NONPROPRIETARY VERSION

SAFETY ANALYSIS REPORT

on

THE HI-STAR ATB 1T Non-Fuel Waste Transport System

By

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3	Ch. 1, 2, 7, 8 Thermal	XH	9/23/15	286711	XH	2/6/17	146414	AM	6/7/19	955614
4	Ch. 1, 7, 8 Containment	PS	9/23/15	170393	N/A	N/A	N/A	PS	6/7/19	851026
5	Ch. 1, 7, 8 Shielding	RT	9/23/15	629065	RT	2/6/17	149430	RT	6/7/19	924557
6	Ch. 1, 7 Criticality	TH	9/23/15	795737	TH	2/6/17	13232	N/A	N/A	N/A
7	Ch. 1, 8 Operations	RM	9/23/15	714695	RM	2/6/17	960710	RM	6/7/19	464428
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14	Chapter 6	TH	9/23/15	89901	TH	2/6/17	476295	N/A	N/A	N/A
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3	Chapter 3	RM	5/4/21		RM	2/18/22		RM	TBD	
4	Chapter 4	EB	5/4/21		N/A	N/A		N/A	N/A	
5	Chapter 5	RST	5/4/21		N/A	N/A		N/A	N/A	
6	Chapter 6	N/A	N/A		N/A	N/A		N/A	N/A	
7	Chapter 7	RM	5/4/21		N/A	N/A		N/A	N/A	
8	Chapter 8	CO	5/4/21		CB	2/18/22		VRP	TBD	
9	Ch. 1, 7, 8 Structural	VRP	5/4/21		VRP	2/18/22		TBD	TBD	
10	Ch. 1, 2, 7, 8 Thermal	RM	5/4/21		RM	2/18/22		TBD	TBD	
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12	Ch. 1, 7, 8 Shielding	RST	5/4/21		N/A	N/A		N/A	N/A	
13	Ch. 1, 7 Criticality	N/A	N/A		N/A	N/A		N/A	N/A	
14	Ch. 1, 8 Operations	RM	5/4/21		RM	2/18/22		TBD	TBD	
15	Ch. 1, 2, 7, 8 Materials	RM	5/4/21		RM	2/18/22		TBD	TBD	
16	Ch. 1, 2, 7, 8 Fabrication	RM	5/4/21		RM	2/18/22		TBD	TBD	

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DOCUMENT CATEGORIZATION

In accordance with the Holtec Quality Assurance Manual and associated Holtec Quality Procedures (HQPs), this document is categorized as a:

- ☐ Calculation Package[3] (Per HQP 3.2)
- ☒ Technical Report (Per HQP 3.2)(Such as a Licensing Report)
- ☐ Design Criterion Document (Per HQP 3.4)
- ☐ Design Specification (Per HQP 3.4)
- ☐ Other (Specify):

DOCUMENT FORMATTING

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

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

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

SAR REVISION STATUS, LIST OF AFFECTED SECTIONS AND REVISION SUMMARY

SAR Title: Safety Analysis Report on HI-STAR ATB 1T Package	
SAR Report No.: HI-2146312	**SAR Revision Number: 5**

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.

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

Each section and appendix in a chapter begins on a fresh page. Unless indicated as a "complete revision" in the summary description of change below, if any change in the content of a chapter is made, the change is indicated by a "bar" in the right page margin and the revision number (annotated in the footer) of the entire chapter is changed. Those chapters that remain unchanged by a SAR revision will indicate the revision level corresponding to the initial revision or the last revision in which changes were made and thus will not match the revision of the whole SAR.

REVISION 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".

<table>
<tr><th colspan="2">Chapter 1: General Information
(includes Glossary and Notation)</th><th>Revision Number.: 5</th></tr>
<tr><th>Section or App.</th><th colspan="2">Summary Description of Change</th></tr>
<tr><td>1.3</td><td colspan="2">Updated with latest revision of HI-STAR ATB 1T Cask licensing drawing.</td></tr>
<tr><th colspan="2">Chapter 2: Structural Evaluation</th><th>Revision Number: 5</th></tr>
<tr><th>Section or App.</th><th colspan="2">Summary Description of Change</th></tr>
<tr><td>2.1</td><td colspan="2">Revised to discuss material properties and design allowables for SA-508 Grade 4N Class 2 material.
• Table 2.1.3B added
• Table 2.1.4B added
Additional editorial changes.</td></tr>
<tr><td>2.2</td><td colspan="2">Revised to discuss SA-508 Grade 4N Class 2 material as an alternate material for the cask containment boundary.
• Table 2.2.1B added</td></tr>
<tr><td>2.3</td><td colspan="2">Revised to discuss SA-508 Grade 4N Class 2 material as an alternate material for the cask containment boundary.</td></tr>
<tr><td>2.5</td><td colspan="2">Editorial changes.</td></tr>
<tr><td>2.6</td><td colspan="2">Revised to discuss that drop simulations using existing SA-517/A514 material are bounding of SA-508 Grade 4N Class 2 material.
Editorial changes.</td></tr>
<tr><td>2.7</td><td colspan="2">Revised to discuss sensitivity simulations conducted for SA-508 4N material.</td></tr>
<tr><td>References</td><td colspan="2">[2.2.2], [2.2.3], & [2.2.4] previously added for HSLA-100 material removed
Revision numbers for [2.6.3] & [2.6.4] updated.</td></tr>
<tr><th colspan="2">Chapter 3: Thermal Evaluation</th><th>Revision Number: 5</th></tr>
<tr><th>Section or App.</th><th colspan="2">Summary Description of Change</th></tr>
<tr><td>3.2</td><td colspan="2">HSLA-100 material properties & discussion previously added to Tables 3.2.1, 3.2.2, & 3.2.3 removed.
Tables 3.2.2 & 3.2.3 revised to include SA-508 Grade 4N material.
Table 3.2.5 revised to no longer specify the emissivity for polished stainless steel.</td></tr>
<tr><td>References</td><td colspan="2">[3.2.9] previously added for HSLA-100 material removed.</td></tr>
</table>

Chapter 4: Containment		**Revision Number.: 3**
Section or App.	**Summary Description of Change**	
	No changes.	
Chapter 5: Shielding Evaluation		**Revision Number: 3**
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Chapter 6: Criticality Evaluation		**Revision Number.: 1**
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Chapter 7: Package Operations		**Revision Number: 3**
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	No changes.	
Chapter 8: Acceptance Tests and Maintenance Program		**Revision Number: 5**
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8.1	Note 2 previously added to Table 8.1.2 to discuss procurement of HSLA-100 material removed. Discussion previously added to Table 8.1.3 for procurement of HSLA-100 material removed. Material options previously added to Table 8.1.4 for HSLA-100 material removed and replaced with SA-508 Grade 4N Class 2 material.	
References	Revision number for [8.1.8] updated.	

End of Change Descriptions

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GLOSSARY AND NOTATION

GLOSSARY

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

BFA-Tank Cassettes (BTCs) are painted carbon steel rectangular structures consisting of a baseplate, tie rods at each corner and the lid. BFA-Cassettes serve as a mechanism for transferring the segmented reactor internals from the reactor internals pool to the BFA-Tanks situated in the HI-STAR ATB 1T cask. BFA-Cassettes contain segmented reactor internals radioactive materials during routine and normal conditions of transportation.

BFA-Tank Strongback is the lifting and handling device that is attached to outer (top) surface of the BFA-Tank lid. Other plant lifting and handling devices interface with the BFA-Tank Strongback.

BFA-Tanks are painted carbon steel rectangular tanks defined by a rectangular shell, baseplate and lid with associated welds and bolts. BFA-Tanks contain BFA-Tank Cassettes loaded with segmented reactors internals radioactive materials during routine and normal conditions of transportation. The loaded BFA-Tank is an example of a Waste package.

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

BTC is an acronym for BFA-Tank Cassette.

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 gasketed flat cover that connects to the top flange of the cask.

Closure Lid Locking System or CLLS consist of locking mechanisms attached to the closure lid that engage the Top Flange to secure the closure lid to the cask for transport, or disengages from the Top Flange to remove the closure lid for loading/unloading purposes. Major components of the CLLS include the closure lid locking wedges and lock bars, and as necessary the hydraulic, pneumatic or other actuating system. The CLLS is remotely actuated for ALARA purposes.

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. Top flange features are machined into the cask inner walls to engage the closure lid and gasket.

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 ATB 1T 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 ATB 1T package.

Docking Protective Cover is placed on the BFA-Tank to prevent water from contaminating the outside of the BFA-Tank during docking operations with the Wet Hood to the Transport Cask.

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 ATB 1T Cask or cask means the cask that receives and contains the segmented reactor internals 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 ATB 1T Package consists of the HI-STAR ATB 1T cask, BFA-Tank and BFA-Cassette, and the licensed radioactive contents loaded for transport.

HI-STAR ATB 1T Packaging consists of the HI-STAR ATB Package without the licensed radioactive contents loaded.

HLW is an acronym for High Level Waste.

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.

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.

Radiation Shielded Strongback is a steel device that serves the dual purpose of placing the vacuum drying cover on the BFA-Tank and providing radiation shielding at the top of the cask and BFA-Tank during the vacuum drying process. The radiation shielded strongback is connected to the vacuum drying cover via the use of twist lift clubs on the radiation shielded strongback.

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.

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 in Table 7.1.2 applies 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.

Terminal Vehicle is an alternative name for the transport vehicle for the HI-STAR ATB 1T Package.

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 locking components), and effects sealing of the Containment Boundary through one or more gaskets.

Transport Frame is a structure that is fitted to the 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, welding machines, and auxiliary equipment (such as the drying system) used during radioactive wastes loading operations and preparation for off-site transportation.

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

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

Vacuum Drying Cover is a device that is placed on top of the BFA-Tank via the Radiation Shielded Strongback to support vacuum drying operations. The plant's vacuum dying system is connected to the vacuum drying cover to vacuum dry the BFA-Tank and its contents.

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 BFA-Tank loaded with the BFA-Tank Cassette (BTC) containing radioactive materials. The loaded BFA-Tank is radiologically clean on its outside, is designed to be compatible with its host cask and is structurally capable of storing the non-fuel waste.

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 BFA-Tank Cassette (BTC) to and from the BFA-Tank.

WPC is an acronym for the Weather Protection Cover.

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 ATB 1T 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 ATB 1T 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 ATB 1T 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.

[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 ATB 1T PACKAGE

The HI-STAR ATB 1T System consists of the cask and the waste package (Types A, B, C, and D) as specified in Table 1.2.1 and Table 7.1.2.

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The BFA-Tank is engineered to fit the containment space of the cask with appropriate clearance to support operational activities. The BFA-Tank is a metallic structure with metal walls intended to provide shielding protection as well as the necessary structural strength for handling purposes. Four different BFA-Tanks (associated with Waste Package Types A through D) are evaluated in this SAR, with their side wall thicknesses being their principal defining characteristic. The external dimensions of all BFA-Tanks are identical to allow the use of a single cask design.

The BFA-Tank is loaded with activated material which is fetched from a storage pool in a nuclear power plant by the BTC. The BTC is loaded with non-fuel wastes meeting the specifications in Subsection 1.2.2 and loaded into the BFA-Tank. The BTC is designed to fit the internal cavity of the BFA-Tank with appropriate clearance to support operational activities. The BFA-Tank may be loaded into the HI-STAR ATB 1T Cask prior to receiving the loaded BTC or a loaded BFA-Tank may be placed directly into the cask. Appropriate steps are taken during the loading process to ensure surfaces of the cask and external surfaces of the BFA-Tank are not contaminated, or are appropriately decontaminated.

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

The HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T Package with the requirements of Subparts E and F of 10CFR71 are provided in this SAR[1].

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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. The outer elastomeric cask closure lid gasket provides a redundant, reliable 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 ATB 1T 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 ATB 1T with design basis contents (Section 5.0 provides the determination of the TI). However, the maximum temperature of accessible surfaces in still air at 38ºC (100ºF) without insolation is in excess of 50ºC (122ºF), and less than 85ºC (185ºF); therefore, pursuant to 10CFR 71.43(g), the HI-STAR ATB 1T packaging must be transported by exclusive use shipment. An empty but previously loaded HI-STAR ATB 1T 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 ATB 1T Packaging is designed to ensure safe transport of NFW.

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In summary, HI-STAR ATB 1T:

- Minimizes dose and achieves ALARA objectives,
- Provides for a structurally robust system,
- Facilitates efficient heat dissipation

[1] The HI-STAR ATB 1T package is also designed to comply with SSR-6 (2012) [1.1.1] Type B(U) package requirements. Certain acceptable criteria, methodology etc. may be stated or specified to address both 10CFR71 and SSR-6 requirements.

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This SAR supports a licensed life of the HI-STAR ATB 1T 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 ATB 1T'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 ATB 1T Package will meet its Design Life of 40 years. The technical considerations that assure the HI-STAR ATB 1T 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 ATB 1T

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	168
	Width	94
	Height	115
Maximum gross weight of the loaded HI-STAR ATB 1T package	Table 7.1.1	
Nominal weight of the empty HI-STAR ATB 1T 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 ATB 1T Packaging consists of three major components (Cask, secondary container and waste basket) as discussed in (a) through (c) below. Additionally, auxiliary equipment, in the form of packaging supports, restraints and weather protection cover typically necessary for package transport, is described in subparagraph (d) below.

a. Cask

As illustrated in the licensing drawing package, HI-STAR ATB 1T is of a rectangular parallelepiped configuration with an inset heavy lid which provides sole access to its contents. The top flange, defined in this SAR as the machined region of the containment walls that interfaces with the closure lid (sealing surface and the lid locking components), is equipped with the facility to secure the closure lid **[**

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The interfacing surfaces of the lid and the flange at the top of the cask body 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.

With the exception of the elastomeric closure lid inner gasket and nickel alloy locking wedges, the Containment Boundary of HI-STAR ATB 1T consists of alloy steel components that include a baseplate, containment walls, closure lid containment plate and associated containment boundary welds. The alloy steel baseplate is welded to alloy steel containment walls of the same material. The baseplate and side walls weldment of the Containment Boundary, along with the closure lid, are buttressed by a thick stainless steel enveloping plate structure which is termed the "Dose Blocker Structure" or DBS, depicted in the drawing package in Section 1.3. 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 weldment of the containment boundary and its surrounding DBS structure are joined by welding along the periphery of the cask where the containment boundary and DBS plates meet near the upper edge of the cask. Similar welds are employed to attach the closure lid dose blocker and containment plates. The Licensing drawing package shows the welds of the Containment Boundary and DBS.

The governing Code for the design of the Containment Boundary of HI-STAR ATB 1T is ASME Code Subsection NB [1.2.1] which has well-articulated rules for plate & shell type structures operating under ambient conditions.

The HI-STAR ATB 1T package has internal and external impact absorbers. The internal impact absorbers are designated the lid spacer, impact absorber spacers and internal side shim assemblies. The aluminum lid spacer may be used as needed to reduce the BFA-Tank top to cask lid gap to minimize impact from postulated drops. The aluminum impact absorber spacers are inserted in the bottom of the cask lid, and minimize the gap between the top of the BFA-Tank and the cask, thus mitigating the secondary impact effects from postulated drop events. Likewise, austenitic stainless steel adjustable inserts are recessed in the side walls of the HI-STAR ATB 1T cask for the same reason.

The external impact absorbers (crushable attachments), which serve the same impact forces reduction function as impact limiters for fuel bearing transport casks, are located on the top, bottom, side, end and corner exterior surfaces of the cask as depicted in the drawing package in Section 1.3. The impact absorbers are made of either aluminum, austenitic stainless steel or an optimized combination of aluminum and austenitic stainless steel. Austenitic stainless steel and aluminum are used for impact energy absorption and to mitigate impact forces during the critical free drop events pursuant to 10 CFR 71.73. These materials also provide excellent fracture strength under cold service conditions.

As can be deduced from the geometry of the HI-STAR ATB 1T cask, the free drop event in 10CFR71.73 which requires postulating an uncontrolled lowering of the package from 9 meters on to an essentially unyielding surface in the orientation expected to result in the maximum damage is the most limiting accident condition for the cask's mechanical design. **[**

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The above crack-arrest characteristic in HI-STAR ATB 1T is similar to that in previously licensed HI-STAR Systems (e.g. HI-STAR 100, HI-STAR 180, HI-STAR 60). DBS parts are made from austenitic stainless steel for maximum ductility and excellent fracture strength under cold service conditions.

Externally, the HI-STAR package presents a rectangular profile with lifting trunnions located on the side walls designed to lift the package with structural safety margins required under NUREG-0612 [1.2.3]. Loading guides (not *important-to-safety*) may be attached to side walls of the cask. Additional lifting attachments, only used for lifting of the closure lid, are welded to the Closure Lid containment plate. These lifting attachments, loading guides and impact absorbers are at various locations on exterior surfaces and corners of the cask. **[**

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The lid lifting attachments and 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. Thus there are no locations on the cask's surface that are vulnerable to a penetrative loading during a drop event. As an alternative to the loading guides, a centering frame (not *important-to-safety*) may be placed on top of the open cask as a guide for loading the BFA-Tank into the cask, thus precluding penetrative forces of the loading guide during a drop event. The centering frame is removed prior to transport. Finally, the mechanical design of the Confinement Boundary is guided by the ASME Code, Subsection NB 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 ASTM austenitic stainless 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 ATB 1T 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.

It should be noted that an insulation board is used in **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** as shown in the drawing package in Section 1.3 and with specifications in the licensing drawing and Appendix 1.A of this chapter, to ensure 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 bounding temperatures for normal and accident conditions of transport.

b. Secondary Containers

The BFA-Tank is defined as the rectangular vessel that conforms to the internal dimensions of the cask as illustrated in the licensing drawings and provides an environmentally sequestered enclosure for NFW.

The BFA-Tank is designed to hold radioactive wastes during transportation. Four waste packages (Types A, B, C, and D) are analyzed for the HI-STAR ATB 1T 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 BFA-Tanks are of similar construction and geometry. The distinguishing feature of each type of BFA-Tank is the thickness of its walls. Each type of BFA-Tank is designed to accommodate the dimensions of a specific type of BTC along with its radioactive contents.

The steel construction of the BFA-Tanks provides shielding of gamma radiation. Principal shielding is provided by BFA-Tanks walls, with greater wall thicknesses coinciding with better shielding for contents with higher specific activities. Additional shielding provided by the top cover and bottom plate of the BFA-Tanks contribute to the all-around shielding performance of the tanks.

The BFA-Tanks are rectangular steel weldments with a steel lid. The walls, lid and bottom of the BFA-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 BFA-Tanks structurally rugged under the routine and normal conditions of transportation in 10 CFR 71.71, including short-term loading/unloading conditions.

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

The lids of the BFA-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.*

The interior and exterior surfaces of the BFA-Tanks (steel weldment and lid) are coated for surface preservation purposes. Coating materials are chosen based on expected service conditions. The coatings are appropriate for exposure to the pool water and radiation as well as environmental exposure. Lubricants are used on the BFA-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 BFA-Tanks are described in Chapter 2.

The BFA-Tank’s exterior dimensions and the cask’s cavity interior dimensions are toleranced such that the potential for significant movement of the BFA-Tank is eliminated. The clearance between the BFA-Tanks walls and the interfacing machined surface of the cask cavity is controlled to be sufficiently small such that the thermal expansion of BFA-Tanks under Design Basis heat load conditions will minimize any gaps at the interface and thus minimize resistance to the outward flow of heat, yet ensure that there is no restraint against free thermal expansion. The cavity space between the top of the BFA-Tanks and the bottom of the closure lid is sufficiently large to allow for thermal expansion, and as noted in Section 1.2.1.7 is fitted with a spacer to reduce the travel distance for the BFA-Tank during an accident to within analyzed limits. The design of the BFA-

Tanks are similar, varying mainly due to handling requirements at the loading facilities. A pictorial view of a typical BFA-Tank is provided in Figure 1.2.1.

c. Waste Baskets

The BTCs are designed to accommodate loading and transfer of radioactive waste from the storage pool to the BFA-Tank in the HI-STAR ATB 1T Cask for transportation. There are four types of BTCs that are currently available for the HI-STAR ATB 1T Package. BTCs are basically of the same design, consisting of a base plate and a lid, separated by tie rods in the corners. BTCs are illustrated in the drawing package in Section 1.3. Each type of BTC is designed to accommodate contents of a given mass and activity and by design assigned to a specific type of BFA-Tank.

The BTCs are rectangular and made of steel. The lids and base plates together with the tie rods of the BTCs are orthogonal with each other and 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 BTCs appropriately rugged under the routine and normal conditions of transportation in 10 CFR 71.71, including short-term loading/unloading conditions.

Of the steel construction of the BTCs, only the lid and base plate are credited in shielding of the gamma radiation.

The welded and metallic construction of the tie rods, base plate and lid of the BTCs enable an uninterrupted heat transmission path, making the BTCs effective heat rejection devices.

The surfaces of the BTCs 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 BTCs 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 BTCs are provided in Chapter 2.

The BTC's exterior dimensions and the BFA-Tank cavity dimensions are toleranced such that the potential for significant movement of the BTC is eliminated. The clearance between the BTCs and the interfacing surface of the BFA-Tank cavity is controlled to be sufficiently small such that the thermal expansion of BTC under Design Basis heat load conditions will minimize any gaps at the interface and thus minimize resistance to the outward flow of heat, yet ensure that there is no restraint against free thermal expansion. A pictorial view of a typical BTC is provided in Figure 1.2.2.

d. Packaging Supports, Restraints and Weather Protection Cover

The HI-STAR ATB 1T 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 ATB 1T 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.

For additional package protection, a Weather Protection Cover (WPC) is secured to the top of the HI-STAR ATB 1T Package to prevent dirt and water from accumulating on the external surfaces of the cask. The WPC is provided with lifting points for manual or hoist handling. The WPC is not a structural component of the HI-STAR ATB 1T Package but is designated as a packaging component when it is used. Since the WPC is not a structural part of the HI-STAR ATB 1T Packaging, it is not required to remain in place under normal condition tests in 10CFR71.71.

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 WPC to the package, rendering the trunnions inoperable during transport.

Although the design of the WPC, a not *important-to-safety* device, is outside the purview of this SAR, the structural and functional performance criteria applicable to the WPC design are set down in the following to ensure a robust design:

(i) The WPC shall have sufficient structural strength and shall be placed on top of the package and fastened such that during transportation its position is not compromised.

(ii) The WPC shall be lightweight and contribute negligible stress to package components.

(iii) The cross section of WPC shall conform to the physical limitations of the transport package and frame.

(iv) The WPC shall be configured to mitigate heat input to the cask by insolation and the presence of the WPC shall not significantly reduce the rate of heat rejection from the cask which occurs to the ambient by convection and radiation.

1.2.1.2 Overall Packaging Dimensions and Weight

The overall dimensions and component weights on the HI-STAR ATB 1T Package are summarized in Tables 1.1.1 and 7.1.1.

The weight of the HI-STAR ATB 1T Package will differ depending on the weight of packaging components (i.e. BTC type, BFA-Tank type) and the contents. However, the maximum gross weight will be set according to the heaviest waste package. The weight of the package contents is discussed in Subsection 1.2.2 below. The maximum gross transport weight of the HI-STAR ATB 1T Package (without the WPC) 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 ATB 1T Containment boundary is defined by a thick steel alloy weldment of a rectangular box profile with a gasketed heavy walled Closure Lid and a CLLS designed 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 ATB 1T cask package is to ensure that it attenuates the radiation emitted by the BFA-Tank's contents to the levels required under the part 71 regulations. The HI-STAR ATB 1T Package is equipped with appropriate shielding to minimize personnel exposure. The HI-STAR ATB 1T Packaging ensures the external radiation standards of 10CFR71.47 under exclusive shipment are met when loaded with the BFA-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 BFA-Tanks and BTCs, and also through self-shielding of metallic waste.

2. The Containment Boundary made of 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 stainless 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.

1.2.1.4 Criticality Control Features

There are no criticality control features in the HI-STAR ATB 1T Package. The limited quantities of fissile materials in the package contents in Table 7.1.2 qualifies the HI-STAR ATB 1T for exemption from classification as a fissile material package per 10 CFR 71.15. Chapter 6 contains additional details.

1.2.1.5 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, and manufactured from a high strength alloy. 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 the engagement shoulder for the lift yoke to engage it. This projection, however, presents a challenge in that the trunnion becomes a hard point that could puncture the cask under a free fall drop impactive event. The federal regulations (as well as the IAEA standards) require the HI-STAR ATB 1T cask be qualified under a free fall event from a height of 30 feet (9 meters) on to an essentially unyielding surface *under any orientation of impact.* The projection of the trunnions, made of a high strength alloy material, however, presents a location of substantial vulnerability if the impact orientation of the cask is aligned with the vertical plane of the trunnions.

The design utilized herein is based on a Holtec patent disclosure which envisages a two part trunnion consisting of a hollow shaft and a solid shaft engineered to have a sliding fit inside the hollow shaft. The hollow shaft is imbedded in the cask's body and strength welded to it. The solid shaft is positioned inside the hollow shaft and held by a thin retainer (keeper) plate to provide a limited axial load bearing capacity. The retainer plate interfaces with the trunnions solid and hollow shafts to prevent movement of the solid shaft during routine handling activities due to the clearance fit between the hollow and solid shafts.

The solid shaft is configured to project sufficiently inside the hollow shaft such that it develops the full stiffness of a cantilevered beam with the hollow shaft serving as the anchor of the cantilever.

A trunnion configured in the above manner has a limited axial load bearing capacity without any reduction in its load bearing capacity which derives from its bending rigidity (which is not impaired by the reduction in its axial load sustaining capacity).

Lifting of the HI-STAR ATB 1T Package requires the use of external handling devices. A lift yoke is typically utilized when the cask is to be lifted and handled vertically. The cask user shall ensure that the Lift Yoke as well as its appurtenances used to lift and handle the HI-STAR ATB 1T meet appropriate specifications.

Figure 1.3.1 provides an example illustration of a package in a transport configuration. The transport frame provides attachment points for tie-downs on two sides of the cask body, which along with the recessed area of the transport frame in which the cask is positioned during transportation prevent excessive vertical or lateral movement of the cask during normal transportation. The cask tie-down points are structurally integral to the package and designed per the applicable requirements of 10 CFR 71.45.

1.2.1.6 Heat Transfer Features

The HI-STAR ATB 1T Package provides effective heat dissipation for safe transport of the BFA-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 ATB 1T Package are conduction, convection and thermal radiation. Heat is transferred by conduction in areas of the cask where the BFA-Tank outer surface comes into contact with the inner surface of the cask containment boundary. The clearance gaps between the BFA-Tank and the cask are designed to be sufficiently small, thereby reducing the thermal resistance through the gaps. Air in the free volume of the cask outside the BFA-Tank contributes to conductive heat transfer across gaps between the metal surfaces of the BFA-Tank and the internal surfaces of the containment system. Metal conduction transfers the heat throughout the BTC, through the BFA-Tank, containment system boundary, and finally through the DBS and other exterior cask components.

The all-metallic (steel) construction of the BTC, BFA-Tank and HI-STAR ATB 1T cask enables the HI-STAR ATB 1T Package to dissipate heat efficiently. Collectively the heat transfer features of HI-STAR ATB 1T 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]** between the containment wall and dose blocker plate. The insulation board ensures **[Proprietary**

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1.2.1.7 Internal Support Features

If required to close the gap between the top of the BFA-Tank and the underside of the cask lid in accordance with analysis, the HI-STAR ATB 1T package may be fitted with an aluminum spacer. The aluminum spacer may be situated on top or beneath the BFA-Tank in the package, to reduce the travel distance between the BFA-Tank and the cask lid/base plates during postulated drop accidents.

Permanent design internal support features of the HI-STAR ATB 1T Package are the aluminum impact absorber spacers and austenitic stainless steel internal side shim assemblies, attached to the bottom of the lid and recessed into the side walls, respectively, for minimizing gaps between the BFA-Tank and the cask. The aluminum spacer may be used in conjunction with the permanent internal support features.

The designs of the internal support features are in the drawing package in Section 1.3 of the SAR.

1.2.1.8 Security Seal

The HI-STAR ATB 1T 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 closure lid covers the only penetration on the cask with access to its contents. The security seal (a *not important-to-safety* (NITS) feature) is attached to the locking wedge lock bar positioning handle after insertion of the locking wedge lock bar, after closure of the lid and prior to transport. Because the cask lid cannot be disengaged and removed without movement of the locking wedge lock bar, the presence of the tamper-indicating seal is an indication that the contents of the package have not been accessed. This tamper seal satisfies requirements of 10 CFR 71.43(b).

1.2.1.9 Packaging Markings

Each HI-STAR ATB 1T 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 ATB 1T cask has completed the final factory acceptance test (FAT) and verification.

1.2.2 Contents of Package

The HI-STAR ATB 1T Package is classified as a Category I Type B package since the maximum activity of the contents to be transported in the HI-STAR ATB 1T Package is above limits shown in Table 1 of Regulatory Guide 7.11 [1.2.5].

The HI-STAR ATB 1T package 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.

This subsection delineates the authorized contents permitted for shipment in the HI-STAR ATB 1T, including general waste type, radioactive material limits, heat load, waste location requirements, weight limitations and other applicable requirements, as applicable and as summarized in Table 1.1.1, Table 1.2.1 and Table 7.1.2.

The radioactive wastes contents are from segmented and non-segmented reactor internals (for example: 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). Radioactive contents are activated stainless steel or Inconel. 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.

The radioactive wastes consist of solid radiation-activated and surface-contaminated reactor internals, secondary waste (i.e. debris/chips) generated by the mechanical cutting process, chip drums (stainless steel) with surface contamination or induced activity and metallic waste filters (stainless steel or ceramic mesh screens) in the chip drums. The chip drums design allows water to drain by gravity, prevents pooling of residual water and facilitates moisture removal during vacuum drying process. The waste components are typically cut by mechanical cutting techniques and segmented with the objective to provide good packing density. Generally BTCs will not be loaded with segments of exactly the same geometry. Segments are not stabilized in the BTC, and will move if the BFA-Tank is upset. The radioactive material is typically in the form of neutron activated metals 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.

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 ATB 1T must be met to ensure compliance with regulatory and safety analysis requirements.

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Radioactive Waste Specification

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 ATB 1T Package may contain plutonium in solid form.

1.2.4 Operational Features

The HI-STAR ATB 1T 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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The HI-STAR ATB 1T Packaging is a completely passive system once the BFA-Tank with contents are loaded and the closure lid is installed. The abbreviated narrative below on typical loading operations helps illustrate the overall simplicity of the loading process. Chapter 7 provides the essential details.

Typical Loading Operations

Loading from Pool (Waste Package Types A, B, C and D)

At the start of loading operations, the cask is configured with the closure lid removed and the BFA-Tank (without lid) loaded into the cask in the designated preparation area. The BTC (without lid) is lowered into the segmented reactor internals pool. Preselected wastes segments and/or chip drums are loaded into the BTC and a visual verification of the loaded contents is performed.

While still underwater, the BTC lid is installed. The wet hood, an ancillary not discussed in detail in this SAR, is inserted into the pool to engage the loaded BTC to provide temporary shielding during transfer operations. The BTC is removed from the pool in the wet hood and placed into the open BFA-Tank in the HI-STAR ATB 1T Cask in the designated preparation area. A Vacuum Drying System (VDS) is used to remove all bulk water from the BFA-Tank loaded with the BTC and its contents, in accordance with Chapter 7 of this SAR. This drying operation may be performed on the BTC either before or after placement of the BTC into the BFA-Tank. Following the drying operations, the BFA-Tank cavity containing the BTC is restored to ambient pressure and the BFA-Tank lid is bolted and sealed closed.

Installation of a previously loaded BFA-Tank (Waste Package Types A, B, C and D)

Alternatively, BFA-Tanks may have been previously loaded in accordance with procedures in Subsection 7.1.2. In this case, the BFA-Tanks exterior accessible surfaces are verified for cleanliness and lid bolts installation to ensure adequate closure before placing the BFA-Tank into the HI-STAR ATB 1T Cask.

Following loading from the pool or installation of a previously loaded BFA-Tank, the cask closure lid is then installed, and locking wedges are engaged. The cask is sealed close with the (unpressurized) ambient air.

Preparation for Transport

The cask is then placed on the transport frame using the lift yoke or other structural/mechanical lifting device, a security seal (tamper device) is attached, tie-down devices are employed to secure the package to the transport frame, the WPC is attached to the top surface of the cask and the transport frame is lifted and moved by the transport vehicle. The HI-STAR ATB 1T Package is then ready for transport. When transporting by vessel, the transport vehicle delivers or acquires the transport frame containing the loaded package to or from the vessel.

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	A	B	C	D
Maximum calculated waste package heat load, kW (Note 1)	1.65	0.99	0.13	0.016
Package Design Basis Heat Load, kW (Note 2)	Table 7.1.2			
Normal Design Pressure, psig (kPa gauge)	5 (35)			

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 ATB 1T 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]

1.3 ENGINEERING DRAWINGS

This section contains a HI-STAR ATB 1T 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 ATB 1T components is required to be in strict compliance with the Drawing Package in this section.

The following HI-STAR ATB 1T System Licensing Drawings are provided in this section:

Drawing Number	Description	Rev.
9786	HI-STAR ATB 1T Cask	9~~8~~
9876	BFA-Tanks and Cassettes	9

[Drawings Withheld in Accordance with 10 CFR 2.390]

Figure 1.3.1 provides an example illustration of the assembled HI-STAR ATB 1T Package in a transport configuration on the transport frame.

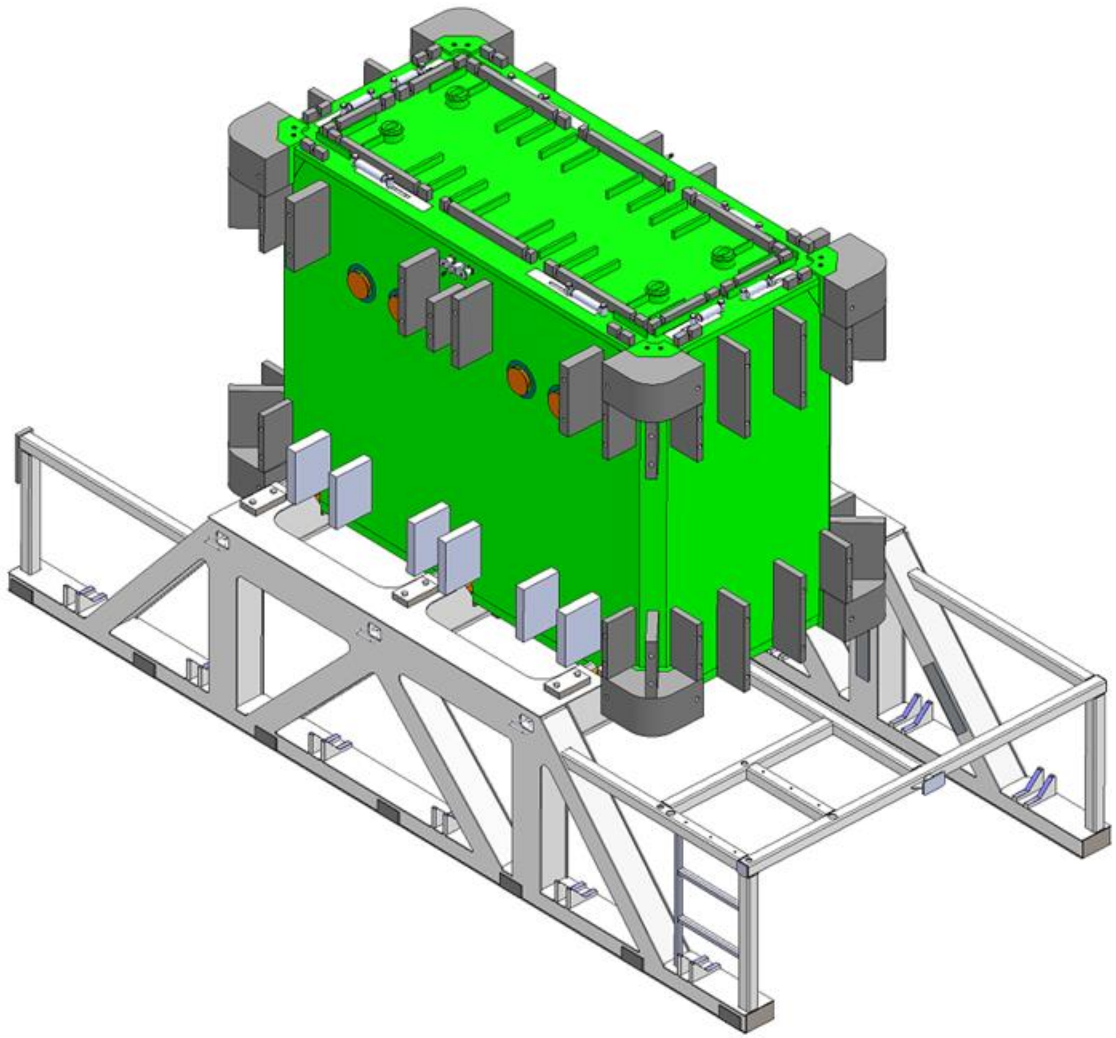

FIGURE 1.3.1: EXAMPLE ILLUSTRATION OF HI-STAR ATB 1T PACKAGE IN TRANSPORT CONFIGURATION

1.4 SUMMARY OF COMPLIANCE WITH 10CFR71 REQUIREMENTS

The HI-STAR ATB 1T Package is designed to comply with the requirements of 10CFR71 for a Type B(U)-96 package. Analyses which demonstrate that the HI-STAR ATB 1T Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR.

The HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T packaging has been identified.

- The applicable codes and standards for the HI-STAR ATB 1T Packaging design, fabrication, assembly, and testing have been identified in the drawing package in Section 1.3.

- The HI-STAR ATB 1T 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 ATB 1T 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] *Intentionally Deleted.*

[1.2.5] 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 Millboards Specifications

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 ATB 1T 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 ATB 1T package.

Appendix 2.A provides introductory information on the principal codes used in the structural analysis (ANSYS and LS-DYNA). Appendix 2.B provides information on the ¼-scale testing of the HI-STAR ATB 1T and the numerical benchmark simulations using 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 ATB 1T 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 ATB 1T containment system.

2.1.1.2 BFA-Tank

BFA-Tanks provide secondary packaging for the contents and are fitted into the HI-STAR ATB 1T cask. All BFA-Tank walls including the top and bottom plates serve as dose blocker parts.

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

2.1.1.3 BFA-Tank Cassettes

BFA-Tank Cassettes (BTC) are loaded into the BFA-Tanks. Only the top and bottom plates of the BTC are classified as dose blocker parts. The specific structural requirements of the BTC 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 ATB 1T 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 ATB 1T 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 ATB 1T's compliance/alternatives thereto.

Conformance with Reg. Guide 7.6 Provisions on the Structural Requirements for HI-STAR ATB 1T Containment Boundary	
1. Material properties, design stress intensities, and fatigue curves are obtained from the ASME Code.	Material properties are obtained from the ASME Code~~, except for the alternative containment boundary material HSLA-100 for which material properties are obtained from applicable material specifications [2.2.2, 2.2.3]~~. Design stress intensities are established based on ASME Code ~~requirements~~ for all containment boundary

Conformance with Reg. Guide 7.6 Provisions on the Structural Requirements for HI-STAR ATB 1T Containment Boundary	
	materials. As there are no significant cyclic loads on the HI-STAR ATB 1T package, fatigue is not critical for this package.
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.
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 ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T cask. This is because the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T 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. Hypothetical Accident Condition Loads (§71.73)

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. Because the package has flat side walls, a side drop event with the penetrant positioned to hit at the precise location of a middle lifting trunnion is evidently one scenario that has the potential to inflict maximum damage. A second puncture scenario that is investigated in this SAR is a 9-meter top down, center-of-gravity over corner (CGOC) drop followed by a 1-meter puncture drop with the penetrant force acting at the same corner location. In other words, the deformed state of the impacted corner following the 9-meter CGOC drop is treated as the initial condition of the package for the 1-meter puncture drop so that the damage is cumulative. Two additional puncture events are also evaluated, as discussed in Section 2.7.

The puncture event may occur under the so-called "hot" (maximum ambient temperature) or "cold" condition at -40ºC (-40ºF). In the latter thermal state, the effects of brittle fracture must also be evaluated. Since the exterior of the HI-STAR ATB 1T package (i.e., Dose Blocker Structure) is made from stainless steel, which is immune to brittle fracture, the consequence of the puncture event will be independent of the minimum service temperature of -40ºF.

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

Deep Water Submergence

Since the HI-STAR ATB 1T 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

The constituent parts of the package, namely, the containment system components, and the dose blocker parts must meet acceptance criteria specific to their function under each loading condition as discussed in the succeeding paragraphs and summarized in Table 2.1.1.

(i) Containment System

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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 2.1.3A through 2.1.6.

Allowable stresses and stress intensities are calculated using the data provided in the ASME Code, Section II, Part D [2.1.4] and Table 2.1.2. For alternative containment boundary material HSLA-100, the design stress intensity values are derived using the criteria from ASME Section II, Part D, Mandatory Appendix 2 [2.1.4] and the mechanical properties from Table 2.2.1B. Tables 2.1.3A through 2.1.6 provide numerical values of the stress intensities, as a function of temperature, for the cask containment system materials, including cask lid locking system.

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 lid locking system and are given in Tables 2.1.3A 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 ATB 1T 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) BFA-Tank

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

(iv) BFA-Tank Cassette (BTC)

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

(v) Cask Crushable Attachments

[

Proprietary Information Withheld in Accordance with 10 CFR 2.390

]

2.1.3 Weights

Section 1.1 provides the overall weights of the HI-STAR ATB 1T Transport package and its constituent components.

2.1.4 Identification of Codes and Standards for Package Design

The design of the HI-STAR ATB 1T 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 ATB 1T Package.

Table 2.1.7 lists each major structure, system, and component (SSC) of the HI-STAR ATB 1T 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 ATB 1T cask are procured to a recognized national consensus standard.

Table 2.1.1: Structural Loading Events and Associated Acceptance Criteria for HI-STAR ATB 1T

#	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. CLLS: The primary bending stress intensity shall be less than 1.5 times the ASME code stress intensity. 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**]
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. CLLS: The primary bending stress	This loading condition corresponds to the Part 71 hypothetical accident condition.

#	Loading Case	Loading	Constituent Part	Stress/Strength Limit	Comment
				intensity shall be less than 3.6 times the ASME code stress intensity. In addition, the primary shear stress must meet Level D limit per ASME Subsection NB. 3. DBS: Must not detach from the cask causing the Part 71 post-accident dose limits to be exceeded.	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	CLLS	Effectiveness of the containment seals must be evaluated	[**Proprietary Information Withheld in Accordance with 10 CFR 2.390**]

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

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

Notes:

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

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

Table 2.1.3A: Design, Levels A and B Stress Intensity – SA-517 & A514

Code: ASME NB
Material: SA-517 & ASTM A514
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 93 (-20 to 200)	241.3 (35)	241.3 (35)	362 (52.5)	362 (52.5)	723.95 (105)	723.95 (105)

Definitions:

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

Notes:

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

Table 2.1.3B: Design, Levels A and B Stress Intensity – SA-508 4N Class 2~~HSLA-100~~

Code: ASME NB
Material: SA-508 4N Class 2
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**					
	S_m	**P_m** (Note 2)	**P_L** (Note 2)	**$P_L + P_b$** (Note 2)	**$P_L + P_b + Q$**	**P_e** (Note 3)
-29 to 66 (-20 to 150)	264.3 (38.3)	264.3 (38.3)	396.4 (57.5)	396.4 (57.5)	792.9 (115)	792.9 (115)

Notes:

1. The stress intensity (S_m) for this material is obtained using the criteria~~relationships~~ from ASME Section II, Part D, Mandatory Appendix 2 [2.1.4] along with material strength data from Table 2.2.1B.
2. Evaluation required for Design condition only per NB-3220.
3. P_e not applicable to vessels per Fig. NB-3221-1.
4. Values are in accordance with stress intensity limits provided in Table 2.1.2. Since the temperature in the containment components is less than 150 °F (per Table 3.1.1 of this SAR), the allowable stress limits are listed for temperatures up to 150 °F only.
5. See Table 2.1.3A for stress classification definitions.

Table 2.1.4A: Level D Stress Intensity – SA-517 & A514

Code: ASME NB
Material: SA-517 & A514
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)		
	P_m	P_L	$P_L + P_b$
-29 to 93 (-20 to 200)	506.8 (73.5)	760.15 (110.25)	760.15 (110.25)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.3A for stress classification definitions.

Table 2.1.4B: Level D Stress Intensity – ~~HSLA-100~~SA-508 4N Class 2

Code: ASME NB
Material: SA-508 4N Class 2
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)		
	P_m	P_L	$P_L + P_b$
-29 to 66 (-20 to 150)	555.0 (80.5)	832.5 (120.8)	832.5 (120.8)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331, along with material strength data from Table 2.2.1B.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2. Since the temperature in the containment components is less than 150 °F (per Table 3.1.1 of this SAR), the allowable stress limits are listed for temperatures upto 150 °F only.
4. See Table 2.1.3A for stress classification definitions.

Table 2.1.5: Design, Levels A and B Stress Intensity – SB-637 N07718

Code: ASME NB
Material: SB-637 N07718
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)	344.7 (50.0)	344.7 (50.0)	517.1 (75.0)	517.1 (75.0)	1034 (150.0)	1034 (150.0)
93 (200)	330.9 (48.0)	330.9 (48.0)	496.4 (72.0)	496.4 (72.0)	992.8 (144.0)	992.8 (144.0)

Notes:

1. S_m is derived based on 2-110 criteria from ASME Section II, Part D, Mandatory Appendix 2.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. Evaluation required for Design condition only per NB-3220.
4. P_e not applicable to vessels per Fig. NB-3221-1.
5. See Table 2.1.3A for stress classification definitions.

Table 2.1.6: Level D Stress Intensity – SB-637 N07718

Code: ASME NB
Material: SB-637 N07718
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)	827.4 (120.0)	1241 (180.0)	1241 (180.0)
93 (200)	794.3 (115.2)	1191 (172.8)	1191 (172.8)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. See Table 2.1.3A for stress classification definitions.

Table 2.1.7: Applicable Codes and Standards for the Materials Procured/Fabricated for the HI-STAR ATB 1T 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 Locking System (CLLS) Wedge	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
7.	Locking Wedge Lock Bar	Structural	ASME Code Section III Subsection NB[1]

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. ~~For HSLA-100 steel, which is an alternate containment boundary material, it is procured per the applicable requirements of [2.2.2] and [2.2.3] as delineated in Holtec purchase specification.~~

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 Containment System

The high strength alloy steel used for the HI-STAR ATB 1T containment system, including the containment baseplate, the containment side walls, the containment end walls, and the closure lid, is either SA-517 or ASTM A514. The material properties used for structural evaluations of SA-517 and A514 are given in Table 2.2.1A.

An alternative high strength ~~low alloy steel named HSLA-100~~material SA-508 4N may be substituted for the cask containment boundary components including the containment baseplate, the containment side walls, the containment end walls, and the closure lid. ~~HSLA-100 steel is widely used in Navy vessels, which possesses high strength properties together with a high degree of low-temperature fracture toughness resistance.~~ As observed from Table 2.2.1B, the strength properties of ~~HSLA-100~~SA-508 4N are superior to those of the ASME and ASTM materials, SA-517 and A514, respectively.

The CLLS locking wedges are made from nickel alloy bar, namely SB-637 N07718. The material properties used for structural evaluations of SB-637 N07718 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 Trunnion Materials

The HI-STAR ATB 1T cask has a total of eight lifting trunnions, as shown in the licensing drawings in Section 1.3. Each trunnion is comprised of a solid shaft and a hollow sleeve, which are made of SB-637 N07718 and SA-182 F XM-19, respectively. The material properties used for SB-637 N07718 are given in Table 2.2.2, while those for SA-182 F XM-19 are given in Table 2.2.3.

2.2.1.3 Dose Blocker Structure

The DBS is made of austenitic stainless-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 Weld Material

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 ATB 1T 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 Crushable Attachments

The crushable attachments are made of stainless steel and aluminum bars or plates, which are strategically connected to the cask exterior (see Figure 2.3.6). The primary function of these exterior attachments 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 Crushable Attachments 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 ATB 1T 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 ATB 1T 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 ATB 1T package is composed primarily of high strength alloy steel and stainless steel, which have a proven history of use in the nuclear industry. The contents of HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T 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 BFA-Tank and BFA-Tank Cassette

The BFA-Tank and BTC 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 BFA-Tanks and the BFA-Tank Cassettes, which are loaded inside the HI-STAR ATB 1T transport cask, do not require fracture toughness testing for the following reasons:

i) The BFA-Tanks and BTC'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 BFA-Tanks, as well as the top and bottom plates of the BFA-Tank Cassettes, are only credited in the shielding evaluation to mitigate dose rates external to the HI-STAR ATB 1T package.
iii) Excluding the normal (NCT) and HAC drop events, the BFA-Tanks and the BFA-Tank Cassettes, while inside the HI-STAR ATB 1T 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 ATB 1T 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 BFA-Tank and BTC 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 BFA-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 BFA-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, a sensitivity study has been performed in Chapter 5 to determine the external dose rate at 1-meter assuming that the BTC bottom plate is 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 BFA-Tank fail under Hypothetical Accident Conditions resulting in a 40 mm wide separation gap along all corner edges of the BFA-Tank. In addition, the shielding evaluation further assumes that the most activated Type A waste bypasses the BTC top plate and occupies the gap between the BFA-Tank walls (see Figure 5.3.9), leaving only the side wall of the HI-STAR ATB 1T cask to provide gamma shielding. This conservative shielding model bounds the potential dose consequences of any thru-wall cracks that may develop elsewhere in BFA-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 BFA-Tank and BTC materials are not required.

Table 2.2.1A: Mechanical Properties of SA-517/A514

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	620.5 (90.0)	723.9 (105.0)	20.4 (29.6)	11.7 (6.5)
66 (150)	603.3 (87.5)	723.9 (105.0)	--	11.9 (6.6)
93 (200)	592.9 (86.0)	723.9 (105.0)	20.0 (29.0)	12.1 (6.7)

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 2.2.1B: Mechanical Properties of ~~HSLA-100~~SA-508 4N Class 2

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	689.5 (100.0)	792.9 (115.0)	19.0 (27.6)	11.7 (6.5)
66 (150)	663.3 (96.2)	792.9 (115.0)	18.9 (27.4)	11.9 (6.6)

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 B in Table TM-1 of [2.1.4].
5. Since the temperature in the containment components is less than 150 ºF (per Table 3.1.1 of this SAR), the allowable stress limits are listed for temperatures upto 150 ºF.

~~1. Source for S_y values is Table A-2 of [2.2.2] for thicknesses greater than 4 inches.~~
~~2. Since the maximum temperature of the HI-ASTAR ATB 1T cask containment components is less than 150º deg. F per Table 3.1.1, only the strength properties belowat 150º degF and below temperature are relevant tofor the structural analysis. The yield strength of HSLA-100 at an elevated temperature of 150º deg. F is derived by scaling down its minimum yield strength at room temperature in proportion to a similar high strength material SA-517 (listed in Table 2.2.1A).~~
~~3. The minimum S_u value at room temperature is established based on HSLA-100the material certification report for HSLA-100 [2.2.3] at room temperature. The ultimate strength for high strength alloy steels do not vary for material elevatedmetal temperatures between -29ºC to 66ºC (-20ºF to 150ºF).~~
~~4. Source for E value is DTRC-SME-90/21 [2.2.3].~~
~~5. Source for α value is Table 2 of [2.2.3].~~

Table 2.2.2: Mechanical Properties of SB-637 N07718

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	1034 (150.0)	1276 (185.0)	19.9 (28.9)	12.8 (7.1)
93 (200)	992.8 (144.0)	1225 (177.6)	19.5 (28.3)	13.0 (7.2)

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

Table 2.2.3: Mechanical Properties of SA-182 F XM-19

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	379.2 (55.0)	689.5 (100.0)	19.5 (28.3)	14.8 (8.2)
66 (150)	343.3 (49.8)	687.4 (99.7)	--	15.1 (8.4)
93 (200)	324.7 (47.1)	685.3 (99.4)	19.0 (27.5)	15.3 (8.5)

Definitions:

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

Notes:

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

Table 2.2.4: Mechanical Properties of SA-240 304

Temperature, ºC (ºF)	S_y	S_u	E	α
-29 to 38 (-20 to 100)	206.8 (30.0)	517.1 (75.0)	19.5 (28.3)	15.5 (8.6)
66 (150)	184.1 (26.7)	503.3 (73.0)	--	15.8 (8.8)
93 (200)	172.4 (25.0)	489.5 (71.0)	19.0 (27.5)	16.0 (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. Source for S_u values is Table U of [2.1.4].
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 G in Table TM-1 of [2.1.4].

Table 2.2.5: Mechanical Properties of Aluminum 6061-T6/T651

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].

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2.3 FABRICATION AND EXAMINATIONS

The HI-STAR ATB 1T 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~~/HSLA-100~~SA-508 4N) 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~~, or the material specification for HSLA-100 as discussed in Chapter 8, as applicable~~. 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 2.3.6, 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 the containment walls and containment baseplate by making the outer groove welds.
iii. Assemble the intermediate dose blocker walls and bottom plate around the containment assembly by making the outer groove welds.
iv. Assemble the outer dose blocker walls and bottom plate around the entire assembly by making the outer groove welds.
v. Machine assembly as required to meet dimensional requirements, form the closure flange with side locking wedge blocks, and prepare for installation of hollow trunnion shafts.
vi. Apply high strength weld overlay to sealing surfaces.
vii. Install and weld the hollow trunnion shafts to the containment walls.
viii. Install the solid trunnions.
ix. Assemble and install the closure lid with O-ring seals.
x. [Proprietary Information Withheld in Accordance with 10 CFR 2.390]
xi. Perform leak test.

The following additional steps to insure high quality welds are employed in the manufacturing of HI-STAR ATB 1T 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 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.3.2 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.3.3 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.3.4 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.3.5 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.3.6 Withheld in Accordance with 10 CFR 2.390]

2.4 GENERAL REQUIREMENTS

As can be seen from the external dimensions of the packaging in Section 1.3, the HI-STAR ATB 1T 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 ATB 1T 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 ATB-1T 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 ATB 1T package is provided with eight 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 eight trunnions shall be used for vertical lifting of the transport package at any time. As discussed in Section 8.1.3, only four of the eight trunnions (one load path) are considered in the lifting analysis. The other four trunnions (second load path) are connected redundantly to the cask lift yoke.

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 Cask Closure Lids and Baseplate During Lifting

2.5.1.2.1 Closure Lid Lifting Attachment

The closure lid contains lid lifting lugs used to move the lid over and onto the closure flange of the cask. The lid lifting lugs are adequately sized to meet allowable stresses in accordance with NUREG-0612 requirements (which are more severe than 10CFR71.45(a) requirements). Strength of materials based calculations are performed to demonstrate safety compliance of the lid lifting lugs.

Minimum safety factors are summarized in Table 2.5.2.

2.5.1.2.2 Baseplate

During lifting of a loaded HI-STAR ATB 1T the containment baseplate is subject to amplified dead load, D*, from the BFA-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 closure lid and CLLS are included in the FE model. The load case considers the loads from the fully loaded BFA-Tank and the self-weight of the baseplate. In this load case, the 15% amplifier is applied to the lifted load. The strength properties and allowable stress intensities are the minimum values for the candidate materials described in paragraph 2.2.1.1.

The results from the analysis of the top-end lift are summarized in Table 2.5.3, where the minimum safety factors for components in the load path are computed using the ASME Level A allowable stress intensities from Table 2.1.3A.

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 ATB 1T 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)	88.99 (10.05)	6.15
Shear Force in Trunnion – kip (kN)	243.48 (10,830.4)	6.57
Bearing Stress in Trunnion hollow Shaft (Comparison with Yield Strength in Compression) – ksi (MPa)	36.18 (249.47)	1.30
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 Closure Lid Lifting Attachments

Item	Value, psi (MPa)	Limit, psi (MPa)	Minimum Safety Factor
Tensile Stress in Lifting Attachment	1,661 (11.45)	7,100 (48.95)	4.27
Shear Stress in Lifting Attachment	894.6 (6.17)	4,097 (28.25)	4.58
Stress in the attachment weld	2,849 (21.6)	4,097 (28.25)	1.44
Note: Safety factor reported in this table are calculated based on the requirements of NUREG-0612 [1.2.3].			

Table 2.5.3: Results for Baseplate Lifting

Item	Value, psi (MPa)	Limit, psi (MPa)†	Minimum Safety Factor
Base Plate, Membrane + Bending Stress	2,648.3 (18.26)	52,500 (362)	19.8
†The stress limit is established in Table 2.1.3A.			

2.6 ROUTINE AND NORMAL CONDITIONS OF TRANSPORT

In this section, the HI-STAR ATB 1T 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 ATB 1T cask along the BFA-Tank and BFA-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 2.A and 2.B provide the QA validation of the LS-DYNA code for evaluating the drop events.

2.6.1 Description of the Finite Element Model

As can be seen from the Licensing drawings, the HI-STAR ATB 1T Package is a rectangular cross section structure with a double wall construction joining a multi-layered baseplate at the bottom. A thick solid lid is secured to the containment walls via a boltless Closure Lid Locking System (CLLS). The Package is a perfectly prismatic structure except for the lifting trunnions and the crushable attachments that protrude from the cask side walls and the closure lid (see Figure 2.3.6). To protect the package from damage during a free drop event, the trunnions and the lid lifting attachments have been designed to be axially collapsible under a moderate axial load as described in Subsection 1.2.1.1. Therefore, the trunnions and the lid lifting attachments don't feature in the finite element model prepared to prognosticate the response of the cask under the impactive and/or impulsive loading scenarios listed in Table 2.1.1.

The methodology involves simulating of the free drops using the 3-D dynamic finite element code LS-DYNA [2.6.1]. As discussed earlier in Section 2.1, LS-DYNA has been proven to be an excellent tool for performing comprehensive evaluation involving impulsive events such as the free drop accident.

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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 a 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 ATB 1T 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. As stated earlier, results in Table 2.6.2 are based on the material option (SA-517/A514) with the lowest strength properties to insure a bounding solution for containment boundary components.

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 are governed by the 30-ft (9-m) drop accidents and are evaluated in Section 2.7.

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

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

It is therefore demonstrated that the BFA-Tanks and BTC'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 ATB 1T 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 ATB 1T 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 ATB 1T 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.

To provide quantitative evidence, the induced stress in the containment shell (at its minimum cross section) under the dead weight of the HI-STAR ATB 1T cask is compared against the endurance limit of SA-517 steel. From Table I-9.1 of the ASME Code [2.1.10], the allowable stress amplitude corresponding to 10^6 cycles is 17.8 ksi. By comparison, the maximum compressive stress in the containment shell under dead weight conditions is less than 200 psi (See calculation package [2.6.4]). Even considering a strength reduction factor of 4 due to the intersecting welds at the corner of the cask containment boundary, the allowable stress amplitude is 17.8 ksi / 4 = 4.45 ksi, which is still an order of magnitude greater than the induced stress level and provides ample protection against dynamic increases during normal conditions of transport. Since the ultimate strength of the alternative containment material ~~HSLA-100~~SA-508 4N is greater than that of SA-517 material, the allowable stress amplitude determined above, based on S-N curves in Figure 1-9.1 of [2.1.10], remains governing.

Therefore, it is concluded that the mechanical vibration effects are essentially ineffective as causative mechanisms for the loss of fatigue endurance capacity of the HI-STAR ATB 1T Transport Package.

Likewise, the cask closure system referred to as CLLS including the wedge lock for the HI-STAR ATB 1T package is not subject to significant load fluctuations under normal operations. During HI-STAR ATB 1T package normal transportation, however, the CLLS may be subject to some inertial loads. The inertial loads on the CLLS are significantly lower than the loads representative of the free drops analyzed in Sections 2.6 and 2.7. It is therefore concluded that the effectiveness of the CLLS secured to the top flange and integrity of the Transport Package in whole remains unaffected during the HI-STAR ATB 1T package transportation.

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 ATB 1T.

When in a horizontal position, the HI-STAR ATB 1T cask is supported over a considerable length of the DBS. Conservatively considering the HI-STAR ATB 1T 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 ATB 1T 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	52.5/362	6.21/42.8	8.46
Containments Wall Plate	Primary Membrane plus Primary Bending	52.5/362	6.6/45.54	7.95
Base Plate	Primary Membrane plus Primary Bending	52.5/362	4.25/29.31	12.35

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	Primary Bending Stress Intensity	284.1 (41.2)	362 (52.5)	1.27	[2.6.3]
		Secondary Stress Intensity	462.6 (67.1)	723.95 (105)	1.56	
	Containment Wall	Primary + Secondary Stress Intensity	249.6 (36.2)	362 (52.5)	1.45	
		Secondary Stress Intensity	413.7 (60)	723.95 (105)	1.75	
	Containment Baseplate	Primary Bending Stress Intensity	249.6 (36.2)	362 (52.5)	1.45	
	CLLS Wedge	Primary Bending Stress Intensity	412.3 (59.8)	506.8 (73.5)	1.23	
Bottom Drop	Containment Baseplate	Primary Bending Intensity	264.8 (38.4)	362 (52.5)	1.37	
	Containment Wall	Primary + Secondary Stress Intensity	388.9/56.4	723.95 (105)	1.86	
	Closure Lid	Primary Bending Intensity	210.3 (30.5)	362 (52.5)	1.72	
	CLS Wedge	Primary Bending Intensity	312.3 (45.3)	506.8 (73.5)	1.62	
Side Drop	Closure Lid	Primary Stress Intensity	291 (42.2)	362 (52.5)	1.24	
	Containment Baseplate	Primary Stress Intensity	291 (42.2)	362 (52.5)	1.24	
	Containment Wall	Primary Bending Stress	299.2 (43.4)	362 (52.5)	1.21	
	Containment Wall	Primary+ Secondary Stress Intensity	513 (74.4)	723.95 (105)	1.41	
	CLLS	Primary Stress	460.6 (66.8)	506.8 (73.5)	1.1	

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, 150 psi	Closure Lid	Primary Membrane plus Primary Bending	52.5 (362)	7.23 (49.83)	7.26
	Containments Wall Plate	Primary Membrane plus Primary Bending	52.5 (362)	10.76 (74.17)	4.88
	Base Plate	Primary Membrane plus Primary Bending	52.5 (362)	4.95 (34.16)	10.6

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

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 BFA Target)	>1,390,000
Total Number of Nodes	>1,750,000

[Figure 2.6.1 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.2 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.3 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.4 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.5 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.6 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.7 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.8 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.9 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.10 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.11 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.12 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.13 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.14 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.15A Withheld in Accordance with 10 CFR 2.390]

[Figure 2.6.15B 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 ATB 1T 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. In addition to the base FE model attributes discussed in Section 2.6, the additional emphasis is given to the FE model per the guidance document [2.7.1]:

i. *Finer Mesh:* The FE model discussed earlier uses a sufficiently dense mesh size and adequately large number of elements through thickness of the shell/lid/baseplate. Regionalized mesh refinement is considered in regions of primary impact which may be subject to heavy deformations. Furthermore, the mesh size and mesh transition at the geometric discontinuities is consistent with the ¼-scale benchmark FE model [2.6.6].

ii. *Upper Bound Material Curve:* While using minimum ASME material properties for the cask containment and the DBS parts lends conservatism to the safety assessment for the package, the material strength properties for the crushable attachments may influence the cask dynamic response. Specifically, the upper bound material strength and elastic modulus may amplify the cask deceleration and the corresponding impact loads during the critical HAC drop events. To rule out any uncertainty and to demonstrate that the safety results for the package containment are not adversely affected, additional sensitivity simulations are performed using the upper bound material flow curve for the crushable components externally attached to the cask. The base model, as discussed earlier, uses the material true stress-strain curve developed based on the ASME minimum material strength properties. On the other hand, the sensitivity simulations consider upper bound material strength properties summarized in Table 8.1.5 of this SAR.

iii. *Sensitivity Simulations with ~~HSLA-100~~SA-508 4N Material:* Inclusion of ~~high strength low alloy steel HSLA-100 as~~ an alternate material option for the containment boundary components, as discussed in Section 2.1.1 of this SAR, warrants additional consideration. Two sensitivity (drop) simulations are performed in order to verify that the HI-STAR ATB 1T package performance is maintained, with no adverse effects, when ~~HSLA-100~~SA-508 4N is substituted as the construction material for the containment boundary components.

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. Side Drop with larger package surface impacting	The package drops with its longitudinal axis horizontally orientated.
4. 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.
5. 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.
6. 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]
7. Sensitivity Simulations	Same as Drop orientation 1 with following changes: Simulation C1: Upper bound material strength properties for the crushable attachments per Table 8.1.5. Simulation C2: Replacing the bonded contacts between the cask and the exterior crushable components are replaced with the tie-break contacts using minimal force capacity to sustain normal transport loads. For further details see reference [2.6.3].
8. Simulations with Alternative Containment Material	Simulation E1: Identical to the Simulation 1 (Top End Drop) in all respects except for the containment material. Specifically, the material true-stress-true-strain curves for containment components are substituted with those for ~~HSLA-100~~SA-508 4N material data. Simulation E2: Identical to the Simulation 6 (Oblique Drop onto Top Lid) in all respects except for the material inputs used for the containment components. Specifically, the material true-stress-

	true-strain curves for containment components are substituted with those for ~~HSLA-100~~SA-508 4N material data. For further details see reference [2.6.3].

As discussed earlier, the structural integrity of the HI-STAR ATB 1T 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 2.7.10 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 crushable attachments. The simulation results also demonstrate that there is no gross failure or separation of the dose blocker components from the cask body.

Figure 2.7.9 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.

Finally, Figure 2.7.12 demonstrates that the support bars interspaced between the Closure Lid and the covering dose blocker plate serve their design objective in limiting the deformation of the closure lid dose blocker plate relative to the closure lid and maintain performance of the thermal insulation board.

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

a) the BFA-Tank walls are not subject to gross failure under the top and bottom end drops;
b) the BFA-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 BFA-Tank satisfies the structural acceptance criteria for the HAC drops.

As previously noted, the top and bottom plate of the BTC'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 BTC during the hypothetical accident conditions (HAC) is applied.

The key results for the sensitivity simulations (C1 and C2 in above table) are summarized in Table 2.7.3. It is shown that the upper bound material strength properties considered for the crushable attachments in the sensitivity simulation have negligible effect on the results. The summary table also indicates that the strength of the connections between the crushable attachments 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.

Lastly, the sensitivity simulations (E1 and E2 in above table) performed for the alternate containment boundary material ~~HSLA-100~~SA-508 4N demonstrate that:

1. The effective stress and/or deformation in the sealing region is diminished with use of stronger containment boundary material. This ensures that the package seal worthiness is unaffected.
2. The primary stresses in the containment components remain within +8.2% of the corresponding stresses computed for the base model with SA-517/A514 material. However, since the allowable stress limits for ~~HSLA-100~~SA-508 4N material are increased by ~~10.5%~~9.5% as compared to SA-517/A514 material (see Tables 2.1.4A and 2.1.4B), the structural safety margins for the containment components are slightly increased with use of ~~HSLA-100~~SA-508 4N material.

It is, therefore, concluded that the overall performance of the HI-STAT ATB 1T package is enhanced when the containment boundary components are constructed with alternative ~~HSLA-100~~SA-508 4N material.

The materials used for the cask exterior crushable attachments and the lid impact absorber spacers must meet the strength limits summarized in Table 8.1.5 of this SAR. If the strength properties for these crushable (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 lid edge aligned with the seals, the side puncture into trunnion hole, the top CG-Over Corner and the bottom CG-Over Corner puncture. 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 CLLS locking wedges 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 and the CLLS.

ii. *Side Puncture Drop onto Trunnion:* The side puncture drop model is identical to the corresponding 9-m side drop model with exception to the following:

1. The impact target is replaced by a 6” diameter vertical steel bar fixed at its base.
2. To render conservative results, the puncture bar is assumed to impact the HI-STAR ATB 1T package inner (containment) shell behind trunnion where the shell wall has reduced thickness of 2.5 in. Moreover, the impact corresponds to the trunnion location closer to the center line of the package maximizing bending in the inner shell. For this governing simulation, the trunnion and the trunnion sleeve material are conservatively ignored (see Figure 2.7.10) imparting maximum impact energy to the inner-most containment shell. This is very conservative approach given the fact that the trunnion outer diameter is smaller than the puncture bar and the trunnion has been designed to collapse axially and embed into the cask under a moderate axial load. Therefore, the presence of trunnion and the trunnions sleeve will dissipate some of the impact energy thereby reducing the deformation to the inner containment shell.

iii. *Top CG-Over Corner Puncture:* The top CG-Over Corner puncture drop model is identical to the corresponding 30 ft (9-m) top C.G.O.C drop model except for that the impact target is replaced by a 6” diameter vertical steel bar fixed at its base

iv. *Bottom CG-Over Corner Puncture:* The bottom CG-Over Corner puncture drop model is identical to the corresponding 30 ft (9-m) bottom C.G.O.C drop model except for that the impact target is replaced by a 6” diameter vertical steel bar fixed at its base.

This CGOC puncture drop simulation warrants a special mention since they are sequenced after the 30 ft. (9-m) free drop event to accumulate the damage to the package from both accidental events viz. 9m drop onto a rigid flat target and 1m drop onto a puncture bar. The deformations in the package and residual stress/strain in cask components are preserved during the sequential puncture drop events. As shown in Figure 2.7.11, both the flat unyielding target required for 30 ft. (9-m) drops and the puncture bar required for the 1-m puncture drop are both built into single FE model. However, the contacts are articulated such that the unyielding flat target appears only for the 30 ft. (9-m) free drop (during the initial impact duration) and is deleted once subsequent to the 30 ft. drop. During the subsequent puncture drop, the velocity of the package is readjusted to reflect initial kinetic energy corresponding to 1-m free drop height and the cask contact with the puncture bar is established.

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 2.7.6 through 2.7.8 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 CLLS. 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 top flange and the closure lid (as well as the locking wedges) are nearly equal under NCT (see Table 3.1.1).

The more significant risk to the CLLS 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 top machined flange is directly exposed to the flame, it heats up more than the closure lid locking wedges 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 top machined flange and the closure lid locking wedges 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 Withheld in Accordance with 10 CFR 2.390]

[Table 2.7.2 Withheld in Accordance with 10 CFR 2.390]

[Table 2.7.2 Withheld in Accordance with 10 CFR 2.390]

[Table 2.7.3 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.1 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.2 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.3 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.4 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.5 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.6 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.7 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.8 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.9 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.10 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.11 Withheld in Accordance with 10 CFR 2.390]

[Figure 2.7.12 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 Lifting Lugs for the Closure Lid likewise meet the Level A condition stress limits of ASME Section III Subsection NB.

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

(iv) 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).

(v) 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).

(vi) 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).

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

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

(ix) The BFA-Tanks and BTC’s meet the required acceptance criteria under the NCT and HAC drops.

Therefore, it is concluded that the HI-STAR ATB 1T 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.

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

[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.

[2.1.8] ASME Boiler & Pressure Vessel Code, Section III, Nonmandatory Appendices EE and FF, American Society of Mechanical Engineers, 2013 Edition.

[2.1.9] NUREG-1617 Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, USNRC, (2000).

[2.1.10] ASME Boiler & Pressure Vessel Code, Section III, Appendices, American Society of Mechanical Engineers, 2013 Edition.

[2.1.11] Deleted.

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

~~[2.2.2] NAVSEA Technical Publication T9074-BD-GID-010/0300, Revision 2, Base Material for Critical Applications: Requirements for Low Alloy Steel Plate, Forgings, Castings, Shapes, Bars and Heads of HY-80/100/130 and HSLA-80/100.~~

~~[2.2.3] Development of Low Carbon, Copper-Strengthened HSLA Steel Plate for Naval Ship Construction, David Taylor Research Center DTRC-SME-90/21.~~

~~[2.2.4] Military Specification, MIL-S-24645 (SH), 4th September 1984.~~

[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 14.0, Ansys Inc., Copyright 2010 SAS IP, Inc.

[2.6.3] Holtec Calculation HI-2177539, Revision 7~~5~~, "Drop Analysis for the HI-STAR ATB 1T Transport Package"

[2.6.4] Holtec Calculation HI-2177540, Revision 6~~4~~, "Structural Calculation Package for HI-STAR ATB 1T 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 ATB 1T 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.

Appendix 2.B: Benchmarking of LS-DYNA for Impact Simulations†

[Proprietary Information Withheld in Accordance with 10 CFR 2.390]

† Under Holtec's configuration control, this appendix will be immediately revised in all submitted SARs if a USNRC request-for-additional-information (RAI) necessitates a change to its contents.

CHAPTER 3: THERMAL EVALUATION

3.0 INTRODUCTION

In this chapter, compliance of the HI-STAR ATB 1T Package to 10CFR Part 71 [3.0.1] regulation thermal requirements is 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 ATB 1T 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 ATB 1T 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 ATB 1T Package are presented in Chapter 1 with structural and mechanical features further described in Chapter 2. The HI-STAR ATB 1T Package geometry is detailed in Section 1.3. The HI-STAR ATB 1T Package consists of a BFA-Tank inside a thick cask equipped with a removable closure lid. Insulation boards are installed in the cask body and closure lid to minimize heat input into the cask during fire accident. The BFA-Tank contains a BFA-Tank Cassette (BTC), and the stainless-steel segments cut from reactor internal components are placed in the BTC. The BFA-Tank cavity and the cask cavity (i.e. the open space between the BFA-Tank external surface and the cask internal surface) are at atmospheric pressure, at time of its sealing. Prior to sealing the BFA-Tank, the residual water inside the BFA-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 ATB 1T Package is provided in Table 1.2.1.

3.1.3 Summary Table of Temperatures

The HI-STAR ATB 1T 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 ATB 1T 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 the shade. The maximum cask accessible surface temperature under this scenario is bounded by the external surface temperature reported in Table 3.1.1 for cask with insolation. The calculated cask surface temperature 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]

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

3.2.1 Material Properties

Materials present in the HI-STAR ATB 1T Packaging include stainless steel (cask dose blocker structure), high strength alloy steel (cask containment), carbon steel (BFA-Tank and BTC), insulation, Inconel, 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 ATB 1T Package thermal analysis, an emissivity specified in Table 3.2.5[†] is applied to the painted surfaces. Henninger [3.2.8] reports the solar absorption coefficient of stainless steel in the range of 0.39 to 0.58. A theoretical bounding solar absorptivity coefficient of 0.6 is applied to all exposed cask surfaces.

The heat is dissipated from the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T Packaging Material Thermal Property References

Material	Emissivity	Conductivity	Density	Heat Capacity
Stainless Steel (machined forgings)	Kern [3.2.3]	ASME [3.2.4]	Marks' [3.2.1]	Marks' [3.2.1]
Stainless Steel Plates	ORNL [3.2.5], [3.2.6]	ASME [3.2.4]	Marks' [3.2.1]	Marks' [3.2.1]
Carbon Steel	Kern [3.2.3]	ASME [3.2.4]	Marks' [3.2.1]	Marks' [3.2.1]
~~HSLA-100~~	~~Note-1~~	~~DTRC [3.2.9]~~	~~DTRC [3.2.9]~~	~~Note-2~~
Air	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Insulation Board	NA	Table 3.2.8		

~~Note-1: All the exposed surfaces of the components made of HSLA-100 are painted. Therefore, the emissivity of painted surfaces as defined in Table 3.2.5 is adopted under normal conditions of transport. During post-fire conditions, the paint on the exposed surfaces is conservatively assumed to be lost for the purpose of thermal analysis. However, all the outer surfaces of the cask will be coated with soot, which results in high emissivities (>0.8). A conservatively lower emissivity, *viz.,* that of unpainted carbon steel (Kern, [3.2.3]), is adopted as this results in reduced heat rejection to the ambient during the post-fire phase, and therefore higher temperatures.~~

~~Note-2: The heat capacity of low alloy steels is fairly invariant across a wide range of compositions, as can be seen from the fact that the variation is ±6% across steels for Groups A through L as defined in ASME [3.2.4]. HSLA-100 is also a low alloy steel, with a similar composition. This variation is insignificant to have any material impact on the total thermal inertia of the system and therefore on the transient thermal response of the cask during hypothetical accident conditions (HAC). Therefore, heat capacity of carbon steel/stainless steel is adopted for HSLA-100 as well. The heat capacity does not play a role in other conditions as safety evaluations are based on steady state analyses.~~

Table 3.2.2: Thermal Conductivity of HI-STAR ATB 1T 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	Type 304 S/S	SA-517/SA-508 Grade 4N	SB-637-N07718	Type 516 Gr. 70 C/S
21 (70)	14.9 (8.6)	41.0 (23.7)	11.1 (6.4)	60.4 (34.9)
38 (100)	15.1 (8.7)	40.8 (23.6)	11.4 (6.6)	60.1 (34.7)
93 (200)	16.1 (9.3)	40.7 (23.5)	12.3 (7.1)	58.3 (33.7)
232 (450)	18.3 (10.6)	39.8 (23.0)	14.7 (8.5)	52.1 (30.1)
371 (700)	20.4 (11.8)	37.4 (21.6)	17.1 (9.9)	46.0 (26.6)
538 (1000)	22.7 (13.1)	34.1 (19.7)	19.9 (11.5)	38.8 (22.4)
677 (1250)	24.7 (14.3)	30.6 (17.7)	22.2 (12.8)	32.2 (18.6)
816 (1500)	26.5 (15.3)	26.1 (15.1)	24.4 (14.1)	26.8 (15.5)

HSLA-100		
35.6 W/m-K@21°C/ 20.6 Btu/ft-hr-°F @70°F	36.3 W/m-K@427°C/ 21.0 Btu/ft-hr-°F @800°F	35.1 W/m-K@538°C/ 20.3 Btu/ft-hr-°F @1000°F

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)
Type 304 S/S	8025 (501)		502 (0.12)
SA-517/SA-508 Grade 4N	7835 (489)		418 (0.1)
SB-637-N07718	8217 (513)		418 (0.1)
Type 516 Gr. 70 C/S	7835 (489)		418 (0.1)
	~~HSLA-100~~	~~7862 (491)~~	~~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 (Machined Forgings)	0.36
Stainless Steel Plates	0.587
~~Polished Stainless Steel [Note 1]~~	~~0.11~~
Carbon steel	0.66
Painted surfaces	0.85
~~Note 1: Emissivity data obtained from [3.2.8].~~	

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 ATB 1T Package Component Temperature Limits

Component	Material	Normal Condition Temperature Limits ºC (ºF)	Fire Accident Temperature Limits ºC (ºF)
Containment Wall Plate	Alloy Steel	426 (800) Note-1	1000 (1832) Note-2
Containment Base Plate	Alloy Steel	426 (800) Note-1	1000 (1832) Note-2
Closure Lid	Alloy Steel	426 (800) Note-1	1000 (1832) Note-2
Dose Blocker Plate	Stainless 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 500ºC (932ºF) 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 CONDITIONS OF TRANSPORT

3.3.1 Computer code

The HI-STAR ATB 1T Package is designed to safely dissipate heat under passive conditions (no wind). The thermal analyses of HI-STAR ATB 1T 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

3.3.2 Maximum Waste Heat Generation Rate

The waste content (primarily stainless steel) is placed in a BTC before loading to a BFA-Tank. As specified in Table 1.2.1, the maximum calculated heat load of waste inside each type of BFA-Tank is different. The maximum calculated heat load inside the BFA-Tank T-200 is much higher than that in the other BFA-Tanks. This is because the amount of waste in a fully loaded BFA-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 BFA-Tank and the maximum permissible Co-60 specific activity of any single waste item loaded into respective BFA-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 BFA-Tank is provided in Table 3.3.1. The maximum waste volumetric heat generation rate is much higher in BFA-Tank T-200 (Type A in Table 3.3.1) than in the other BFA-Tanks. The BFA-Tanks are all of the similar construction and geometry. Therefore, BFA-Tank T-200, which has both the maximum calculated heat load and the maximum waste volumetric heat generation rate, is considered to be the limiting BFA-Tank. The BFA-Tank T-200 is adopted for the 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 a number of time varying parameters. The solar heat flux strongly depends upon the time of the day as well as on latitude and day of the year. Also, the presence of clouds and other atmospheric conditions (dust, haze, etc.) can significantly attenuate solar intensity levels. In the interest of conservatism, the solar attenuation effects of dust, haze, angle of incidence and latitude are neglected.

The 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 ATB 1T 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 ATB 1T 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 ATB 1T 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 ATB 1T 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:

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

Laminar range:

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

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 ATB 1T Package

As noted in Section 1.1, there are different types of BFA-Tank and BTC. The design details (illustrated in Section 1.3) indicate that BFA-Tanks are all of the same construction and geometry. The distinguishing feature of each type of BFA-Tank is the wall thickness. Each type of BFA-Tank is designed to accommodate the dimensions of a type of BTC and its radioactive contents. As discussed in Section 3.3.2, the BFA-Tank T-200 with the design basis heat load and the maximum waste volumetric heat generation rate is considered to be the limiting BFA-Tank and is adopted as the license basis BFA-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 ATB 1T Package. The three dimensional view of the HI-STAR ATB 1T 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 gas in the plenum area inside the BFA-Tank cavity and the cask cavity (i.e. between BFA-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.

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

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3.3.6 <u>Hypothetical Loading Distributions of Waste Content</u>

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

(1) <u>Concentrated Heat Load Distribution</u>

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 BTC. For this concentrated heat load distribution, the waste content is modeled as a rectangular stainless steel box that locates at the center of the BTC cavity. For conservatism, the volumetric heat generation rate of the waste content is slightly higher than the maximum volumetric heat generation rate in Table 3.3.1. 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 BTC 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 BTC is neglected. Therefore, this hypothetical heat load distribution overestimates the maximum temperature of the waste content.

(2) <u>Uniform Heat Load Distribution</u>

It is considered that the volume averaged temperature of the BFA-Tank cavity is the highest if all the waste content is uniformly distributed inside the BTC. For this uniform heat load distribution, the BTC 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 limiting BFA-Tank T-200 with design basis heat load specified in Table 1.2.1. The results are reported in Table 3.3.3. **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** The BFA-Tank T-200 under the uniform heat load distribution described above is the limiting loading scenario and is adopted for the license basis model.

3.3.7 <u>Grid Sensitivity Study</u>

To ensure mesh independent CFD results, a grid sensitivity study is performed for the thermal model of the HI-STAR ATB 1T cask with BFA-Tank T-200 assuming uniform heat load distribution. Per ASME V&V [3.3.3], it is recommended that the refined mesh size in 3D should be about 2.2 times the previous mesh size. This recommended criterion is satisfied by the meshes specified in Table 3.3.4 that gives a brief summary of the different sets of grids evaluated. The maximum waste temperature is compared and the difference caused by the mesh size is negligible. Therefore, the simulation results are independent on the mesh size and no further mesh refinement is necessary. Mesh 2 is adopted for the thermal evaluation of the HI-STAR ATB 1T Package.

3.3.8 <u>Heat and Cold</u>

3.3.8.1 <u>Maximum Temperatures</u>

As required by transport regulations, the HI-STAR ATB 1T 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 ATB 1T Package.

3.3.8.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR ATB 1T 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 ATB 1T Package uniformly approaches the cold ambient temperature. The inner closure lid seals and stainless-steel material of construction of HI-STAR ATB 1T, as discussed in Chapter 2, will perform satisfactorily in cold environmental conditions. Likewise, the HI-STAR ATB 1T stainless 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 ATB 1T 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 ATB 1T Package is heated by the waste before the cask is sealed. Thus, the initial cavity bulk air temperature inside the HI-STAR ATB 1T Package is higher than the ambient temperature, and the cavity pressure reported in Table 3.1.3 is conservatively overestimated.

3.3.10 Sensitivity Study of Contact Gap Impact

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3.3.11 Acceptance Criteria for BFA-Tank Vacuum Drying Operation

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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]

Table 3.3.4: Grid Independent Study

BFA-Tank T-200	**Mesh Size**	**Waste Maximum Temperature °C**
Mesh 1	621,858	190.6
Mesh 2	1,430,714	189.4
Mesh 3	3,449,833	189.3

[Table 3.3.5 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 ATB 1T 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 802ºC (1475°F).

The temperature history of the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T steady state temperature distribution under normal condition of transport is used as the initial condition for fire accident evaluation.

The fire accident is assumed to occur after the drop and puncture accidents that are evaluated in Section 2.7. The following two 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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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 1.5) is designed and included in the thermal model. Under the normal condition, the BFA-Tank stands on the containment base plate of the cask. After the drop accident, the position of the BFA-Tank depends on the configuration of the cask. The position of the BFA-Tank inside the cask is expected to have insignificant impact on the cask temperature since the decay heat inside the cask is small as compared to the 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. [

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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 ATB 1T 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 ATB 1T 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 ATB 1T 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 a post fire cooldown of the cask for a period of approximately 2 hours is computed. 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. As shown in Figure 3.4.1(a), this period is sufficient for the cask containment boundary components and the closure lid seals to reach the maximum temperatures and begin to recede under the fire accident post the top end drop and puncture accidents, which is the more bounding of the two scenarios as described earlier. The results of the analysis are evaluated below.

3.4.3 Maximum Temperatures and Pressures

3.4.3.1 Maximum Temperatures

The HI-STAR ATB 1T 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 for Scenario 2 is graphed in Figure 3.4.1(a). The maximum temperatures reached during fire and post-fire cooldown are reported in Table 3.1.2 for this bounding scenario. 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 more than 100 times 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 BFA-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 BFA-Tank inside the cask cavity.

3.4.3.2 Maximum Pressure

Due to the uncertainty of the BFA-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 volume averaged temperature of the cask containment boundary components is 154ºC (277ºF). The maximum cask cavity average temperature under the fire condition is conservatively overestimated by adding 160ºC (288ºF) to that under the normal condition. 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 BFA-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 BFA-Tank and the cask under the as-installed condition to facilitate loading of the BFA-Tank.

b. The gap will grow during the fire event because the heat-up of the BFA-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 ATB 1T Package has sufficient internal clearance to insure 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	0.6	N/A	0.6
Emissivity of Cask Outer Surfaces	0.587	0.9 (fire emissivity)	0.587

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(a) Withheld in Accordance with 10 CFR 2.390]

FIGURE 3.4.1 (b): Deleted

FIGURE 3.4.2: Deleted

3.5 SAFETY CONCLUSIONS

The safety analyses performed in this chapter demonstrate that:

1. During normal condition of transport under maximum specified ambient temperature, i.e. 38ºC (100ºF) 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 85ºC (185ºF) 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 ATB 1T 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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CHAPTER 4: CONTAINMENT

4.0 INTRODUCTION

This chapter demonstrates the HI-STAR ATB 1T 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]. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the HI-STAR ATB 1T 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 utilizing NUREG/CR-6487, Containment Analysis for Type B Packages Used to Transport Various Contents [4.0.3], and Regulatory Guide 7.4, Leakage Tests on Packages for Shipment of Radioactive Materials [4.0.4] as content guides.

The containment system boundary for the HI-STAR ATB 1T 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 Closure Lid Locking System (CLLS). 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 conditions of transport.

The HI-STAR ATB 1T 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 ATB 1T 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 Subsection 4.3. The condition of the elastomeric seal gaskets of HI-STAR ATB 1T cask will be verified each time the HI-STAR ATB 1T 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 ATB 1T packaging consists of the cask components which form the inner cavity volume used to house a BFA-TANK that contains a BTC loaded with radioactive waste. The BFA-TANK and BTC do not provide containment function. The containment vessel components create an enclosed rectangular parallelepiped cavity sufficient for insertion and enclosure of the BFA-TANK.

4.1.2 Containment Penetrations

HI-STAR ATB 1T 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 ATB 1T 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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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 top flange is equipped with the facility to secure the closure lid via a set of rapidly installable and retractable Closure Lid Locking System (CLLS). Prior to shipment the CLLS locking mechanisms are engaged to ensure the package lid remains engaged with the HI-STAR ATB 1T package during shipment and cannot be opened unintentionally or by a pressure that may arise within the containment vessel.

[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 BFA-TANK is transferred and sealed into the HI-STAR ATB 1T package system there is no 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 ATB 1T cask contains a BFA-TANK. The only free space that remains within the cask is the space between the BFA-TANK and the cask. Prior to loading the BFA-TANK into the HI-STAR ATB 1T cask, it is ensured that the HI-STAR ATB 1T 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 BFA-TANK is drained and dried prior to its final closure; therefore, any BFA-TANK leak would not introduce any explosive gases into the cask cavity. The interior of the BFA-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 were 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 ATB 1T containment boundary. 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 ATB 1T containment packaging tests in Chapter 8 incorporate the appropriate leakage test procedure and sensitivity. The leakage rates for the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T containment packaging tests in Chapter 8 incorporate the pre-shipment leakage test procedure and leakage rate sensitivity.

4.3.3 Periodic Leakage Rate Test

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 ATB 1T 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 ATB 1T containment packaging tests in Chapter 8 incorporate the maintenance leakage test procedure and leakage rate sensitivity.

4.4 CONTAINMENT CALCULATIONS

The HI-STAR ATB 1T 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 ATB 1T 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 utilizing NUREG/CR-6487, Containment Analysis for Type B Packages Used to Transport Various Contents [4.0.3], and Regulatory Guide 7.4, Leakage Tests on Packages for Shipment of Radioactive Materials [4.0.4] as content guides.

4.4.1 Assumptions

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4.4.2 Methodology

The waste transported in HI-STAR ATB 1T is limited to non-fissile reactor related waste irradiated at various NPPs. In accordance with NUREG/CR-6487 [4.0.3], 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 ATB 1T. 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 ATB 1T 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)." [4.0.3]. Therefore all surface activity is assumed to be ^{60}Co with the amount provided in Table 4.4.3.

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:

$$C_i = \frac{f_i A_S}{V} \qquad \textbf{(4-1)}$$

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 4.4.4,
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 4.4.4, and A_{SC} is activity surface density of the contaminated solids [Bq/cm^2; (Ci/cm^2)] shown in Table 4.4.4,
V is the free volume inside the containment vessel [cm^3].

Calculated activity concentrations for normal and hypothetical accident conditions are provided in Table 4.4.5.

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 ATB 1T package.

$$RA_i = C_i \times V \qquad \textbf{(4-2)}$$

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 4.4.6.

4.4.2.4 Allowable Radionuclide Release Rates

The containment criterion for the HI-STAR ATB 1T System under normal conditions of transport is given in 10CFR71.51(a)(1). This criterion requires that a package have a radioactive release rate less than $A_2 \times 10^{-6}$ in one hour, where A_2 is determined 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:

$$R_N = L_N C_N \leq A_2 \times 2.78 \times 10^{-10}/\text{second} \qquad \textbf{(4-3)}$$

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 ATB 1T System under Hypothetical accident conditions is given in 10CFR71.51(a)(2). This criterion requires that a package have a radioactive release rate less than A_2 in one week.

$$R_A = L_A C_A \leq A_2 \times 1.65 \times 10^{-6}/\text{second} \quad \textbf{(4-4)}$$

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 4-3 and 4-4 are used to determine the allowable radionuclide release rates for each condition of transport with results provided in Table 4.4.7.

4.4.2.5 Allowable Leakage Rates at Operating Conditions

The allowable leakage rates at operating conditions were determined by dividing the allowable release rates by the appropriate source term activity concentration (modifying Equations 4-3 and 4-4).

$$L_N = \frac{R_N}{C_N} \quad \text{or} \quad L_A = \frac{R_A}{C_A} \quad \textbf{(4-5)}$$

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 Equations 4-5 are the allowable leakage rates at the upstream pressure. Table 4.4.7 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 were 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 were used as 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 was calculated by solving Equation 4-6 for D, the leak hole diameter.

$$L_{@P_u} = \left[\frac{2.49\text{x}10^6\ D^4}{a\ u} + \frac{3.81\text{x}10^3\ D^3 \sqrt{\frac{T}{M}}}{a\ P_a} \right] \left[P_u - P_d \right] \frac{P_a}{P_u} \qquad \textbf{(4-6)}$$

where,

$L_{@Pu}$ 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 gas molecular weight [g/mole] from ANSI N14.5, Table B1 *[8.1.4]*,

u is the fluid viscosity for air [cP] from Reference [4.4.2]

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 4.4.2.

The bounding leak hole diameter at operating conditions was determined by solving Equation 4-6 for 'D' where $L_{@Pu}$ is L_N and L_A in Table 4.4.7 for normal and hypothetical accident conditions of transport, respectively. Other parameters to solve Equation 4-6 are presented in Table 4.4.2.

Using this leak hole diameter and the temperature and pressure specified for reference test conditions provided in Table 4.4.2, Equation 4-6 was 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:

$$Q_{u\text{-}i} = L_{u\text{-}i} \times P_{u\text{-}i} \quad \textbf{(4-7)}$$

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 4-7, 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.

To account for the short term release in Table 4.4.9, the allowable leak rate for hypothetical accident condition in Table 4.4.8 is reduced by 20%. Since the activity corresponding to 20% of A_2 value (2.16 Ci), bounds the activity in Table 4.4.9, the containment criterion for the HI-STAR ATB 1T System under hypothetical accident conditions given in 10CFR71.51(a)(2) is satisfied.

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.

4.4.2.7 Lid Leakage Evaluation Under 10CFR Part 71 30-foot Drop Accident

Under a 30 ft oblique drop accident simulation, the containment lid/flange geometry yield unloading of the lid seals in excess of the seal useful (allowable) spring back for short time duration. To evaluate potential leakage a physical gap is conservatively postulated beyond the allowable spring back and gas leakage computed. Flow under the lid and seal gaps is conservatively modeled using turbulent friction factor and flow loss correlations [4.4.4]. This approach differs from use of NUREG/CR-6487 [4.0.3] correlations for molecular and continuum flows as justified below. Maximum gaps obtained under drop simulations are conservatively overstated to maximize leakage flow [4.4.5]. An upperbound activity release under drop event is computed and tabulated in Table 4.4.9. The release is well below the 10CFR71.51(a)(2) accident limit.

ATB1T lid leakage calculations under the gap openings obtained during 30-foot drop accident simulations have considered NUREG/CR-6487 methodologies and concluded as follows:

- The flow conditions do not satisfy NUREG continuum, molecular and choked flow criteria as evaluated below.
- NUREG methodology is contra-indicated for computing lid leakage under drop accident conditions.

NUREG Flow Condition	NUREG Criteria	Lid Leakage Condition [4.4.6]	Remarks
Continuum Flow	Section 2.2.1: Reynolds No. (Re) < 2100	Top End Drop: Re = 5818 Slap Down Drop: Re = 31717 & 5838 (Short & Long Edges)	Does not satisfy continuum flow criteria
Molecular Flow	Section 2.2.2: Mean Free Path (λ) > diameter of leakage path (d)	λ (Air) = 142.2 nm (0.000142 mm) Top End Drop: d (gap opening) = 2.286 mm Slap Down Drop: d (gap opening) = 3.81 mm & 2.286 mm (Short & Long Edges)	Does not satisfy molecular flow criteria
Choked Flow	Section 2.2.3: Down Stream Pressure Pd < 50% Upstream Pressure Pu	Pd = 14.7 psi 50% Pu = 9.65 psi	Does not satisfy choked flow criteria

The above conclusions are consistent with 1 to 250 micron gaps range considered for gas flows in the NUREG methodology (NUREG/CR-6487, Section 2.2.5). Gaps obtained under drop accidents are much greater. Flows under these conditions are in the turbulent zone (Re > 4,000 [4.4.4]) which are suitably evaluated adopting friction factor correlations articulated in the fluid mechanics literature.

[Table 4.4.1 Withheld in Accordance with 10 CFR 2.390]

Table 4.4.2: Parameters for Normal and Test Conditions

Parameter	Normal Conditions	Hypothetical Accident Conditions	Reference Air Test Conditions
Upstream Pressure (P_u)	NCT BFA-Tank Cavity Pressure in Table 3.1.3	HAC BFA-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 BFA-Tank Cavity Bulk Temperature in Table 3.1.3	HAC BFA-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)	0.0222 cP (air) [4.4.2]	0.0283 cP (air) [4.4.2]	0.0184 cP (air) [4.4.2]
Seal Gasket Seating Width (a)	0.59 cm [DWG 9786]	0.59 cm [DWG 9786]	0.59 cm [DWG 9786]

Table 4.4.3: Isotope Inventory

Nuclide	**Inventory**
Gases	
N/A	N/A
Crud	
^{60}Co	597.6 Ci (2.211×10^{13} Bq)
Volatiles	
N/A	N/A
Fines	
N/A	N/A

[Table 4.4.4 Withheld in Accordance with 10 CFR 2.390]

[Table 4.4.5 Withheld in Accordance with 10 CFR 2.390]

Table 4.4.6: Total Source Term Effective A_2 for Normal and Hypothetical Accident Conditions

Equipment	Effective A_2
Normal Transport Conditions	
HI-STAR ATB 1T	10.8 Ci (0.4 × 10^{12} Bq)
Hypothetical Accident Conditions	
HI-STAR ATB 1T	10.8 Ci (0.4 × 10^{12} Bq)

Table 4.4.7 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 ATB 1T	3.0×10^{-9} Ci/s (111 Bq/s)	129×10^{-6} cm^3/s
Accident Conditions		
HI-STAR ATB 1T	17.82×10^{-6} Ci/s (659×10^3 Bq/s)	115×10^{-3} cm^3/s

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 ATB 1T	2.10×10^{-4} cm^3/s	2.10×10^{-4} atm-cm^3/s, Air (2.12×10^{-5} Pa-m^3/s, Air)
Accident Conditions		
HI-STAR ATB 1T	1.12×10^{-1} cm^3/s	1.12×10^{-1} atm-cm^3/s (1.135×10^{-2} Pa-m^3/s, Air)

Table 4.4.9: Activity Release from Lid Leakage Evaluation Under 10CFR Part 71 30-foot Drop Accident

Activity	Top End Drop 0.141 Ci (5.22 x 10^9 Bq) Slap Down Drop 1.538 Ci (56.91 x 10^9 Bq)

CHAPTER 4 REFERENCES

[4.0.1] 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.

[4.0.2] *Intentionally Deleted*

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[4.0.4] U.S. Nuclear Regulatory Commission, Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Materials", June 1975.

[4.1.1] American Society of Mechanical Engineers (ASME), Boiler and Pressure Vessel Code, Section III, Division 1, Subsection NB, Class 1 Components, 1993 Edition.

[4.4.1] "Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purposes", Technical Reports Series No. 389, Activities in Tables XVI to XXI, and Surface Activity Densities in Annexes I-1 to I-9 International Atomic Energy Agency, Vienna, 1998.

[4.4.2] Bolz et.al., "CRC Handbook of Tables for Applied Engineering Science", 2nd edition, pages 11-12, CRC Press, 1976.

[4.4.3] H.D Oak et. al., "Technology, Safety and Costs of Decommissioning a Reference Boiling Water Reactor Power Station", NUREG/CR~0672-Vol.2, Appendix E, Tables E.2-4 and E.2-6, Pacific Northwest Laboratory, 1980.

[4.4.4] "Flow of fluids through valves, fittings and pipe", Crane Technical Paper No. 410, Fifteenth Printing, 1976.

[4.4.5] Table 8.4, ATB1T Drop Calculation Package HI-2177539, Rev. 4.

[4.4.6] Containment Analysis for HI-STAR ATB 1T, HI-2156697, Rev. 2, Holtec Report.

CHAPTER 5 - SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR ATB 1T Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter.

The HI-STAR ATB 1T is designed to accommodate different types of BFA Tanks, with different tank wall thicknesses. The outer dimensions are the same for all types of BFA tanks. The HI-STAR ATB 1T cavity and outer dimensions are provided in the Engineering Drawings, Section 1.3. The BFA tank and BTC dimensions are provided in the Engineering Drawings, Section 1.3. Additionally the maximum Co-60 specific activity for each BFA tank type is listed in Table 7.1.2. 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 ATB 1T 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 ATB 1T.
- 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 ATB 1T.
- Analyses for the HI-STAR ATB 1T'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 ATB 1T 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 ATB 1T is intended to serve as a transportation cask for transporting one BFA-tank (per transport) containing irradiated and contaminated steel reactor internals. The steel BFA tank and BTC plates also provide additional gamma shielding. The dimensions of the shielding components of both the HI-STAR ATB 1T cask and the BFA tanks are shown in the drawing package in Section 1.3. The shielding material densities are listed in Table 5.3.1.

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 BFA tank, with its specific activity in Table 7.1.2 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 BFA tank 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.

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.1.3.1 Routine and Normal Conditions

The shielding analysis confirms that the HI-STAR ATB 1T 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 5.1.1. 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 ATB 1T 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 ATB 1T, 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 ATB 1T 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 ATB 1T have been calculated at a distance of 2 m from the outer lateral surfaces of the cask, for the locations shown in Figure 5.1.2. 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 ATB 1T 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 ATB 1T'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 BFA tanks, and damage (reduction in shielding thickness) to the impacted surface of the HI-STAR ATB 1T cask as a result of the 9-meter (30 foot) drop.

Some indentation and localized thickness reduction of the HI-STAR ATB 1T 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 BFA 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 ATB 1T 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 5.1.3 shows the dose locations at 1 meter from the surface for the conditions of the HI-STAR ATB 1T Package after postulated accident conditions.

The maximum dose rate results of several hypothetical accident conditions are presented in Table 5.1.3. All values in Table 5.1.3 and Table 5.4.4 are below the regulatory limit of 10 mSv/h.

Analyses summarized in this section demonstrate the HI-STAR ATB 1T 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 REMOVED]	Surface Dose Rates (mSv/hr)	[PROPRIETARY INFORMATION REMOVED]	10 CFR 71.47 Limit (mSv/hr)
Entire cavity filled with a uniform source of maximum specific activity and maximum waste density		0.913		2
		1.088		2
		1.177		2
		1.123		2

[1] **[PROPRIETARY INFORMATION REMOVED]**

TABLE 5.1.2
MAXIMUM 2-METER DOSE RATES FOR MAXIMUM SPECIFIC ACTIVITY WASTE CONTENT (UNIFORM) UNDER NORMAL CONDITIONS[1]

Normal Condition	[PROPRIETARY INFORMATION REMOVED]	2 meter Dose Rates (mSv/hr)	[PROPRIETARY INFORMATION REMOVED]	10 CFR 71.47 Limit (mSv/hr)
Entire cavity filled with a uniform source of maximum specific activity and maximum waste density		0.048		0.1
		0.048		0.1
		0.048		0.1
		0.048		0.1

[1] **[PROPRIETARY INFORMATION REMOVED]**

TABLE 5.1.3
MAXIMUM 1-METER DOSE RATES FOR MAXIMUM SPECIFIC ACTIVITY WASTE CONTENT UNDER SEVERAL ACCIDENT CONDITIONS[1]

Accident Condition, [PROPRIETARY INFORMATION REMOVED]	Tank Type	1 meter Dose Rates (mSv/hr)	[PROPRIETARY INFORMATION REMOVED]	10 CFR 71.51 Limit (mSv/hr)
		8.6	0.37	10.0

[1] **[PROPRIETARY INFORMATION REMOVED]**

TABLE 5.1.4
DISTANCES FOR THE 0.02 mSv/h DOSE RATE REQUIREMENT FOR THE HI-STAR ATB 1T FOR NORMAL CONDITIONS[1]

Distance (meters)	[PROPRIETARY INFORMATION REMOVED]	Dose Rate (mSv/hr)	[PROPRIETARY INFORMATION REMOVED]	10 CFR 71.47 Limit (mSv/hr)
5		0.016		0.02
5		0.016		
5		0.016		
5		0.016		

[1] **[PROPRIETARY INFORMATION REMOVED]**.

TABLE 5.1.5
MAXIMUM 1-METER DOSE RATES FOR MAXIMUM SPECIFIC ACTIVITY WASTE CONTENT (UNIFORM) UNDER NORMAL CONDITIONS[1]

Normal Condition	[PROPRIETARY INFORMATION REMOVED]	1 meter Dose Rates (mSv/hr)	[PROPRIETARY INFORMATION REMOVED]	HI-STAR ATB 1T Transport Index
[PROPRIETARY INFORMATION REMOVED]		0.072		7.2
		0.071		
		0.069		
		0.068		

[1] **[PROPRIETARY INFORMATION REMOVED]**.

FIGURE 5.1.1: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.1.2: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.1.3: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

5.2 SOURCE SPECIFICATION

The non-fuel waste content to be qualified for transportation in the HI-STAR ATB 1T 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. Dimensions of the inner cavities and the thickness of the BFA tank walls vary according to BFA 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 ATB 1T 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). The neutron source (n/s/kg) in Table 7.1.2 is an input to the neutron dose calculations presented in Table 5.4.5 and demonstrates dose rates from neutron emitting radionuclides will 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-1617 states that “In general, only gammas from approximately 0.8 MeV-2.5 MeV will contribute significantly to the external radiation levels” [5.2.1]. 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 [5.2.2], 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 provides some source term calculations showing the relative contribution of radionuclides other than Co-60 [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390].

5.3 SHIELDING MODEL

The shielding analysis of the HI-STAR ATB 1T was performed with MCNP 5 1.51 [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 ATB 1T 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 ATB 1T Package for normal conditions includes the BFA tank and BTC top and bottom plates.

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

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 ATB 1T 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 shows a cross sectional view of the HI-STAR ATB 1T cask under normal conditions as modeled in MCNP. Figure 5.3.2 shows a cross section of the trunnion area of the HI-STAR ATB 1T cask under normal conditions as modeled in MCNP. Figure 5.3.3 shows a cross sectional view of the HI-STAR ATB 1T cask under hypothetical accident conditions [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.3.1.1.1 Normal Conditions modeling

The conditions and tests specified in 10CFR 71.71 for normal conditions [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.3.1.1.2 Hypothetical Accident Conditions Modeling

Under the drop accident conditions the BFA tank and BTC 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 BFA tank fail. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

For the BTC, the situation is different. Since the tie rods of the BTC are not strong enough, and assumed to fail under certain hypothetical accident conditions, a relocation of the top and bottom plates of the BTC is feasible. The bounding case would be a relocation of the bottom plate of the BTC in the BFA-200 tank, since this plate has the largest thickness of all BTC top and bottom plates (150 mm), and the BFA-200 tanks contain waste with the highest activity.

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

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. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.3.1.2.2 Accident Conditions Source Configuration

The accident conditions follows the same source modeling approach as the normal conditions with two additional considerations:

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.3.1.3 Material Properties

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

TABLE 5.3.1

[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.1: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.2: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.3: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.4: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.5: HI-STAR ATB 1T CASK ENCLOSING BFA TANK AND BTC, CROSS-SECTIONAL VIEW. FIGURE IS NOT DRAWN TO SCALE.

FIGURE 5.3.6: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.7: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.8: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.9: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.10: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.11: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

FIGURE 5.3.12: [PROPRIETARY FIGURE REMOVED PER 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 will assure that the actual dose rates will always be below the calculated dose rates, and below the regulatory limits. Selected key assumptions are:

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

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.

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

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 Chapter 1, the waste specifications, and the material compositions listed in Section 5.3.

[PROPRIETARY TEXT REMOVED PER 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

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.4.4 EXTERNAL RADIATION LEVELS

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

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

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

TABLE 5.4.1 (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Gamma Energy (MeV)	**(mSv/h)/ (photon/cm^2-s)** †
2.6	3.82E-05
2.8	4.01E-05
3.25	4.41E-05
3.75	4.83E-05
4.25	5.23E-05
4.75	5.60E-05
5.0	5.80E-05
5.25	6.01E-05
5.75	6.37E-05
6.25	6.74E-05
6.75	7.11E-05
7.5	7.66E-05
9.0	8.77E-05
11.0	1.03E-04
13.0	1.18E-04
15.0	1.33E-04

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

TABLE 5.4.1 (CONTINUED)

FLUX-TO-DOSE CONVERSION FACTORS
(FROM [5.4.1])

Neutron Energy (MeV)	Quality Factor	(mSv/hr)†/(n/cm²-s)
2.5E-8	2.0	3.67E-5
1.0E-7	2.0	3.67E-5
1.0E-6	2.0	4.46E-5
1.0E-5	2.0	4.54E-5
1.0E-4	2.0	4.18E-5
1.0E-3	2.0	3.76E-5
1.0E-2	2.5	3.56E-5
0.1	7.5	2.17E-4
0.5	11.0	9.26E-4
1.0	11.0	1.32E-3
2.5	9.0	1.25E-3
5.0	8.0	1.56E-3
7.0	7.0	1.47E-3
10.0	6.5	1.47E-3
14.0	7.5	2.08E-3
20.0	8.0	2.27E-3

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

TABLE 5.4.2
[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.4.3
[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.4.4
[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.4.5
[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.4.6
[PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.4.7

[PROPRIETARY TABLE REMOVED PER 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 ATB 1T Shielding Calculation Package HI-2156583. Revision 5. Holtec International.

[5.2.1] NUREG-1617, SRP for Transportation Packages for Spent Nuclear Fuel, USNRC, Washington, DC, March 2000.

[5.2.2] 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.

APPENDIX 5.A
WASTE CHARACTERIZATION - SHIELDING EVALUATION

5.A.1 INTRODUCTION

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.A.2 METHODOLOGY

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.A.3 INPUT DATA AND ASSUMPTIONS

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

5.A.4 CALCULATIONS AND RESULTS

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

TABLE 5.A.1: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.A.2: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.A.3: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.A.4: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.A.5: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

TABLE 5.A.6: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

APPENDIX 5.A REFERENCES

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

CHAPTER 6: CRITICALITY EVALUATION

6.0 INTRODUCTION

The HI-STAR ATB 1T is designed to serve as a transportation cask for radioactive wastes material. The total weight of the fissile material to be transferred in the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T 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. 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 applicable to the transport of the HI-STAR ATB 1T 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, "European Agreement Concerning the International Carriage of Dangerous Goods by Road" and the RID, "European Agreement Concerning the International Carriage of Dangerous Goods by Rail" may be 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 operation of the HI-STAR ATB 1T. Written procedures are required and will be developed or modified to account for such items as handling and storage of systems, structures and components identified as *important-to-safety*, heavy load handling, specialized instrument calibration, special nuclear material accountability, 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 design limits during loading operations.

Material selection and verification shall be performed by the user in accordance with written, approved procedures that ensure that waste materials authorized in the CoC are loaded into the HI-STAR ATB 1T cask.

Control of the package operation 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 ATB 1T Cask can be loaded under the following possible Loading Scenarios (LS):

LS-1) Loading of a BTC from a storage pool into a prepared HI-STAR ATB 1T Cask, with a pre-installed BFA-Tank;

LS-2) Installation of a previously loaded BFA-Tank into a HI-STAR ATB 1T Cask;

For transport, the cask is secured to a transport vehicle (truck, railcar, barge, etc.) either directly or indirectly via a Transport Frame. The Transport Frame may include a Work Platform to provide access to the cask and shall include a Weather Protection Cover (WPC). The cask may be loaded or unloaded while attached to the Transport Frame. The Work Platform (if used) 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 HI-STAR ATB 1T Cask under these Loading Scenarios are described below.

7.1.1 Preparation for Loading of a HI-STAR ATB 1T Cask

7.1.1.1 General Preparations (Applicable to all Loading Scenarios)

1. If necessary, the empty HI-STAR ATB 1T Cask is transported to the loading area using the Transport Frame and transport vehicle.

2. Visual examination is performed on the empty HI-STAR ATB 1T Cask to ensure that there are no outward visual 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 Section 8.2.4(ii). Loading preparations will resume only after corrective actions and/or repairs have been completed.

3. If required, the empty HI-STAR ATB 1T Cask is lifted from the Transport Frame by its Lifting Trunnions and placed on the loading area floor. Temporary work platforms may be installed around the cask to allow convenient access.

4. 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.

5. The Cask Lid Locking System (CLLS) is disengaged by removing the Locking Wedge Lock Bars and actuating the CLLS operating system. The cask lid lifting device is installed and the cask lid is then removed.

6. Examination of the cask lid o-ring seal gasket condition is performed and, if necessary, replaced per Table 8.2.1.

7. Examination of the cask o-ring sealing surface condition is performed and, if necessary, repaired to eliminate any potential leakage paths, and tested per Subsection 8.2.3.

8. Any foreign material is removed from inside the cask's Containment space.

9. A site-specific evaluation is used to determine if the maximum loaded weight and maximum specific activity of the contents to be loaded in the Waste Package complies with the CoC limits in Table 7.1.1 and Table 7.1.2.

7.1.1.2 Additional Preparations for Loading of a BTC from Storage Pool (LS-1 only)

1. The BFA-Tank lifting device is installed and an empty BFA-Tank is loaded into the HI-STAR ATB 1T Cask.

2. The BFA-Tank cover is unbolted and removed, using the BFA-Tank lifting device.

3. A Docking Protective Cover is installed to close off the gap between the BFA-Tank and the inside of the cask to prevent contamination of the BFA-Tank exterior and of the cask interior during installation of the BTC.

7.1.2 Cask Loading

7.1.2.1 LS-1: Loading of a BTC from Storage Pool into the HI-STAR ATB 1T Cask

1. The BTC is loaded in accordance with a site-specific loading plan which includes procedures for cutting, weighing, measuring and marking waste component parts.

2. A loaded BTC is lifted from the pool to the refueling area floor inside a radiation shielded Wet Hood.

3. The Wet Hood (with the BTC) is lifted over the HI-STAR ATB 1T cask (with empty BFA-Tank) and mated to the cask.

4. The BTC is lowered into the BFA-Tank and the Wet Hood is disengaged and removed.

5. The Docking Protective Cover is removed and a radiation shielded Drying Cover is placed on the cask.

6. A vacuum drying system is connected to the Drying Cover. Vacuum drying is performed at parameters listed in Table 7.1.1 to remove all bulk water from the cask.

7. The Drying Cover is removed and the BFA-Tank cover is placed on the BFA-Tank, using the BFA-Tank lifting device. A radiation shield may be installed on the cask to reduce personnel dose during subsequent activities.

8. The BFA-Tank lid bolts are installed and torqued to wrench tight.

9. If installed, the radiation shield is disengaged from the cask and removed.

ALARA Warning:
Dose rates near the open ATB1T cask with BFA-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.

10. Verification of the cask o-ring sealing surface cleanliness is performed. Any foreign material is removed.

7.1.2.2 LS-2: Loading of a BFA-Tank into the HI-STAR ATB 1T Cask

1. Prior to installation, the loaded BFA-Tank is certified to have been loaded in accordance with the procedure described in Section 7.1.2.1, or with a site-specific procedure that ensures the BFA-Tank has been dried to remove bulk moisture per Table 7.1.1 and the lid bolts have been installed wrench tight. A site-specific loading cask may have been used in lieu of the HI-STAR ATB 1T cask.

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

2. Verification of the loaded BFA-Tank cleanliness is performed. Any foreign material is removed from the outer surface of the BFA-Tank.

3. The BFA-Tank cover bolts are verified to be installed and torqued to the value recommended by the supplier of the BFA-Tank.

4. If required, Corner Guides may be installed to guide the BFA-Tank into the cask.

5. The BFA-Tank lifting device is installed and the loaded BFA-Tank is lifted and placed in the prepared HI-STAR ATB 1T Cask.

6. The BFA-Tank lifting device is removed from the BFA-Tank.

7. If used, the Corner Guides are removed or disengaged.

7.1.3. Cask Closure (Applicable to All Loading Scenarios)

1. The cask lid is prepared for installation by:

    a. Ensuring that the CLLS is in the fully disengaged position;

    b. Verification of the cask lid o-ring gaskets cleanliness and removing any foreign material;

    c. Attaching the cask lid lifting device.

2. The cask lid is lifted and placed on the cask. The cask lid lifting device is removed.

3. The CLLS is moved to the locked position *and* the Locking Wedge Lock Bars are engaged. Successful insertion of the Locking Wedge Lock Bars is the only acceptance criteria required to ensure that the CLLS remains fully engaged with the cask body and closure lid during shipment, thus maintaining containment.

4. Leak testing of the sealed cask is performed per Section 8.2.3.

5. If necessary, the temporary work platform is removed from the work site.

7.1.4. <u>Preparation for Transport (Applicable to All Loading Scenarios)</u>

1. If necessary, the loaded HI-STAR ATB 1T Cask is lifted by its Lifting Trunnions and placed on the Transport Frame.

2. If not already fastened, the cask is fastened to the Transport Frame.

3. Final radiation surveys of the cask surfaces per 10CFR71.47 [7.1.3] and 49CFR173.443 [7.1.2] are performed and if necessary, the HI-STAR ATB 1T Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents.

4. A security seal (tamper device) is attached to the sealed cask.

5. The WPC is installed on the cask and transport frame. The installed WPC is secured to the cask lifting trunnions, rendering them inoperable for lifting the cask.

6. The loaded cask is given a final examination according to user procedures to ensure that all conditions for transport have been met.

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

Table 7.1.1: Package Control Parameters & Their Bases

#	Item	Requirement	Basis
1	Maximum weight of the loaded HI-STAR ATB 1T Package, lb	249,122 (113,000 kg)	Estimated based on the materials of construction.
2	Nominal weight of the empty HI-STAR ATB 1T cask (no waste package), lb	136,686 (62,000 kg)	
3	Maximum permissible weight of the cask contents (waste package), lb	112,436 (51,000 kg) (Note 1)	
4	Vacuum drying pressure and time	8 millibar maximum for 2 hours minimum	Sufficient for removal of all bulk water from cask.

Notes
1. "Waste package" in this SAR is defined as the secondary container, the waste basket, dunnage, and radioactive contents according to Table 7.1.2. Design basis safety analyses may use upper or lower bound weight values, as appropriate, to ensure conservatism.

Table 7.1.2: Cask and Waste Package Control Parameters (Sheet 1 of 2)

Waste Package Type	A	B	C	D
Representative Wall Thickness of the Waste Package (mm)	200	150	100	50
Permissible Secondary Container Model No.	BFA-Tank T-200	BFA-Tank T-150	BFA-Tank T-100	BFA-Tank T-50
Permissible Waste Basket Model No.	BFA-Tank Cassette T-200	BFA-Tank Cassette T-150	BFA-Tank Cassette T-100	BFA-Tank Cassette T-50
Maximum permissible Co-60 specific activity of any single waste item loaded into respective BFA-Tank (GBq/Kg)	1400	180	23	3
Maximum permissible specific activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of any single waste item loaded into respective BFA-Tank (GBq/Kg)	140	18	2.3	0.3
Maximum permissible Co-60 activity of fully loaded BFA-Tank (Bq)	3.60E+15	2.16E+15	2.76E+14	3.45E+13
Maximum permissible Activity of Radionuclides, Excluding Co-60, with Gamma Energies > 0.45 MeV of fully loaded BFA-Tank (Bq)	3.60E+14	2.16E+14	2.76E+13	3.45E+12
Maximum permissible Co-60 activity of non-fixed surface contamination (Bq)	2.211E+13			
Maximum permissible quantity of fissile material (including SNM) (grams)	2			
Minimum cooling time of waste (years)	1.0			
Maximum permissible heat load (kW)	1.75			

Table 7.1.2: Cask and Waste Package Control Parameters (Sheet 2 of 2)

Maximum Permissible Waste Material Neutron Source per unit mass (n/s/kg)	20

Notes

1. Not used.
2. The user shall verify prior to loading the ATB 1T cask that the specific activity of the waste components to be loaded have been pre-calculated (i.e. calculated prior to loading the ATB 1T 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 maximum values specified in this Table. 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 corresponding specific activity limit in Table 7.1.2.
3. Dose rate surveys shall be performed prior to shipment as specified in this Chapter to verify an acceptable loading of the HI-STAR ATB-1T cask in addition to demonstrating compliance with 10CFR71.47 [7.1.3].
4. 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.

7.2. PACKAGE UNLOADING

7.2.1 Receipt of Package from Carrier

1. The HI-STAR ATB 1T 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 Section 8.2.4(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 ATB 1T 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 the designated preparation area.

4. The WPC is removed from the cask to allow access to the cask lifting trunnions for lifting the cask.

5. 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 ATB 1T Cask is unfastened from the Transport Frame.

2. If required, the HI-STAR ATB 1T Cask is lifted from the Transport Frame by its Lifting Trunnions and placed in the designated unloading area. Temporary work platforms may be installed around the cask to allow convenient access.

3. The cask lid lifting device is installed on the cask lid.

4. The CLLS is disengaged by disengaging the Locking Wedge Lock Bars and actuating the CLLS operating system.

ALARA Warning:
Dose rates near the open HI-STAR ATB 1T Cask may require additional ALARA controls. Appropriate personnel shielding and radiation monitoring should be specified by the cask user to limit personnel dose ALARA.

5. The cask lid is removed and set in a designated area. Care is taken to prevent damage to the cask o-ring gaskets and to maintain lid cleanliness.

6. The BFA-Tank lifting device is installed and the BFA-Tank is lifted from the cask and placed in its designated storage area.

7. 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. The CLLS is moved to the locked position. The Locking Wedge Lock Bars are engaged to ensure the CLLS remains engaged with the cask body during shipment.

5. If necessary, the HI-STAR ATB 1T 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. Final verification that the empty cask meets all conditions for transport is performed according to user procedures.

8. Following the above checks, the empty cask is released for transport.

7.4 OTHER OPERATIONS

There are no other operations for the HI-STAR ATB 1T 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 49 “Transportation”, Part 172 "Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements and Security Plans."

[7.1.2] *U.S. Code of Federal Regulations,* Title 49 “Transportation”, Part 173, "Shippers – General Requirements for Shipments and Packagings,"

[7.1.3] *U.S. Code of Federal Regulations,* Title 10, “Energy”, Part 71 "Packaging and Transportation of Radioactive Material".

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 ATB 1T 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 [8.0.1].

8.1 ACCEPTANCE TESTS

In this section the inspections and acceptance tests to be performed on the HI-STAR ATB 1T Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR ATB 1T 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 ATB 1T Packaging (including waste packaging with important to safety 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. For HI-STAR ATB 1T casks not transported in the USA, the BFA-Tanks and BFA-Tank Cassettes may be manufactured under a separate and equivalent QA program.

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 ATB 1T Packaging shall become part of the final quality documentation package.

8.1.2 Weld Examination

The examination of HI-STAR ATB 1T 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 in order 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 acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. Examinations, including Visual (VT), Radiographic (RT), and Liquid Penetrant (PT) or Magnetic Particle (MT), apply to these welds as defined by the code. These welds shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450 and examined after repair in the same manner as the original weld. If used, 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 Top, Side, and Bottom cask impact absorbers shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5300. These welds shall be repaired in accordance with ASME Code Section III, Article NF-4450 and examined after repair in the same manner as the original weld. These weld requirements are not applicable to not *important-to-safety* (NITS) welds (e.g. seal welds) on the cask.

3. NITS welds shall be examined and repaired in accordance with written and approved procedures.

8.1.3 Structural and Pressure Tests

The cask containment boundary will be examined and tested by 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.

The structural strength and stiffness of crushable attachments to the package and the closure lid impact absorber spacer, which serve to absorb significant portion of energy from package impact event, are very crucial to maintain 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. The components which serve the purpose impact absorbers are specifically identified in the transport package licensing drawing. Furthermore, these materials must be physically tested for the key material properties listed in Table 8.1.5. Accordingly, Table 8.1.5 specifies the range of strength properties for these crushable and impact absorber components and these key properties must be unequivocally met during the cask fabrication. In light of the key safety function of these components, the HI-STAR ATB 1T package is evaluated for upper and lower bound strength properties defined in Table 8.1.5. Further details regarding the numerical simulations are discussed in Sections 2.6 and 2.7.

8.1.3.1 Trunnions

Eight trunnions (4 pairs) near the top of the cask on opposing long sides are provided for vertical lifting and handling of the loaded or empty cask during loading and unloading operations. Trunnions of a pair are on either side of the cask in the configuration indicated in the drawing package in Section 1.3. The four pairs of trunnions constitute two load paths for lifting and handling. The inner-most/centrally located two pairs of trunnions constitute the inner path and the two outer-most pairs of trunnions define the outer path. Four of the eight trunnions (one load path) are effectively in use when the cask is lifted. The other four trunnions (second load path) are connected redundantly to the cask lift yoke. 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 least two pairs of lifting trunnions (one load path) shall be tested for vertical lifting and handling of the package in accordance with ANSI N14.6 at 300% of the maximum design-basis lifting load (Table 7.1.1) in the configuration matching the lifting equipment. The second pair (second load path) of lifting trunnions may be tested in accordance with ANSI N14.6 at either 150% or 300% of the maximum design basis lifting load (150% if used as redundant lifting appurtenances). Load tests may be performed in excess of the test loads specified above provided an engineering evaluation is performed to ensure trunnions or other cask components will not be damaged by the load test. The test load shall be applied for a minimum of 10 minutes. 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. Test results shall be documented and shall become part of the final quality documentation package.

8.1.3.2 Pressure Testing

Pressure testing of the HI-STAR ATB 1T package is not required. The Maximum Normal Operating Pressure (MNOP) for the HI-STAR ATB 1T package does not exceed the 5 psig threshold in 10 CFR 71.85(b).

8.1.4 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 disengaging the CLLS or as justified by the requirements in SAR Paragraph 8.2.4(v).

In case of an unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change, retesting shall be performed using the same test 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 by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A [8.1.2]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

Fabrication leakage rate test results shall become part of the final quality documentation package. The pre-shipment leakage rate test shall be documented in accordance with the user's quality assurance program.

8.1.5 Component and Material Tests

8.1.5.1 Containment Seals (Gaskets)

Cask containment seals are elastomeric seals that 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.

8.1.5.2 Impact Testing

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. Fracture toughness testing of nickel alloy, austenitic stainless steel components and austenitic stainless steel weld metal is not required. Non-containment boundary metallic components and associated welds identified in the drawing package in the CoC are either austenitic stainless steel or nickel alloy, and therefore exempt from brittle fracture testing in accordance with ASME Section III, Subsections NF-2311 (components), and NF-2430 (associated welds) [8.1.1]. Brittle fracture testing of the BFA-Tanks and BTCs is not required.

Test results shall become part of the final quality documentation package.

8.1.6 Shielding Tests

Pre-Shipment Testing after First Loading

A shielding effectiveness test shall be performed prior to the first shipment as specified in the following paragraph.

Following the first waste loading of each HI-STAR ATB 1T package, a shielding effectiveness test 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 and BFA-Tank/BTC combination 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 ATB 1T 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	Type of Leakage Test (from ANSI N14.5-2014, App. A) 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 • Top Flange • Closure Lid • Containment Boundary Welds	A.5.3	1×10^{-4} atm-cm^3/s, Air (1×10^{-5} Pa-m^3/s, Air)	5×10^{-5} atm-cm^3/s, Air (5×10^{-6} Pa-m^3/s, Air)
	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 and A.5.4		
Pre-Shipment Acceptance Test (Note 2)	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 and A.5.4		

Table 8.1.1 (Sheet 2 of 2):
Containment System Leak Test Specifications

Leakage Test	Components Tested	Type of Leakage Test (from ANSI N14.5-2014, App. A) 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 • 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 and A.5.4		
Periodic Leakage Acceptance Test	• Closure Lid Inner Seal	A.5.1, A.5.2, A.5.3 and A.5.4		

Notes:
1. 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.

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Table 8.1.2 (Sheet 1 of 3): ASME Code Boiler & Pressure Vessel Code and Other Standards Applicable to HI-STAR ATB 1T

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Criteria	Welding (Fabrication and Qualification)	Inspection	Testing
Cask Containment boundary (except closure seals)	ASME Code Section III Subsection NB-2000 ~~(Note 2)~~	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
Trunnions	ASME Code Section II	NUREG-0612	NUREG-0612	Not Applicable	Chapter 8 of this SAR	Chapter 8 of this SAR
Locking Wedge Lock Bar	ASME Section II	No gross yielding, buckling or failure	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Closure Lid and Cask Body Insulation Boards	Note 1	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Closure Lid Lift Lug	ASME Section II	NUREG-0612	NUREG-0612	Not Applicable	Not Applicable	Not Applicable
Cask Dose Blocker Structure (DBS)	ASME 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

Table 8.1.2 (Sheet 2 of 3) : ASME Code Boiler & Pressure Vessel Code and Other Standards Applicable to HI-STAR ATB 1T

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Criteria	Welding (Fabrication and Qualification)	Inspection	Testing
BFA-Tanks	Note 1	Walls, Top Cover and Base Plate **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** Welds **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	Not Applicable	Not Applicable	Not Applicable
BTC	Note 1	Corners Tie Rods **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]** Top and Bottom **[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Spacers for top or bottom of BFA-Tanks, Impact Absorber Spacer, Internal Side Shim Assembly	ASTM or ASME Section II	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

Table 8.1.2 (Sheet 3 of 3) : ASME Code Boiler & Pressure Vessel Code and Other Standards Applicable to HI-STAR ATB 1T

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Criteria	Welding (Fabrication and Qualification)	Inspection	Testing
Top, Bottom, and Side Walls Impact Absorbers (Steel)	ASTM or ASME 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	Not Applicable
Top, Bottom, Side Walls and Corner Walls Impact Absorbers (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
Corners Impact Absorbers (Aluminum and Steel)	ASTM or ASME Section II	**[Proprietary Information Withheld in Accordance with 10 CFR 2.390]**NCT	Not Applicable	Not Applicable	Chapter 8 of this SAR	Not Applicable

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

~~Note 2: HSLA-100 steel, which is an alternate containment boundary material described in Section 2.2, is procured per the applicable requirements of [2.2.2] and [2.2.3] as delineated in Holtec purchase specification.~~

Table 8.1.3: ASME Code Requirements and Alternatives for the HI-STAR ATB 1T 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. ~~For HSLA-100, which is an alternate containment boundary material described in Section 2.2, CMTRs will be provided in accordance with Holtec purchase specification.~~
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 ATB 1T is to be marked and identified in accordance with 10CFR71. Code stamping is not required. QA data package prepared in accordance with Holtec's approved QA program.
Cask Containment System	NB-2330	Establish 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 [1.2.5] is used for materials less than 4 inches thick and Reg. Guide 7.12 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 per Reg. Guides 7.11 and NUREG/CR 3826.

Table 8.1.4 : Fracture Toughness Test Criteria: Containment System
(Sheet 1 of 4)

Item	Material	Thickness in. (mm.)	Qualification to LST of -29°C (-20°F) (Note 2)		Qualification to LST of -40°C (-40°F) (Note 2)	
			Charpy V-Notch Temperature	Drop Weight Test Temperature (Note 1)	Charpy V-Notch Temperature	Drop Weight Test Temperature (Note 1)
Weld Metal for NB Welds (Walls and Baseplate Interface)	As required	3.75 (95.25) (Maximum)	$T_{NDT} \leq$ - 50°C (-58°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430.	Drop Test not Required	$T_{NDT} \leq$ - 61.1°C (-78°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430.	Drop Test not Required
Weld Metal for NB Welds (Side and End Walls Interface)	As required	6.5 (165.1) (Maximum)	$T_{NDT} \leq$ -57.2°C (-71°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430.	Drop Test not Required	$T_{NDT} \leq$ -68.3°C (-91°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430.	Drop Test not Required

Table 8.1.4 : Fracture Toughness Test Criteria: Containment System
(Sheet 2 of 4)

Item	Material	Thickness in. (mm.)	Qualification to LST of -29°C (-20°F) (Note 2)		Qualification to LST of -40°C (-40°F) (Note 2)	
			Charpy V-Notch Temperature	Drop Weight Test Temperature	Charpy V-Notch Temperature	Drop Weight Test Temperature
Containment Baseplate	A514, SA-517, or ~~HSLA-100~~SA-508 4N Class 2	3.75 (95.25) (Maximum)	$T_{NDT} \leq$ -83.3°C (-118°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -83.3°C (-118°F) per R.G. 7.11	$T_{NDT} \leq$ -94.4°C (-138°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -94.4°C (-138°F) per R.G. 7.11
Containment Side Wall	A514, SA-517, or ~~HSLA-100~~SA-508 4N Class 2	6.5 (165.1) (Maximum)	$T_{NDT} \leq$ -61.7°C (-79°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -61.7°C (-79°F) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)	$T_{NDT} \leq$ -72.8°C (-99°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -72.8°C (-99°F) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)

Table 8.1.4 : Fracture Toughness Test Criteria: Containment System (Sheet 3 of 4)

Item	Material	Thickness in. (mm.)	Qualification to LST of -29ºC (-20ºF) (Note 2)		Qualification to LST of -40ºC (-40ºF) (Note 2)	
			Charpy V-Notch Temperature	Drop Weight Test Temperature	Charpy V-Notch Temperature	Drop Weight Test Temperature
Containment End Wall	A514, SA-517, or HSLA-100SA-508 4N Class 2	6.5 (165.1) (Maximum)	$T_{NDT} \leq$ -61.7ºC (-79ºF) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -61.7ºC (-79ºF) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)	$T_{NDT} \leq$ -71.7ºC (-99ºF) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -72.8ºC (-99ºF) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)
Closure Lid	A514, SA-517, or HSLA-100SA-508 4N Class 2	6.5 (165.1) (Maximum)	$T_{NDT} \leq$ -61.7ºC (-79ºF) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -61.7ºC (-79ºF) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)	$T_{NDT} \leq$ -72.8ºC (-99ºF) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330.	$T_{NDT} \leq$ -72.8ºC (-99ºF) per fracture initiation criteria developed in the NUREG/CR-3826 (Notes 3 and 4)

Table 8.1.4 : Fracture Toughness Test Criteria: Containment System
(Sheet 4 of 4)

Notes:

1. 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. If T_{NDT} is determined based on drop weight testing then materials shall be tested in accordance with ASTM E604, due to the material minimum yield strength above 70 ksi per NUREG/CR-1815.
2. The cask may be qualified to either an LST of -20ºF (-29ºC) or -40ºF (-40ºC).
3. Component to undergo 100% volumetric examination to confirm absence of flaws which exceed the critical values as defined in NUREG/CR-3826 Table 3. 100% volumetric re-examination is required for cask components qualified per NUREG/CR-3826 following cask operations which result in impactive or impulsive loadings in excess of those defined in the normal conditions of transport.
4. In lieu of qualification per NUREG/CR-3826, qualification per Reg. Guide 7.12 [8.1.5] may be applied.
5. Containment System components with exemption from brittle fracture testing in accordance with ASME Section III, Subsection NB-2300 are not listed in this table.

Table 8.1.5 : Material Properties for Package Crushable Attachments and Closure Lid Impact Absorbers

Material	**S/S 304**		**Aluminum 6061**	
Key Property[Note 1]	**Minimum**	**Maximum**	**Minimum**	**Maximum**
Yield Strength - ksi	26.7	32.6	34.6	40.8
Ultimate Strength - ksi	73.0	89.1	42.0	49.6
Percentage Area Reduction - %	65 [Note 2]	N/A [Note 4]	42 [Note 3]	N/A [Note 4]

Notes:

1. As detailed in material benchmark report [8.1.6], the material yield strength, ultimate strength and percentage area reduction at failure are the key material inputs required to construct a true stress-strain curve for any component to be used in LS-DYNA numerical simulations.
2. The minimum percentage area reduction for S/S 304 material is conservatively estimated from NUREG 1864 [8.1.7].
3. The minimum percentage area reduction for Aluminum 6061 material is conservatively estimated based on the material physical testing documented in [8.1.6].
4. A larger percentage area reduction implies higher material ductility and energy absorption capacity. In terms of the drop analysis, the crushable attachments will dissipate more energy during the impact event. Therefore, the upper bound (or maximum) percentage area reduction for these materials, intended to absorb energy during the impacts, is not limiting for the safety determination.

8.2 MAINTENANCE PROGRAM

8.2.1 Overview

An ongoing maintenance program for the HI-STAR ATB 1T Package will be prepared and issued prior to the delivery and first use of the HI-STAR ATB 1T 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 ATB 1T 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 ATB 1T package is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions. Furthermore, the cask exterior is almost entirely fabricated from stainless steel material and its surfaces may be coated for preservation, including corrosion resistance. As a result, only minimal maintenance will be required over its lifetime, and this maintenance would primarily result from weathering effects, and pre- and post-usage requirements for transportation. Typical of such maintenance would be seal replacement, and leak testing following seal replacement. Such maintenance requires methods and procedures no more demanding than those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR ATB 1T Package is provided in Table 8.2.1.

8.2.2 Structural and Pressure Tests

No periodic structural or pressure tests on the packaging following the initial acceptance tests are required to ensure continuing performance.

8.2.3 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 periodic and maintenance leakage rate tests.

If the pre-shipment leakage rate test expires (after 1 year), a periodic leakage rate test of the containment seals must be performed prior to transport. This periodic leakage rate test is valid for 1 year. Also see Table 8.2.1.

Maintenance leakage rate testing shall be performed prior to returning a package to service following maintenance, repair (such as a weld repair), or replacement of containment system components (such as containment seal 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, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed using the same test 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 by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A [8.1.2]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

The periodic and maintenance leakage rate test results shall be documented and maintained as required by the user's quality assurance program.

8.2.4 Component and Material Tests

(i) Shielding Materials

Periodic testing of the package shielding integrity shall be performed within 5 years of the last shielding effectiveness test prior to package transport using written and approved procedures. The periodic testing shall be performed by radiation measurements with either loaded contents or a check source using written and approved procedures and calibrated radiation detection equipment. Measurements shall be taken at locations designated by plant staff for comparison with calculated values to assess the continued effectiveness of the shielding. The calculated values shall be representative of the loaded contents and cooling time or the particular check source used for the measurements. If 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.

The tests results shall be documented and maintained as required by user's quality assurance program.

(ii) Packaging Surfaces

Accessible internal and external surfaces (including impact mitigation features) of the packaging shall require visual verification of no damage prior to each waste loading to ensure that the packaging effectiveness is not significantly reduced. Visual verifications of the cask, the BFA-Tanks and BTCs shall be performed for surface coating and component damage including surface denting, surface penetrations, weld cracking, 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.

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) <u>Packaging Fasteners</u>

Cask impact absorbers and BFA-Tanks 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.

Cask threaded fasteners 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.

BFA-Tank bolts shall be examined to ensure the requirements in the licensing drawing are met. Fasteners not meeting the requirements shall be replaced.

Installation of the cask impact absorbers and bolts and BFA-Tank lids and bolts is foreseen to be a one-time event. Impact absorbers shall remain attached to the cask during loading, unloading and transport operations. Similarly, frequent installation and removal of BFA-Tank lid bolts, following loading and closure of the BFA-Tank is not anticipated. Therefore fatigue analysis for bolts and internal threads (as required) is not required.

(iv) <u>Closure Lid Locking System:</u>

The Closure Lid Locking System (CLLS), as shown in the Licensing drawing, is designed for rapid and remotely operated de-energizing of the seal and disassembly of the joint. The near ambient pressure environment in the cask eliminates the need for a large preload applied by the CLLS ensuring that the stress levels in fastening structure will remain well below the material endurance limit. Thus fatigue failure of the CLLS is ruled out as is creep because of near ambient temperature states in the CLLS. A periodic verification that the CLLS has not been severely damaged by an inadvertent operation while in service is required.

(v) <u>Cask Trunnions</u>

Cask 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 lifting device and trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require repair or replacement of the trunnion and/or repair of the cask.

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

(vi) Closure Seals

The HI-STAR ATB 1T Packaging is equipped with elastomeric seals on the closure lid to ensure leakage meets the criteria in Table 8.1.1. The closure seals are shipped from the factory pre-inspected and carefully packaged. Once installed and compressed, the seals should not be disturbed by disengagement of the CLLS. 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. Disengagement and removal of the CLLS requires visual verification that the seal remains free of debris, does not exhibit damage (i.e. no tears or gouges), and does 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. Seals which have been in service for more than 12 months shall be replaced the next time that the CLLS is disengaged. Closure seals are specified for long-term use and do not require additional maintenance.

(vii) Thermal Tests

Periodic thermal performance testing for the HI-STAR ATB 1T 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 ATB 1T cask.

(viii) Miscellaneous Tests

No additional tests are required for the HI-STAR ATB 1T Packaging, packaging components, or packaging materials.

Table 8.2.1:
Maintenance Program Schedule

Task	Schedule
Cask surface visual verification. (See Paragraph 8.2.4(ii))	Prior to each Non-Fuel Waste (NFW) loading.
BFA-Tanks and BTCs accessible surfaces visual verification (See Paragraph 8.2.4(ii))	Prior to emplacement into the cask.
Packaging fasteners visual verification (See Paragraph 8.2.4(iii))	Prior to each loading and emplacement of BFA-Tank into cask.
CLLS visual verification (See Paragraph 8.2.4(iv))	Prior to each transport.
Cask trunnion visual inspection (See Paragraph 8.2.4(v))	Prior to each NFW loading.
Pre-shipment leakage test of containment system seal (Subsection 8.2.3)	Following each NFW loading.
Periodic leakage rate test of containment system seals (Subsection 8.2.3)	Prior to off-site package transport if period from last test exceeds 1 year.
Maintenance leakage rate test of containment system seals (Subsection 8.2.3)	Prior to returning package to service following maintenance, repair or replacement of containment boundary components.
Seal replacement for Closure Lid (See Paragraph 8.2.4(vi))	Following disengagement of the CLLS 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 during the next CLLS visual verification.
Shielding Test (See Paragraph 8.2.4(i))	At the beginning of each licensing period.

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.

[8.0.1] U.S. Code of Federal Regulations, Title 10, "Energy", Part 71, "Packaging and Transportation of Radioactive Materials."

[8.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2007 Edition, 2008 Addenda (Section IX, 2013 for FSW only unless otherwise indicated).

[8.1.2] American Society for Nondestructive Testing, "Personnel Qualification and Certification in Nondestructive Testing," Recommended Practice No. SNT-TC-1A, December 2006.

[8.1.3] 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.

[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] U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1m) But Not Exceeding 12 Inches (0.3m)," Regulatory Guide 7.12, June 1991.

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

[8.1.7] NUREG-1864, "A Probabilistic Risk Assessment of a Dry Cask Storage System at a Nuclear Power Plant".

[8.1.8] Holtec Calculation HI-2177539, Revision 7~~5~~, "Drop Analysis for the HI-STAR ATB 1T Transport Package".