads is therefore not required.

(iv) <u>Cask Lifting Trunnions</u>

Cask Lifting Trunnions shall be inspected prior to each cask lifting. The accessible parts of the trunnions (areas outside the cask), and the local cask areas shall be visually examined to ensure no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between the lifting device and the trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require repair or replacement of the trunnion and/or repair of the cask.

Following any replacements and/or repair, load testing shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria.

(v) <u>Closure Seals</u>

The HI-STAR 330 Packaging is equipped with elastomeric seals on the Cask flange to ensure leakage meets the criteria in Table 8.1.1. The closure seals are shipped from the factory pre-inspected and carefully packaged. Seals are considered to be reusable until pre-shipment leakage testing indicates that they can no longer meet the leakage criteria or they fail a visual inspection.

Removal of the Cask Closure Lid requires visual verification that the seals remain free of debris, do not exhibit damage (i.e. no tears or gouges), and do not exhibit excessive compression set (i.e. no evidence of closure seal compression set, such as flattening of the visible seal surface). If seals are deemed acceptable, they may be reused. Closure seals are specified for long-term use and do not require additional maintenance.

(vi) Thermal Tests

Periodic thermal performance testing for the HI-STAR 330 is not required. Due to the low design basis heat load package components temperatures are maintained significantly below specified temperature limits. Furthermore, there are no special purpose materials of construction that could be affected in the long-term and therefore no credible mechanism for significant loss of heat rejection capacity in the HI-STAR 330 cask.

(vii) Miscellaneous Tests

No additional tests are required for the HI-STAR 330 Packaging, packaging components, or packaging materials.

Table 8.2.1: Maintenance Program Schedule

Task	SAR Reference Section	Schedule
Cask surface visual verification	Paragraph 8.2.3(ii)	Prior to each Non-Fuel Waste (NFW) loading.
Liner Tank accessible exterior surfaces visual verification	Paragraph 8.2.3(ii)	Prior to emplacement into the cask.
Packaging fasteners visual verification	Paragraph 8.2.3(iii)	Prior to each loading and emplacement of Liner Tank into cask.
Cask lifting trunnion visual inspection	Paragraph 8.2.3(iv)	Prior to each NFW loading.
Pre-shipment leakage test of containment system seal	Subsection 8.2.2	Following each NFW loading.
Periodic leakage rate test of containment system seals	Subsection 8.2.2	Prior to off-site package transport if period from last test exceeds 1 year.
Maintenance leakage rate test of containment system seals	Subsection 8.2.2	Prior to returning package to service following maintenance, repair or replacement of containment boundary components.
Seal replacement for closure lid	Paragraph 8.2.3(v)	Following removal of the Cask Closure Lid if the seal is not considered reusable (damaged, not free of debris, exhibits excessive compression set) or if seal fails to meet the leakage criteria for pre-shipment, periodic or maintenance during testing. Seals which have been in use for over one year shall be replaced.
Closure lid bolt replacement	Paragraph 8.2.3(iii)	Replace every 250 bolting cycles.
Containment top flange service life	Paragraph 8.2.3(iii)	10,000 bolting cycles.

Chapter 8 References

The following generic industry references have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table.

[8.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI (2013)

[8.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, December 2006.

[8.1.3] 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.

[8.1.4] 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.

[8.1.5] 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 (0.1m) But Not Exceeding 12 Inches (0.3m)”, U.S. Nuclear Regulatory Commission, Washington, D.C., June 1991.

[8.1.6] HI-2210251, Revision 0, “Benchmarking of Material Stress-Strain Curves in LS-DYNA”.