NON-PROPRIETARY VERSION

SAFETY ANALYSIS REPORT

on

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

By

Holtec International
Holtec Center
One Holtec Drive
Marlton, NJ 08053
(holtecinternational.com)

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1	Chapter 1	RN	9/23/15	690986	RN	2/6/17	828788	RN	N/A	N/A
2	Ch. 1, 7, 8 Structural	RJ	9/23/15	161798	VP	2/6/17	485603	N/A	N/A	N/A
3	Ch. 1, 2, 7, 8 Thermal	XH	9/23/15	286711	XH	2/6/17	146414	N/A	N/A	N/A
4	Ch. 1, 7, 8 Containment	PS	9/23/15	170393	N/A	N/A	N/A	N/A	N/A	N/A
5	Ch. 1, 7, 8 Shielding	RT	9/23/15	629065	RT	2/6/17	149430	RT	N/A	N/A
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	N/A	N/A
8	Ch. 1, 2, 7, 8 Materials	RM	9/23/15	852068	RM	2/6/17	130397	RM	N/A	N/A
9	Ch. 1, 2, 7, 8 Fabrication	RM	9/23/15	282805	RM	2/6/17	827428	RM	N/A	N/A
10	Chapter 2	RJ	9/23/15	431272	VP	2/6/17	401188	VP	N/A	N/A
11	Chapter 3	XH	9/23/15	545590	XH	2/6/17	481432	N/A	N/A	N/A
12	Chapter 4	PS	9/23/15	30261	N/A	N/A	N/A	RT	N/A	N/A
13	Chapter 5	RT	9/23/15	639791	RT	2/6/17	331449	RT	N/A	N/A
14	Chapter 6	TH	9/23/15	89901	TH	2/6/17	476295	N/A	N/A	N/A
15	Chapter 7	RM	9/23/15	680091	RM	2/6/17	80134	RM	N/A	N/A
16	Chapter 8	RN	9/23/15	22243	RN	2/6/17	906572	RN	N/A	N/A

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DOCUMENT NAME: Safety Analysis Report on the HI-STAR ATB 1T Package	DOCUMENT CATEGORY: ☒ GENERIC ☐ PROJECT SPECIFIC

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		Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #	Author's Initials	Date Approved	VIR #
1	Chapter 1	RN	N/A	N/A						
2	Ch. 1, 7, 8 Structural	VP	N/A	N/A						
3	Ch. 1, 2, 7, 8 Thermal	XH	N/A	N/A						
4	Ch. 1, 7, 8 Containment	PS	N/A	N/A						
5	Ch. 1, 7, 8 Shielding	RT	N/A	N/A						
6	Ch. 1, 7 Criticality	N/A	N/A	N/A						
7	Ch. 1, 8 Operations	RM	N/A	N/A						
8	Ch. 1, 2, 7, 8 Materials	RM	N/A	N/A						
9	Ch. 1, 2, 7, 8 Fabrication	RM	N/A	N/A						
10	Chapter 2	VP	N/A	N/A						
11	Chapter 3	XH	N/A	N/A						
12	Chapter 4	PS	N/A	N/A						
13	Chapter 5	RT	N/A	N/A						
14	Chapter 6	N/A	N/A	N/A						
15	Chapter 7	RM	N/A	N/A						
16	Chapter 8	RN	N/A	N/A						

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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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3. Revisions to this document may be made by adding supplements to the document and replacing the "Table of Contents", this page and the "Revision Log".

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:** Proposed Rev. 2A

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".

Chapter 1: General Information (includes Glossary and Notation)	Revision Number.: 2A
Section or App.	**Summary Description of Change**
Glossary	**Proposed Revision 2A:** Added definition of *Single Waste Item*.
1.0	No changes
1.1	**Proposed Revision 2:** Editorial to text to better distinguish waste package Type E from Types A through D. Other related minor editorial changes throughout Section 1.1. **Proposed Revision 2A:** Editorial clarification added to 8th paragraph of Section 1.l, regarding functions of inner and outer closure lid seals as barriers against radioactive materials leakage from the containment boundary. Text revised in Section 1.1 (ii) to clarify that cask ITS components, except seals, are made of materials that preclude brittle fracture under cold conditions.
1.2	**Proposed Revision 2:** Specify additional permissible contents in Subsection 1.2.2. Clarify typical location operations for waste packages Types A through E in Subsection 1.2.4. Editorial changes to distinguish waste package Type E from Types A through D throughout Section 1.2. **Proposed Revision 2A:** Added wedge pins as locking wedge components to Paragraph 1.2.1.1(a). Deleted redundant statement on brittle fracture from the same paragraph. Other editorial minor clarifications made to paragraph. ANSI N14.5 reference number in Paragraph 1.2.1.3 updated.
1.3	**Proposed Revision 2A:** No changes to SAR text, but new drawings revisions added (9876 Rev.5 and 9786 Rev. 4).
1.4	No changes
References	**Proposed Revision 2A** ANSI N14.5 reference deleted from [1.2.4].
Chapter 2: Structural Evaluation	**Revision Number: 2A**
Section or App.	**Summary Description of Change**
2.0	No Changes.
2.1	**Proposed Revision 2A:** The strain based acceptance criteria Table is update. Clarifications added for Zonal classification of the cask containment boundary as a result of RAI 2-1. The

	corresponding figures 2.1.1A and 2.1.1B are updated. New material SA-182 FXM-19 is considered for the cask top flange. Pertaining discussion and the allowable strength Table is accordingly added in this revision.
2.2	**Proposed Revision 2A:** New material SA-182 FXM-19 is considered for the cask top flange. The material strength Table is added in this revision. Allowable stress limits for the HI-STAR containment shell and the baseplate components are revised. The trunnion material specification is changed to SB-637 N07718, accordingly the strength Table is revised. This is in response to RAI 2-20.
2.3	No Changes.
2.4	No Changes.
2.5	**Proposed Revision 2A:** Results Table for the lifting attachments are updated as a result of RAI's 2-2, 2-3 and 2-20.
2.6	**Proposed Revision 2A:** As depicted in the cask latest drawing revision 9786, some design enhancements are considered in the cask closure lid and top flange regions. These design enhancements provide additional assurance against loss of containment and limit the strains in the containment boundary. The analysis is also revised to address NRC RAI's 2-4 through 2-16. As a result these design changes and the RAI's particularly related to the FE (simulation) model, all NCT drop simulations are revised. Correspondingly, all the result Tables are revised.
2.7	**Revision 2:** In subsection 2.7.1, clarification is added regarding the upper bound material curve used for the sensitivity simulations. Removed reference to the safeguards report (i.e. [2.7.3]). **Proposed Revision 2A:** As depicted in the cask latest drawing revision 9786, some design enhancements are considered in the cask closure lid and top flange regions. These design enhancements provide additional assurance against loss of containment and limit the strains in the containment boundary The analysis is also revised to address NRC RAI's 2-4 through 2-16. As a result these design changes and the RAI's particularly related to the FE model, all HAC simulations are revised. Correspondingly, all the result Tables are revised. To address RAI 2-17 related to the fire accident loading, a calculation is added in section 2.7. It is demonstrated that the fire accident will not cause any further plastic deformations to the containment boundary components.

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2.8	No Changes	
References	**Revision 2:** Deleted reference [2.7.3]. **Proposed Revision 2A:** A new reference 2.1.11 is added. Existing references updated to the latest relevant revisions.	
Appendix 2.A	No Changes	
Appendix 2.B	**Proposed Revision 2A:** Figure 2.B1 title is moved to page where the figure is depicted. This is just a format change.	
Chapter 3: Thermal Evaluation		**Revision Number: 2A**
Section or App.	**Summary Description of Change**	
3.0	No changes.	
3.1	No changes.	
3.2	No changes.	
3.3	**Proposed Revision 2A:** Editorial change is made to Subsection 3.3.8.2 for clarification. Editorial change is made to Subsection 3.3.10 for clarification.	
3.4	**Proposed Revision 2A:** Editorial change is made to Subsection 3.4.2 and Table 3.4.1 to address cask heat dissipation after fire.	
3.5	No changes.	
References	No changes.	
Chapter 4: Containment		**Revision Number.: 2A**
Section or App.	**Summary Description of Change**	
4.0	No changes	
4.1	No changes	
4.2	No changes	
4.3	No changes	
4.4	**Proposed Revision 2:** An explanation that cites NUREG/CR-6487 is added to Paragraph 4.4.2.1 to explain that "the effect of 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." **Proposed Revision 2A:**	

	Assumptions in Section 4.4.1 are modified as a result of NRC RAI 4-4.
References	No changes
Chapter 5: Shielding Evaluation	**Revision Number.: 2A**
Section or App.	**Summary Description of Change**
5.0	No changes
5.1	**Proposed Revision 2A:** Tally descriptions for normal and accident conditions are added and the tally specifications section of the HI-STAR ATB 1T Shielding Calculation Package is referenced. Accident case with source material in gap along bottom long side edge and material erosion from drop accident is added to Table 5.1.3 as accident case with highest dose rates.
5.2	**Proposed Revision 2:** Editorial changes are added as a result of NRC RSIs to better describe waste characterization of content including physical form, material properties, radioactive characteristics.
5.3	**Proposed Revision 2A:** Accident case with source material in gap along bottom long side edge and material erosion is described. Case with Inconel 718 as source material in MCNP is described.
5.4	**Proposed Revision 2A:** Dose rate results with Inconel 718 as source material in MCNP are presented in Table 5.4.2 and Table 5.4.3. Accident case that previously had highest dose rates is moved from Table 5.1.3 to Table 5.4.4.
References	**Proposed Revision 2A:** Reference *"[5.1.3] HI-STAR ATB 1T Shielding Calculation Package HI-2156583. Holtec International. Latest Revision."* is added.

Appendix 5.A	**Proposed Revision 2:** Entire Appendix is added as a result of NRC RSIs to better describe waste characterization of content including physical form, material properties, radioactive characteristics. No revision bars are included since Appendix 5.A is added in whole with this revision. Source term calculations are added to Appendix 5.A [1] to provide more information on radionuclides other than Cobalt-60 that also contribute to package dose rates. SAS2H and ORIGEN-S are used to calculate the gamma source terms as a function of burnup (180,000 MWD/MTU and 360,000 MWD/MTU) at several cooling times (1, 2, 3, 5, and 10 years) for irradiated reactor internals made of stainless steel and Inconel 718. Table 5.A.3 through Table 5.A.6 show that by limiting Co-60 to the specific activity in Table 7.1.2, and by requiring a cooling time of at least 1 year (Table 7.1.2), that the radionuclides other than Co-60 (i.e. Mn-54, Fe-59, Co-58, and Nb-94) that contribute to package dose rates are limited to contribute less than 10% additional to package dose rates.	
Chapter 6: Criticality Evaluation		**Revision Number.: 1**
Section or App.	**Summary Description of Change**	
6.0	No changes	
Chapter 7: Package Operations		**Revision Number: 2A**
Section or App.	**Summary Description of Change**	
7.0	**Proposed Revision 2A:** Requirement for lifting devices added.	
7.1	**Proposed Revision 2:** Description of package loading options clarified. Steps added for loading options LS-2 and LS-3. Note 1 revised in Table 7.1.2; table reorganized to clarify control parameters for Type E waste package. **Proposed Revision 2A:** Actions in response to detected cask damage added. Cask o-ring replacement schedule specified. Function of docking protective cover added. Acceptance criteria for CLLS engagement confirmation are added.	
7.2	**Proposed Revision 2:** Revised to described steps for removal of contents if loaded per LS-3 option. **Proposed Revision 2A:** Actions in response to detected cask damage added.	
7.3	No changes	

7.4	No changes	
References	No changes	
Chapter 8: Acceptance Tests and Maintenance Program		**Revision Number: 2A**
Section or App.	**Summary Description of Change**	
8.0	No changes	
8.1	**Proposed Revision 2:** Minor editorial change to Subsection 8.1.6. **Proposed Revision 2A:** Leak testing requirements in Subsection 8.1.4 are updated in accordance with ANSI N14.5 2014 and to align with the HI-STAR 190 SAR [Docket 71-9373]. Paragraph 8.1.5.2 is updated to clarify that cask ITS components, except seals, are made of materials that preclude brittle fracture under cold conditions. Clarification made that pre-shipment shielding tests measurements shall be compared to calculated values for specific loaded contents. Table 8.1.1 updated to reference ANSI N14.5 (2014), and specify all allowable leakage tests methods for a given test. Deleted Table 8.1.5 (Non-containment boundary fracture toughness test criteria).	
8.2	**Proposed Revision 2:** Minor editorial change to Subsection 8.2.3. **Proposed Revision 2A:** Leak testing requirements in Subsection 8.2.3 are updated in accordance with ANSI N14.5 2014 and to align with the HI-STAR 190 SAR. Closure seals maintenance requirements in Subsection 8.2.4 (v) and Table 8.2.1 have been updated to align with the HI-STAR 190 SAR [Docket 71-9373] and include requirement to replace seals in service for more than 12 months.	
References	**Proposed Revision 2A:** Added reference [8.1.4] for ANSI N14.5 (2014) and updated year of reference [8.1.2].	

End of Change Descriptions

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CHAPTER 1: GENERAL INFORMATION

CHAPTER 2: STRUCTURAL EVALUATION

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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 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.

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

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

Cooling Time (or post-irradiation decay time, PCDT) for 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.

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

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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.

Top Flange means the monolithic steel structure which supports the Closure Lid 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.

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 1×10^{-2} std cm^3/s air to 1×10^{-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 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, D and E) as specified in Table 1.2.1 and Table 7.1.2.

[Text Withheld in Accordance with 10 CFR 2.390]

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 wall thickness being the principal differentiator. 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 typically 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 do not come in contact with contaminated material at any time.

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 worse 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].

[Text Withheld in Accordance with 10 CFR 2.390]

The cask closure lid and inner closure lid seal 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 seal 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 38^{o}C (100^{o}F) without insolation is in excess of 50^{o}C (122^{o}F), and less than 85^{o}C (185^{o}F); 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.

[Text Withheld in Accordance with 10 CFR 2.390]

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.

[Text Withheld in Accordance with 10 CFR 2.390]

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 (Length, Width, Height), in. (Note 1)	132, 53, 92
Outside dimensions of the HI-STAR Cask/Package (Length, Width, Height), in. (Note 1)	147, 71, 114
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 is equipped with the facility to secure the closure lid

[Text Withheld in Accordance with 10 CFR 2.390]

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 seal

[Text Withheld in Accordance with 10 CFR 2.390]

the Containment Boundary HI-STAR ATB 1T consists of stainless steel components that include a baseplate, containment walls, top flange, closure lid and associated containment boundary welds. The stainless steel baseplate is welded to stainless steel containment walls of the same material. The baseplate and side walls weldment of the Containment Boundary is buttressed by a thick 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. **[Text Withheld in Accordance with 10 CFR 2.390]**

The Top Flange of the cask is joined to both the Containment Boundary walls and the DBS using full penetration welds. The Licensing drawing package shows the welds of the Containment Boundary and DBS.

The governing Code for 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. For purposes of material procurement, the Top Flange and Closure Lid must meet the requirements of NB-2000, even though as discussed in Chapter 2 of this SAR, portions of the Top Flange and Closure Lid are designated a part of the DBS and hence non-code.

The HI-STAR ATB 1T package has no external impact limiters that typify fuel bearing transport casks. Therefore, the absorption of energy under a part 71 free drop event must occur by plastic deformation of the cask's massive stainless steel structure. 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.

[Text Withheld in Accordance with 10 CFR 2.390]

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 also made from austenitic stainless steel for maximum ductility and excellent fracture strength under cold service conditions. The top region of the cask relies on the heavy top flange to protect the Containment Boundary under a "top down CG- over- the- corner" free drop event.

Externally, the HI-STAR package presents a flat walled rectangular profile except for the lifting trunnions located on the side walls designed to lift the package with structural safety margins required under NUREG-0612 [1.2.3], and foldable loading guides (not *important-to-safety*) that may be attached to side walls of the cask. Lifting attachments and lid supports on top of the Closure Lid are other potential sources of protrusion.

[Text Withheld in Accordance with 10 CFR 2.390]

The lifting attachments and lid supports are within the dimensional boundaries of the cask and arranged on top of the closure lid to ensure that during drop events stresses are evenly distributed across the surface of the closure lid and stress limits are not exceeded. Thus there are no locations on the cask's surface that are vulnerable to a penetrative loading during a drop event. Finally, the mechanical design of the Confinement Boundary is guided by the ASME

Code, Subsection NB with respect to stress limits for normal operations, 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.

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 the BTC and radioactive waste during transportation. Five waste packages (Types A, B, C, D and E) are analyzed for the HI-STAR ATB 1T Package, four of which (Types A through D) employ the BFA-Tank. 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 its wall thickness. Each type of BFA-Tank is designed to accommodate the dimensions of a specific type of BTC along with its radioactive contents.

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 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 lid and base plate of the BFA-Tanks contribute to the all-around shielding performance of the tanks.

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 provided in Chapter 2.

The BFA-Tank's exterior dimensions and the cask's cavity dimensions are toleranced such that the potential for significant movement of the BFA-Tank is eliminated. The clearance between the BFA-Tanks 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 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, held together 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 both waterways and roadways 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 and restraints shall be designed as appropriate for either land or 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 land transport, the upper end of the HI-STAR ATB 1T Package may be protected by a Weather Protection Cover (WPC) to prevent dirt and water from accumulating on the external surfaces of the cask. The WPC is provided with lifting points for manual and 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 may be used to secure the WPC to the package or otherwise rendered 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 the top surface of the closure lid top cover and secured to the trunnions with fasteners 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 stainless steel 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 shielding analysis credits the attenuation of gamma radiation through three sequential metal masses in 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 BTCs and BFA-Tanks, and also through self-shielding of metallic waste.

2. The Containment Boundary made of a high integrity stainless 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 also 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.

Gamma radiation is attenuated (as credited by the safety analysis) by the Containment Boundary and DBS for waste package Type E.

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 seal welded to a retainer (keeper) plate to provide a limited axial load bearing capacity. The retainer plate interfaces with the trunnions solid and hollow shafts (bolts) 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 trunnion such that it develops the full stiffness of a cantilevered beam with the hollow shaft serving as the anchor of the cantilever. This is achieved by insuring that the solid shaft projects 1/2 to 1 diameter inside the hollow shaft.

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 illustration of a typical package transport configuration. The transport frame provides attachment points for tie-downs on all 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.

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.

1.2.1.7 Internal Support Features

If required, in accordance with analysis, the HI-STAR ATB 1T package shall be fitted with aluminum spacers in accordance with the drawing package in Section 1.3. The aluminum spacer(s) shall 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 drops.

The HI-STAR ATB 1T Package does not require other internal support features. The waste packages are essentially in conformal contact with the cask cavity.

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. 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 that is attached to the locking wedge locking pin, is placed on the package after installation of the locking wedge locking pin after closure of the lid and prior to transport.

After installation of the cask lid, engagement of the cask locking wedges is verified by the locking wedge locking pin shown in the drawing package in Section 1.3. A wire tamper-indicating seal with a stamped identifier may be attached to the installed locking wedge locking pin. Because the cask lid cannot be disengaged and removed without movement of the locking wedge locking pin, 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).

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). The radioactive wastes consists 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 reactor-internals are typically made of stainless steel. 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. As discussed in Section 1.1, the payload of the Type E Waste Package may include stainless steel dunnage.

[Text Withheld in Accordance with 10 CFR 2.390]

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).

[Text Withheld in Accordance with 10 CFR 2.390]

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, with attached telescopic strong-back is inserted into the pool to engage the loaded BTC for the lift and provide temporary shielding. 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. Alternatively, the BFA-Tank may be loaded before placement directly into the HI-STAR ATB 1T Cask.

A Vacuum Drying System (VDS) is connected to the BFA-Tank and used to remove all bulk water in accordance with Chapter 7 of this SAR.

Following the drying operations, the BFA-Tank cavity containing the BTC is brought to ambient pressure and the BFA-Tank lid is bolted and sealed close.

Pre-Loaded BFA-Tanks (Waste Package Types A, B, C and D)

BFA-Tanks must have been previously loaded in accordance with procedures in Subsection 7.1.2. The BFA-Tanks exterior accessible surfaces are inspected for cleanliness and lid bolts inspected to ensure adequate closure. BFA-Tanks are loaded into the HI-STAR ATB 1T Cask.

Loading of Wastes Directly into Cask (Waste Package Type E)

NFW and optional dunnage are loaded directly into the HI-STAR ATB 1T in accordance with Subsection 7.1.2.

Cask Closure

Next the cask lid 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, WPC is attached to the top surface of the cask (as deemed necessary by the user) 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 and tests (acceptance criteria and maintenance program requirements) required to prepare the package for shipment are specified in Chapter 8 of this SAR.

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Table 1.2.1: Package Design Basis Heat Load and Normal Design Pressure

Waste Package Type	A	B	C	D	E
Maximum calculated waste package heat load, kW (Note 1)	1.65	0.99	0.13	0.016	0.0033
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:
[Figure Withheld in Accordance with 10 CFR 2.390]

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FIGURE 1.2.2:
[Figure 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. In particular, this drawing package includes:

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

The manufacturing of the HI-STAR ATB 1T components is required to be in strict compliance with the Drawing Package in this section.

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

[Drawings Withheld in Accordance with 10 CFR 2.390]

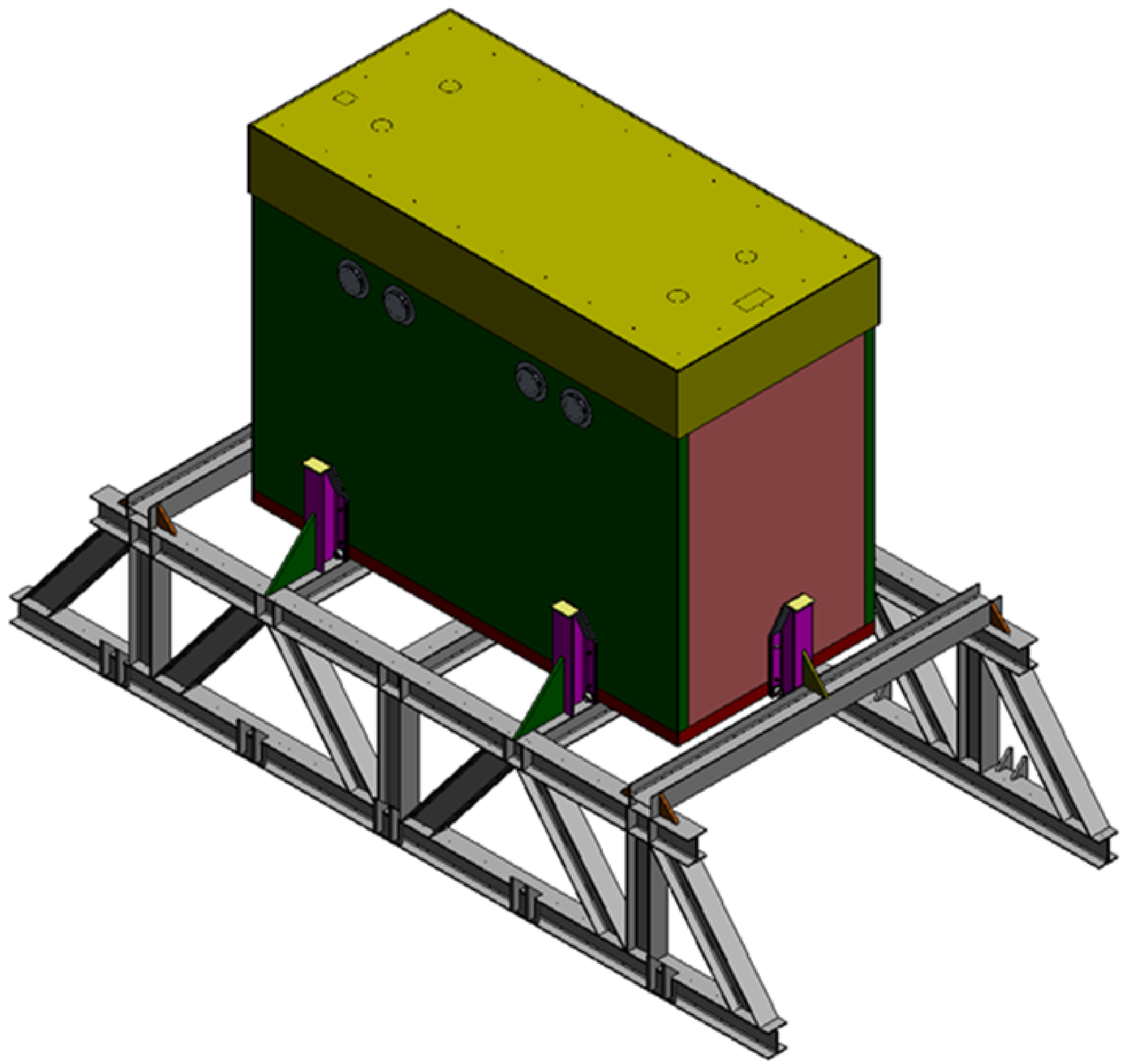

FIGURE 1.3.1: ILLUSTRATION OF HI-STAR ATB 1T PACKAGE TYPICAL TRANSPORT CONFIGURATION

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 verifying 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.

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CHAPTER 1 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table.

[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.

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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.

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2.1 STRUCTURAL DESIGN

2.1.1 Discussion

This subsection presents the essential characteristics of the principal structural members and systems that are important to the safe operation of the HI-STAR 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 and Nonmandatory Appendices EE and FF are 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, will be discussed in this SAR.

2.1.1.3 BFA-Tank Cassettes

BTC's 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 will be discussed in this SAR.

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 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 impact limiters to deal during accident scenarios of 10CFR71.73.

The historical approach to invoke ASME code section III, subsection NB, espoused in Regulatory Guide 7.6 [2.1.1], needs to be modified to perform an appropriate safety analysis on a cask of HI-STAR ATB 1T genre because the g-loads under the 9-meter drop condition are expected to be in excess of 500 g's. Local deformation of the cask structure under such large g-loads is unavoidable. Therefore, for such extreme impact events it is appropriate to use inelastic methods as recommended in NRC staff publication [2.1.7] and Appendices EE and FF of the ASME Code Section III [2.1.8]. However, Subsection NB is the reference Code for structural qualification of the package under normal handling and under Normal Conditions of transport (NCT). The structural qualification of the trunnions 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]. Only for the cases involving large concentrated impactive loads (viz. Free Drop from 9 meters) is recourse to an inelastic model necessary to accurately characterize the package's response. 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.

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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.	As there are no significant cyclic loads on the HI-STAR ATB 1T package, fatigue curves of the ASME Code are not utilized.
2. Under NCT, the limits on stress intensity are those limits defined by the ASME Code for primary membrane and for primary membrane plus bending for Level A conditions.	This guidance is fully complied with; see Table 2.1.1.
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 pre-supposes linear analysis. It is replaced with the inelastic acceptance criterion (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 applicable to elastic analysis which is not used in the accident analysis of HI-STAR ATB 1T.

2.1.2.1 Loading and Load Combinations

In addition to handling loads, 10CFR71 and Regulatory Guide 7.6 define two loading conditions 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 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 1 inch 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 be dropping horizontally 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 the large side of the cask is evidently the scenario that will inflict maximum damage.

Finally, because stainless steel (the material of construction for the Package) is not vulnerable 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
Puncture	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

The containment system, as identified in the drawing package in Section 1.3 and described in Section 1.2, consists of the containment base plate, the containment side walls, the top flange, the closure lid, and the cask lid locking system. Under Normal Conditions of Transport, these components are designed to meet the Level A stress intensity limits per ASME Section III, Subsection NB for all loading conditions. For Hypothetical Accident Conditions of Transport, however, the structural acceptance criteria are dependent on the nature of the loading event and the location on the containment system. Specifically, for non-energy-limited accident events (e.g., immersion in water), the entire containment system is designed to meet the Level D stress intensity limits per ASME Section III, Subsection NB. For energy-limited events (i.e., 9-meter free drop, puncture) the containment system is divided into three zones with differing acceptance criteria. The three zones, which are identified as Zones A, B, and C, are depicted in Figure 2.1.1 and further discussed below.

[Text Withheld in Accordance with 10 CFR 2.390]

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2.1.3 Weights

Section 1.1 provides the overall weights of the HI-STAR 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], and Appendix FF [2.1.8] that are cited herein are used for the design of the containment system of the HI-STAR ATB 1T Package.

Table 2.1.2 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 & handling	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 & handling	Containment boundary	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 & handling of Closure lid	Closure Lid Lift lugs	Same as #1 above	Per NUREG-0612
4	A	Lifting and Handling of Closure Lid	Closure lid body	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 boundary 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. In addition, the primary shear stress must meet Level A limit per ASME Subsection NB. 3. The DBS must not detach from the cask causing the Part 71 normal condition dose limits to be exceeded.	This loading condition corresponds to the Part 71 normal condition. The critical normal drop events are: 1. Vertical drop top down 2. Vertical drop bottom down 3. Side drop with primary impact on the larger surface of the package. 4. CG over corner bottom down. 5. CG over corner top down
6	C	Free drop from 9 meters	Cask body & lid, depending on the	1. Zone A (see Figure 2.1.1): Must meet strain limits per ASME	The inelastic strain limits are based on the guidance in

#	Loading Case	Loading	Constituent Part	Stress/Strength Limit	Comment
			orientation of drop	Appendix FF. 2. Zone B (see Figure 2.1.1): Gap between closure lid and top flange must remain less than useful seal springback subsequent to the drop event. 3. Zone C (see Figure 2.1.1): No specified strain limit. 4. CLLS: Must not sustain gross deformation. 5. DBS: Must not detach from the cask causing the Part 71 post-accident dose limits to be exceeded.	Appendix FF of the ASME Code Division 1 and Division III (WB). The critical HAC drop events are: 1. Vertical drop top down 2. Vertical drop bottom down 3. Side drop with primary impact on the larger surface of the package. 4. CG over corner bottom down. 5. CG over corner top down 6. Oblique Drop on Top Lid (a.k.a. Slapdown)
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. Containment boundary must remain un-punctured.
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	The lid to flange opening due to differential thermal expansion must be below the useful springback of the seals.

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Table 2.1.2: 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 Base plate	Containment Boundary	ASME Code Section III Subsection NB[1]
2.	Containment Wall	Containment Boundary	ASME Code Section III Subsection NB[1]
3.	Containment Top Flange	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 Locking Pin	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.

Table 2.1.3A: Stress Limits for Containment Closure Lid at Reference Temperature of 200 ^{o}F (93.3 ^{o}C) - Level A Service Condition

Code: ASME NB
Material: SA-240 304
Item: Stress Intensity

Stress Category	**Limit per NB -3220**	**Value MPa (ksi)**
Primary Membrane, P_m	S_m	138 (20.0)
Local Membrane, P_L	$1.5S_m$	207 (30.0)
Membrane plus Primary Bending	$1.5S_m$	207 (30.0)
Primary Membrane plus Primary Bending	$1.5S_m$	207 (30.0)
Membrane plus Primary Bending plus Secondary	$3S_m$	414 (60.0)

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:

Source for S_m is Table 2A of ASME Section II, Part D.

Table 2.1.3B Allowable Stress Limits for the HI-STAR ATB-1T Package Containment Shell and Containment Baseplate (Note 1)

Code: ASME NB
Material: SA-240 304
Item: Stress Intensity

SA 240 304 Material (Base Metal) @ 200 deg. F		
Stress Category	**Limit per NB -3220**	**Value MPa (ksi)**
Primary Membrane, P_m	S_m	165.5 (24.0)
Local Membrane, P_L	$1.5S_m$	248.2 (36.0)
Membrane plus Primary Bending	$1.5S_m$	248.2 (36.0)
Primary Membrane plus Primary Bending	$1.5S_m$	248.2 (36.0)
Membrane plus Primary Bending plus Secondary	$3S_m$	496.4 (72.0)

Note 1: The stress intensity (S_m) of the 304 S/S material is related to its yield strength (S_y) by the relationship S_m = 2/3 (S_y). In addition it is noted from ASME part II D Table 2A, that the material stress intensity remains constant for temperatures between -20F to 300 °F. The basis for establishing design stress intensity for austenitic steels is further corroborated in Appendix 2 of ASME Section II, Part D. Accordingly, for the given yield strength of 36 ksi, the stress intensity for this specially procured 304 material is computed as 24 ksi.

Table 2.1.4: Stress Limits for CLLS at Reference Temperature 158 °F (70 °C) - Level A Service Condition

Stress Category	Limit per NB 3220	SB-637 N07718 MPa (ksi)
Primary Bending Stress	2 x S_m	673.3 (97.7)
Average Primary Shear Stress	$0.6S_m$	202.0 (29.3)
Maximum Primary Shear Stress	$0.8S_m$	269.4 (39.0)
Primary plus Secondary and Peak Shear Stress	$3S_m$	1010 (146.5)

Definitions:

S_m = Stress intensity values per ASME Code

Notes:

Source for S_m for SB-637 is Table 4 of ASME Section II, Part D.

Table 2.1.5: Stress Limits for Top Flange Material at Reference Temperature of 150 °F (66 °C) - Level A Service Condition

Code: ASME NB
Material: SA-182 FXM-19
Item: Stress Intensity

Stress Category	Limit per NB -3220	Value MPa (ksi)
Primary Membrane, P_m	S_m	228.9 (33.2)
Local Membrane, P_L	$1.5S_m$	343.4 (49.8)
Membrane plus Primary Bending	$1.5S_m$	343.4 (49.8)
Primary Membrane plus Primary Bending	$1.5S_m$	343.4 (49.8)
Membrane plus Primary Bending plus Secondary	$3S_m$	686.7 (99.6)

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:

Source for S_m is Table 2A of ASME Section II, Part D.

Figure 2.1.1A:

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Figure 2.1.1B:

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2.2 MATERIALS

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

2.2.1 Containment Boundary

Austenitic stainless steel is the sole material used in the manufacturing of the HI-STAR ATB 1T Containment Boundary including the Closure Lid and the Top Flange. The material properties in Table 2.2.1A are listed at a reference temperature that bounds the temperature of the Package components during normal service.

2.2.2 Trunnion & CLLS Materials

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2.2.3 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.

2.2.4 Containment Closure Seals

The containment integrity of the HI-STAR ATB 1T package relies on two O-ring joints as shown in the licensing drawing in Section 1.3.

To ensure that the effectiveness of the leak barriers is optimal, the grooves are machined in the precise configuration and surface finish called for the elastomeric gasket selected for this application. Elastomeric gaskets are characterized by a relatively small compression force to "seat" them in the groove and hence the required "seating load" (an ASME Boiler & Pressure Vessel code term) is not an important parameter. The size of the O-ring in relation to the size of the groove, on the other hand, is a critical dimension that is based on the gasket supplier's test data and which must be controlled through the gasket Procurement Specification. The gaskets shall be procured as an Important-to-Safety part. Table 2.2.2 provides the minimum threshold pressure required on the O-ring gasket to ensure leaktightness. Strictly speaking, leakage is likely to occur only if the seal unloads beyond the threshold limit listed in Table 2.2.2.

2.2.5 Nonstructural Materials-Dose Blocker Structure

The DBS is also entirely made of austenitic stainless steel. The DBS girdles the containment boundary and thus may act in concert with the containment shell during Hypothetical Accident Conditions of Transport. Necessary structural properties for the DBS are provided in Table 2.2.1.

2.2.6 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 of stainless steel which has 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 Boundary due to gamma fluence from the cask's waste package.

2.2.7 Packaging Coatings and Consumable Chemical Products

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Table 2.2.1A: Material Properties of Cask Closure Lid

Austenitic Stainless Steel SA-240 304			
Property	**Unit**	**@ 200 °F (93.3 °C)**	**@ 150 °F (66 °C)**
Yield Strength, S_y	MPa (ksi)	172.4 (25)	184 (26.7)
Ultimate Strength, S_u	MPa (ksi)	489.5 (71)	503 (73)
Young's Modulus, E	MPa x 10^4 (psi x 10^6)	18.96 (27.5)	19.2 (27.81)
Weight Density	kg/m^3 (lb/in^3)	8,027 (0.290)	
Poisson's Ratio		0.3	

Notes:
1. The material yield, ultimate strengths and elastic modulus values are obtained from ASME code [2.1.4].

Table 2.2.1B: Material Properties of Cask Containment Shell and Containment Baseplate

Austenitic Stainless Steel SA-240 304			
Property	**Unit**	**@ 200 °F (93.3 °C)**	**@ 150 °F (66 °C)**
Yield Strength, S_y	MPa (ksi)	184 (26.7)	206.8 (30)
Ultimate Strength, S_u	MPa (ksi)	489.5 (71)	503 (73)
Young's Modulus, E	MPa x 10^4 (psi x 10^6)	18.96 (27.5)	19.2 (27.81)
Weight Density	kg/m^3 (lb/in^3)	8,027 (0.290)	
Poisson's Ratio		0.3	

Notes:
1. The material ultimate strengths and elastic modulus values are obtained from ASME code [2.1.4].
2. As noted on the licensing drawings per Section 1.3, the minimum yield strength of this material shall be 36 ksi @ room temperature. The yield strength at elevated temperatures is obtained by rationing the corresponding strength values based on minimum strength properties from ASME code [2.1.4].

Table 2.2.1C: Key Material Properties for CLLS and Trunnions

SB-637 N07718 and Nickel Alloy			
Property	**Unit**	**@ 150 °F (66 °C)**	**@ 200 °F (93 °C)**
Yield Strength, S_y	MPa (ksi)	1014 (147)	992.9 (144)
Ultimate Strength, S_u	MPa (ksi)	1246 (180.7)	1224.5 (177.6)
Young's Modulus, E	MPa x 10^4 (psi x 10^6)	19.7 (28.49)	195.1 (28.3)

Notes:
1. The material yield, ultimate strengths and elastic modulus values are obtained from ASME code [2.1.4].
2. Source for Sy values is ratioing design stress intensity values and Table Y-1 of [2.1.4], as applicable.
3. Source for Su values is ratioing design stress intensity values and Table U of [2.1.4], as applicable.

Table 2.2 Material Properties of Cask Top Flange

Austenitic Steel SA-182 FXM-19			
Property	**Unit**	**@ 150 °F (66 °C)**	**@ 200 °F (93 °C)**
Yield Strength, S_y	MPa (ksi)	343.4 (49.8)	324.7 (47.1)
Ultimate Strength, S_u	MPa (ksi)	687 (99.7)	685.3 (99.4)
Young's Modulus, E	MPa x 10^4 (psi x 10^6)	191.7 (27.81)	189.6 (27.5)

Notes:
1. The material yield, ultimate strengths and elastic modulus values are obtained from ASME code [2.1.4].

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Table 2.2.2: Critical Characteristics for Cask Containment Seals

[Table Withheld in Accordance with 10 CFR 2.390]

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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 weldment of rectangular cross section. The inner walls and baseplate of the cask are fabricated of material qualified to Subsection NB of the ASME code. The Top Flange and the Closure Lid are monolithic sections, also made of austenitic stainless steel (Type 304) and also procured to ASME Section III Subsection NB specifications. The inner walls, inner baseplate, Top Flange and Closure lid constitute the Containment Boundary of the cask. The outer walls baseplates constitute the Dose Blocker Structure (DBS). The DBS components are non-code and provide a prophylactic envelope around the Containment to protect it from environmental hazards as well as direct impact during an accident event. The DBS materials are procured to ASTM specifications and are metallurgically identical to the Containment Boundary material. To prevent rigid localized stiff impacts during drop accidents or other impulsive loads, the cask attachments protruding out from the exterior body of the HI-STAR ATB 1T cask shall be made collapsible. Specifically, these attachments will be ensured not to influence the impact loading during the drop events.

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Figure 2.3.1:

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Figure 2.3.2:

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Figure 2.3.3:

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Figure 2.3.4:

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Figure 2.3.5:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.3.6:

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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: 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: 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 drawing package 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 drawing package shown 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 methodology (classical beam theory) 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 lids contain lid lifting lugs used to move the lids 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). Basic 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 analysis is performed. The closure lid and CLLS is included in the FE model. The load case applies the loads from the fully loaded BFA-Tank and the self-weight to the baseplate. In this load case, the 15% amplifier is applied to the lifted load.

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

2.5.1.3 Failure of Lifting Devices

10CFR71.45 also requires that the lifting attachments permanently attached to the cask be designed in a manner such that a structural failure during lifting will not impair the ability of the transportation package to meet other requirements of Part 10CFR71. The ultimate load carrying capacity of the lifting trunnions is governed by the cross section of the trunnion external to the cask rather than by any section within the cask. Loss of the external shank of the lifting trunnion will not cause loss of any other structural or shielding function of the HI-STAR ATB 1T cask; therefore, the requirement imposed by 10CFR71.45(a) is satisfied.

2.5.2 Tie-Down Devices

There are no tie-down devices that are a structural part of the package. Therefore, 10CFR71.45(b) is not applicable to the HI-STAR ATB 1T Package.

The transport frame restraints which secure the HI-STAR ATB 1T package base in-place during its transportation are not part of the HI-STAR ATB 1T package.

2.5.3 Safety Evaluation of Lifting and Tie-Down Devices

Cask lifting attachments have been considered in Subsection 2.5.1.

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

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Table 2.5.1: Results for Cask Trunnion Analysis

Item	Calculated Value	Safety Factor
Bending Moment in Trunnion – kip-in (kN-m)	88.23 (9.97)	22.25
Shear Force in Trunnion – kip (kN)	73.5 (327)	20.14
Bearing Stress in Trunnion hollow Shaft (Comparison with Yield Strength in Compression) – ksi (MPa)	37.5 (258.5)	1.26
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	679 (4.68)	7,100 (48.95)	10.46
Shear Stress in Lifting Attachment	1,088 (7.5)	4097 (28.25)	3.77
Stress in the attachment weld	3,131 (21.6)	7,100 (48.95)	2.27
Note: Safety factor reported in this table are calculated based on the requirements of NUREG-0612 [1.2.3].			

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Table 2.5.3: Results for Baseplate Lifting

Item	Value, psi (MPa)	Limit, psi (MPa)†	Minimum Safety Factor
Base Plate, Membrane + Bending Stress	9,013 (62.14).	30,000 (206.84)	3.33
†The stress limit is established in Table 2.1.3.			

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 the stress/deformation analysis. 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 analysis is conducted using computer code ANSYS [2.6.2] when necessitated. For dynamic loading scenarios involving impacts (transport package drops pursuant to 10CFR71), the state of the art numerical analysis code LS-DYNA is used. Appendices 2A and 2B provides the QA validation of the LS-DYNA code for evaluating the drop events.

2.6.1 Description of the Finite Element Model

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 double walled baseplate at the bottom and a solid single wall flange at the top. A thick solid lid is secured to the top flange via a boltless Closure Lid Locking System (CLLS). The Package is perfectly prismatic structure except for the lifting trunnions that protrude from the sides. To protect the package from damage by its own trunnions during a tip-over or free drop event, the trunnions have been designed to be axially collapsible under a moderate axial load as described in Subsection 1.2.1.1. Therefore, the trunnions 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]. LS-DYNA is also used to determine the internal stresses and strains in the cask. 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 large 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 2.6.13 show the maximum shear stress induced in the cask containment components. The induced primary and secondary stress intensity can be computed using the maximum shear stress contours from these figures. Correspondingly the safety factor in the containment boundary component is determined.

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.

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 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 austenitic stainless steel. From Table I-9.2 of the ASME Code [2.1.10], the allowable stress amplitude corresponding to 10^6 cycles is 18.3 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 18.3 ksi / 4 = 4.57 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.

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.

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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	30/207	8.11/55.92	3.70
Containments Wall Plate	Primary Membrane plus Primary Bending	30/207	11.38/78.46	2.64
Base Plate	Primary Membrane plus Primary Bending	30/207	4.73/32.63	6.34

Table 2.6.2: Summary Results for the Containment Shell, Baseplate and the Closure Lid – 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	182/26.4	206.8/30	1.14	[2.6.3]
		Secondary Stress Intensity	335.1/48.6	413.7/60	1.23	
	Containment Shell	Primary + Secondary Stress Intensity	271.9/31.6	496.4/72	2.28	
	Containment Flange	Primary + Secondary Stress Intensity	424/61.5	686.7/99.6	1.62	
	Containment Baseplate	Primary Bending Stress Intensity	194.4/28.2	248.2/36	1.28	
	Containment Welds	Primary Stress	124.1/18	172.4/25	1.39	
	CLLS Wedge	Primary Bending Stress Intensity	96.5/14	675.7/98	7	
		Primary Shear Stress	17.4/2.53	202.7/29.4	11.6	
Bottom Drop	Containment Baseplate	Primary Bending Intensity	122.7/17.8	248.2/36	2.02	
	Containment Shell	Primary + Secondary Stress Intensity	188.9/27.4	496.4/72	2.63	
	Containment Welds	Primary Stress	144.4/20.95	172.4/25	1.19	
	Closure Lid	Primary Bending Intensity	193.1/28	206.8/30	1.07	

		Primary + Secondary Stress Intensity	330.9/48	413.7/60	1.25	
Side Drop	Closure Lid	Primary Stress Intensity	172.4/25	206.8/30	1.2	
	Containment Baseplate	Primary Stress Intensity	144.8/21	248.2/36	1.71	
	Containment Shell	Primary Bending Stress	212.4/30.8	248.2/36	1.17	
	Containment Shell	Secondary Stress Intensity	263.4/38.2	496.4/72	1.88	
	Containment Welds	Primary Stress	153.1/22.2	172.4/25	1.13	
C.G.O.C Drop (With Primary Impact at Top Corner)	Closure Lid	Primary Stress Intensity	165.5/24	206.8/30	1.25	
		Secondary/Peak Stress Intensity	275.8/40	413.7/60	1.5	
	Containment Shell	Primary + Secondary Stress Intensity	100.7/14.6	496.4/72	4.93	
	CLLS	Primary Stress Intensity	193.1/28	686.7/98	3.5	
	Containment Welds	Primary Stress Intensity	83/12.05	172.4/25	2.07	
	Top Flange	Secondary Stress Intensity	551.6/80	413.7/99.6	1.25	
C.G.O.C Drop (With Primary Impact at Bottom Corner)	Containment Baseplate	Secondary Stress Intensity	187.5/27.2	413.7/60	2.21	
	Containment Shell	Secondary Stress Intensity	216.5/31.4	496.4/72	2.29	

	Containment Welds	Primary Stress	83.4/12.1	172.4/25	2.07	

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, 135 psi	Closure Lid	Primary Membrane plus Primary Bending	30.0 (207)	5.60 (38.61)	5.36
	Containments Wall Plate	Primary Membrane plus Primary Bending	30.0 (207)	2.80 (19.33)	10.7
	Base Plate	Primary Membrane plus Primary Bending	30.0 (207)	1.04 (7.18)	28.8

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

Table 2.6.4: Key FE Model Data

Item	Value
Weight of the Empty Package	Refer to Table 1.1.1 of this SAR
Weight of the Cask Contents (Loaded Waste Package)	
Cask Inside Dimensions	
Cask Outside Dimensions	
Total Number of Elements (including BFA Target)	>2,170,000
Total Number of Nodes	>1,880,000

Figure 2.6.1:

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Figure 2.6.2:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.3:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.4

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.5

[Figure Withheld in Accordance with 10 CFR 2.390]

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Figure 2.6.6

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.7:

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Figure 2.6.8

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.9

[Figure Withheld in Accordance with 10 CFR 2.390]

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Figure 2.6.10

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.11a

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.11b

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.12:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.6.13:

[Figure 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]:

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To induce maximum damage to the Package components all plausible orientations of the transport package, with respect to the horizontal rigid 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)	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)	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 correspond to the quarter-scale package oblique top-down drop [2.6.6]
7. Sensitivity Simulation	The FE model used for this sensitivity case is identical to Simulation 1 with the exception that upper bound material strength properties are used for the stainless steel components.

The typical plastic strain plots for the side drop are captured in the Figures 2.7.1 and 2.7.2. The strain in the CLLS for the limiting Top End drop is shown in Figure 2.7.3.

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The key results for the 9 m (30 ft.) drop simulations are summarized in Table 2.7.1.

The strain limits in the containment boundary components, as discussed in Subsection 2.1.1, are satisfied for all the postulated drop accidents. The calculation package [2.6.3] illustrates the strain/stress results for all other drop accidents.

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

Finally, 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.

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.

Lastly, the key results for the sensitivity simulation is summarized in Table 2.7.3. It is shown that the upper bound material strength properties considered for the package stainless steel components in the sensitivity simulation have negligible effect on the results. More importantly, the overall conclusion reached from the base simulations remains unchanged.

The locking wedge locking pin, which secures the CLLS Wedges in place and arrests its relative movement during the drop events is demonstrated to remain functional.

In order to provide additional safety assurance and to improve the margin of safety against seal leakage (containment breach), an additional closure lid restraint feature is provided on the short sides of the top flange/closure lid, as shown in drawing 1.3 of this SAR.

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To this effect, additional sensitivity simulation is performed to reflect this restraint feature in the FE model, as documented in [2.6.3].

This additional restraint feature is only introduced as a defense-in-depth design feature and the actual safety evaluation for the package containment is solely based on the CLLS mechanism originally provided on the closure lid longer edge/surface. As a result, the additional restraint feature analyzed is designated as NITS and its typical dimensions and properties are discussed in Holtec report [2.6.3].

The joint opening (gasket relaxation) from this sensitivity simulation subsequent to the drop accident significantly reduced as compared to the governing 30-ft (9-m) Slapdown drop accident. It is therefore, demonstrated that the addition of the restraint bars on the shorter edge of the containment closure lid significantly limits the gap opening between the closure lid and the top flange thereby providing additional safety assurance against containment breach. The strain results for other containment components also meet the acceptance strain criteria.

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.

Three limiting transport package orientations are considered for the 1-meter (40-inches) puncture drop events viz., the top end puncture onto the closure lid, the side puncture into trunnion hole 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 challenges the closure lid and could 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.

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. *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 drop simulation warrants a special mention since it is sequenced after the 30 ft. (9-m) free drop event to accumulate the damage to the package from both accidental events. The damage/deformations including material erosion (failure) in the package and residual stress/strain in cask components are preserved during this sequential drop event. 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 contact birth and death times for both targets are tuned such that the unyielding flat target applicable only for the 30 ft. (9-m) free drop is active during the initial impact duration and is deleted once it dissipates the energy corresponding to the 30 ft. drop. On the other hand the location of puncture bar impact and birth time for the puncture bar contacting the package is adjusted such that it participates only in the later 1-m free drop onto puncture bar. Once the 30 ft. (9-m) drop energy is dissipated by the cask the velocity of the package is readjusted to reflect energy corresponding to 1-m package drop onto puncture bar.

A mild steel bar is added to the FE model, placed in the proper orientation, and fixed to the ground (unyielding surface). The package is then assumed to have a known initial velocity at contact with the bar. The governing results of this evaluation are summarized in Tables 2.7.2. Figures 2.7.6 through 2.7.8 show the key strain 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 strains in the closure flange, closure lid, containment shell, and 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 leak tight subsequent to the critical HAC drop events.

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

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

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). Moreover, the locking wedge material (SB-637 N07718) has a slightly lower coefficient of thermal expansion than the top flange and closure lid material (Type 304 SS), so the thermal loading under NCT will not result in any increased stress on the CLLS due to differential thermal growth.

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 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 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 2.2.2. 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 calculation package [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 calculation package [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: Strain Results for the 9-m (30-ft) HAC Drops (Note 1)

Simulation	Component	Average Strain (Allowable Average Strain) (Note 2) – %	Maximum Strain (Allowable Peak Strain) (Note 3) – %	Reference
Top End Drop	Closure Lid	3 (22.5)	10 (55.3)	[2.6.3]
	Containment Shell + Baseplate	1.16 (22.5)	1.94 (55.3)	
	Containment Welds	2 (25.5)	3 (46.1)	
	Containment Top Flange	2 (20.1)	5 (42.5)	
	Seal Seating Region	1.2 (20.1)	N/A	
	CLLS	0.02 (7.6)	N/A	
Bottom End Drop	Closure Lid	1.5 (22.5)	3 (55.3)	
	Containment Shell + Baseplate	1.8 (22.5)	3 (55.3)	
	Containment Welds	1.5 (25.5)	3 (46.1)	
	Containment Top Flange	0.8 (20.1)	1.9 (42.5)	
	Seal Seating Region	0.35 (20.1)	N/A	
	CLLS	0.06 (7.6)	N/A	
Side Drop	Closure Lid	3 (22.5)	6 (55.3)	
	Containment Shell + Baseplate	3 (22.5)	6 (55.3)	
	Containment Welds	3 (25.5)	6 (46.1)	
	Containment Top Flange	6 (20.1)	12 (42.5)	
	CLLS	0.25 (7.6)	N/A	
C.G.O.C (Top End)	Closure Lid	13.7 (28.6)	45 (55.3)	
	Containment Shell + Baseplate	2.25 (22.5)	4.5 (55.3)	
	Containment Welds	3 (25.5)	6 (46.1)	
	Containment Top Flange	10 (20.1)	30 (42.5)	
	CLLS Wedge	0.5 (9.6)	N/A	
	Closure Lid	3 (22.5)	10 (55.3)	

C.G.O.C (Bottom End)	The results for the 30-ft CGOC drop followed by 1-m CGOC drop are summarized in Table 2.7.2.			
Slapdown Drop	Closure Lid	< 12 (28.6)	< 40 (55.3)	
	Containment Shell + Baseplate	0.84 (28.6)	2.1 (55.3)	
	Containment Welds	0.29 (25.5)	2.9 (46.1)	
	Containment Top Flange	15 (20.1)	23.7 (42.5)	
	CLLS Wedge	1.4 (9.6)	N/A	

Notes:

Note (1) The values reported in the parenthesis are allowable strains and those induced in the containment components are reported outside the parenthesis. The effective strain reported in this table account for the traixiltiy factor which is implemented in within LS-Dyna post-processing as discussed in section 8.0. The strain values reported here are bounding based on the strain contours from the applicable strain plots.

Note (2) The strains reported under this column correspond to the average through thickness of the component evaluated. Furthermore the induced strain values are conservatively estimated based on the strain fringes which typically bound the through thickness average strain value accounting for triaxiality.

Note (3) The strains reported under this column correspond to the peak strain. As recommended by Section FF-1142 of [2.1.8], the induced effective strain accounting for triaxiality factor excludes the hot spots (points of numerical singularity).

Note (4) The maximum strain locations for the Oblique drops a.k.a the Top CGOC and Top-Slapdown drops correspond to the local/global structural discontinuities. Accordingly, the local strain limits per Appendix A are used for these locations. Likewise the weld locations correspond to the local/global structural discontinuities, therefore, strain limits corresponding to the local or global structural discontinuity are applied.

N/A implies either not applicable or not appropriate.

Table 2.7.2: Strain Results for the 1-m (40-inches) HAC Puncture Drops (Note 1)

Simulation	**Component**	**Average Strain (Allowable Average Strain) – %**	**Maximum Strain (Allowable Peak Strain) – %**
Top End Puncture	Closure Lid	10 (22.5)	14.13 (55.3)
Side Puncture (Note 4)	Containment Shell	19.7 (28.6)	39 (55.3)
Bottom C.G.O.C 30 ft. Drop Followed by 1-m Puncture Drop (Note 4)	Containment Baseplate	25 (28.6)	40 (55.3)
	Containment Welds	20 (25.5)	35(46.1)

Note (1) The values reported in the parenthesis are allowable strains and those induced in the containment components are reported outside the parenthesis. The effective strain reported in this table account for the traixiltiy factor which is implemented in within LS-Dyna post-processing as discussed in section 8.0. The strain values reported here are bounding based on the strain contours from the applicable strain plots.

Note (2) The strains reported under this column correspond to the average through thickness of the component evaluated. Furthermore the induced strain values are conservatively estimated based on the strain fringes which typically bound the through thickness average strain value accounting for triaxiality.

Note (3) The strains reported under this column correspond to the peak strain. As recommended by Section FF-1142 of [2.1.8], the induced effective strain accounting for triaxiality factor excludes the hot spots (points of numerical singularity).

Note (4) The maximum strain locations for the Side and Bottom CGOC drops correspond to the local/global structural discontinuities. Accordingly, the local strain limits per Appendix A are used for these locations.

Table 2.7.3: Results from Sensitivity Runs – Governing HAC Drop

Simulation	**Component**	**Average Strain/Peak Strain - Base Simulation – in/in.**	**Average Strain/Peak Strain - Sensitivity Simulation – in./in.**
Top End Drop (Simulation 1 Vs. Simulation 10)	Closure Lid	3 (5)	3 (8)
	Containment Shell + Baseplate	1.16 (1.94)	1.0 (1.9)
	Containment Welds	2 (3)	2 (2.8)
	Containment Top Flange	2 (5)	2 (5)

The strain values reported here are bounding based on the strain contours from the applicable strain plots.

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Table 2.7.4 Comparison of Initial Energy to the Residual Energy

Simulation Number	Initial Energy (lbf-in)	Residual Energy (lbf-in)	Ratio of Residual Energy to Initial Energy (%)	Second load step is warranted
# 1	8.95 e+7	1.025 e+6	1.15	No
# 2 (Primary Impact)	8.95 e+7	3.91 e+6	4.4	Yes
# 2 (Secondary Impact)	4.59 e6	5.3 e +5	0.6 when compared to the initial energy 8.95 e+7	No
# 3	8.95 e+7	1.94 e+6	2.17	No
# 4	8.93 e+7	8.6 e+5	0.96	No
# 5	8.95 e+7	1.49 e+6	1.66	No
# 6	8.95 e+7	2.08 e+6	2.32	No

Note: The arrows indicate the input energy from primary impact to the secondary impact simulation.

Figure 2.7.1:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.2

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.3

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.4:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.5:

[Figure Withheld in Accordance with 10 CFR 2.390]

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Figure 2.7.6:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.7:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.8:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.9:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.10:

[Figure Withheld in Accordance with 10 CFR 2.390]

Figure 2.7.11:

[Figure 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) An inelastic dynamic analysis of the impactive events listed in Table 2.1.1 (Cases C and D) with due consideration of material strain rate and triaxiality effects is conducted and it is shown to meet the acceptance criteria discussed in Subsection 2.1.2, which accords with the strain limits specified by ASME Nonmandatory Appendix FF [2.1.8].

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

(viii) 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] Doug Ammerman and Gordon Bjorkman, “Strain-Based Acceptance Criteria for Section III of the ASME Boiler and Pressure Vessel Code”, Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials, PATRAM 2007, October 21-26, 2007, Miami, Florida, USA.

[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] Strain-Based Acceptance Criteria for Energy-Limited Events, 2009 ASME Pressure Vessels and Piping Division Conference, July 2009, U.S.Department of Energy Idaho National Laboratory.

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

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

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

[2.6.2] ANSYS, Version 14.0, Ansys Inc., Copyright 2010 SAS IP, Inc.

[2.6.3] Holtec Calculation HI-2177539, Revision 1, “Drop Analysis for the HI-STAR ATB 1T Transport Package”

[2.6.4] Holtec Calculation HI-2177540, Revision 1, “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.

[2.7.1] 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:

[PROPRIETARY APPENDIX WITHHELD IN ITS ENTIRETY PER 10 CFR 2.390]

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 38^{o}C (100°F) and in the shade, no accessible surface of the package would have a temperature exceeding 85^{o}C (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 38^{o}C (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 802^{o}C (1475°F) for a period of 30 minutes [§71.73(c)(4)].

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

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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 all-stainless steel cask equipped with a removable closure lid. 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 38^{o}C (100^{o}F) 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 85^{o}C (185^{o}F).

Table 3.1.1: HI-STAR ATB 1T Normal Transport Maximum Temperatures (Max Design Ambient Temperature plus Solar Insolation)

Component	Temperature ^oC (^oF)
Waste	195 (383)
Cask Containment Wall Plates	66 (151)
Cask Containment Base Plate	71 (160)
Cask Top Flange	63 (145)
Cask Closure Lid	65 (149)
Cask Closure Lid Inner Seal	61 (142)
Cask Closure Lid Outer Seal	61 (142)
Cask Intermediate Side Dose Blocker Plates	66 (151)
Cask Intermediate Bottom Dose Blocker Plate	71 (160)
Cask Outer Side Dose Blocker Plates	65 (149)
Cask Outer Bottom Dose Blocker Plate	71 (160)
Cask External Surface	71 (160)

Table 3.1.2: Hypothetical Fire Accident Maximum Temperatures

Component		Initial Temperature °C (°F)	End of Fire Temperature °C (°F)	Post-Fire Temperature °C (°F)
Cask Containment Boundary	Wall and Base Plates	71 (160)	329 (624)	356 (673)
	Top Flange	63 (145)	759 (1398)	759 (1398)
	Closure Lid	65 (149)	611 (1132)	611 (1132)
Volume Average of Cask Containment Boundary Components		60 (140)	195 (383)	220 (428)
Cask Closure Lid Seals	Inner	61 (142)	200 (392)	299 (570)
	Outer	61 (142)	218 (424)	303 (577)

Table 3.1.3: HI-STAR ATB 1T Containment Boundary Pressure Under Normal Transport & Design Basis Fire Conditions

BFA-Tank T-200		Absolute Pressure kPa (psia)	Cavity Bulk Temperature ^{o}C (^{o}F)
Normal Transport	BFA-Tank Cavity (Note-1)	134.7 (19.5)	118 (244)
	Cask Cavity (Note-2)	116.5 (16.9)	65 (149)
Design Basis Fire Accident	BFA-Tank Cavity (Note-1)	189.9 (27.5)	278 (532) (Note-3)
	Cask Cavity (Note-2)	171.6 (24.9)	225 (437) (Note-3)

Notes:
1. The BFA-Tank cavity bulk temperature is the volume averaged temperature of air and waste inside the sealed BFA-Tank. The volume percentage of the waste is small and thus the BFA-Tank cavity bulk temperature is slightly overestimated. If the BFA-Tank leaks, the hot air inside the BFA-Tank can flow into the cask cavity and an equilibrium pressure will be reached in the cask cavity and the BFA-Tank cavity. This equilibrium pressure is lower than the BFA-Tank cavity pressure inside the sealed BFA-Tank.
2. The cask cavity bulk temperature is the volume averaged temperature of air outside the BFA-Tank, which is based on the assumption that the BFA-Tank is sealed. If the BFA-Tank leaks, the cask cavity pressure will reach the equilibrium pressure that is bounded by the cavity pressure inside the sealed BFA-Tank.
3. As described in Section 3.4.3.2, the cavity pressure under design basis fire accident condition is estimated by conservatively assuming 160^{o}C (288^{o}F) increase in the cavity bulk temperature from the normal transport condition.

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), carbon steel (BFA-Tank and BTC), 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, 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.

Surface emissivity data for key materials of construction are provided in Table 3.2.5. The emissivity properties of painted surfaces are generally excellent. 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 absorbtivity 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]
Air	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]

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)	
SOLID		
Material	Stainless Steel (Type 304)	Carbon Steel
Temperature °C (°F)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)
20 (68)	14.8 (8.55)	60.4 (34.91)
50 (122)	15.3 (8.84)	59.8 (34.56)
150 (302)	17.0 (9.82)	55.9 (32.31)
250 (482)	18.6 (10.75)	51.4 (29.71)
350 (662)	20.1 (11.62)	47.0 (27.16)
450 (842)	21.5 (12.43)	42.7 (24.68)
550 (1022)	22.9 (13.23)	38.2 (22.08)
650 (1202)	24.3 (14.04)	33.5 (19.36)
750 (1382)	25.7 (14.85)	29.1 (16.82)

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)
Stainless Steel	8025 (501)	502 (0.12)
Carbon Steel	7835 (489)	418 (0.1)
Air	(Ideal Gas Law)	1006 (0.24)

Table 3.2.4: Air Viscosity Variation with Temperature

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

Table 3.2.5: Summary of Material Surface Emissivity Data

Material	Emissivity
Stainless Steel (Machined Forgings)	0.36
Stainless Steel Plates	0.587
Carbon steel	0.66
Painted surfaces	0.85

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

[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 °C (°F)	Fire Accident Temperature Limits °C (°F)
Containment Wall Plate	Stainless Steel	426 (800) Note-1	1000 (1832) Note-2
Containment Base Plate	Stainless Steel	426 (800) Note-1	1000 (1832) Note-2
Top Flange	Stainless Steel	426 (800) Note-1	1000 (1832) Note-2
Closure Lid	Stainless Steel	426 (800) Note-1	1000 (1832) Note-2
Closure Lid Seals	Elastomeric	See Table 2.2.2	See Table 2.2.2

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.

3.3 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 (essentially 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 same 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 absorbtivity.

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:

$$h = 0.19\,(\Delta T)^{1/3}\ (\text{Vertical}, GrPr > 10^9)$$
$$h = 0.22\,(\Delta T)^{1/3}\ (\text{Heated Horizontal Plate Facing Upward}, GrPr > 2x10^7)$$
$$(\text{in conventional U.S. units})$$

Laminar range:

$$h = 0.29\,(\frac{\Delta T}{L})^{1/4}\ (\text{Vertical}, GrPr < 10^9)$$
$$h = 0.27\,(\frac{\Delta T}{L})^{1/4}\ (\text{Heated Horizontal Plate Facing Upward}, GrPr < 2x10^7)$$
$$(\text{in conventional U.S. units})$$

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 9×10^5 for the cask external surface average temperature at about 60°C (140°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 (~10°F).

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) [**Text Withheld in Accordance with 10CFR2.390**]

(ii) **[Text Withheld in Accordance with 10CFR2.390]**

(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) [Text Withheld in Accordance with 10CFR2.390]

3.3.6 Hypothetical Loading Distributions of Waste Content

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) Concentrated Heat Load Distribution

It is considered that the temperature of the waste content is the highest if all the waste content is concentrated at the center of the 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) Uniform Heat Load Distribution

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.

[Text Withheld in Accordance with 10 CFR 2.390]

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.

[Text 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 Grid Sensitivity Study

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 Heat and Cold

3.3.8.1 Maximum Temperatures

As required by transport regulations, the HI-STAR ATB 1T Package is evaluated under hot ambient conditions defined in 10CFR71. These conditions are 38^{o}C (100^{o}F) 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 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 21°C (70°F), 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

[Text Withheld in Accordance with 10CFR2.390]

[Text Withheld in Accordance with 10CFR2.390]

[Text Withheld in Accordance with 10CFR2.390]

3.3.11 Acceptance Criteria for BFA-Tank Vacuum Drying Operation

[Text Withheld in Accordance with 10CFR2.390]

[Text Withheld in Accordance with 10CFR2.390]

Table 3.3.1:
[Table Withheld in Accordance with 10CFR2.390]

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/m2)
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:

[Table Withheld in Accordance with 10CFR2.390]

Table 3.3.4: Grid Independent Study

BFA-Tank T-200	Mesh Size	Waste Maximum Temperature ^{o}C (^{o}F)
Mesh 1	564,028	194.64 (382.35)
Mesh 2	1,287,800	194.62 (382.32)
Mesh 3	2,922,480	194.59 (382.26)

Table 3.3.5:

[Table Withheld in Accordance with 10CFR2.390]

FIGURE 3.3.1:

[Figure Withheld in Accordance with 10CFR2.390]

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 802^{o}C (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 38^{o}C (100^{o}F) 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 CGOC top end drop accident is considered to be the worst scenario for the cask to survive the following fire accident due to the local damage of the maintenance cover and the local deformation of the cask. After the CGOC top end drop accident, the cask may stand on the long side dose blocker plate, the short side dose blocker plate, or the top maintenance cover. The cask has the largest external surface exposed to the fire if it stands on the short side dose blocker plate. This cask position is adopted for the fire evaluation, as shown in Figure 3.4.2. The maintenance cover is assumed to be lost though it is only locally damaged near the corner that hits the ground.

To ensure the cask containment boundary is intact under the fire accident, the major concern is the temperature of the cask containment boundary components especially the closure lid seals. 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 cask cavity is simplified to be a solid volume with uniform heat generation and effective thermal properties.

[Text Withheld in Accordance with 10CFR2.390]

The simplified cask model under the normal condition is adopted as the initial condition 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 802°C (1475°F) 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 and unit absorbtivity 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. Thermal insulation boundary condition is applied to the surface where the cask stands on the ground. 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 1.5 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, this period is sufficient for the cask containment boundary components and the closure lid seals to reach the maximum temperatures and begin to recede. 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 802°C (1475°F) lasting for 30 minutes, followed by a post fire cooldown for a sufficient duration to allow the cask containment boundary components and the closure lid seals to reach the maximum temperatures. The temperature history of the cask containment boundary components and the closure lid seals is graphed in Figure 3.4.1. The maximum temperatures reached during fire and post-fire cooldown are reported in Table 3.1.2. The temperatures of the cask containment boundary components are below their respective safety limits.

As shown in Figure 3.4.2, the seal temperature is the highest at the top corner where it is heated by fire from three sides. It is noted that the maintenance cover is assumed to be totally lost in the fire evaluation. In fact, the maintenance cover at the top corner will be intact after the drop accident. The maintenance cover will prevent the closure lid from direct exposure to fire and thereby reduce the temperature increase in the seals at the top corner. On the bottom corner, the maintenance cover may be damaged and the cask may be deformed after the drop. The impact of the local deformation of the cask is small and is not taken into account in the fire evaluation. The seal temperature at the bottom corner is much lower than the maximum seal temperature at the top corner. Thus, the local deformation of the cask at the bottom corner will not cause the seal temperature to exceed its limit.

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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.

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 not explicitly modeled in the fire evaluation. The increase in the average temperature of the cask cavity is expected to be 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 about 160^{o}C (288^{o}F). The maximum cask cavity average temperature under the fire condition is conservatively overestimated by adding 160^{o}C (288^{o}F) 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 the latter is made of a more thermally expansive material (stainless steel) compared to the former (carbon steel).

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	Yes	Yes
Surface Convection	Natural	Forced	Natural
Cask Surface Solar Absorbtivity	0.6	0.6	0.6
Emissivity of Cask surface	0.36	0.9 (fire emissivity)	0.36

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	649^{o}C to 1093^{o}C (843^{o}C avg.) 1200^{o}F to 2000^{o}F (1550^{o}F avg.)
Convective Coefficient	25.5 W/m^2-K (4.5 Btu/ft^2-hr-^{o}F)

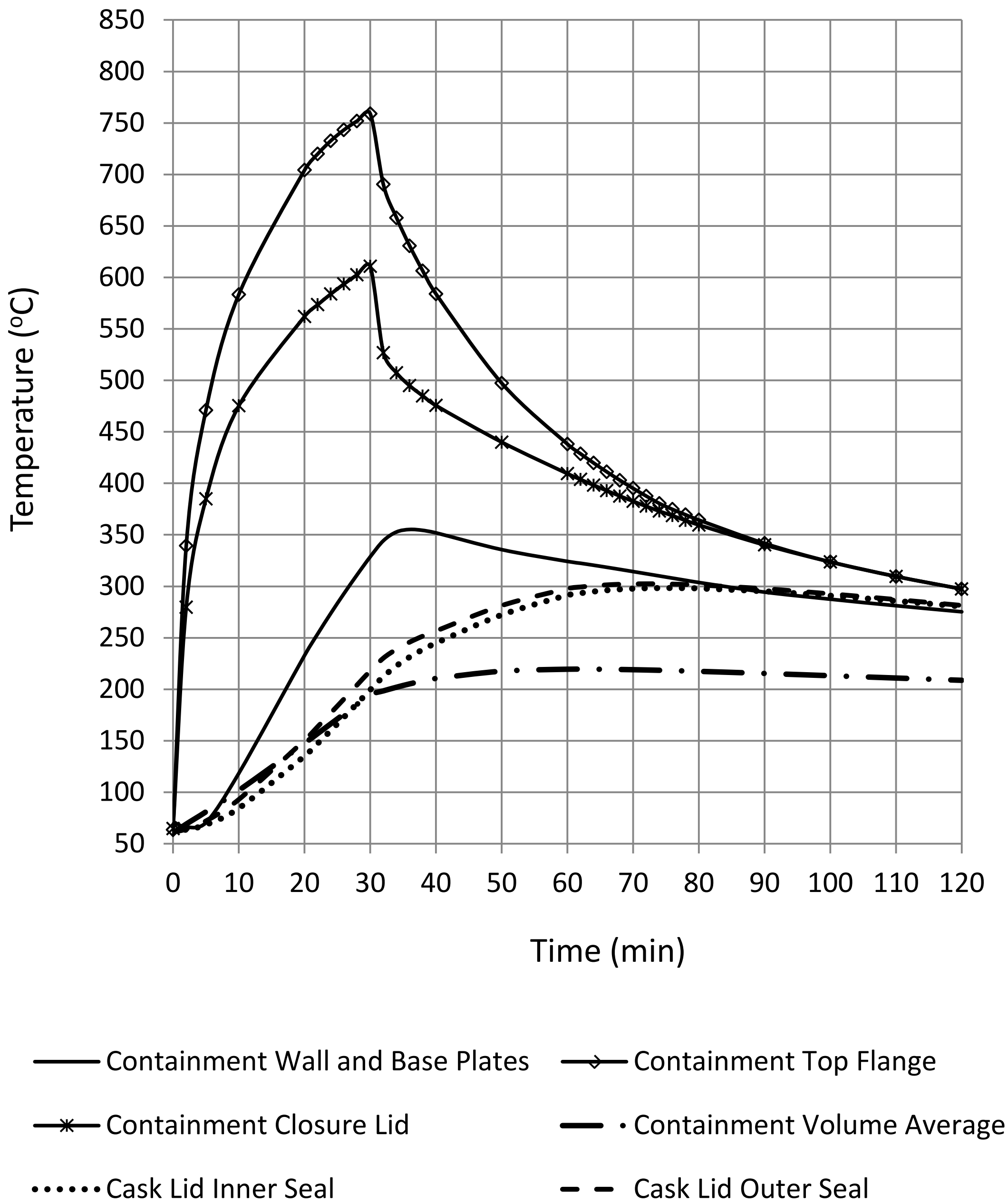

FIGURE 3.4.1: HI-STAR ATB 1T FIRE AND POST FIRE COOLDOWN TEMPERATURE HISTORY

FIGURE 3.4.2:

[Figure Withheld in Accordance with 10CFR2.390]

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

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

3. Because permissible waste in the HI-STAR 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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[3.2.3] Kern, D.Q., "Process Heat Transfer," McGraw Hill Kogakusha, (1950).

[3.2.4] ASME Boiler and Pressure Vessel Code, Section II, Part D, 2013 Edition.

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

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

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

[3.3.1] FLUENT Computational Fluid Dynamics Software (Fluent, Inc., Centerra Resource Park, 10 Cavendish Court, Lebanon, NH 03766).

[3.3.2] "Integrated Data Base Report -1996: U. S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics," Appendix B, Characteristics of Important Radionuclides, DOE/RW-0006, Rev. 13, December 1997.

[3.3.3] "Standard for Verification and Validation in Computational Fluid Dynamics and Heat Transfer", ASME V&V 20-2009.

[3.4.1] "Thermal Measurements in a Series of Large Pool Fires", Sandia Report SAND85 – 0196 TTC – 0659 UC 71, Page 41, August 1971.

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 a containment system fabrication verification test before the first use as described in Chapter 8. The containment system fabrication verification test is performed at the factory as a part of the HI-STAR ATB 1T acceptance testing. The welds of the containment boundary and the inner seal of the closure lid are leakage tested in accordance with ANSI N14.5. A containment system periodic verification tests is described in Subsection 4.3. The elastomeric seals of HI-STAR ATB 1T cask will be inspected each time the HI-STAR ATB 1T is loaded and if needed replaced as described in Chapter 7.

4.1 CONTAINMENT BOUNDARY

[Text Witheld in Accordance with 10 CFR 2.390]

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 seals and welds designed and tested to provide containment. Seals and welds are individually discussed below. The seals 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 Seals

[Text Witheld in Accordance with 10 CFR 2.390]

4.1.3.2 Containment Welds

[Text Witheld in Accordance with 10 CFR 2.390]

Full-penetration welds are specified for the plates that form the cask containment shell. Full-penetration welds are also specified for the inner shell to the top flange and base plate welds. 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: [Figure Witheld 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 verification 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

[Text Witheld in Accordance with 10 CFR 2.390]

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[Text Witheld in Accordance with 10 CFR 2.390]

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.

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

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:

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

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.

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

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 provide 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.

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

where,

$L_{@Pu}$ is the allowable leakage rate at the upstream pressure for normal and accident conditions [cm³/s],
a is the capillary length or Seal 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:

$$Q_{u-i} = L_{u-i} \times P_{u-i} \tag{4-7}$$

where,

Q_{u-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-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-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-N}) and accident (Q_{u-A}) conditions, with values presented in Table 4.4.8. The most limiting value was conservatively selected as the basis for leakage rate acceptance criterion. The conservatively reduced value of leakage rate acceptance criterion is presented in Table 8.1.1.

Table 4.4.1: [Table Witheld 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)	1.48 atm (150 kPa)	4.0 atm (405.3 kPa)	1 atm (101.3 kPa)
Downstream Pressure (P_d)	1 atm (101.3kPa)	1 atm (101.3kPa)	0.01 atm (1 kPa)
Temperature (T)	122 °C (395 K)	802 °C (1075 K)	25 °C (298 K)
Molecular Weight (M)	29 g/mol (air)	29 g/mol (air)	29 g/mol (air)
Viscosity (u)	0.0227 cP (air)	0.0434 cP (air)	0.0184 cP (air)
Seal Seating Width (a)	0.89 cm	0.89 cm	0.89 cm

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: [Table Witheld in Accordance with 10 CFR 2.390]

Table 4.4.5: [Table Witheld 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)

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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)	114×10^{-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	7.22×10^{-2} cm^3/s	7.22×10^{-2} atm-cm^3/s (7.31×10^{-3} Pa-m^3/s, Air)

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*

[4.0.3] B.L. Anderson et al., "Containment Analysis for Type B Packages Used to Transport Various Contents", NUREG/CR-6487, UCRL-ID-124822, Lawrence Livermore National Laboratory, November 1996.

[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, 1995 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.

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 five 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 five 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.

Dose rate results of several hypothetical accident conditions are presented in Table 5.1.3. All values in this table 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		0.170		2
		0.166		2
		0.161		2
		0.168		2
		0.162		2

[1] Maximum allowed Co-60 specific activity (Table 7.1.2) + an additional 10% to conservatively account for other radionuclides is modeled for each BFA tank type.

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		0.044		0.1
		0.044		0.1
		0.043		0.1
		0.044		0.1
		0.045		0.1

[1] Maximum allowed Co-60 specific activity (Table 7.1.2) + an additional 10% to conservatively account for other radionuclides is modeled for each BFA tank type.

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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)
		2.7		10.0
		8.0		*10.0*

[1] Maximum allowed Co-60 specific activity (Table 7.1.2) + an additional 10% to conservatively account for other radionuclides is modeled for each BFA tank type.

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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		0.014		0.02
5		0.014		0.02
5		0.014		0.02

[1] Maximum allowed Co-60 specific activity (Table 7.1.2) + an additional 10% to conservatively account for other radionuclides is modeled for each BFA tank type.

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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]		0.069		7.0
		0.068		
		0.066		
		0.066		
		0.067		

[1] Maximum allowed Co-60 specific activity (Table 7.1.2) + an additional 10% to conservatively account for other radionuclides is modeled for each BFA tank type.

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]

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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, and is therefore not considered in the dose analyses.

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 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].

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5.3.1.2 Source Configuration

5.3.1.2.1 Normal Conditions Source Configuration

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

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]

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FIGURE 5.3.5: [PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]

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

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

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

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

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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 5.4.2
[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]

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. Holtec International. Latest Revision.

[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]

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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), 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 10CFR 71.5, shall be complied with for package use in the US and/or for US package export and import. For transport outside US territory and under the approval or jurisdiction of one or more foreign competent authorities, other requirements such as the ADR, "European Agreement Concerning the International Carriage of Dangerous Goods by Road" and the RID, "European Agreement Concerning the International Carriage of Dangerous Goods by Rail" may be 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.

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7.1 PACKAGE LOADING

The HI-STAR ATB 1T Cask can be loaded under the following three possible Loading Scenarios (LS). Refer to Table 7.1.2 for descriptions of the Waste Package Types:

LS-1) Loading of a BTC from a storage pool into a prepared HI-STAR ATB 1T Cask, with a pre-installed BFA-Tank (Waste Package Types A through D);

LS-2) Installation of a previously loaded BFA-Tank (Waste Package Types A through D) into a HI-STAR ATB 1T Cask;

LS-3) Loading of waste directly into the HI-STAR ATB 1T Cask, designated as Waste Package Type E.

For transport, the cask is fastened to a Transport Frame which is carried by a dedicated transport vehicle. The Transport Frame may include a Work Platform to provide access to the cask and a Weather Protection Cover (WPC). The cask may be loaded or unloaded while attached to the Transport Frame.

The essential elements required to prepare and load the HI-STAR ATB 1T Cask under either scenario 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. The empty HI-STAR ATB 1T Cask is visually receipt inspected per Table 8.2.1 to verify 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

Locking Pins *and Shear Bars* and actuating the CLLS operating system. The cask lid is then removed.

6. The cask lid o-ring seal is inspected and replaced *per Table 8.2.1*, if necessary.

7. The cask o-ring sealing surfaces are inspected and, if necessary, repaired and tested per Paragraph 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 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. An empty BFA-Tank is loaded into the HI-STAR ATB 1T Cask.

2. The BFA-Tank lid is unbolted and removed.

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 in 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. If required, alignment pins are provided in the cask to aid fitup of the Wet Hood with 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. If required, alignment pins are provided in the cask to aid fitup of the Drying Cover with 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 lid is placed on the BFA-Tank. A radiation shield may be installed on the cask to reduce personnel dose during subsequent activities. If required, alignment pins are provided in the cask to aid installation of the BFA-Tank lid with the BFA-Tank.

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.

10. If installed, the cask alignment pins are removed and any attachment holes are plugged.

11. The cask o-ring sealing surface is inspected for cleanliness. 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, with the exception that a site-specific loading cask may be 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. The loaded BFA-Tank is inspected for cleanliness. Any foreign material is removed from the outer surface of the BFA-Tank.

3. The BFA-Tank lid bolts are inspected to ensure they are installed and torqued to the value recommended by the supplier of the BFA-Tank.

4. If installed, the cask alignment pins are removed and any attachment holes are plugged.

5. The Foldable Corner Guides are moved into place to guide the BFA-Tank into the cask.

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

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

8. The Foldable Corner Guides are disengaged.

7.1.2.3 LS-3: Loading of Waste Directly into the HI-STAR ATB 1T Cask

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

2. A radiation shielded Drying Cover is placed on the cask. If required, alignment pins are provided in the cask to aid fitup of the Drying Cover with the cask.

3. 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.

4. The Drying Cover is removed. A radiation shield may be installed on the cask to reduce personnel dose during subsequent activities.

5. If installed, the cask alignment pins are removed and any attachment holes are plugged.

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

7. The cask o-ring sealing surface is inspected for cleanliness. Any foreign material is removed.

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 dis-engaged position;

   b. Inspecting the cask lid o-rings for cleanliness and removing any foreign material;

   c. Attaching the lid lifting device.

2. The cask lid is lifted and placed on the cask.

3. The CLLS is moved to the locked position *and* the Locking Wedge Locking Pins *and Shear Bars* are inserted. *Successful insertion of the Locking Wedge Locking Pins 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. Preparation for Transport (Applicable to All Loading Scenarios)

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.

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

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

Table 7.1.1:

[Table Withheld in Accordance with 10 CFR 2.390]

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Table 7.1.2:
[Table Withheld in Accordance with 10 CFR 2.390]

Table 7.1.2 Notes:
[Table Withheld in Accordance with 10 CFR 2.390]

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 inspected to verify 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, on the Transport Frame, is placed in the designated preparation area.

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.

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

4. The CLLS is disengaged by removing the Locking Wedge Locking Pins *and Shear Bars* and actuating the CLLS operating system.

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

6. If the cask is loaded per LS-1 or LS-2, the BFA-Tank is lifted from the cask and placed in its designated storage area. If the cask is loaded per LS-3, the contents are removed per site-specific procedures and transferred to designated storage locations.

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. The cask lid o-ring and the cask o-ring sealing surface are inspected for any damage that may compromise the performance of the seal. Any foreign material from inside the cask is removed.

2. The cask lid is lifted and placed on the cask.

3. The CLLS is moved to the locked position. The Locking Wedge Locking Pins *and Shear Bars* are inserted to ensure the CLLS remains engaged with the cask body during shipment.

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

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

6. The empty cask is given a final inspection according to user procedures to verify that all conditions for transport have been met.

7. 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 verify that the structures, systems and components (SSCs) classified as *important-to-safety* have been fabricated, assembled, inspected, tested, accepted, and maintained in accordance with the requirements set forth in this Safety Analysis Report (SAR), all applicable regulatory requirements, and the Certificate of Compliance (CoC). The acceptance criteria and maintenance program described in this chapter is in full compliance with the requirements of 10CFR Part 71 Subpart G [8.0.1].

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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.

The following shall be verified as part of visual inspections and measurements:

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

The visual inspection and measurement results for the HI-STAR 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 (except **[Text Withheld in Accordance with 10 CFR 2.390]**) 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 verify fabrication in accordance with the drawings.

1. Containment boundary welds including any attachment welds (and temporary welds to the containment boundary) shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NB, Article NB-5300. Examinations, Visual (VT), Radiographic (RT), and Liquid Penetrant (PT) or Magnetic Particle (MT), apply to these welds as defined by the code. These welds shall be repaired in accordance with the requirements of the ASME Code Section III, Article NB-4450 and examined after repair in the same manner as the original weld. 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 in the cask DBS 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 leak tightness test, MT, and/or PT, as specified in the licensing drawing and this Chapter) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

8.1.3.1 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 top trunnions (areas visible outside the cask), and the local cask areas shall then be visually examined to verify that no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and top trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require replacement of the trunnion and/or repair of the cask. 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 verifying trunnion material mechanical properties meet ASME Code Section II requirements provide further verification of the trunnion load capabilities. Test results shall be documented and shall become part of the 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).

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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 is performed for each loading prior to transport. This pre-shipment leakage rate test is valid for 1 year as long as the seals 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 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

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

The HI-STAR ATB 1T Cask employs *important-to-safety* components made from materials that are not susceptible to brittle fracture and therefore exempt from brittle fracture testing. Brittle fracture testing of the BFA-Tanks and BTCs is not required.

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

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8.1.6 Shielding Tests

Post Fabrication Testing

The total wall/shielding material thickness is equal to or greater than the thickness in the drawing package.

An inspection using a calibrated radiation detector and a Co-60 source will be performed. Acceptance criteria will be defined by comparative measure on mock-up or reference blocks produced using the casting technique used for the as-built cask components and having calibrated defects.

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 (when applicable) 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.

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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	$1x10^{-4}$ 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*		
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 2.
2. *Per ANSI N14.5 (para. 7.6.4), an alternative pre-shipment leakage rate acceptance criterion that may be used in lieu of the reference air leakage rate L_R, is "No Detected Leakage" when tested to a sensitivity of $1x10^{-3}$ ref-cm^3/s. The following conditions apply to the testing of gasketed joints:*
   a. *The joint gasket must be reusable (e.g. elastomeric seals).*
   b. *The gasket was previously installed and the gasketed joint qualified to a leak rate not more than the reference air leakage rate L_R as specified in the table above (i.e. the prequalified gasket was never replaced).*

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 2): 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	ASME Code Section III Subsection NB-3000 **[Withheld in Accordance with 10 CFR 2.390]**	ASME Code Section III Subsection NB-3000 **[Withheld in Accordance with 10 CFR 2.390]**	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	Note 1	NUREG-0612	NUREG-0612	Not Applicable	Chapter 8 of this SAR	Chapter 8 of this SAR
Locking Wedge Locking Pin, Locking Pin Lock and Locking Pin Insert	ASME Section II	No gross yielding or buckling	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Strongback Lifting Attachments and Maintenance Cover	ASME Section II	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Cask Dose Blocker Structure (DBS)	ASTM	**[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
Cask Lid Spacer Bar	ASME Section II	No gross failure	Not Applicable	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V	Not Applicable

Table 8.1.2 (Sheet 2 of 2) : 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 **[Withheld in Accordance with 10 CFR 2.390]** Welds **[Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	Not Applicable	Not Applicable	Not Applicable
BTC	Note 1	Corners Tie Rods **[Withheld in Accordance with 10 CFR 2.390]** Top and Bottom **[Withheld in Accordance with 10 CFR 2.390]**	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Spacers for top and bottom of BFA-Tanks	ASTM or ASME Section II	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable

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

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.
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.

Table 8.1.4 : Intentionally Deleted

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Table 8.1.5 : Intentionally Deleted

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 is almost entirely fabricated from stainless steel material. 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 verify 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 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 verification 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 verification 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 external surfaces of the packaging shall be visually inspected for damage prior to each waste loading to ensure that the packaging effectiveness is not significantly reduced. Visual inspections 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, the cask sealing surface shall be cleaned and visually inspected for scratches, pitting or roughness, and affected surface areas shall be polished smooth or repaired as necessary in accordance with written and approved procedures.

(iii) Closure Lid Locking System:

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 inspection of the CLLS is required to ensure that the structure has not been severely damaged by an inadvertent operation in service.

(iv) Cask Trunnions

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 verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and trunnion), distortion or cracking of the trunnion or adjacent cask areas shall require repair or replacement of the trunnion and/or repair of the cask.

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

(v) 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 that the seal be visually inspected to ensure it remains free of debris, does not exhibit damage (i.e. no tears or gouges), and does not exhibit excessive compression set (i.e. the seal projects past the plane of the top seating surface of the seal groove). If seals are deemed acceptable, they may be 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.

(vi) 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.

(vii) Miscellaneous Tests

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

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Table 8.2.1:
Maintenance Inspections and Tests Program Schedule

Task	Schedule
Cask surface visual inspection. (See Paragraph 8.2.4(ii))	Prior to each Non-Fuel Waste (NFW) loading.
BFA-Tanks and BTCs accessible surfaces visual inspection (See Paragraph 8.2.4(ii))	Prior to emplacement into the cask.
CLLS visual inspection (See Paragraph 8.2.4(iii))	Prior to each transport.
Cask trunnion visual inspection (See Paragraph 8.2.4(iv))	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(v))	*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 inspection cycle.*
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.