NON-PROPRIETARY VERSION

SAFETY ANALYSIS REPORT

on

THE HI-STAR 80 PACKAGE

(Revision 4.A)

by

Holtec International
KPS Technology Campus
1 Holtec Blvd
Camden, NJ 08104
(holtecinternational.com)

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1	Chapter 1	LEH	06/20/16	986776	LEH	8/16/16	337331	LEH	8/23/16	241155
2	1, 7, 8 Structural	JZ	06/20/16	77161	JZ	8/16/16	486091	N/A	N/A	N/A
3	1, 7, 8 Thermal	XH	06/20/16	58417	XH	8/16/16	936130	N/A	N/A	N/A
4	1, 7, 8 Containment	NK	06/20/16	211541	NK	8/16/16	808113	N/A	N/A	N/A
5	1, 7, 8 Shielding	DM	06/20/16	553333	DM	8/16/16	512023	N/A	N/A	N/A
6	1, 7, 8 Criticality	TH	06/20/16	414119	TH	8/16/16	587847	N/A	N/A	N/A
7	1, 7, 8 Operations	JAG	06/20/16	502479	JAG	8/17/16	333373	N/A	N/A	N/A
8	1, 2, 7, 8 Materials	MBN	06/20/16	554530	MBN	8/16/16	231895	N/A	N/A	N/A
9	1, 2, 7, 8 Fabrication	MBN	06/20/16	341392	MBN	8/16/16	887189	N/A	N/A	N/A
10	Chapter 2	JZ	06/20/16	393961	JZ	8/16/16	689141	N/A	N/A	N/A
11	Chapter 3	XH	06/20/16	327061	XH	8/16/16	846734	XH	8/23/16	485410
12	Chapter 4	NK	06/20/16	150267	NK	8/16/16	392668	NK	N/A	N/A
13	Chapter 5	DM	06/20/16	132617	DM	8/16/16	710135	DM	N/A	N/A
14	Chapter 6	TH	06/20/16	943321	TH	8/17/16	38509	TH	N/A	N/A
15	Chapter 7	JAG	06/20/16	860227	JAG	8/16/16	177883	JAG	N/A	N/A
16	Chapter 8	RN	06/20/16	389844	RN	8/16/16	694981	LEH	8/23/16	230662
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1	Chapter 1	LEH	9/4/2018	785200	BAS	7/28/2021		
2	1, 7, 8 Structural	CB	9/4/2018	166511	JZ	7/28/2021		
3	1, 7, 8 Thermal	XH	9/4/2018	318419	RM	7/28/2021		
4	1, 7, 8 Containment	NK	9/4/2018	931812	BK	7/28/2021		
5	1, 7, 8 Shielding	BK	9/4/2018	825501	BK	7/28/2021		
6	1, 7, 8 Criticality	TH	9/4/2018	227398	TH	7/28/2021		
7	1, 7, 8 Operations	JAG	9/4/2018	918785	MBN	7/28/2021		
8	1, 2, 7, 8 Materials	RK	9/4/2018	277568	NG	7/28/2021		
9	1, 2, 7, 8 Fabrication	MBN	9/4/2018	132142	MBN	7/28/2021		
10	Chapter 2	CB	9/4/2018	773879	JZ	7/28/2021		
11	Chapter 3	XH	9/4/2018	947393	RM	7/28/2021		
12	Appendix 3.A	RK	9/4/2018	382959	N/A	N/A		
13	Appendix 3.B	RK	9/4/2018	413386	N/A	N/A		
14	Chapter 4	NK	9/4/2018	19413	BK	7/28/2021		
15	Chapter 5	BK	9/4/2018	690899	BK	7/28/2021		
16	Chapter 6	TH	9/4/2018	74006	TH	7/28/2021		
17	Chapter 7	JAG	9/4/2018	97072	BAS	7/28/2021		
18	Chapter 8	LEH	9/4/2018	742720	BAS	7/28/2021		
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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):		

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

SAR REVISION STATUS, LIST OF AFFECTED SECTIONS AND REVISION SUMMARY

SAR Title: Safety Analysis Report on HI-STAR 80 Package	
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ABOUT THIS SAR

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

REVISION STATUS AND CONFIGURATION CONTROL

SAR review and verification are controlled at the chapter level and changes are annotated at the chapter level. Chapters include chapter sections, chapter appendices and chapter supplements (as applicable). The revision of this SAR is at least the same as the latest revision of any chapter in this SAR; however, the whole SAR revision is also leveled up when incorporating a new revision to a licensing drawing that did not require a corresponding change to the text of any SAR chapter. Licensing drawings are controlled individually within the Holtec's drawing configuration control system and therefore have their own revision level.

A chapter section 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). A section in a chapter supplement is identified by a numeral followed by a roman numeral followed by a numeral each separated by a decimal (e.g. 1.I.1). Each chapter section, each chapter appendix and each chapter supplement begins on a fresh page.

Unless indicated as a "complete revision" in the summary description of change below, SAR changes are indicated by a "bar" in the right page margin and the revision number (annotated in the footer) of the entire chapter is changed. Those whole 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 bars of chapters that remain unchanged by a SAR revision may or may not be shown.

The revision number of the whole SAR is annotated in the footer of every page of the 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. The summary description of change of any previous chapter revision is replaced by "no changes".

Chapter 1: General Information (includes Glossary and Notation)	**Revision Number: 4A**
Section or App.	**Summary Description of Change**
Glossary	N/A
1.0	N/A
1.1	N/A
1.2	N/A
1.3	Updated to include reference to critical dimension report
1.4	
1.5	
1.6	
References	Included new critical dimension report
1.A	

Chapter 2: Structural Evaluation	**Revision Number: 4A**
Section or App.	**Summary Description of Change**
2.0	
2.1	Updated bolt examination and partially loaded package
2.2	
2.3	
2.4	
2.5	
2.6	
2.7	Updated discussion of MNOP
2.8	
2.9	
2.10	
2.11	
References	
Appendix 2.A	

Chapter 3: Thermal Evaluation	Revision Number: 4
Section or App.	**Summary Description of Change**
3.0	No change
3.1	
3.2	
3.3	
3.4	
References	
Appendix 3.A	
Appendix 3.B	

Chapter 4: Containment Evaluation	Revision Number: 4
Section or App.	**Summary Description of Change**
4.0	No change
4.1	
4.2	
4.3	
4.4	
4.5	
4.6	
References	

Chapter 5: Shielding Evaluation	Revision Number: 4A
Section or App.	**Summary Description of Change**
5.0	
5.1	
5.2	
5.3	Updated description of lower tie plate modeling
5.4	Corrected table references, and dose rate results
References	
Appendix 5.A, 5.B, 5.C, and 5.D	
Appendix 5.E	
Appendix 5.F	

Chapter 6: Criticality Evaluation	Revision Number: 4
Section or App.	**Summary Description of Change**
6.0	No change
6.1	
6.2	
6.3	
6.4	

6.5	
6.6	
6.7	
6.8	
References	
6.A	
6.B	

Chapter 7: Package Operations	Revision Number: 4A
Section or App.	**Summary Description of Change**
7.0	
7.1	Updated to fix notes on pressure
7.2	
7.3	
7.4	
References	
7.A	
7.B	
7.C	
7.D	

Chapter 8: Acceptance Tests and Maintenance Program	Revision Number: 4A
Section or App.	**Summary Description of Change**
8.0	
8.1	Updated leakage rate table
8.2	
References	

End of Change Descriptions

GLOSSARY AND NOTATION

GLOSSARY

AFR is an acronym for Away From Reactor.

ALARA is an acronym for As Low As Reasonably Achievable.

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

Axial Blanket means the sections at the top and/or bottom of the active length of the fuel with enrichments lower than the axial center of the fuel.

Basket Shims are aluminum alloy parts (typically extrusions) that serve to maintain the fuel basket coaxial with the cask's storage cavity.

BWR is an acronym for Boiling Water Reactor.

Cask is a generic term used to describe a device that is engineered to hold high level waste, including spent nuclear fuel, in a safe configuration.

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

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

Commercial Spent Fuel (**CSF)** refers to nuclear fuel used to produce energy in a commercial nuclear power plant.

Containment Boundary means the enclosure formed by the cask inner shell welded to a bottom plate and top flange plus dual closure lids with seal(s) and associated penetration port closure(s) and seal(s).

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

Cooling Time (or post-irradiation decay time, PCDT) for a spent fuel assembly is the time between reactor shutdown and the time the spent fuel assembly is loaded into the cask. Cooling Time is also referred to as the "age" of the CSF.

Critical Characteristic means a feature of a component or assembly that is necessary for the component or assembly to render its intended safety function. Critical characteristics of a material

are those attributes that have been identified, in the associated material specification, as necessary to render the material's intended safety function.

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

Damaged Fuel Assembly is a fuel assembly with known or suspected cladding defects, as determined by a review of records, greater than pinhole leaks or hairline cracks, empty fuel rod locations that are not filled with dummy fuel rods, whose structural integrity has been impaired such that geometric rearrangement of fuel or gross failure of the cladding is expected based on engineering evaluations, or that cannot be handled by normal means. Also see fuel debris.

Damaged Fuel Container (or Canister) (DFC) means a specially designed vessel for damaged fuel or fuel debris, which may permit gaseous and liquid media to escape while minimizing dispersal of gross particulates or which may be hermetically sealed. The DFC features a lifting location, which is suitable for remote handling of a loaded or unloaded DFC. Also see Quivers.

DBE means Design Basis Earthquake.

DCSS is an acronym for Dry Cask Storage System.

Design Heat Load is the computed heat rejection capacity of the HI-STAR package with a specific fuel basket with CSF stored in uniform storage with the ambient at the normal temperature and the peak cladding temperature (PCT) at 400 ºC. The Design Heat Load is less than the thermal capacity of the system by a suitable margin that reflects the conservatism in the system thermal analysis.

Design Life is the minimum duration for which the component is engineered to perform its intended function if operated and maintained in accordance with the instructions provided by the system supplier.

Design Report is a document prepared, reviewed and QA validated in accordance with the provisions of Holtec's Quality Program. The Design Report shall demonstrate compliance with the requirements set forth in the Design Specification. A Design Report is mandatory for systems, structures, and components designated as *Important-to-Safety*. The SAR serves as the Design Report for the HI-STAR 80 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 80 package.

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

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

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

Expanded Containment Boundary means a second barrier against leakage of radiological contents of the package engineered into the system for added safety or to meet a specific jurisdictional regulation.

Fastener Strain Limiter is a device to protect the impact limiter fastener bolts from experiencing excessive axial strain.

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 not 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.

FSAR is an acronym for Final Safety Analysis Report.

Fuel Basket means a honeycombed cavity structure with square openings that can accept a fuel assembly of the type for which it is designed.

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

GTCC is an acronym for Greater Than Class C waste.

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

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

HI-STAR 80 Cask or cask means the cask that receives and contains the spent nuclear fuel. It provides the containment system boundary for radioactive materials and fulfills all requirements of 10CFR71 to merit certification as a B(U) package.

HI-STAR 80 Package consists of the HI-STAR 80 cask and fuel basket with two impact limiters installed at the extremities, a personnel barrier if required, and the licensed radioactive contents loaded for transport.

HI-STAR 80 Packaging consists of the HI-STAR 80 Package without the licensed radioactive contents loaded.

Holtite™ is the trade name for the neutron shielding materials used in the HI-STAR/HI-STORM family of casks.

Impact Limiters means a set of fully enclosed energy absorbers that are attached to the top and bottom of the cask during transport. The impact limiters are used to absorb kinetic energy resulting from normal and hypothetical accident drop conditions. The HI-STAR impact limiters are called AL-STAR.

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

Incore Grid Spacers are fuel assembly grid spacers located within the active fuel region (i.e., not including top and bottom spacers).

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

LLNL is an acronym for Lawrence Livermore National Laboratory.

Leaktight means the degree of package containment that in a practical sense precludes any significant release of radioactive materials. This degree of containment is achieved by demonstration of a leakage rate less than or equal to 1 x 10^{-7} ref-cm^3/s of air at an upstream pressure of 1 atmosphere (atm) absolute (abs) and a downstream pressure of 0.01 atm abs or less. (Note: Reference Cubic Centimeter per Second (ref-cm^3/s) means a unit of leakage rate of one cubic centimeter of dry air per second at 1 atm abs pressure (760 mm Hg) and 25ºC, and Reference Air Leakage Rate means the allowable leakage rate converted to reference cubic centimeter per second (ref-cm^3/s).)

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

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

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

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

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

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

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

MGDS is an acronym for Mined Geological Depository System.

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

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

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

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

Neutron Absorber Material is a generic term used in this SAR to indicate any neutron absorber material qualified for use in the HI-STAR/HI-STORM fuel basket.

Neutron Shielding means a material used to thermalize and capture neutrons emanating from the radioactive spent nuclear fuel.

Neutron Sources means specially designed inserts for fuel assemblies that produce neutrons for startup of the reactor.

Non-Fuel Hardware (NFH) means high-level waste not used to produce thermal energy in the reactor. Examples of NFH are Burnable Poison Rod Assemblies (BPRAs), Thimble Plug Devices (TPDs), Control Rod Assemblies (CRAs), Axial Power Shaping Rods (APSRs), Wet Annular Burnable Absorbers (WABAs), Rod Cluster Control Assemblies (RCCAs), Control Element Assemblies (CEAs), primary and secondary neutron source assemblies (NSAs), water displacement guide tube plugs, orifice rod assemblies, and vibration suppressor inserts.

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.

ORNL is an acronym for Oak Ridge National Laboratory

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

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

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

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

PWR is an acronym for Pressurized Water Reactor.

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

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

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

SAR is an acronym for Safety Analysis Report.

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

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

SNF is an acronym for Spent Nuclear Fuel (also referred to as CSF in this SAR).

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.

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

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

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

Uniform Fuel Loading is a fuel loading strategy where any authorized fuel assembly may be stored in any fuel storage location, subject to other restrictions in the CoC, such as those applicable to non-fuel hardware, and damaged fuel containers.

Undamaged Fuel Assembly is defined as a fuel assembly without known or suspected cladding defects greater than pinhole leaks and hairline cracks, and which can be handled by normal means. Fuel assemblies without fuel rods in fuel rod locations shall not be classified as Undamaged Fuel Assemblies unless dummy fuel rods are used to displace an amount of water greater than or equal to that displaced by the original fuel rod(s).

Water Tight is defined as a degree of leaktightness that in a practical sense precludes any significant intrusion of water through all water exclusion barriers. This degree of leaktightness 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."

ZPA is an acronym for Zero Period Acceleration.

Zr means any zirconium-based fuel cladding material authorized for use in a commercial nuclear power plant reactor. Any reference to Zircaloy fuel cladding in this SAR applies to any zirconium-based fuel cladding material. This SAR permits Zircaloy 2, Zircaloy 4, ZIRLO, M5, E110, Optimized Zirlo, HiFi, Ziron, Duplex and Axiom fuel cladding material as allowable contents. For some of the newer materials in this list, such as HiFi, Ziron, Duplex and Axiom, the justification is documented in [1.0.14].

NOTATION

α Mean Coefficient of thermal expansion, cm/cm-°C x 10^{-6} (in/in-°F x 10^{-6})

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

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

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

f: Factor-of-Safety (dimensionless)

m: Metric for bolted joint leakage

P_b Primary bending stress intensity

P_e Expansion stress

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

P_L Local membrane stress intensity

P_m Primary membrane stress intensity

Q Secondary stress

S_u Ultimate Stress, MPa (ksi)

S_y Yield Stress, MPa (ksi)

S_m Stress intensity values per ASME Code

T_c: Allowable fuel cladding temperature

T_p: Peak computed fuel cladding temperature

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

β: Weight percent of boron carbide in the neutron shield

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

Γ: Total gasket spring back in the unloading cycle

Δ: Initial inter-part gap immediately before impact

δ: Lateral (global) deflection of the basket panel

δ_g: Maximum permissible gasket relaxation to maintain leak tightness

δ_{max}: Maximum value of δ

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

ξ: Weight percent of hydrogen in the neutron shield material

ρ: Density

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

ψ: Thermal conductivity

θ Orientation of free drop

CHAPTER 1: GENERAL INFORMATION

1.0 OVERVIEW

This Safety Analysis Report (SAR)[1] for the HI-STAR 80 Package is a compilation of information and analyses in the format suggested in Reg. Guide 7.9 [1.0.1] to support a United States Nuclear Regulatory Commission (USNRC) licensing review for certification as a spent nuclear fuel transportation package pursuant to the provisions of 10CFR71 Subpart D [1.0.2] and 49CFR173 [1.0.3].

HI-STAR 80 is the model name of a transport cask engineered to serve as a type B(U)F-96 packaging for transporting radioactive material (including but not limited to commercial spent fuel (CSF) and low to high level non-fuel waste (NFW)) under exclusive use shipment pursuant to 10CFR71.47. This SAR considers only CSF and reactor-related non-fuel waste[2] as the package contents.

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.

In this SAR, U.S. units are the official units of measure (values in S.I. units, if presented alongside equivalent U.S. units, are for information only).

Section 1.6 of this SAR discusses quality assurance program and package design control for the HI-STAR 80 Package.

[1] See Glossary for definition and abbreviation of terms used throughout this SAR.
[2] The terms reactor-related non-fuel waste, non-fuel waste and core components are used interchangeably in this SAR.

1.1 INTRODUCTION TO THE HI-STAR 80 PACKAGE

The HI-STAR 80 Package is a cylindrical metal cask with impact limiters qualified to carry either CSF or NFW and engineered to be shipped by rail, road and seagoing vessel. Several key design concepts of the HI-STAR 80 Package are directly adapted from Holtec's various licensed transport, storage and transfer cask systems (see Table 1.1.1).

Figures 1.1.1 and 1.1.2 provide pictorials of the exterior of the HI-STAR 80 Cask and HI-STAR 80 Packaging, respectively. The drawing package in Section 1.3 details the important-to-safety features considered in the packaging evaluation and also includes certain details on not-important-to-safety features. For the reader's convenience and clarity, additional pictorials of the cask and packaging components are provided throughout this SAR.

The HI-STAR 80 Cask containment system is engineered to parallel the anatomical design and construction of the containment system of HI-STAR 180 [1.0.4]. More specifically, the containment system materials of construction, welding joint details, NDE requirements, seal joint type, and Code of construction for the HI-STAR 80 Packaging, are identical or similar to those of the HI-STAR 180 Packaging. Furthermore, the double closure lid system of the HI-STAR 80 is identical in concept to the HI-STAR 180 system.

The HI-STAR 80 Cask body extensive shielding system is engineered to parallel the anatomical design and construction features of the HI-STAR 60 [1.0.7], HI-STAR 100 [1.0.6] and HI-TRAC [1.0.9 and 1.0.11]. Radial shielding is provided by four principal materials; lead, steel, [WITHHELD PER 10 CFR 2.390] and Holtite™ in a layered configuration to optimize the shielding of neutron and gamma radiation emitted from the package's radioactive contents. Axial shielding is provided at the top by thick steel closure lids (enhanced by lead and Holtite) and at the bottom by lead, Holtite, and steel. The optimized placement of the shielding materials provides for a transportation package that fulfills 10CFR71 radiation level limits and ALARA objectives.

The HI-STAR 80 Package employs a bare basket within a cask; however, the system also lends itself to be employed as an overpack over a sealed fuel canister (e.g. Enclosure Vessel or MPC). The certification for a canisterized basket is not sought at this time. The enhanced protection against release of radionuclides that would be provided by a hermetically sealed canister is restored in the HI-STAR 80 cask by the use of two independent closure lids, where both closure lids are designated as containment boundary components. By ensuring that each bolted lid joint is engineered to meet the leakage rate acceptance criterion of SAR Table 8.1.1 under the normal and hypothetical accident conditions of transport, each joint will also meet the much less severe water exclusion criterion with ample margin. The inner and outer closure lids each feature concentric annular seals providing multiple barriers against leakage.

The HI-STAR 80 fuel baskets (see Table 1.1.2) are identical in material and construction and similar in overall design to those employed in the HI-STAR 180. The material is a high temperature metal matrix composite (MMC) of aluminum and boron carbide, manufactured using the powder metallurgy process under the trade name Metamic-HT™, and used as the principal constituent material for the Fuel Basket. Metamic-HT has been qualified and licensed

for use in transport, under HI-STAR 180 Docket No. 71-9325 [1.0.4], HI-STAR 180D Docket No. 71-9367 [1.0.13], and storage casks, under HI-STORM 100 Docket 72-1014 [1.0.11] and HI-STORM FW Docket 72-1032 [1.0.9]. MMCs are commonly used because of their high conductivity, uniform boron dispersion, chemical stability, and strength characteristics.

The HI-STAR 80 Package also employs non-fuel waste baskets (see Table 1.1.3) made from corrosion resistant steel designed to hold non-fuel radioactive waste with or without secondary packaging.

Finally, the structural design embodiment and construction for the HI-STAR 80 Package AL-STAR impact limiters are identical to those used in the HI-STAR 180 Package (Docket No. 71-9325) and are fully described in this SAR.

Table 1.1.4 provides dimensional and weight data on the HI-STAR package utilized in the various safety analyses summarized in this SAR.

The HI-STAR 80 Package complies with all of the requirements of 10CFR71 for a Type B(U)F-96 package. In particular, the prescribed maximum normal operating pressure (MNOP) of 700 kPa (100 lb/in^2) for a type B(U) package is observed. No pressure relief device or feature intended to allow continuous venting during transport is provided on the HI-STAR 80 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 80 Package with the requirements of Subparts E and F of 10CFR71 are provided in this SAR[1].

The criticality safety index (CSI) for the HI-STAR 80 Package is 0.0, as an unlimited number of packages will remain subcritical under the procedures specified in 10CFR71.59(a) (Subsection 6.1.3 provides the determination of the CSI). The transport index (TI) is in excess of 10 for the HI-STAR 80 Package (Section 5.0 provides the determination of the TI). Therefore, the HI-STAR 80 Package must be transported by exclusive use shipment (10CFR71.47). An empty but previously loaded HI-STAR 80 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 80 Packaging is designed to ensure safe transport of SNF. Some of the key features of the HI-STAR 80 Packaging that enhance its effectiveness are:

- Honeycomb design of the fuel basket to achieve high structural rigidity
- Optimized arrangement of neutron and gamma shielding materials within the system to minimize dose and achieve ALARA objectives

[1] The HI-STAR 80 package is also designed to comply with SSR-6 (2012) [1.1.1] Type B(U)F package requirements. Certain acceptance criteria, methodology etc. may be stated or specified to address both 10CFR71 and SSR-6 requirements; however, no specific SSR-6 paras. are referenced in this SAR.

- High heat rejection capability through the use of a highly conductive fuel basket material

- High strength cryogenic material in the containment system boundary (as in HI-STAR 180) to assure protection from fracture under sub-zero transport conditions

This SAR supports a licensed life of the HI-STAR 80 package of 5 years, after which a renewal by the USNRC is based upon an affirmative safety assessment to support such renewal. Even though the safety analysis is not required to address more than 5 years, all safety evaluations are based on a design or service life of at least 40 years to provide a suitable degree of conservatism. This is accomplished by using materials of construction that have been exhaustively tested and determined capable of withstanding HI-STAR 80's operating environments without degradation and with negligible reduction if any, in their capability to render their intended function (materials of construction and testing are discussed in Section 1.2 and Section 2.2 of this SAR). A maintenance program, as specified in Chapter 8, is implemented to ensure the HI-STAR 80 Package will meet its Design Life. The technical considerations that assure the HI-STAR 80 performs its design functions throughout its Design Life include all areas germane to the long-term integrity of the system, such as:

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

Table 1.1.1

HI-STAR Family of Transport Packages and HI-TRAC Family of Transfer Casks (USNRC Docketed Only)

Model No.	USNRC Docket and SAR Reference	Year First Certified	Content (Fuel Type or other)	Approx. Cask Cavity Length (inch)	Approx. Cask ID (inch)	Approx. Cask OD (inch)
HI-STAR 100 / HI-STAR HB	71-9261 [1.0.5]	1998	BWR & PWR	191 1/8	68 3/4	86 1/4
HI-STAR 60	71-9336 [1.0.7]	2009	PWR	139 5/8	42 1/2	82
HI-STAR 180	71-9325 [1.0.4]	2009	PWR	140 5/8	72 7/8	106 1/4
HI-STAR 180D	71-9367 [1.0.13]	2014	PWR	115 7/8	72 7/8	106 3/4
HI-STAR 190	71-9373 [1.0.10]	2017	BWR & PWR	190 3/4 (SL) 213 1/4 (XL)	76	107 1/4
HI-STAR 80	71-9374 [this SAR]	2018	BWR & PWR & NFW	180 1/4	48 7/8	89 1/4
HI-STAR ATB-1T	71-9375 [1.0.12]	2021	NFW	N/A	N/A	N/A
HI-TRAC 100 100D 125 125D	72-1014 [1.0.11]	2000 and later	BWR & PWR	191 1/4	68 3/4	88 3/4 88 3/4 93 93 3/4
HI-TRAC VW	72-1032 [1.0.9]	2011	BWR & PWR	182 (for MPC-37) 191 for (MPC-89)	76 1/4	95 ¼ for MPC-32 94 ¾ for MPC-89
Note: Dimensions are taken from respective licensing drawing packages approved at the time of this writing. Dimensions are nominal and may be rounded.						

Table 1.1.2

Permissible “Fuel Packages” for HI-STAR 80 (Note 1 and 2)

Canister or Fuel Basket Model No. (Notes 3 and 4)	Fuel Type	Fuel Package Type	Basket Structural Material and Neutron Absorber	Damaged Fuel Container or Other Secondary Packaging
F-12P	PWR	Bare Basket	Metamic-HT	Quivers (Note 5)
F-32B	BWR	Bare Basket	Metamic-HT	Quivers (Note 5)

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

Table 1.1.3

Permissible "Non-Fuel Waste Packages" for HI-STAR 80 (Note 1)

Canister or Basket Model No.	Waste Package Type and Structural Material	Secondary Packaging Model No.	Secondary Packaging Type and Structural Material	Waste Type
NFWB-1 (Note 2)	Holtec Designed Stainless Steel Non-Fuel Waste Basket	CCC-1 (Optional) (Note 3)	Plant Specific Stainless Steel Core Component Cassette	Reactor-Related Non-Fuel Waste (also referred to as Core Components) (See Table 1.2.3)

Notes
1. Refer to SAR Subsection 1.2.2 and Chapter 7 for specific package contents.
2. See licensing drawing package in SAR Section 1.3.
3. Secondary packaging CCC-1 is located within basket NFWB-1. The model no. assigned to the secondary packaging is for the purposes of identification in this SAR. CCC-1 is not a component requiring design approval as discussed in SAR Paragraph 1.2.1.1.

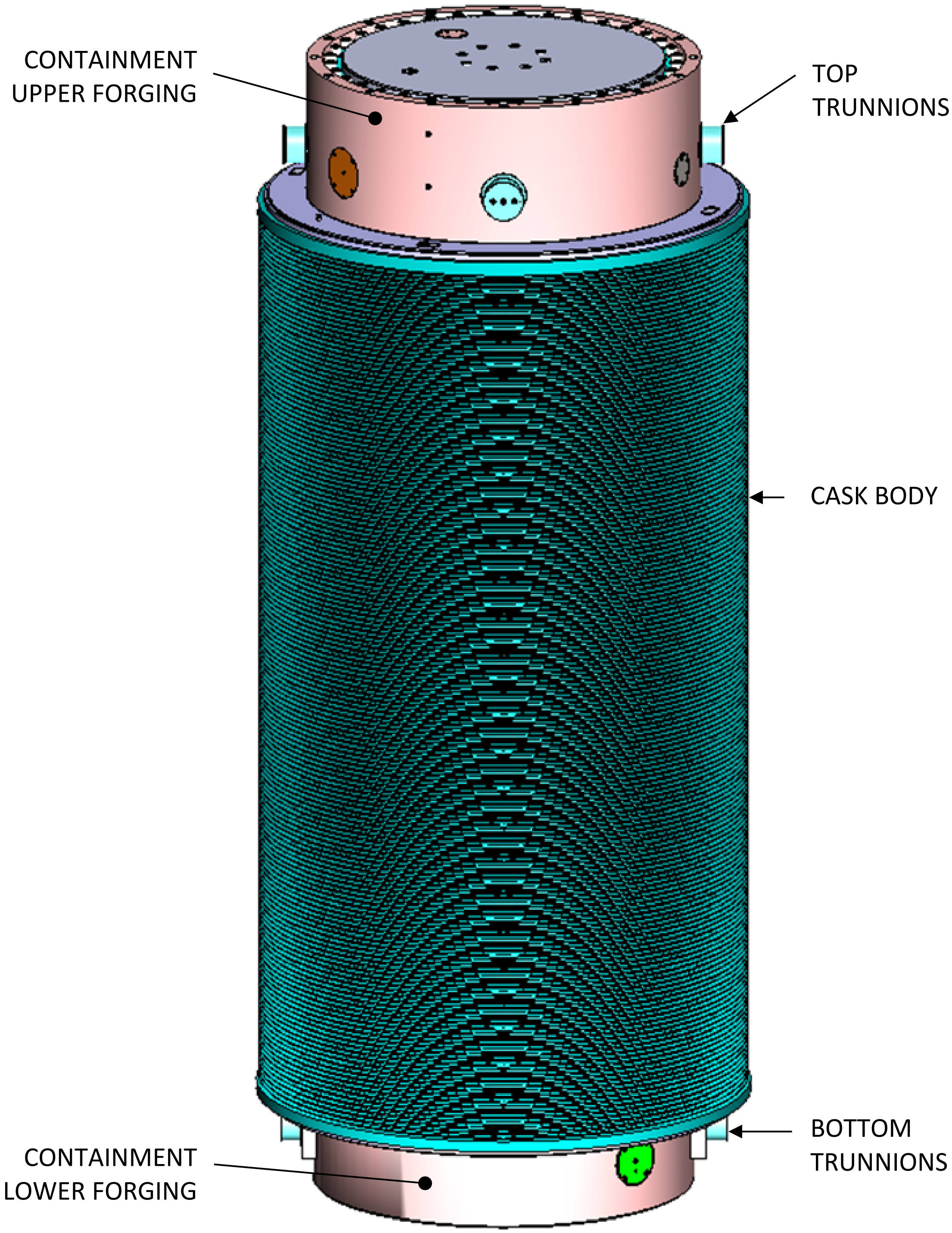
Table 1.1.4

Overall Dimensions and Weights of HI-STAR 80

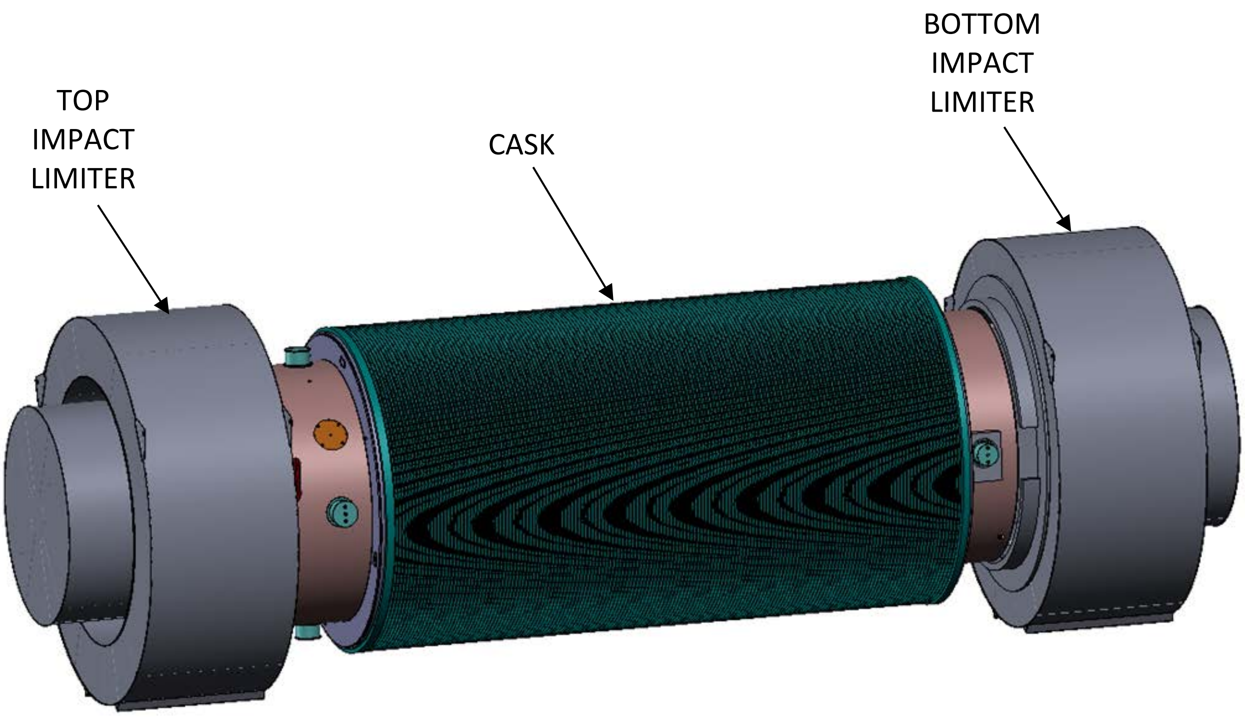
Item	Nominal Value
DIMENSIONS (Note 1)	
Inside Diameter of the Cask Cavity	Table 1.1.1
Outside Diameter of the Cask	Table 1.1.1
Length of the Cask, inch	212
Outside Enveloping Diameter of the Packaging, inch	107
Length of the Packaging, inch	313
WEIGHTS (Note 2)	
Maximum Gross Weight of HI-STAR 80 Package (no Personnel Barrier)	See Appendix 7.A
Nominal Empty Packaging Weight (with either F-12P or F-32B Fuel Basket and no Personnel Barrier)	See Appendix 7.A
Nominal Empty Packaging Weight (with NFWB-1 Basket and no Personnel Barrier and no Secondary Packaging)	See Appendix 7.A

Notes

1. All dimensions are approximate and may be rounded. Design basis safety analyses use dimensions provided in the drawing package and/or elsewhere in this SAR and may use upper or lower bound values, as appropriate, to ensure conservatism.
2. The actual as-built packaging (i.e. empty) weight will vary slightly due to dimensional tolerances and small variations in material density. A verification of the as-manufactured empty packaging weight is not strictly required because the safety analysis contained in this SAR considers such variations to ensure that the analyses are bounding.



[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
FIGURE 1.1.1 – EXTERIOR PICTORIAL VIEW OF THE HI-STAR 80 CASK
(Refer to the drawing package in Section 1.3 for details)



Note: Personnel Barrier Not Shown.

FIGURE 1.1.2 – EXTERIOR PICTORIAL VIEW OF HI-STAR 80 PACKAGING
(Refer to the drawing package in Section 1.3 for details)

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 80 Packaging consists of the four major components (Cask, Fuel Basket or Non-Fuel Waste Basket, Impact Limiters and Personnel Barrier) discussed in (a) through (d) below. Additionally, auxiliary equipment, in the form of packaging supports and restraints typically necessary for package transport, is described in subparagraph (e) and secondary packaging is described in subparagraph (f) below.

a. Cask

The HI-STAR 80 Cask is a cylindrical metal cask designed to hold "Fuel Packages" and "Non-Fuel Waste Packages". The main function of the cask is containment and shielding. The containment of the radiological contents is provided by a cryogenic nickel steel shell (the CCS) welded to a stainless steel forging (the Containment Lower Forging) at the bottom and to a suitably machined stainless steel forging (the Containment Upper Forging) at the top. The Containment Closure Flange is equipped with machined surfaces to fasten two independent stainless steel or cryogenic nickel steel closure lids, each equipped with concentric seals. All containment gasket bearing surfaces that are not already austenitic stainless steel are weld clad with austenitic stainless steel. The Containment System Boundary, including both closure lids, is designed and manufactured to ASME Section III Division 1, Subsection NB [1.2.1] as clarified in this SAR. Cask design details are shown in the drawing package in Section 1.3.

For purposes of description, the HI-STAR 80 cask is divided into six constituent parts, each with distinct roles and features, as follows:

1) The Cask Containment Shell (CCS): The innermost cylindrical member of the cask containment system made from cryogenic nickel steel forging or plate.
2) Cask Bottom Region (CBR): The CBR consists of a thick stainless steel forging, namely the Containment Baseplate, featuring neutron and gamma shielding material and stainless steel plate(s) for additional dose reduction.
3) Cask Top Region (CTR): The CTR consists of a massive stainless steel forging, namely the Containment Closure Flange, featuring neutron shielding material for additional dose reduction.
4) Double Closure Lid System (DCLS): The DCLS consists of two specially shaped lids, the Inner and Outer Closure Lids, with two machined concentric grooves in each lid to provide containment protection. The Inner Closure Lid consists of a thick shield plug and separate bolted retainer ring. The bolted lid joints are engineered to meet the leakage rate acceptance criterion of SAR Table 8.1.1 under the normal and hypothetical

accident conditions of transport. See SAR Appendix 1.A for information on Moderator Exclusion applicable only to Fuel Packages.

5) Gamma Capture Space (GCS): The GCS refers to the annular space around the Containment Shell featuring lead and radial gussets enclosed by an intermediate shell assembly. The space is non-structural in its function and has the principal role to block gamma radiation.
6) Neutron Capture Space (NCS): The NCS refers to the outermost annular space around the intermediate shell assembly featuring an outer shield cylinder composite of neutron shielding material and [WITHHELD PER 10 CFR 2.390]. The space is non-structural in its function and has the principal role to block neutron radiation.

The above description of the constituent parts is summarized in Table 1.2.1 for ease of reference. Figure 1.2.1 provides a cut-away view of the HI-STAR 80 cask to illustrate the above constituent parts.

All materials used in the HI-STAR 80 Cask are widely used in nuclear applications and in low temperature applications. [

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]

b. Baskets

The permissible baskets currently available for the HI-STAR 80 Package include both fuel baskets and non-fuel waste baskets as indicated in Table 1.1.2 and 1.1.3. Their design details are illustrated in the drawing package in Section 1.3.

Fuel Baskets:

Fuel baskets are of a honeycomb construction and feature multiple storage locations as indicated in Table 1.1.2. The main function of the fuel basket is criticality control. Figures with basket storage cell locations are provided in Chapter 7 and cross-sectional views are provided in the drawing package in Section 1.3.

Certain fuel baskets feature the so-called “flux-trap construction”. Flux traps are two parallel plates consisting of neutron absorbing material separated by a small gap and are located between two adjacent facing fuel assemblies. The fuel baskets are designed for all fresh fuel (i.e. no burnup credit).

The honeycomb design of the fuel basket arrays the cell walls in two orthogonal sets of plates; consequently, the walls of the cells are either completely coplanar (no offset) or orthogonal with each other. The coplanar honeycomb design of the basket renders it extremely rugged under lateral drop scenarios. The final form of the fuel basket plates is extruded and has the dimensional precision that rivals machining. As a result, the fuel basket is assured to be a cellular structure with excellent dimensional precision, specifically regarding verticality and cross-sectional dimensions. Furthermore, the cell-to-cell connectivity inherent in the honeycomb basket structure provides an uninterrupted heat transmission path, making the fuel baskets an effective heat rejection device.

Precision extruded and/or machined blocks of aluminum alloy with axial holes or forming axial holes (basket shims) are installed in the peripheral space between the fuel basket and the enclosure vessel to provide near conformal contact surfaces between the basket shims and the fuel basket. The basket shim assemblies are secured to the fuel basket to form a single unit with the fuel basket. The major functions of the basket shims are heat transfer and lateral structural support to the fuel basket. The axial holes in the basket shims serve as the passageway for the flow of the helium gas under natural convection.

Non-Fuel Waste Baskets:

Non-Fuel Waste (NFW) baskets are stainless steel weldments designed to fix the location of secondary packaging within the cask cavity. The geometry of the NFW baskets provide conformal or near conformal contact for the secondary packaging. To provide the necessary structural support for the payload, NFW baskets are typically heavy wall, gusset reinforced, or a hybrid of the two. The NFW basket fits precisely into the cask cavity in a manner that minimizes movement of its contents. The drawing package in Section 1.3 provides the details of the NFW basket design(s) identified in Table 1.1.3.

NFW baskets are identified in Table 1.1.3 and paired with secondary packaging if applicable.

c. Impact Limiters:

Two impact limiters (also referred to as AL-STAR 80) are installed at the two extremities of the HI-STAR 80 Cask and provide energy absorption capability for the normal and hypothetical accident conditions of transport. The impact limiters feature extremely rigid cylindrical barrels (backbone structures) that engage the top and bottom of the cask with a near snug fit. Each impact limiter backbone is enveloped by crushable material, which in turn is enclosed by a stainless steel skin. The selection of the crushable material ensures that the performance of the impact limiters will be essentially insensitive to the ambient environment (temperature and humidity). The AL-STAR 80 impact limiters are of the same design genre as the AL-STAR 180 used in the HI-STAR 180 Package (Docket No. 71-9325). The following key design features typify the AL-STAR 80 impact limiters:

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

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

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

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

- The top impact limiter features a skirt in the form of a cup-shaped shell that fits the outside of the cask top forging with a small radial clearance. The bottom impact limiter also features a skirt in the form of a cup-shaped shell that fits on the outside of the cask bottom forging with a small radial clearance.

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

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

Impact limiter details are shown in the drawing package in Section 1.3. The *critical characteristics* and the attainment of the required critical characteristics through a comprehensive qualification process and production testing are discussed in Chapters 2 and 8, respectively.

d. Personnel Barrier:

During transport the cask lies in a horizontal orientation with the two impact limiters on its two extremities. Pursuant to 10CFR71.43(g), a personnel barrier is placed over the cask to provide a physical barrier against manual access to hot, 50°C (122°F) or higher, accessible areas of the package and limit hot accessible areas of the package to less than 85°C (185°F). According to Chapter 3 of this SAR the temperature of accessible surface of package exceeds 50°C (122°F) but is maintained less than 85°C (185°F) with the use of the personnel barrier; therefore, transport of the HI-STAR 80 Package must be performed under exclusive use shipment and with the personnel barrier installed.

The personnel barrier is not a structural part of the HI-STAR 80 Packaging but is designated as a packaging component for routine conditions of transport. Since the personnel barrier is not a

structural part of the HI-STAR 80 packaging, it is not required to remain in place under normal condition tests in 10CFR71.71.

[

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

]

e. Packaging Supports and Restraints:

The HI-STAR 80 Package lends itself to a horizontal packaging assembly for transport as shown in Figure 1.3.1 and Figure 1.3.2 and is engineered for shipment by seagoing vessel, railroads and roadways using appropriate supports and restraints. Illustrative examples of packaging supports and restraints for rail transport and road transport are provided in Figure 1.3.1 and Figure 1.3.2. The arrangement of packaging supports and restraints may vary as long as the package is properly secured and qualified for the specific mode of transport. Tapered wedge shims that close the gap between the impact limiters and the axial restraints (longitudinal stops) of the transport vehicle are examples of auxiliary equipment that may be used to restrain the package against axial movement. Except for the cask bottom trunnions when implemented as tie down devices, supports and restraints such as the transport frame, longitudinal stops, support saddles, slings or straps and wedge shims are not structural parts of the HI-STAR 80 Package and, as such, are designated as auxiliary equipment.

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

complied with. For shipments outside the U.S., foreign competent authority requirements or other international guidance may apply (See discussion on tie-down devices in SAR Section 2.5).

In the HI-STAR 80 transport package configuration, the cask trunnions are not qualified to be used to lift the HI-STAR 80 Package (i.e., loaded cask with impact limiters). In the transport configuration, the cask trunnions must be either rendered inoperable or must be engaged as tie-down devices depending on the tie-down configuration as shown in Figure 1.3.1 and Figure 1.3.2. Therefore, any structural part of the HI-STAR 80 package (i.e. the cask trunnions) that could be inadvertently used to lift the package is rendered inoperable per 10CFR71.45(a).

f. Secondary Packaging:

There is no secondary packaging for the HI-STAR 80 Package containing fuel assemblies as indicated in Table 1.1.2.

Non-fuel waste secondary packaging may be used for the HI-STAR 80 Package containing non-fuel waste as indicated in Table 1.1.3. Secondary packaging model CCC-1 is a rectangular shaped canister (typically a weldment) made from stainless steel that has a baseplate, four walls and may or may not have a top plate. Thus the walls of CCC-1 conform to the walls of non-fuel waste basket NFWB-1. CCC-1 is not hermetically sealed and permits its contents to be drained and dried. Secondary packaging CCC-1 is optional and not-important-to-safety; therefore, not a component requiring design approval.

1.2.1.2 Overall Packaging Dimensions and Weight

The overall dimensions and general weights of the HI-STAR 80 Package are summarized in Table 1.1.1 and Chapter 7.

The maximum gross transport weight of the HI-STAR 80 Package, (without the personnel barrier) is provided in Chapter 7 and marked on the packaging nameplate.

The nominal weights for the HI-STAR 80 Package main components, nominal weight of the cask and package at maximum capacity with design basis contents are provided in Section 2.1. The weight of the package contents is discussed in Subsection 1.2.2 below.

1.2.1.3 Containment Features

The Containment System forms an internal cylindrical cavity for housing fuel or non-fuel waste packages. The Containment Boundary is formed by a cryogenic steel inner shell (containment shell) welded at the bottom to a thick bottom plate (containment lower forging) and welded at the top to a heavy top flange (containment upper forging). Two closure lids are recessed into the containment upper forging and configured to protect the closure bolts and seals in the event of a drop accident. The inner closure lid system defines the containment boundary. The outer closure lid system along with the inter-lid space also meets the design and manufacturing criteria to be

merged with the inner containment space to define an expanded containment boundary. The expanded containment boundary will play its role only in the unlikely event that the boundary defined by the inner lid fails to hold. Both the inner closure lid and the outer closure lid feature concentric seals. The inner seal of each lid are containment seals while the equally proficient outer seals of each lid provide redundant closure. The containment closure flange features inter-seal test ports for the inner and outer closure lid seals. Each inter-seal test port is closed by threaded port plug and seal. The inner lid inter-seal test port plug and seal are containment closure features while the outer lid inter-seal test port plug and seal are redundant closure features. A vent orifice and a spray cooling orifice are located on the containment upper forging and a drain orifice is located on the containment lower forging, are all closed by threaded plug (or cap) and seal and additionally by bolted cover plate and seal (all are containment closure features). The inner closure lid has no penetrations. The outer closure lid has an access port that is closed by a threaded port plug and seal (outer containment closure features) and by a bolted port cover plate and seal (a redundant closure feature). A schematic of containment system components is shown in the drawing package in Section 1.3 and also in Figures in Chapter 4 (all components with the primary function of containment are shown in these schematics).

All containment features have been engineered to perform the containment function with final qualification by leak testing according to ANSI N14.5 [8.1.6] as specified in Chapter 8, Table 8.1.2 and to the leakage acceptance criterion specified in Chapter 8, Table 8.1.1. Chapter 4, devoted to the containment evaluation provides the regulatory basis for qualifying the inner and expanded containment boundaries as competent enclosures against release of radionuclides under the provisions of 10 CFR 71.

1.2.1.4 Moderator Exclusion Features

The HI-STAR 80 packaging is designed to transport both moderate burnup (MBF) and high burnup fuel (HBF). To address concerns with the structural integrity of HBF under accident conditions, and its potential impact on criticality safety, the design of HI-STAR 80 provides utmost assurance of water exclusion under a postulated 10CFR 71.73 accident scenario. Details of the design measures, technical confirmation and additional defense-in-depth measures to meet the intent and performance objectives of ISG-19 [1.2.16] are described in Appendix 1.A. The overall licensing approach on HBF is summarized in Section 1.4.

1.2.1.5 Neutron and Gamma Shielding Features

The HI-STAR 80 Cask Containment is circumscribed by the Gamma Capture Space (GCS) and the Neutron Capture Space (NCS), described in the foregoing, that respectively attenuate gamma radiation and neutron fluence emitted from the contained fuel to minimal practical levels consistent with ALARA principles. The HI-STAR 80 Packaging ensures the external radiation standards of 10CFR71 are met when loaded with design basis contents. The drawing package in Section 1.3 and the summary description in Section 1.1 provide information on the configuration of neutron and gamma shielding features.

While most of the shielding in the transport package is contained in the body of the cask and specifically in the Gamma Capture Space (GCS) and the Neutron Capture Space (NCS) described in Section 1.1, a certain amount of shielding is also provided by the Fuel Basket, the Basket Shims, and the loaded contents. The arrangement of the shielding materials shown in the licensing drawings reflects the shielding optimization carried out for the HI-STAR 80 cask.

During transport, the impact limiters provide additional gamma shielding (steel) at the ends of the cask and help prevent loss of shielding as a result of normal and accident conditions of transport by encapsulation of the containment top forging and the bottom forging regions. Note that for normal conditions of transport and hypothetical accident conditions, the impact limiters are credited for shielding as discussed in Chapter 5.

Critical Characteristics of the Holtite Neutron Shielding Material used in the safety analyses are provided in Table 1.2.5.

1.2.1.6 Criticality Control Features

Criticality control in the HI-STAR 80 Packaging for SNF is provided by the coplanar grid work of the Fuel Basket honeycomb, made entirely of the Metamic™-HT extruded borated metal matrix composite plates. Metamic-HT is the neutron absorber in the HI-STAR 80 Packaging. Thus the neutron absorber is not attached to the cell walls by a mechanical means that may be vulnerable to detachment. Hence, the locational fixity of the neutron absorber is guaranteed.

Criticality control features do not apply to the HI-STAR 80 Packaging for non-fuel waste because the contents are restricted to non-fissile or fissile exempt classifications.

There are no moderators in the HI-STAR 80 Packaging for either fuel or non-fuel packages. The fuel basket flux trap design features described in Paragraph 1.2.1.1 above and illustrated in the licensing drawings are criticality control features in certain HI-STAR 80 fuel baskets.

Because the neutron absorber and flux traps extends to the entire length of the fuel basket (unlike the basket designs wherein a non-structural neutron absorber covers a portion of the stainless steel walls of the basket), axial movement of the fuel during transport does not have an adverse reactivity consequence.

1.2.1.6.1 Qualification of Metamic-HT

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METAMIC-HT was first certified by the USNRC in 2009 for use in the HI-STAR 180 transport application under Docket No. 71-9325 as the sole constituent material for the fuel basket types F-37 and F-32 for transporting high burn up and MOX fuel. Subsequently, MPC-68M, a Metamic-HT equipped fuel basket for BWR fuel was certified in the HI-STORM 100, Docket No. 72-1014. All fuel baskets presently used in HI-STORM FW (Docket No. 72-1032), HI-STORM UMAX (Docket No. 72-1040) and HI-STORM 180D (Docket No. 71-9367) utilize METAMIC-HT for neutron absorbing and structural functions.

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The ASME Code allows the use of different code editions for different components: Per ASME Section III, NCA-1140, all items of a nuclear power plant may be constructed to a single Code Edition and Addenda, or each item may be constructed to individually specified Code Editions and Addenda. FSW weld procedure qualification was originally performed to the 2007 Edition of the ASME Code with certain essential variables that do not change. There is no requirement to re-qualify FSW weld procedures to a later edition of the Code. All welding by FSW process shall meet the applicable requirements of ASME Section IX per the edition specified in Chapter 8 of this SAR. The 2013 edition of the ASME Code is the first edition that incorporated FSW. Furthermore, per ASME Section IX, QG-108, joining procedures, procedure qualifications, and performance qualifications that were made in accordance with Editions and Addenda of Section IX, as far back as the 1962 Edition may be used in any construction for which the current Edition has been specified.

1.2.1.7 Lifting and Tie-Down Devices

Lifting trunnions are attached to the cask containment closure flange for lifting and also for rotating the cask body between vertical and horizontal positions. Four lifting trunnions are located 90° apart in the sides of the top flange. Two additional trunnions are attached near the

bottom extremity of the cask and located 180° apart to provide a built-in pivoting axis for cask rotation. The bottom trunnions are slightly off-center to facilitate the rotation direction of the cask. Each pair of top lifting trunnions is qualified to independently lift the cask in compliance with stress margins specified in 10CFR71.45, NUREG-0612 [1.2.3] and Regulatory Guide 3.61 [1.2.4].

The lifting, upending, and downending of the HI-STAR 80 Package requires the use of external handling devices. A lift yoke is typically utilized when the cask is to be lifted and handled vertically and to perform upending and downending. Upending and downending are typically performed with the cask pivoting on an ancillary tilting device specifically designed for this purpose. Lift yokes, other purposed structural/mechanical lifting devices, and/or slings may be used to lift the cask in the horizontal orientation.

Cask trunnions are a structural part of the package which may be used as tie-down devices as specified in Paragraph 1.2.1.1 item "e" and as illustrated in the figures in Section 1.3.

1.2.1.8 Heat Transfer Features

The HI-STAR 80 Package can safely transport SNF by maintaining the fuel cladding temperature below the limits for normal and accident conditions consistent with the guidance in the NRC Interim Staff Guidance, ISG-11 Rev. 3 [1.2.5]. The temperatures of the fuel cladding and core components are dependent on the decay heat and the heat dissipation capabilities of the cask. The SNF decay heat and core component decay heat are passively dissipated without any mechanical or forced cooling. The primary heat transfer mechanisms in the HI-STAR 80 Package are conduction and thermal radiation. The heat load of a design basis non-fuel waste package with core component payload is substantially lower than that of a design basis fuel package.

The free volume of the space under the inner closure lid (storage cavity) and the cask inter-lid space are filled with a gas as specified in Chapter 7 during fuel and non-fuel loading operations. For Fuel Packages, helium backfill provides an inert dry atmosphere for the fuel cladding, the helium gas also provides conductive heat transfer between each assembly and the surrounding basket walls and across any gaps between the metal surfaces inside the containment system. Metal conduction transfers the heat throughout the fuel basket, through the containment system boundary, and finally through the cask body and other exterior cask components.

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The distinguishing features of the HI-STAR 80 cask that enables it to dissipate high heat loads efficiently are:

i. A high conductivity fuel basket material (Metamic-HT) and coplanar honeycomb basket design which facilitates an efficient transmission of heat along the fuel basket's walls.

ii. Use of aluminum alloy shims to provide a near conformal contact between the basket and the inner surface of the HI-STAR 80 containment shell.

iii. Use of a highly conductive outer shield cylinder configured to eliminate any interruption in the conduction heat transfer path from the inside to the outside of the cask body.

iv. Use of body-extensive surface enhancements (circumferential fins), on the cask enclosure shell.

The above heat transfer features including the surface enhancement are detailed in the drawing package in Section 1.3. The surface enhancement is required to meet transport package design objectives and is an integral part of the enclosure shell. The surface enhancement is further discussed in Chapter 3 of this document.

1.2.1.9 Internal Support Features

The HI-STAR 80 Package fuel baskets are equipped with basket shims engineered to provide near conformal support for the fuel basket and facilitate heat transfer. The fuel basket shims are fabricated from a high strength aluminum alloy. To further enhance thermal performance, the fuel basket shims are directly welded to the fuel basket. Mechanical and thermal properties of the fuel basket shim material are provided in Section 2.2 and Subsection 3.2.1. See additional description in Subparagraph 1.2.1.1 (b).

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

1.2.1.10 Anti-Rotation Devices

The HI-STAR 80 Package is equipped with internal anti-rotation device(s), also referred to as basket alignment bar, to prevent the rotation of the fuel basket and basket shims within the cask. The anti-rotation device is a steel component that is attached to the cask containment shell as shown in the drawing package in Section 1.3. The anti-rotation devices are not important-to-safety.

1.2.1.11 Packaging Markings

Each HI-STAR 80 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 80 Packaging component has completed the fabrication acceptance test program and been accepted by and authorized by Holtec International.

1.2.2 Contents of Package

The HI-STAR 80 Package is classified according to Regulatory Guide 7.11 [1.2.2] as a Category I Type B package to encompass all approved contents. The following paragraphs describe spent fuel content and non-fuel radioactive waste content.

1.2.2.1 Spent Nuclear Fuel

The HI-STAR 80 package equipped with fuel basket is designed for transportation of UO_2 fuel from a nuclear power plant over the plant's entire life cycle, including transport of all fuel assemblies after the plant shutdown. The range of cask content does therefore need to encompass a wide range of fuel parameters, including the following:

- Fuel with a wide range of burnup to be transported after shortest possible cooling time.
- UO_2 fuel with a wide initial enrichment range; and
- MOX fuel, of various isotopic compositions.

The resulting loading conditions that need to be satisfied are discussed in the remainder of this subsection and provided in Appendix 7.D.

Table 7.D.1 lists the acceptable physical characteristics of the fuel assemblies qualified for transportation in the HI-STAR 80 package. Assemblies are limited to the maximum initial enrichment given in Table 7.D.1.

The maximum mass of radioactive material permitted for transport in the HI-STAR 80 Package is shown in Table 1.2.2. The maximum was calculated assuming the fuel basket is completely filled with fuel assemblies at the maximum allowable fuel mass.

The maximum mass of fissile material permitted for transport in the HI-STAR 80 Package is also shown in Table 1.2.2. The maximum was calculated assuming the fuel basket is completely filled with bounding UO_2 fuel assemblies.

The radioactive and fissile material is in the form of solid fuel pellets with a maximum fuel density shown in Table 1.2.2. There are no moderating material or neutron absorbers in the contents, nor any other material that would create a chemical, galvanic or other reaction leading to the release of combustible gases.

The maximum weight of the radioactive payload is shown in Table 1.2.2.

Figures in Appendix 7.D provide cross sectional views of the fuel baskets storage cell layouts. The storage cells are numbered as shown in these figures to facilitate the specification of loading conditions.

A representative fuel assembly bounding axial burnup distribution is listed in Table 1.2.6.

Overall, the loading conditions provided in Appendix 7.D are cask content specifications used by all relevant disciplines to define suitable bounding loadings for demonstrating compliance with 10CFR Part 71 regulations. The loading conditions, which try to balance the need for simplicity with the demand of low dose, are required to achieve the most expedited removal of high heat load, low cooling time and high-burnup fuel.

The “Quiver” in Chapter 7 refers to a precision designed and manufactured prismatic box sized to store discrete fuel rods that may be in a slightly or severely damaged state. The external cross section dimensions of the Quiver emulate that of a standard BWR or PWR assembly. Figure 1.2.2 provides a representative illustration of the Quiver. The Quiver is stored in a nuclear plant’s Fuel Pool for wet storage and in a storage or transport cask for dry storage or transport. The Westinghouse SKB Quiver specification [1.2.20] provides a complete set of design, manufacturing, testing and operational requirements of the Quiver. The Quiver maintains its contents (fuel rods) in an inert (helium filled) environment, thus precluding the risk of in-service corrosion of its contents. For purposes of this SAR, the performance characteristics of the Quiver relevant to transport set down by its designer/supplier in [1.2.20] are utilized. The Quiver produced by any other supplier must meet the performance criteria in this SAR to be acceptable for transport in the HI-STAR 80. The structural performance criteria are specified in Chapter 2, the thermal performance criteria are specified in Chapter 3, and the criticality performance criteria are specified in Chapter 6. Essential operational steps, limits, and requirements are specified in Chapter 7 and Appendix 7.D, including but not limited to, initial backfill, backfill gas, heat load restrictions, location/quantity restrictions, dryness condition, leakage rate condition. Quivers are lifted and handled in the same manner as fuel assemblies and are classified important to safety.

1.2.2.2 Non-Fuel Radioactive Waste

The HI-STAR 80 package equipped with a non-fuel radioactive waste canister and/or waste basket is designed for transportation of reactor-related radioactive non-fuel waste. Table 1.1.3 provides the permissible non-fuel packages including associated secondary packaging and Table 1.2.3 provides the key characteristics of the qualified contents and the required loading conditions for each non-fuel package.

The radioactive wastes contents may be solid segmented or non-segmented reactor-related non-fuel waste. The radioactive wastes may include both solid radiation-activated and surface-contaminated wastes. Reactor related waste is typically made of stainless steel. A limited quantity of fissile and SNM is allowed as specified in Table 1.2.3. Process waste or significant

quantities of dispersible solids are not allowable contents. Package payload content will vary and expected to fill the non-fuel waste packaging. Package payload content may be physically stabilized (e.g. with stainless steel dunnage or other not-important-to-safety features) within the non-fuel waste packaging for operational convenience.

1.2.3 Special Requirements for Plutonium

The contents of package provided in Section 1.2.2 and to be transported in the HI-STAR 80 Package contain plutonium in solid form and in varying quantities.

1.2.4 Operational Features

The HI-STAR 80 Packaging has been developed to facilitate loading and unloading of fuel with ALARA protection against handling accidents and a minimum number of handling evolutions by simplicity of handling and optimum payload capacity. Operations are similar to other HI-STAR models (see Table 1.1.1) which means there are no complex operational features or steps that that may encumber the crew with excessive dose.

The HI-STAR 80 cask body features three thru-wall penetrations (also referred to as ports or orifices) that communicate with the storage cavity through the containment boundary, (two ports on the containment upper forging and one port on the containment lower forging). The ports are the spray cooling port, the vent port and the drain port. All ports are configured to minimize radiation streaming as indicated in the drawing package in Section 1.3. The cask outer closure lid features an access port that communicates with the inter-lid space. The cask inner closure lid has no ports. Inter-seal test ports (some of which penetrate through the cask top forging) and other test ports exist to facilitate leakage testing.

Operations can be briefly summarized as follows:

1. The water filled cask is loaded with authorized contents, then dewatered, dried, gas backfilled, bolted shut and leakage tested.
2. Impact Limiters are attached to the HI-STAR and the package is transported on a transport frame in the horizontal orientation with personnel barrier.
3. The cooling spray port can be used for initial water cooling of the cask cavity with spent fuel contents during unloading operations prior to cask cavity water flooding.

The HI-STAR 80 when loaded and sealed in accordance with the guidance in Chapter 7, is a completely passive system. Chapter 7 provides the essential elements of cask operations. Chapter 8 provides the acceptance criteria and maintenance requirements for the package and packaging.

Table 1.2.1

Major Constituent Parts of the HI-STAR 80 Cask

Item No.	Part Name	Principal Function	Comments
1	Cask Containment Shell (CCS)	Containment of radionuclides, pressure retention and radiation blockage	Items 1, 2, 3 and 4 comprise the cask's containment system; all parts must meet ASME Section III Subsection NB in all respects.
2	Cask Bottom Region (CBR)	Containment of radionuclides, pressure retention and radiation blockage; Mounting surface for the bottom impact limiter	The only structural welded joint is with the containment shell which is butt welded and volumetrically examined to meet the ASME code. The Cask Bottom Region provides the location for the bottom cask trunnions and the location for a drain port.
3	Cask Top Region (CTR)	Containment of radionuclides, pressure retention and radiation blockage; seating surface for the Double Closure Lid system and mounting surface for the top Impact Limiter	The only structural welded joint is with the containment shell which is butt welded and volumetrically examined to meet the ASME code. Top Forging provides the location for the cask top trunnions, the location for a vent port, a spray cooling port and a fine-machined gasket seating surface for each Closure Lid.
4	Double Closure Lid System (DCLS)	Defines the top region of the Containment Boundary. Serves to provide access to the Fuel Package or NFW package.	Must meet Section III Subsection NB of the ASME Code and must be sufficiently robust to withstand loadings under accident conditions of transport.
5	Gamma Capture Space (GCS)	Blockage of gamma radiation, rendered by the mass of lead installed to preclude macro-voids and large spatial discontinuities.	The annular space defined by the external surface of the Containment Shell on its inside and the Intermediate Shell (IS) on its outside. The annular space is reinforced by radial steel ribs and filled with lead and in local areas filled with additional steel.
6	Neutron Capture Space (NCS)[1]	Attenuation of neutrons, rendered by Holtite	The annular space defined by the Outer Shield Cylinder (OSC) surrounding the the Cask Intermediate Shell (CIS). The OSC serves as a [WITHHELD PER 10 CFR 2.390] encasement for the Holtite. with pressure relief features.

[1] Safety evaluations summarized in Chapters 2 through 6 of this SAR that retain numerical analysis performed on an earlier design version of the NCS have been supplemented by additional safety evaluations as appropriate to conclude the safety case for the current design.

Table 1.2.2 [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 1.2.3: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 1.2.3: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 1.2.4: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 1.2.5: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 1.2.6: Typical Axial Burnup Profile NORMALIZED DISTRIBUTION BASED ON BURNUP PROFILE		
PWR DISTRIBUTION		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.5485
2	4-1/6% to 8-1/3%	0.8477
3	8-1/3% to 16-2/3%	1.0770
4	16-2/3% to 33-1/3%	1.1050
5	33-1/3% to 50%	1.0980
6	50% to 66-2/3%	1.0790
7	66-2/3% to 83-1/3%	1.0501
8	83-1/3% to 91-2/3%	0.9604
9	91-2/3% to 95-5/6%	0.7338
10	95-5/6% to 100%	0.4670
BWR DISTRIBUTION		
Interval	**Axial Distance From Bottom of Active Fuel (% of Active Fuel Length)**	**Normalized Distribution**
1	0% to 4-1/6%	0.2200
2	4-1/6% to 8-1/3%	0.7600
3	8-1/3% to 16-2/3%	1.0350
4	16-2/3% to 33-1/3%	1.1675
5	33-1/3% to 50%	1.1950
6	50% to 66-2/3%	1.1625
7	66-2/3% to 83-1/3%	1.0725
8	83-1/3% to 91-2/3%	0.8650
9	91-2/3% to 95-5/6%	0.6200
10	95-5/6% to 100%	0.2200

FIGURE 1.2.1: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

FIGURE 1.2.2: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

1.3 ENGINEERING DRAWINGS

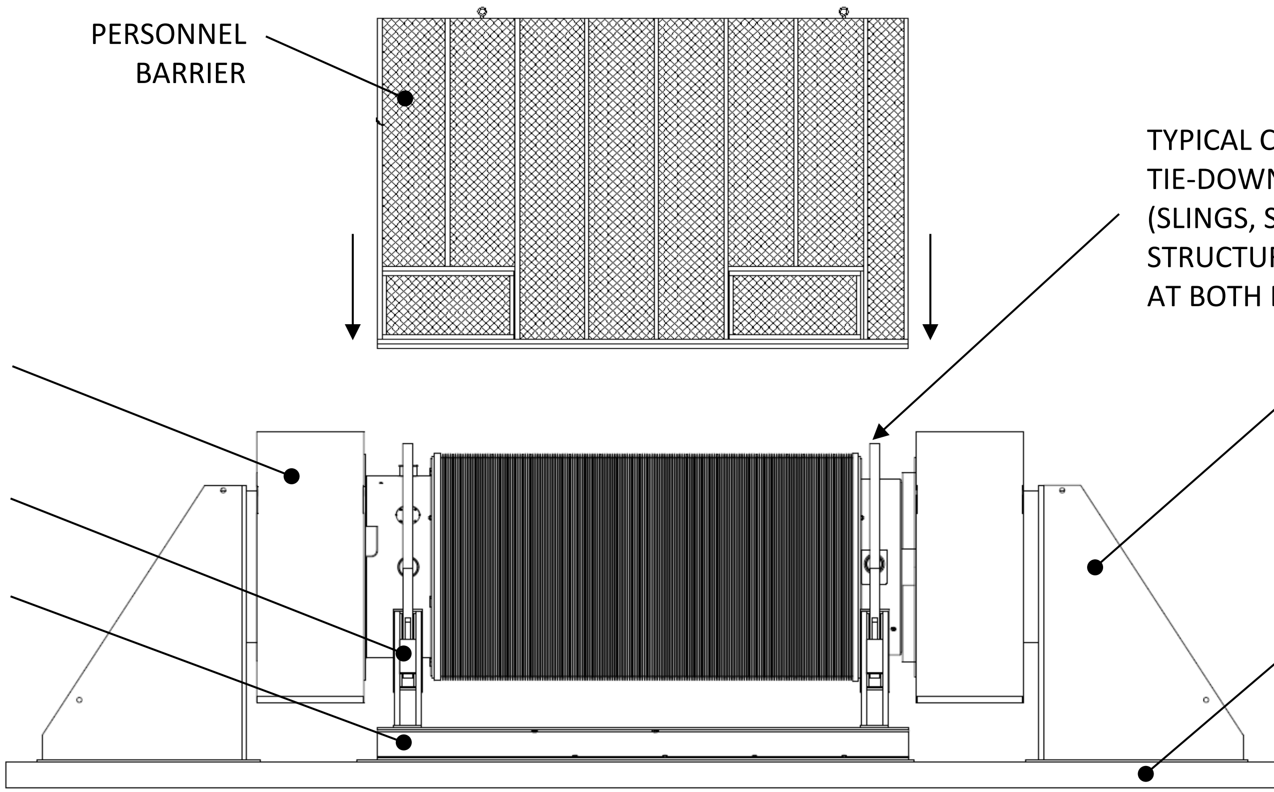
This section contains a HI-STAR 80 Drawing Package prepared under Holtec's QA Program. This drawing package contains the details of the safety features considered in the analysis documented in this SAR. In particular, this drawing package includes:

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

The manufacturing of the HI-STAR 80 components is required to be in strict compliance with the Drawing Package in this section. Additional dimensional requirements are provided in Reference [1.3.1].

Figures 1.3.1 through 1.3.3 provides illustrations of the HI-STAR 80 Package on various modes of transport to illustrate the use of personnel barrier, transport cradles and other typical auxiliary components such as package supports and restraints.

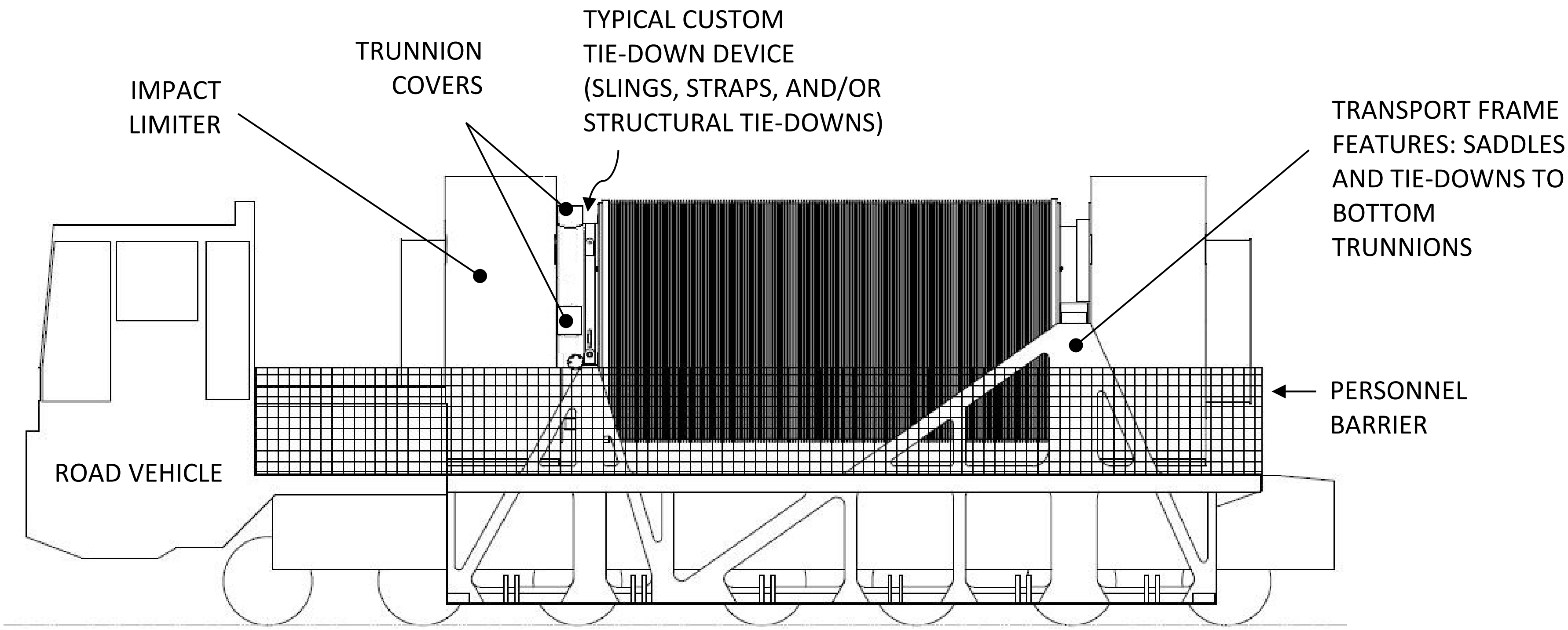
HI-STAR 80 Drawing Package: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390



Notes:

1. The tie-down configuration shown in this figure does not employ tie-downs that are a structural part of the package; therefore, the requirements of 10CFR71.45(b)(1) and (b)(3) are not applicable; however, any structural part of the HI-STAR 80 Package that could be used to tie-down the package (e.g. accessible trunnions) must be rendered inoperable in accordance with 10CFR71.45(b)(2). In this illustration the trunnions have been rendered inoperable by custom tie-down device.
2. The width of the vehicle must be the same or greater than the nominal value used in Chapter 5 for the evaluation of radiation level limits at 2 meters.
3. This figure provides the basis for Figure 7.A.2 of this SAR.

FIGURE 1.3.1: ILLUSTRATION OF HI-STAR 80 TYPICAL ROAD AND RAIL TRANSPORT CONFIGURATION



Notes:

1. The tie-down configuration shown in this figure employs tie-downs that are a structural part of the package (the bottom trunnions) therefore the requirements of 10CFR71.45(b)(1), (b)(2) and (b)(3) are applicable. However this tie-down configuration is not qualified to withstand the static forces specified in 10CFR71.45(b)(1) as discussed in SAR Section 2.5; therefore, the HI-STAR 80 Package cannot be shipped in the US with this tie-down configuration. See Figure 1.3.1 for an illustration of shipment in the US. Accessible top trunnions must be rendered inoperable by trunnion covers (shown here), by custom tie-down device, or other blocking ancillary device.
2. The width of the vehicle must be the same or greater than the nominal value used in Chapter 5 for the evaluation of radiation level limits at 2 meters.
3. This figure provides the basis for Figure 7.A.1 of this SAR.

FIGURE 1.3.2: ILLUSTRATION OF HI-STAR 80 TYPICAL ROAD TRANSPORT CONFIGURATION WHEN USING THE HI-STAR 80 BOTTOM TRUNNIONS AS TIE-DOWN DEVICES

1.4 SUMMARY OF COMPLIANCE WITH 10CFR71 REQUIREMENTS

The HI-STAR 80 Package complies with the requirements of 10CFR71 for a Type B(U)F-96 package. Analyses which demonstrate that the HI-STAR 80 Package complies with the requirements of Subparts E and F of 10CFR71 are provided in this SAR. The HI-STAR 80 Package complies with the general standards for all packages, 10CFR71.43, as demonstrated in Chapter 2. Under the tests specified in 10CFR71.71 (normal conditions of transport) the HI-STAR 80 Package is demonstrated to sustain no impairment of its safety function capability, enabling the HI-STAR 80 Package to meet the requirements of 10CFR71, Paragraphs 71.45, 71.51, and 71.55 (see discussion on high burnup fuel below). Under the tests specified in 10CFR71.73 (hypothetical accident conditions) and 10CFR71.61 (special requirement for irradiated nuclear fuel shipments), the damage sustained by the HI-STAR 80 Package is shown to be within the permissible limits set forth in 10CFR71, Paragraphs 71.51, and 71.55 (see discussion on high burnup fuel below).

The HI-STAR 80 Package meets the structural, thermal, containment, shielding and criticality requirements of 10CFR71, as described in Chapters 2 through 6. The package operations; and acceptance tests and maintenance program provided in Chapters 7 and 8 ensure compliance of the package with the requirements of 10CFR71.

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

- The HI-STAR 80 Packaging description including the drawing package provided in Section 1.3 provides an adequate basis for evaluation of the HI-STAR 80 Packaging against the 10CFR71 requirements for each technical criterion. Each drawing is identified, consistent with the text of the SAR, and contains appropriate annotations to explain and clarify information on the drawing.

- The NRC-approved Holtec International quality assurance program for the HI-STAR 80 packaging has been identified.

- The applicable codes and standards for the HI-STAR 80 Packaging design, fabrication, assembly, and testing have been identified in the drawing package in Section 1.3 and in Chapter 2.

- Allowable contents in the HI-STAR 80 Packaging are specified in Section 1.2.

High Burnup Fuel (HBF) Considerations:

In recognition of the uncertainty surrounding the cladding material properties of HBF, consistent with the approach used in HI-STAR 180 (docket number 71-9325), a multi-layered safety-focused strategy to transport HBF has been adopted for HI-STAR 80. As summarized below, this licensing approach addresses the potential for HBF reconfiguration under hypothetical

accident conditions of transport (HAC) and normal conditions of transport (NCT)[1] from both safety and regulatory compliance perspectives:

1. HBF is loaded as undamaged[2] and with high expectation to remain undamaged under loading/unloading and NCT.
2. The package design, with double closure lid, is qualified to preclude moderator intrusion under NCT and HAC.
3. The leakage rate acceptance criteria in SAR Table 8.1.1 precludes any containment concerns with HBF under NCT and HAC.
4. A finite element defense-in-depth "best estimate" fuel rod analysis is performed with a significantly more stringent failure strain limit (acceptance criterion) than previously used to provide reasonable assurance that fuel rod damage or breakage will not occur under NCT and HAC.
5. An all Metamic-HT basket minimizes the criticality safety implications of potential HBF reconfiguration under NCT and HAC.
6. Containment boundary integrity is maintained under hypothetical 100% rod rupture with coincident hypothetical fire accident consistent with RG 7.6 [2.1.2] (HAC).
7. Cask handling drops are rendered non-credible through qualification of cask top trunnions using increased stress factors (See SAR Paragraph 1.2.1.7) and robust handling procedures.
8. Compliance with ISG-11 Rev. 3 [1.2.5] for NCT, HAC and loading/unloading.
9. The package is evaluated under the (non-mechanistic) assumption of reconfigured fuel[3] under NCT and HAC from both safety and regulatory compliance perspectives.

The detailed approach specific to HAC is addressed in Appendix 1.A of this SAR and is first based on moderator exclusion by package design (double closure lid and containment boundary integrity analysis) and supported by a series of conservative defense-in-depth evaluations.

Among the defense-in-depth evaluations for NCT and HAC, a best-estimate rod integrity safety case is made by a series of realistic, but conservative assumptions. The finite element fuel rod analysis summarized in Chapter 2, Section 2.11, of this SAR demonstrates that the fuel rods will not undergo failure under the normal conditions of transport described in 71.71 nor during the hypothetical accident conditions in 71.73. A positive safety margin against a primary failure of the fuel rods is determined to exist even under the worst case accident scenario.

In addition, HI-STAR 80 has been designed with yet another level of defense-in-depth that manifests in the fact that the package is safe and in regulatory compliance[4] even if significant fuel reconfiguration were to occur. To demonstrate this fact, the criticality analysis in Chapter 6 of this SAR presents various cases with fuel reconfiguration where it is assumed that the fuel rods subdivide into smaller rodlets and rearrange into different configurations. All evaluations are performed for internal fully flooded conditions, despite the fact that the package is designed

[1] Loading/unloading conditions are also considered in this SAR.
[2] The fuel is uncanisterized. The certification for canning of fuel is not sought.
[3] All basket cells are assumed loaded with HBF.
[4] In this context, regulatory compliance only applies post HAC since fuel reconfiguration is not allowed under NCT under the present regulatory framework.

to ensure moderator exclusion under accident conditions. All cases show a negligible change in reactivity compared to the design basis condition with undamaged fuel. Additionally, all design basis criticality calculations assume unburned (fresh) fuel, while the concerns of the cladding property apply to high burnup fuel, i.e. fuel of 45 GWd/mtU or more. The reactivity reduction that is associated with this high burnup adds additional margin to the safety case. Similarly, thermal analysis and shielding analysis in Chapter 3 and 5 of this SAR, respectively, evaluate the package under the assumption of reconfigured fuel.

The overall licensing approach (including the defense-in-depth approach) from both safety and regulatory compliance perspectives is summarized in Table 1.4.

In conclusion, the deterministic structural analyses show that the HBF fuel rods will not fail under normal or accident conditions of transport. However, even if a significant rod breakage and rearrangement is assumed to have occurred, the required regulatory margin of safety against criticality will still be met. This assertion of guaranteed subcriticality is true despite formulating the criticality safety analysis with a very conservative set of assumptions.

The combination of conservative assumptions and analyses with a robust design provide a reasonable assurance that the HI-STAR 80 package containing HBF will protect public health and safety under all the required scenarios postulated by 10 CFR Part 71.

Table 1.4.1: Multi-Layered Approach for Transport Safety for HBF

Primary Safety Case

Main Approach	Applicable Condition		
	HAC	**NCT**	**Loading/Unloading**
Moderator Exclusion	By design and defense-in-depth safety analysis Compliance with 10CFR71.55(e), See Appendix 1.A	By design only (water filled package maintains subcriticality)	Not Applicable
Other Design Features and Analysis; and Operating Objectives	See applicable items under general makeup of licensing approach for HBF in Section 1.4 of this SAR		

Defense-In-Depth Safety Case

Regulatory and Operating Conditions[5]	**Best Estimate Structural Assessment of HBF Integrity**	Additional Defense-In-Depth Evaluations[6]		
		Thermal Compliance with 71.43	**Criticality** Compliance with 71.55(b),(d), and (e)	**Shielding** Compliance with 71.47 and 71.51
9 Meter Drop (HAC)	No rod break or permanent lateral deformation of lattice (See Appendix 1.A and Chapter 2, Section 2.11)	Analysis of severe hypothetical fuel reconfiguration based on 100% fuel rod failure (See Appendix 1.A and Chapter 3, Subsection 3.4.5)	Analysis of various hypothetical reconfigurations (See Appendix 1.A and Chapter 6, Paragraph 6.3.5.1)	Analysis of various hypothetical reconfigurations (See Appendix 1.A and Chapter 5, Subsection 5.4.5)
0.3 Meter Drop (NCT)	No rod break or permanent lateral deformation of lattice (See Chapter 2, Section 2.11)	Analysis of hypothetical fuel reconfiguration based on 3% fuel rod failure (See Chapter 3, Subsections 3.3.7 and 3.4.5)	Analysis of various hypothetical reconfigurations (See Chapter 6, Paragraph 6.3.5.2)	Assessment based on minor permanent lattice deformation and, limited rod slide out (See Chapter 5, Paragraph 5.3.1.2)
Vibration (NCT)	No rod break or permanent lateral deformation of lattice (See Chapter 2, Subsection 2.6.5)	Covered by thermal analysis with hypothetical reconfigured fuel for 0.3 Meter Drop	Covered by criticality analysis with hypothetical reconfigured fuel for 0.3 Meter Drop	Covered by shielding assessment of minor permanent lattice deformation and limited rod slide out for 0.3 Meter Drop
Cask Reflood (Unloading)	No rod break or permanent lateral deformation of lattice (See Chapter 2, Subparagraph 2.6.1.3.5)	Not Applicable (See Chapter 2, Subparagraph 2.6.1.3.5)	Covered by criticality analysis with hypothetical reconfigured fuel for 0.3 Meter Drop	Not applicable and covered by NCT shielding assessment above.

[5] The most severe conditions have been selected to provide reasonable assurance for defense-in-depth safety case.

[6] Best estimate structural assessment of HBF demonstrates with reasonable assurance that HBF will not reconfigure under NCT, HAC or loading/unloading conditions. Additional defense-in-depth evaluations are performed under the assumption of reconfigured fuel for NCT and HAC.

1.5 LOCATION OF PROPERTIES OF SPECIAL PURPOSE MATERIALS

Requirements for special purpose materials and parts (essentially non-code materials) utilized in the HI-STAR 80 package such as Holtite, containment seals, impact limiter crush materials, etc., are provided in their proper context in this SAR and are thus scattered across this document. To ensure that the applicable properties of such materials used in the safety analyses are correctly extracted in the Purchasing Specification for each special purpose material, Table 1.5.1 provides the location where the required information can be found in this SAR.

Table 1.5.1: Location of Properties of Special Purpose Materials in This SAR

Item No.	Material	Location
1	Holtite-B [1.2.7]	Table 1.2.5 Table 2.1.12 Subsection 3.2.1 Table 3.2.1 Table 3.2.2 Table 3.2.7 Table 3.2.12 Table 5.3.3 Table 8.1.10
2	Metamic -HT [1.2.9]	Subparagraph 1.2.1.6.1 Table 1.2.4 Section 1.3 (Drawings 9796 and 9797) Table 2.1.12 Table 3.2.1 Table 3.2.5 Table 3.2.6 Table 3.2.7 Table 5.3.2 Table 8.1.5
3	Containment Seals	Section 1.3 (Drawing 9800) Subparagraph 2.2.1.1.6 Table 2.1.12 Table 2.2.10 Table 3.2.12
4	AL-STAR Impact Limiter Crush Material	Section 1.3 (Drawing 9801) Table 2.1.12 Table 2.2.8 Paragraph 2.7.1.1 Table 3.2.1 Table 3.2.2 Table 3.2.7

1.6 QUALITY ASSURANCE AND DESIGN CONTROL

1.6.1 Quality Assurance Program:

The HI-STAR 80 Package design, material acquisition, fabrication, assembly, and testing shall be performed in accordance with Holtec International's QA program. Holtec International's QA program was originally developed to meet NRC requirements delineated in 10CFR50, Appendix B, and was expanded in the early 90s to include provisions of 10CFR71, Subpart H, and 10CFR72, Subpart G, for structures, systems, and components (SSCs) designated as *important-to-safety*. NRC approval of Holtec International's QA program is documented by the Quality Assurance Program Approval for Radioactive Material Packages (NRC Form 311), Approval Number 0784, Docket No. 71-0784.

1.6.2 Package Design Control:

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

CHAPTER 1 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

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

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

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

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

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

[1.0.6] “Final Safety Analysis Report for the HI-STAR 100 Cask System”, Holtec Report HI-2012610, latest revision, USNRC Docket No. 72-1008.

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

[1.0.8] “Safety Analysis Report for the HI-STAR 63 Package”, Holtec Report HI-2073777, latest revision (design approval by MEST in South Korea).

[1.0.9] “Final Safety Analysis Report on the HI-STORM FW System”, Holtec Report HI-2114830. Latest revision, USNRC Docket No. 72-1032.

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

[1.0.11] "Final Safety Analysis Report for the HI-STORM 100 Cask System", Holtec Report HI-2002444, latest revision, USNRC Docket No. 72-1014.

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

[1.0.13] "Safety Analysis Report for the HI-STAR 180D Package", Holtec Report HI-2125175, latest revision, USNRC Docket No. 71-9325.

[1.0.14] "VNF's Statement regarding Zr-based Alloys Cladding Materials for Spent Nuclear Fuel Transportation Purposes", Report DMG1273679, Version 2.0, Vattenfall Nuclear Fuel AB, December 16, 2022

[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 2010 Edition.

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

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

[1.2.4] Regulatory Guide 3.61 (Task CE306-4) "Standard Format for a Topical Safety Analysis Report for a Spent Fuel Storage Cask", USNRC, February 1989.

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

[1.2.6] Not Used.

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[1.2.7] "Holtite-B Sourcebook", Holtec Report HI-2167314, Latest Revision. (Holtec Proprietary)

[1.2.8] NUREG-1617, Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, 2000.

[1.2.9] "Metamic-HT Qualification Sourcebook", Holtec Report No. HI-2084122, Latest Revision (Holtec Proprietary)

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

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

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

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

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

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

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

[1.2.17] Australian Standard, AS 1565-1996 “Copper and Copper Alloys – Ingots and Castings”, 1996

[1.2.18] ASM International, “ASM Specialty Handbook - Copper and Copper Alloys”, 2001

[1.2.19] ASM International, ASM Handbook Volume 2, “Properties and Selection: Nonferrous Alloys and Special-Purpose Materials”, 2002.

[1.2.20] “SKB Quiver – Data for external use”, Report NRT 18-403, Latest Revision (Westinghouse Electric Sweden AB Proprietary).

[1.3.1] “Critical Dimensions Report for the HI-STAR 80,” Holtec Report HI-2220600, Latest Revision

APPENDIX 1.A: PROPRIETARY APPENDIX WITHHELD PER 10 CFR 2.390

CHAPTER 2: STRUCTURAL EVALUATION

2.0 INTRODUCTION

This chapter presents a synopsis of the Design Criteria relevant to the mechanical and structural characteristics of the HI-STAR 80 Package that ensure compliance with the performance requirements of 10CFR71, and it summarizes all structural evaluations and analyses of the package, pursuant to the provisions of 10CFR71.61, 10CFR71.71, and 10CFR71.73.

In particular, the objectives of this chapter are twofold:

a. To demonstrate that the structural performance of the HI-STAR 80 Package has been adequately evaluated for the normal conditions of transport and for the hypothetical accident conditions set forth in 10CFR71.61, 10CFR71.71, and 10CFR71.73.

b. To demonstrate that the HI-STAR 80 Package design has adequate structural integrity to meet the regulatory requirements of 10CFR71.61, 10CFR71.71, and 10CFR71.73.

Among the topical areas addressed in this chapter are:

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

Appendix 2.A provides introductory information on the principal codes used in the structural analysis (ANSYS and LS-DYNA). Appendix 2.B in HI-STAR 180 SAR [1.0.4] provides a comprehensive summary of the three-stage benchmarking effort by Holtec International to establish the veracity of the LS-DYNA solution for predicting the peak deceleration of the package

and crush performance of the AL-STAR impact limiters. A discussion of the finite element discretization level to ensure that the solutions are fully converged is also provided.

To facilitate regulatory review, throughout this chapter, the assumptions and conservatism inherent in the analyses are identified along with a complete description of the analytical methods, models, and acceptance criteria. A summary of other considerations germane to satisfactory structural performance, such as protection against corrosion, creep (in the Metamic-HT fuel basket), and brittle fracture, is also provided.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter are essentially identical to those used in the USNRC approved SARs for HI-STAR 180 (Docket #71-9325) and HI-STAR 180D (Docket #71-9367).

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 80 Package. These members are the containment system components (together with those parts that render the radiation shielding function in the cask), the structural components that constitute the fuel basket and the surrounding support, and the impact limiters needed to protect the package in the event of a hypothetical accident event (10CFR71.73).

2.1.1.1 Cask

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

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

The HI-STAR 80 cask consists of three discrete regions; namely:

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

The containment space (or space within the containment boundary as identified in the drawing package in Section 1.3 and described in Sections 1.2 and 4.1) is the heart of the package. It must ensure a leak-resistant enclosure for its contents under all normal and accident conditions of transport.

Accordingly, it is designed to meet the most rigorous industry requirements, to the extent germane to its function, of Section III, Subsection NB of the ASME Boiler & Pressure Vessel Code [2.1.1]. Section 1.5.2.6 of NUREG-1617 [2.1.11] states the following:

"ASME has published Section III, Division 3, ASME Boiler and Pressure Vessel (B&PV Division 3) Code for the design and construction of the containment system of SNF transport packagings. NRC staff expects full compliance with the B&PV Division 3 Code for the containment system, including the services of an Authorized Inspection Agency. However, the SAR may justify alternatives as appropriate."

In this SAR, ASME Section III, Division 1, Subsection NB is used for the design and construction of the HI-STAR 80 containment system, in lieu of the Division 3 Code, since Subsection NB has an established history of use and NRC approval for similar cask designs (e.g., HI-STAR 100, HI-STAR 60, HI-STAR 180, and HI-STAR 180D).

Unlike the commonly used bolted lid configuration used in metal casks (such as the HI-STAR 180 cask certified in docket number 71-9325), the gasket sealing system in HI-STAR 80 utilizes a decontamination-friendly closure plug and retainer ring system (see drawing package in Section 1.3) that has the following essential design attributes:

1. The cask inner lid (also called the plug) has no bolt holes that may provide hideout surfaces for contaminants in the fuel pool during the cask's submersion in the pool.
2. The plug seals against the cask's flange via two self-energizing gaskets in a *controlled metal-to-metal contact* joint arrangement used in all Holtec HI-STAR casks. As explained in references [2.7.7, page 144] and [2.1.20], the controlled metal-to-metal contact joint protects the gaskets from over-compression and establishes a contact force reserve that protects the seals from unloading during an impulsive event acting to loosen them. The axially outward load exerted by a cask's contents under the governing "top down vertical free drop" event of 10CFR71.73 wherein the cask's contents will slam against the plug is an example of a *seal threatening load* (hereafter called STL, for convenience) against which the containment integrity of the cask must be protected by a suitable closure joint design.
3. As shown in the licensing drawing, the pre-load on the plug is exerted by a tapered *retainer ring* which is bolted via the blind tapped holes in the flange. The tapered surface of the ring is in conformal contact with the plug's inclined surface. The blind holes in the flange are protected by the cask connection adapter against the intrusion of contaminants while the cask is in the pool.
4. The number, size and axial load in the bolts shall be established to meet the following requirements:
    a. The contact stress on the metal-to-metal contact surface under the “seating condition” is below the yield strength of the interfacing materials.
    b. The maximum average tensile stress developed in the bolts during the limiting STL remains below the bolts’ material yield strength.
    c. The contact pressure at the ring/plug interface does not exceed the yield point during the limiting STL event.
5. To insure that the tapered ring will not get wedged in after bolt preloading or a STL event, the angle of taper A, should be such that the tan of A is greater than the friction coefficient at the inclined interface. The angle (45 degrees) selected in the design is conservative since the typical friction coefficient at steel/steel interface is less than 0.8 [2.1.21]. It may be necessary to weld overlay the interfacing parts with a suitable material to prevent galling under extremely severe STLs.

The wedge assisted closure design described above is derived, for cask applications, from the self-energizing closure design used to sustain extremely high pressures in cylindrical vessels used to contain potentially explosive materials [2.7.7, pp 297-304].

The inter-lid space (or expanded containment space as described in Section 1.2 and Section 4.1) is the space between the outer closure lid and the inner closure lid. The inter-lid gap between the closure lids is sufficiently small as shown in the drawing package such that the outer closure lid

reinforces the inner closure lid and both lids can act in tandem in the event of a hypothetical drop accident when the fuel and the lid are potentially subjected to large impact forces. This feature limits the maximum deflection in the inner lid and keeps check on the demand on the inner lid bolting and the corresponding seals. The structural analysis models developed for analyzing the hypothetical drop accident condition (see Subsection 2.7.1.1) consider the structural interaction of the two closure lids by defining a surface-to-surface contact between the two lids to capture this design feature. The outer closure lid gasketed joint is accordingly designed to have the same level of sealing reliability as the inner closure lid joint. The double lid closure feature in the HI-STAR 80 Package is not a Part 71 requirement: It has been incorporated into the package to help establish the necessary level of technical confidence to rule out moderator intrusion into the space under the inner closure lid in the sequence of accident events set forth in 10CFR71.73, which culminates in water submergence (see Appendix 1.A).

[

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] The cylindrical vessel walls that buttress the containment shell, as described in Section 1.2 and identified in the drawing package in Section 1.3, are dose blocker parts that provide gamma and neutron attenuation. To perform their function, the dose blocker parts must not undergo extensive damage resulting in an appreciable loss of shielding capacity under normal and accident conditions of transport.

To minimize the axial gap between the top of the fuel assemblies and the inner closure lid, the population of the fuel common to the host reactor plant is surveyed and the cask cavity length is accordingly controlled as discussed in Section 1.2.

2.1.1.2 Fuel and Core Component Cassette Baskets and Fuel Basket Support

The structural function of the fuel basket and fuel basket support (basket shims) (see drawing package in Section 1.3) in the transport mode is to maintain the position of the fuel in a sub-critical configuration. In its role as the guarantor of subcriticality, the fuel basket must exhibit global physical integrity (i.e., no potential for large plastic deformation or structural failure in the active fuel region) under the most structurally demanding conditions of transport (see 2.1.2.2 (ii) for acceptance criterion). The Non-Fuel Waste Basket (NFWB) for transporting BWR control rods, neutron sources, temporary burnable absorbers and various forms of metal scrap does not play any role in maintaining sub-criticality because the contents are non-fissile (see Subsection 6.1.1). However, it is designed to ensure that it can maintain its gross configuration under the most severe accident condition of transport.

2.1.1.3 Impact Limiters

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

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]

The impact limiter configured on the above design platform is referred to as "AL-STAR" and is used in all models of HI-STAR transport packages, including the first package (HI-STAR 100) and subsequent packages labeled HI-STAR HB, HI-STAR 180, HI-STAR 60, HI-STAR 180D, HI-STAR 190, and this package (HI-STAR 80).

The structural function of the impact limiters (shown in the drawing package in Section 1.3) in the transport mode is to cushion the HI-STAR 80 cask and the contained fuel during normal transport package handling, and during a hypothetical drop accident. Under all postulated impact events applicable to the HI-STAR 80 Transport Package, the impact limiter must stay attached to the package and mitigate the inertia forces. The impact limiters and other appurtenances such as the support saddle necessary for the transport package must also meet all applicable regulatory requirements.

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

2.1.2 Design Criteria

Regulatory Guide 7.6 [2.1.2] provides guidance for design criteria for the structural analysis of shipping cask containment vessels. Loading conditions and load combinations for transport are defined in 10CFR71 [2.1.3] and in Regulatory Guide 7.8 [2.1.4]. Consistent with the provisions of these documents, the central objective of the structural requirements presented in this section is to ensure that the HI-STAR 80 Package possesses sufficient structural capability to meet the demands of both normal (10CFR71.71) and hypothetical accident conditions (10CFR71.73) of transport articulated in the regulatory guidance documents, specifically Reg. Guide 7.6. The following table provides a synoptic matrix to demonstrate the explicit compliance with the seven regulatory positions with respect to the Containment Boundary stated in Regulatory Guide 7.6.

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

USNRC's Regulatory Position regarding the Containment Boundary for the Transport Package
6. Under accident conditions, the values of primary membrane stress intensity should not exceed the lesser of $2.4S_m$ and $0.7S_u$ (ultimate strength), and primary membrane plus bending stress intensity should not exceed the lesser of $3.6S_m$ and S_u.
7. The extreme total stress intensity range should be less than $2S_a$ at 10 cycles as given by the appropriate fatigue curves.

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

- The dose blocker parts are required to remain in place and functional after all Normal and Hypothetical Accident Conditions of Transport.

- The fuel basket is required to maintain its shape so as to ensure reactivity control after all Normal and Hypothetical Accident Conditions of Transport. The NFWB must not experience gross collapse under the most severe accident condition of transport.

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

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

2.1.2.1 Loading and Load Combinations

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

The loadings applicable to the HI-STAR 80 package can be broadly divided into five categories, namely:

1. permanent loads
2. design condition loads
3. handling loads
4. normal condition of transport loads
5. hypothetical accident condition loads

1. Permanent Loads

Permanent loads in HI-STAR 80 arise from bolt pre-load to seat the gasketed joints. The pre-load applied to the cask closure lid bolts seats the elastomeric seals and creates a contact pressure on the inside metal-to-metal annulus, referred to as the "land", to protect the joint from unacceptable

leakage under postulated impact loading events. Bolt pre-load produces a state of stress in the closure lids, the cask containment upper forging, and the cask inner shell region adjacent to the flange.

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

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

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

2. Design Condition Loads

The ASME Code [2.1.1] requires that a pressure vessel be qualified to a design internal and external (if applicable) pressure. The Design Pressure should be selected to bound all normal operating condition pressures. The applicable Design Temperature, likewise, should be one that bounds the metal temperature of the affected pressure parts under all normal service conditions. For the HI-STAR 80 Package, the Design Internal Pressure and Design Temperatures, set down in Table 2.1.1, accordingly bound all service condition values.

Stress analysis of the containment system under the Design Pressure is required to demonstrate compliance with “NB” stress limits, as identified in [2.1.1], for the containment system material and to demonstrate that the bolted joints meet the leakage rate requirement specified in Table 8.1.1. The Design Temperature is utilized to establish the applicable allowable stress intensity, S_m, for the “pressure part” (a term used in the ASME B&PV Code). The following pressure loading scenarios are identified:

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

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

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

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

Table 2.1.1 provides the above values of design basis internal and external pressures. The Design Internal Pressure of the Cask Cavity Space is conservatively set higher than the Cask Cavity Space MNOP.

The most adverse possible internal pressure state occurs under the simultaneous effect of fire and 100% rod rupture. This pressure is bounded by the accident condition internal pressure specified in Table 2.1.1.

The case of deep submergence (10CFR71.61) is enveloped by the accident condition external pressure specified in Table 2.1.1.

As discussed in Paragraph 2.1.1.1, there is no additional restraint load from the fuel assemblies on the cask closure lid.

3. Handling Loads

The lifting attachments (or interfacing lift points) in the HI-STAR 80 cask are designed to meet the stress limits set forth by NUREG-0612 [2.1.5] and 10CFR71.45(a), which require that the primary stresses in a lifting point must be less than the smaller of 1/10 of the material ultimate strength and 1/3 of the material yield strength while subject to the lifted load that includes an appropriate dynamic load amplifier. These limits apply to the cask lifting trunnions and to the threaded holes in the lids. An associated requirement is an evaluation of the stress intensity state in the cask baseplate when the package is being lifted. Baseplate loads considered are the self-weight of the baseplate plus attached shielding, the fuel, the fuel basket, and the fuel basket supports. Under lifting (and handling) condition a 15% load amplifier is applied as discussed in Section 2.5. The HI-STAR 80 cask component acceptance limits are based on the Level A stress intensity allowables from ASME Code, Section III, Subsection NB.

Section 2.5 documents the lifting analyses applicable to the HI-STAR 80 package.

4. Normal Conditions of Transport Loads

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)

External pressure loads ((a) and (b) above) are clearly enveloped by the design external pressure set by a deep submersion of the package (10CFR71.61). This condition is evaluated in Section 2.7. The normal operating conditions (e) are evaluated to demonstrate that the containment meets the requirements of the ASME Code (as clarified in Subsection 2.1.4) to be designated as a “pressure vessel”. The “1-foot drop event” (c) evaluation is the “Side Drop”. The HI-STAR 80 Package is assumed to drop with its axis parallel with respect to the horizontal surface, such that the collision of the two impact limiters with the target is coincident in time. Vibratory loads transmitted to the HI-STAR 80 Package (d) by the transport vehicle will produce negligibly small stresses in comparison with stresses that will be produced by the loadings described previously. Therefore, vibratory loading is neglected in the analyses performed herein. Fatigue considerations due to mechanical vibrations are further discussed in Section 2.6.

Based on the above considerations, the governing Load Combinations to be considered in Section 2.6, for both Heat (38 °C) and Cold (-40°C) conditions, are:

- Load Combination N1:
  Bolt pre-load plus Design Internal pressure and Normal operating temperature
- Load Combination N2:
  Free drop from 1 foot plus Bolt pre-load and Maximum Normal Operating Pressure (MNOP).

5. Hypothetical Accident Condition Loads

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

a. Free Drop of 9 m (30 ft) (10CFR71.73 (c) (1))
b. Puncture (10CFR71.73 (c)(3))
c. Engulfing fire @ 800ºC (1475ºF) (10CFR71.73 (c)(4))
d. Immersion in 15 m (50 ft) head of water (10CFR71.73 (c) (6)).

a. Free Drop

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

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

- Top End Drop: This drop condition is the opposite of the preceding case. The outer closure lid withstands the impact load transmitted through the impact limiter, and the inner closure

lid withstands the impact from the contained fuel, fuel basket, and fuel basket supports (basket shims).

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

- Bottom Center-of-Gravity Over-the-Corner Drop: In this drop scenario, the HI-STAR 80 Package is assumed to impact an essentially unyielding surface with its center-of-gravity directly above its initial point of contact in the drop event.

- Top Center-of-Gravity Over-the-Corner Drop: This loading case is identical to the preceding case, except that the package is assumed to be dropping with its top end down and its center-of-gravity is aligned over the initial point of contact.

- Slapdown – Initial Impact at Top End: In this case, the package drops with its axis at a small angle with the horizontal with the top end impacting first. Subsequent to the primary impact, the package begins to rotate with the bottom end impacting the target at a later time (secondary impact). Higher decelerations are experienced during the secondary impact. The governing slapdown angle, θ, is determined by a parametric analysis.

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

b. <u>Puncture</u>

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

- Side Puncture: This event consists of a 1-m (40-in) free drop (impact limiters are ignored) onto a stationary and vertical mild steel bar of 15 cm (6 in) diameter with its leading edge (top edge) rounded to 6 mm (1/4-in) radius. The bar is assumed to be of such a length as to cause maximum damage to the cask. The package is assumed to be dropping horizontally with the penetrant force being applied at the mid-length of the cask.

- Top End Puncture: This event is similar to the preceding case except the penetrant force is assumed to act at the center of the outer closure lid. Because of the proximity of the bolted joints, this case is considered limiting for an end puncture.

The above loading events may occur under the so-called “hot” (maximum ambient temperature) or “cold” condition at -40ºC (-40ºF). In the latter thermal state, the effects of brittle fracture must also be evaluated.

c. <u>Fire</u>

Fire is not a mechanical loading event; its chief consequence is to challenge the integrity of the neutron shielding material. The results are presented in Chapter 3. The results show that the gas pressure inside the containment system remains below the accident pressure limit for the package (see Table 2.1.1). Based on the temperature changes established in Chapter 3, an evaluation is performed to demonstrate that the land compression load at the lid/flange joint does not degrade to an unacceptable value.

d. Immersion

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

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

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

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

2.1.2.2 Acceptance Criteria

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2.1.3 Weights and Centers of Gravity

Table 2.1.9 provides the weights of the individual HI-STAR 80 components as well as the total Transport Package weights, and the weight of the heaviest loaded HI-STAR 80 Cask.

Table 2.1.10 provides the location of the center of gravity (CG) for the package relative to the bottom surface of the bottom impact limiter. The CG is assumed to be located on the cask centerline since the non-axisymmetric effects of the cask plus contents are negligible.

2.1.4 Identification of Codes and Standards for Package Design

The design of the HI-STAR 80 Package does not invoke ASME Code Section III in its entirety. Specific Code paragraphs in NB-3000 of Section III, Subsection NB of the ASME Boiler and Pressure Vessel Code (ASME Code) [2.1.1], and Appendix F [2.1.10] that are cited herein are invoked for design of the containment system of the HI-STAR 80 Package.

Table 2.1.11 lists each major structure, system, and component (SSC) of the HI-STAR 80 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 8.1.8 lists some alternatives to the ASME Code where appropriate. Table 8.1.7 provides applicable sections of the ASME Code and other documents for Material Procurement, Design, Fabrication, and Inspection, and Testing pursuant to the guidance in NUREG 1617 [2.1.11].

All materials and sub-components that do not constitute the containment system in the HI-STAR 80 cask are procured to ASTM or ASME Specifications, except for the fuel basket (made of Metamic-HT) and the neutron shield sold under the trade name Holtite B described in Chapter 1.

The *critical characteristics* of all materials set down in this SAR establish the minimum requirements that must be met by the material. The applicable *critical characteristics* for each part in the HI-STAR 80 cask are listed in Table 2.1.12 with the required limiting values, as applicable.

2.1.5 Partially Loaded Package

The HI-STAR 80 is allowed to load with only one fuel assembly as a partially loaded package. The structural integrity of the partially package is confirmed to be maintained. The detailed evaluation is documented in Appendix H to Reference [2.6.1].

Table 2.1.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

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

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

Notes:

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

* Not required by the ASME Code, Section III, Subsection NB. However, meeting the Level A stress intensity limits defined in the table for the three stress categories ensures a satisfaction of the relevant stress intensity criteria for transport cask design specified by Reg. Guide 7.6 and by the ASME Code, Section III, Division 3;

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

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

Stress Category	**Level A**	**Level D**
Average Service Stress	$2S_m$	Yield Strength
Maximum Service Stress (tension + bending but no stress concentrations)	$3S_m$	Ultimate Strength Joint's Sealing Function Maintained (see Note 2)

Notes:

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

Table 2.1.4a: Design, Level A: Stress Intensity – SA-203 E

Code: ASME NB
Material: SA-203 E
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)					
	S_m	P_m (Note 1)	P_L (Note 1)	$P_L + P_b$ (Note 1)	$P_L + P_b + Q$	P_e (Note 2)
-29 to 38 (-20 to 100)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
93,3 (200)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
149 (300)	160.6 (23.3)	160.6 (23.3)	241.3 (35.0)	241.3 (35.0)	481.9 (69.9)	481.9 (69.9)
204 (400)	157.9 (22.9)	157.9 (22.9)	237.2 (34.4)	237.2 (34.4)	473.7 (68.7)	473.7 (68.7)
260 (500)	148.9 (21.6)	148.9 (21.6)	223.4 (32.4)	223.4 (32.4)	446.8 (64.8)	446.8 (64.8)

Definitions:

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

Notes:

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

Table 2.1.4b: Level D Stress Intensity – SA-203 E

Code: ASME NB
Material: SA-203 E
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**		
	$\mathbf{P_m}$	$\mathbf{P_L}$	$\mathbf{P_L + P_b}$
-29 to 38 (-20 to 100)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
93.3 (200)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
149 (300)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
204 (400)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
260 (500)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4a for stress classification definitions.

Table 2.1.5a: Design, Level A: Stress Intensity – SA-350 LF3

Code: ASME NB
Material: SA-350 LF3
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)					
	S_m	P_m (Note 3)	P_L (Note 3)	$P_L + P_b$ (Note 3)	$P_L + P_b$ +Q	P_e (Note 4)
-29 to 38 (-20 to 100)	160.6 (23.3)	160.6 (23.3)	240.9 (35.0)	240.9 (35.0)	481.9 (69.9)	481.9 (69.9)
93.3 (200)	157.9 (22.9)	157.9 (22.9)	236.9 (34.4)	236.9 (34.4)	473.7 (68.7)	473.7 (68.7)
149 (300)	152.4 (22.1)	152.4 (22.1)	228.6 (33.2)	228.6 (33.2)	457.2 (66.3)	457.2 (66.3)
204 (400)	147.5 (21.4)	147.5 (21.4)	221.3 (32.1)	221.3 (32.1)	442.5 (64.2)	442.5 (64.2)
260 (500)	140.0 (20.3)	140.0 (20.3)	210.0 (30.5)	210.0 (30.5)	420.0 (60.9)	420.0 (60.9)
316 (600)	129.6 (18.8)	129.6 (18.8)	194.4 (28.2)	194.4 (28.2)	388.8 (56.4)	388.8 (56.4)
371 (700)	116.5 (16.9)	116.5 (16.9)	174.8 (25.4)	174.8 (25.4)	349.5 (50.7)	349.5 (50.7)

Notes:

1. Source for S_m is Table 2A of ASME Section II, Part D.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. Evaluation required for Design condition only per NB-3220.
4. P_e not applicable to vessels per Fig. NB-3221-1.
5. See Table 2.1.4a for stress classification definitions.

Table 2.1.5b: Level D, Stress Intensity – SA-350 LF3

Code: ASME NB
Material: SA-350 LF3
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)		
	P_m	**P_L**	**$P_L + P_b$**
-29 to 38 (-20 to 100)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
93.3 (200)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
149 (300)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
204 (400)	337.8 (49.0)	506.8 (73.5)	506.8 (73.5)
260 (500)	335.8 (48.7)	506.8 (73.5)	506.8 (73.5)
316 (600)	311.0 (45.1)	462.6 (67.7)	462.6 (67.7)
371 (700)	279.9 (40.6)	419.9 (60.9)	419.9 (60.9)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4a for stress classification definitions.

Table 2.1.6a: Design, Level A: Stress Intensity – SA-965 F304/SA-182 F304

Code: ASME NB
Material: SA-965 F304/SA-182 F304
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)					
	S_m	**P_m** (Note 3)	**P_L** (Note 3)	**$P_L + P_b$** (Note 3)	**$P_L + P_b$ +Q**	**P_e** (Note 4)
-29 to 38 (-20 to 100)	137.9 (20.0)	137.9 (20.0)	206.8 (30.0)	206.8 (30.0)	413.7 (60.0)	413.7 (60.0)
93.3 (200)	137.9 (20.0)	137.9 (20.0)	206.8 (30.0)	206.8 (30.0)	413.7 (60.0)	413.7 (60.0)
149 (300)	137.9 (20.0)	137.9 (20.0)	206.8 (30.0)	206.8 (30.0)	413.7 (60.0)	413.7 (60.0)
204 (400)	128.2 (18.6)	128.2 (18.6)	192.4 (27.9)	192.4 (27.9)	384.7 (55.8)	384.7 (55.8)
260 (500)	120.7 (17.5)	120.7 (17.5)	181.0 (26.25)	181.0 (26.25)	362.0 (52.5)	362.0 (52.5)
316 (600)	114.5 (16.6)	114.5 (16.6)	171.7 (24.9)	171.7 (24.9)	343.4 (49.8)	343.4 (49.8)
371 (700)	108.9 (15.8)	108.9 (15.8)	163.4 (23.7)	163.4 (23.7)	326.8 (47.4)	326.8 (47.4)

Notes:

1. Source for S_m is Table 2A of ASME Section II, Part D.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. Evaluation required for Design condition only per NB-3220.
4. P_e not applicable to vessels per Fig. NB-3221-1.
5. See Table 2.1.4a for stress classification definitions.

Table 2.1.6b: Level D, Stress Intensity – SA-965 F304

Code: ASME NB
Material: SA-965 F304
Item: Stress Intensity

Temperature °C (°F)	Classification and Value, MPa (ksi)		
	P_m	P_L	$P_L + P_b$
-29 to 38 (-20 to 100)	330.9 (48.00)	496.4 (72.00)	496.4 (72.00)
93.3 (200)	320.0 (46.41)	479.9 (69.61)	479.9 (69.61)
149 (300)	298.3 (43.26)	447.4 (64.89)	447.4 (64.89)
204 (400)	288.1 (41.79)	432.2 (62.68)	432.2 (62.68)
260 (500)	285.7 (41.44)	428.6 (62.16)	428.6 (62.16)
316 (600)	274.7 (39.84)	412.0 (59.76)	412.0 (59.76)
371 (700)	274.7 (39.84)	412.0 (59.76)	412.0 (59.76)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4a for stress classification definitions.

Table 2.1.6c: Level D, Stress Intensity – SA-182 F304

Code: ASME NB
Material: SA-182 F304
Item: Stress Intensity

Temperature °C (°F)	**Classification and Value, MPa (ksi)**		
	P_m	**P_L**	**$P_L + P_b$**
-29 to 38 (-20 to 100)	330.9 (48.00)	496.4 (72.00)	496.4 (72.00)
93.3 (200)	330.9 (48.00)	496.4 (72.00)	496.4 (72.00)
149 (300)	319.5 (46.34)	479.3 (69.51)	479.3 (69.51)
204 (400)	307.8 (44.64)	461.7 (66.96)	461.7 (66.96)
260 (500)	289.6 (42.00)	434.4 (63.00)	434.4 (63.00)
316 (600)	274.7 (39.84)	412.0 (59.76)	412.0 (59.76)
371 (700)	261.4 (37.92)	392.2 (56.88)	392.2 (56.88)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4a for stress classification definitions.

Table 2.1.7a: Design, Level A: Stress Intensity – SA-182 FXM-19

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

Temperature °C (°F)	Classification and Value, MPa (ksi)					
	S_m	P_m (Note 3)	P_L (Note 3)	$P_L + P_b$ (Note 3)	$P_L + P_b + Q$	P_e (Note 4)
-29 to 38 (-20 to 100)	229.6 (33.3)	229.6 (33.3)	344.4 (49.95)	344.4 (49.95)	688.8 (99.9)	688.8 (99.9)
93.3 (200)	228.2 (33.1)	228.2 (33.1)	342.3 (49.65)	342.3 (49.65)	684.7 (99.3)	684.7 (99.3)
149 (300)	216.5 (31.4)	216.5 (31.4)	324.8 (47.1)	324.8 (47.1)	649.5 (94.2)	649.5 (94.2)
204 (400)	209.6 (30.4)	209.6 (30.4)	314.4 (45.6)	314.4 (45.6)	628.8 (91.2)	628.8 (91.2)
260 (500)	204.8 (29.7)	204.8 (29.7)	307.2 (44.55)	307.2 (44.55)	614.3 (89.1)	614.3 (89.1)
316 (600)	201.3 (29.2)	201.3 (29.2)	302.0 (43.8)	302.0 (43.8)	604.0 (87.6)	604.0 (87.6)
371 (700)	198.6 (28.8)	198.6 (28.8)	297.9 (43.2)	297.9 (43.2)	595.7 (86.4)	595.7 (86.4)

Notes:

1. Source for S_m is Table 2A of ASME Section II, Part D.
2. Values are in accordance with stress intensity limits provided in Table 2.1.2.
3. Evaluation required for Design condition only per NB-3220.
4. P_e not applicable to vessels per Fig. NB-3221-1.
5. See Table 2.1.4a for stress classification definitions.

Table 2.1.7b: Level D, Stress Intensity – SA-182 FXM-19

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

Temperature °C (°F)	**Classification and Value, MPa (ksi)**		
	P_m	**P_L**	**$P_L + P_b$**
-29 to 38 (-20 to 100)	482.7 (70.0)	724.0 (105.0)	724.0 (105.0)
93.3 (200)	479.8 (69.58)	719.6 (104.37)	719.6 (104.37)
149 (300)	454.7 (65.94)	682.0 (98.91)	682.0 (98.91)
204 (400)	439.7 (63.77)	659.5 (95.65)	659.5 (95.65)
260 (500)	430.0 (62.37)	645.1 (93.55)	645.1 (93.55)
316 (600)	423.3 (61.39)	634.9 (92.08)	634.9 (92.08)
371 (700)	417.0 (60.48)	625.5 (90.72)	625.5 (90.72)

Notes:

1. Level D allowables per NB-3225 and Appendix F, Paragraph F-1331.
2. Average primary shear stress across a section loaded in pure shear may not exceed 0.42 S_u.
3. Values are in accordance with stress intensity limits provided in Table 2.1.2.
4. See Table 2.1.4a for stress classification definitions.

Table 2.1.8: Design Stress Intensity – Bolting Material

Code: ASME NB
Material: SA-193 B7 (Bolt < 2.5 inch diameter),
SA-564 630 (H1100)
& SB-637 N07718 (Bolt ≤ 6 inch diameter),
Item: Stress Intensity

Temperature °C (°F)	**Design Stress Intensity SA-193 B7 MPa (ksi)**	**Design Stress Intensity SA-564 630 MPa (ksi)**	**Design Stress Intensity SB-637 MPa (ksi)**
-29 to 38 (-20 to 100)	241.3 (35)	322.0 (46.7)	344.7 (50)
93.3 (200)	224.8 (32.6)	322.0 (46.7)	330.9 (48)
149 (300)	216.5 (31.4)	322.0 (46.7)	323.4 (46.9)
204 (400)	210.3 (30.5)	313.0 (45.4)	317.8 (46.1)
260 (500)	203.4 (29.5)	306.8 (44.5)	314.4 (45.6)
316 (600)	195.8 (28.4)	313.0 (43.8)	310.95 (45.1)
343 (650)	-	302.0 (43.4)	-
371 (700)	185.5 (26.9)	-	308.9 (44.8)

Notes:

1. Level A and D limits per Table 2.1.3
2. Table 2.2.2 contains other mechanical and thermal properties of the bolting material.
3. Source for design stress intensity values for SA-193 B7 and SB-637 N07718 is Table 4, and that for SA-564 630 is Table 2A of ASME Section II, Part D.

Table 2.1.9: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 2.1.10: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 2.1.11: Applicable Codes and Standards for the Materials Used in The HI-STAR 80 Packaging

	Item	Principal Function	Applicable Codes and Reference Standard
1.	Containment Baseplate	Containment Boundary	ASME Code Section III Subsection NB
2.	Containment Shell	Containment Boundary	ASME Code Section III Subsection NB
3.	Containment Closure Flange	Containment Boundary	ASME Code Section III Subsection NB
4.	Inner Closure Lid Plug and Retainer Ring	Containment Boundary	ASME Code Section III Subsection NB
5.	Outer Closure Lid	Containment Boundary	ASME Code Section III Subsection NB
6.	Inner Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
7.	Outer Closure Lid Bolts	Containment Boundary	ASME Code Section III Subsection NB
8.	Vent and Drain Port Plugs	Containment Boundary	ASME Code Section II
9.	Seals and Gaskets	Containment Boundary	Non-Code (Manufacturer's Catalog and Test Data)
10.	Fuel Basket (Metamic-HT)	Positioning of Fuel Assemblies and Quivers for Criticality Control	Non-Code (Manufacturer's Test Data [1.2.9])
11.	Dose Blocker Plates	Gamma Shielding	ASME Code Section III Subsection NF
12.	Holtite-B	Neutron Shielding	Non-Code (Manufacturer's Test Data [1.2.17])
13.	Trunnions	Lifting and Handling	ASME Code Section II, 10CFR71.45 and NUREG-0612

Table 2.1.11: Applicable Codes and Standards for the Materials Used in The HI-STAR 80 Packaging (Continued)

	Item	Principal Function	Applicable Codes and Reference Standard
14.	Basket Shims	Positioning of Basket in the Containment Cavity	ASTM B221
15.	Impact Limiter Backbone Plate Material	Structural Support of Impact Limiter	ASME Code Section II
16.	Impact Limiter Attachment Rods and Nuts	Structural Support of Impact Limiter	ASME Code Section II
17.	Impact Limiter Crush Material	Impact Energy Absorption	Non-Code (Manufacturer's Catalog and Test Data)
18.	Impact Limiter Fastener Strain Limiter	Protection of Impact Limiter Fasteners Against Excessive Stress/Strain	Non-Code (Manufacturer's Catalog and Test Data)

Notes:

1. Materials for ITS components not listed above shall meet ASME, ASTM, or other standard industrial codes, as approved by Holtec International. Materials for NITS components shall meet standard industrial codes or the manufacturer's product sheets as approved by Holtec International.

Table 2.1.12: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

2.2 MATERIALS

2.2.1 Mechanical Properties and Specifications

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

2.2.1.1 Structural Materials

2.2.1.1.1 Nickel Alloy, Low-Alloy Steel and Stainless Steels

The nickel alloy, low-alloy and stainless steels used to fabricate HI-STAR 80 transport cask containment boundary components are SA-203E, SA-350 LF3, and SA-965 F304/SA-182 F304, respectively. The material properties (used in structural evaluations) of SA-203 E, SA-350 LF3 and SA-965 F304/SA-182 F304 are given in Table 2.2.1.

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

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

2.2.1.1.2 Bolting and Trunnion Materials

Material properties (for structural evaluations) of the closure lid bolting and trunnion materials used in the HI-STAR 80 Package are given in Tables 2.2.2 and 2.2.3.

2.2.1.1.3 Fuel Basket

The Fuel Basket is made of Metamic-HT.

Metamic-HT, a high strength, nanotechnology-based counterpart of the classic Metamic neutron absorber material, is extensively characterized in the supplier’s report [1.2.9]. Minimum guaranteed values (MGVs) of Metamic-HT, based on the supplier’s test report (as adopted by Holtec) [1.2.9] are provided in Table 8.1.5.

2.2.1.1.4 Weld Material

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

All non-destructive examinations specifications will comply with Section V of the ASME Code.

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

2.2.1.1.5 Impact Limiter

The impact limiter for the HI-STAR 80 Package is shown in the drawing package in Section 1.3. The impact limiter consists of a rigid cylindrical core, a cylindrical skirt that girdles the cask forging, the energy absorbing material, an outer skin, and attachment bolts. The energy absorbing material is positioned in the impact limiter to realize adequate crush modulus in all potential impact modes. The external surface of the impact limiter consists of a stainless steel skin to provide long-term protection against weather and inclement environmental conditions. Attachment bolts are also made of stainless steel, which imparts a high fracture toughness and high ductility in the entire temperature range of service.

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

The material properties for the stainless and carbon steels, for structural evaluations, are provided in Tables 2.2.4 and 2.2.5, respectively. Material properties for the stainless steel impact limiter attachment bolts are provided in Table 2.2.6.

Two properties of the energy absorbing material germane to its function are the crush strength and the nominal density. The crush strength is the more important of the two properties; the density is significant in establishing the total weight of the package. A characteristic load-crush relation of the energy absorbing material is shown in Figure 2.2.1 for a constant crush area. The relation shows an initial sharp peak, then an essentially constant force over a large crush depth, followed

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

For the HI-STAR 80 cask, three crush strengths are utilized to optimize the impact limiter's performance. The drawing package in Section 1.3 shows the location of the crush materials for predominately lateral impact (designated as Type 2) and for predominately longitudinal impact (designated as Type 1 and Type 3); Table 2.2.8 documents the impact limiter crush strengths in tabular form. The crush strength, being a critical characteristic, will be specified in the purchase specification for material procurement.

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

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2.2.1.1.6 Closure Lid Seals

The containment integrity of the HI-STAR 80 Package relies on a double closure lid system with elastomeric seals, as shown in the licensing drawings in Section 1.3. The sealing action against the release of the cask's contents is provided by the two concentric seals located in each of the two annular grooves per lid. Each seal acts autonomously, thus providing a double barrier against leakage for each closure lid.

To ensure that the effectiveness of the leak barriers is optimal, the grooves are machined in the precise configuration and surface finish called for the type of elastomeric gasket selected for this application. The gasket chosen for the HI-STAR 80 cask must fulfill the principal requirements set down in the following:

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2.2.1.2 Nonstructural Materials

2.2.1.2.1 Lead Gamma Shielding Material

Lead is not considered as a structural member of the HI-STAR 80 Package. However, it is included in the dynamic simulation models for Normal and Accident Conditions of Transport. Applicable

mechanical properties of lead are provided in Table 2.2.9.

2.2.1.2.2 Holtite Neutron Shielding Material

The non-structural properties of the neutron shielding material are provided in Section 1.2. Holtite B does not serve a structural function in the HI-STAR 80 package.

2.2.1.2.3 Fuel Basket Supports

The fuel basket supports (basket shims and basket anti rotation keys), made of aluminum alloy, provide the heat transfer bridge between the basket and the cask inside surface, and serve to position the fuel basket. Representative mechanical properties for the basket supports are tabulated in Table 2.2.7.

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2.2.1.2.4 Cask Coating

The HI-STAR 80 cask exterior steel surfaces are coated with a conventional surface preservative such as Carboguard® 890 (see www.carboline.com for product data sheet) and/or equivalent surface preservative. Carboguard ® 890 and equivalent surface preservatives have provided years of proven performance on HI-STAR 100 casks. In addition, exterior surfaces of the cask are easily inspected and recoated as necessary. For cask coatings, alternate surface preservatives are determined equivalent per the recommendation of a coating manufacturer and with Holtec approval. Carboguard 890 is the product name at the time of this SAR writing. Chemically identical products with different names are permitted. Other coatings that can be shown to have

had proven performance in similar applications and environments are permitted.

2.2.1.2.5 Cask Liner

A cask liner is required to protect containment boundary steel components against increased corrosion from submersions into the spent fuel pools. The HI-STAR 80 cask cavity and inter-lid space carbon steel surfaces (except for threaded features) may be lined with either a) conventional surface preservative, b) an atomized deposit of a corrosion resistant layer such as aluminum oxide or c) other methods (such as stainless steel weld overlay) according to the drawing package in Section 1.3. Conventional surface preservative over aluminum oxide is also acceptable where supported by manufacturer recommendation.

a) Conventional Surface Preservative

The HI-STAR 80 cask interior steel surfaces may be coated with conventional surface preservatives such as Thermaline® 450 (see www.carboline.com for product data sheet) or equivalent surface preservative. Thermaline® 450 and equivalent surface preservatives have provided years of proven performance on HI-STAR 100 casks. Conventional surface preservatives refer to sprayed/rolled on and cured “paints”. Although interior cask surfaces are not accessible for routine liner repair during loaded cask operation, the dry helium environment protects cask contents and internals, including cask liners from long-term degradation. Conventional surface preservatives shall be applied in accordance with the manufacturer’s recommendation and to the recommended dry film thickness. Conventional surface preservatives shall not result in significant chemical reaction with borated water. Thermaline® 450 is the product name at the time of this SAR writing. Chemically identical products with different names are permitted. The following critical characteristics are specified conservatively for conventional surface preservatives and in order of importance to guide the in the selection of equivalent surface preservatives:

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b) Aluminum Oxide

Aluminum oxide provides excellent corrosion resistance and is compatible with the cask aluminum basket supports. An aluminum oxide veneer provides superior performance and durability over conventional surface preservatives and provides sufficiently high emissivity (as specified in

Chapter 3, Table 3.2.6).

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

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

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

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

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

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

c) Other surface preservation methods.

The cask liner surfaces may be protected using other methods which provide suitable corrosion resistance along with the heat transfer characteristics used in the thermal analysis. These methods include weld overlay, explosive bonding, and lining with a thin corrosion resistant sheet material. Use of these alternate methods is permitted provided that the heat transfer effectiveness of the cask containment boundary with the liner maintains fuel cladding and cask component temperatures within the design limits. The heat transfer effectiveness is maintained provided the minimum emissivity valued for the cask interior surfaces meets or exceeds the value of listed in Table 3.2.6 and the through wall thermal conductivity of the cask is not significantly reduced.

2.2.2 Chemical, Galvanic or Other Reactions

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]. All of these materials have a long history of non-galvanic behavior within close proximity of each other. The external surfaces of the cask are coated to preclude surface oxidation. The internal surfaces of the cask are lined to preclude any significant surface oxidation. The coatings and liners do not chemically react significantly with borated

water. The cask is dried and helium backfilled as discussed in Chapter 7 to eliminate any credible corrosion from moisture and oxidizing gases. [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390
] Therefore, chemical, galvanic or other reactions involving the cask materials are unlikely and are not expected.

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In accordance with NRC Bulletin 96-04 [2.2.4], a review of the potential for chemical, galvanic, or other reactions among the materials of the HI-STAR 80 Package, its contents and the operating environment, which may produce adverse reactions, has been performed. As a result of this review, no operations were identified which could produce adverse reactions. No closure welding is performed and thus hydrogen generation while the cask is in the pool is of minor consequence to cask operations based on previous experience with the same cask materials. Because no welding activities are involved in the cask closure operations, the potential of a hydrogen ignition event does not exist.

2.2.3 Effects of Radiation on Materials

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

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

• High Temperature Creep Rate (During Irradiation)	

The HI-STAR 80 Package is composed of materials that either have a proven history of use in the nuclear industry or have been extensively tested. The radiation levels from spent nuclear fuel do not affect the packaging materials. Gamma radiation damage to metals (e.g., aluminum, stainless steel, and carbon steel) does not occur until the fluence level reaches 10^{18} rads or more. The 50-year gamma fluence (assuming design basis fuel for 50 years without radioactive decay) from the spent nuclear fuel transported in the HI-STAR 80 Package is on the order of 1.25×10^9 rads and reduces significantly as it penetrates through cask components. Moreover, significant radiation damage due to neutron exposure does not occur for neutron fluences below approximately 10^{19} n/cm^2 [2.2.3, 2.2.4, 2.2.5], which is far greater than the 50-year neutron fluence from spent nuclear fuel transported in the HI-STAR 80 Package, which is on the order of 1.25×10^{16} n/cm^2 assuming design basis fuel for 50 years without radioactive decay. Also, as indicated in reference [2.2.3], "The effects listed in the table above are generally less significant at elevated temperatures for a given fluence and some defects can be removed by heating (annealing)."

As discussed in Section 1.2 and its references, the Metamic-HT neutron absorber and Holtite have been tested extensively to prove that it will not degrade over the service life of the package.

Table 2.2.1a: Mechanical Properties of SA-350 LF3/SA-203 E

Temperature °C (°F)	**SA-350 LF3/SA-203 E for Cask Containment Boundary**					
	S_y	**S_u**	**E**	**α**	**S_y**	**S_u**
-73.30 (-100)	258.6 (37.5)	482.6 (70.0)	19.72 (28.6)	-	275.8 (40.0)	482.6 (70.0)
37.78 (100)	258.6 (37.5)	482.6 (70.0)	19.03 (27.6)	11.7 (6.5)	275.8 (40.0)	482.6 (70.0)
93.33 (200)	235.8 (34.3)	482.6 (70.0)	18.68 (27.1)	12.06 (6.7)	252.3 (36.6)	482.6 (70.0)
148.89 (300)	228.9 (33.2)	482.6 (70.0)	18.41 (26.7)	12.42 (6.9)	244.1 (35.4)	482.6 (70.0)
204.4 (400)	220.6 (32.0)	482.6 (70.0)	18.07 (26.2)	12.78 (7.1)	235.8 (34.2)	482.6 (70.0)
260 (500)	209.6 (30.4)	482.6 (70.0)	17.72 (25.7)	13.14 (7.3)	224.1 (32.5)	482.6 (70.0)
316 (600)	194.4 (28.2)	482.6 (70.0)	17.31 (25.1)	13.32 (7.4)	207.5 (30.0)	482.6 (70.0)

Definitions:

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

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

Table 2.2.1b: Mechanical Properties of SA-965 F304/SA-182 F304

Temperature ºC (ºF)	SA-965 F304/SA-182 F304 for Cask Forgings				
	S_y	S_u (SA-965 F304)	S_u (SA-182 F304)	E	α
-73.30 (-100)	206.8 (30.0)	482.6 (70.0)	517.1 (75.0)	20.13 (29.2)	-
37.78 (100)	206.8 (30.0)	482.6 (70.0)	517.1 (75.0)	19.51 (28.3)	15.48 (8.6)
93.33 (200)	172.4 (25.0)	457.1 (66.3)	489.5 (71.0)	18.96 (27.5)	16.02 (8.9)
148.89 (300)	154.4 (22.4)	426.1 (61.8)	456.4 (66.2)	18.62 (27.0)	16.56 (9.2)
204.4 (400)	142.7 (20.7)	411.6 (59.7)	441.3 (64.0)	18.20 (26.4)	17.1 (9.5)
260 (500)	133.8 (19.4)	408.2 (59.2)	437.1 (63.4)	17.86 (25.9)	17.46 (9.7)
316 (600)	126.9 (18.4)	408.2 (59.2)	437.1 (63.4)	17.44 (25.3)	17.82 (9.9)

Definitions:

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

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

Table 2.2.1c: Mechanical Properties of SA-182 FXM-19

Temperature ºC (ºF)	**SA-182 FXM-19 for Inner Lid Retainer Ring**			
	S_y	S_u	**E**	α
-73.30 (-100)	379.2 (55.0)	689.5 (100.0)	20.13 (29.2)	-
37.78 (100)	379.2 (55.0)	689.5 (100.0)	19.51 (28.3)	14.76 (8.2)
93.33 (200)	324.8 (47.1)	482.6 (99.4)	18.96 (27.5)	15.30 (8.5)
148.89 (300)	298.6 (43.3)	457.1 (94.2)	18.62 (27.0)	15.66 (8.7)
204.4 (400)	280.6 (40.7)	426.1 (91.1)	18.20 (26.4)	16.02 (8.9)
260 (500)	267.5 (38.8)	411.6 (89.1)	17.86 (25.9)	16.38 (9.1)
316 (600)	257.9 (37.4)	408.2 (87.7)	17.44 (25.3)	16.56 (9.2)

Definitions:

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

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

Table 2.2.2a: Mechanical Properties of SA-193 Grade B7

SA-193 Grade B7 [less than 64 mm (2.5 in) diameter] for Containment Boundary Port Cover Bolts				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	724.0 (105.0)	861.8 (125.00)	20.3 (29.5)	11.7 (6.5)
93.3 (200)	675.9 (98.0)	861.8 (125.00)	19.99 (29.0)	12.06 (6.7)
149 (300)	648.8 (94.1)	861.8 (125.00)	19.65 (28.5)	12.42 (6.9)
204 (400)	630.9 (91.5)	861.8 (125.00)	19.31 (28.0)	12.78 (7.1)
260 (500)	610.2(88.5)	861.8 (125.00)	18.89 (27.4)	13.14 (7.3)
316 (600)	588.1 (85.3)	861.8 (125.00)	18.55 (26.9)	13.32 (7.4)
371 (700)	555.72 (80.6)	824.6 (119.6)	18.06 (26.2)	13.68 (7.6)

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6] for ferrous materials.
2. Source for S_u values is Table U of [2.1.6] for ferrous materials, or from Section II, Part A. Where ultimate strength is unavailable, values above 300 deg. F are based on 100 deg.F value multiplied by ratio of yield strength at room temperature to yield strength at desired temperature.
3. Source for α values is Tables TE-1 and TE-4 of [2.1.6] for ferrous materials.

Table 2.2.2b: Mechanical Properties of SA-564 630 H1100 and SB-637

SA-564 630 (H1100 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	792.9 (115)	965.3 (140)	19.8 (28.68)	11.16 (6.2)
93.3 (200)	732.9 (106.3)	965.3 (140)	19.1 (27.8)	11.34 (6.3)
149 (300)	701.9 (101.8)	965.3 (140)	18.8 (27.2)	11.52 (6.4)
204 (400)	677.8 (98.3)	938.4 (136.1)	18.4 (26.7)	11.70 (6.5)
260 (500)	656.4 (95.2)	919.8 (133.4)	18. (26.1)	11.70 (6.5)
288 (550)	647.8 (93.95)	912.9 (132.4)	17.8 (25.8)	11.88 (6.6)
SB-637 N07718 (less than or equal to 6 inches diameter)				
38 (100)	1034 (150.0)	1276 (185.0)	19.83 (28.76)	12.9 (7.1)
93.3 (200)	992.8 (144.0)	1225 (177.6)	19.51 (28.3)	13.0 (7.2)
149 (300)	970.1 (140.7)	1196 (173.5)	19.24 (27.9)	13.2 (7.3)
204 (400)	953.5 (138.3)	1176 (170.6)	18.96 (27.5)	13.4 (7.5)
260 (500)	943.2 (136.8)	1163 (168.7)	18.75 (27.2)	13.6 (7.6)
316 (600)	932.9 (135.3)	1151 (166.9)	18.48 (26.8)	13.9 (7.7)

Definitions:

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

Notes:

1. Source for S_y values is ratioing design stress intensity values and Table Y-1 of [2.1.6], as applicable.
2. Source for S_u values is ratioing design stress intensity values and Table U of [2.1.6], as applicable.
3. Source for E values is Tables TM-1 and TM-4 of [2.1.6], as applicable.
4. Source for α values is Table TE-1 of [2.1.6] for ferrous materials. Values for α are for H1075 condition in lieu of H1100 condition.

Table 2.2.3: Mechanical Properties of SA-564 630

SA-564 630 for Trunnions† (H1100 Condition)				
Temperature, ºC (ºF)	S_y	S_u	E	α
38 (100)	792.9 (115)	965.3 (140)	19.8 (28.68)	11.16 (6.2)
93.3 (200)	732.9 (106.3)	965.3 (140)	19.1 (27.8)	11.34 (6.3)
149 (300)	701.9 (101.8)	965.3 (140)	18.8 (27.2)	11.52 (6.4)
204 (400)	677.8 (98.3)	938.4 (136.1)	18.4 (26.7)	11.70 (6.5)
260 (500)	656.4 (95.2)	919.8 (133.4)	18. (26.1)	11.70 (6.5)
288 (550)	647.8 (93.95)	912.9 (132.4)	17.8 (25.8)	11.88 (6.6)
† Material SB-637 N07718 is also a candidate trunnion material, which if used, must instead satisfy the strength requirement specified in Table 2.1.12.				

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6] for ferrous materials.
2. Source for S_u values is Table U of [2.1.6] for ferrous materials.
3. Source for α values is Table TE-1 of [2.1.6] for ferrous materials. Values for α are for H1075 condition in lieu of H1100 condition.

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

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

Definitions:

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

Notes:

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

Table 2.2.5: Miscellaneous Materials – Mechanical Properties

Temperature ºC (ºF)	SB 209-6061-T6/T62/T651			
	S_y	S_u	α	E
37,8 (100)	241.3 (35.0)	289.6 (42.0)	22.32 (12.4)	6.90 (10.0)
93,3 (200)	232.4 (33.7)	270.3 (39.2)	23.4 (13.0)	6.62 (9.6)
149 (300)	188.9 (27.4)	244.8 (35.5)	23.94 (13.3)	6.34 (9.2)
260 (350)	137.9 (20.0)	193.0 (28)	24.12 (13.4)	6.17 (8.95)
204 (400)	91.7 (13.3)	141.3 (20.5)	24.48 (13.6)	6.00 (8.7)

Table 2.2.5 (Continued): Miscellaneous Materials – Mechanical Properties

Temperature °C (°F)	SA-516 Grade 70 or A516 Gr 70			
	S_y	S_u	α	E
38 (100)	262.0 (38.0)	482.6 (70.0)	11.7 (6.5)	20.17 (29.26)
93.3 (200)	239.9 (34.8)	482.6 (70.0)	12.06 (6.7)	19.86 (28.8)
149 (300)	231.7 (33.6)	482.6 (70.0)	12.42 (6.9)	19.51 (28.3)
204 (400)	224.1 (32.5)	482.6 (70.0)	12.78 (7.1)	19.24 (27.9)
260 (500)	213.7 (31.0)	482.6 (70.0)	13.14 (7.3)	18.82 (27.3)
316 (600)	200.6 (29.1)	482.6 (70.0)	13.32 (7.4)	18.27 (26.5)
371 (700)	187.5 (27.2)	482.6 (70.0)	14.04 (7.8)	17.58 (25.5)

Definitions:

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

Notes:

1. Source for S_y values is Table Y-1 of [2.1.6].
2. Source for S_u values is Table U of [2.1.6] and additionally by scaling the room temperature values using the data from [2.2.7] for SB-209-6061 materials.
3. Source for α values is material group 1 in Table TE-1 or TE-2 of [2.1.6].
4. Source for E values is "Carbon steels with C less than or equal to 0.30%" in Table TM-1 of [2.1.6] or Table TM-2 for SB-209-6061 materials.

Table 2.2.6: Yield and Ultimate Strength of Impact Limiter Attachment Bolts

SA-193 B8S Classes 1C and 1D		
Temp. ºC (ºF)	**S_y**	**S_u**
Room Temperature	345 (50.0)	655 (95.0)
204.4 (400)	255.1 (37)	596.7 (86.545)

Definitions:

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

Notes:

1. Source for S_y and S_u values at room temperature is Table 3 of [2.1.6].
2. Since the SA 193-B8S bolt material properties are not listed at the elevated temperatures, the elevated temperature strength properties for SA 193-B8S bolt are derived by proportioning the strength properties of SA 193-B8RA Class 1 bolt material at elevated temperature to the room temperature. The two bolting materials share similar chemical compositions.

Table 2.2.7: Basket Shims – Nominal Mechanical Properties

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

Definitions:

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

Notes:

1. Source for E values is "Properties of Aluminum Alloys", page 82 [2.2.7].
2. Source for the S_y, S_u, and % Elongation values at room temperature is ASTM Specification B221M [2.2.9]. Strength values at elevated temperatures are factored lower-bound values corresponding to 10,000 hours at temperature from [2.2.7]. The strength reduction factor is taken as the ratio of the strength value at room temperature from [2.2.9] to the typical strength value at room temperature from [2.2.7]. Elongation values at elevated temperatures are obtained in the same manner.
3. Source for α is Table TE-2 of [2.1.6] (values listed in TE-2 are also considered representative of Aluminum Alloy (2219-T8511) (UNS No. A92219)).

Table 2.2.8: Critical Characteristics of the Impact Limiter Crush Material, and Fastener Strain Limiters

Item & Property Category	Value	Comment
Crush strength (nominal), σ_c, of crush material, psi (Primary property) • Type 1 • Type 2 • Type 3	(Target volumetric average value) See table 8.1.11	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
Density (reference) of crush material, lb/ft^3 (kg/m^3) (Secondary property) • Type 1 • Type 2 • Type 3	22.08 (353.7) 27.37 (438.4) 8.66 (138.7)	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]
[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]	[PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 2.2.9: Mechanical Properties of Lead

LEAD:	-40°C (-40°F)	-29°C (-20°F)	21°C (70°F)	93°C (200°F)	149°C (300°F)	193°C (380°F)	316°C (600°F)
Yield Strength, MPa (psi)	4.83 (700)	4.69 (680)	4.41 (640)	3.38 (490)	2.62 (380)	1.31 (190)	0.138 (20)
Modulus of Elasticity, MPa (ksi)	1.65E+4 (2.4E+3)	1.65E+4 (2.4E+3)	1.59E+4 (2.3E+3)	1.38E+4 (2.0E+3)	1.31E+4 (1.9E+3)	1.255E+4 (1.82E+3)	1.03E+4 (1.5E+3)
Tangent Modulus MPa (psi)	N/A	N/A	N/A	N/A	N/A	11.514 (1,670)	N/A
Coefficient of Thermal Expansion, 1/°C (1/°F)	28.1E-6 (15.6E-6)	28.3E-6 (15.7E-6)	29.0E-6 (16.1E-6)	29.9E-6 (16.6E-6)	31.0E-6 (17.2E-6)	N/A	36.4E-6 (20.2E-6)
Poisson's Ratio		0.40					
Density, kg/m^3 (lb/cubic ft.)		11,340 (708)					

Note: Mechanical properties of lead at 193 °C are taken from [2.2.10]. The values at other temperatures are taken from various references: References [2.2.6] and [2.2.11] provide the yield strength data for lead; the modulus of elasticity of lead can be found from Reference [2.2.12]; and the Poisson's ratio and density data for lead are documented in Reference [2.2.13].

Table 2.2.10: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 2.2.11: Structural Capacity Data on the Quiver

Item	Data	Comment
Total weight	232 kg (BWR) 449 kg (PWR)	Weight is less than a normal fuel assembly
Normal handling	Withstand all handling with Quiver max loaded	
Free drop event under normal condition of transport [§71.71]	Withstand 30 cm drop in all directions without leaking	No loss of radiological confinement capability
Accident condition of transport [§71.73]	Free drop from 9 meters on to an essentially rigid surface	The maximum axial and lateral decelerations sustained by the Quiver under the most adverse drop configuration shall be less than 210g (BWR)/217g (PWR) and 410g (BWR)/449g (PWR), respectively per [1.2.20]
Design Pressure	500 kPa (5 bar) at 300 ˚C	

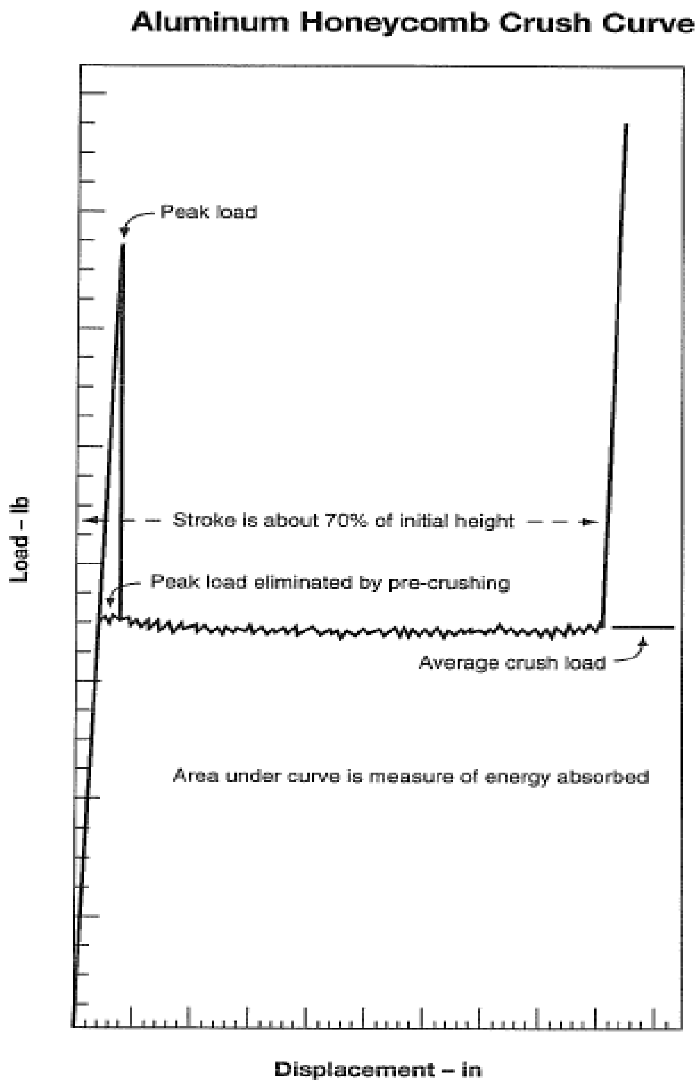

Figure 2.2.1: Aluminum Honeycomb Load vs. Crush Curve (Typical, reproduced from Ref. [2.2.1])

2.3 FABRICATION AND EXAMINATIONS

2.3.1 Fabrication

Consideration of the manufacturing process of a cask must be an integral part of its design evolution to ensure that the as-engineered cask can be manufactured to meet the intents of the design. For HI-STAR 80, as in all other cask models, Holtec International utilizes the following key criteria during the design stage to ensure that design objectives will be realized during manufacturing:

i. The tolerances specified for the sub-components are achievable with state-of-the-art equipment and machinery.

ii. The design is not overly reliant on tight tolerances to ensure functional compliance.

iii. Suitable (compatible) material combinations are specified whenever two dissimilar materials are to be welded.

iv. Post-weld heat treatment and other means to alleviate weld shrinkage stresses are specified, as appropriate, to enhance the quality of the hardware and to comply with the applicable ASME Code.

v. The manufacturing sequence must permit all required non-destructive examinations to be performed and remedial repairs to be made to ensure compliance with the applicable codes and standards. This requirement is particularly relevant to the Containment Boundary in which the butt-welded joints must undergo 100% volumetric examination.

vi. The manufacturing sequence must permit machining of critical surfaces, such as the gasket seating surfaces in the top flange, to be carried out after all welding and forming related operations (that inevitably produce distortion) have been completed.

vii. The manufacturing steps do not involve operations that entail unnecessary risk to worker safety.

The above objectives are fully realized in the manufacturing process envisioned for HI-STAR 80. Of course, there are several candidate manufacturing sequences that will meet the above criteria. In the following, an overview of one such acceptable fabrication sequence for the HI-STAR 80 is presented to illustrate its fabricability while meeting the above objectives. Other sequences may be used provided they meet the above criteria for quality fabrication

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2.3.2 Examinations

The design, material procurement, fabrication, and inspection of the HI-STAR 80 are performed in accordance with applicable codes and standards. The following fabrication controls and required inspections shall be performed on the HI-STAR 80 in order to assure compliance with the SAR and the Certificate of Compliance.

1. Materials of construction specified for the HI-STAR 80 are identified in the drawings. Important-to-safety (ITS) materials shall be procured with certification and supporting documentation as required by ASME Code, Section II (when applicable); the applicable subsection of ASME Code Section III (when applicable); and Holtec procurement specifications. Materials and components shall be receipt inspected for visual and dimensional acceptability, material conformance to specification requirements, and traceability markings, as applicable. Material traceability is maintained throughout fabrication for ITS items through a computerized process that has been implemented by Holtec International in the manufacture of all safety-significant components.

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

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

4. The HI-STAR 80 containment boundary shall be examined and tested by a combination of methods (including helium leak test, pressure test, VT, RT, UT, MT and/or PT, as applicable) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging. All Category A and B welds are subject to 100% volumetric examination per Subsection NB of the ASME Code.

5. Grinding and machining operations of the HI-STAR 80 containment boundary shall be controlled through written and approved procedures and quality assurance oversight to ensure that material removal operations do not reduce base metal wall thicknesses of the boundaries beyond that allowed by the design. The thicknesses of base metals shall be ultrasonically tested, as necessary, in accordance with written and approved procedures to verify base metal thickness meets design requirements.

6. Dimensional inspections of the HI-STAR 80 shall be performed in accordance with written and approved procedures in order to verify compliance to design drawings and fit-up of individual components. All inspections of critical dimensions and functional fit-up tests shall be documented.

7. Lifting trunnions are provided for lifting and handling of the HI-STAR 80. The trunnions are designed, inspected, and tested following guidance of NUREG-0612 and 10CFR71.45(a). A carefully engineered design to eliminate local stress risers in the highly-stressed regions of the trunnion during lift operations and excellent stress margins ensure that the lifting trunnions will work reliably. Further, pursuant to the defense-in-depth approach of NUREG-0612, acceptance criteria for the lifting trunnions have been established in conjunction with other considerations applicable to heavy load handling.

   In order to ensure that the lifting trunnions do not have any hidden material flaws, the lifting trunnions shall be tested at 300% of the maximum design (service) lifting load. The load shall be applied for a minimum of 10 minutes to the pair of lifting trunnions. The accessible parts of the trunnions (areas outside the HI-STAR cask), and the local HI-STAR 80 cask areas shall then be visually examined to verify no deformation, distortion, or cracking has occurred. Testing shall be performed in accordance with written and approved procedures.

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

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

9. The majority of materials used in the HI-STAR 80 cask body are ferritic steels. ASME Code Section III and Regulatory Guides 7.11 and 7.12 require that certain materials be tested in order to assure that these materials are not subject to brittle fracture failures.

Drop weight testing and Charpy impact testing of each plate and forging for the HI-STAR 80 containment boundary are carried out in accordance with Table 8.1.8. Weld material used in welding the containment boundary is also tested as specified in Table 8.1.8.

Non-containment portions of the HI-STAR 80, as required, shall be impact tested in accordance with Table 8.1.9. Test results shall be documented and shall become part of the final quality documentation record package.

10. A containment boundary leakage test of the welded structure shall be performed at any time after the containment boundary fabrication is complete. Preferably, this test should be performed at the completion of fabrication. The leakage test instrumentation shall have a minimum test sensitivity of one half of the leak test rate. Containment boundary welds shall have indicated leakage rates not exceeding leak test acceptance criteria. At the completion of fabrication, the helium leakage through all containment boundary penetrations shall be demonstrated to not exceed the leakage rate acceptance criteria provided in Chapter 8.

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

12. The HI-STAR 80 shall be inspected for cleanliness and proper preparation for shipping in accordance with written and approved procedures.

13. A completed quality documentation record package shall be prepared and maintained during fabrication of each HI-STAR 80 to include detailed records and evidence that the required inspections and tests have been performed for important to safety items. The quality document record package shall be reviewed to verify that the HI-STAR 80 has been fabricated and inspected in accordance with the governing Certificate-of-Compliance.

14. Metamic-HT welding and welder qualifications, requirements, and examinations will be in accordance with Paragraph 1.2.1.6, Subsection 8.1.2, and the drawing package in Section 1.3.

Figure 2.3.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.3: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.4: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.5: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.6: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.7: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.8: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.3.9: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

2.4 GENERAL REQUIREMENTS

The compliance of the HI-STAR 80 Packaging to the general standards for all packaging, specified in 10CFR71.43, is demonstrated in the following subsections.

2.4.1 Minimum Package Size

As can be seen from the external dimensions of the packaging, in Section 1.3, the HI-STAR 80 Packaging meets the requirements of 10CFR71.43(a).

2.4.2 Tamper-Indicating Feature

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

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

2.4.3 Positive Closure

There are no quick-connect/disconnect valves in the containment boundary of the HI-STAR 80 Packaging. [

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2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Lifting Attachments

Per Reg. Guide 7.9, this subsection presents analyses for all lifting operations applicable to the transport of a HI-STAR 80 package to demonstrate compliance with requirements of paragraph 71.45(a) of 10CFR71.

The HI-STAR 80 Package has the following types of lifting attachments: four lifting trunnions located on the cask top flange and threaded holes on each closure lid that serve as attachment locations to lift the cask closure lids. For the purposes of this discussion, it is assumed that either pair of two top opposing trunnions may be used to lift the entire loaded cask; however, if both pairs are engaged for lifting, then the second pair of trunnions may be designed as redundant lifting trunnions (See SAR Paragraph 8.1.3.1 for trunnion testing requirements). The drawing package in Section 1.3 shows the location of the lifting trunnions.

The evaluation of the adequacy of the lifting attachments entails careful consideration of the applied loading and associated stress limits. The load combination D+H, where H is the "handling load", is the generic case for all lifting adequacy assessments. The term D denotes the dead load. Quite obviously, D must be taken as the bounding value of the dead load of the component being lifted. Table 2.1.9 provides package component weights. In all lifting analyses considered in this document, the handling load H is assumed to be equal to 0.15D. In other words, the inertia amplifier during the lifting operation is assumed to be equal to 0.15g. This value is consistent with the guidelines of the Crane Manufacturer's Association of America (CMAA), Specification No. 70, 1988 [2.5.5], Section 3.3, which stipulates a dynamic factor equal to 0.15 for slowly executed lifts. Thus, the "apparent dead load" of the component for stress analysis purposes is $D^* = 1.15D$. Unless otherwise stated, all lifting analyses in this chapter use the "apparent dead load", D^*, in the lifting analysis.

For use as part of a transportation package, the lifting attachments that are a part of the HI-STAR 80 package are designed to meet the requirements of 10CFR71.45(a) and NUREG-1617 [2.1.11]. Accordingly, the lifting attachments are required to maintain a safety factor of 3 based on trunnion material yield strength. The lifting attachments that are part of the HI-STAR 80 package are also required to meet the design provisions of NUREG-0612 [2.1.5], which specify safety factor of 10 on ultimate strength to ensure safe handling of heavy loads in critical regions within nuclear power plants. Hence the lifting attachments are analyzed to meet a minimum safety factor of 3 based on material yield strength and a safety factor of 10 based on material ultimate strength.

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

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

2.5.1.1 Cask Trunnion Analysis

The lifting trunnion for the HI-STAR 80 cask is presented in the drawing package provided in Section 1.3. The four top lifting trunnions for HI-STAR 80 are circumferentially spaced at 90 degrees, however, only two top trunnions circumferentially spaced 180 degrees apart shall be engaged at any instant of time to perform the lifting operations. The trunnions are designed for a two-point lift and are sized to satisfy the aforementioned NUREG-0612 criteria. The trunnion material is identified in the drawing package shown in Section 1.3. There are also two bottom trunnions at the base of the cask. The bottom trunnions may be used as rotation supports when changing package orientation from vertical to horizontal (or vice- versa). In this case, the bottom trunnions may support 100% of the load but they are not acting as lifting trunnions so the requirements of a safety factor of 3 on yield strength need not be satisfied.

The embedded top lifting trunnion is analyzed as a cantilever beam subjected to a line load applied at the outer edge of the trunnion (see Figure 2.5.1). This assumption is clearly very conservative because the moment arm of the load has been maximized. In reality the loading is distributed over the exposed surface of the trunnion with the resultant acting closer to the root of the cantilever than the mid-span location. A Strength of Materials methodology (classical beam theory) is used to represent the trunnion as a cantilever beam with a solid circular cross section. The bending moment and shear force at the root of the trunnion cantilever are compared against allowable values based on either yield or ultimate strength. Calculations demonstrate (Holtec Proprietary Report [2.1.12]) that the stresses in the top lifting trunnions, computed in the manner of the foregoing, comply with requirements of paragraph 71.45(a) of 10CFR71, and NUREG-0612 strength limits. Key results are presented in Table 2.5.1A where it is shown that all safety factors meet the requirements for the trunnions per 10CFR71.45(a) and NUREG-0612.

As discussed previously, the bottom trunnion during an upending/downending operation experiences a load up to 100% of the cask weight. The bottom trunnion is similar to the top trunnion in terms of load bearing capacity and is not required to the meet the very stringent stress limits in NUREG-0612 and 10CFR71.45(a). Therefore, the structural evaluation of the bottom trunnion for the topending/downending operation scenario is enveloped by the top lifting trunnion analysis discussed above. Key results for the bottom trunnions are presented in Table 2.5.1B.

2.5.1.2 Cask Closure Lids and Baseplate During Lifting

2.5.1.2.1 Closure Lid Lifting Holes

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

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

2.5.1.2.2 Baseplate

During lifting of a loaded HI-STAR 80 the containment lower forging is subject to amplified dead load, D* from the spent fuel, from the fuel basket, from the fuel basket supports, from the self-weight of the baseplate and any attached shielding, and from internal pressure. Note that the internal pressure loading bounds the weight of the water inside the cask, which acts during cask lifting from the loading pool, effective on the baseplate when the lifting operation is performed. To analyze this condition, the baseplate and a portion of the containment shell is modeled using the ANSYS finite element code [2.5.2] and a static analysis performed. The lid is included in the model, and the bolted connection is simulated by merged nodes (common nodes) at the lid to shell interface. The load case applies the loads from the fuel, the fuel basket, the fuel basket supports and the self-weight to the baseplate. Maximum normal operating pressure (MNOP) load is also applied normal to the inner surface of the containment boundary (viz. the baseplate, the containment shell and the primary lid). In this load case, the 15% amplifier is applied to the lifted load. The fuel load is modeled as a uniform pressure on the baseplate, and the fuel basket and fuel basket supports are modeled as pressure loadings on an annulus adjacent to the outer edge of the baseplate. For simplicity and conservatism, the loading condition during the lifting of a loaded HI-STAR 80 is included in the evaluation of Load Combination N1, which effectively bounds both design and Level A service load conditions in terms of structural demand to the HI-STAR 80 containment boundary. Figure 2.6.3 shows the ANSYS model and the applied load, along with the distribution of temperature on the containment boundary.

Details of the evaluation and locations of maximum stress intensity are provided in the calculation package [2.1.12]. The calculation package contains additional plots of the stress distribution in the containment shell and baseplate. The results of the bounding ANSYS analysis that includes the loading of the top-end lift are summarized in Table 2.6.5, where the minimum safety factors for components in the load path are computed using the ASME Design and Level A allowable stress intensities from Table 2.1.2.

2.5.1.3 Failure of Lifting Attachments

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 80 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 HI-STAR 80 package for transport in the U.S.. All tie-down devices (saddle, tie-down straps, and book ends), as illustrated in Figure 1.3.1, are part of the transport conveyance and accordingly are not designed in this SAR. For

transport outside the U.S. by road and sea, however, the bottom trunnions may be utilized as a tie-down device as shown in Figure 1.3.2. For the latter case, a detailed structural evaluation has been performed for the bottom trunnion to ensure that the relevant IAEA regulation [2.5.6] for tie-down device are satisfied and the results are documented in Reference [2.1.12] and summarized in Table 2.5.1B.

The cask transport frame that supports and secures the cask during the cask transportation is not part of the HI-STAR 80 package. The loads used to design these components may be determined using the load amplifiers given by the American Association of Railroads (AAR) Field Manual, Rule 88 [2.5.4] or other appropriate standard.

2.5.3 Safety Evaluation of Lifting Attachments and Tie-Down Devices

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

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

Table 2.5.1A: Key Safety Factors of HI-STAR 80 Top Trunnions

Item	Calculated Value	Safety Factor
Bending stress (Comparison with Yield Strength in Tension) - ksi (MPa)	12.217 (84.239)	2.68
Shear stress (Comparison with Yield Strength in Shear) - ksi (MPa)	5.837 (40.246)	3.37
Bearing Stress on Top Forging during Load Testing (3 Times Lifting Weight) - ksi (MPa)	24.457 (168.625)	1.23
Bending Moment (Comparison with Ultimate Moment) - kip-in (MN-m)	4,890 (0.552)	1.37
Shear Force (Comparison with Ultimate Shear Force) - kip (MN)	125.0 (0.556)	2.30

Notes:

As noted previously, safety factor in this table represents the margin above the mandated value of 3 on yield strength per 10CFR71.45(a) and 10 on ultimate strength per NUREG-0612.

Governing transport package weight from Table 2.1.9 plus the weight of the water (while lifting from the spent fuel pool) is considered in this evaluation.

Table 2.5.1B: Key Safety Factors of HI-STAR 80 Bottom Trunnions When Used As a Tie-Down Device for Transportation outside the US by Road and Sea in the Configuration As Shown in Figure 1.3.2

Item	Calculated Stress, ksi(MPa)	Allowable Stress, ksi (MPa)	Safety Factor
Bearing Stress	19.527 (134.63)	20.7 (140.72) (based on yield strengths of trunnion and bottom forging materials)	1.06
Maximum Bending Stress	50.257 (346.51)	98.3 (677.76) (based on trunnion material yield strength)	1.96
Maximum Shear Stress	21.775 (150.13)	58.98 (406.65) (based on 60% of trunnion material yield strength)	2.71

Table 2.5.2: Key Safety Factors for HI-STAR 80 Closure Lid Lifting Holes

Item	Value, kg (lb.)	Capacity, kg (lb.)	Minimum Safety Factor
Inner Closure Lid Direct Load	6.26×10^3 (1.38×10^4)	2.517×10^4 (5.55×10^4)	4.02
Outer Closure Lid Direct Load	2.191×10^3 (4.83×10^3)	3.869×10^3 (8.529×10^4)	1.766

Notes:

Safety factor in this table represents the margin above the mandated value of 3 on yield strength and 10 on ultimate strength per 10CFR71.45(a) and NUREG-0612 [2.1.5].

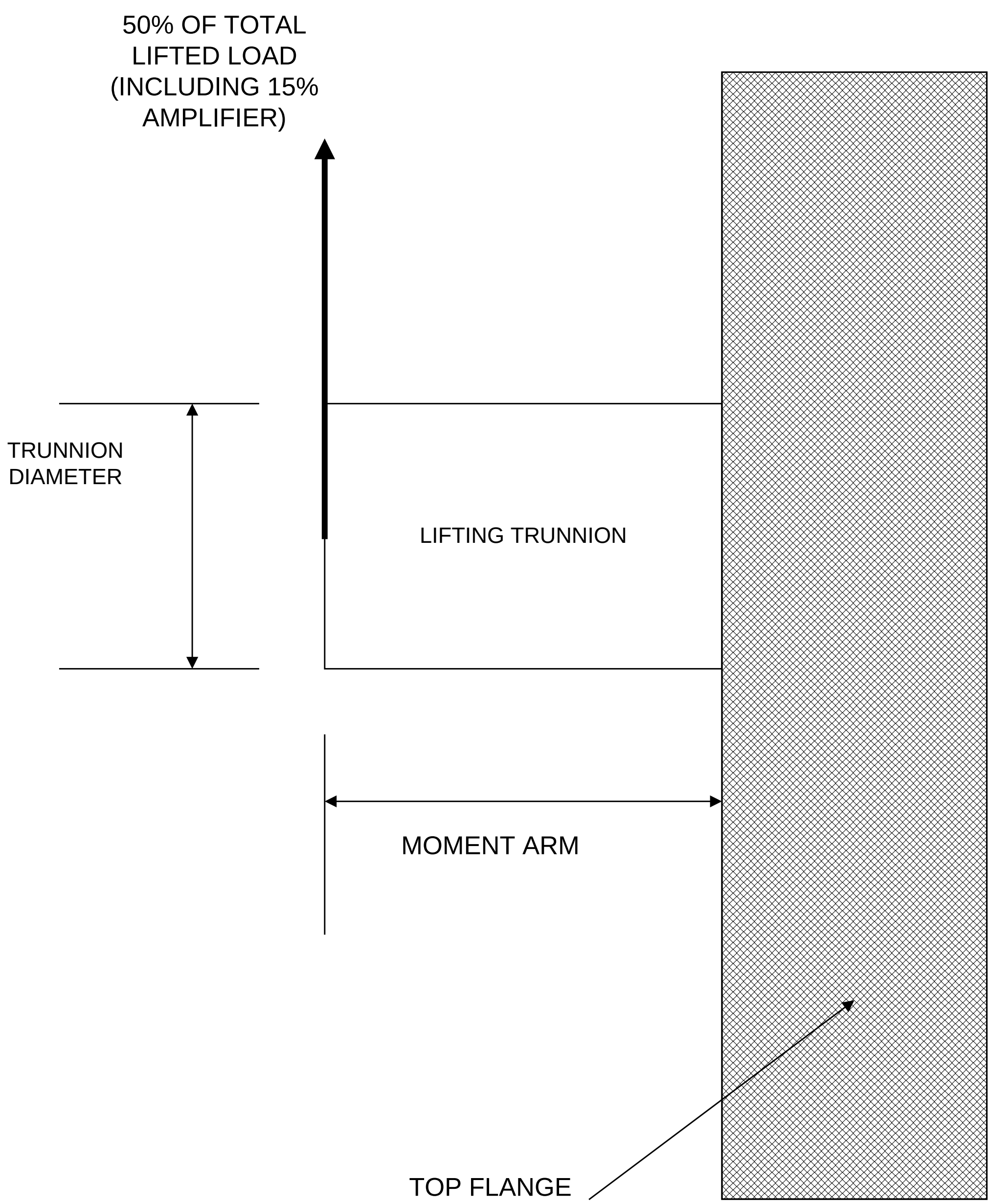

Figure 2.5.1: Top Lifting Trunnion with Applied Force

2.6 NORMAL CONDITIONS OF TRANSPORT

In this section, the HI-STAR 80 package, consisting of the cask and the AL-STAR impact limiter, when subjected to the normal conditions of transport specified in 10CFR71.71, is shown to meet the design criteria in Section 2.1 (which are derived from the stipulations in 10CFR71.43 and 10CFR71.51). The vehicle utilized for the stress/deformation analysis is a comprehensive 3-D finite element simulation of the package on Q.A.-validated codes (see Appendix 2.A). 3-D finite element models of the cask, the fuel basket, and the two impact limiters have been prepared and assembled into a complete system to evaluate all of the Normal and Accident Conditions of Transport that involve an impact event. The stress analysis of the cask containment boundary is carried out using a 3-D finite element model or a simplified plate-and-shell theory solution, as appropriate. The stress intensity limits applicable to the containment boundary, as summarized below, are the central focus of the required qualifications.

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

ii. The containment boundary must also meet the same Level A stress intensity limits when subject to a 0.3-meter (1 ft) side drop with impact limiters in place. For this dynamic analysis, the entire package is modeled and a comprehensive 3-D finite element simulation of the package drop performed using a public domain, QA validated computer code (Appendix 2.A). For this purpose, 3-D finite element models of the cask, the fuel basket, the fuel basket supports, and the two AL-STAR impact limiters have been prepared.

As discussed in Appendix 2.B of HI-STAR 180 SAR [1.0.4], the AL-STAR impact limiter was subjected to a series of "9-meter drop tests" on quarter-scale models during the licensing of HI-STAR 100 in the late 90's. The scale model was of the type A-4 in the parlance of Reference [2.7.11]. The quarter-scale drop test results were correlated with a classical contact mechanics-based simulation model to predict the HI-STAR 100 Package's response under *any* drop orientation [2.2.2, 2.7.9]. The test data and the analytical correlation model provided the basis of NRC's transport certification of the HI-STAR 100 package in the late 90s (Docket # 71-9261).

The scale model test data from the H-STAR 100 certification effort has been used to develop an LS-DYNA-based dynamic simulation model to prognosticate the response of the AL-STAR impact limiter. As discussed in Appendix 2.B of [1.0.4], the LS-DYNA model simulates the scale model crush tests with acceptable accuracy. Because of the benchmarked LS-DYNA model, it has been possible to simulate a far greater number of drop scenarios than could be done by physical testing. Equally important, the LS-DYNA solution provides insights into the crush phenomena, such as margin to failure, which was only crudely inferable from scale model physical tests.

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

2.6.1 Heat

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

The thermal evaluation of the HI-STAR 80 package is reported in Chapter 3, wherein the material temperatures that are needed for the structural evaluations are discussed.

2.6.1.1 Summary of Pressures and Temperatures

Tables 2.1.1 and 2.6.2 summarize values for pressure and temperatures (based on the thermal analysis in Chapter 3) that are used as inputs, as necessary, for the analyses undertaken to structurally qualify the HI-STAR 80 under Normal (Hot) Conditions of Transport.

2.6.1.2 Differential Thermal Expansion

The effect of thermal expansion is closely related to the presence and consideration of gaps in the package, hence both thermal expansion and gaps are discussed together in this subsection.

The appropriate thermal solutions for the HI-STAR 80 fuel and NFWB (including the connected basket supports) and the cask body are discussed in Chapter 3, for the Normal Conditions of Transport under hot conditions. Conservative estimates of free thermal expansion of the components in the HI-STAR 80 package are obtained using the computed temperatures, together with conservatively chosen coefficients of thermal expansion, and the calculations and results are documented in the thermal calculation package referenced in Section 3.4. Table 3.4.2 documents the radial and axial expansions prior to and after heat-up.

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In summary, under Normal Hot Conditions of Transport, the HI-STAR 80 package internals are not subject to restraint of free thermal expansion. Therefore, subsequent buckling or significant fuel basket deformation due to differential thermal expansions that can afflict a transport package with heat producing contents is not credible for the HI-STAR 80 package.

2.6.1.3 Stress Calculations

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

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

The Package is analyzed for the Load Combinations N1 and N2 listed in Section 2.1 using the finite element codes ANSYS [2.5.2] and LS-DYNA [2.5.3], and the models described in Section 2.7 and in the Holtec Proprietary calculation packages [2.1.12] and [2.6.1]. For the simulation of the normal operating condition (Load Combination N1 consisting of maximum internal pressure and temperature), the package orientation is not significant. For the 1-foot free drop condition (Load Combination N2), the package is oriented at a 0-degree angle with respect to the horizontal rigid target, and the package has an initial downward vertical velocity given by

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

so that V = 96.3 inch/sec (244.6 cm/sec)

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

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

2.6.1.3.2 Fatigue Considerations

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

- Cask Fatigue Considerations

As shown in the following, the cask in the HI-STAR 80 Package does not require a detailed fatigue analysis because all applicable cyclic loadings are well within the range that permits exemption from fatigue analysis per the provisions of Section III of the ASME Code. Paragraph NB-3222.4 (d) of Section III of the ASME Code provides five criteria that are strictly material and design condition dependent to determine whether a component can be exempted from a detailed fatigue analysis. The sixth criterion is applicable only when dissimilar materials are involved, which is not the case in the HI-STAR 80 cask (the carbon steel containment shell and stainless steel forgings have similar thermal expansion properties and Young's Modulus).

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

i. Atmospheric to Service Pressure Cycle

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

$$n < f(3S_m)$$

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

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

Since 1,000 pressurizations in the 30-year service life of the cask is an upper bound estimate, it is concluded that projected pressurizations of the HI-STAR 80 components do not warrant a usage factor evaluation.

ii. <u>Normal Service Pressure Fluctuation</u>

Fluctuations in the service pressure during normal operation of a component are considered if the total pressure excursion δ_p exceeds Δ_p.

where

Δ_p = Design pressure * S/(3S_m)

S = Value of S_a for one million cycles.

Using the above mentioned tables and appropriate fatigue curves,

$$(\Delta_p)_{overpack} = \frac{(145)\,(12{,}500)}{(3)\,(20{,}850)} = 28.98\ psi\ (0.200\ \text{MPa})$$

During normal operation the pressure field in the cask is steady state. Therefore, pressure fluctuations during normal operation are negligibly small and nowhere approach the limit computed. Therefore, normal service pressure oscillations do not warrant a fatigue usage factor evaluation.

iii. <u>Temperature Difference - Startup and Shutdown</u>

Fatigue analysis is not required if the temperature difference ΔT between any two adjacent points on the component during normal service does not exceed $S_a/2E\alpha$, where S_a is the cyclic stress amplitude for the specified number of startup and shutdown cycles. E and α are the Young's Modulus and instantaneous coefficients of thermal expansion (at the service temperature). Assuming 1,000 startup and shutdown cycles, Table 2.2.1 (conservatively assuming a service temperature of 450°F) and the appropriate ASME fatigue curve in Appendix I of Section III of the ASME Code give:

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

There are no locations on the cask where ΔT between any two adjacent points approaches this value. Therefore, it is evident that this temperature criterion is satisfied for 1,000 startup and shutdown cycles.

iv. <u>Temperature Difference - Normal Service</u>

Significant temperature fluctuations that require consideration in this criterion are those in which the range of temperature difference between any two adjacent points under normal service conditions is larger than S/2Eα where S corresponds to 10^6 cycles. Substituting gives:

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

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

v. Mechanical Loads

Mechanical loadings of appreciable cycling occur in the HI-STAR 80 Package only during transportation. The stress cycling under transportation conditions is considered significant if the stress intensity amplitude is greater than S_a corresponding to 10^6 cycles. It, therefore, follows that the stress intensity range that exempts the cask is 25,000 psi (172.4MPa).

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

In conclusion, the cask does not require fatigue evaluation under the exemption criteria of the ASME Code.

- Fatigue Analysis of Closure Bolts

The maximum tensile stress range, developed in the cask closure bolts during normal operating conditions, occurs during the preload operation. The maximum bolt stress is permitted to have the value $2S_m$ (Table 2.1.3). For the closure lids bolt material (SA-564 630 H1100), the value of S_m at 350°F (177°C) is 46.05 ksi (317.5 MPa) per Table 2.1.8, and the Young's modulus is 26,950 ksi (185,800 MPa). Therefore, incorporating a fatigue strength reduction factor of 4, the effective stress intensity amplitude using Figure I-9.4 (ASME Code, Section III Appendices [2.1.10]) is (ratioing the modulus used in the figure to the modulus used here):

$$S_a = \frac{(46.05)\,(4)\,(30\,e+06)}{26.95\,e+06}$$
$$= 205.0\text{ ksi} = 1414\,MPa$$

Using Figure I-9.4 of [2.1.10], the permissible number of cycles is 241; this sets a limit on the number of permitted loadings for a set of closure lid bolts.

A similar fatigue evaluation for an alternative closure lid bolting material SB-637 N07718 is

performed and the corresponding permissible number of cycles is determined as follows:

$$S_a = \frac{(46.5)\,(4)\,(29.8\,e+06)}{27.7\,e+06}$$
$$= 200.1\,\text{ksi} = 1380\,MPa$$

Using Figure I-9.7 of [2.1.10], the permissible number of cycles is 257; this sets a limit on the number of permitted loadings if SB-637 N07718 material is used for the closure lid bolts.

- Fatigue Analysis of Port Cover Plate Bolts and Spray Colling Cover Plate Bolts

The maximum tensile stress range, developed in the cover plate bolts during normal operating conditions, occurs during the preload operation. The maximum bolt stress is permitted to have the value $2S_m$ (Table 2.1.3). At a temperature of 350°F (177°C), the port cover plate bolt material (SA-193 B7) may be pre-stressed up to 61.9 ksi (426.8 MPa). The alternating stress intensity in the bolt is equal to 1/2 of the maximum stress intensity, or 30.95 ksi (213.4 MPa). Per Table 2.2.2, the Young's modulus is 28,250 ksi (194,800 MPa). Therefore, incorporating a fatigue strength reduction factor of 4, the effective stress intensity amplitude using Figure I-9.4 (ASME Code, Section III Appendices) is (ratioing the modulus used in the figure to the modulus used here):

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

Using Figure I-9.4 of [2.1.10], the permissible number of cycles is 588; this sets a limit on the number of permitted loadings for the cover plate bolts.

- Fatigue Considerations for the Containment Upper Forging Internal Closure Bolt Threads

Fatigue of the threads in the containment upper forging is also evaluated. Based on the nominal diameter and the thread engagement length, the total shear area of the cask closure bolt threads can be computed. The maximum shear stress on the threaded area of the flange is calculated based on a bounding bolt axial stress of 80 ksi under normal transport condition. The resulting shear tress is:

$$\tau = 9.72 \text{ ksi } (67.0 \text{ MPa})$$

The stress intensity in the closure flange threads is equal to twice the maximum shear stress, and the alternating stress intensity in the threads, S_a, is equal to 1/2 of the total stress. Conservatively, using the bounding cask temperature of 400°F, the Young's Modulus (Table 2.2.1) is 26,400 ksi (182,022 MPa).

The effective stress amplitude accounting for the fatigue strength reduction and Young's Modulus effects is given by

$$S_a = \frac{(9.72)\,(4)\,(28.3)}{26.4} = 41.7\,\text{ksi} \qquad (287.4MPa)$$

Using Figure I-9.2 of [2.1.10], the allowable number of cycles is approximately equal to 20,000.

Therefore, the *maximum service life of the closure flange threads is 20,000 cycles* of torque and un-torque of the cask closure system.

- Fatigue Considerations for the Vent/Drain Bushing, Spray Cooling Cap, Inner Lid Test Port Plug and the Plug Insert Threads, Orifice Helical and Spray Cooling Thread Insert, Inner and Outer Closure Lid Threaded Bolt Helical Inserts

Fatigue of these stainless steel threads are conservatively evaluated below. Based on the cask design pressure (see Table 2.1.1) and the known shear stress of the closure lid bolt threads, the maximum shear stress of the threads is conservatively estimated to be:

$$\tau = 10.0 \text{ ksi} \;\; (69.0 \text{ MPa})$$

The stress intensity of the threads is equal to twice the maximum shear stress, and the alternating stress intensity in the threads, S_a, is equal to 1/2 of the total stress. Using the bounding cask temperature of 400 °F, the Young's Modulus of material (SA-479 S21800) is 27,600 ksi (190,295 MPa) per Table TM-1 of [2.1.10].

The effective stress amplitude accounting for the fatigue strength reduction and Young's Modulus effects is given by

$$S_a = \frac{(10.0)\,(4)\,(28.3)}{27.6} = 41.0\,\text{ksi} \qquad (282.8MPa)$$

Using Figure I-9.2 of [2.1.10], the allowable number of cycles is approximately equal to 20,000.

Therefore, the *maximum service life of the vent/drain bushing and spray cooling cap threads is 20,000 cycles* of loading and unloading of the cask.

- Fatigue Considerations for the Vent/Drain Bronze Plugs

Fatigue of the bronze plugs are governed by their threads, which are conservatively evaluated below. Based on the cask design pressure (see Table 2.1.1), the maximum shear stress of the threads is conservatively estimated to be:

$$\tau = 10.0 \text{ ksi} \;\; (69.0 \text{ MPa})$$

The stress intensity of the threads is equal to twice the maximum shear stress, and the alternating stress intensity in the threads, S_a, is equal to 1/2 of the total stress. Using the bounding cask temperature of 400 °F, the Young's Modulus of plug material (SB-505 C95400) is 14,100 ksi (97,216 MPa) per Table TM-3 of [2.1.10].

The effective stress amplitude accounting for the fatigue strength reduction and Young's Modulus effects is given by

$$S_a = \frac{(10.0)\,(4)\,(28.3)}{14.1} = 80.3\,\text{ksi} \qquad (553.5\,MPa)$$

Using Figure I-9.2 of [2.1.10], the allowable number of cycles is approximately equal to 2,400.

Therefore, the *maximum service life of vent/drain bronze plugs is 2,400 cycles* of loading and unloading of the cask.

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

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

2.6.1.3.3 Stability of the Metamic Fuel Basket Plates

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

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2.6.1.3.4 Closure Lid Flanged Joint

The closure lid-to-flange joint in all HI-STAR family of casks is engineered to be a “controlled compression joint” (see Figure 2.6.1) widely used in the pressure vessel industry (see [2.7.7, Chapter 3, pp 144-51]).

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2.6.1.3.5 Re-flood Event

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2.6.1.4 Comparison with Allowable Stresses

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

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

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

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

2.6.1.4.1 Results for Pressure Boundary Stress Intensity

Results from the finite element analyses for Load Combinations N1 and N2 are tabulated for normal heat conditions of transport in Holtec Proprietary calculation packages [2.1.12] and [2.6.1], respectively. For Load Combination N1, a static finite element model is constructed using ANSYS [2.5.2] using shell elements to model the through-thickness behavior of the containment shell and the baseplate. The tabular results include contributions from mechanical and thermal loading and are needed to insure satisfaction of primary and primary plus secondary stress limits for normal conditions of transport. For the purpose of this calculation only, the closure lid-shell junction is modeled assuming a clamped connection in recognition that the sufficiently large preload from the closure lid bolts (see Table 2.2.10), necessary to insure continued sealing subsequent to the drop events, will preclude relative rotations at the joint under the internal pressure. The analysis considers the combined effects of the internal pressure (conservatively using the design internal pressure) in Table 2.1.1 and the operating temperature distribution (Table 2.6.2). As discussed in Paragraph 2.5.1.2.2, this analysis also includes the additional loading applied to the baseplate during the top-end lift of a loaded HI-STAR 80. Figure 2.6.3 shows the finite element model, and Figure 2.6.4 shows the graphical results, both reproduced from [2.1.12].

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

For Load Combination N2, a dynamic finite element model implemented in LS-DYNA [2.5.3] is used to determine the peak deceleration of the cask and stress intensity results of the cask containment boundary components for structural integrity evaluation.

The key results for Load Combinations N1 and N2 are summarized, in Tables 2.6.5 and 2.6.6, respectively, wherein the minimum safety factor for different components of the cask for each of the load combinations is presented. All safety factors are conservatively computed using allowable stresses based on the maximum normal operating temperatures (see Tables 2.1.1 and 2.6.2, for component temperatures, and Table 2.6.3 for allowable stress intensity).

2.6.1.4.2 Result Summary for Normal Heat Condition for Transport

- Maximum Cask Deceleration

Table 2.6.4 lists the maximum cask deceleration calculated for Load Combination N2 (i.e., the 0.3-meter side drop) using the LS-DYNA model.

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

Table 2.6.5 is a summary table that includes primary and primary plus secondary stress intensity safety factors (per Table 2.1.2) for Load Combination N1 associated with the Normal (Heat) Conditions of Transport. Table 2.6.6 provides similar results for Load Combination N2. The

tabular results demonstrate that all safety factors exceed 1.0 at the key locations for each component of the containment boundary.

- Status of Lid Bolts and Seals

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Based on the results of the above analyses for normal heat conditions of transport, the following conclusions are reached.

i. No bolt overstress is indicated under any loading event associated with Normal Conditions of Transport. As expected, the tensile stress in the bolts remains essentially unchanged from its initial preload state for reasons discussed in Subsection 2.6.1.

ii. The closure lid seals, including port cover seals, do not unload beyond the minimum force corresponding to the useful springback (per Table 2.2.10) required to maintain containment under Load Combinations N1 and N2; therefore, the seals continue to perform their function under Normal Conditions of Transport.

- ASME Pressure Test Condition

See Paragraph 8.1.3.2 for pressure test specifications.

- Performance of Non-Containment Components of Package

The Holtec Proprietary calculation package documenting all of the finite element solutions [2.6.1] contains graphical visualizations of the stress intensity and deformation for every component in the HI-STAR 80 package. In particular, the fuel basket and the dose blocker parts surrounding the containment shell are surveyed to evaluate their performance and compare with the acceptance criteria in Section 2.1. Table 2.6.7 summarizes the acceptance criteria for performance of the non-containment components of the HI-STAR 80. From Table 2.6.7, it is established that the surveyed components meet the acceptance requirements stated for Load Combination N2.

- Summary of Results for Normal Heat Conditions of Transport

Tables 2.6.4 through 2.6.7 present a concise summary of safety factors and performance results for the HI-STAR 80 for the Normal Heat Condition of Transport.

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

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

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

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

iv. The containment boundary seals, which includes the closure lid seals and the vent and drain port cover seals, do not unload beyond the minimum force required to maintain sealing function (per Table 2.2.10).

Therefore, the HI-STAR 80 Package, under the Normal Heat Conditions of Transport, has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.

2.6.2 Cold

The Normal Cold Condition of Transport assumes a lower bound ambient environmental temperature of -40°F (-40°C). As discussed in Regulatory Guide 7.8, the cask should be evaluated for the case with no internal heat, minimum internal pressure and increased external pressure under the cold ambient temperature condition. A discussion of the resistance to failure due to brittle fracture is provided in Section 2.1.

The value of the ambient temperature has two principal effects on the HI-STAR 80 Package, namely:

i. The steady-state temperature of all material points in the cask will go up or down by the amount of change in the ambient temperature.

ii. As the ambient temperature drops, the absolute temperature of the contained helium will drop accordingly, producing a proportional reduction in the internal pressure in accordance with the Ideal Gas Law.

In other words, for a given heat load, the temperature gradients in the cask components under steady-state conditions will remain essentially the same regardless of the value of the ambient temperature. The internal pressure, on the other hand, will decline with the lowering of the ambient temperature. Since the stresses under normal transport condition arise principally from pressure and thermal gradients, it follows that the stress field in the cask under a bounding "cold" ambient would be smaller than the "heat" condition of normal transport, treated in the preceding subsection.

In addition, allowable stresses generally increase with decreasing temperatures. Safety factors, therefore, will be greater for an analysis at cold temperatures than at hot temperatures. Therefore, the safety factors reported for the hot conditions in Subsection 2.6.1 provide the limiting margins. However, since the bolt preloads may be altered by a change in the environmental temperature, the effect of bolt temperature changes on the level of preload, subsequent to the initial application of preload, must be considered and is evaluated in the Holtec Proprietary calculation package [2.1.12]. Based on the change in modulus and coefficients of thermal expansion, the relative growth (or shrinkage) of a preloaded bolt connecting the lid to the flange is established by classical strength of materials procedure. The results from that calculation are summarized below:

Remaining Total Preload of Closure Lid Bolts at the Extreme Cold Condition (-40°F)		
Item	SA-564 630 (H1100) Bolt	SB-637 N07718 Bolt
Outer Closure Lid Bolts kN (lbf)	2,520 (567,000)	3,090 (695,000)
Inner Closure Lid Bolts kN (lbf)	10,800 (2,420,000)	11,300 (2,550,000)

The remaining total preload of closure lid bolts under the extreme cold condition is acceptable since it is still significantly greater than the required closure lid seal seating load listed in Table 2.2.10. Namely, the change in bolt preload will have an insignificant effect on structural calculations and therefore safety factors and sealing are essentially unaffected by the environmental change.

As no liquids are included in the HI-STAR 80 Package design, loads due to expansion of freezing liquids are not considered.

2.6.2.1 Differential Thermal Expansion

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

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

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

It is concluded that the HI-STAR 80 package meets the requirement that there be no restraint of free thermal expansion, under Normal Cold Conditions of Transport, that would lead to primary stresses greater than the applicable ASME Level A limit.

2.6.3 Reduced External Pressure

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

2.6.4 Increased External Pressure

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

2.6.5 Vibration

During transport, vibratory motions occur which could cause low-level stress cycles in the package due to beam-like deformations. If any of the package components have natural frequencies in the flexible range (i.e., below 33 Hz), then resonance may amplify the low level input into a significant stress response. Strength of materials calculations are performed to establish that vibrations are not an issue in transport of the HI-STAR 80.

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

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

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

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2.6.6 Water Spray

The condition is not applicable to the HI-STAR 80 Package per [2.1.4].

2.6.7 Free Drop

The structural analysis of a 0.3-meter (1-foot) free drop under the heat condition is documented in Paragraph 2.6.1.4. As demonstrated in Paragraph 2.6.1.4 safety factors are well over 1.0 (see Table 2.6.6 for Load Combination N2). The discussion in subsection 2.6.2 demonstrates why the cold condition is not a bounding condition for the 0.3-meter (1-foot) free drop.

2.6.8 Corner Drop

This condition is not applicable to the HI-STAR 80 Package per [2.1.3].

2.6.9 Compression

This condition is not applicable to the HI-STAR 80 Package per [2.1.3].

2.6.10 Penetration

This condition is not applicable to the HI-STAR 80 Package per [2.1.4].

Table 2.6.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

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

Location	Pressure kPa (psig)	Bounding Component Temperature ºC (ºF) †
Containment Shell (Top) ††	Refer to Table 2.1.1	188 (370)
Containment Shell (Middle) ††		193 (380)
Containment Shell (Bottom) ††		179 (355)
Containment Bottom Forging		191 (375)
Inner Closure Lid		182 (360)
Outer Closure Lid		168 (335)
Containment Upper Forging		200 (392)
Enclosure Shell End Caps		155 (311)
Cylindrical Lead		191 (375)
Bottom Steel Insert		168 (335)
Intermediate Shells		177 (350)
Gamma Shield Ribs		191 (375)
Inner Closure Lid Bolts		171 (340)
Outer Closure Lid Bolts		166 (330)
Enclosure Shell		177 (350)
Impact Limiter Backbone		166 (330)
Impact Limiter Aluminum Honeycomb		104 (220)
Fuel Basket – Ends (Outer Cells)		250 (482)
Fuel Basket – Ends (Intermediate Cells)		280 (536)
Fuel Basket – Ends (Center Cells)		300 (572)
Fuel Basket – Middle (Outer Cells)		300 (572)
Fuel Basket – Middle (Intermediate Cells)		330 (626)
Fuel Basket – Middle (Center Cells)		357 (675)

Notes:

†Temperatures listed bound the results in Chapter 3 for the governing package configuration with 32 loaded BWR fuel assemblies.

†† Excluding the stainless steel overlay layer.

Table 2.6.3: Containment Boundary Component Allowable Stresses*
(Normal and Accident Conditions of Transport)

ITEM	NORMAL †	ACCIDENT†	TEMPERATURE
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	NA	432.2 (62.68)	204°C (400°F)
Inner Closure Lid – Primary + Secondary Stress Intensity – MPa (ksi)	384.7 (55.8)	NA	204°C (400°F)
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	NA	439.8 (63.78)	177°C (350°F)
Outer Closure Lid – Primary + Secondary Stress Intensity – MPa (ksi)	399.2 (57.9)	NA	177°C (350°F)
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	NA	337.8 (49.0)	204°C (400°F)
Containment Shell – Primary Membrane + Primary Bending Stress Intensity – MPa (ksi)	NA	506.8 (73.5)	204°C (400°F)
Containment Shell – Primary + Secondary Stress Intensity – MPa (ksi)	442.6 (64.2)	NA	204°C (400°F)
Baseplate – Primary Membrane + Bending Stress Intensity – MPa (ksi)	NA	432.2 (62.68)	204°C (400°F)
Baseplate – Primary + Secondary Stress Intensity – MPa (ksi)	384.7 (55.8)	NA	204°C (400°F)
Inner Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	635.0 (92.1)	689.82 (100.05)	177°C (350°F)
Outer Lid Bolts – Average Service Stress (Stress Intensity) – MPa (ksi)	635.0 (92.1)	689.82 (100.05)	177°C (350°F)
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	689.82 (100.05)††	951.82 (138.05)	177°C (350°F)
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	689.82 (100.05)††	951.82 (138.05)	177°C (350°F)
Retainer Ring - Maximum Service Stress (Stress Intensity) – MPa (ksi)	305.6 (44.325)‡	633.5 (91.875)¥	191°C (375°F)

* Based on the lower-bound mechanical properties of all candidate materials for the component at its bounding temperature under normal condition of transport.
† Obtained from Section 2.1.
†† Lesser of 3Sm and S_y is used for conservatism.
‡ Lesser of NB stress limit and S_y of the material.
¥ Lesser of NB stress limit and S_u of the material.

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

Method	α_{max} (g's)
Numerical (LS-DYNA) Solution	28.9

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

Location and Stress Intensity Component	Calculated Value
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	4,716 SF=5.92
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	16,666 SF=1.67
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	2,770 SF=6.71
Containment Shell – Primary + Secondary Stress Intensity – MPa (ksi)	6,852 SF=4.07
Baseplate – Primary Bending Stress Intensity at Center – MPa (ksi)	10,589 SF=2.63
Baseplate – Primary + Secondary Intensity at Periphery – MPa (ksi),	7,578 SF=7.63

Note: “SF” means Safety Factor.

Table 2.6.6: Results for 1-Ft (0.3 m) Drop Analysis

Item	Allowable from Table 2.6.3	Calculated Value	Safety Factor
Primary + Secondary stress intensity of the inner closure lid – MPa (ksi)	384.7 (55.8)	105.2 (15.26)	3.66
Primary + Secondary stress intensity of the outer closure lid – MPa (ksi)	399.2 (57.9)	104.5 (15.16)	3.82
Primary + Secondary stress intensity of the containment shell – MPa (ksi)	442.6 (64.2)	116.6 (16.91)	3.80
Primary + Secondary stress intensity of the cask baseplate – MPa (ksi)	384.7 (55.8)	118.0 (17.12)	3.26

Note: "SF" means the Safety Factor. †As an example, the stress distribution in the containment shell under 1-Ft (0.3 m.) side drop is shown in Figure 2.6.5.

Table 2.6.7: Key Performance Objectives for Non-Containment Components of the HI-STAR 80

Criterion	Load Combination N1	Load Combination N2
Stress Intensity in Dose Blocker Parts – Primary Stress Intensity Below Ultimate Strength	-	Yes
Fuel Basket Deformation - Maximum Total Deflection < 0.73 mm	Yes	Yes

Table 2.6.8: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 2.6.9: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

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

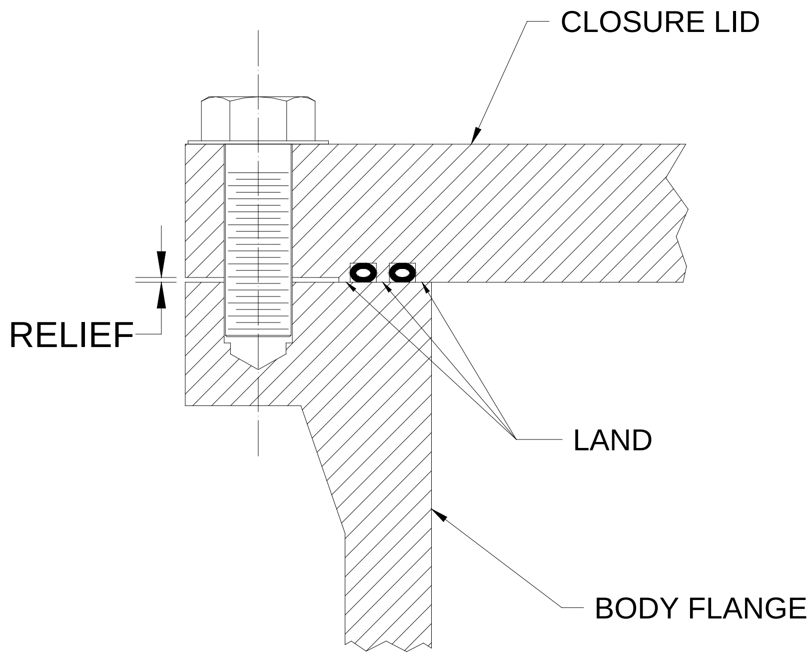

Figure 2.6.1: Essential Elements of a Classical "Controlled Compression Joint" (for Illustration Only)

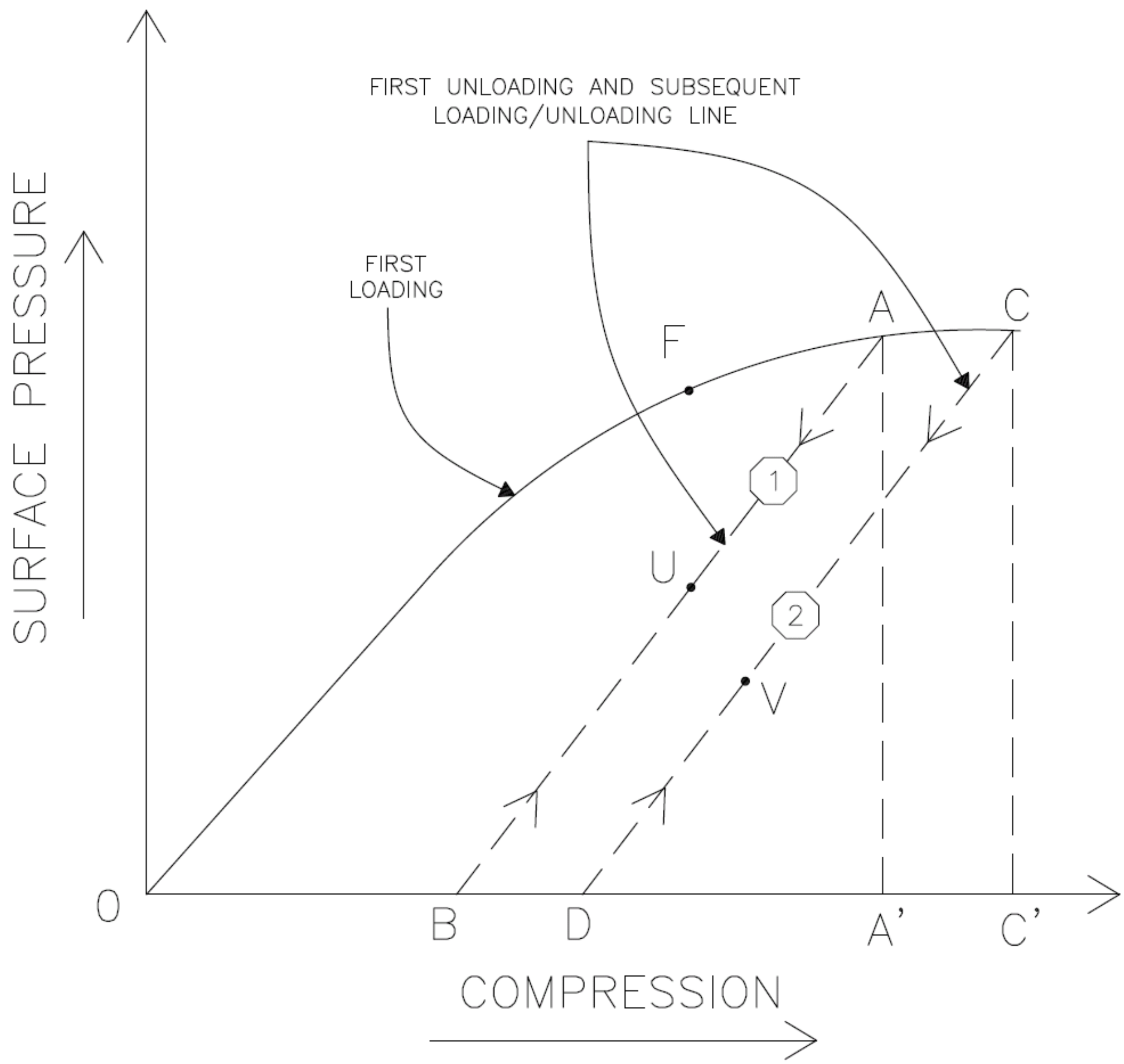

Figure 2.6.2: Loading and Unloading Curves for a Typical Gasket

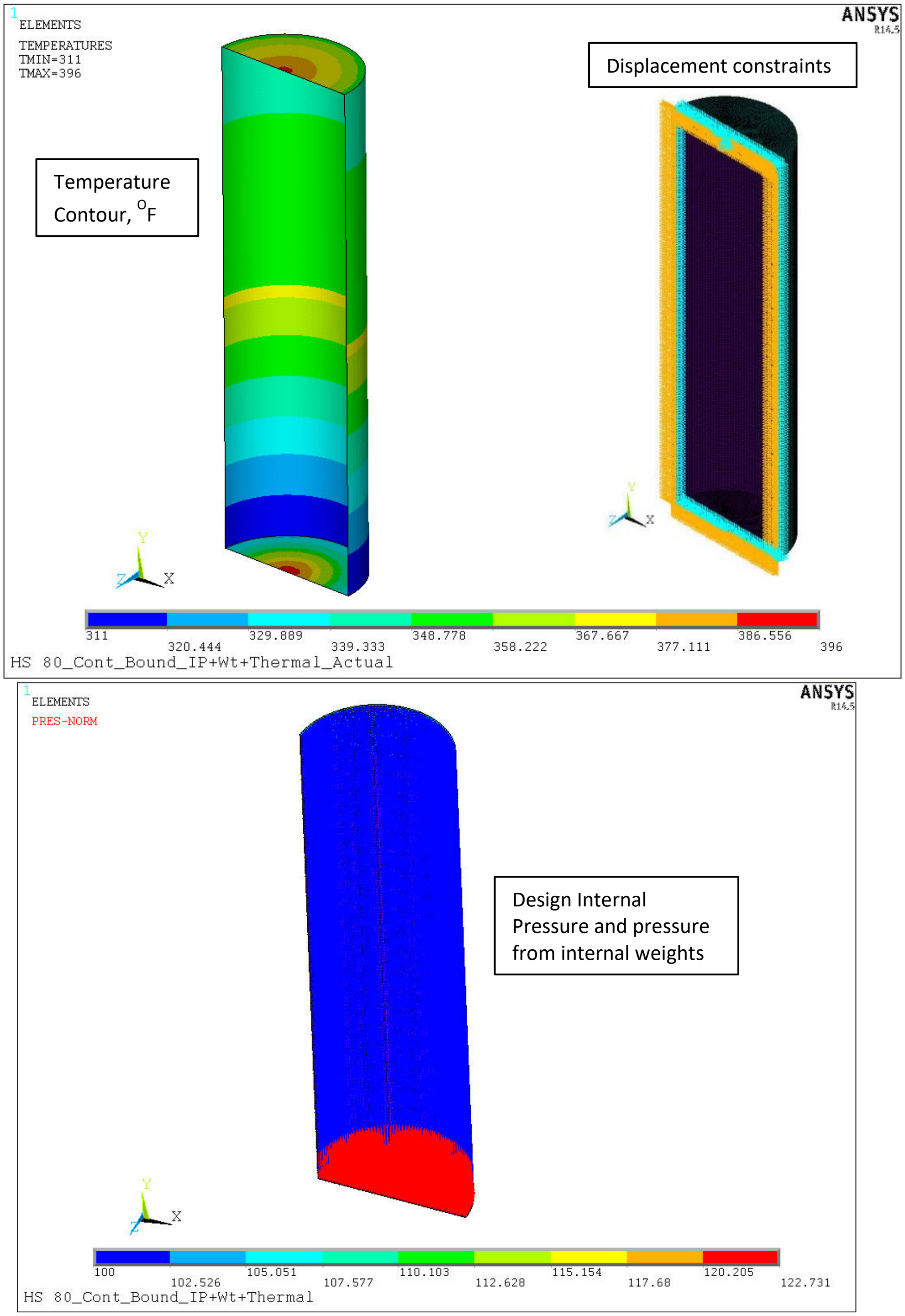

Figure 2.6.3: Finite Element Model for Load Combination N1

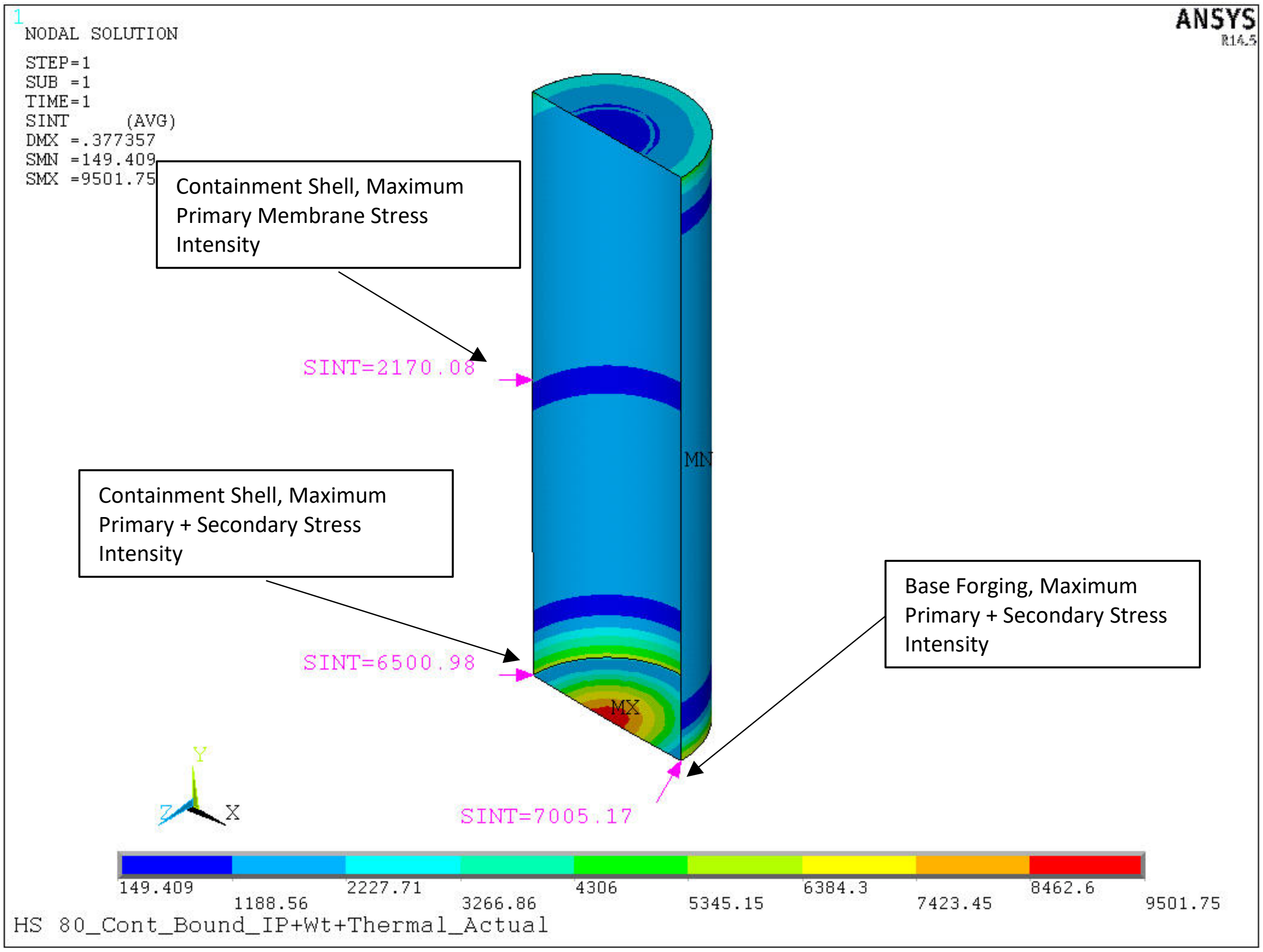

Figure 2.6.4: Results for Stress Intensity for Load Combination N1

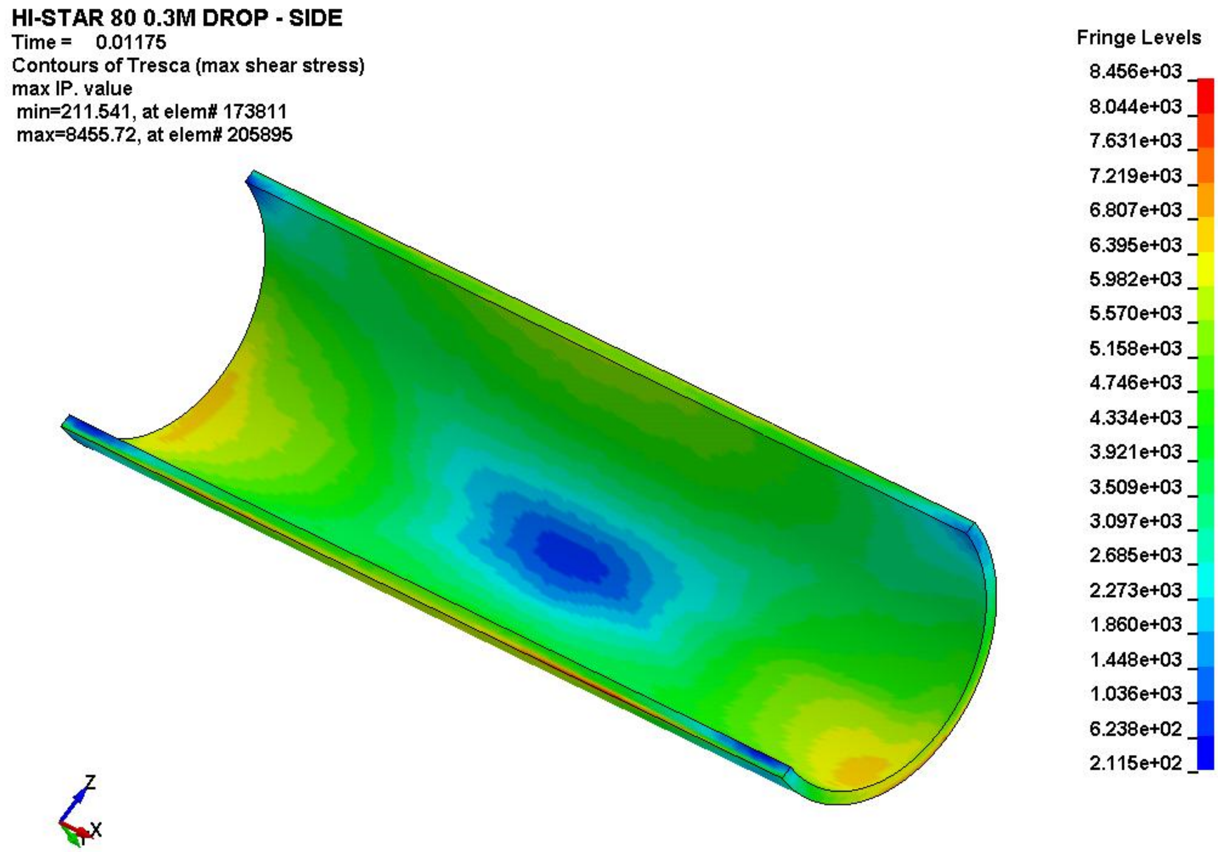

Figure 2.6.5: LS-DYNA Maximum Shear Stress (0.5 Times Stress Intensity) Distribution in Containment Shell for 1-Ft Side Drop

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

It is shown in the following subsections that the HI-STAR 80 Package meets the safety criteria set forth in 10CFR71 when it is subjected to the hypothetical accident conditions specified in 10CFR71.73. In particular, required technical data is presented herein to support the conclusion that HI-STAR 80 Package, when subjected to hypothetical accident conditions, will maintain its structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements.

The hypothetical accident conditions, as defined in 10CFR71.73 and explained in Regulatory Guide 7.9, are applied to the HI-STAR 80 Package as a sequence of loading events. The package is first subject to a 9-meter (30-foot) drop. As required by the regulations, the "free drop" should be assumed to occur in the orientation that will cause maximum damage. To identify the most vulnerable orientation the drop simulation is performed in four candidate orientations. From the post-impact package configuration determined to have the most damaging orientation, the package is then subject to a 1-meter (40-inch) drop onto a 15 cm (6.0 inch) diameter mild steel pin (of length sufficient to impart the impact energy to the cask structure through penetrant action). In the third step, the package is subject to an 800°C (1475°F) temperature fire environment for 30 minutes. Finally the package is subject to water immersion.

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

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2.7.1 9-meter Free Drop

2.7.1.1 Problem Description and Dynamic Model

As specified in 10CFR71.73, the performance and structural integrity of the HI-STAR 80 Package must be evaluated for the most severe drop scenarios. The appurtenance that is critical to protecting the integrity of the containment boundary during a high momentum collision event is the AL-

STAR impact limiter.

The central purpose of the impact limiter, defined as an essential package appurtenance in Section 1.2, is to limit the package maximum deceleration, α_{max}. The HI-STAR package, consisting of the loaded cask and top and bottom impact limiters, is essentially a cylindrical body with a very rigid interior (namely, the cask) surrounded by a pair of relatively soft crushable structures. The crushable structure (impact limiter) should deform and absorb the kinetic energy of impact without detaching itself from the cask, disintegrating, or otherwise malfunctioning. A falling cylindrical body may theoretically impact the target surface in an infinite number of orientations; the impact limiter must limit decelerations to insure that stress intensity and performance limits, as described in Section 2.1, are satisfied, and to ensure that the impact limiter does not detach from the cask, regardless of the impact orientation. In general, a drop event orientation is defined by the angle of the HI-STAR 80 longitudinal axis, “θ”, with the impact surface. In this notation, $\theta = 0°$ means a side drop and $\theta = 90°$ implies a vertical or end drop scenario. In any orientation, the drop height is measured from the lowest point on the package.

An intermediate value of θ at which the point of impact is directly below the center of gravity (C.G.) of the HI-STAR package warrants special mention. This drop orientation is traditionally called the C.G.-over-corner (CGOC) configuration. The CGOC orientation, “θ_c”, is the demarcation line between single and dual impact events. At $90° > \theta > \theta_c$ the leading end of the package (denoted as the “primary” impact limiter) is the sole participant in absorption of incident kinetic energy. At $\theta < \theta_c$ drop orientations, the initial impact and crush of the leading (primary) impact limiter is followed by the downward rotation of the package with the initial impact surface acting as the pivot, culminating in the impact of the opposite (secondary) impact limiter on the target surface. In the dual impact scenarios, the first and second impact limiter crush events are referred to as the “primary” and “secondary” impacts, respectively. It is reasonable to speculate that for certain values of θ, the secondary impact may be the more severe of the two. Figures 2.7.1 through 2.7.4 illustrate the orientation of a (generic) cask at the initiation of a drop event.

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Finally, the package design must satisfy all criteria in ambient temperature conditions (temperature and humidity) that may prevail during transport. Therefore, the impact limiter design must be functionally insensitive to the ambient temperature and humidity.

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

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

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

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The remaining design objectives, namely, limiting of the maximum rigid body deceleration under the 9-meter drop event and preventing contact of the cask with the unyielding surface, is demonstrated by the LS-DYNA [2.5.3] finite element code, as discussed earlier. LS-DYNA has been benchmarked extensively by others [2.7.5, 2.7.6] and by Holtec using the test data from the static tests of the crush material and, more importantly, from the quarter-scale model 9-meter drop experiments carried out at the Oak Ridge National Laboratory in support of HI-STAR 100 Part 71 certification in the late 90s [2.7.4] (see Appendix 2.B of [1.0.4]) and at the Idaho National Laboratory in support of DOE multi-canister overpacks [2.7.16]. As discussed in Appendix 2.B of [1.0.4] and [2.7.15], the LS-DYNA simulation model is a credible and reliable vehicle for determining the HI-STAR 80 Package's impact performance. LS-DYNA has been used by Holtec

International in a wide variety of impact scenarios in dry storage projects [2.7.10].

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The previously described key attributes implemented in the HI-STAR 80 LS-DYNA model take advantage of the state-of-art numerical analysis capability of the finite element code for simulating transient, nonlinear impact events. With good accuracy demonstrated in the benchmarking effort (Appendix 2.B of [1.0.4] and [2.7.16]) as well in the analysis independently performed by the NRC/PNNL investigators [2.7.5], the previously described HI-STAR 80 finite element model is deemed to be able to predict the impact response of the package under various accidental drop conditions with reliable accuracy.

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2.7.1.2 Simulation of Drop Events

As discussed before, the free drop of the package from 9 meters onto an essentially unyielding surface is simulated for a number of orientations using LS-DYNA. The peak g-loads from each drop simulation, α_{max}, in both axial and lateral direction (to the cask's axis) are computed, as well as the stresses developed in the HI-STAR 80 package.

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

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

Under certain categories of events, there may be more than one drop "orientation". The orientation of drop, θ, is defined by the angle between the horizontal plane and the axis of the cask pointed from its base to its lid at the instant of impact. $\theta = 90^o$ is a vertical-end drop event with bottom-down configuration (see Figure 2.7.1). Similarly, $\theta = 0\ ^o$ means side (lateral) drop (see Figure 2.7.3).

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

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

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

As can be seen from Table 2.7.3, upper as well as lower bound properties of the crush material are analyzed in LS-DYNA to ensure that the largest value of α_{max} and maximum crush, d_{max}, have been identified and evaluated. The majority of the drop simulations are performed using the upper bound properties of the crush material in order to maximize the impact deceleration and the

induced stresses in the cask components. The side drop orientation (see Figure 2.7.5C) is repeated using the lower bound properties for the crush material to confirm that the cask body (between impact limiters) does not contact the ground due to the increased crush depth.

The initial velocity of the package corresponding to a free fall from 9 meters at impact in all impact scenarios is 13.39 m/sec (43.9 ft/sec).

2.7.1.3 Summary of Results

Table 2.7.3 summarizes the maximum values of α_{max} for the axial and lateral direction from all of the drop scenarios simulated on LS-DYNA. Table 2.7.4 summarizes the maximum stress and deformation results from all of the analyzed drop scenarios.

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

i. For the dual impact scenarios (i.e. slapdown drop accident), the secondary impact is always more severe than the primary impact. The maximum deceleration and impact limiter crush occur in the region of the secondary impact.

ii. All body bolt stresses meet the acceptance criteria from Table 2.1.3 demonstrating that there is no risk of failure of any bolt fastened to the top forging.

iii. The impact limiters remain connected to the cask subsequent to the drop accident.

iv. The closure lid seals are fully functional after the governing 9-m drop event, which is ensured by satisfying the stress criteria of the closure lid bolts.

v. The maximum axial/lateral deceleration sustained by the Quivers remain below the design limit specified in Table 2.2.11.

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

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

For convenience, the allowable stress limits necessary for the safety evaluation of each part are compiled in Table 2.6.3.

Based on the tabular results presented in Tables 2.7.4 and 2.7.6 it is concluded that:

- The primary stress intensities for the containment components are below the ASME NB limits for all drop configurations.

- The closure lid bolts show no gross yielding and the gaskets remain under a compressed state at the conclusion of the event. Therefore, continued bolted joint effectiveness in the wake of the 9-meter free drop event is assured.

- The dose blocker parts surrounding the containment shell remains intact.

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

- The lead, used for gamma shielding in the HI-STAR 80, is included in the LS-DYNA model. The lead is characterized by the properties given in Table 2.2.9. A review of all drop and puncture simulation results confirms that the predicted minor lead slump is bounded by the assumed value in the shielding evaluation (see Section 5.1).

- Since the ability to accurately predict and evaluate large displacements is included within the LS-DYNA algorithm, the effect of any instability is automatically accounted for. Based on the evaluated results, it is concluded that there is no buckling of the containment components during any of the postulated Hypothetical Accident events.

- Impact limiters remain attached to the cask subsequent to the drop event.

2.7.1.4 Fracture Analysis

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2.7.2 Crush

An evaluation of package crush is not required for the HI-STAR 80.

2.7.3 Puncture

10CFR71 specifies that a puncture event be considered as a hypothetical accident condition subsequent to the hypothetical 9-meter drop event. For this event, it is postulated that the package falls freely through a distance of 1 meter (40 inch) and impacts a 15 cm (6 inch) diameter mild steel bar. The effects of the puncture drop will, quite ostensibly, be most severe when the steel bar is perpendicular to the impact surface. Therefore, all puncture analyses assume that the bar is perpendicular to the impact surface. Puncture is considered on the sidewall and on the top end (a puncture on the bottom end is not bounding since there is a full welded connection, rather than a bolted connection that needs to remain intact).

LS-DYNA simulation model is used to examine the hypothetical puncture accidents. The same FE model used for top-end drop is retained for the top end puncture analysis. A mild steel bar, having the appropriate dimensions, is added to the model, placed in the proper orientation, and fixed to the ground. The package is then assumed to have a known initial velocity at contact with the bar. Details of the simulation model and the results (all output figures) for the top end puncture and side puncture are provided in the Holtec Proprietary calculation package [2.6.1]. The key results of the puncture analysis are also listed in Table 2.7.4.

The results from the puncture analyses yield the following conclusions:

i. The bolted joint maintains its integrity; the margin-against-leakage parameter, m, (defined in Table 2.6.1) remains at the maximum possible value of 10.

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

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

iv. The puncture accident does not lead to unacceptable shielding effectiveness.

The above results confirm the structural adequacy of the package under the “puncture” event of 10CFR71.73.

2.7.4 Thermal

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

1. The metal temperature, averaged across <u>any</u> section of the containment boundary, remains below the maximum permissible temperature for the Level A condition in

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

2. Internal interferences among the constituents of the HI-STAR 80 Package do not develop due to their differential thermal expansion during and after the fire event.

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

Table 2.7.5 provides a summary of the key results obtained from the continued sealing analysis under the fire accident; the details of the solution are documented in the Holtec Proprietary calculation package [2.1.12]. A 3-D ANSYS finite element model is employed to evaluate the effect of the fire accident on the bolted closure lids. Because of the differences in coefficient of thermal expansion between the lid and flange and the bolt, the bolt loads increase from their starting value, but the increase is balanced by increased compression on the land. Therefore, the fire event, occurring after a 9-meter drop accident or a puncture, does not lead to loss of seal integrity in either lid. The package, therefore, meets all acceptance criteria set down in Section 2.1 for the postulated fire event.

2.7.4.1 Summary of Pressures and Temperatures

Section 3.4 contains a discussion of the peak temperatures occurring during and after the fire event. It is concluded in that section that:

1. The containment boundary, protected by the dose blocker components, remains below 750°F (SA-203 E or SA-350 LF3 material).
2. The containment boundary that is within the confines of the impact limiters remains below 700°F (SA-965/182 F304 material).
3. The portion of the containment boundary directly exposed to the fire may have local outer surface temperatures in excess of 700°F, but the bulk metal temperature of the material volume remains under 700°F . All metal temperatures remain well below the "threshold damage temperature".
4. The Holtite-B neutron shield material experiences temperatures in excess of its design limit, leading to a loss in the cask's neutron shielding capacity.

2.7.4.2 Differential Thermal Expansion

Differential thermal expansions under the limiting conditions of the fire event are evaluated in Subsection 3.4.4. The analyses show that, under the fire condition, there is no restraint of free thermal expansion of the fuel basket.

2.7.4.3 Stress Calculations

Strength of materials calculations are used to evaluate the performance of the bolted joint in the Containment Boundary. Analyses show that:

i. The primary stress intensities in the Containment Boundary remain below the Level D limits.

ii. The bolt stresses in the Containment Boundary joint, due to differential thermal expansion, rise but remain below the Level D limits.

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

2.7.5 Immersion - Fissile Material

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

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

2.7.6 Immersion - All packages

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

2.7.7 Deep Water Immersion Test

The HI-STAR 80 containment boundary is subject to an all-around external pressure of 2.0 MPa (290 psi) after applying initial bolt preload. Code Case N-284 is used to evaluate the propensity for containment shell instability assuming the dose blocker parts do not prevent the 290 psi pressure from acting directly on the outer surface of the containment shell. The Holtec Proprietary calculation package [2.1.12] contains the supporting details; it is demonstrated there that there is no yielding of the vessel and that there is no elastic or plastic instability of the containment shell. Since the external pressure acts in a direction to add additional pressure to the lands of the lids, seal opening is not a concern for this accident. The primary stress intensity in the lids, assuming that the lids are subject to 290 psi and are conservatively considered as simply supported plates at

the bolt circle, meet the Level D ASME Code limits (this is easily demonstrated by examining the results for the N1 normal load condition summarized in Section 2.6). In-leakage of water through the containment system boundary seals is confirmed to be non-credible to satisfy the intent of ISG-19 [1.2.16]. Therefore, the package meets all acceptance criteria given in Section 2.1 under this immersion condition.

2.7.8 Summary of Damage

The results presented in Subsections 2.7.1 through 2.7.7 show that the HI-STAR 80 Package meets the requirements of 10CFR71.61 and 10CFR71.73. All (plausibly) vulnerable orientations of free drop have been analyzed. Two puncture events have also been considered and reported in the tables in Section 2.7. All safety factors are greater than 1.0 for the hypothetical accident conditions of transport, and the sealing function is maintained at the end of each event and at the end of the sequence. The fuel basket does not experience any primary plastic strain after any of the accidents simulated in this safety analysis effort. Therefore, the HI-STAR 80 package, under the hypothetical accident conditions of transport, has adequate structural integrity to satisfy the subcriticality, containment, shielding, and temperature requirements of 10CFR71.

Specifically, the analyses summarized in this section show that:

i. The HI-STAR 80 containment space will remain inaccessible to the moderator under the immersion event of 10CFR71.73, which follows free drop, puncture, and fire.

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

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

iv. The fuel basket panel deflection in the active fuel region is less than the limit specified in Table 2.6.7 to ensure subcriticality.

Table 2.7.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 2.7.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

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

Case No.	Drop Scenario	θ	Maximum Computed Deceleration in g's α_{max}		Maximum Crush Inch		Reference Figure	Comments
			Axial	Lateral	Allowable* Value	Computed Value		
1.	End drop – bottom down (UB**)	90	61.5	-	16.625	11.6	2.7.1	
2.	End drop – top down (UB)	90	90.0	-	16.625	12.135	2.7.1	
3.	Side drop (UB)	0	-	80.9	8.781	7.981	2.7.3	
4.	C.G.-over-corner drop – top down (UB)	79.153	47.73	9.15	29.0	16.3	2.7.2	
5.	Oblique drop (slap down) – primary impact at the top end (UB)	7	-	129.6	8.781	7.691	2.7.4	Bounding results of the primary and secondary impacts are reported
6.	Oblique drop (slap down) – primary impact at the bottom end (UB)	7	-	102.0	8.781	7.793	2.7.4	Bounding results of the primary and secondary impacts are reported
7.	Side drop (LB)	0	-	77.43	8.781	8.652	2.7.3	

* Allowable crush based on distance to closest point on steel backbone, except for end drop where allowable crush is the distance to the outer end of the honeycomb blocks with a larger diameter.

** "UB" indicates Upper Bound crush strength values are used in drop simulation; "LB" indicates Lower Bound crush strength values are used in drop simulation.

Table 2.7.4: - Bounding Results from 9-M Drop and 1-M Drop Puncture Simulations

Item	Allowable Value†	Calculated Value	Safety Factor	Governing Accident
Outer Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	439.8 (63.78)	271.0 (39.3)	1.62	1-M Top End Drop Puncture
Inner Closure Lid – Primary Bending Stress Intensity – MPa (ksi)	432.2 (62.68)	239.0 (34.66)	1.81	9-M Top End Drop
Containment Shell – Primary Membrane Stress Intensity – MPa (ksi)	337.8 (49.0)	279.8 (40.58)	1.21	9-M Side Drop
Cask Baseplate – Primary Bending Stress Intensity – MPa (ksi)	432.2 (62.68)	142.7 (20.7)	3.03	9-M Bottom End Drop
Retainer Ring - Maximum Service Stress (Stress Intensity) – MPa (ksi)	633.5 (91.875)	244.0 (35.38)	2.60	9-M Top End Drop
Inner Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	951.82 (138.05)	722.4 (104.78)	1.32	9-M Top End Drop
Outer Lid Bolts – Maximum Service Stress at Extreme Fiber (Stress Intensity) – MPa (ksi)	951.82 (138.05)	856.9 (124.28)	1.11	9-M Slapdown (Bottom First)
Maximum Penetration into the Cask Body by the Puncture Bar (inches)	16.28*	10.78	1.51	1-M Side Drop Puncture
Maximum Axial/Radial Lead Slumps (inches)	NA	0.81/3.55	NA	9-M Vertical/ 9-M Slapdown
Lid Seals Remain Sufficiently Compressed after the Drop Accident?	Yes			
Impact Limiters Remain Attached to the Cask	Yes			

Note: †Allowable stresses are obtained from Table 2.6.3. *The total penetration to the containment shell outer surface.

Table 2.7.5: Bolted Joint Performance Under the Fire Event

ITEM	INITIAL PRELOAD CONDITON	STEADY-STATE FIRE CONDITION
Inner Closure Lid Bolt – Average Service Stress MPa (ksi)	413.7 (60)	537 (77.9)
Outer Closure Lid Bolt – Average Service Stress MPa (ksi)	137.9 (20)	392 (56.8)

Table 2.7.6: Key Performance Objectives for Non-Containment Components of the HI-STAR 80

Criterion	Result
Effective Stress in Dose Blocker Components – Primary Effective Stress Below Ultimate Strength	Yes
Fuel Basket Deformation – Maximum Total Deflection < 0.73 mm	Yes

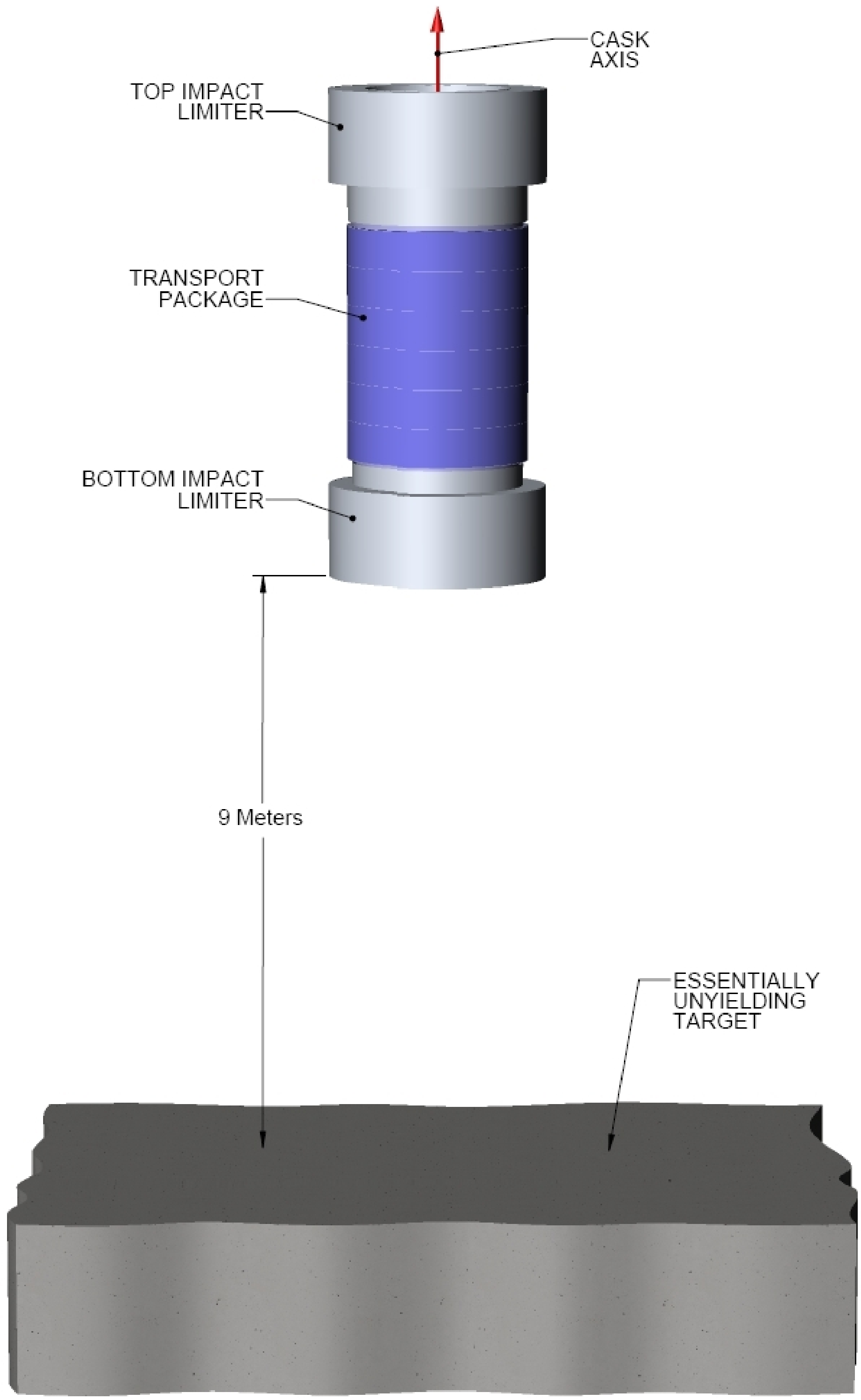

Figure 2.7.1: End Drop, θ = 90

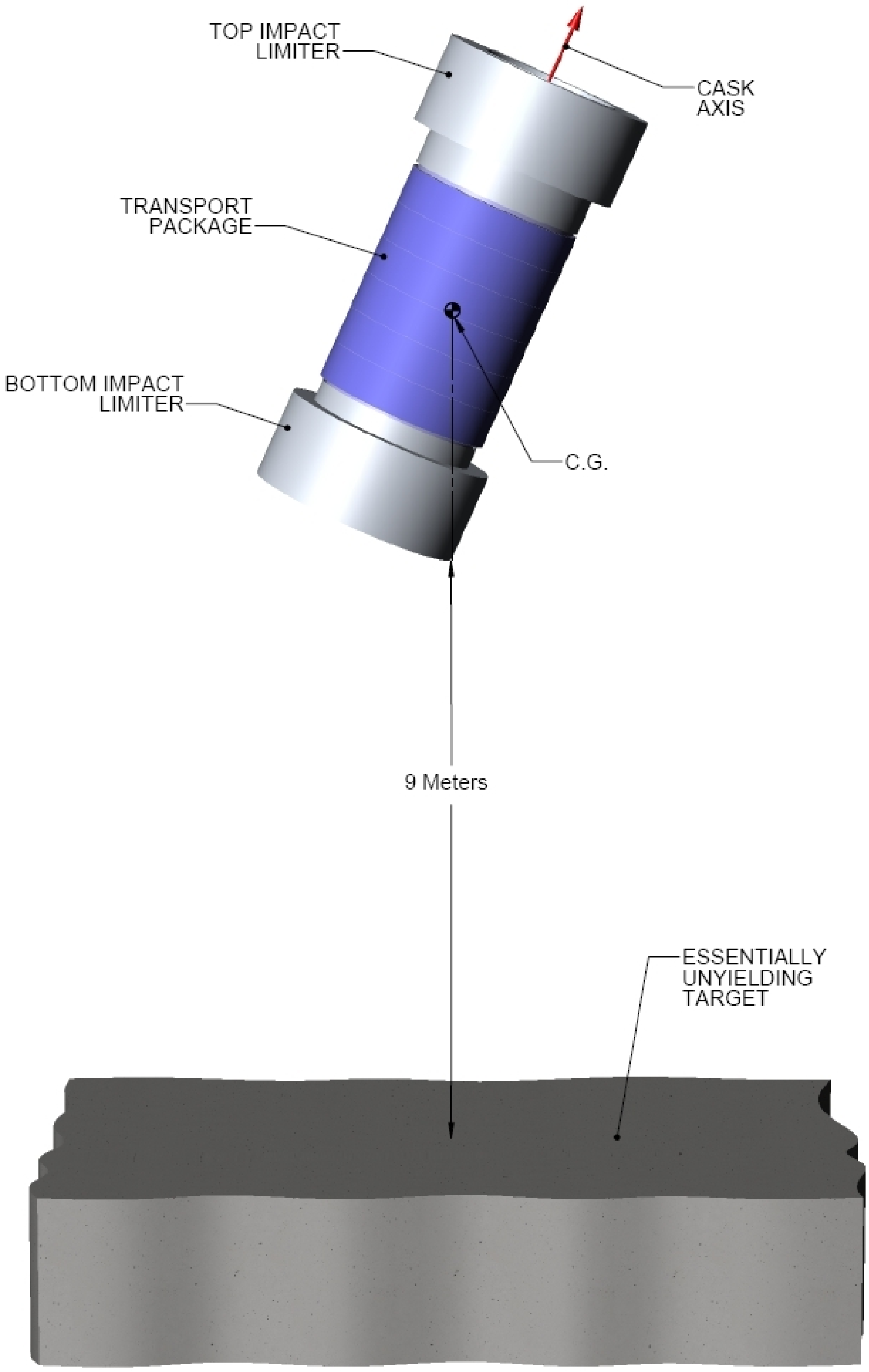

Figure 2.7.2: Center-of-Gravity-Over-Corner Drop

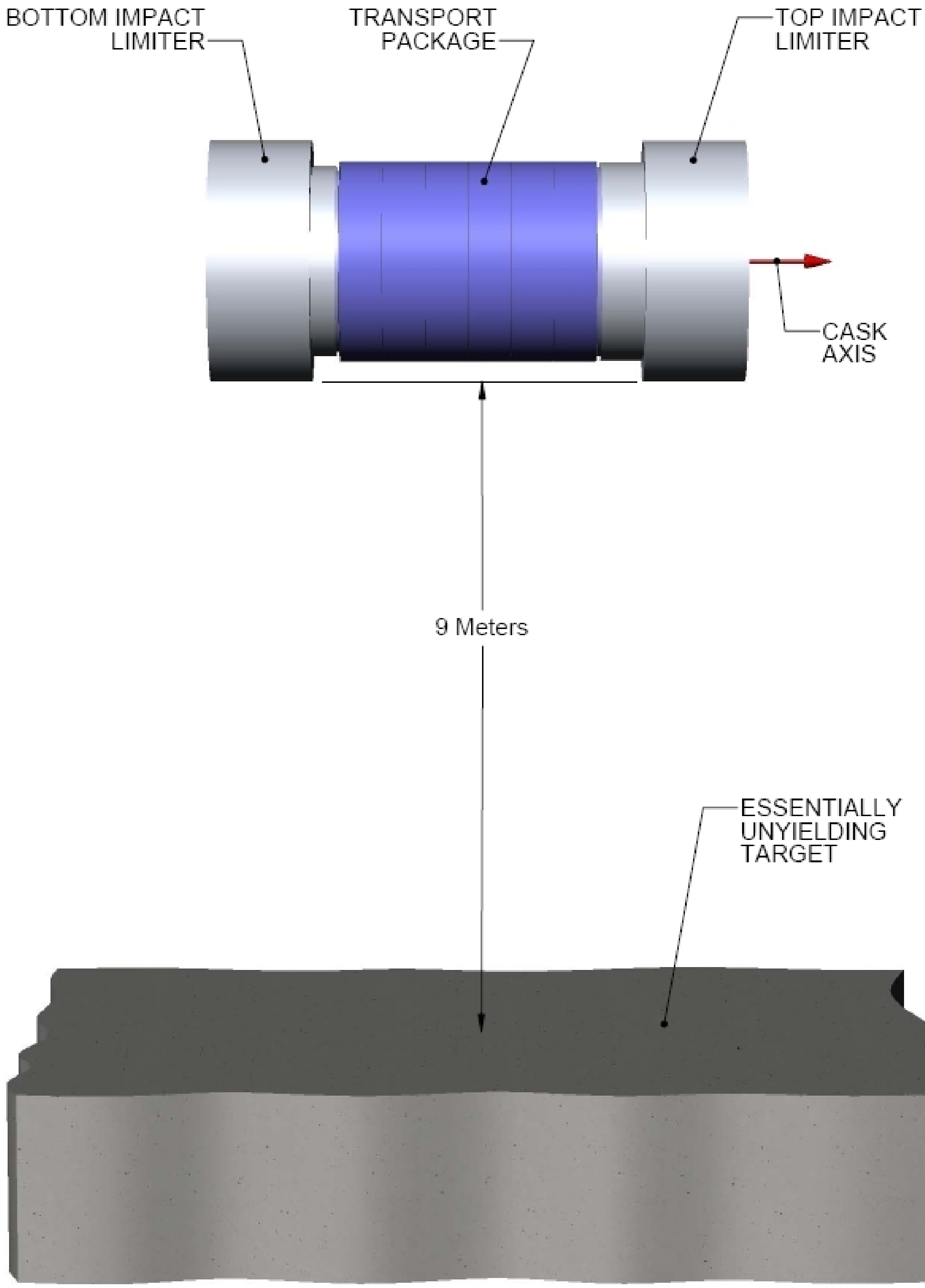

Figure 2.7.3: Side Drop, θ = 0 Degrees

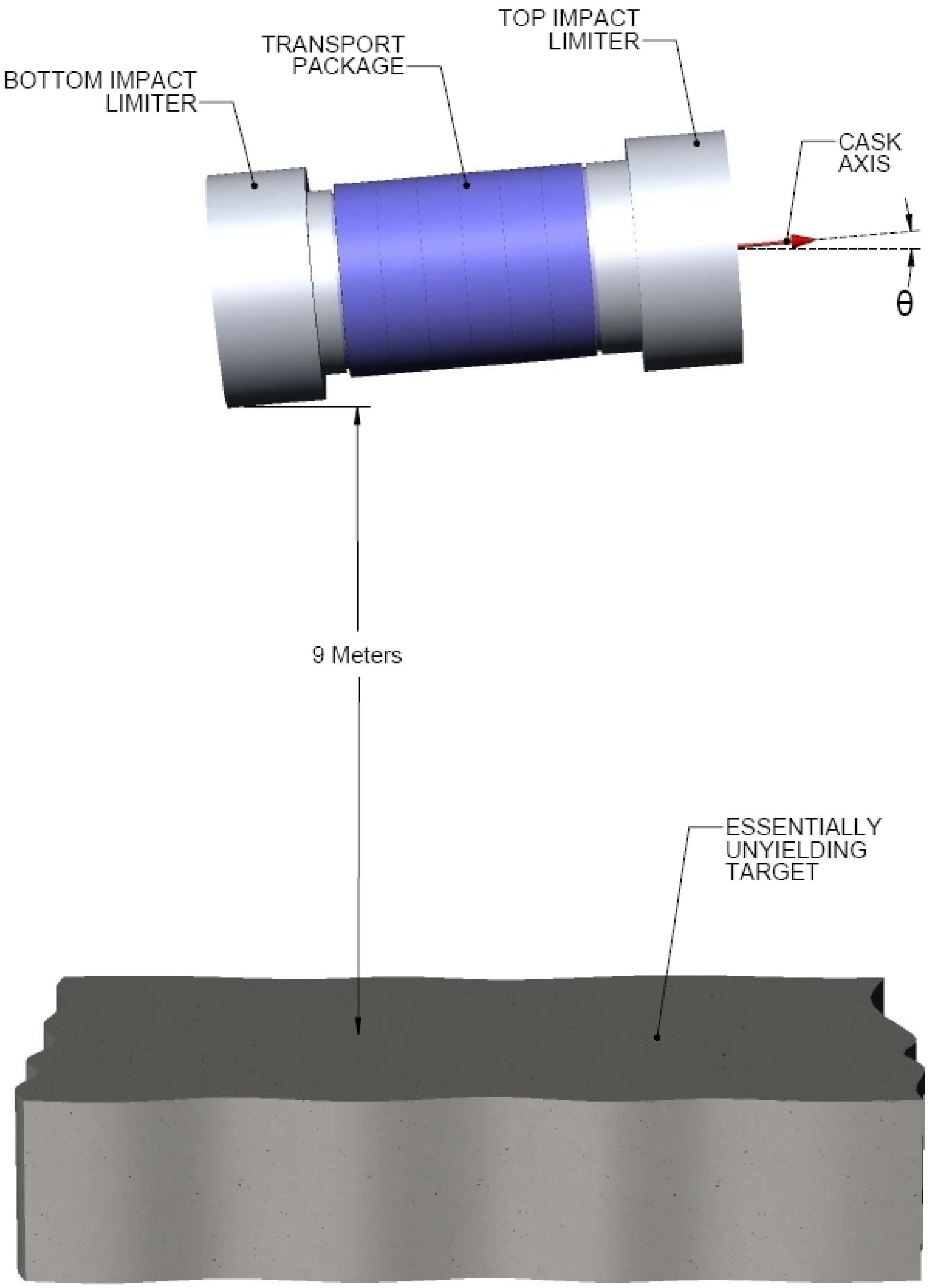

Figure 2.7.4: Oblique Drop (Slapdown), θ Selected to Maximize Secondary Impact

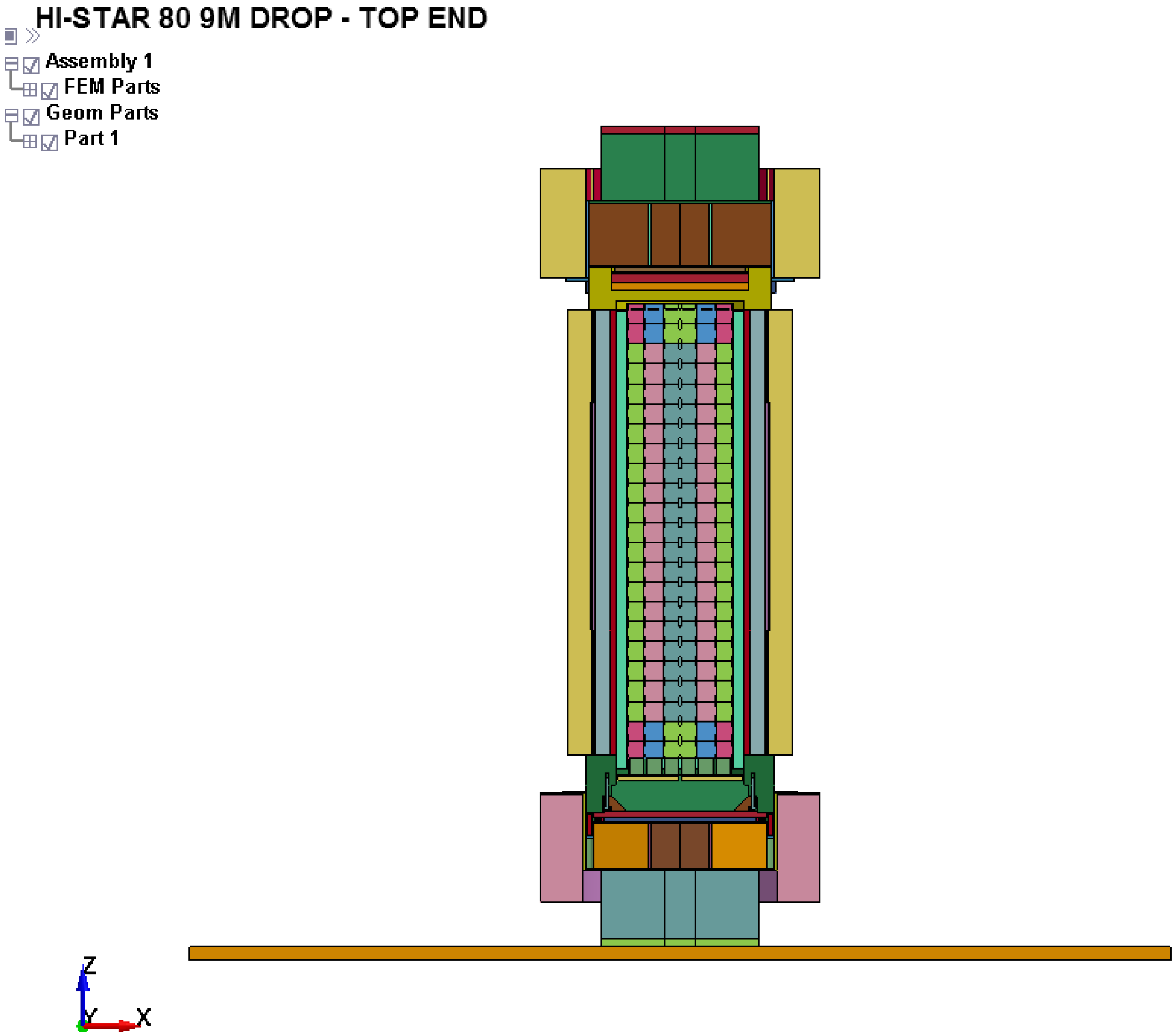

Figure 2.7.5A: HI-STAR 80 Package LS-DYNA Half Model – for Top End & CGOC Drops

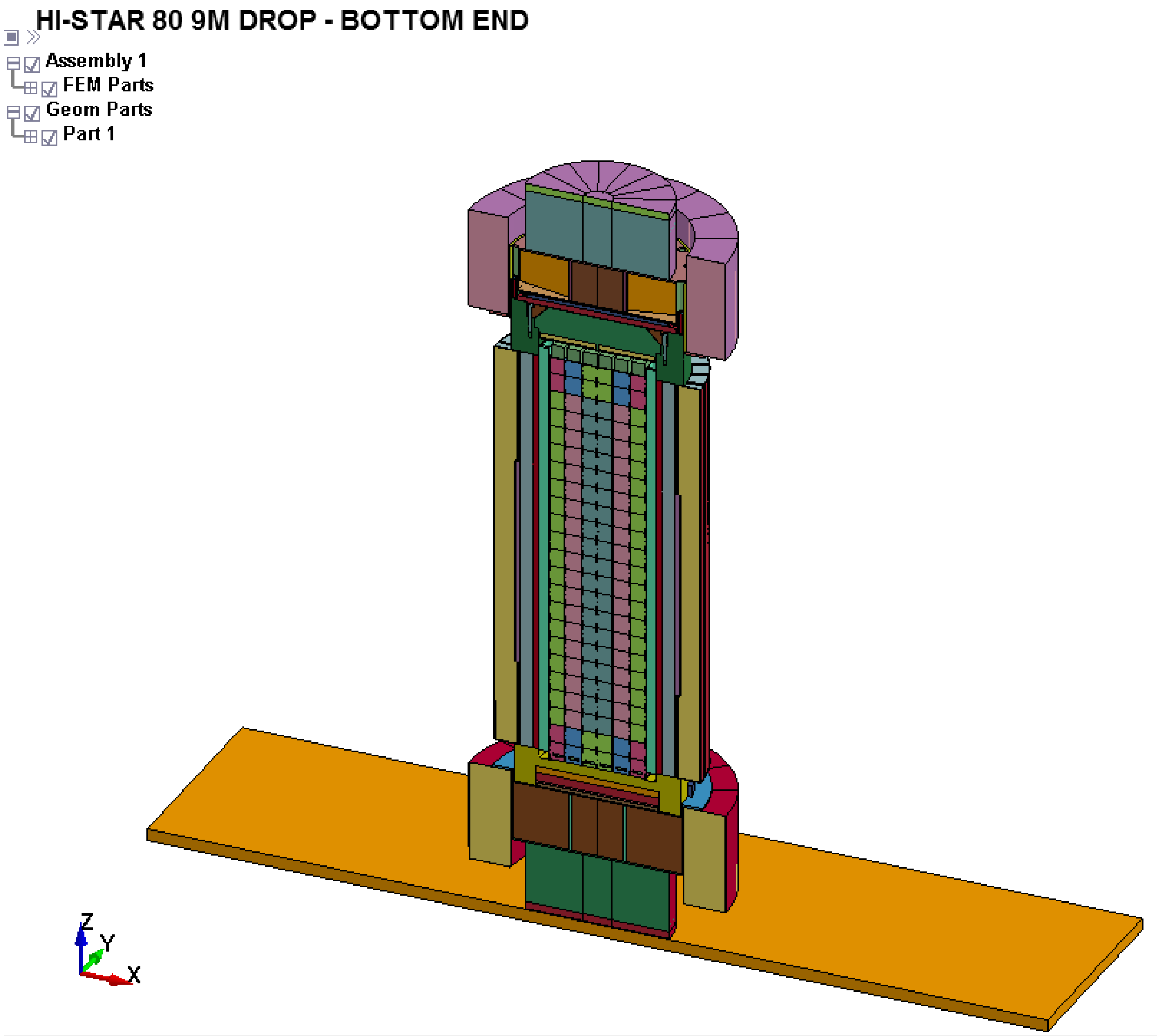

Figure 2.7.5B: HI-STAR 80 Package LS-DYNA Half Model – for Bottom End Drop

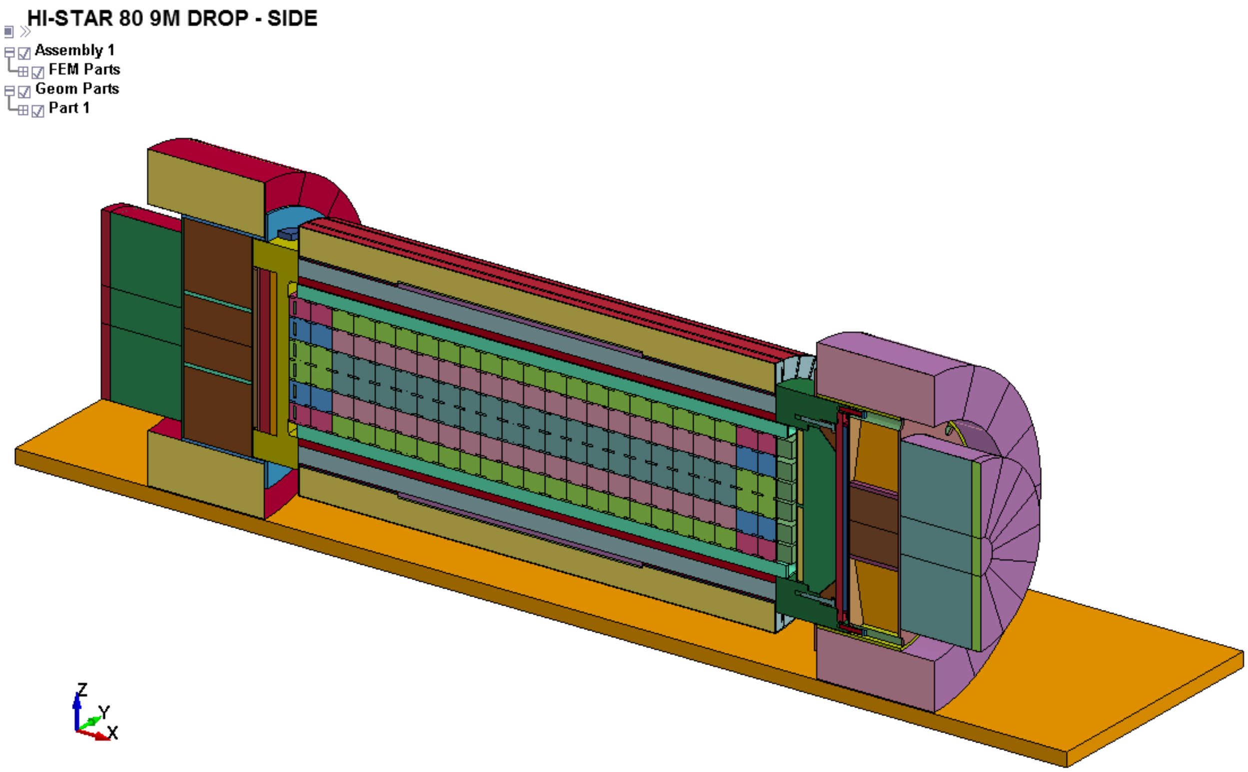

Figure 2.7.5C: HI-STAR 80 Package LS-DYNA Half Model – for Side Drops

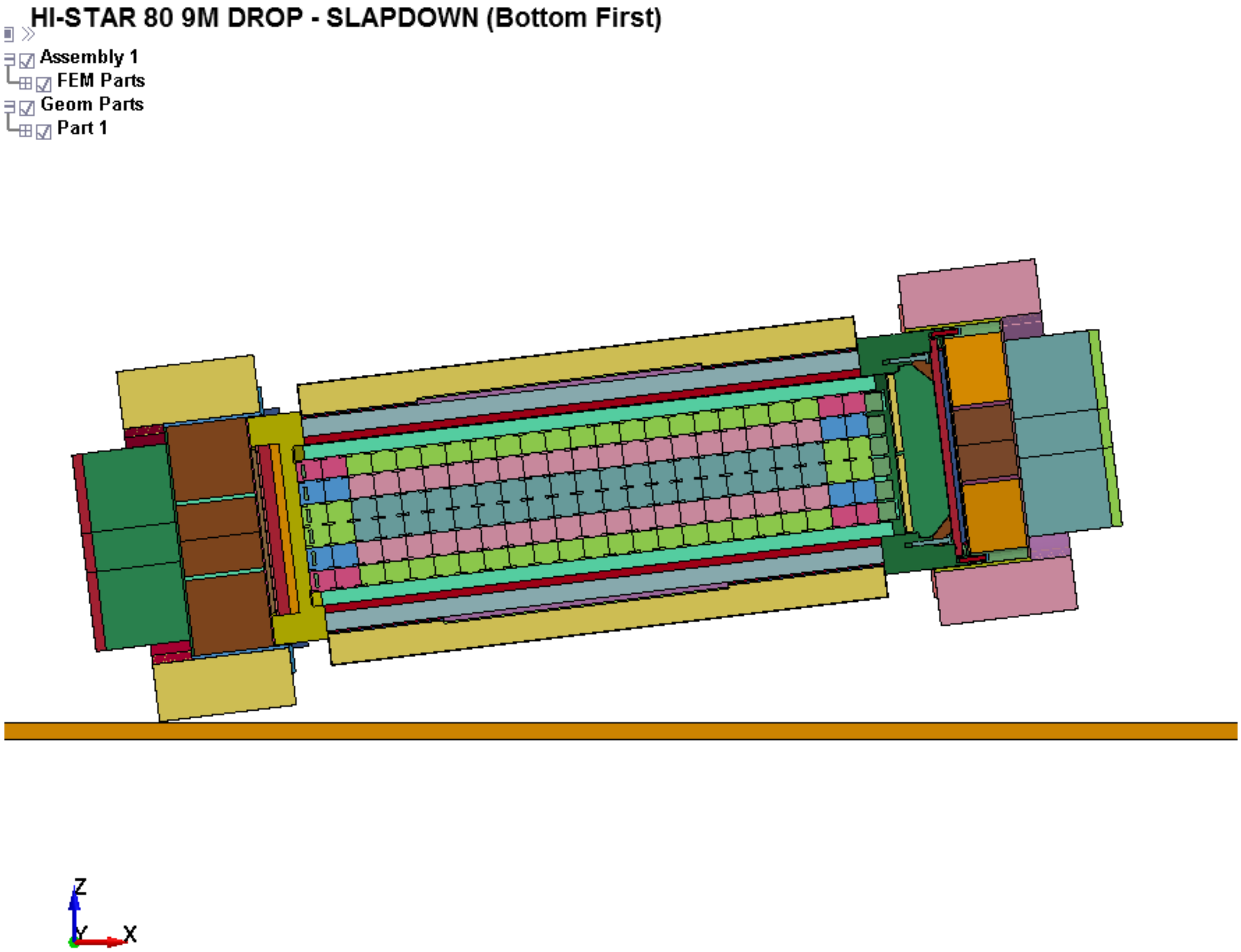

Figure 2.7.5D: HI-STAR 80 Package LS-DYNA Half Model – for Oblique Drops

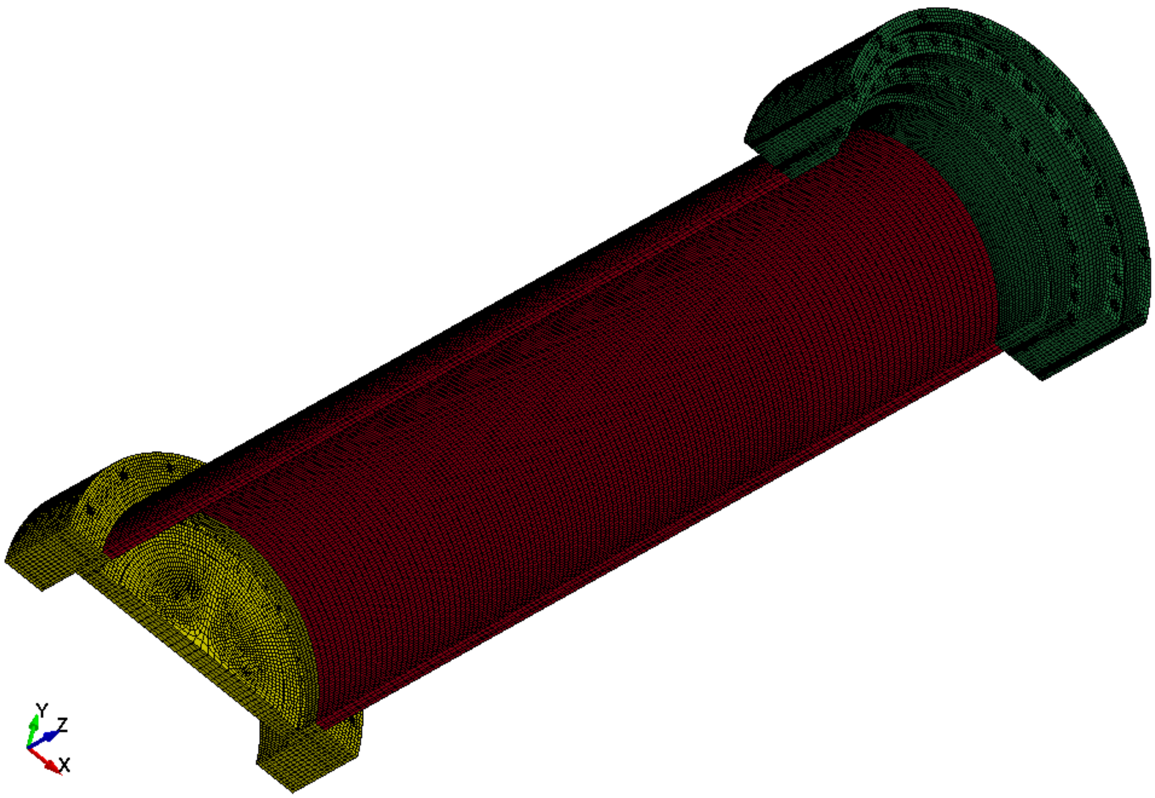

Figure 2.7.6: Finite Element Grid for HI-STAR 80 Cask Body Containment Components (Excluding Closure Lids and Closure Bolts)

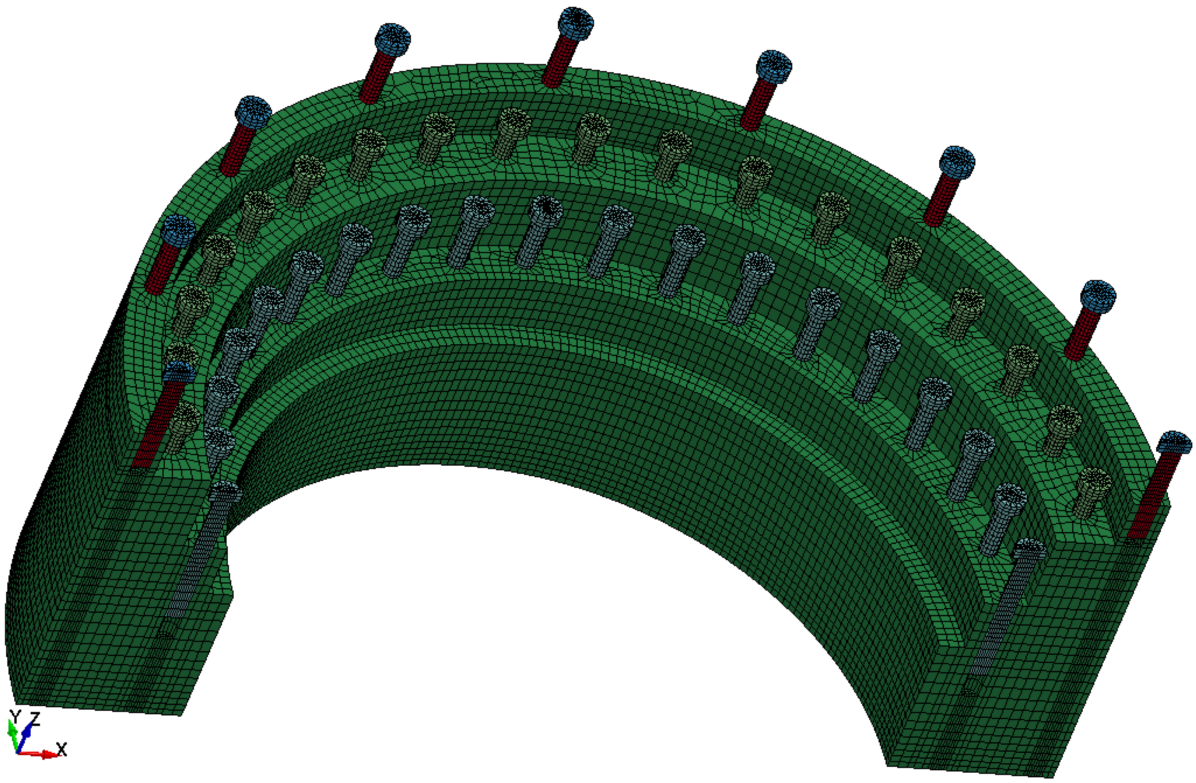

Figure 2.7.7: Finite Element Grid for HI-STAR 80 Top Forging and Bolts

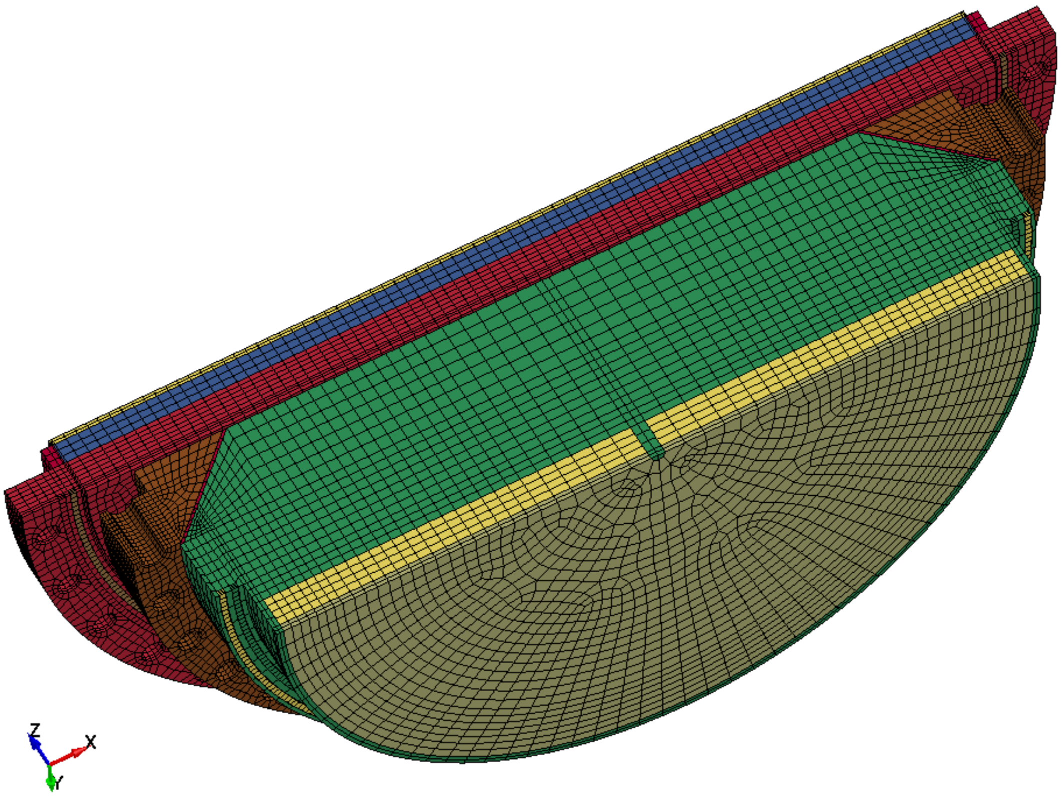

Figure 2.7.8: Finite Element Grid for HI-STAR 80 Closure Lids, Seals, and Inner Lid Plug Retainer Ring

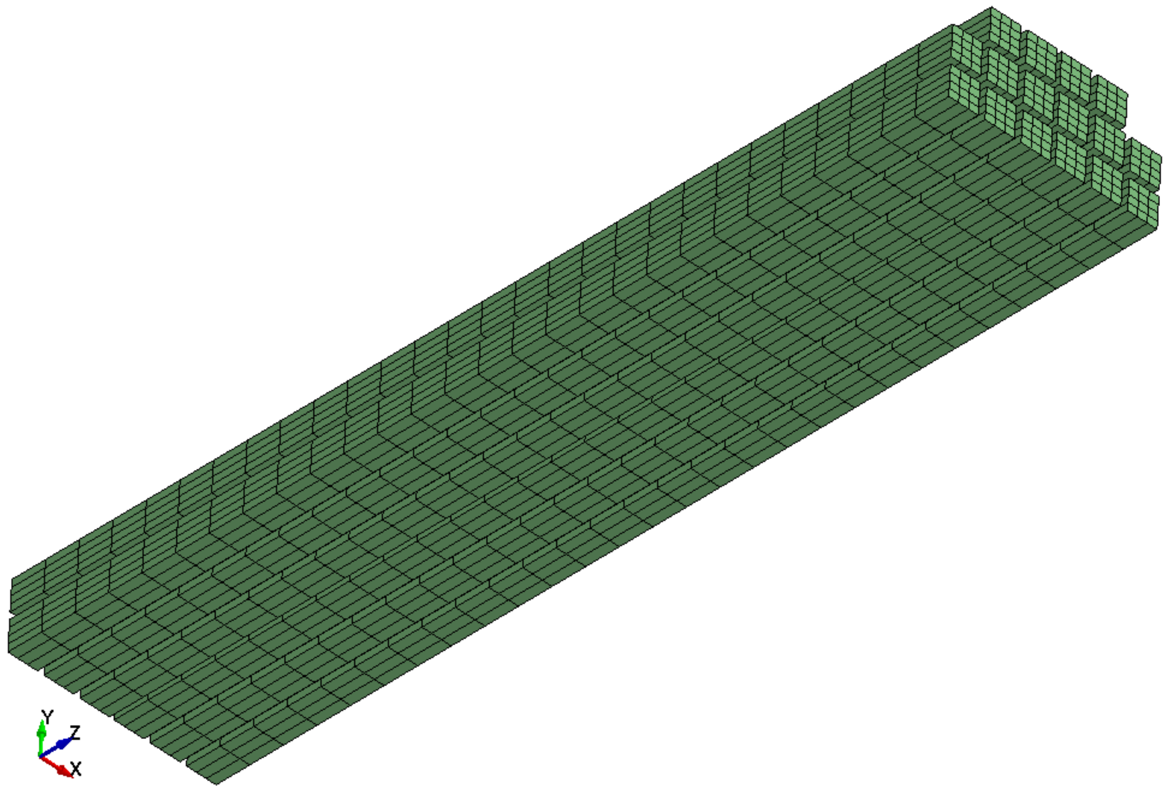

Figure 2.7.9: Fuel Assembly Array Model

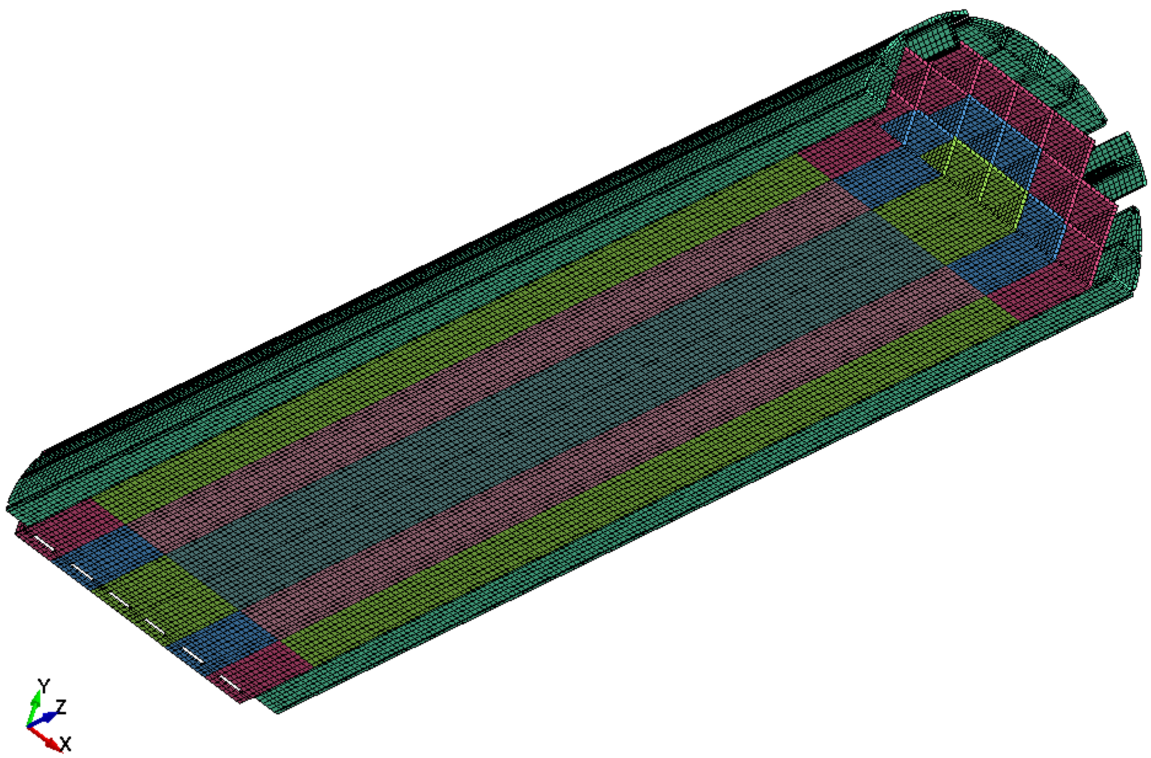

Figure 2.7.10: LS-DYNA Model of F-32B Fuel Basket and Basket Support

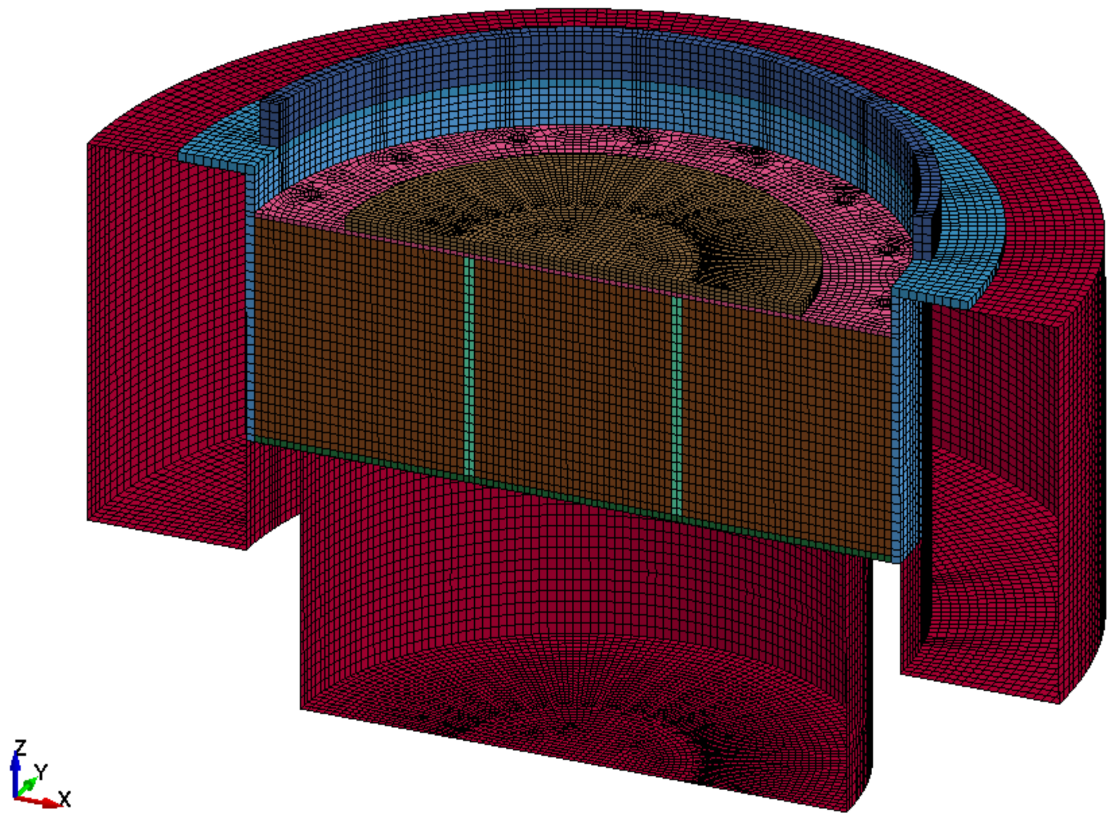

Figure 2.7.11A: LS-DYNA Model of Bottom Impact Limiter (w/o aluminum honeycomb)

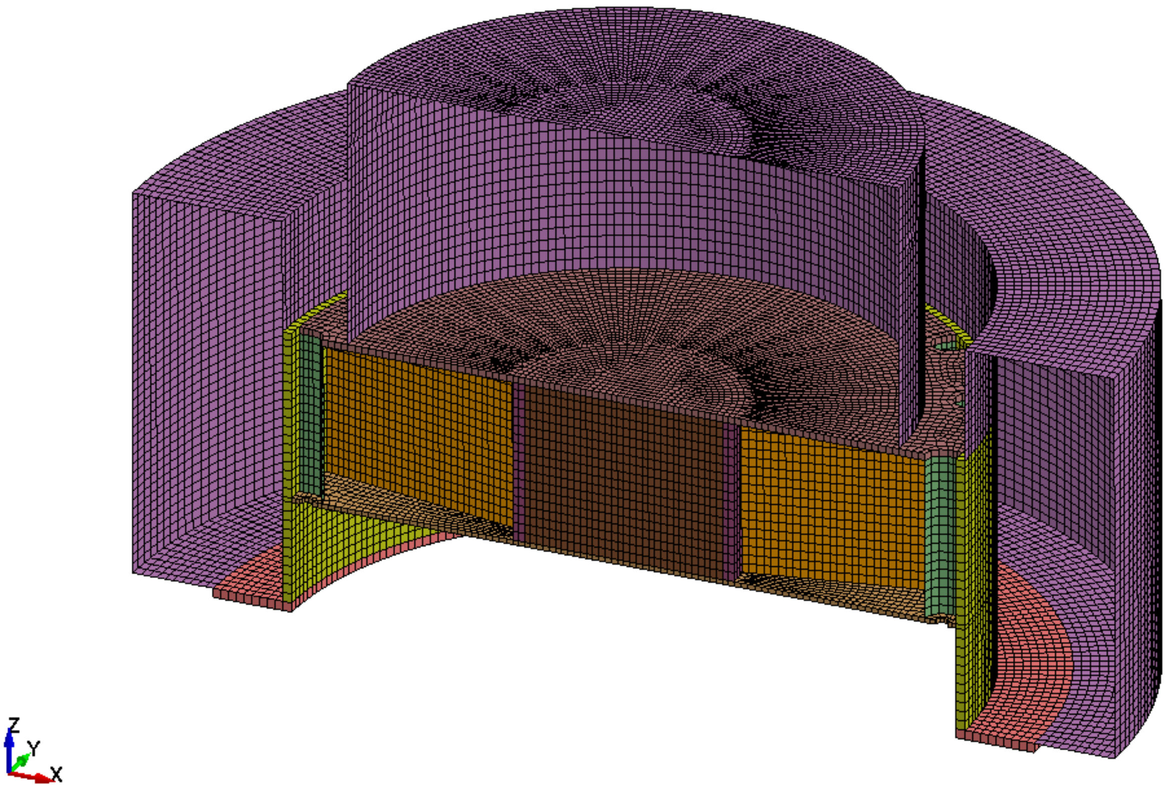

Figure 2.7.11B: LS-DYNA Model of Top Impact Limiter (w/o aluminum honeycomb)

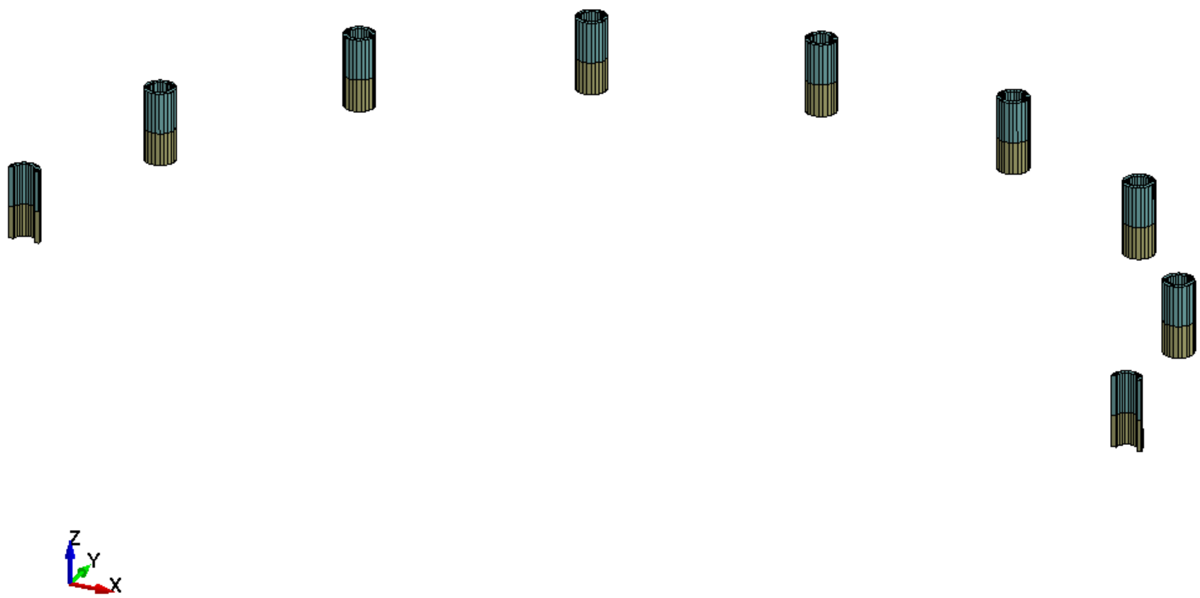

Figure 2.7.11C: LS-DYNA Models of the FSL (in Top Impact Limiter)

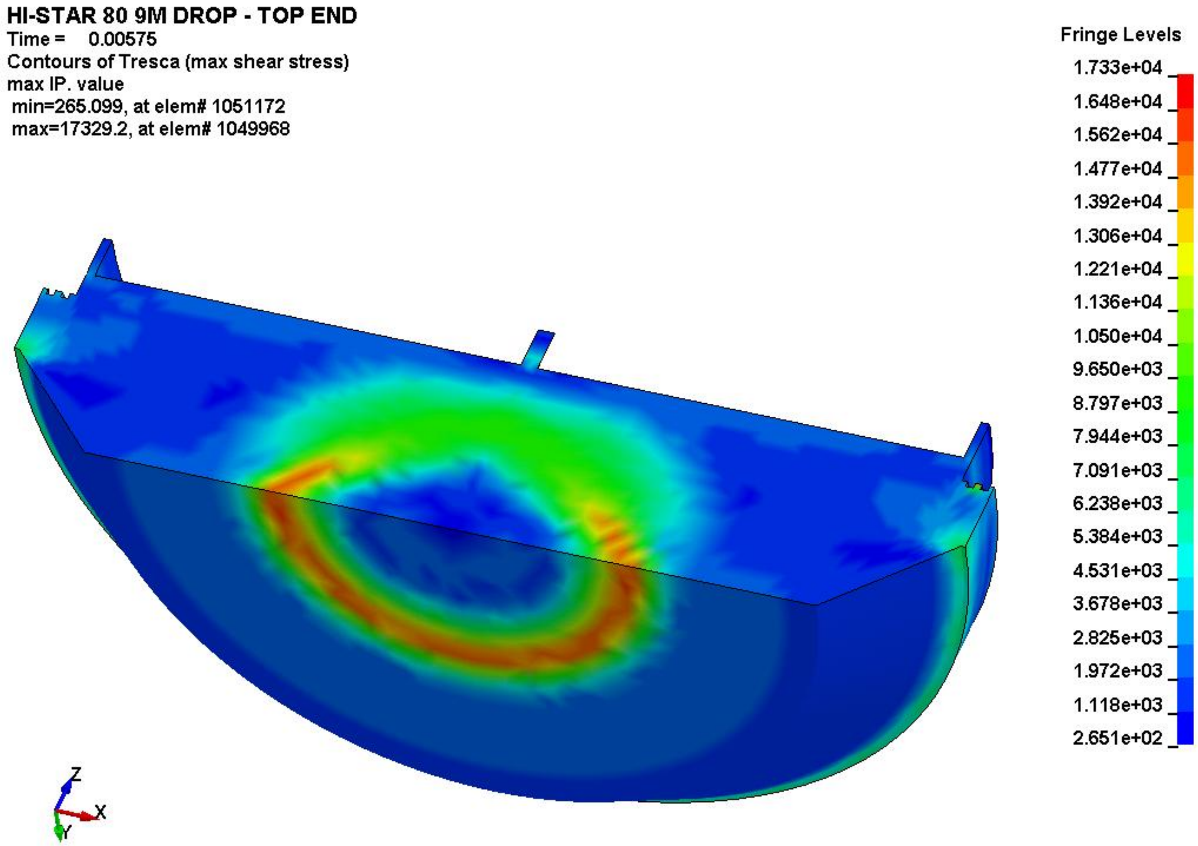

Figure 2.7.12: Maximum Shear Stress (Stress Intensity = 2×17.33 ksi) of the Inner Closure Lid Plug - 30' Top End Drop

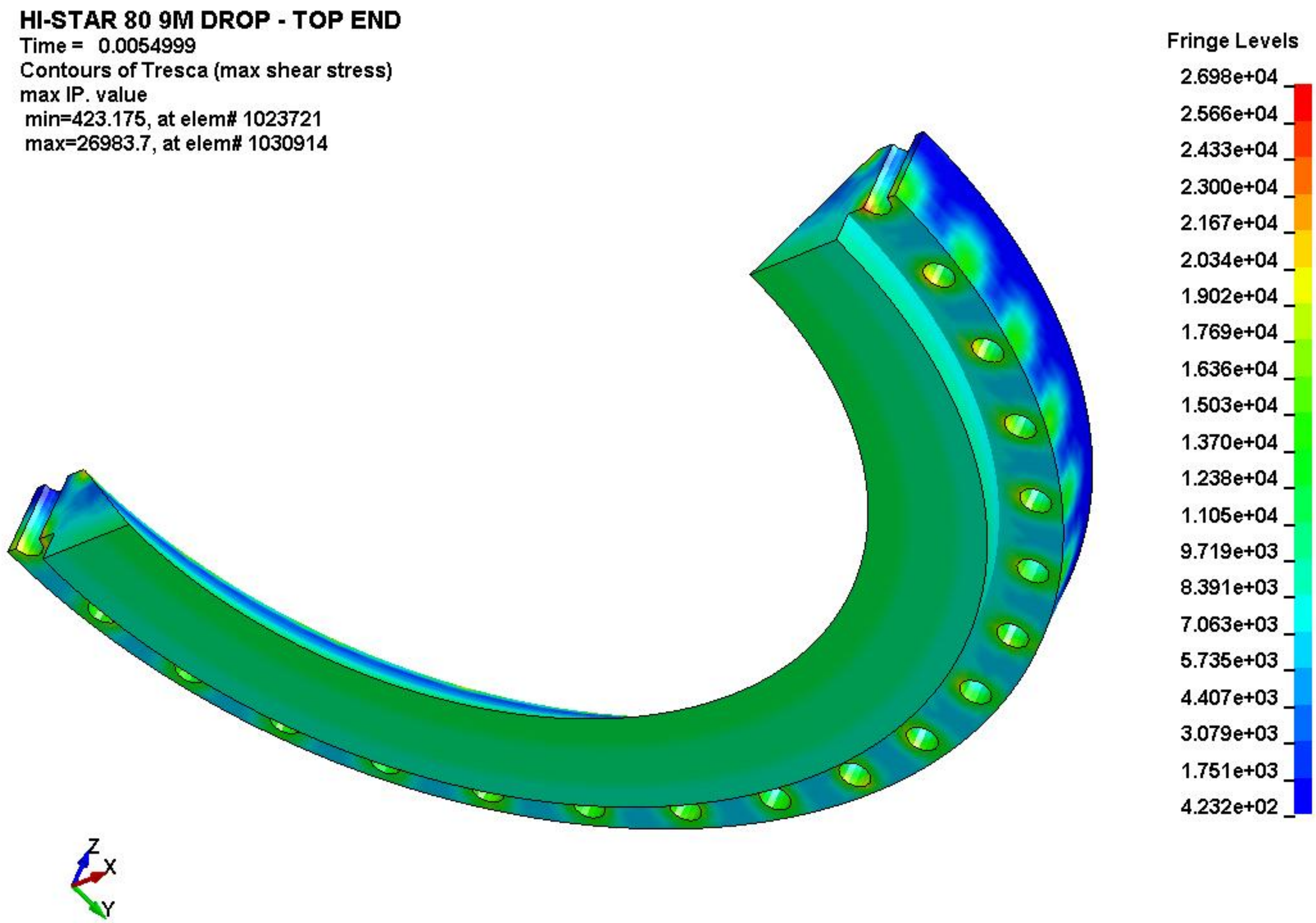

Figure 2.7.13: Maximum Shear Stress (Primary Stress Intensity = 2×17.69 ksi) of the Inner Lid Plug - 30' Top End Drop

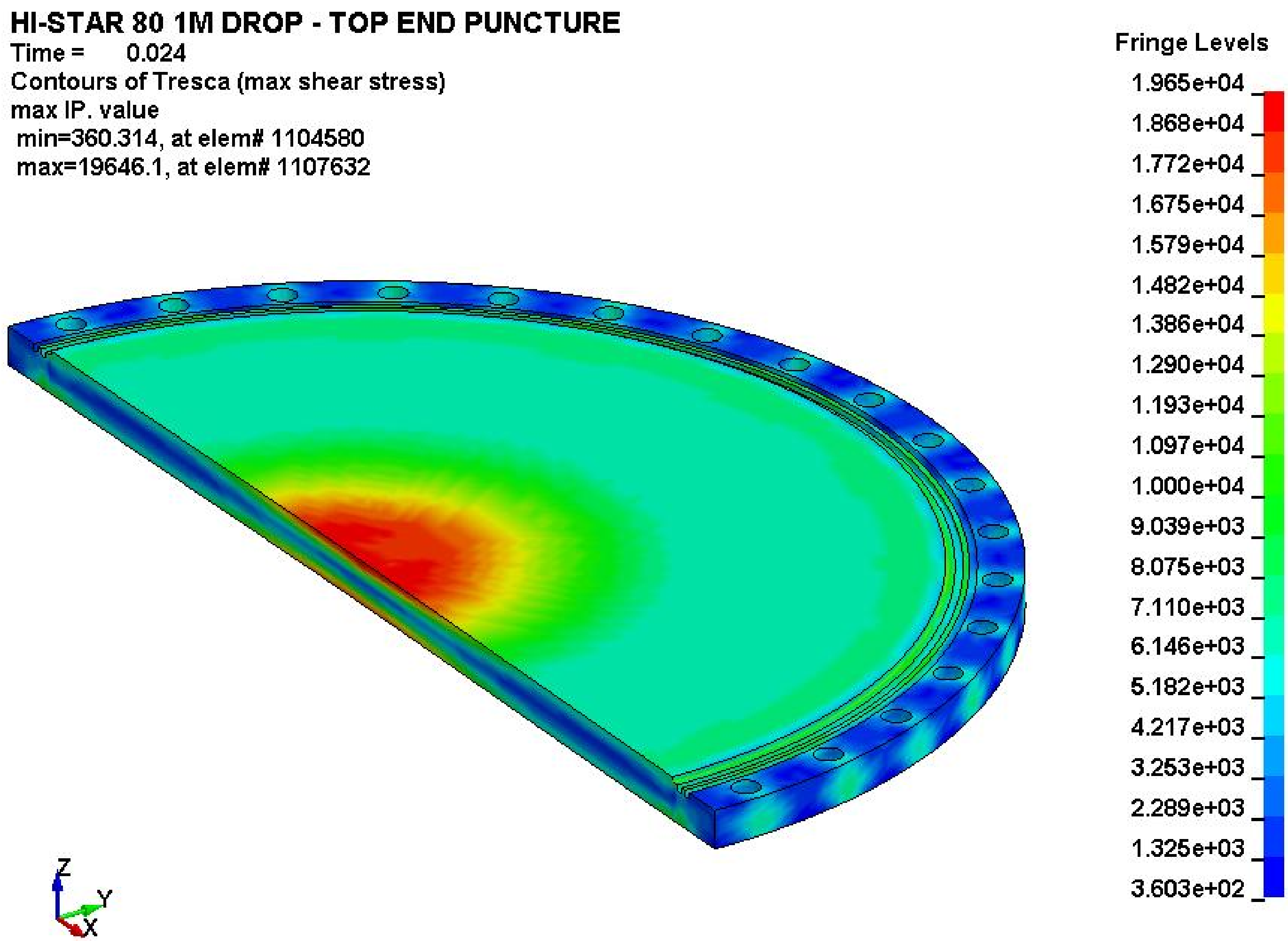

Figure 2.7.14: Maximum Shear Stress (Primary Stress Intensity: 39.3 ksi = 2×19.65 ksi) of the Outer Closure Lid – 1M Top End Drop Puncture

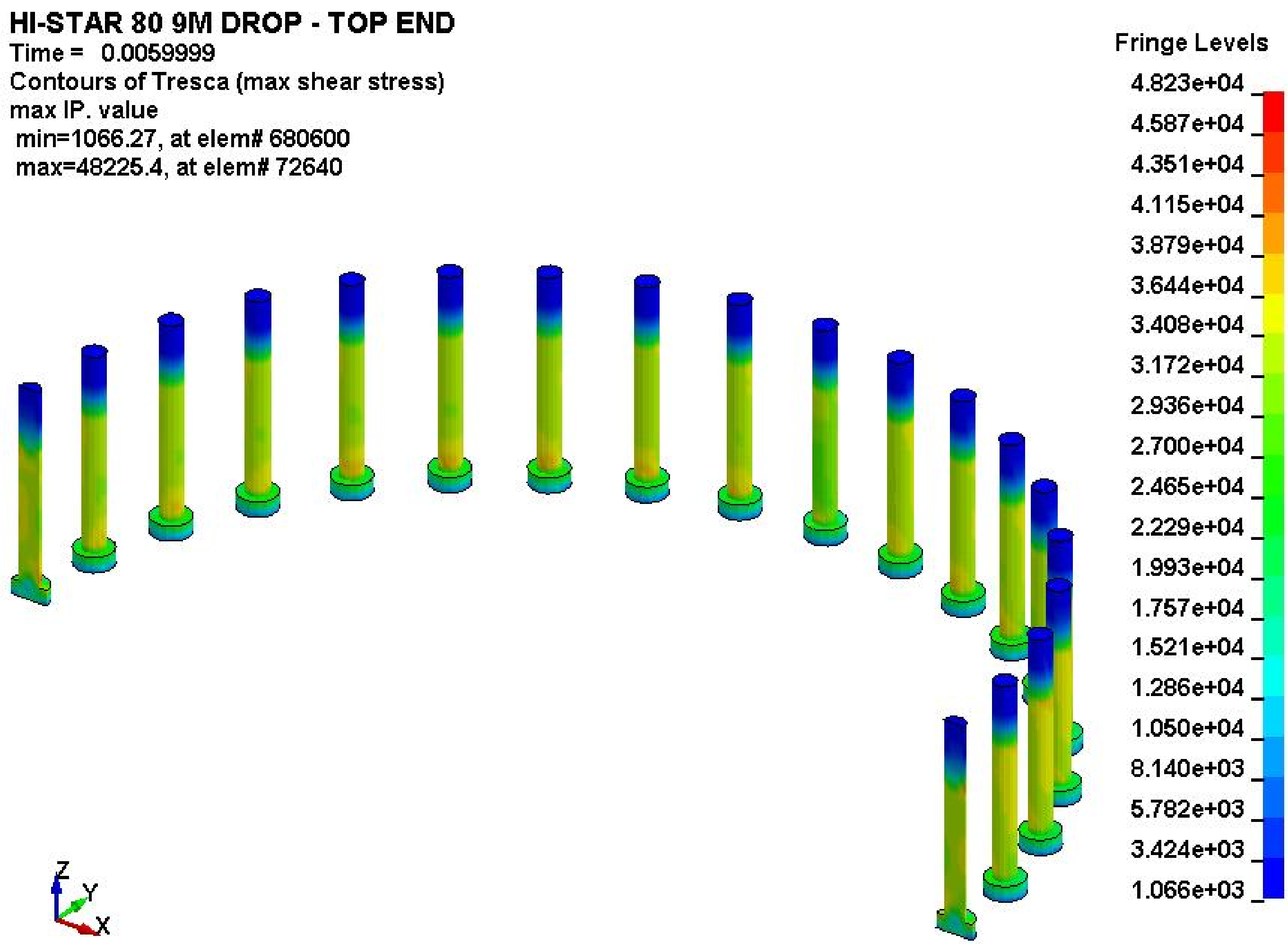

Figure 2.7.15: Maximum Shear Stress of Inner Lid Bolts - 30' Top End Drop
(Average Stress Intensity = (41.15+34.08) ksi, Stress Intensity at Extreme Fiber w/o Stress Concentration = 2×41.15 ksi)

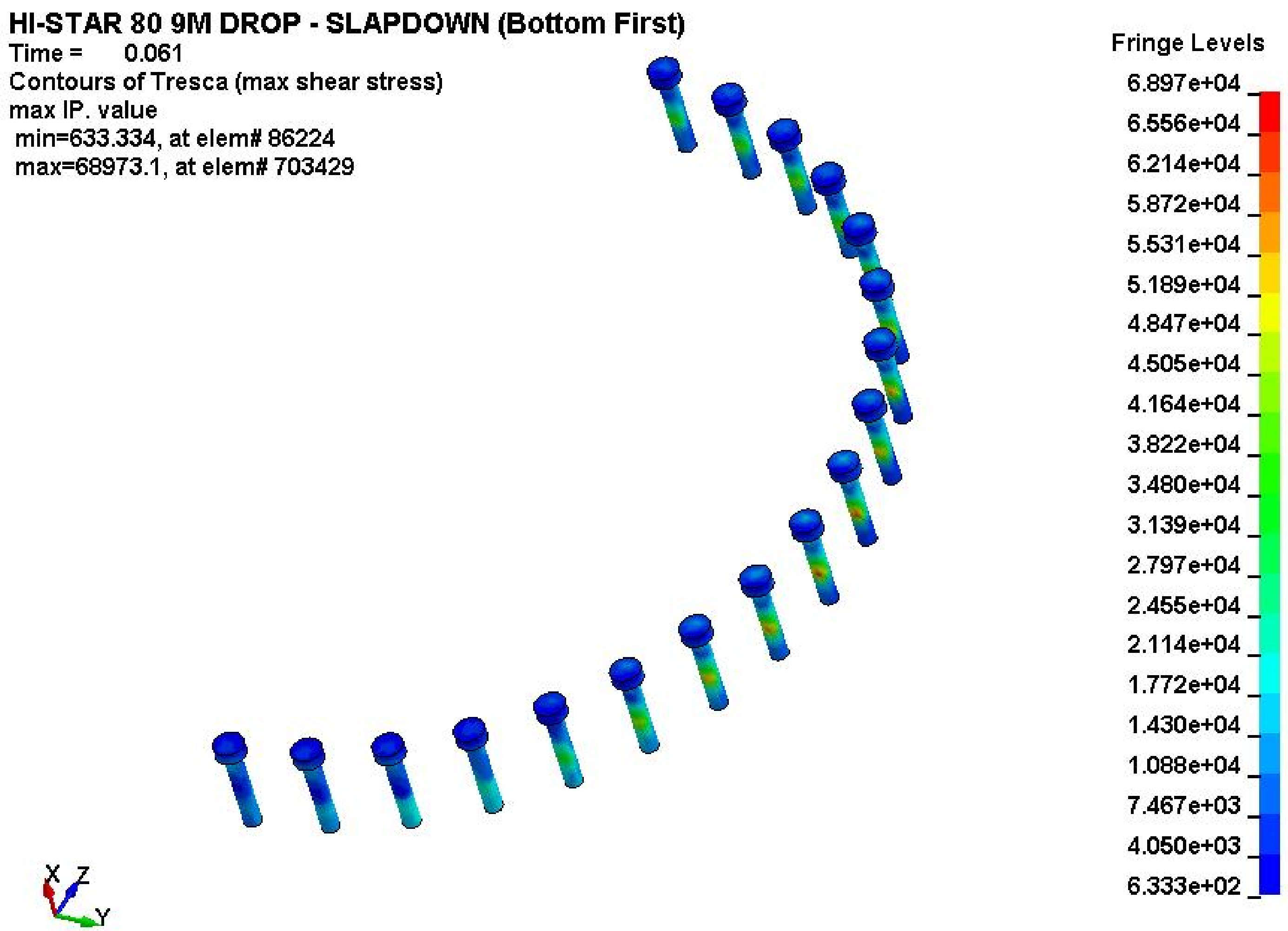

Figure 2.7.16: Maximum Shear Stress of the Outer Lid Bolts – 30' Slapdown Drop (Bottom First)
(Average Stress Intensity = (62.14+21.14) ksi, Stress Intensity at Extreme Fiber w/o Stress Concentration = 2×62.14 ksi)

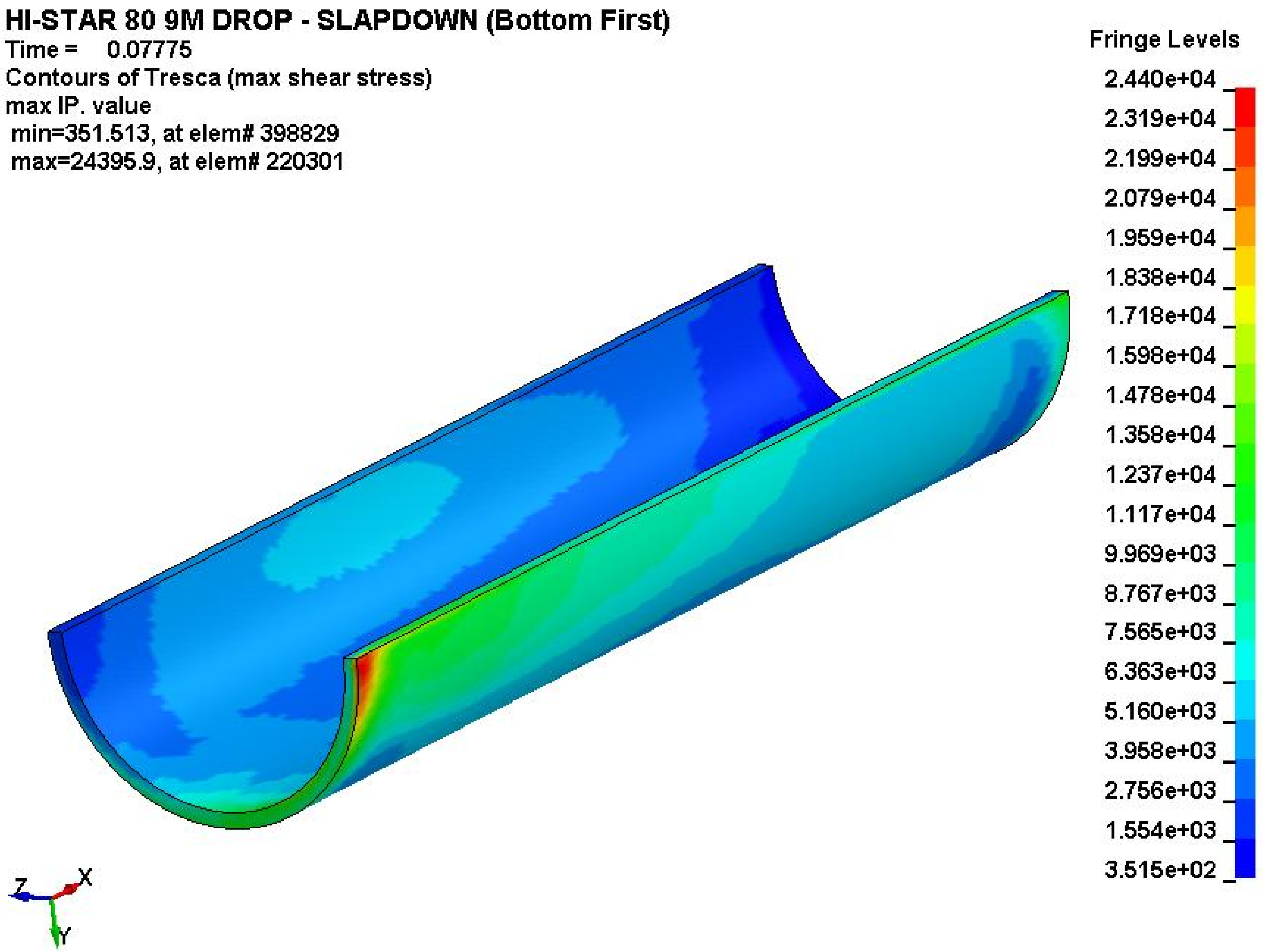

Figure 2.7.16: Maximum Shear Stress of the Containment Shell – 30' Slapdown Drop (Bottom First)

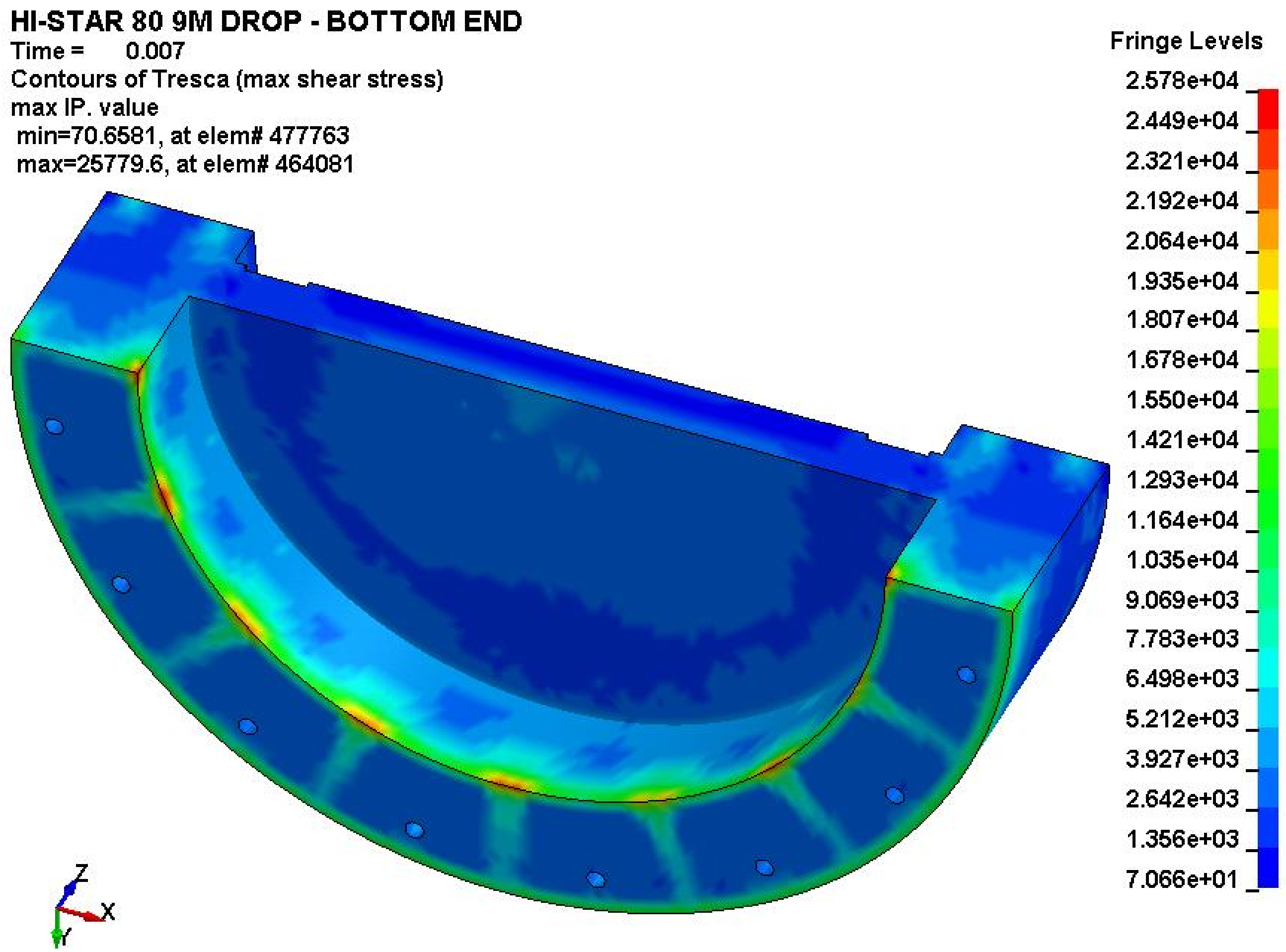

Figure 2.7.17: Maximum Shear Stress (Primary Stress Intensity = 2×10.35 ksi) of the Baseplate - 30' Bottom End Drop

2.8 ACCIDENT CONDITIONS FOR AIR TRANSPORT OF PLUTONIUM

This section is not applicable to the HI-STAR 80 Package. This application does not seek approval for air transport of plutonium and, therefore, does not address the accidents defined in 10CFR71.74.

2.9 ACCIDENT CONDITIONS FOR FISSILE MATERIALS FOR AIR TRANSPORT

This section is not applicable to the HI-STAR 80 Package. This application does not seek approval for air transport of fissile materials and, therefore, does not address the accidents defined in 10CFR71.55(f).

2.10 SPECIAL FORM

This section is not applicable to the HI-STAR 80 Package. This application does not seek approval for transport of special form radioactive material; therefore, the requirements of 10CFR71.75 are not applied.

2.11 FUEL RODS

The cladding of the fuel rods is the first boundary for confining radiological matter in the HI-STAR 80 Transport Cask. Analyses have been performed in Chapter 3 to ensure that the maximum temperature of the fuel cladding is well below ISG-11, Rev. 3 regulatory limits [2.11.1].

The vertical drop of the package, leading to a rapid axial deceleration of the stored fuel and the consequent flexural strains, is recognized as the most vulnerable free drop configuration from the standpoint of potential damage to the fuel [2.11.2, 2.11.3]. Fortunately, the problem of large inertial loading of fuel has been comprehensively studied in the published NUREG/CR-1864 [2.11.5] and studies conducted by Pacific Northwest National Laboratory (PNNL) and USNRC [2.11.4], which obsolesces prior analyses and provides a robust and conservative basis for prognosticating fuel damage under vertical drop events.

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PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

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Table 2.11.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 2.11.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.3: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.4: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.5a: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.5b: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.5c: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Figure 2.11.6: **PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390**

CHAPTER 2 REFERENCES

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

[2.1.1] ASME Boiler & Pressure Vessel Code, Section III, Subsection NB, American Society of Mechanical Engineers, 2010 Edition.

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

[2.1.3] 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.

[2.1.4] 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.

[2.1.5] NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants," United States Nuclear Regulatory Commission, July, 1980.

[2.1.6] ASME Boiler & Pressure Vessel Code, Section II, Parts A and D, American Society of Mechanical Engineers, 2010 Edition.

[2.1.7] 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", United States Nuclear Regulatory Commission, June, 1991.

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

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

[2.1.10] ASME Boiler & Pressure Vessel Code, Section III, Appendices, American Society of Mechanical Engineers, 2010 Edition.

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

[2.1.12] Structural Calculation Package for the HI-STAR 80 Transport Cask System, Holtec International Proprietary Report HI-2156553, Latest revision.*

[2.1.13] "Safety Analysis Report on the HI-STAR 63 package", Holtec Report HI-2073777, Revision 3.

[2.1.14] ASME Boiler & Pressure Vessel Code, Section III, Subsection NF, American Society of Mechanical Engineers, 2010 Edition.

[2.1.15] Not Used.

[2.1.16] Holtec Position Paper DS-331, "Structural Acceptance Criteria for the Metamic-HT Fuel Basket", Rev. 1.

[2.1.17] NUREG/CR-3826, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick."

[2.1.18] Not Used .

[2.1.19] Not Used.

[2.1.20] "Mechanics of Sealing Action in a Controlled Compression Flanged Joint," Holtec position paper DS-337, Revision 1.

[2.1.21] "Friction, Wear, and Microstructure of Unfubricated Austenitic Stainless Steel," by K. L. Hsu, T. M. Ahn, and D. A. Rigm Ohio State University. *ASME Wear of Materials*-1979.

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[2.2.1] Hexweb Honeycomb Attributes and Properties, HEXCEL Corp, Pleasanton, CA., 2006. (web site is www.hexcel.com).

[2.2.2] "Safety Analysis Report for the HI-STAR 100 Package", Holtec Report HI-951251,

latest revision, Docket No. 71-9261.

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

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

ANSYS Mechanical

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

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

LS-DYNA

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

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

* This appendix contains generic information and is identical to the one submitted in the HI-STAR 60 SAR and HI-STAR 180 SAR. Under Holtec's configuration control, this appendix will be immediately revised in all submitted SARs if a USNRC request-for-additional-information (RAI) necessitates a change to its contents.

CHAPTER 3: THERMAL EVALUATION

3.0 INTRODUCTION

In this chapter, compliance of the HI-STAR 80 Package to 10 CFR Part 71 [1.0.2] and ISG-11, Rev. 3 [3.3.3] thermal requirements is evaluated for normal transport and hypothetical accident conditions of transport. The analysis considers passive rejection of decay heat from the Spent Nuclear Fuel (SNF) or non-fuel waste to a 10CFR71- mandated environment for normal transport and hypothetical fire accident conditions.

The 10CFR71 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. With respect to the initial conditions for the events of normal conditions of transport and hypothetical accident conditions, the demonstration of compliance with the requirements of 10CFR71 must be based on the ambient temperature preceding and following the event remaining constant at that value between a bounding -40^{o}C (-40°F) and 38^{o}C (100°F) which is most unfavorable for the feature under consideration. The initial internal pressure within the containment must be considered to be the maximum normal operating pressure [§71.71(b) and §71.73(b)].

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

4. For normal conditions of transport, a cold event consisting of an ambient temperature of -40°C (-40°F) in still air and shade must be evaluated [§71.71(c)(2)].

5. Evaluation for hypothetical accident conditions is to be based on sequential application of the specified events, in the prescribed order, to determine their cumulative effect on a package [§71.73(a)].

6. For hypothetical accident conditions, a thermal event consisting of a fully engulfing hydrocarbon fuel/air fire with an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 802^{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 80 Package. Section 3.2 lists the material properties data required to perform the thermal analyses and the applicable temperature limits criteria required to demonstrate the adequacy of the HI-STAR 80 Package design under normal and hypothetical accident conditions. Thermal analyses for the normal transport are described and evaluated in Section 3.3. Thermal analyses for hypothetical accident conditions are described and evaluated in Section 3.4.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation for normal conditions of transport documented in this chapter are similar to those used in the SAR for HI-STAR 180 certified in Docket #71-9325 and for HI- STAR 180D certified in Docket #71-9367.

3.1 DESCRIPTION OF THERMAL DESIGN

3.1.1 Design Features

Design details of the HI-STAR 80 Package are presented in Chapter 1 and structural and mechanical features are described in Chapters 1 and 2. The HI-STAR 80 Package geometry is detailed in Holtec drawings included in Chapter 1. All materials of construction are itemized in the drawings. The assembled packaging with impact limiters installed is shown in Chapter 1 (see Figures 1.3.1 and 1.3.2). As shown in these figures, the HI-STAR 80 Package is equipped with a personnel barrier to prevent access to hot cask surfaces. The HI-STAR 80 package employs a fuel basket or a non-fuel waste basket inside a thick steel cask with twin (inner and outer) bolted closure lids. The HI-STAR 80 package is designed with the F-12P fuel basket to transport up to 12 PWR fuel assemblies, the F-32B fuel basket to transport up to 32 BWR fuel assemblies, the non-fuel waste basket (NFWB-1) to transport non-fuel waste. The H-STAR 80 package is also designed to accommodate quivers to transport damaged fuel rods. For the transport of fuel assemblies or quivers with the F-12P or F-32B fuel basket, the cask cavity is dried and backfilled with helium prior to lid closure. This provides a stable and inert environment for the transport of the Spent Nuclear Fuel (SNF). The cask cavity containing the non-fuel waste can be backfilled with either helium or air. Heat is transferred from the cask to the environment by passive heat transport mechanisms only.

The HI-STAR 80 Package is designed to safely dissipate heat under passive conditions (no wind). During transport, the HI-STAR 80 Package is placed in a horizontal position with impact limiters installed at both ends of the cask. Under normal transport conditions, the cask contents (fuel basket with fuel assemblies or non-fuel waste basket with core components) rest on solid surfaces. Direct contact between the cask and its contents enhances heat dissipation. To transport fuel assemblies with the F-12P or F-32B fuel basket, the cask cavity is backfilled with helium prior to cask closure. A double-lid design is engineered to eliminate air in-leakage during transport and to prevent water ingress under a hypothetical water immersion accident. Presence of a substantially more conductive medium (helium) relative to air in the cavity spaces aids heat transfer by minimizing gap resistances and dissipating heat by natural convection in the cavity peripheral spaces.

The fuel basket (F-12P and F-32B) is a matrix of rectangular shaped fuel compartments sized to store Spent Nuclear Fuel (SNF). The fuel basket is formed by a honeycomb structure of thick Metamic-HT plates. The fuel basket is surrounded by an array of shaped aluminum spacers (basket shims) in the cask cavity peripheral spaces. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390] Cross-sectional views of the F-12P and F-32B basket designs are provided in Chapter 1. Heat is dissipated in the fuel basket principally by conduction of heat in the highly conductive Metamic-HT plates arrayed in two orthogonal directions. Heat dissipation in the fuel basket peripheral spaces is by a combination of contact heat transfer, helium conduction and radiation across narrow peripheral spacer gaps and by conduction through the basket shims. The fuel basket and the basket shims reside in a containment boundary formed by the containment shell, containment upper and lower forgings and two closure lids. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390] The cask body exterior is engineered with low profile fins to

enhance heat transfer area and concomitant dissipation of heat.

Similar to the F-12P and F-32B baskets, the non-fuel waste basket (NFWB-1) is a square shaped compartment formed by stainless steel plates to store non-fuel waste. The non-fuel waste basket is surrounded by supporting pipes and plates. The cross-sectional view of the non-fuel waste basket design is provided in Chapter 1. Heat is dissipated from the basket to the cask body by a combination of contact heat transfer, conduction through a gaseous medium and radiation. Since the decay heat released by the core components (see Table 7.D.8) is significantly lower than the decay heat of the fuel assemblies (see Table 7.D.1), the temperature of the HI-STAR 80 cask with the non-fuel waste basket to transport core components will be much lower than the temperature of the HI-STAR 80 cask with the fuel basket to transport fuel assemblies. Due to the significantly lower decay heat for a cask loaded with non-fuel waste, it is not necessary to backfill the cask cavity with helium to improve its thermal performance. Therefore, from this point forward in this chapter, the thermal analysis will focus on the thermal performance of the HI-STAR 80 cask with the fuel basket (F-12P and F-32B) to transport spent nuclear fuel assemblies.

The helium backfill gas is an integral part of the HI-STAR 80 thermal design to transport spent nuclear fuel. The helium fills all the spaces between solid components and provides an improved conduction medium (compared to air) for dissipating decay heat. Additionally, helium in the spaces between the basket and the cask cavity is heated differentially and dissipates heat by the so-called “Rayleigh” convection. To ensure that the helium gas is retained and not diluted by lower conductivity air, the cask containment boundary is designed as an ASME Section III pressure vessel equipped with high integrity double seals in both the inner and outer closure lids. This ensures the presence of helium during transport. The helium gas is therefore retained in an undiluted state, and may be credited in the thermal analyses. The thermal conductivity of helium varies with temperature and pressure. For all the helium backfill pressure ranges specified in Table 7.1.4, the thermal conductivity of helium is essentially independent of pressure. The dependence of the helium thermal conductivity on temperature is considered in the thermal analyses.

An important thermal design criterion imposed on the HI-STAR 80 Package is to ensure that the peak fuel cladding temperatures are below regulatory limits. An equally important design criterion is to minimize temperature gradients within the fuel basket to minimize thermal stresses. In order to meet these design objectives, the HI-STAR 80 fuel basket is designed to possess certain distinctive characteristics, which are summarized in the following.

The cask cavity design minimizes resistance to heat transfer within the basket and basket periphery regions. This is ensured by designing the fuel basket with highly conductive Metamic-HT plates. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390] The cask cavity design incorporates top and bottom plenums with interconnected downcomer paths to facilitate heat dissipation by internal helium circulation. This mode of heat transfer is always active due to the uneven power distribution in the cask and the gravity. The top and bottom plenums are formed between the cask ends and fuel basket lateral flow holes in the top and bottom sections of each fuel cell wall. The fuel basket is designed to minimize structural discontinuities (i.e., gaps),

which can introduce large thermal resistances to heat flow. Consequently, temperature gradients are minimized in this design, which results in lower thermal stresses within the basket. Low thermal stresses are also ensured by provisions in the cask design that permit unrestrained axial and radial thermal growth of the basket.

The thermal analysis of the HI-STAR 80 Package considers all three fundamental modes of heat transfer: conduction, natural convection and thermal radiation. On the outside surface of the package, heat is dissipated to the environment by buoyancy induced convective air-flow (natural convection) and thermal radiation. Within the cask body, heat dissipation is principally by heat conduction. Inside the cask cavity, heat dissipation is conservatively limited to conduction and radiation. Between surfaces (e.g., between neighboring fuel rods) heat is transported by a combination of conduction through a gaseous medium and thermal radiation. Finally buoyancy-induced convective heat transport occurs within the open spaces of the cask cavity. Heat transfer between the basket external surface and enclosure shell inside wall is enhanced by the so-called “Rayleigh” effect in differentially heated cavities [3.1.1]. In the interest of conservatism, convective heat transfer in the cavity spaces is neglected. Therefore, it is not necessary to backfill the cask cavity with high-pressure helium to enhance the convective heat transfer inside the cask cavity for transportation.

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

3.1.2 Contents Decay Heat

The fuel loading is required to comply with both the decay heat and burnup limits of fuel assemblies in Chapter 7 (Table 7.D.1). The cask, assembly, and quiver design heat loads are defined in Chapter 1 and Chapter 7 (Table 7.D.1). These tables define the permissible heat load patterns for the F-12P and F-32B baskets. The aggregate cask heat load, Q_d, under all transportation configurations is limited to the value specified in Chapter 7 (Table 7.D.1). The maximum permissible decay heat for a cask with NFWB-1 basket is specified in Table 7.D.8.

3.1.3 Summary Table of Temperatures

The HI-STAR 80 Package temperatures are analyzed under normal transport condition for both F-12P and F-32B fuel baskets. The permissible loading patterns for both baskets are evaluated and details on the bounding scenario are discussed in Section 3.3. The hypothetical fire accident event is evaluated for thermally bounding scenario, i.e. F-32B fuel basket with 32 fuel assemblies (FA). The modeling of the thermal problem is discussed in Sections 3.3 and 3.4. The analysis results are provided in Table 3.1.1.A for the limiting loading scenario in F-12P basket and Table 3.1.1.B for the limiting loading scenario in F-32B basket. The analysis result for the thermally bounding scenario under the hypothetical fire accident event is presented in Table 3.1.3. The HI-STAR 80 normal transport and hypothetical accident temperatures comply with

the normal and accident temperature limits specified in Tables 3.2.10, 3.2.11 and 3.2.12.

3.1.4 Summary Table of Maximum Pressures

The HI-STAR 80 Package containment boundary pressures are computed for normal transport condition and hypothetical fire accident event. The numerical modeling is discussed in Sections 3.3 and 3.4. The analysis results are provided in Table 3.1.2.A for the limiting loading scenario in F-12P basket, Table 3.1.2.B for the limiting loading scenario in F-32B basket, and Table 3.1.4 for the thermally bounding scenario under the hypothetical fire accident event. The HI-STAR 80 normal transport and hypothetical accident containment pressures comply with the pressure limits specified in Chapter 2, Table 2.1.1.

3.1.5 Cask Surface Temperature Evaluation

In accordance with the regulatory requirement specified in 10CFR71 (§71.43(g)), the cask external surface temperature is computed in still air at 38^{o}C (100^{o}F) and in the shade. Under this scenario, the maximum computed cask surface temperature reported in Table 3.1.5 is above the allowable surface temperature limit of 85^{o}C (185^{o}F). To meet the accessible surface temperature limit, a personnel barrier as defined in Chapter 1 will be required. The personnel barrier must be engineered to provide personnel protection without adversely impacting cask and fuel temperatures. In Section 3.3, a personnel barrier is conservatively defined and evaluated for the package under the thermally limiting scenario.

Table 3.1.1.A: HI-STAR 80 with F-12P Normal Transport Maximum Temperatures

Material/Component	Temperature °C (°F) With 12 FA
Fuel Cladding	367(693)
Fuel Basket	294(561)
Containment Shell	169(336)
Neutron Shield Note-1	153(307)
Lead Note-1	164(327)
Cask Finned Surface	128(262)
Containment Lower Forging	156(313)
Containment Upper Forging	156(313)
Inner Closure Lid Note-2	118(244)
Outer Closure Lid Note-2	109(228)
Inner Closure Lid Seals Note-3	
Inner Seal	118(244)
Test Port Plug Seal	118(244)
Vent Port Seals	121(250)
Drain Port Seals	130(266)
Spray Cooling Seals	121(250)
Outer Closure Lid Seals Note-3	
Inner Seal	108(226)
Test Plug Seal	112(234)
Basket Shims	248(478)
Impact Limiter Crush Material	
• Bottom Bulk	72(162)
• Bottom Maximum	82(180)
• Top Bulk	72(162)
• Top Maximum	79(174)

Note-1: The temperature of neutron shield and gamma shield components with the highest temperature is reported.
Note-2: In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported.
Note-3: The temperature of most limiting seals relied upon for containment function is reported herein. All the containment boundary seals are identified in Chapter 4.

Table 3.1.1.B: HI-STAR 80 with F-32B Normal Transport Maximum Temperatures

Material/Component	Temperature °C (°F)
	With 32 FA
Fuel Cladding	374(705)
Fuel Basket	343(649)
Containment Shell	175(347)
Neutron Shield Note-1	158(316)
Lead Note-1	170(338)
Cask Finned Surface	132(270)
Containment Lower Forging	161(322)
Containment Upper Forging	160(320)
Inner Closure Lid Note-2	124(255)
Outer Closure Lid Note-2	113(235)
Inner Closure Lid Seals Note-3 Inner Seal Test Port Plug Seal Vent Port Seals Drain Port Seals Spray Cooling Seals	 123(253) 122(252) 125 (257) 135(275) 125 (257)
Outer Closure Lid Seals Note-3 Inner Seal Test Plug Seal	 112(234) 116(241)
Basket Shims	246(475)
Impact Limiter Crush Material • Bottom Bulk • Bottom Maximum • Top Bulk • Top Maximum	 73(163) 83(181) 73(163) 80(176)

Note-1: The temperature of neutron shield and gamma shield components with the highest temperature is reported.
Note-2: In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported.
Note-3: The temperature of most limiting seals relied upon for containment function is reported herein. All the containment boundary seals are identified in Chapter 4.

Table 3.1.2.A: HI-STAR 80 with F-12P Maximum Normal Operating Pressures (MNOP)

<table>
<tr><th colspan="2">Condition</th><th>Absolute Pressure
kPa (psia)
(Note-1)</th><th>Cavity Bulk
Temperature
°C (°F)</th></tr>
<tr><td colspan="4">With 12 FA</td></tr>
<tr><td rowspan="3">Cask Cavity
MNOP
(Note-2)</td><td>Initial Maximum Backfill</td><td>199.9 (29.0)Note-3</td><td>21.1 (70)</td></tr>
<tr><td>Normal Condition</td><td>354.4(51.4)</td><td rowspan="2">249(480)</td></tr>
<tr><td>With 3% Rods Rupture (Note-4)</td><td>369.6(53.6)</td></tr>
<tr><td rowspan="2">Inter-Lid Space</td><td>Initial Maximum Backfill</td><td>118.6 (17.2)Note-3</td><td>21.1 (70)</td></tr>
<tr><td>Normal Condition</td><td>155.1(22.5)</td><td>112(234)</td></tr>
<tr><td colspan="4">Note-1: The coincident gage pressure defined as pressure above 1 atm ambient pressure is below the gage pressure limit under normal transport specified in Table 2.1.1.
Note-2: Pressure analysis in accordance with heat condition specified in 10 CFR 71.71(c)(1) in the absence of venting, external ancillary cooling or operational controls.
Note-3: The HI-STAR 80 helium backfill pressure limits are specified in Chapter 7 (Table 7.1.4). For a bounding evaluation, the upper bound limit is used in the pressure calculations.
Note-4: In accordance with NUREG-1617 [3.1.3], 3% of the rods are assumed to be breached releasing 100% fill gas and 30% fission gas to containment.</td></tr>
</table>

Table 3.1.2.B: HI-STAR 80 with F-32B Maximum Normal Operating Pressures (MNOP)

<table>
<tr><th colspan="2">Condition</th><th>Absolute Pressure
kPa (psia)
(Note-1)</th><th>Cavity Bulk
Temperature
°C (°F)</th></tr>
<tr><td colspan="4">With 32 FA</td></tr>
<tr><td rowspan="3"><u>Cask Cavity MNOP</u>
(Note-2)</td><td>Initial Maximum Backfill</td><td>199.9 (29.0) Note-3</td><td>21.1 (70)</td></tr>
<tr><td>Normal Condition</td><td>359.9(52.2)</td><td rowspan="2">257(495)</td></tr>
<tr><td>With 3% Rods Rupture (Note-4)</td><td>380.6(55.2)</td></tr>
<tr><td rowspan="2">Inter-Lid Space</td><td>Initial Maximum Backfill</td><td>118.6 (17.2) Note-3</td><td>21.1 (70)</td></tr>
<tr><td>Normal Condition</td><td>156.5(22.7)</td><td>116(241)</td></tr>
<tr><td colspan="4">Note-1: The coincident gage pressure defined as pressure above 1 atm ambient pressure is below the gage pressure limit under normal transport specified in Table 2.1.1.
Note-2: Pressure analysis in accordance with heat condition specified in 10 CFR 71.71(c)(1) in the absence of venting, external ancillary cooling or operational controls.
Note-3: The HI-STAR 80 helium backfill pressure limits are specified in Chapter 7 (Table 7.1.4). For a bounding evaluation, the upper bound limit is used in the pressure calculations.
Note-4: In accordance with NUREG-1617 [3.1.3], 3% of the rods are assumed to be breached releasing 100% fill gas and 30% fission gas to containment.</td></tr>
</table>

Table 3.1.3: Hypothetical Fire Accident Maximum HI-STAR 80 Temperatures

Material/Component	Initial Condition Note-1 °C (°F)	During Fire °C (°F)	Post Fire Cooldown °C (°F)
Fuel Cladding	374(705)	374(705)	464(867)
Fuel Basket	343(649)	344(651)	436(817)
Containment Shell	175(347)	241(466)	284(543)
Inner Closure Lid Note-2	124(255)	125(257)	180(356)
Inner Closure Lid Seals Note-3			
Inner Seal	123(253)	137(279)	182(360)
Test Port Plug Seal	122(252)	229(444)	229(444)
Vent Port Seals	125 (257)	297(567)	297(567)
Drain Port Seals	135(275)	206(403)	209(408)
Spray Cooling Seals	125(257)	282(540)	282(540)
Outer Closure Lid Seals Note-3			
Inner Seal	112(234)	118(244)	200(392)
Test Plug Seal	116(241)	116(241)	171(340)
Basket Shims	246(475)	256(493)	338(640)
Lead note-4	170(338)	302(576)	309(588)

Note-1: The initial condition is the bounding F-32B basket with 32 fuel assemblies reported in Table 3.1.1.B.
Note-2: In accordance with temperature limits Table 3.2.10 Note (a) the maximum section temperatures of structural members are reported.
Note-3: The temperatures of most limiting seals relied upon for containment function is reported herein. All the containment boundary seals are defined in Chapter 4.
Note-4: The temperature of gamma shield component with the highest temperature is reported.

Table 3.1.4: Maximum HI-STAR 80 Hypothetical Fire Accident Pressures

Condition	Absolute Pressure Note-1 kPa (psia)	Cavity Bulk Temperature °C (°F)
No fuel rods rupture	417.1(60.5)	341(646)
With assumed 100% fuel rods rupture Note-2	1214.9(176.2) Note-3	

Note-1: The coincident gage pressure defined as pressure above 1 atm ambient pressure is below the accident condition fuel cavity and inter-lid space gage pressure limits specified in Table 2.1.1.
Note-2: Pressure analysis is based on NUREG 1617 [3.1.3] requirements: Release of 100% of the rods fill gas and 30% of the significant radioactive gases from ruptured rods.
Note-3: The HI-STAR 80 fuel cavity accident pressure bounds the inter-lid pressure.

Table 3.1.5: HI-STAR 80 Normal Transport Surface Maximum Temperature in Shade

Component	Temperature °C (°F)
Surface Temperature	125(257)

3.2 MATERIAL PROPERTIES AND COMPONENT SPECIFICATIONS

3.2.1 Material Properties

Materials present in the HI-STAR 80 Packaging include structural steels, aluminum, copper, lead, neutron shielding material (Holtite-B), neutron absorber (Metamic-HT), impact limiter crush material and helium. In Table 3.2.1, a summary of references used to obtain cask material properties for performing all thermal analyses is presented.

Thermal conductivity data of neutron shielding materials, impact limiter crush material, lead, aluminum, copper and helium are provided in Table 3.2.2. Thermal conductivities of fuel, cask structural steels, and fuel basket (Metamic-HT) are provided in Tables 3.2.3, 3.2.4,3.2.5 and 3.2.13, respectively.

Surface emissivity data for key materials of construction are provided in Table 3.2.6. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390] However, in the HI-STAR 80 thermal analysis, a solar absorbtivity of 1.0 is conservatively applied on the external surfaces of the cask. For polished surfaces of the impact limiters, a solar absorbtivity specified in Table 3.2.6 is applied, similar to that used in HI-STAR 180D Docket 71-9367.

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

The HI-STAR 80 Package exposed surfaces heat transfer coefficient is calculated by accounting for 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 [3.2.8], GrPr is expressed as $L^3 \Delta T\ Z$, where L is the diameter of the cask, ΔT is the cask surface-to-ambient temperature differential and Z is a parameter which is a function of air properties evaluated at the average film temperature. The temperature dependence of Z for air is provided in Table 3.2.9.

The long-term thermal stability and radiation resistance of Holtite-B is discussed in Chapter 1. The Holtite-B thermal stability test temperature, reported in Table 1.2.5, is above the maximum operating temperature of Holtite-B (See Table 3.1.1.A and Table 3.1.1.B). Holtite-B is capable of operating at this temperature in sustained use without a significant weight loss.

3.2.2 Component Specifications

The HI-STAR 80 Package materials and components which are required to be maintained below maximum pressure and temperature limits for safe operation, to ensure their intended functions, are summarized in Chapter 2 (Table 2.1.1) and Chapter 3 (Tables 3.2.10, 3.2.11 and 3.2.12), respectively. These materials and components do not degrade under exposure to extreme low

temperatures. As defined by transport regulations, the HI-STAR 80 Package cold service temperature is conservatively limited to -40°C (-40°F).

Long-term stability of the neutron shield material (Holtite-B) under normal transport conditions is ensured when material exposure temperatures are maintained below the permissible limits. The cask seals ensure leak tightness of the closure plates if the manufacturer's recommended design temperature limits are not exceeded. Integrity of SNF during transport requires demonstration of HI-STAR 80 Package fuel cladding temperatures below regulatory limits for Moderate Burnup Fuel (MBF) and High Burnup Fuel (HBF). In the HI-STAR 80 thermal evaluation, the cladding temperature limits of ISG-11, Rev. 3 [3.3.3] are adopted (See Table 3.2.11). These limits are applicable to all fuel types, burnup levels and cladding materials approved for power generation. Neutron absorber material (Metamic-HT) used for criticality control is stable in excess of 538°C (1000°F). Neutron absorber materials are manufactured using B_4C and aluminum. B_4C is a refractory material that is unaffected by high temperatures and aluminum is solid at temperatures in excess of 538°C (1000°F). For conservatism temperature limits well below the threshold of material integrity are adopted.

For evaluation of the HI-STAR 80 Package's thermal performance under hypothetical accident conditions, lowerbound material temperature limits for short-duration events are defined in Tables 3.2.10, 3.2.11 and 3.2.12.

Table 3.2.1: Summary of HI-STAR 80 Packaging Materials Thermal Property References

Material	Emissivity	Conductivity	Density	Heat Capacity
Helium	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Air	NA	Handbook [3.2.2]	Ideal Gas Law	Handbook [3.2.2]
Zircaloy Cladding	EPRI [3.2.3]	NUREG [3.2.6] IAEA [3.2.9]	Rust [3.2.4]	Rust [3.2.4]
UO_2	Not Used	NUREG [3.2.6] IAEA [3.2.9]	Rust [3.2.4]	Rust [3.2.4]
Stainless Steel (machined forgings)	Kern [3.2.5]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Stainless Steel Plates	ORNL [3.2.13], [3.2.14]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Carbon Steel	Kern [3.2.5]	ASME [3.2.7]	Marks [3.2.1]	Marks [3.2.1]
Aluminum 2219 T8511	Handbook [3.2.18]	ASM [3.2.12]	ASM [3.2.12]	ASM [3.2.12]
Holtite-B	Not Used	Handbook [3.2.17]	Table 1.2.5	Polymer Handbook [3.2.15]
Metamic-HT	Note-1	Note-1	Note-1	Note-1
Impact Limiter Crush Material	NA	Note-2	Table 2.2.8	ASME [3.2.7]
Lead	NA	Handbook [3.2.2]	Handbook [3.2.2]	Handbook [3.2.2]
Copper C81500	Handbook [3.2.11]	DATASHEET [3.2.16] Handbook [3.2.11]	DATASHEET [3.2.16] Handbook [3.2.11]	DATASHEET [3.2.16] Handbook [3.2.11]

Note-1: The thermal properties of Metamic-HT used in the safety analysis are presented in Table 1.2.4.
Note-2: Nominal values of thermal conductivity are specified in Table 3.2.2.

Table 3.2.2: Thermal Conductivity of HI-STAR 80 Cask Materials

Material	@ 37.8°C (100°F) W/m-K (Btu/ft-hr-°F)	@ 93.3°C (200°F) W/m-K (Btu/ft-hr-°F)	@ 232.2°C (450°F) W/m-K (Btu/ft-hr-°F)	@ 371.1°C (700°F) W/m-K (Btu/ft-hr-°F)	@ 537.8°C (1000°F) W/m-K (Btu/ft-hr-°F)
Helium Note-4	0.1537 (0.0888)	0.1686 (0.0976)	0.2227 (0.1289)	0.2722 (0.1575)	0.3271 (0.1890)
Lead Note-3	34.4 (19.9)	33.6 (19.4)	31.0 (17.9)	16.1 (9.30)	15.4 (8.89)
Air Note-5	0.0265 (0.0153)	0.0299 (0.0173)	0.0389 (0.0225)	0.047 (0.0272)	0.0582 (0.0336)
Impact Limiter Crush Material Note-1	[PROPRIETARY INFORMATION REMOVED]				
	[PROPRIETARY INFORMATION REMOVED]				
	[PROPRIETARY INFORMATION REMOVED]				
[PROPIN REMOVED] Note-2	[PROPRIETARY INFORMATION REMOVED]				
Aluminum 2219 T8511	120 (69.3)				
Copper C81500 Note-6	300 (173.3)				

Note-1: [PROPRIETARY INFORMATION REMOVED].
Note-2: [PROPRIETARY INFORMATION REMOVED].
Note-3: The melting point of lead is 327°C (621°F). For temperature above the melting point, the thermal conductivity of liquid lead is presented. Thermal conductivity of liquid lead at 700°C (1292°F) is 15.0W/m-K (8.70Btu/ft-hr-°F).
Note-4: Thermal conductivity of helium at 927°C (1701°F) is 0.414W/m-K (0.239Btu/ft-hr-°F).
Note-5: Thermal conductivity of air at 800°C (1472°F) is 0.0698W/m-K (0.0404Btu/ft-hr-°F).
Note-6: Lowerbound thermal conductivity from Reference [3.2.16] is adopted in thermal evaluations. The thermal conductivity values adopted in the fire accident evaluation are presented in Table 3.2.13.

Table 3.2.3: Thermal Conductivity of Fuel Assembly Materials

Fuel Cladding		**Fuel (UO_2) Note-1**	
Temperature °C (°F)	Conductivity W/m-K (Btu/ft-hr-°F)	Temperature °C (°F)	Conductivity W/m-K (Btu/ft-hr-°F)
200 (392)	14.3 (8.28)	37.8 (100)	2.59 (1.49)
300 (572)	15.1 (8.76)	231.1 (448)	2.38 (1.37)
400 (752)	16.6 (9.60)	298.9 (570)	2.31 (1.33)
500 (932)	18.06 (10.44)	422.8 (793)	2.20 (1.27)
600 (1112)	19.81 (11.45)	600 (1112)	2.07 (1.19)
Note-1: The lower value from NUREG [3.2.6] and IAEA [3.2.9] for fuel pellet burnup of 76MWD/kgU is presented. A conservatively lowerbound value is adopted in the thermal evaluations.			

Table 3.2.4: Thermal Conductivity of ASME Materials in HI-STAR 80 Cask

Material	SA203E SA350-LF3 SA-517 GR E,F,P	SA-240-304 SA-965-F304 SA-479-304	SA-182 FXM-19	Carbon Steel
Temperature °C (°F)	Thermal Conductivity W/m-K (Btu/ft-hr-°F)			
20 (68)	41.0 (23.70)	14.8 (8.55)	11.1 (6.42)	60.4 (34.91)
50 (122)	40.8 (23.58)	15.3 (8.84)	11.6 (6.70)	59.8 (34.56)
150 (302)	40.4 (23.35)	17.0 (9.82)	13.3 (7.69)	55.9 (32.31)
250 (482)	39.5 (22.83)	18.6 (10.75)	15.0 (8.67)	51.4 (29.71)
350 (662)	37.8 (21.85)	20.1 (11.62)	16.7 (9.65)	47.0 (27.16)
450 (842)	35.8 (20.69)	21.5 (12.43)	18.4 (10.63)	42.7 (24.68)
550 (1022)	33.9 (19.59)	22.9 (13.23)	20.0 (11.56)	38.2 (22.08)
700 (1292)	29.1 (16.82)	25.0 (14.45)	22.4 (12.95)	31.2 (18.03)
815 (1500)	26.1 (15.1)	26.5 (15.3)	24.2 (14.0)	26.8 (15.5)

Table 3.2.5: [PROPRIETARY INFORMATION REMOVED]

Table 3.2.6: [PROPRIETARY INFORMATION REMOVED]

Table 3.2.7: [PROPRIETARY INFORMATION REMOVED]

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

Temperature °C (°F)	Helium Viscosity 10^{-6} N-s/m (Micropoise)	Temperature °C (°F)	Air Viscosity 10^{-6} N-s/m (Micropoise)
75.2 (167.4)	22.05 (220.5)	0 (32.0)	17.20 (172.0)
93.5 (200.3)	22.82 (228.2)	21.4 (70.5)	18.24 (182.4)
147.4 (297.4)	25.06 (250.6)	126.8 (260.3)	22.94 (229.4)
174.9 (346.9)	26.18 (261.8)	170.2 (338.4)	24.63 (246.3)
239.4 (463.0)	28.87 (288.7)	297.3 (567.1)	29.30 (293.0)
281 (537.8)	29.98 (299.8)	372 (701.6)	31.67 (316.7)
392 (737.6)	33.88 (338.8)	581.2 (1078.2)	37.76 (377.6)
608 (1126.4)	40.93 (409.3)	709.3 (1309)	41.05 (410.5)
815 (1500)	47.03 (470.3)	809.1 (1488)	43.65 (436.5)
Note-1: Obtained from Rohsenow and Hartnett [3.2.2].			

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

Temperature (°F)	Z (ft^{-3} $°F^{-1}$)
40	2.1×10^6
140	9.0×10^5
240	4.6×10^5
340	2.6×10^5
440	1.5×10^5
620	6.3×10^4
980	1.9×10^4
1520	5.1×10^4
Note-1: Obtained from Jakob and Hawkins [3.2.8]	

Table 3.2.10: HI-STAR 80 Structural Materials Temperature Limits

Component	Material	Normal Condition Temperature Limits[(a)] °C (°F)	Short Term Operations & Accident Temperature Limits[(a)] °C (°F)
Fuel Basket	Metamic-HT	400 (752)[(b)]	500 (932)[(e)]
Basket Shims	Alloy 2219-T8511	400 (752)[(f)]	500 (932)[(e)]
Containment Shell	Cryogenic Steel	271 (520)[(c)]	371 (700) (Structural Accidents)[(d)] 400 (752) (Fire Accident)[(e)]
Containment Upper and Lower Forgings	Stainless Steel	232 (450)[(c)]	426 (800) (Structural Accidents)[(d)] 1000 (1832) (Fire Accident)[(e)]
Inner and Outer Closure Lids	Stainless Steel	204 (400)[(c)]	426 (800)[(d)]
Copper Shells and Ribs	Copper Chromium C81500	204 (400) [(f)]	426 (800) (Structural Accidents)[(d)] 1000 (1832) (Fire Accident)[(e)]
Non-Fuel Waste Basket	Stainless Steel	426 (800)[(d)]	500 (932)[(e)]

Notes

(a) The ASME Code requires that the vessel design temperature be established with appropriate consideration of internal or external heat generation. In accordance with ASME Section III Code, Para. NCA-2142 the design temperature is set at or above the structural members' section temperature defined as the maximum through thickness mean metal temperature of the part under consideration. The section temperatures of the structural members shall not exceed the temperatures limits tabulated herein.

(b) The temperature limits of Metamic-HT are bounded by the maximum material qualification test temperatures [1.2.9].

(c) The normal condition temperature limits conservatively bound the ASME Code temperature limits.

(d) The temperature limits are set to the maximum permissible metal temperature in Section II of the ASME Code.

(e) To preclude melting, the short term and fire accident temperature limits are set well below the melting temperature of structural steel, copper, Metamic-HT and Aluminum alloys.

(f) The normal condition temperature limits conservatively bound the melting temperature of copper.

Table 3.2.11: Fuel Cladding Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Short Term Operations & Accident Temperature Limits °C (°F)
Fuel Cladding (Moderate Burnup Fuel)	See Note-1	400 (752)	570 (1058)
Fuel Cladding (High Burnup Fuel)	See Note-1	400 (752)	400 (752) (Short Term Operations) 570 (1058) (Accident)
Note-1: Fuel cladding temperature limits are applicable to all cladding materials approved for power generation [3.3.3].			

Table 3.2.12: HI-STAR 80 Component Temperature Limits

Component	Material	Normal Condition Temperature Limits °C (°F)	Short Term Operations & Accident Temperature Limits °C (°F)
Inner Closure Lid Inner Seal Inner Closure Lid Test Port Plug Seal Outer Closure Lid Inner Seal Outer Closure Lid Test Plug Seal Drain Port Outer Containment Seal Drain Port Bushing /Plug Seals	Note-1	[PROPIN REMOVED]	[PROPIN REMOVED] Note-5
Spray Cooling Inner Seal Spray Cooling Cover Plate Inner Seal Vent Port Outer Containment Seal Vent Port Bushing /Plug Seals	Note-1	[PROPIN REMOVED]	[PROPIN REMOVED] Note-6
Neutron Shield	Holtite-B	[PROPIN REMOVED]	Note-2
Gamma Shield	Lead	316 (600)	316 (600) Note-4
Impact Limiter Bulk	HoneyComb	Table 2.2.8	NA Note-3

Note-1: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**
Note-2: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**
Note-3: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**
Note-4: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**
Note-5: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**
Note-6: **[PROPRIETARY INFORMATION REMOVED PER 10 CFR 2.390]**

Table 3.2.13: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.2.14: Quiver Thermal Specifications

Decay Heat	Table 7.D.1
Initial Helium Backfill	Table 7.1.8
Design Pressure	Table 2.2.11
Quiver Temperature Limit	300^{o}C
Quiver Seal Temperature Limit	300^{o}C

3.3 THERMAL EVALUATION UNDER ROUTINE AND NORMAL CONDITIONS OF TRANSPORT

3.3.1 Overview of the Thermal Model

As stated in Section 3.1, the temperature of the HI-STAR 80 cask with non-fuel waste basket to transport core components will be much lower than the temperature of the HI-STAR 80 cask with fuel basket to transport fuel assemblies. Therefore, the thermal performance of the HI-STAR 80 cask with the fuel basket to transport fuel assemblies is evaluated in this chapter. The analyses bound those for the HI-STAR 80 cask with non-fuel waste basket to transport core components.

The HI-STAR 80 Package is designed to safely dissipate heat under passive conditions (no wind). Under normal transport conditions, the cask contents (fuel basket with fuel assemblies or non-fuel waste basket with core components) rest on solid surfaces. Direct contact between the cask and its contents enhances heat dissipation. Nevertheless to engineer a robust measure of conservatism a hypothetical bounding configuration (levitating basket) is assumed. In addition, the fuel, fuel basket assembly (basket and basket shims) and cask are assumed to be in concentric alignment (i.e. they do not make physical contact).

The HI-STAR 80 Package is designed with the F-12P fuel basket to transport up to 12 PWR fuel assemblies, the F-32B fuel basket to transport up to 32 BWR fuel assemblies, and the NFWB-1 basket to transport core components. Additionally, the HI-STAR 80 package is also designed to transport up to 4 quivers in PWR and 12 quivers in BWR as shown in Chapter 7. The cask is rated for different heat loads for different basket types, as discussed in Chapter 1. According to the results presented in Table 3.3.4, the highest cladding temperature is reached in the F-32B basket with 32 fuel assemblies. Therefore, the HI-STAR 80 Package with the F-32B basket to transport 32 fuel assemblies is evaluated for compliance with transport regulations.

The HI-STAR 80 Package thermal analysis is performed using the FLUENT CFD code [3.3.2]. FLUENT is a well-benchmarked CFD code validated by the code developer with an array of theoretical and experimental works from technical journals. Additionally, Holtec has Q.A. validated FLUENT within the company’s quality assurance program and confirmed the code's capability to reliably predict temperature fields in dry storage [3.3.4] using independent full-scale test data from a loaded cask [3.2.3]. The code has a long history of usage for obtaining NRC approval of fuel storage in transport and storage casks. A list of dockets wherein USNRC relied on FLUENT thermal models for cask certification is given in Table 3.3.3.

To define a limiting pattern, an array of bounding fuel storage configurations is analyzed using 3D thermal models of the F-12P and F-32B baskets. Modeling details of the principal thermal transport mechanisms are provided in the following.

3.3.1.1 Fuel Region Effective Planar Conductivity

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

The fuel-rods region effective planar conductivity is defined as the calculated equivalent conductivity of the fuel-rods cross section by including conduction and radiation heat transfer. Because radiation is proportional to the fourth power of absolute temperature, the effective conductivity is a strong function of temperature. The 2-D CFD model is used to characterize fuel resistance at several representative boundary temperatures (i.e. the basket storage cell inner surface temperatures for PWR and the fuel channel inner surface temperatures for BWR) and the effective thermal conductivity as a function of temperature is obtained and presented in Table 3.3.1.A and Table 3.3.1.B.

3.3.1.2 Heat Rejection from Cask and Impact Limiter Surfaces

The exposed surfaces of the HI-STAR 80 Package dissipate heat by radiation and external natural convection heat transfer. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

3.3.1.3 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 insolation energy absorbed by the HI-STAR 80 Package is the product of incident insolation and the package absorbtivity. A bounding absorbtivity of 1.0 is assumed for the external surfaces of the cask. For polished surfaces of the impact limiters, a solar absorbtivity obtained from robust sources is applied (See Table 3.2.6). The 12-hour insolation is specified in 10CFR71. However, slightly higher insolation summarized in Table 3.3.2, is adopted in the evaluations. During normal transport conditions, the HI-STAR Package is cyclically subjected to solar heating during the 12-hour daytime period followed by cooling during the 12-hour nighttime. However, due to the large mass of metal and the size of the Package, the dynamic time lag exceeds the 12-hour heating period. Accordingly, the HI-STAR Package model includes insolation at exposed surfaces averaged over a 24-hour time period. The 24-hour insolation applied on the HI-STAR 80 Package is presented in Table 3.3.2.

3.3.1.4 Description of HI-STAR 80 3D Model

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

The HI-STAR 80 Package thermal analysis is based on a 3D thermal model of the HI-STAR 80 cask that properly accounts radiation, conduction and external natural convection modes of heat transfer. The model is constructed using an array of conservative assumptions to bias the results of the thermal analysis towards much reduced computed margins. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

To this model insolation heat (Table 3.3.2) is applied on all external surfaces of the HI-STAR 80 Package assuming 100% absorption for cask external surfaces. Natural convection and radiation from exposed surfaces are enabled to model heat dissipation to ambient air. Using this model, steady state HI-STAR 80 Package temperatures in still air for the limiting decay heat distribution defined in Subsection 3.3.1.5 are computed and evaluated in the next section.

3.3.2 Heat and Cold

3.3.2.1 Maximum Temperatures

As required by transport regulations the HI-STAR 80 Package is evaluated under hot ambient conditions defined in 10CFR71. These conditions are 38°C (100°F) ambient temperature, still air and insolation (Table 3.3.2). To ensure a bounding evaluation, the design heat load and a limiting heat load distribution (See Section 3.3.1) are assumed. Under this array of adverse conditions, the maximum steady state temperatures of the package structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3.1 and results reported in Section 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature (Tables 3.1.1.A and 3.1.1.B) is well within the ISG-11, Rev. 3 temperature limit (Table 3.2.11).

- The maximum temperature of fuel basket (Tables 3.1.1.A and 3.1.1.B) is well within the design temperatures (Table 3.2.10).

- The maximum temperatures of the containment boundary and lid seals (Tables 3.1.1.A and 3.1.1.B) are well below the design temperatures (Tables 3.2.10 and 3.2.12, respectively).

- The maximum temperatures of the basket shims (Tables 3.1.1.A and 3.1.1.B) are well below the design temperature limits (Table 3.2.10).

- The neutron shielding material (Holtite-B) temperature (Tables 3.1.1.A and 3.1.1.B) is within its design limit (Table 3.2.12).

- The gamma shielding material (lead) temperature (Tables 3.1.1.A and 3.1.1.B) is within its design limit (Table 3.2.12).

The temperatures of the HI-STAR 80 Package during normal transport are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The above observations lead to the conclusion that the temperature field in the HI-STAR 80 Package loaded with heat emitting SNF complies with all regulatory requirements for normal conditions of transport. In other words, the thermal environment in the HI-STAR 80 Package is

conducive to safe transport of spent nuclear fuel and non-fuel waste under the design basis heat loads defined in Chapter 7.

3.3.2.2 Minimum Temperatures

As specified in 10CFR71, the HI-STAR 80 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 80 Package uniformly approaches the cold ambient temperature. All HI-STAR 80 Package materials of construction satisfactorily perform their intended function in the transport mode at this minimum postulated temperature condition. Evaluations in Chapter 2 demonstrate the acceptable structural performance of the package materials at low temperature. The HI-STAR 80 shielding and criticality materials (Holtite-B, lead and Metamic-HT) are unaffected by exposure to cold temperatures.

3.3.2.3 Personnel Barrier Evaluation

As defined in Chapter 1, personnel barrier is an open lattice cage placed around the HI-STAR 80 cask to prevent access to the hot surfaces. The open structure ensures that movement of ambient air is not unduly restricted and the cask temperatures are not impacted. To provide an additional layer of assurance a thermal calculation is performed assuming bounding personnel barrier characteristics defined in Table 3.3.7. The thermal calculation deployed the same 3D HI-STAR 80 thermal model articulated in the sections above. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

The personnel barrier impact is evaluated for the thermally bounding scenario, i.e. the F-32B basket with 32 fuel assemblies. The cask temperatures with personnel barrier are tabulated in Table 3.3.8. The results show that the cask temperatures are essentially unchanged by the deployment of the personnel barrier.

3.3.3 Maximum Normal Operating Pressure (MNOP)

The HI-STAR 80 cavity is de-moisturized and backfilled with dry helium after fuel loading and prior to lid closures. The MNOP evaluation considers the following source of gases:

Initial Backfill:
The HI-STAR 80 cavity is assumed to be backfilled to the maximum permissible pressure (Chapter 7, Table 7.1.4).

Water Vapor:
The HI-STAR 80 cavity and its stored fuel are de-moisturized to a very low vapor pressure (Chapter 7, Table 7.1.2). As this pressure is dwarfed by the helium backfill pressure it is neglected in the MNOP calculations.

Helium from Radioactive Decay:
The helium from radioactive decay is dwarfed by the generation of fission products during power generation. These products are assumed to be released into the HI-STAR 80 cavity under hypothetical rod ruptures. As radioactive decay is a small fraction of the fission gas releases it is neglected in the MNOP calculations.

Generation of Flammable Gases:
The HI-STAR 80 Package uses non-reactive materials of construction. Generation of flammable gases is not credible.

Fuel Rod Failures:
In accordance with NUREG 1617 [3.1.3], 3% of the fuel rods are assumed to be breached.

During normal transport conditions, the gas temperature within the cavity rises to its maximum operating temperature as determined by the thermal evaluation described earlier. The gas pressure inside the cavity increases monotonically with rising temperature. The pressure rise is determined using the Ideal Gas Law.

The HI-STAR 80 Maximum Normal Operating Pressure (MNOP) is calculated for the §71.71(c)(1) heat condition (38^{o}C (100^{o}F) ambient, still air & insolation) and design maximum heat load. Based on a 30% release of the significant radioactive gases and 100% release of the rod fill gas from postulated cladding breaches (3%) the cask cavity space MNOP is computed and reported in Section 3.1.4. The HI-STAR 80 cavity pressures presented in Tables 3.1.2.A and 3.1.2.B show that the MNOP is well below the design pressure of the containment boundary (Table 2.1.1).

The evaluation of pressures and temperatures reached during transport provides reasonable assurance of safe transport of spent nuclear fuel and non-fuel waste packaged in a HI-STAR 80 Package. This conclusion is based on the technical data and analyses presented in this chapter in conjunction with provisions of 10 CFR Part 71, appropriate regulatory guides, applicable codes and standards, and accepted engineering practices.

3.3.4 Time-to-Boil Limits

In accordance with NUREG-1536 [3.1.2], water inside the HI-STAR 80 cavity is not permitted to boil during fuel loading operations. In this manner operational concerns due to vapor formation and two-phase conditions are avoided. To meet this requirement time limits are defined herein for completion of wet operations upon removal of a loaded HI-STAR 80 cask from the pool.

When the HI-STAR 80 cask is removed from the pool, the combined water, fuel and cask metal mass absorb the decay heat emitted by the fuel assemblies. This results in a slow temperature rise of the cask with time, starting from an initial temperature of the contents. The rate of temperature rise is limited by the thermal inertia of the HI-STAR 80. To obtain a bounding heat-up rate

determination, the 3-D Fluent methodology articulated in this chapter may be deployed or alternatively a conservative adiabatic heat up calculation defined below may be adopted. The adiabatic heat up calculation assumes the following:

i. Obtain the heat input Q from the fuel assemblies loaded in the cask.
ii. Heat dissipation to air by natural convection and radiation from the cask is neglected.
iii. Water mass in the cask cavity is understated by 50% for conservatism.

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

$$\frac{dT}{dt} = \frac{Q}{C_h} \qquad \text{Eqn. (3.3.1)}$$

where:

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

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

$$t_{max} = \frac{T_{boil} - T_{initial}}{(dT/dt)} \qquad \text{Eqn. (3.3.2)}$$

where:

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

Example values of t_{max} under design maximum heat load are tabulated in Table 3.3.6 at several representative $T_{initial}$ temperatures.

3.3.5 Additional Measures During Extended Duration Operations

In the unlikely event that the maximum allowable time provided in Table 3.3.6 is found to be insufficient to complete wet transfer operations, forced water circulation may be provided to remove the decay heat from the cask cavity. During forced circulation relatively cooler water enters the drain port connection and heated water exits from the vent port. The minimum water flow rate required to maintain the water temperature below boiling is determined as follows:

$$M_W = \frac{Q_c}{C_{pW}\,(T_{max} - T_{in})} \qquad \text{Eqn. (3.3.3)}$$

where:

Q_c = cask decay heat, W (Btu/hr)
M_W = minimum water flow rate, kg/s (lb/hr)
C_{pw} = water heat capacity, J/kg-^oC (Btu/lb-^oF)
T_{max} = cask user selected maximum cavity water temperature, ^oC (^oF) (must be less than 100^oC (212^oF))
T_{in} = water supply temperature, ^oC (^oF)

3.3.6 Fuel Temperatures during Moisture Removal Operations

The initial loading of SNF in the HI-STAR 80 requires the water within the cask cavity be drained and replaced with helium. Since the design maximum heat loads are high, this operation may be carried out using one of the following drying approaches:

3.3.6.1 Vacuum Drying

Prior to the start of the HI-STAR 80 draining operation, the cask cavity is flooded with water. The presence of water in the cask cavity ensures that the fuel cladding temperatures are lower than design basis limits by large margins. As the heat generating active fuel length is uncovered during the draining operation, the fuel and basket mass undergo a gradual heat up from the initially cold conditions when the heated surfaces are submerged under water. Following the draining operation the HI-STAR 80 cavity is lined up to vacuum pump and the cavity pressure is substantially lowered to facilitate fuel drying. However, at the design basis heat loads in HI-STAR 80 cask, the peak cladding temperature of high burnup fuel (HBF) cannot be maintained below the ISG-11, Revision 3 limit of 400^oC (752^oF) under a vacuum condition of infinite duration. Under this scenario, cycles of vacuum drying resulting in heatup followed with cooling by helium are performed until drying criteria specified in Chapter 7 is achieved. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

3.3.6.2 Forced Helium Dehydration

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

3.3.7 Fuel Reconfiguration under Normal Condition

Fuel assemblies are loaded in the fuel basket as intact and remain intact prior to and during normal conditions of transport. However, there is a potential (based on uncertainties) that the fuel may reconfigure during transportation. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

The temperature results of such a steady state analysis are reported in Table 3.3.10. All

component temperatures are below their respective temperature limits under normal condition. The cavity pressure and the inter-lid space pressure due to the hypothetical 3% fuel reconfiguration are reported in Table 3.3.11. The pressures are well below the design pressures of the containment boundary (Table 2.1.1). Therefore, all the safety conclusions made in Sections 3.3.2 and 3.3.3 also remain applicable to hypothetical fuel reconfiguration event.

3.3.8 Evaluation of Use of Quivers

Quiver is defined in Chapter 1 as precision engineered box to store slightly or severely damaged fuel rods in a helium backfilled environment to preclude risk of in-service corrosion. Prior to loading in quivers, the fuel rods are punctured and depressurized. The principal parameters relevant to thermal evaluation of transporting quivers in HI-STAR 80 package, viz. helium backfill, cladding temperature limit, design heat load, and design pressure are defined in Table 3.2.14.

The allowable cell-wise heat loads of the intact fuel assemblies and damaged fuel rods when quivers are transported are presented in Chapter 7. [PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

The component temperatures for casks with PWR and BWR fuel when quivers are loaded are presented in Tables 3.3.12 and 3.3.13 respectively. Due to the lower allowable heat loads when quivers are used compared to the heat loads when quivers are not used (See Table 7.D.1), the component temperatures are significantly lower than those presented in Section 3.1. In particular, the computed temperatures of the fuel cladding of the intact fuel assemblies and cask components are significantly lower than those reported in Section 3.1.

During normal transport and hypothetical accident conditions, the gas temperature within the quiver cavity rises as determined by the thermal evaluations presented above. The gas pressure inside the cavity increases monotonically with rising temperature. The pressure is determined using the ideal gas law.

Due to the rise in temperatures of the quivers from room temperature conditions, differential expansion between the quiver surfaces and the basket/cask occurs. To ensure that there is no interference between the quivers and the basket/cask under operating conditions, the radial expansions between the quivers and the basket, and the axial expansions between the quivers and the cask are computed and presented in Table 3.3.14. The results show that there is no interference among the components under operating conditions.

Results for component temperatures and quiver pressures for casks with PWR and BWR fuel under normal conditions are presented in Tables 3.3.12 and 3.3.13 respectively. The results show that:

1. Peak cladding temperatures are bounded by those presented in Section 3.1.
2. Quiver meets the temperature limits presented in Table 3.2.14.
3. Quiver pressure meets the design pressure limit presented in Table 3.2.14.

Leak tightness of quivers as required by Table 7.1.8 operational requirements is reasonably assured as the maximum computed temperatures and pressures remain within quiver design limits (Table 3.2.14).

Table 3.3.1.A: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.1.B: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.1.C: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.1.D: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.2: Insolation Data

Surface Type	12-Hour Insolation (Note-1)		24-Hour Insolation Adopted in Analysis	
	(g-cal/cm^2)	(W/m^2)	(g-cal/cm^2)	(W/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
Note-1: The 12-Hour Insolation is slightly higher than the value provided in 10CFR71.				

Table 3.3.3: History of FLUENT for Securing Transport and Storage Cask Certifications

USNRC Docket Number	Project
72-1008	HI-STAR 100 Storage
71-9261	HI-STAR 100 Transport
72-1014	HI-STORM Storage
72-22	Private Fuel Storage Facility
72-27	Humboldt Bay ISFSI
72-26	Diablo Canyon ISFSI
72-17	Trojan ISFSI
71-9325	HI-STAR 180 Transport
71-9336	HI-STAR 60 Transport
72-1032	HI-STORM FW Storage
71-9367	HI-STAR 180D Transport

Table 3.3.4: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.5: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.6: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.7: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.8: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.9: (Deleted)

Table 3.3.10: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.11: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.12: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.13: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.3.14: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

FIGURE 3.3.1: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

FIGURE 3.3.2-A: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

FIGURE 3.3.2-B: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

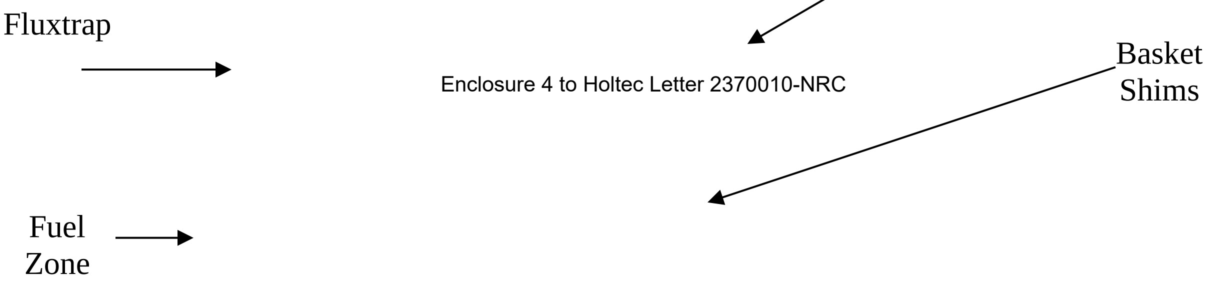

FIGURE 3.3.3: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

FIGURE 3.3.4: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

FIGURE 3.3.5: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

FIGURE 3.3.6: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

3.4 THERMAL EVALUATION UNDER HYPOTHETICAL ACCIDENT

As mandated by 10 CFR Part 71 requirements, the HI-STAR 80 Package is subjected to a sequence of hypothetical accidents. The objective is to determine and assess the cumulative damage sustained by the package. The accident scenarios specified in order are: (1) a 9 m (30 foot) free drop onto an unyielding surface; (2) a 1 m (40-inch) drop onto a mild steel bar; (3) exposure to a 30-minute fire at 802ºC (1475°F) and (4) immersion under a 0.9 m (3 ft) head of water. The initial conditions for the fire accident specify steady state at an ambient temperature between -40ºC (-40°F) and 38ºC (100°F). In the HI-STAR 80 Package hypothetical fire accident evaluation, insolation with a theoretical bounding absorbtivity equal to unity is applied. The effects of the accidents (1), (2) and (4) are evaluated in Chapter 2. In this section, the effects of accident (3) are evaluated. The initial condition prior to fire accident is the hot ambient environment for normal transport under the thermally limiting scenario, i.e. F-32B fuel basket with 32 fuel assemblies and design basis heat load (See Section 3.3). The fire accident evaluation is performed assuming an adverse combination of factors that overestimate heat input during fire followed by an underestimation of heat rejection to the environment after the fire.

During the free drop event specified in 10CFR71, the crush material in the impact limiters is locally crushed. However, the impact limiters survive the drop events without structural collapse and remain attached to the cask during and after the event. During the puncture event specified in 10CFR71, the cask's exterior shell may be locally pierced but with no gross damage to the cask or its internals. Because of these reasons the global thermal performance of the HI-STAR 80 cask is unaffected by the drop events.

During fire, the resin bonding the impact limiter's corrugated aluminum honeycomb layers is destroyed thus severely degrading the normal-to-layers direction conductivity. In the interest of conservatism, the undegraded crush material conductivity is assumed during fire to maximize heat input and an opposite assumption is used to minimize post-fire heat dissipation by applying air conductivity for the normal-to-layers direction (see Table 3.4.1).

During fire, the neutron shield region enclosed within the cooper shells can exceed its temperature limit thereby reducing the ability of the package to reject heat after the fire. To conservatively evaluate this hypothetical accident condition, thermal conductivity of air is applied to those neutron shield pockets where its temperature limit is exceeded during post-fire cooldown to minimize post-fire cooling.

The temperature history of the HI-STAR 80 Package is monitored during the 30-minute fire and during post-fire cooldown for a sufficient length of time for the cask and fuel to reach maximum temperatures. The impact of transient temperature excursions on HI-STAR 80 Package materials is evaluated.

3.4.1 Initial Conditions

In accordance with transport regulations the HI-STAR 80 Package fire accident is evaluated under hot ambient initial conditions (§10CFR71.71(c)(1) and §10CFR71.73(b)). These

conditions are 38°C (100°F) ambient temperature, still air and insolation. The HI-STAR 80 bounding steady state temperature distribution under hot ambient conditions reported in Section 3.1.3 is adopted as the initial condition for fire accident evaluation.

3.4.2 Fire Conditions

As required by transport regulations the HI-STAR 80 Package is evaluated under an all-engulfing fire at 802°C (1475°F) lasting for 30 minutes (§10CFR71.73(c)(4)). The regulations specify a minimum fire emissivity (0.9) and lowerbound package absorbtivity (0.8) for hypothetical accident evaluation. In the HI-STAR 80 fire accident evaluation, the minimum specified emissivity and conservatively postulated absorbtivity are adopted.

Heat input to the HI-STAR 80 Package while engulfed in a fire is from a combination of radiation and forced convection heat transfer. This can be expressed by the following equation:

$$q_F = h_{fc}\,(T_F - T_s) + \sigma\alpha\,\varepsilon\,[T_F^4 - T_s^4]$$

where:

- q_F = fire heat input, W/m^2 (Btu/ft^2-hr)
- T_F = fire condition temperature 1075K (1935°R)
- T_S = package surface temperature K (°R)
- h_{fc} = forced convection heat transfer coefficient W/m^2-K [Btu/ft^2-hr-°F] (See Table 3.4.3)
- ε = flame emissivity (0.9 (min.) in accordance with transport regulations)
- α = package absorbtivity (0.8 (min.) in accordance with transport regulations)
- σ = Stefan-Boltzmann Constant 5.67×10^{-8} W/m^2-K^4 (0.1714×10^{-8} Btu/ft^2-hr-°R^4)

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

Using this model, the transient heat up of the cask and it's internals during the 30-minute fire is computed. At the end of the fire the hot ambient condition is restored and a post fire cooldown of the cask for a period of 20 hours is computed. As shown in Figure 3.4.1, this period is sufficient for the cask internals (principally the SNF) to reach their maximum temperatures and begin to recede. The results of the analysis for the thermally limiting scenario, i.e. F-32B fuel basket with 32 fuel assemblies and design basis heat load, are evaluated in the next section. An explicit thermal analysis of the fire accident conditions for F-12P fuel basket is not required due to the following reasons:

1. The difference in the thermal inertia of the cask with 32 fuel assemblies in F-32B basket and with 10 fuel assemblies in F-12P basket is less than 3%. Such a small difference in the thermal inertia does not have a significant effect on the temperature field during short-term and accident conditions.
2. Under normal condition, i.e. the initial condition of fire, the F-32B basket with 32 fuel assemblies yields the bounding fuel cladding temperature, component temperatures and containment boundary pressure.

3. The maximum permissible heat load in F-12P basket is significantly lower than that in F-32B basket. Therefore, the temperatures in F-32B basket are expected to be higher than F-12P basket during the fire accident conditions.

3.4.3 Maximum Temperatures and Pressures

3.4.3.1 Maximum Temperatures

The HI-STAR 80 Package is evaluated under a hypothetical fire accident at 802°C (1475°F) lasting for 30 minutes. To ensure a bounding evaluation, the limiting decay heat pattern (See Section 3.1.3) and hot initial conditions are assumed. Under this array of adverse conditions, the maximum temperatures reached in the cask structural members and its contents (SNF) are computed. The temperatures are computed using the 3D thermal model described in Section 3.3, applying the fire accident thermal loads and computing the time-dependent response of the package to the 30-minute fire followed by a post fire cooldown for a sufficient duration to allow the cask and its contents to reach their maximum temperatures. The temperature histories of the critical components (cladding, basket, seals and containment shell) are graphed in Figure 3.4.1 and maximum temperatures reached during fire and post-fire cooldown are reported in Section 3.1.3. The following observations are derived by inspecting the temperature field obtained from the thermal analysis:

- The maximum fuel cladding temperature (Table 3.1.3) is well within the ISG-11, Rev. 3 accident temperature limit (Table 3.2.11).

- The maximum temperature of fuel basket (Table 3.1.3) is well within its accident design temperature (Table 3.2.10). The maximum temperature of the basket shims (Table 3.1.3) is well below the accident temperature limit (Table 3.2.10).

- The maximum temperatures of the containment boundary (Table 3.1.3) are well below the ASME Code limits (Tables 3.2.10).

- The maximum temperatures of the containment seals (Table 3.1.3) are well below the accident temperature limit (Table 3.2.12).

- The maximum temperature of lead (Table 3.1.3) is below its accident temperature limit (Table 3.2.12).

The HI-STAR 80 Package fire accident temperatures are reported in Section 3.1.3. The temperatures are below the regulatory temperature limits (Table 3.2.11), ASME Code temperature limits (Table 3.2.10) and components safe operating temperature limits (Table 3.2.12). The thermal evaluation provides reasonable assurance of safety in the event of a fire. This conclusion is based on the technical data and analyses presented in this chapter in conjunction with provisions of 10 CFR Part 71, appropriate regulatory guides, applicable codes

and standards, and accepted engineering practices.

3.4.3.2 Maximum Pressures

The HI-STAR 80 containment pressure is computed based on the maximum temperatures of the cask contents (fuel basket and fuel) reached during the fire accident. The calculations use an array of conservative assumptions listed below:

- i) Maximum initial fill pressure (Chapter 7, Table 7.1.4)
- ii) 100% rods rupture
- iii) 100% release of rods fills gas and 30% release of fission gases
- iv) Lowerbound cavity free volume

The maximum containment pressures are tabulated in Section 3.1.4. The results show that the pressures are well below the containment boundary design pressure (Table 2.1.1).

3.4.4 Maximum Thermal Stresses

The HI-STAR 80 Package is designed to ensure a low state of thermal stress in the structural members. This is ensured by using high conductivity materials (Metamic-HT and low alloy steels) to minimize temperature gradients and large fit-up gaps to allow unrestrained thermal expansion of the package internals (fuel basket) during normal transport. The differential thermal expansion of the fuel basket during normal transport is calculated in Reference [3.4.1] and results provided in Table 3.4.2. The normal transport gaps are bounding during fire because of the expansion of the cask body under direct fire heating. As thermal interference is precluded during fire a low state of thermal stress prevails in the cask.

Due to the rise in temperatures of the quivers from room temperature conditions, differential expansion between the quiver surfaces and the basket/cask occurs. To demonstrate that there is no interference between the quivers and the basket/cask under operating conditions, the radial expansions between the quivers and the basket, and the axial expansions between the quivers and the cask are computed and presented in Table 3.4.7. The results show that there is no interference among the components under operating conditions.

3.4.5 Fuel Reconfiguration under Accident Condition

Fuel assemblies are loaded in the fuel basket as intact and remain intact prior to and during normal conditions of transport. However, there is a potential (based on uncertainties) that the fuel may reconfigure during transportation. **[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]**
The temperature results of such a steady state analysis for a defense-in-depth hypothetical scenario are reported in Table 3.4.4. The results show that all component temperatures are below their respective temperature limits. The cask cavity pressure and the inter-lid space pressure are bounded by those during the fire accident reported in Table 3.1.4. Therefore, the containment boundary remains intact with non-mechanistic fuel reconfiguration. The licensing approach to

address the potential for high burnup fuel reconfiguration is delineated in Chapter 1.

3.4.6 Evaluation of Quivers under Hypothetical Accident Conditions

The temperatures and pressures of the HI-STAR 80 package when quivers are used are calculated under hypothetical accident conditions presented in Section 3.4.1. The results for casks loaded with PWR and BWR fuel are presented in Tables 3.4.5 and 3.4.6 respectively. The results show that the temperatures and pressure of all components including the Quivers meet their respective limits presented in Table 3.2.14 under hypothetical accident conditions.

Table 3.4.1: Hypothetical Fire Accident Assumptions

	Initial Condition	30-minute Fire	Post-Fire Equilibrium
1. Neutron shield conduction Note-1	Yes (Understated Conductivity)	Yes (Undegraded material Conductivity)	No (Air conductivity applied to the neutron shield pockets that exceed its temperature limit)
2. Insolation	Yes	Yes	Yes
3. Surface Convection	Natural	Forced	Natural
4. Impact limiter conduction Note-2 Parallel to Aluminum Layers Normal to Aluminum Layers	 Table 3.2.2 Table 3.2.2	 Table 3.2.2 Table 3.2.2	 Table 3.2.2 Air conductivity
5. Cask Surface Solar Absorbtivity	1.0	1.0	1.0
6. Emissivity Cask surface Polished Surfaces (impact limiter)	 [PROPIN REMOVED] Table 3.2.6	 0.9(fire emissivity) 0.9(fire emissivity)	 [PROPIN REMOVED[Table 3.2.6
Note-1: **[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]** Note-2: **[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]** Note-3: **[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]**			

Table 3.4.2: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.4.3: Sandia Pool Fire Test Data[Note-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°C to 1093°C (843°C avg.) 1200°F to 2000°F (1550°F avg.)
Convective Coefficient	25.5 W/m^2-K (4.5 Btu/ft^2-hr-°F)
Note-1: From Sandia large pool fires report [3.4.2], Page 41.	

Table 3.4.4: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.4.5: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.4.6: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

Table 3.4.7: [PROPRIETARY TABLE REMOVED PER 10 CFR 2.390]

FIGURE 3.4.1: **[PROPRIETARY FIGURE REMOVED PER 10 CFR 2.390]**

CHAPTER 3 REFERENCES

The following generic industry and Holtec produced references may have been consulted in the preparation of this document. Where specifically cited, the identifier is listed in the SAR text or table. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

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*Supporting document submitted with the HI-STAR 80 License Application.

Appendix 3.A

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

Appendix 3.B

[PROPRIETARY TEXT REMOVED PER 10 CFR 2.390]

CHAPTER 4: CONTAINMENT

4.0 INTRODUCTION

This chapter demonstrates HI-STAR 80 cask containment system compliance with the permitted activity release limits specified in 10CFR71 for both normal and hypothetical accident conditions of transport [4.0.1]. Satisfaction of the containment criteria, expressed as the leakage rate acceptance criterion, ensures that the loaded HI-STAR 80 cask will not exceed the allowable radionuclide release rates. Leakage rates are determined in accordance with the recommendations of ANSI N14.5 [8.1.6], 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 for HI-STAR 80 cask consists of the components, seals and welds identified in the drawing package in Section 1.3 and also in Figure 4.1.1 When transporting High Burnup Fuel (HBF), both the inner and outer closure lids are containment system components whose closure joints must be tested prior to shipment. Likewise, in that case, both the inner and outer parts of the vent and drain ports and the spray cooling port are part of the containment system and must be tested prior to shipment. When not transporting HBF, only one of the lids and parts (inner or outer) must be tested.

Chapter 2 of this report shows that all containment system components are maintained within their code-allowable stress limits and elastomeric seals remain compressed during all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Chapter 3 of this report shows that the peak containment system component temperatures and pressures are within the design basis limits for all normal and hypothetical accident conditions of transport as defined in 10CFR71.71 and 10CFR71.73. Since both the containment system is shown to remain intact and the temperature and pressure design bases are not exceeded, the design basis leakage rates are not exceeded during normal or hypothetical accident conditions of transport.

HI-STAR 80 will be used to transport spent fuel and activated core components from BWR and PWR nuclear power plants. A description and key characteristics of the waste contents are provided in Chapter 7. When spent fuel assemblies are loaded, the leakage rate acceptance criterion is a reference leakage rate calculated in Section 4.6, and specified in Table 8.1.1. When activated core components are loaded, the leakage rate acceptance criterion is a reference leakage rate calculated in Section 4.5, and specified in Table 8.1.1.

HI-STAR 80 cask is subjected to a fabrication leakage rate test before the first loading. The fabrication leakage rate test is performed at the factory in accordance with the requirements of ANSI N14.5 specified in Chapter 8 as part of HI-STAR 80 cask acceptance testing. HI-STAR 80 cask is also subjected to a pre-shipment leakage rate test after each cask loading and closure. The pre-shipment leakage rate test is performed in accordance with the requirements ANSI N14.5 specified in Chapter 8 by the user as final acceptance testing of HI-STAR 80 cask containment system. The elastomeric seals of HI-STAR 80 cask are to be checked and tested for each cask loading and closure, and if necessary replaced.

Additional requirements and clarification are provided in Section 4.4 and Chapter 8, where Table 8.1.2 provides the testing requirements for all containment boundary components.

4.1 DESCRIPTION OF THE CONTAINMENT SYSTEM

The containment system for the HI-STAR 80 cask consists of the following components, and their respective welds:

- Containment shell including cladding
- Containment upper forging
- Containment lower forging
- Inner closure lid (including inner seal, retainer ring, bolts and helical thread inserts, and leak test port with test port plug and seal)
- Outer closure lid (including inner seal, bolts, test plug, test plug seal, and helical thread inserts)
- Vent and drain port (each including bronze plug, bushing and bushing /plug seal, inner port cover plate, and port outer containment seal)
- Spray cooling port (including cap, cap inner seal, cover plate, cover plate inner seal, cover plate bolts and helical thread insert)

The principal layout of the containment boundary and containment system components is shown in Figure 4.1.1. Details on all components are specified in the drawing package in Section 1.3.

The containment system components for the HI-STAR 80 system are designed and fabricated in accordance with the requirements of ASME Code, Section III, Subsection NB [1.2.1], to the maximum extent practicable as clarified in Chapter 2 of this SAR. Chapter 1 specifies design criteria for the containment system. Section 2.1 provides the applicable code requirements. Exceptions to specific code requirements with complete justifications are presented in Section 8.

4.1.1 Containment Vessel

The cask containment vessel consists of components which form the inner containment space and the space between the inner and outer lid. The containment vessel is represented by the containment shell, containment lower forging, containment upper forging, and inner and outer closure lids. These are the main containment system components that create an enclosed cylindrical cavity for the containment of the enclosed radiological content. The materials of construction for the containment system are specified in the drawing package in Section 1.3. No valve or pressure relief device is specified on the HI-STAR 80 containment system.

4.1.2 Containment Penetrations

The cask containment system penetrations include the spray cooling port, the outer closure lid test plug, the inner closure lid leak test port, and the vent and drain port. Each penetration has elastomeric seals. The containment penetrations are designed and tested to ensure that the radionuclide release rates specified in 10CFR71.51 will not be exceeded.

4.1.3 Seals and Welds

The cask uses a combination of seals and welds designed and tested to provide containment during normal transport conditions, and during and after hypothetical accident conditions of transport. Seals and welds are individually discussed below.

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

4.1.3.1 Containment Seals

The containment system seals are designed and fabricated to meet the design requirements of the HI-STAR 80 cask specified in Chapter 2, and in accordance with the manufacturer's recommendations. Chapter 7 describes the operating procedures required for proper seal function. Seal and closure details are provided in the drawing package in Section 1.3.

4.1.3.1.1 Inner Closure Lid

The cask inner closure lid uses two concentric elastomeric seals to form the closure with the containment upper forging surface. In the inner closure lid, the inner seal is the containment seal, and the outer elastomeric seal provides redundant closure. The leak test port provides access to the volume between the two elastomeric lid seals. Following leakage rate testing of the inner closure lid inner seal, a threaded plug with an elastomeric seal is installed in the leak test port hole. Since this inner closure lid test port plug seal is a containment seal, it is independently tested for leakage to verify containment performance, using an ancillary cover of the test port hole. After the seal performance is verified, a redundant port plug with seal is installed in the test port hole to provide redundant closure.

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

4.1.3.1.2 Outer Closure Lid

The cask outer closure lid uses two concentric elastomeric seals to form the closure with the containment upper forging surface. In the outer closure lid, the inner seal is the containment seal, and the outer elastomeric seal provides redundant closure. In the outer closure lid, the containment boundary seal is tested for leakage through a test port. The test port provides access to the volume between the two elastomeric lid seals. Following leakage rate testing of the outer closure lid inner seal, a test plug with a elastomeric seal is installed on the test port hole to provide redundant closure.

The outer closure lid contains a test plug to allow gas samples to be taken from the inter-lid space after a transport and before the outer lid is removed. This test plug is leakage tested using an ancillary test cover. The plug is covered by a bolted cover plate equipped with elastomeric seals to provide a redundant closure.

The outer closure lid containment sealing surfaces are not subject to corrosion due to the presence of

redundant closure features that prevent exposure to the environment external to the cask. In any case, the seal materials of construction are highly corrosion resistant

4.1.3.1.3 Vent and Drain Ports

The vent and drain ports are identical with respect to their sealing function. Both contain two inner seals and one outer containment seal, and those are independently tested. Of the two inner seals, one is located between the forging and the bushing, and one between the busing and the bronze plug. These are leak testet using an ancillary test cover of the port. The outer containment seal is located between the forging and the inner port cover plate. The inner port cover plate contains a test port that provides acces to the volume between the two inner seals and the outer seal. Following leakage rate testing of the inner port outer containment seal, a test plug with a elastomeric seal is installed on the test port hole to provide redundant closure.

4.1.3.1.4 Spray Cooling Port

The spray cooling port has two independent cover plates, the spray cooling cap and the spray cooling port cover plate, both equipped with two concentric elastomeric seals, and each with a test port that provides acces to the volume between the two seals. Following leakage rate testing of either cover plate seal, a test plug with a elastomeric seal is installed on the plate’s test port hole to provide redundant closure.

4.1.3.2 Containment Welds

The cask containment system welds consist of full penetration welds forming the containment shell, the full penetration weld connecting the containment shell to the containment upper forging, and the full penetration weld connecting the containment lower forging to the containment shell. All containment system boundary welds are fabricated and inspected in accordance with ASME Code Section III, Subsection NB. The weld details and examinations are shown in the drawing package in Section 1.3.

4.1.4 Closure Lids

The cask inner and outer closure lids are secured using multiple lid bolts around the perimeter. Torquing of lid bolts compresses the concentric elastomeric seals between the closure lids and the containment upper forging forming the closure lid seal. For the inner lid the bolt pressure is applied through a retainer ring.

Closure of the vent and drain ports is provided in each case by threading-in the bushing, the bronze plug and the inner port cover plate. Torquing of these components compresses the respective elastomeric seals, namely between the bushing and the forging, between the bronze plug and the bushing and between the cover plate and the forging, to form the port seals.

Closure of the test plug in the outer lid is provided by threading-in the plug. Torquing of the plug compresses the elastomeric seal between the plug and the lid to form the seals.

Closure of the spray cooling port cover plates is provided using multiple port cover plate closure bolts around the perimeter. Torquing of the threaded inner port cover plate and the bolts of the outer port cover plate compresses the port cover plate concentric elastomeric seals between the containment upper forging and the plates to form the port seals.

Closure of the inner closure lid leak test port is provided by a test port plug and seal installed in the penetration. Torquing of the plug compresses the elastomeric seal between the plug and the upper forging.

Bolt torquing patterns, lubrication requirements, and torque values are provided in Section 7. The torque values are established to maintain leakage rate criteria containment during normal and accident conditions of transport. Torque values for the inner and outer closure lid bolts preclude separation of the closure lids from the containment upper forging as clarified in Chapter 2. The lid bolts cannot be opened unintentionally or by a pressure that may arise within the package.

Figure 4.1.1: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

4.2 CONTAINMENT UNDER NORMAL CONDITIONS OF TRANSPORT

Chapter 2 of this report shows that all containment system components are maintained within their code-allowable stress limits and the elastomeric seals remain compressed during all normal conditions of transport as defined in 10CFR71 [4.0.1]. Chapter 3 of this report shows that all containment system components are maintained within their peak temperature and pressure limits for all normal conditions of transport as defined in 10CFR71 [4.0.1]. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (provided in Table 8.1.1) will not be exceeded during normal conditions of transport.

4.2.1 Containment Criteria

The leakage rate criteria presented in Table 8.1.1 shall be used for all containment system leakage tests for HI-STAR 80. Compliance with the leak rate criteria provided in Table 8.1.1 for HI-STAR 80 ensures that the radionuclide release rates specified in 10CFR71 [4.0.1] will not be exceeded during normal conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Section 8.

4.2.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5.

4.3 CONTAINMENT UNDER HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

Chapter 2 of this report shows that all containment system components are maintained within their code-allowable stress limits and the elastomeric seals remain compressed during all hypothetical accident conditions of transport as defined in 10CFR71 [4.0.1]. Chapter 3 of this report shows that all containment system components are maintained within their peak temperature and pressure limits for all hypothetical accident conditions of transport as defined in 10CFR71 [4.0.1]. Since the containment system remains intact without exceeding temperature and pressure limits, the design basis leakage rate (provided in Table 8.1.1) will not be exceeded during hypothetical accident conditions of transport.

4.3.1 Containment Criteria

The leakage rate criteria presented in Table 8.1.1 shall be used for all containment system leakage tests for HI-STAR 80. Compliance with the leak rate criteria provided in Table 8.1.1 for HI-STAR 80 ensures that the radionuclide release rates specified in 10CFR71 [4.0.1] will not be exceeded during hypothetical accident conditions of transport. Containment allowable leakage rate criteria and the type of tests specified are provided in Section 8.

4.3.2 Leak Test Sensitivity

The sensitivity for the leakage test instrument shall be equal to one-half of the allowable leakage rate in accordance with ANSI N14.5.

4.4 LEAKAGE RATE TESTS FOR TYPE B PACKAGES

All leakage rate testing of the cask containment system shall be performed in accordance with the guidance in ANSI N14.5 [8.1.6]. Chapter 8 provides the containment system components to be tested and the type of leakage test to be performed for post-fabrication, pre-shipment, periodic, and maintenance qualification.

4.4.1 Fabrication Leakage Rate Test

The fabrication leakage rate test demonstrates that the containment system, as fabricated, provides the required level of containment. The fabrication leakage test for HI-STAR 80 package is performed at the fabrication facility to ensure that the welded enclosure vessel will maintain its containment function.

Additionally, after fabrication of all components, the inner and outer closure lids are installed and the mechanical seals are tested to ensure that the fit-up of the inner and outer closure lids with the containment flange will meet the leakage rate acceptance criteria after NFWB-1 loading.

The entire containment boundary, including base material, welds, seals, closures, valves, or other boundary elements, will be leakage-rate tested during the fabrication process, in accordance with the requirements of ANSI N14.5 specified in Chapter 8.

4.4.2 Pre-Shipment Leakage Rate Test

The pre-shipment leakage rate test demonstrates that the containment system closure has been properly performed. Pre-shipment leakage rate testing is performed by the user before each shipment, after the contents are loaded and the containment system is assembled. The pre-shipment leakage rate test remains valid for 1 year.

4.4.3 Periodic Leakage Rate Test

The periodic leakage rate test demonstrates that the containment system closure capabilities have not deteriorated over an extended period of use. A periodic leakage rate test is only required if the most current leakage rate test occurred more than twelve months prior to package transport. Periodic leakage rate testing is performed by the user before each shipment if the previous leakage rate test has expired. The periodic leakage rate test remains valid for 1 year.

4.4.4 Maintenance Leakage Rate Test

The maintenance leakage rate test demonstrates that the containment system provides the required level of containment after undergoing maintenance, repair and or containment component replacement; and shall be performed prior to returning a package to service.

Only portions affected by the maintenance are maintenance leakage tested as stated in Subsection 8.2.2.

4.5 REQUIREMENTS FOR NORMAL AND HYPOTHETICAL ACCIDENT CONDITIONS OF NFWB-1 TRANSPORT

HI-STAR 80 System is designed to meet the radioactive release limit requirements of 10CFR71 [4.0.1]. Allowable leakage rates are determined for HI-STAR 80 with NFWB-1 in accordance with the requirements of ANSI N14.5 [8.1.6], and utilizing NUREG/CR-6487 [4.5.1] as guides.

4.5.1 Assumptions

PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

4.5.2 Analysis and Results

The allowable leakage rates for the containment boundary under normal and hypothetical accident conditions of transport at operating conditions for HI-STAR 80 System are presented in this subsection.

To calculate the leakage rates for a particular contents type and transportation condition, the following were determined: the source term concentration for the releasable material; the effective A_2 of the individual contributors; the releasable activity; the effective A_2 for the total source term; the allowable radionuclide release rates; and the allowable leakage rates at transport (normal and accident) conditions. Using the equations for continuum and molecular flow, the corresponding leakage hole diameters were calculated. Then, using these leak hole diameters, the corresponding allowable leakage rates at test conditions were calculated. Parameters were utilized in a way that ensured conservatism in the final leakage rates for the conditions, contents, and package arrangements considered.

The input parameters for normal, hypothetical accident and test conditions are presented in Table 4.5.2.

The methodology and analysis results for HI-STAR 80 System are summarized below. The results are shown in Table 4.5.9.

4.5.2.1 Source Terms for NFWB-1

The non-fuel inventory for HI-STAR 80 is limited to irradiated non-fissile core components in solid form. The waste is considered as non-dispersible. The contents are non fissile or fissile exempted and is mainly consisting of metal or ceramics. Radioactive gases are not associated with the waste contents and considered negligible if any are present.

The specific guidance in NUREG/CR-6487 [4.5.1], Chapter 4 "Solid Byproduct or Special Nuclear Materials" is followed in determining the appropriate source terms for NFWB-1. 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 aerolization (spallation) of surface contamination into the containment vessel fill gas to form a releasable aerosol. The containment analysis for HI-STAR 80 assumed non-dispersible solids with no fines made of the bulk radioactive material.

Therefore the source-terms from releasable activity arise from surface crud. The crud spallation fractions for normal and accident conditions are assumed.

Table 4.5.3 presents the isotope inventory used in the calculation. Table 4.5.4 summarizes the parameters from NUREG/CR-6487 [4.5.1] used in this analysis. Table 4.5.4 also provides the estimated total surface area of the waste transported in NFWB-1 and the surface activity density. Total source term results for the HI-STAR 80 System are presented on Table 4.5.5.

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 4.5.4,

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 4.5.4, and A_{SC} is activity surface density of the contaminated solids [Bq/cm^2; (Ci/cm^2)] shown in Table 4.5.4,

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

Calculated activity concentrations for normal and hypothetical accident conditions are provided in Table 4.5.5.

4.5.2.2 Releasable Activity

The releasable activity is the product of the activity concentration and free volume in containment boundary of HI-STAR 80 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].

4.5.2.3 Determination of A_2 Value

As described in Paragraph 4.5.2.1, 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 4.5.6.

4.5.2.4 Allowable Radionuclide Release Rates

The containment criterion for the HI-STAR 80 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 x 10^{-6} in one hour, where A_2 is determined in paragraph 4.5.2.3.

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

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

where,

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

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

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

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

The containment criterion for the HI-STAR 80 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.

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

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 4.5.7.

4.5.2.5 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).

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

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 4.5.7 summarizes the allowable leakage rates at the upstream pressures.

4.5.2.6 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.

$$L_{@P_u} = \left[\frac{2.49x10^6 \ D^4}{a\ u} + \frac{3.81x10^3 \ D^3 \sqrt{\frac{T}{M}}}{a\ P_a} \right] \left[P_u - P_d \right] \frac{P_a}{P_u} \qquad \textbf{(4-6)}$$

where,

$L_{@Pu}$ is the allowable leakage rate at the upstream pressure for normal and accident conditions [cm^3/s],
a is the capillary length or Seal 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 B-1 [8.1.6],
u is the fluid viscosity for air [cP] from Reference [4.5.2],
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 4.5.2.

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 4.5.7 for normal and hypothetical accident conditions of transport, respectively. Other parameters to solve Equation 4-6 are presented in Table 4.5.2.

Using this leak hole diameter and the temperature and pressure specified for reference test conditions provided in Table 4.5.2, Equation 4-6 was solved for the volumetric leakage rate at reference test conditions. Volumetric leakage rates for normal (L_{u-N}) and accident (L_{u-A}) conditions are specified in Table 4.5.8.

Equation B-1 of ANSI N14.5 [8.1.6] is used to express this volumetric leakage rate into a mass-like flow rate as follows:

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

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 4.5.8. 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.

4.5.2.7 Leak Test Sensitivity

The sensitivity (S) for the leakage test procedures is established by ANSI N14.5 [8.1.6] as:

$$S = \frac{1}{2} \text{ Leakage Rate} \quad \textbf{(4-8)}$$

The leak test sensitivity under reference test conditions is presented in Table 4.5.9 8.1.1.

Table 4.5.1
Free Volume (cm^3)

Equipment	Volume (cm^3)
HI-STAR 80	4.90E+06

Table 4.5.2: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

Table 4.5.3
Isotope Inventory

Nuclide	Inventory
Gases	
N/A	N/A
Crud	
^{60}Co	61,550 Ci (2.28×10^{15} Bq)
Volatiles	
N/A	N/A
Fines	
N/A	N/A

Table 4.5.4
Values found in NUREG/CR-6487 used in the Leakage Rate Analysis and Crud Surface Activity Density, and Surface Area of Contaminated Solids

Parameter	Normal Conditions	Hypothetical Accident Conditions
Activity fraction of the surface contamination that spalls-off (f_N, f_A)	0.15	1
Crud Surface Activity Density (A_{SC})	1.4×10^{-2} Ci/cm^2 (5.16×10^{8} Bq/cm^2)	1.4×10^{-2} Ci/cm^2 (5.16×10^{8} Bq/cm^2)
Surface Area of Contaminated Solids stored in HI-STAR 80 (S_{AS})	4.41×10^{6} cm^2	4.41×10^{6} cm^2

Table 4.5.5
Total Source Term for the HI-STAR 80 System (C_{Total})

Equipment	Activity Concentration C_N and C_A
Normal Transport Conditions	
HI-STAR 80	1.88×10^{-3} Ci/cm^3 (6.956×10^7 Bq/cm^3)
Accident Conditions	
HI-STAR 80	1.26×10^{-2} Ci/cm^3 (4.662×10^8 Bq/cm^3)

Table 4.5.6
Total Source Term Effective A_2 for Normal and Hypothetical Accident Conditions

Equipment	Effective A_2
Normal Transport Conditions	
HI-STAR 80	10.8 Ci (0.4×10^{12} Bq)
Hypothetical Accident Conditions	
HI-STAR 80	10.8 Ci (0.4×10^{12} Bq)

Table 4.5.7
Allowable Release Rates & 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 80	3.01×10^{-9} Ci/s (111 Bq/s)	1.60×10^{-6} cm^3/s
Accident Conditions		
HI-STAR 80	17.8×10^{-6} Ci/s (658.6×10^{3} Bq/s)	1.42×10^{-3} cm^3/s

Table 4.5.8
Calculated Allowable Leak Rates at Reference Test 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 80	5.18×10^{-7} cm^3/s	5.18×10^{-7} atm-cm^3/s, Air (5.25×10^{-8} Pa-m^3/s, Air)
Accident Conditions		
HI-STAR 80	1.90×10^{-4} cm^3/s	1.90×10^{-4} atm-cm^3/s (1.93×10^{-5} Pa-m^3/s, Air)

Table 4.5.9
Calculated Leakage Rates Acceptance Criteria under Reference Test Condition

HI-STAR 80 Reference Test	Leakage Rate Acceptance Criterion	Sensitivity
atm-cm^3/sec, Air	5.0E-07	2.5E-07
Pa-m^3/s, Air	5.0E-08	2.5E-08

4.6 REQUIREMENTS FOR NORMAL AND HYPOTHETICAL ACCIDENT CONDITIONS OF SPENT FUEL TRANSPORT

HI-STAR 80 System is designed to meet the radioactive release limit requirements of 10CFR71 [4.0.1]. Allowable leakage rates for HI-STAR 80 with spent fuel are determined in accordance with the requirements of ANSI N14.5 [8.1.6], and utilizing NUREG/CR-6487 [4.5.1] as guides. The permeation leakage rate is determined in accordance with ISO 12807 [4.6.1].

4.6.1 Assumptions

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4.6.2 Analysis and Results

The leakage rates for normal and hypothetical accident conditions of transport at operating conditions and the allowable leakage rates at test conditions for the HI-STAR 80 packaging are determined using the methodology described in NUREG/CR-6487 [4.5.1]. To calculate the leakage rates for a particular contents type and transportation condition, the following are determined: the source term concentration for the releasable material; the effective A_2 of the individual contributors; the releasable activity; the

effective A_2 for the total source term; the allowable radionuclide release rates; the allowable leakage rates at transport (operating) conditions. Using the equations for continuum and molecular flow, the corresponding leakage hole diameters are calculated. Then, using these leak hole diameters, the corresponding allowable leakage rates at test conditions are calculated. Parameters are utilized in a way that ensured conservatism in the final leakage rates for the conditions, contents, and packages considered.

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The methodology is described in this section.

4.6.2.1 Radioactice Content of the Package

In accordance with NUREG/CR-6487 [4.5.1], the following contributions are considered in determining the releasable source term for packages designed to transport irradiated fuel rods: (1) the radionuclides comprising the fuel rods, (2) the radionuclides on the surface of the fuel rods, and (3) the residual contamination on the inside surfaces of the vessel. NUREG/CR-6487 [4.5.1] goes on to state that a radioactive aerosol can be generated inside a vessel when radioactive material from the fuel rods or from the inside surfaces of the container becomes airborne. The sources for the airborne material are: (1) residual activity on the cask interior, (2) fission and activation-product activity associated with corrosion-deposited material (crud) on the fuel assembly surface, and (3) the radionuclides within the individual fuel rods. In accordance with NUREG/CR-6487 [4.5.1], contamination due to residual activity on the cask interior surfaces is negligible as compared to crud deposits on the fuel rods themselves and therefore may be neglected. The source term considered for this calculation results from the spallation of crud from the fuel rods and from the fines, gases and volatiles which result from cladding breaches.

As a conservative approach and to simplify calculations, it is assumed that crud spallation and cladding breaches occur instantaneously and simultaneously after fuel loading and container closure operations. Therefore, activity density that results in the containment vessel from crud spallation and cladding breaches is available for immediate release from the containment vessel should a leak occur.

The bounding isotope inventory for isotopes other than ^{60}Co (crud) is calculated with the TRITON and ORIGAMI/ORIGEN modules of the SCALE 6.2.1 system. The inventories for F-12P and F-32B are based on fuel assemblies with burnup, enrichment, and cooling time combinations stated in Table 4.6.1. The bounding isotope inventories for F-12P and F-32B baskets are provided in Table 4.6.4.

4.6.2.1.1 Volume in the Containment Vessel

The containment system boundary for the HI-STAR 80 packaging consists of the containment shell and associated components. Cavity volume and its reference are provided in Table 4.6.2.

4.6.2.1.2 Source Activity Due to Crud Spallation from Fuel Rods

Crud is a loosely adherent material or a tightly adherent layer on the outside surface of the fuel rods, which may become dislodged under some circumstances. The activity density that results inside the containment vessel as a result of crud spallation from spent fuel rods can be formulated as:

$$C_{crud} = \frac{f_C M_A f_B}{V} \qquad \textbf{(4-9)}$$

where:

C_{crud} is the activity density inside the containment vessel as a result of crud spallation [Ci/cm^3];
M_A is the total crud activity inventory per assembly [Ci/assy];
f_C is the crud spallation fraction;
N_A is the number of assemblies; and
V is the free volume inside the containment vessel [cm^3].
f_C values for normal and accident conditions of transportation are provided in Table 4.6.2.

The majority of the activity associated with crud is due to ^{60}Co [4.5.1]. The inventory for ^{60}Co is determined by using the crud surface activity (provided in Table 4.6.2) multiplied by the surface area per assembly (from Table 4.6.2). The source term is then decay corrected using the basic radioactive decay equation:

$$A(t) = A_0 e^{-\lambda t} \qquad \textbf{(4-10)}$$

where:

A(t) is activity at time t [Ci/assembly];
A_0 is the initial activity [Ci/assembly];
λ is the $\ln 2/t_{1/2}$ (where $t_{1/2}$ = 5.271 years for ^{60}Co); and
t is the time in years.

The total activity inventory for the isotope i is calculated my multiplying the assembly inventory of isotope i times number of fuel assemblies in a cask.

The C_{crud} values for the bounding patterns are provided in Tables 4.6.5(a) and 4.6.5(b) for F-12P and F-32B, respectively.

4.6.2.1.3 Source Activity Due to Releases of Fines from Cladding Breaches

A breach in the cladding of a fuel rod may allow radionuclides to be released from the resulting cladding defect into the interior of the cask. If there is a leak in the containment vessel, then the radioisotopes emitted from a cladding breach that are aerosolized may be entrained in the gases escaping from the shipping container and result in a radioactive release to the environment.
The activity concentration inside the containment vessel due to fines being released from cladding breaches is given by:

$$C_{fines} = \frac{f_F I_{fines} N_A f_B}{V} \qquad \textbf{(4-11)}$$

where:

C_{fines} is the activity concentration inside the containment vessel as a result of fines released from cladding breaches [Ci/cm^3];
f_F is the fraction of a fuel rods mass released as fines as a result of a cladding breach;
I_{fines} is the activity inventory [Ci/assy];
N_A is the number of assemblies,
f_B is the fraction of rods that develop cladding breaches, and
V is the free volume inside the containment vessel [cm^3].

f_F and f_B values for normal and accident conditions of transportation are provided in Table 4.6.2.

The C_{fine} values for the bounding patterns are provided in Tables 4.6.6(a) and 4.6.6(b) for F-12P and F-32B, respectively.

4.6.2.1.4 Source Activity Due to Releases of Gases from Cladding Breaches

If a cladding failure occurs in a fuel rod, a large fraction of the gap activity gases will be introduced into the free volume of the system. Tritium and Krypton-85 are typically the major sources of radioactivity among the gases present [4.5.1].

The activity concentration due to the release of gases from a cladding breach is given by:

$$C_{gas} = \frac{f_G I_{gas} N_A f_B}{V} \qquad \textbf{(4-12)}$$

where:

C_{gas} is the releasable activity concentration inside the containment vessel due to gases released from cladding breaches [Ci/cm^3];
F_G is the fraction of gas that would escape from a fuel road that developed a cladding breach;
I_{gas} is the gas activity inventory [^{3}H, ^{129}I, ^{85}Kr, ^{81}Kr, ^{127}Xe] [Ci/assy];
N_A is the number of assemblies;
f_B is the fraction of rods that develop cladding breaches; and
V is the free volume inside the containment vessel [cm^3].

f_G and f_B values for normal and accident conditions of transportation are provided in Table 4.6.2.

The C_{gas} values for the bounding patterns are provided in Tables 4.6.7(a) and 4.6.7(b) for F-12P and F-32B, respectively.

4.6.2.1.5 Source Activity Due to Releases of Volatiles from Cladding Breaches

Volatiles such as cesium, strontium, and ruthenium, can also be released from a fuel rod as a result of a cladding breach.

The activity concentration due to the release of volatiles is given by:

$$C_{vol} = \frac{f_V I_{vol} N_A f_B}{V} \quad \textbf{(4-13)}$$

where:

C_{vol} is the releasable activity concentration inside the containment vessel due to volatiles released from cladding breaches [Ci/cm^3],
f_V is the fraction of volatiles that would escape from a fuel rod that developed a cladding breach,
I_{vol} is the volatile activity inventory [^{89}Sr, ^{90}Sr, ^{137}Cs, ^{135}Cs, ^{134}Cs, ^{103}Ru, ^{106}Ru] [Ci/assy],
N_A is the number of assemblies,
f_B is the fraction of rods that develop cladding breaches, and
V is the free volume inside the containment vessel [cm^3].

f_V and f_B values for normal and accident conditions of transportation are provided in Table 4.6.2.

The C_{vol} values for the bounding patterns are provided in Tables 4.6.8(a) and 4.6.8(b) for F-12P and F-32B, respectively.

4.6.2.1.6 Total Source Term for the HI-STAR 80 System

The total source term is determined by combining equations 4-9, 4-11, 4-12, and 4.13:

$$C_{total} = C_{crud} + C_{fines} + C_{gaes} + \quad \textbf{(4-14)}$$

where C_{total} has units of Ci/cm^3.

Bounding C_{Total} values are provided in Tables 4.6.9(a) and 4.6.9(b) for F-12P and F-32B, respectively.

4.6.2.2 Effective A_2 of Individual Contributors (Crud, Fines, Gases, and Volatiles)

The A_2 of the individual contributions (i.e., crud, fines, gases, and volatiles) are determined in accordance with NUREG/CR-6487 [4.5.1]. As described in 2.1.2 above, the majority of the activity due to crud is from ^{60}Co. The A_2 value used for crud is the same as that for ^{60}Co found in 10 CFR 71, Appendix A [4.0.1], which is provided in Table 4.6.11.

In accordance with 10 CFR 71.51(b) [4.0.1], the methodology presented in 10 CFR 71 Appendix A for mixtures of different radionuclides is used to determine the effective A_2 values for the gases, volatiles, and fines.

$$A_2 \text{ for a mixture} = \frac{1}{\sum_i \frac{f_i}{(A_2)_i}} \quad \textbf{(4-15)}$$

where:

f_i is the fraction of activity of nuclide i in the mixture, and
$(A_2)_i$ is the appropriate A_2 value for the nuclide i.

10 CFR 71.51(b) [4.0.1] also states that for Krypton-85, an effective A_2 value equal to 10 A_2 may be used.

The effective A_2 values for the bounding patterns are provided in Tables 4.6.10 through 4.6.13 for F-12P and F-32B.

4.6.2.3 Releasable Activity

The releasable activity is the product of the respective activity concentration (C_{fines}, C_{gas}, C_{crud}, and C_{vol}) and the respective containment volume. The releasable activity of fines, volatiles, crud and gases are determined using this methodology.

$$\textit{Releasable Activity [Ci] = Activity Concentration [Ci/cm}^3\textit{] x Volume [cm}^3\textit{]} \qquad \textbf{(4-16)}$$

The releasable activity values for the bounding patterns are provided in Tables 4.6.14(a) and 4.6.14(b) for F-12P and F-32B, respectively.

4.6.2.4 Effective A_2 for the Total Source Term

Using the releasable activity and the effective A_2 values from the individual contributors (i.e., crud, fines, gases, and volatiles), the effective A_2 for the total source term is calculated for each loading case, for normal transportation and hypothetical accident conditions. The methodology used to determine the effective A_2 is the same as that used for a mixture, which is provided in Equation 4-15.

The effective A_2 for the bounding patterns are provided in Tables 4.6.16(a) and 4.6.16(b) for F-12P and F-32B, respectively.

4.6.2.5 Allowable Radionuclide Release Rates

The containment criterion for the HI-STAR 80 system under normal conditions of transport is given in 10 CFR 71.51(a)(1) [4.0.1]. This criterion requires that a package have a radioactive release rate less than A_2 x 10^{-6} in one hour, where A_2 is the Effective A_2 for the total source term in the packaging. Additionally, 10 CFR 71 specifies that for hypothetical accident conditions, the quantity that may be released in one week is A_2 (Effective A_2 for the total source term).

NUREG/CR-6487 [4.5.1] provides the following equations for the allowable release rates.

Equation 4-17, for normal conditions:

$$R_N = L_N C_N \leq A_2 \times 2.78\text{x}10^{-10} \text{ /second} \qquad \textbf{(4-17)}$$

where:

R_N is the release rate for normal transport [Ci/s]

L_N is the volumetric gas leakage rate [cm^3/s]

C_N is the total source term activity concentration [Ci/cm^3]
A_2 is the appropriate effective A_2 value [Ci].

Equation 4-18, for hypothetical accident conditions:

$$R_A = L_A C_A \leq A_2 \times 1.65 \times 10^{-6} \text{ /second} \quad \textbf{(4-18)}$$

where:
R_A is the release rate for hypothetical accident conditions [Ci/s]
L_A is the volumetric gas leakage rate [cm^3/s]
C_A is the total source term activity concentration [Ci/cm^3]
A_2 is the appropriate effective A_2 value [Ci].

The allowable release rates for the bounding patterns are provided in Tables 4.6.16(a) and 4.6.16(b) for F-12P and F-32B, respectively.

4.6.2.6 Allowable Leakage Rates at Operating Conditions

The allowable upstream leakage rates at operating conditions were determined by dividing the allowable release rates by the appropriate source term activity concentration.

$$L_N = \frac{R_N}{C_N}(1 - f_P) \quad \textbf{(4-19)}$$

$$L_A = \frac{R_A}{C_A} \quad \textbf{(4-20)}$$

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 [Ci/s];
C_N or C_A is the total source term activity concentration for normal (N) or accident (A) conditions [Ci/cm^3]; and
f_P Permeation factor, provided in Table 4.6.15.

The permeation calculation is provided in [4.6.3].

The allowable leakage rates determined using Equations 4-19 and 4-20 are the allowable leakage rates at the upstream pressure.

The allowable leakage rates for the bounding patterns are provided in Tables 4.6.16(a) and 4.6.16(b) for F-12P and F-32B, respectively.

4.2.6.7 Allowable Leakage Rates at Test Conditions

The leakage rate discussed thus far is determined at operating conditions (either normal or accident). The following provides details of the methodology used to convert the allowable leakage rate at

operating conditions to an allowable leakage rate at 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 [4.5.1], the corresponding leak hole diameters were calculated for each analyzed case and transport condition by solving Equation 4-21 for D, the leak hole diameter.

$$L = \left[\frac{2.49 \times 10^6 D^4}{a\,u} + \frac{3.81 \times 10^3 D^3 \sqrt{\frac{T}{M}}}{a\,P_a} \right] [P_u - P_d] \times \frac{P}{P} \qquad \textbf{(4-21)}$$

where:

$L_{@Pu}$ is the allowable leakage rate at the upstream pressure for normal and accident conditions [cm^3/s];
a is the capillary length [cm];
T is the temperature for normal or accident conditions [K];
M is the gas molecular weight [g/mole] = 4.0 from ANSI N14.5, Table B1 [8.1.6];
u is the fluid viscosity for helium [cP] from Rohsenow and Hartnett [4.5.2];
P_u is the upstream pressure [atm];
P_d is the downstream pressure for normal or accident conditions [atm];
P_a is the average pressure; $P_a = (P_u + P_d)/2$ for normal or accident conditions [atm]; and
D is the capillary diameter [cm].

The leak hole diameter is determined by solving Equation 4-21 for 'D' where $L_{@Pu}$ is the most restrictive allowable leakage rate at the upstream pressure and using the parameters for normal and accident conditions of transport presented in Table 4.6.3. The corresponding leak hole diameter is determined for condition of transport.

Using these leak hole diameters, and the temperature and pressures for test conditions, Equation 4-21 is solved for the volumetric leakage rates at test conditions.

Equation B.1 of ANSI 14.5 [8.1.6] is used to express this volumetric leakage rate into a mass-like flow rate (Q_u) as follows:

$$Q_u = L_u * P_u \qquad \textbf{(4-22)}$$

where:

L_u is the upstream volumetric leakage rate [cm^3/s];
Q_u is the mass-like helium leak rate [atm-cm^3/sec]; and
P_u is the upstream pressure [atm].

The leakage test sensitivity is discussed in Paragraph 4.5.2.7.

The allowable helium leakage rates under test for the bounding patterns are provided in Tables 4.6.17(a) and 4.6.17(b) for F-12P and F-32B, respectively. The bounding acceptance criteria and leakage test sensitivities are provided in Table 8.1.1.

Tables 4.6.1 through 4.6.17: PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390

CHAPTER 4 REFERENCES

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

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

[4.0.2] Not Used

[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] Not Used.

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

[4.5.2] W.M. Rohsenow, J.P. Hartnett, and Y.I. Cho, Handbook of Heat Transfer, McGraw-Hill Companies, New York, 1998.

[4.5.3] "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.

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

[4.6.1] International Standard ISO 12807:2018(E), "Safe Transport of Radioactive Materials — Leakage Testing on Packages."

[4.6.2] K. Brehm, K.H. Ecker, H.P. Weise, , H. Kowalewsky, H.P Weise, Permeation through Elastomeric O-ring Seals, IAEA-SM-286/44P.

[4.6.3] Containment Analysis for HI-STAR 80 Loaded with Spent Fuel, HI-2201022, Revision 0.

CHAPTER 5 - SHIELDING EVALUATION

5.0 INTRODUCTION

The shielding analysis of the HI-STAR 80 Package to demonstrate compliance with 10CFR71.47 and 10CFR71.51 is presented in this chapter. HI-STAR 80 is designed to accommodate one fuel basket or a core component cassette basket (the NFWB-1). The loaded fuel basket may be either an F-12P or an F-32B. The F-12P basket contains up to 12 PWR assemblies, and the F-32B basket contains up to 32 BWR fuel assemblies. Control components placed in the PWR assemblies may also be transported in the F-12P basket in selected locations. Core components can be transported in the NFWB-1 and are contents that are non-fissile or fissile exempted, and consists of mainly metal or ceramics.

In order to offer the user flexibility in fuel loading, HI-STAR 80 is qualified for a range of burnup, enrichment and cooling time combinations. The F-32B can be loaded with UO_2 fuel only, or a mixture of UO_2 and MOX fuel, while the F-12P can only be loaded with UO_2 fuel. The burnup, enrichment and cooling time combinations are described in Appendix 7.D, and all combinations have been explicitly analyzed and found to be acceptable compared to the regulatory limits, or shown to be bounded by explicitly analyzed combinations.

In addition to storing undamaged PWR and BWR fuel assemblies, the HI-STAR 80 system is designed to transport PWR and BWR fuel rods which may be leaking, broken, or fragmented (as explained in Appendix 7.D). PWR and BWR fuel rods which are leaking, broken, or fragmented, are required to be loaded into quivers prior to loading in the HI-STAR 80. Subsection 5.4.12 provides more detail on quivers.

The core components that are qualified for the NFWB-1 are comprised of fuel channels, transition pieces, spacer grids, intact neutron monitors, BWR control rods, or burnable absorbers. The limiting activities and characteristics for those are also specified in Appendix 7.D.

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 80 has been designed to meet a dose rate limit of 0.1 mSv/h at 2 meters from the surface of the vehicle, the dose rate at 1 meter from the package could be greater than 0.1 mSv/h and the transport index could exceed 10. Therefore, HI-STAR 80 must be shipped by exclusive use shipment as discussed in Section 1.1.

The shielding analyses were performed with MCNP5 1.51 [5.1.1] developed by Los Alamos National Laboratory (LANL). The source terms for all fuel assemblies were calculated with the TRITON, ORIGAMI and ORIGEN sequences from the SCALE 6.2.1 systems [5.1.2]. This is a recent version on the SCALE code, providing substantial improvements over earlier versions such as SCALE 5.1 used in Holtec's approved Storage and Transportation FSARs and SAR under separate docket numbers [5.1.4]. Detailed descriptions of the MCNP models and the source term calculations are presented in Sections 5.3 and 5.2, respectively.

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 190 (Docket #71-9373) to a large extent.

Overall, this chapter contains the following information:

- A description of the shielding features of the Package.
- 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 80.

Analyses for the HI-STAR 80'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 80 packaging with respect to radiation shielding consist of the fuel basket or core component cassette basket and the basket support structures, the cask including the two lids, the cask body, lower forging, and the central steel structures of the impact limiters. The main shielding is provided by the cask body. The cask body steel and lead, the lids, and lower forging provide the main gamma shielding, while the neutron shielding is provided by the Holtite neutron absorber embedded in those parts. In the radial direction, the neutron absorber is located outside of the lead region and inside of a support structure. The fuel basket or NFWB together with the basket supports maintain the fuel assemblies or the core component cassette in a fixed position within the package, and also provide additional gamma shielding. Any shielding effect of the crushable impact limiter material and its surrounding steel skin is neglected for both normal and accident conditions, but the backbone structures of the impact limiters are considered. The dimensions of the shielding components are shown in the drawing package in Section 1.3. The conservative dimensions, the shielding material densities and material compositions are presented in Subsection 5.3.

5.1.2 Summary of Maximum Radiation Levels for Packages Loaded with Spent Fuel

The dose rates are based on selected burnups between 10000 and 70000 MWD/MTU, and corresponding initial U-235 enrichment and cooling times for different numbers of fuel assemblies in each basket, as listed in Appendix 7.D, also encompassing the various fuel assembly types that are qualified. Each burnup, enrichment, and cooling time combination is independently evaluated for the given number of assemblies and it is verified that the calculated dose rates are less than the regulatory limits. In this subsection, for each dose location, only the highest dose rates are reported, taken at the surface and at 2 m under normal conditions, and at 1 m under accident conditions.

The dose rates listed in this subsection are maximum values, considering axial, radial and azimuthal variations as applicable. This is achieved by specifying a reasonably fine grid of dose locations around the cask, and selecting the highest values. Details on dose locations are provided in Subsection 5.3.4.

5.1.2.1 Normal Conditions

As discussed in Section 1.1, HI-STAR 80 will be transported by exclusive use shipment and complies with 10CFR71.47(b).

Dose rates are calculated on the package surface at locations shown in Figure 5.1.1. Results are presented in Tables 5.1.1 and 5.1.2 for the F-32B and F12P baskets, respectively.

All values are below 2 mSv/h, therefore showing that HI-STAR 80 complies with 10CFR71.47(b)(1). It should be noted that the additional conditions stated in 10CFR71.47(b)(1)(i)

through (iii) (closed vehicle; fixed position; no loading/unloading) do not have to be met by HI-STAR 80, since the surface dose rate does not exceed 2 mSv/h.

The calculated dose rates on the surface of the package 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. HI-STAR 80 therefore complies with 10CFR71.47(b)(2).

The maximum 2 meter dose rates for HI-STAR 80 have been calculated at a distance of 2 meters from transport vehicle outer lateral surfaces for the side cask location and 2 meters from the impact limiters for the top and bottom locations. The total width of the transport vehicle is 270 cm. Results are presented in Tables 5.1.3 and 5.1.4 for the F-32B and the F-12P baskets, respectively. Tables 5.1.3 and 5.1.4 show that all dose rates at 2 m from the transport vehicle outer lateral surfaces and from the top and bottom impact limiters are below 0.1 mSv/h. HI-STAR 80 therefore complies with 10CFR71.47(b)(3).

Dose rates have also been calculated to determine the distance necessary to comply with the 0.02 mSv/hr requirement specified in 10CFR71.47(b)(4) for any normally occupied space. Results are presented in Tables 5.1.5 and 5.1.6 for the F-32B and F-12P baskets, respectively. The results presented in Tables 5.1.5 and 5.1.6 identify the distances necessary from Dose Locations 4 and 5 (the top and bottom of HI-STAR 80 (see Figure 5.1.1)) which exposed personnel must maintain in order meet the 0.02 mSv/h requirement. Therefore, if the normally occupied space of the vehicle is at a distance less than the values specified in Tables 5.1.5 or 5.1.6, radiation dosimetry is required for personnel to comply with 10CFR71.47(b)(4).

The analyses summarized in this section demonstrate HI-STAR 80's compliance with the 10CFR71.47(b) limits.

5.1.2.2 Hypothetical Accident Conditions

The hypothetical accident conditions of transport presented in Section 2.7 have four consequences that affect the shielding materials. These are the damage to the neutron shield as a result of the design basis fire, damage to the impact limiters as a result of the 9-meter (30 foot) drop, localized damage from the pin drop, and lead slump as a result of the 9-meter (30-foot) drop. For the hypothetical accident condition of the design basis fire the shielding analysis conservatively assumes the neutron shield material is completely lost. With respect to the impact limiter, it is assumed that the crush materials of the impact limiters and their outer skin are completely lost, and that only the impact limiters steel backbone is present. This is appropriate and conservative, since the structural evaluations of the drop conditions show that the impact limiters remain attached to the cask, and that only local crushing of the impact limiters occurs. The lead slump resulting from the 9-meter drop is also modeled, as discussed in detail in Section 5.3.3. Finally, the localized damage of the cask outer surface from the pin drop is explicitly modeled under the accident calculations. All those conditions are modeled concurrently in a single model.

Throughout the hypothetical accident condition, the axial location of the fuel will remain practically fixed within the baskets (see Paragraph 5.3.1.2). Chapter 2 shows that the basket of HI-STAR 80 cask remains essentially unaltered throughout the hypothetical accident conditions.

Some small localized deformations of the basket might be possible during drop accidents. However, such localized deformations will have a negligible impact on the dose rate at 1 meter from the surface.

Figure 5.1.2 shows the dose locations at 1 meter from the surface for the conditions of the HI-STAR 80 Package after the postulated accident. Corresponding maximum dose rates are listed in Tables 5.1.7 and 5.1.8 for the F-32B and F-12P baskets, respectively. All values in these tables are below the regulatory limit of 10 mSv/h.

Analyses summarized in this section demonstrate the HI-STAR 80 Package's compliance with the 10CFR71.51 radiation dose limit.

5.1.3 Summary of Maximum Dose Rates for the NFWB-1

The core components that can be transported in the NFWB-1 are contents that are non-fissile or fissile exempted, and consists of mainly metal or ceramics.

The maximum specific source strengths of the core components are limited such that the dose rate limits in 10CFR71.47 and 10CFR71.51 are not exceeded for HI-STAR 80 containing the NFWB-1, see Appendix 7.D for a specification of those limits. The surface and 2 meter dose rates from the HI-STAR 80 containing the NFWB-1 with the maximum permitted specific source strengths for normal conditions are listed in Tables 5.1.9 and 5.1.10, respectively. The 1 meter dose rates from HI-STAR 80 containing the NFWB-1 with the maximum permitted specific source strengths for accident conditions are listed in Table 5.1.11. Refer to Subsection 5.4.8 for the methodology used to determine specific source strength limits for the NFWB-1.

Analyses summarized in this section demonstrate the HI-STAR 80 Package's compliance with the 10CFR71.47 and 10CFR71.51 radiation dose rate limits.

TABLE 5.1.1

MAXIMUM DOSE RATES ON THE SURFACE OF THE HI-STAR 80 PACKAGE WITH THE F-32B BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]					Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
1						1.774	2
2						0.720	2
3						1.176	2
4						0.033	2
5						0.077	2

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.2

MAXIMUM DOSE RATES ON THE SURFACE OF THE HI-STAR 80 PACKAGE WITH THE F-12P BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]						Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
1							1.312	2
2							0.587	2
3							1.595	2
4							0.039	2
5							0.062	2

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.3

MAXIMUM DOSE RATES AT 2 METERS FROM THE HI-STAR 80 PACKAGE WITH THE F-32B BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]					Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
2 [3]						0.091	0.1
4						0.010	0.1
5						0.022	0.1

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies
[3] Dose rate at this location is taken as 2 meters from the outer lateral surface of the transport vehicle which has a width of 270 cm.

TABLE 5.1.4

MAXIMUM DOSE RATES AT 2 METERS FROM THE HI-STAR 80 PACKAGE WITH THE F-12P BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]						Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
2 [3]							0.090	0.1
4							0.011	0.1
5							0.024	0.1

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies
[3] Dose rate at this location is taken as 2 meters from the outer lateral surface of the transport vehicle which has a width of 270 cm.

TABLE 5.1.5

DISTANCES FOR THE 0.02 mSv/h DOSE RATE REQUIREMENT FOR THE HI-STAR 80 PACKAGE WITH THE F-32B BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]						Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
4							0.010	0.02
5							0.012	0.02

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.6

DISTANCES FOR THE 0.02 mSv/h DOSE RATE REQUIREMENT FOR THE HI-STAR 80 PACKAGE WITH THE F-12P BASKET FOR NORMAL CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]							Totals with Uncertainties (mSv/hr)	10 CFR 71.47 Limit (mSv/hr)
4								0.011	0.02
5								0.013	0.02

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.7

MAXIMUM DOSE RATES AT 1 METER FROM THE HI-STAR 80 PACKAGE WITH THE F-32B BASKET FOR ACCIDENT CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]					Totals with Uncertainties (mSv/hr)	10 CFR 71.51 Limit (mSv/hr)
1						3.465	10
2						8.947	10
3						2.389	10
4						0.116	10
5						0.454	10

[1] Refer to Figure 5.1.2 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.8

MAXIMUM DOSE RATES AT 1 METER FROM THE HI-STAR 80 PACKAGE WITH THE F-12P BASKET FOR ACCIDENT CONDITIONS

Dose Point Location [1]	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]						Totals with Uncertainties (mSv/hr)	10 CFR 71.51 Limit (mSv/hr)
1							2.534	10
2							7.739	10
3							2.394	10
4							0.126	10
5							0.361	10

[1] Refer to Figure 5.1.2 for dose point locations.
[2] Includes gammas from irradiated stainless steel dummy rods in assemblies

TABLE 5.1.9

MAXIMUM DOSE RATES ON THE SURFACE OF THE HI-STAR 80 PACKAGE WITH THE NFWB-1 FOR NORMAL CONDITIONS WITH BOUNDING NFW SOURCE STRENGTHS

Dose Point Location [1]	Dose Rate, mSv/hr including Uncertainties	10 CFR 71.47 Limit (mSv/hr)
1	1.900	2
2	0.983	2
3	1.900	2
4	0.002	2
5	0.057	2

[1] Refer to Figure 5.1.1 for dose point locations.

TABLE 5.1.10

MAXIMUM DOSE RATES AT 2 METERS FROM THE HI-STAR 80 PACKAGE WITH THE NFWB-1 FOR NORMAL CONDITIONS WITH BOUNDING NFW SOURCE STRENGTHS

Dose Point Location [1]	Dose Rate, mSv/hr including Uncertainties	10 CFR 71.47 Limit (mSv/hr)
2 [2]	0.0782	0.1
4 [3]	0.0005	0.1
5 [3]	0.0178	0.1

[1] Refer to Figure 5.1.1 for dose point locations.
[2] Dose rate at this location is conservatively taken at 2 meters from the outer lateral surface of the cask.
[3] The dose rates at these locations are below the 0.02 mSv/hr limit, and therefore 2 meters from the top and bottom is also distance from the top and bottom to meet the 0.02 mSv/hr dose rate limit.

TABLE 5.1.11

MAXIMUM DOSE RATES AT 1 METER FROM THE HI-STAR 80 PACKAGE WITH THE NFWB-1 FOR ACCIDENT CONDITIONS WITH BOUNDING GEOMETRY AND NFW SOURCE STRENGTHS

Dose Point Location [1]	Dose Rate, mSv/hr including Uncertainties	10 CFR 71.51 Limit (mSv/hr)
1	1.003	10
2	0.829	10
3	1.391	10
4	0.006	10
5	3.282	10

[1] Refer to Figure 5.1.2 for dose point locations.

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

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

5.2 SOURCE SPECIFICATION

The principal sources of radiation in HI-STAR 80 are:

- Gamma radiation originating from the following sources (see Subsection 5.2.1)

    1. Decay of radioactive fission products
    2. Secondary photons from neutron capture in fissile and non-fissile nuclides
    3. Hardware activation products generated during core operations.

- Neutron radiation originating from the following sources (see Subsection 5.2.2)

    1. Spontaneous fission
    2. α,n reactions in fuel materials
    3. Secondary neutrons produced by fission from subcritical multiplication
    4. γ,n reactions (this source is negligible).

The neutron and gamma source terms were calculated with the TRITON/ORIGAMI/ORIGEN modules of SCALE 6.2.1 [5.1.2]. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

The fuel assemblies to be qualified for transportation in HI-STAR 80 are PWR and BWR UO_2 assemblies, as well as BWR mixed oxide (MOX) assemblies. A description of the design basis fuel assemblies for the source term calculations is provided in Table 5.2.1 and Table 5.2.2. The steel and Inconel hardware masses for the design basis BWR and PWR fuel assemblies are listed in Table 5.2.3. Several other assembly types are included in the qualification. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Subsections 5.2.1 and 5.2.2 describe the calculation of the gamma and neutron source terms for fuel assemblies, respectively. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]. Subsection 5.2.3 describes the source terms associated with control components for the PWR assemblies. Subsection 5.2.4 describes the source terms for the core components to be transported in the core component cassette basket, NFWB-1.

5.2.1 Gamma Source

Table 5.2.4 provides the gamma source in photons/s for selected BWR UO_2 fuel assemblies. Table 5.2.5 provides the gamma source in photons/s for selected PWR UO_2 fuel assemblies. Table 5.2.6 provides the gamma source in photons/s for selected BWR MOX fuel assemblies. All tables provide the values of the source terms per assembly for the specified assembly-average burnup. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

ORIGAMI was used to calculate a ^{60}Co activity level for the desired burnup and decay time. The methodology used to determine the activation level was developed from Reference [5.2.3] and is described here.

1. The activity of the ^{60}Co in curies (Ci) from the irradiation of 10 grams of ^{59}Co is calculated using ORIGAMI. The flux used in the calculation was the in-core fuel region flux at full power.

2. The activity calculated in Step 1 for the region of interest was scaled by the masses of steel and Inconel in each non-fuel region and the ^{59}Co impurity in Table 5.2.3 and by the appropriate neutron flux scaling factors listed in Table 5.2.7. The neutron flux scaling factors were taken from Reference [5.2.3].

Table 5.2.8 and Table 5.2.9 provide the ^{60}Co activity for BWR and PWR UO_2 assemblies, respectively, utilized in the shielding calculations in the non-fuel regions of the assemblies. Table 5.2.10 provides the ^{60}Co activity for BWR MOX assemblies utilized in the shielding calculations in the non-fuel regions of the assemblies.

In addition to the two sources already mentioned, a third source arises from (n,γ) reactions in the material of the HI-STAR 80 cask. This source of photons is properly accounted for in MCNP when a neutron calculation is performed in the coupled neutron-gamma mode.

5.2.2 Neutron Source

It is well known that the neutron source strength for a UO_2 assembly increases as enrichment decreases, for a constant burnup and decay time. This is due to the increase in Pu content in the fuel that increases the inventory of other transuranium nuclides such as Curium. For this reason, lower bound enrichments are specified in the approved content in Appendix 7.D. The gamma source also varies with enrichment, although only slightly.

Table 5.2.11 provides the neutron source in neutrons/s for BWR UO_2 fuel assemblies. Table 5.2.12 provides the neutron source in neutrons/s for PWR UO_2 fuel assemblies. Table 5.2.13 provides the neutron source in neutrons/s for BWR MOX fuel assemblies. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.2.3 PWR Control Rod Source

PWR control rods (control components) are permitted for transportation in the F-12P basket for the HI-STAR 80. The PWR control rods are burned for 17 years or less with PWR assemblies in the reactor. At full power, the control rods are assumed to operate in a fully withdrawn position with respect to the active fuel region, which is listed as a requirement for the control rods in Appendix 7.D. Even when fully withdrawn from the active fuel region, the bottom ends of the control rods are present in the upper portion of the fuel assembly (the gas plenum and upper tie plate region) since they are never fully removed from the fuel assembly during normal operation. Therefore, only the lower portion of the control rod will be significantly activated. When the control rod is transported in the HI-STAR 80, the activated portion of the control rod will be in the lower portion of the cask. The control rod cladding is composed of stainless steel. The control rod absorber material is AgInCd, with mass fractions of Ag, In, and Cd of 0.8, 0.15, and 0.05, respectively, also listed as a requirement for the control rods in Appendix 7.D.

The source terms for the PWR control rods are calculated using TRITON and ORIGEN in the SCALE 6.2.1 code package. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

The masses of the stainless steel cladding and AgInCd absorber in the gas plenum and upper tie plate region as well as the neutron flux scaling factors are listed in Table 5.2.14. The minimum cooling time for the PWR control rods is chosen to be 1 year (12 months), independent of the cooling time of the assemblies they are placed in. The ^{60}Co activity from the stainless steel cladding and the AgInCd gamma source terms are chosen as bounding values over the range of burnups from 0 to 360,000 MWD/MTU. The bounding ^{60}Co activity from the stainless steel cladding is listed in Table 5.2.15. The bounding gamma source from the AgInCd absorber is listed in Table 5.2.16. The decay heats for the PWR control rods are also listed in Table 5.2.15 and Table 5.2.16.

5.2.4 Core Components Source

The core components to be transported in the NFWB-1 are contents that are non-fissile or fissile exempted, and consist of mainly activated or contaminated metals or ceramics (see Table 7.D.8). The contents of the core components could be of arbitrary shapes and geometries.

The source terms are the result of the activation and contamination of those components during core operation. The dominant source is from Co-60, as a result of activation of the Co-59 present

in the materials which are predominantly stainless steel. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.2.5 Design Basis and Alternative Assembly Types

Tables 5.2.17 and 5.2.18 show the assemblies listed in Appendix 7.D with typical or bounding dimensions and typical or bounding fuel densities. The tables also show for each assembly type the total mass of fuel, and the mass of fuel per unit length of the active region (specific mass). The following discussion focuses first on the selection of the design basis assembly, and secondly on how the differences between those tables and Tables 7.D.2 and 7.D.3 to ensure that the design basis assemblies bound all assemblies as they are specified in Appendix 7.D.

5.2.5.1 Selection of Design Basis Assemblies

In general, the assembly types selected as design basis are those with the highest mass and/or specific mass. Additionally, several other assembly types, termed alternative assemblies, are evaluated with mass or specific mass close the values for the design basis assembly.

PWR, Table 5.2.17

The assembly type 17x17S2 has both the highest UO2 mass and the highest specific UO2 mass and is used as the design basis assembly. Two other assemblies, one each with a 15x15 and 17x17 pattern are selected as an alternative assembly. Those are again evaluated in Section 5.4.9 in comparison to the design basis assembly, and some minor adjustment factors for dose rates are derived from this comparison, and included in the bounding dose rates presented in Section 5.1.

BWR, Table 5.2.18

There is no single assembly type that combines the highest UO2 mass and the highest specific UO2 mass. However, the assembly type designated as 10x10S2 has a significantly higher UO2 mass than all other assemblies, and the second highest specific UO2 mass. This assembly is therefore selected as design basis. Three other assembly types are selected as alternatives since they show a comparable specific mass, one with a 10x10 rod pattern, and two with 11x11 rods patterns. Those are evaluated in Section 5.4.9 in comparison to the design basis assembly, and some minor adjustment factors for dose rates are derived from this comparison, and included in the bounding dose rates presented in Section 5.1. No 8x8 or 9x9 assemblies were analyzed as alternatives, since those show significantly lower UO2 mass and specific UO2 mass.

5.2.5.2 Differences between Fuel Specifications in Tables 5.2.17/18 and 7.D2/3

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]. Based on this, all assemblies characterized in Appendix 7.D are bounded by the analyses presented in this Chapter 5.

TABLE 5.2.1
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.1 (Continued)
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.2
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.3
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.4
CALCULATED GAMMA SOURCE PER ASSEMBLY FOR SELECTETD BWR UO_2 FUEL ASSEMBLIES

Lower Energy	Upper Energy	60000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 24 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 31 months Cooling Time
(MeV)	(MeV)	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
4.50E-01	7.00E-01	4.24E+15	4.16E+15	3.95E+15
7.00E-01	1.00E+00	1.80E+15	1.74E+15	1.61E+15
1.00E+00	1.50E+00	2.42E+14	2.27E+14	2.04E+14
1.50E+00	2.00E+00	1.65E+13	1.39E+13	1.08E+13
2.00E+00	2.50E+00	1.86E+13	1.37E+13	9.04E+12
2.50E+00	3.00E+00	1.02E+12	8.37E+11	6.22E+11
	Total	6.32E+15	6.16E+15	5.78E+15

TABLE 5.2.5
CALCULATED GAMMA SOURCE PER ASSEMBLY FOR SELECTED PWR UO_2 FUEL ASSEMBLIES

Lower Energy	Upper Energy	60000 MWD/MTU 5.0 wt. % U-235 18 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 26 months Cooling Time
(MeV)	(MeV)	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
4.50E-01	7.00E-01	1.00E+16	1.05E+16	1.03E+16
7.00E-01	1.00E+00	4.47E+15	4.55E+15	4.41E+15
1.00E+00	1.50E+00	6.00E+14	6.08E+14	5.74E+14
1.50E+00	2.00E+00	4.28E+13	4.07E+13	3.45E+13
2.00E+00	2.50E+00	5.07E+13	4.43E+13	3.35E+13
2.50E+00	3.00E+00	2.65E+12	2.50E+12	2.08E+12
	Total	1.52E+16	1.57E+16	1.54E+16

TABLE 5.2.6
CALCULATED GAMMA SOURCE PER ASSEMBLY FOR BWR MOX FUEL ASSEMBLIES

Lower Energy	Upper Energy	55000 MWD/MTIHM 4.5 wt. % Pu-fiss 21 months Cooling Time	60000 MWD/MTIHM 4.5 wt. % Pu-fiss 23 months Cooling Time	65000 MWD/MTIHM 4.5 wt. % Pu-fiss 29 months Cooling Time
(MeV)	(MeV)	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
4.50E-01	7.00E-01	3.20E+15	3.12E+15	2.94E+15
7.00E-01	1.00E+00	1.32E+15	1.29E+15	1.19E+15
1.00E+00	1.50E+00	2.22E+14	2.14E+14	1.97E+14
1.50E+00	2.00E+00	1.41E+13	1.21E+13	9.46E+12
2.00E+00	2.50E+00	8.95E+12	6.97E+12	4.60E+12
2.50E+00	3.00E+00	7.34E+11	5.85E+11	4.12E+11
	Total	4.76E+15	4.65E+15	4.34E+15

TABLE 5.2.7
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.8
CALCULATED ^{60}Co SOURCE FOR SELECTED BWR UO_2 ASSEMBLIES

	60000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 24 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 31 months Cooling Time
Region	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
Below LTP	7.555E+10	7.600E+10	7.672E+10
LTP	2.090E+12	2.102E+12	2.122E+12
Fuel	1.796E+13	1.807E+13	1.824E+13
GP	3.767E+10	3.789E+10	3.826E+10
UTP	1.041E+12	1.047E+12	1.057E+12

TABLE 5.2.9
CALCULATED ^{60}Co SOURCE FOR SELECTED PWR UO_2 ASSEMBLIES

	60000 MWD/MTU 5.0 wt. % U-235 18 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 26 months Cooling Time
Region	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
LTP	3.165E+12	3.355E+12	3.456E+12
Fuel	2.993E+13	3.172E+13	3.267E+13
GP	6.906E+11	7.319E+11	7.540E+11
UTP	2.302E+12	2.440E+12	2.513E+12

TABLE 5.2.10
CALCULATED ^{60}Co SOURCE FOR SELECTED BWR MOX ASSEMBLIES

	55000 MWD/MTIHM 4.5 wt. % Pu-fiss 21 months Cooling Time	60000 MWD/MTIHM 4.5 wt. % Pu-fiss 23 months Cooling Time	65000 MWD/MTIHM 4.5 wt. % Pu-fiss 29 months Cooling Time
Region	(Gammas/sec)	(Gammas/sec)	(Gammas/sec)
Below LTP	4.930E+10	4.806E+10	4.677E+10
LTP	1.364E+12	1.329E+12	1.294E+12
Fuel	1.172E+13	1.142E+13	1.112E+13
GP	2.458E+10	2.397E+10	2.332E+10
UTP	6.790E+11	6.620E+11	6.442E+11

TABLE 5.2.11
CALCULATED NEUTRON SOURCE PER ASSEMBLY FOR SELECTED BWR UO_2 FUEL ASSEMBLIES

Lower Energy	Upper Energy	60000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 24 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 31 months Cooling Time
(MeV)	(MeV)	(Neutrons/sec)	(Neutrons/sec)	(Neutrons/sec)
1.00E-01	4.00E-01	3.64E+07	4.86E+07	6.29E+07
4.00E-01	9.00E-01	7.93E+07	1.06E+08	1.37E+08
9.00E-01	1.40E+00	7.93E+07	1.06E+08	1.37E+08
1.40E+00	1.85E+00	6.33E+07	8.46E+07	1.10E+08
1.85E+00	3.00E+00	1.18E+08	1.57E+08	2.04E+08
3.00E+00	6.43E+00	1.08E+08	1.45E+08	1.88E+08
6.43E+00	2.00E+01	1.05E+07	1.42E+07	1.88E+07
	Total	4.94E+08	6.61E+08	8.58E+08

TABLE 5.2.12
CALCULATED NEUTRON SOURCE PER ASSEMBLY FOR SELECTED PWR UO_2 FUEL ASSEMBLIES

Lower Energy	Upper Energy	60000 MWD/MTU 5.0 wt. % U-235 18 months Cooling Time	65000 MWD/MTU 5.0 wt. % U-235 21 months Cooling Time	70000 MWD/MTU 5.0 wt. % U-235 26 months Cooling Time
(MeV)	(MeV)	(Neutrons/sec)	(Neutrons/sec)	(Neutrons/sec)
1.00E-01	4.00E-01	7.19E+07	9.56E+07	1.24E+08
4.00E-01	9.00E-01	1.57E+08	2.09E+08	2.70E+08
9.00E-01	1.40E+00	1.57E+08	2.08E+08	2.69E+08
1.40E+00	1.85E+00	1.25E+08	1.67E+08	2.15E+08
1.85E+00	3.00E+00	2.34E+08	3.10E+08	4.00E+08
3.00E+00	6.43E+00	2.14E+08	2.84E+08	3.67E+08
6.43E+00	2.00E+01	2.04E+07	2.74E+07	3.58E+07
	Total	9.78E+08	1.30E+09	1.68E+09

TABLE 5.2.13
CALCULATED NEUTRON SOURCE PER ASSEMBLY FOR SELECTED BWR MOX FUEL ASSEMBLIES

Lower Energy	Upper Energy	55000 MWD/MTIHM 4.5 wt. % Pu-fiss 21 months Cooling Time	60000 MWD/MTIHM 4.5 wt. % Pu-fiss 23 months Cooling Time	65000 MWD/MTIHM 4.5 wt. % Pu-fiss 29 months Cooling Time
(MeV)	(MeV)	(Neutrons/sec)	(Neutrons/sec)	(Neutrons/sec)
1.00E-01	4.00E-01	2.17E+08	2.53E+08	2.91E+08
4.00E-01	9.00E-01	4.73E+08	5.53E+08	6.36E+08
9.00E-01	1.40E+00	4.73E+08	5.53E+08	6.35E+08
1.40E+00	1.85E+00	3.77E+08	4.41E+08	5.07E+08
1.85E+00	3.00E+00	7.00E+08	8.19E+08	9.43E+08
3.00E+00	6.43E+00	6.45E+08	7.58E+08	8.76E+08
6.43E+00	2.00E+01	6.34E+07	7.56E+07	8.88E+07
	Total	2.95E+09	3.45E+09	3.98E+09

TABLE 5.2.14
DESCRIPTION OF PWR CONTROL ROD CONFIGURATION FOR SOURCE TERM CALCULATIONS

Axial Dimension Relative to Bottom of Active Fuel			Flux Factor	Mass of SS Cladding (kg)	Mass of AgInCd Absorber (kg)
Start (cm)	Finish (cm)	Length (cm)			
0	17	17	0.2	0.5892	2.4226
17	30	13	0.1	0.4505	1.8526

TABLE 5.2.15
BOUNDING ^{60}Co SOURCE IN THE STAINLESS STEEL CLADDING FOR PWR CONTROL RODS FOR A COOLING TIME OF 1 YEAR

Axial Dimension Relative to Bottom of Active Fuel			Co-60 from SS Cladding (Curies)	Decay Heat from SS Cladding, watts
Start (cm)	Finish (cm)	Length (cm)		
0	17	17	2.356E+01	3.943E-01
17	30	13	9.006E+00	1.507E-01

Co-60 from SS Cladding (Curies/kg)	Decay Heat from SS Cladding, watts/kg
1.9992E+02	3.3461E+00

TABLE 5.2.16
BOUNDING AgInCd ABSORBER SOURCE FOR PWR CONTROL RODS FOR A COOLING TIME OF 1 YEAR

E Low (MeV)	E High (MeV)	GP Region	UTP Region
		(Gammas/sec)	(Gammas/sec)
3.00E-01	4.50E-01	2.58E+12	9.86E+11
4.50E-01	7.00E-01	7.46E+13	2.85E+13
7.00E-01	1.00E+00	1.03E+14	3.95E+13
1.00E+00	1.50E+00	1.92E+13	7.35E+12
1.50E+00	2.00E+00	9.69E+12	3.71E+12
2.00E+00	2.50E+00	1.51E+09	5.76E+08
2.50E+00	3.00E+00	3.72E+07	1.42E+07
Total		2.09E+14	8.00E+13
Decay Heat, watts		2.98E+01	1.14E+01

E Low (MeV)	E High (MeV)	Total
		(Gammas/sec/kg)
3.00E-01	4.50E-01	5.32E+12
4.50E-01	7.00E-01	1.54E+14
7.00E-01	1.00E+00	2.13E+14
1.00E+00	1.50E+00	3.97E+13
1.50E+00	2.00E+00	2.00E+13
2.00E+00	2.50E+00	3.11E+09
2.50E+00	3.00E+00	7.68E+07
Total		4.32E+14
Decay Heat, watts /kg		6.1553E+01

TABLE 5.2.17
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.2.18
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

5.3 SHIELDING MODEL

The shielding analysis of HI-STAR 80 was performed with MCNP5 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 HI-STAR 80 in the shielding analysis. MCNP 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 80 Package for normal conditions has the neutron shield and parts of the impact limiters in place. The MCNP model for the hypothetical accident condition replaces all of the neutron shield materials with voids. Additionally, it models voids in the radial lead, inner lid lead, and lead in the bottom forgings for the lead slump following a 9 meter drop (refer to Section 5.3.3 for the details of the lead slump models). The shielding effect of the crush material in the impact limiters, including the outer skin surrounding that material, is conservatively neglected in all MCNP models. However, the steel structure of the impact limiter (backbone) directly attached to the cask is retained in all analyses, consistent with the results and conclusions of the structural analyses of the cask documented in Chapter 2. In addition to the conditions stated above, for the hypothetical accident condition, localized reduced lead thickness is modeled for the puncture event, and parts of the structure containing the neutron absorber is neglected in the puncture impact area (refer to Section 5.3.3 for details of the puncture event models). Under normal conditions, credit was taken for the outer dimensions of the impact limiters, i.e. the axial surface dose locations are based on the distance from the impact limiters cover plates.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

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 80 Package. These drawings were used to create the MCNP models used in the radiation transport calculations. Figures 5.3.1 and 5.3.2 show the cross sectional views of the HI-STAR 80 cask loaded with F-32B and F-12P baskets respectively, as they were modeled in MCNP. Figure 5.3.3 and Figure 5.3.4 shows the MCNP model of the F-32B and F-12P baskets. Figure 5.3.5 shows a cross sectional view of HI-STAR 80 side wall. Figures 5.3.6 and 5.3.7 provide the as-modeled views of the impact limiters during normal conditions. The crush material in the impact limiter is not shown in Figure 5.3.6 and Figure 5.3.7 because it was conservatively neglected in the MCNP calculations.

The drawings in Section 1.3 provide tolerances for selected dimensions. The dimensions where the tolerances are considered to have a significant effect on dose rates, with a special focus on

those dose rates with smaller margins to the regulatory limits, are conservatively modeled as minimum values in the design basis calculations. Table 5.3.9 lists those dimensions together with their nominal values and with the values used in the model. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Any other dimension specified in the drawings in Section 1.3 with a tolerance is also modeled at the minimum dimension, with the exception of [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

The conditions and tests specified in 10CFR71.71 for normal conditions have no effect on the configuration of the cask. Therefore no additional considerations are necessary for these conditions and tests.

During the MCNP modeling process a few modeling simplifications were made, and there are some other minor deviations between the dimensions in the drawings and those used in the modeling. The major differences between model and drawings are listed and discussed here.

<u>F-32B and F-12P Baskets Modeling Simplifications</u>

1. The aluminum shims thickness around the periphery of the baskets is modeled as a constant thickness as indicated in the drawings in Section 1.3. There are small gaps where the shims come together which are not modeled. This is acceptable since these gaps are small and will not have any significant impact on the dose rates.

<u>NFWB-1 Modeling Simplifications</u>

1. Only the steel core basket is modeled, which provides additional gamma shielding, for normal conditions. The support plates, guide bars, and lifting lugs are conservatively neglected in the MCNP models. For accident conditions, the NFWB-1 is not modeled and the source region can be anywhere within the HI-STAR 80 cavity.

HI-STAR 80 Modeling Simplifications

1. There is a sump at the bottom of the inside cavity of the cask to enhance draining. This localized reduction in the thickness of the bottom of the cask was not modeled. Since there is significant shielding in this area of HI-STAR 80, this localized reduction in shielding will not affect the calculated dose rates.

2. The Holtite plug in the upper forgings at 290 degrees is modeled with a depth of 12 inches. After final design of the spray port was complete, this Holtite plug was changed to a depth of 4 inches. Test cases were run previously for the F-32B with 32 BWR UO_2 assemblies and for the F12P with 12 PWR assemblies to determine the impact on the dose rates at this location. From the test cases, it was determined that this modeling deviation has a negligible impact on the dose rates at this location and is still bounded by the maximum dose rate for the upper trunnion area.

3. In the modeling of the impact limiters, only the steel portions, shown in Figure 5.3.6 and Figure 5.3.7, were represented. This includes the strongback plates, gussets, support rings, and shield rings of the top and bottom impact limiter. Conservatively, the crush materials of the impact limiters and the outer shells surrounding them were not modeled.

4. The bolts utilized for closure of the inner and outer lid are not modeled, but rather the bolt hole locations are modeled as a solid material.

5. All empty spaces in and around the cask are represented by voids in the model. This is acceptable, since any absorption and scattering in air would have a very small effect in comparison to the dose rates at the close distances analyzed here.

HI-STAR 80 Modeling Deviations

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.3.1.2 Fuel and Source Configuration

In the model, homogenized regions represent the fuel assembly. Calculations on a similar cask design were performed to determine the acceptability of homogenizing the fuel assembly versus explicit modeling. Based on these calculations it can be concluded that homogenization of the fuel assembly is acceptable without loss of accuracy. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.3.1.3 Streaming Through Radial Ribs

The HI-STAR 80 cask utilizes Holtite as a neutron absorber in radial and axial directions. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.3.2 Material Properties

Composition and densities of the various materials used in the HI-STAR 80 shielding analyses are given in Table 5.3.3. Further information on the Holtite and Metamic neutron absorbers is provided in Section 1.2. All of the materials and their geometries are represented in the MCNP model.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

Section 3.3 demonstrates that all materials used in HI-STAR 80 remain at or below their design temperatures during all normal conditions. Therefore, the shielding analysis does not address changes in the material density or composition as a result of temperature changes.

During normal operations, the depletion of B-10 in the Metamic and the Holtite neutron shield is negligible. Based on calculations prepared for a similar cask model, the fraction of B-10 atoms that are depleted in 50 years is less than 1E-6 in both the Metamic and Holtite. Therefore, the shielding analysis does not need to address any changes in the composition of the Metamic or Holtite as a result of neutron absorption.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.3.3 Lead Slump and Puncture Event for Hypothetical Accident Conditions

The parameters used to model the void spaces in the radial lead shield, the lead in the inner lid, and the lead in the lower forgings for the lead slump following a 9 meter drop accident are given in Table 5.3.7. For accident conditions, the lead is reduced in the radial direction and the thickness is reduced in the axial direction by the values given in Table 5.3.7.

The parameters used to model the puncture event are given in Table 5.3.7a. The puncture is modeled as a cylindrical reduction in lead thickness. The axis of the cylinder is modeled at approximately the midplane of the fuel. For the support structure containing the neutron absorber material, a cylindrical section with the diameter of the impacted bar is simply removed from the model, i.e. replaced by a void.

5.3.4 Tally Specifications

The dose rate values listed in Tables 5.1.1 through 5.1.11, with corresponding dose point locations illustrated in Figures 5.1.1 and 5.1.2, are computed using MCNP volume tallies. In radial direction, the dose locations are represented by cylindrical rings with a thickness of 1 cm at the surface of the package, at 1 m from the package and at 2 m from the vehicle. In the axial direction, the dose locations are cylindrical disks with a thickness of 1 cm at various distances from the package. Further details are discussed below.

Radial Tallies

- Dose Location 2 (Side Tallies)
  This dose location captures the maximum dose rate around the radial shield cylinder, i.e. the axial section of the cask that contains the Holtite and Lead radial shields. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

- Dose Locations 1 and 3
  These are the dose locations adjacent to the impact limiter skirt and the upper and lower forgings of the cask. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

Axial Tallies

The tally volumes located on the top and bottom surfaces, 1 meter and 2 meter positions of the cask were composed the following way:

- Dose Locations 4 and 5
  In axial direction, the tally volumes are circular disks that are divided into radial sections, each about 20 cm wide.

The dose locations for both radial and axial tallies are also described in Section 5.4.4.

TABLE 5.3.1
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.2
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.3
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.4
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.5

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.6
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.7
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.7a
[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.8

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.9

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.3.9 (Continued)

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

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

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

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

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

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

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

FIGURE 5.3.7: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

5.4 SHIELDING EVALUATION

5.4.1 Methods

The MCNP5 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 and ENDF/B-VII. 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 is essentially the same code that has been used as the shielding code in all of Holtec's dry storage and transportation analyses. It should be noted that the principal approach in the shielding analysis here is similar to the approach in licensing applications previously reviewed and approved by the USNRC.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.2 Input and Output Data

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

for each principal dose location, the highest dose rate from any of those calculation are determined and reported in this chapter.

5.4.3 Flux-to-Dose-Rate Conversion

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.4 External Radiation Levels

The maximum normal and accident dose rates in the tables in Section 5.1 are based on specific fuel loadings in terms of the number of assemblies for each basket (i.e., 10 or 12 PWR assemblies in the F-12P basket and 24, 28 or 32 BWR assemblies in the F-32B basket), as well as specific burnup and cooling time combinations. The dose rates in Section 5.1 are bounding for all fuel loadings listed in Appendix 7.D. The normal and accident dose rates from the NFWB-1 are based on the bounding specific source strengths as listed in Tables 5.4.33 and 5.4.34.

Figure 5.1.1 shows the dose locations on the surface and the condition of the HI-STAR 80 Package during normal transport. Each of these dose locations has a corresponding location at 2 m from the outer lateral surface of the vehicle frame except locations 1 and 3. Dose locations 1 and 3 are covered by Dose Location 2 at 2 m from the vehicle. The azimuthal dose values are taken from the dose point locations that are shown in Figure 5.3.5. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.5 Fuel Reconfiguration

The licensing approach for high burnup fuel (HBF) reconfiguration is discussed in Section 1.4. The structural analyses of fuel rods in Section 2.11 show that the fuel is expected to remain essentially undamaged during the hypothetical accident conditions. The design basis calculations for the hypothetical accident conditions therefore use the same model to represent fuel as the calculations for normal conditions. The current subsection presents additional calculations to show that even if some fuel reconfigurations should occur under both normal or accident conditions, the dose rates would still be expected to remain below the regulatory limits.

5.4.5.1 Fuel Reconfiguration Under Hypothetical Accident Conditions

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

The results from the three scenarios described above along with a nominal reference case for accident conditions are shown in Table 5.4.2 for the F-32B with 32 BWR UO_2 assemblies and Table 5.4.3 for the F-12P with 12 PWR UO_2 assemblies.

The results are presented in Tables 5.4.2 and 5.4.3 for the 70000 MWD/MTU burnup case, This case is selected because with the assumed loss of all Holtite, the dose rates becomes neutron dominated and the higher neutron dose rates occur for the higher burnup fuel. The results show that the design basis dose rates are bounding or similar to the reconfigured dose rates for most of the dose locations. Further, all analyzed fuel reconfiguration scenarios meet the dose rate regulatory requirements. It can therefore be concluded that any fuel reconfiguration during hypothetical accident conditions would not result in dose rates that exceed the regulatory limits. Additionally, it should be noted that as stated in Section 5.3 only the strongback plates, gussets, support rings, and shield rings of the top and bottom impact limiters are modeled in the MCNP models of accident conditions, while the other structural steel components of the impact limiters were conservatively neglected. Including those components in the MCNP models would further decrease the dose rates under hypothetical accident conditions.

5.4.5.2 Fuel Reconfiguration Under Normal Conditions

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

The surface dose rate results from this scenario described above along with a nominal reference case for normal conditions are shown in Table 5.4.4 for the F-32B with 32 BWR UO_2 assemblies and Table 5.4.5 for the F-12P with 12 PWR UO_2 assemblies. The 2 meters dose rate results from this scenario described above along with a nominal reference case for normal conditions are shown in Table 5.4.6 for the F-32B with 32 BWR UO_2 assemblies and Table 5.4.7 for the F-12P with 12 PWR UO_2 assemblies. As for the accident conditions evaluated in the previous paragraph, the

results show that the design basis dose rates are bounding or similar to the reconfigured dose rates for most of the dose locations, and that all results are below the regulatory limits.

5.4.6 Dummy Rods Replacing Fuel Rods

5.4.6.1 Irradiated Stainless Steel Dummy Rods

The dose rates from up to 4 irradiated stainless steel dummy rods in specific assembly locations were included in all design basis calculations using the following methodology. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]. Results from these calculations are included in all results presented for the design basis calculation in Section 5.1.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

Results are presented in Tables 5.4.17 and 5.4.18 for F-32B and F-12P surface dose rates and Tables 5.4.19 and 5.4.20 for F-32B and F-12P 2 meter dose rates for normal conditions. Results are presented in Tables 5.4.21 and 5.4.22 for F-32B and F-12P 1 meter dose rates for accident conditions. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.6.2 Dose Rates for Fuel Assembly Class 17x17S1 Containing 25 Irradiated Stainless Steel Dummy Rods

Per Appendix 7.D, PWR fuel assembly class 17x17S1 may contain 25 irradiated stainless steel rods. Dose rates are calculated for the design basis PWR fuel assembly where 25 irradiated stainless steel rods are placed in two assemblies out of the four inner basket cells, instead just 4 rods as for the design basis calculations. The same methodology as discussed in Section 5.4.6.1 is used to calculate the dose rates from the fuel assemblies containing stainless steel rods, only the 25 irradiated stainless steel rods are used instead of four and the number of assemblies containing the rods is two instead of four. The surface and 2 meter dose rates for the F-12P basket containing two assemblies with 25 irradiated stainless rods are given in Tables 5.4.29 and 5.4.30 for normal conditions. The 1 meter dose rates for the F-12P basket containing two assemblies with 25 irradiated stainless steel rods are given Table 5.4.31 for accident conditions. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.6.3 Zircaloy or Non-Irradiated Steel Dummy Rods

To comply with criticality requirements, it is necessary to fill empty fuel rod locations, e.g. where damaged fuel rods were removed, with dummy rods which can be made from zircaloy or stainless steel. An arbitrary number of irradiated zircaloy rods or non-irradiated stainless steel rods within an assembly are permitted to be transported since there is not a significant radiation source from irradiation of zircaloy rods or non-irradiated stainless steel rods.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.8 Source Strength and Dose Rate Evaluations for the NFWB-1

The NFWB-1 is developed to transport various core components as described in Subsection 5.1.3. The qualification of those components, and the specification of the limits specified in Appendix 7.D for the NFWB-1, is based on an evaluation of the various important characteristics of the components as they apply to the transportation conditions.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.4.34 shows the results from the surface source evaluation. Since for the surface source the self shielding of the material has an insignificant effect, this model is only evaluated using steel as the source material.

Dose rates are listed in Tables 5.1.9 through 5.1.11, for all conditions and all relevant dose locations. For each condition and dose location, the maximum value from any of the energy groups is listed there.

Overall, the calculations and evaluations presented in this Subsection show that with the limits derived here, that are specified in Appendix 7.D for the NWFB-1, all dose rates are below the regulatory limits.

5.4.9 Dose Rates from Other Fuel Assembly Types

This subsection determines the dose rates from fuel types other than the design basis BWR and PWR fuel assemblies and establishes any additional adjustments that need to be applied to the dose rates from the design basis fuel types. For BWR fuel, the dose rates from three additional fuel assemblies are calculated. For PWR fuel, the dose rates from two additional fuel assemblies are calculated. These additional fuel types are selected based on the highest initial mass of uranium for all BWR and PWR fuel types available for transport, see Subsection 5.2.5 for a more detailed discussion.

Dose rate results for other fuel type in the F-32B and F-12P at the surface and 2 meters for normal conditions are listed in Tables 5.4.23 through 5.4.26. Dose rate results for other fuel types in the F-32B and F-12P at 1 meter for accident conditions are listed in Tables 5.4.27 and 5.4.28. In all tables, the results of the reference case are also provided, which are the results for the design basis fuel at the same burnup, cooling time and enrichment combination and the same loading configuration. Note that these reference dose rates are different from those listed in Section 5.1, since they are calculated here for a given burnup, enrichment, cooling time and loading

combination, whereas the results in Section 5.1 present maximum values over all qualified conditions.

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.10 Minimum Holtite Thickness Study

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.11 Empty Basket Cells (Partially Loaded Cask)

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

5.4.12 Fuel Rods in Quivers

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

TABLE 5.4.1

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

Gamma Energy (MeV)	**(mSv/h)/ (photon/cm^2-s) †**
0.01	3.96E-05
0.03	5.82E-06
0.05	2.90E-06
0.07	2.58E-06
0.1	2.83E-06
0.15	3.79E-06
0.2	5.01E-06
0.25	6.31E-06
0.3	7.59E-06
0.35	8.78E-06
0.4	9.85E-06
0.45	1.08E-05
0.5	1.17E-05
0.55	1.27E-05
0.6	1.36E-05
0.65	1.44E-05
0.7	1.52E-05
0.8	1.68E-05
1.0	1.98E-05
1.4	2.51E-05
1.8	2.99E-05
2.2	3.42E-05

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

TABLE 5.4.1 (CONTINUED)

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

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

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

TABLE 5.4.1 (CONTINUED)

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

Neutron Energy (MeV)	**Quality Factor**	**(mSv/h)/(n/cm^2-s) †, ††**
2.5E-8	2.0	3.67E-05
1.0E-7	2.0	3.67E-05
1.0E-6	2.0	4.46E-05
1.0E-5	2.0	4.54E-05
1.0E-4	2.0	4.18E-05
1.0E-3	2.0	3.76E-05
1.0E-2	2.5	3.56E-05
0.1	7.5	2.17E-04
0.5	11.0	9.26E-04
1.0	11.0	1.32E-03
2.5	9.0	1.25E-03
5.0	8.0	1.56E-03
7.0	7.0	1.47E-03
10.0	6.5	1.47E-03
14.0	7.5	2.08E-03
20.0	8.0	2.27E-03

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

†† The Quality Factor is included.

TABLE 5.4.2 Through TABLE 5.4.5

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.4.6

Deleted (See table 5.4.4)

TABLE 5.4.7

Deleted (See table 5.4.5)

TABLE 5.4.8 through TABLE 5.4.16

Deleted

TABLE 5.4.17

TOTAL DOSE RATES (mSv/hr) ON THE HI-STAR 80 PACKAGE WITH THE ACTIVE FUEL REGION DENSITY MODELED AS THE DENSITY OF [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390] FOR THE F-32B BASKET CONTAINING 32 BWR UO_2 ASSEMBLIES - NORMAL CONDITIONS

Dose Point Location	Reference Case	Reduced Fuel Region Density Case	10 CFR 71.47 Limit
Bounding Cases for the following Burnup (MWD/MTU), Enrichment (wt. %) and Cooling Time (months) Combinations: 50000 / 4.0 / 17, 70000 / 5.0 / 31			
Surface			
1	1.5412	1.5478	2
2	0.6066	0.6081	2
3	0.8470	0.8484	2
4	0.0212	0.0212	2
5	0.0582	0.0584	2
2 m			
2	0.0873	0.0874	0.1
4	0.0056	0.0056	0.1
5	0.0157	0.0157	0.1

TABLE 5.4.18

TOTAL DOSE RATES (mSv/hr) ON THE HI-STAR 80 PACKAGE WITH THE ACTIVE FUEL REGION DENSITY MODELED AS THE DENSITY OF [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390] FOR THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES - NORMAL CONDITIONS

Dose Point Location	Reference Case	Reduced Fuel Region Density Case	10 CFR 71.47 Limit
Bounding Cases for the following Burnup (MWD/MTU), Enrichment (wt. %) and Cooling Time (months) Combinations: 10000 / 3.5 / 4, 30000 / 3.5 / 12, 50000 / 4.0 / 12, 70000 / 5.0 / 26			
Surface			
1	1.0357	1.0358	2
2	0.5469	0.5469	2
3	1.3900	1.3901	2
4	0.0336	0.0336	2
5	0.0592	0.0592	2
2 m			
2	0.0889	0.0889	0.1
4	0.0076	0.0076	0.1
5	0.0207	0.0207	0.1

TABLE 5.4.19

Deleted (See table 5.4.17)

TABLE 5.4.20

Deleted (See table 5.4.18)

TABLE 5.4.21

TOTAL DOSE RATES (mSv/hr) AT 1 METER FROM THE HI-STAR 80 PACKAGE WITH THE ACTIVE FUEL REGION DENSITY MODELED AS THE DENSITY OF [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390] **FOR THE F-32B BASKET CONTAINING 32 BWR UO_2 ASSEMBLIES – ACCIDENT CONDITIONS**

Dose Point Location	Reference Case	Reduced Fuel Region Density Case	10 CFR 71.51 Limit
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 31 months			
1	3.2532	3.2547	10
2	8.4945	8.4957	10
3	2.1096	2.1109	10
4	0.1010	0.1010	10
5	0.3732	0.3738	10

TABLE 5.4.22

TOTAL DOSE RATES (mSv/hr) AT 1 METER FROM THE HI-STAR 80 PACKAGE WITH THE ACTIVE FUEL REGION DENSITY MODELED AS THE DENSITY OF [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390] **FOR THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES – ACCIDENT CONDITIONS**

Dose Point Location	Reference Case	Reduced Fuel Region Density Case	10 CFR 71.51 Limit
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months			
1	2.4244	2.4244	10
2	7.1835	7.1835	10
3	2.2300	2.2301	10
4	0.1201	0.1201	10
5	0.3403	0.3403	10

TABLE 5.4.23

TOTAL DOSE RATES (mSv/hr) ON THE SURFACE OF THE HI-STAR 80 PACKAGE FOR OTHER BWR FUEL TYPES FOR THE F-32B BASKET CONTAINING 32 BWR UO_2 ASSEMBLIES – NORMAL CONDITIONS

Dose Point Location	Reference Case	Assembly Type 10x10S7	Assembly Type 11x11S1	Assembly Type 11x11S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 6 months					
1	0.4645	0.0881	0.1009	0.1014	
2	0.5515	0.2873	0.3431	0.3374	
3	0.2751	0.2762	0.2758	0.2778	
4	0.0008	0.0008	0.0008	0.0008	
5	0.0109	0.0071	0.0079	0.0078	
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 11 months					
1	0.7145	0.1557	0.1820	0.1776	
2	0.6172	0.3416	0.3820	0.3807	
3	0.4890	0.4945	0.4838	0.4882	
4	0.0020	0.0024	0.0020	0.0023	
5	0.0193	0.0110	0.0122	0.0119	
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 17 months					
1	1.1756	0.3344	0.3814	0.3957	
2	0.6066	0.3624	0.3849	0.3865	
3	0.7199	0.7568	0.7219	0.7123	
4	0.0088	0.0104	0.0088	0.0090	
5	0.0355	0.0193	0.0212	0.0223	-
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 31 months					
1	1.5412	0.6076	0.7323	0.7143	
2	0.3514	0.3090	0.2858	0.2962	
3	0.8470	0.8952	0.8342	0.8467	
4	0.0212	0.0252	0.0230	0.0228	
5	0.0582	0.0286	0.0299	0.0322	

Note: For Assembly Types see Section 5.2 including Table 5.2.18

TABLE 5.4.24

TOTAL DOSE RATES (mSv/hr) ON THE SURFACE OF THE HI-STAR 80 PACKAGE FOR OTHER PWR FUEL TYPES FOR THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES – NORMAL CONDITIONS

Dose Point Location	Reference Case	Assembly Type 15x15S1	Assembly Type 17x17S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 4 months				
1	0.4562	0.4906	0.4699	
2	0.5457	0.5722	0.5683	
3	0.5389	0.5068	0.5069	
4	0.0013	0.0014	0.0013	
5	0.0321	0.0327	0.0319	
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 12 months				
1	0.4830	0.5159	0.5152	
2	0.5469	0.5669	0.5675	
3	0.7242	0.6903	0.6808	
4	0.0033	0.0030	0.0029	
5	0.0353	0.0358	0.0361	
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 12 months				
1	0.6916	0.7523	0.7468	
2	0.5189	0.5347	0.5307	
3	1.0488	1.0315	1.0605	
4	0.0153	0.0162	0.0156	
5	0.0469	0.0479	0.0472	
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months				
1	1.0357	1.1058	1.1243	
2	0.3719	0.3733	0.3729	
3	1.3900	1.3875	1.3916	
4	0.0336	0.0320	0.0342	
5	0.0592	0.0598	0.0600	

Note: For Assembly Types see Section 5.2 including Table 5.2.17

TABLE 5.4.25

TOTAL DOSE RATES (mSv/hr) 2 METERS FROM THE HI-STAR 80 PACKAGE FOR OTHER BWR FUEL TYPES FOR THE F-32B BASKET CONTAINING 32 BWR UO_2 ASSEMBLIES – NORMAL CONDITIONS

Dose Point Location	Reference Case	Assembly Type 10x10S7	Assembly Type 11x11S1	Assembly Type 11x11S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 6 months					
2	0.0687	0.0584	0.0611	0.0614	
4	0.0002	0.0002	0.0002	0.0002	
5	0.0055	0.0032	0.0035	0.0036	
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 11 months					
2	0.0818	0.0706	0.0734	0.0737	
4	0.0005	0.0006	0.0006	0.0005	
5	0.0082	0.0051	0.0051	0.0052	
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 17 months					
2	0.0873	0.0777	0.0783	0.0792	
4	0.0027	0.0028	0.0020	0.0022	
5	0.0123	0.0071	0.0075	0.0080	
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 31 months					
2	0.0638	0.0617	0.0569	0.0579	
4	0.0056	0.0066	0.0047	0.0053	
5	0.0157	0.0098	0.0095	0.0106	

Note: For Assembly Types see Section 5.2 including Table 5.2.18

TABLE 5.4.26

TOTAL DOSE RATES (mSv/hr) AT 2 METERS FROM THE HI-STAR 80 PACKAGE FOR OTHER PWR FUEL TYPES FOR THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES – NORMAL CONDITIONS

Dose Point Location	Reference Case	Assembly Type 15x15S1	Assembly Type 17x17S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 4 months				
2	0.0825	0.0835	0.0828	
4	0.0003	0.0003	0.0003	
5	0.0146	0.0137	0.0135	
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 12 months				
2	0.0881	0.0890	0.0881	
4	0.0008	0.0008	0.0008	
5	0.0161	0.0149	0.0150	
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 12 months				
2	0.0889	0.0894	0.0894	
4	0.0038	0.0038	0.0035	
5	0.0183	0.0181	0.0178	
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months				
2	0.0720	0.0738	0.0742	
4	0.0076	0.0075	0.0076	
5	0.0207	0.0186	0.0193	

Note: For Assembly Types see Section 5.2 including Table 5.2.17

TABLE 5.4.27

TOTAL DOSE RATES (mSv/hr) AT 1 METER FROM THE HI-STAR 80 PACKAGE FOR OTHER BWR FUEL TYPES FOR THE F-32B BASKET CONTAINING 32 BWR UO_2 ASSEMBLIES – ACCIDENT CONDITIONS

Dose Point Location	Reference Case	Assembly Type 10x10S7	Assembly Type 11x11S1	Assembly Type 11x11S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 31 months					
1	3.2532	2.2842	2.2948	2.3003	
2	8.4945	8.5012	7.8280	7.9106	
3	2.1096	2.2775	2.0441	2.0507	
4	0.1010	0.1133	0.0970	0.0991	
5	0.3732	0.2025	0.1981	0.1958	

Note: For Assembly Types see Section 5.2 including Table 5.2.18

TABLE 5.4.28

TOTAL DOSE RATES (mSv/hr) AT 1 METER FROM THE HI-STAR 80 PACKAGE FOR OTHER PWR FUEL TYPES FOR THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES – ACCIDENT CONDITIONS

Dose Point Location	Reference Case	Assembly Type 15x15S1	Assembly Type 17x17S2	[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months				
1	2.4244	2.3823	2.3607	
2	7.1835	7.3226	7.2546	
3	2.2300	2.2137	2.1995	
4	0.1201	0.1179	0.1175	
5	0.3403	0.3497	0.3527	

Note: For Assembly Types see Section 5.2 including Table 5.2.17

TABLE 5.4.29

TOTAL DOSE RATES (mSv/hr) ON THE SURFACE OF THE HI-STAR 80 PACKAGE FOR TWO PWR ASSEMBLIES IN THE INNER FOUR CELLS CONTAINING 25 IRRADIATED STAINLESS STEEL DUMMY RODS IN THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES - NORMAL CONDITIONS

Dose Point Location	Reference Case	2 Assemblies Containing 25 Irradiated SS Dummy Rods in the Inner 4 Cells of the Basket	10 CFR 71.47 Limit
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 4 months			
1	0.4562	0.4529	2
2	0.5457	0.5477	2
3	0.5389	0.5421	2
4	0.0013	0.0013	2
5	0.0321	0.0324	2
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 12 months			
1	0.4830	0.4806	2
2	0.5469	0.5454	2
3	0.7242	0.7235	2
4	0.0033	0.0032	2
5	0.0353	0.0353	2
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 12 months			
1	0.6916	0.6993	2
2	0.5189	0.5202	2
3	1.0488	1.0492	2
4	0.0153	0.0154	2
5	0.0469	0.0470	2
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months			
1	1.0357	1.0142	2
2	0.3719	0.3911	2
3	1.3900	1.4506	2
4	0.0336	0.0336	2
5	0.0592	0.0547	2

TABLE 5.4.30

TOTAL DOSE RATES (mSv/hr) AT 2 METERS FROM THE HI-STAR 80 PACKAGE FOR TWO PWR ASSEMBLIES IN THE INNER FOUR CELLS CONTAINING 25 IRRADIATED STAINLESS STEEL DUMMY RODS IN THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES- NORMAL CONDITIONS

Dose Point Location	Reference Case	2 Assemblies Containing 25 Irradiated SS Dummy Rods in the Inner 4 Cells of the Basket	10 CFR 71.47 Limit
Burnup = 10000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 4 months			
2	0.0825	0.0827	0.1
4	0.0003	0.0003	0.1
5	0.0146	0.0145	0.1
Burnup = 30000 MWD/MTU, Enrichment = 3.5 wt. %, Cooling Time = 12 months			
2	0.0881	0.0882	0.1
4	0.0008	0.0008	0.1
5	0.0161	0.0160	0.1
Burnup = 50000 MWD/MTU, Enrichment = 4.0 wt. %, Cooling Time = 12 months			
2	0.0889	0.0889	0.1
4	0.0038	0.0038	0.1
5	0.0183	0.0184	0.1
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months			
2	0.0720	0.0727	0.1
4	0.0076	0.0077	0.1
5	0.0207	0.0201	0.1

TABLE 5.4.31

TOTAL DOSE RATES (mSv/hr) AT 1 METER FROM THE HI-STAR 80 PACKAGE FOR TWO PWR ASSEMBLIES IN THE INNER FOUR CELLS CONTAINING 25 IRRADIATED STAINLESS STEEL DUMMY RODS IN THE F-12P BASKET CONTAINING 12 PWR UO_2 ASSEMBLIES – ACCIDENT CONDITIONS

Dose Point Location	Reference Case	2 Assemblies Containing 25 Irradiated SS Dummy Rods in the Inner 4 Cells of the Basket	10 CFR 71.51 Limit
Burnup = 70000 MWD/MTU, Enrichment = 5.0 wt. %, Cooling Time = 26 months			
1	2.4244	2.4183	10
2	7.1835	7.1834	10
3	2.2300	2.2351	10
4	0.1201	0.1201	10
5	0.3403	0.3415	10

TABLE 5.4.32

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

TABLE 5.4.33

LIMITING SPECIFIC SOURCE STRENGTHS IN THE NWFB-1 IN GAMMA/SEC/KG

Energy Range (MeV) or Isotope	PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]					Bounding (minimum) Value
Material						
0.45-0.7						1.15E+14
0.7-1.0						8.78E+12
1.0-1.5						6.73E+11
1.5-2.0						1.26E+11
2.0-2.5						4.79E+10
2.5-3.0						2.30E+10
Co-60						9.13E+11

TABLE 5.4.34

LIMITING SPECIFIC SURFACE SOURCE STRENGTHS IN THE NWFB-1 IN GAMMA/SEC/M^2

Energy Range (MeV) or Isotope	Bounding Value
0.45-0.7	1.64E+16
0.7-1.0	1.40E+15
1.0-1.5	1.32E+14
1.5-2.0	2.99E+13
2.0-2.5	1.22E+13
2.5-3.0	5.83E+12
Co-60	1.64E+14

Table 5.4.35. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.4.36. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.4.37. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Table 5.4.38. [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

FIGURE 5.4.1: [PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390].

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. Active Holtec Calculation Packages which are the repository of all relevant licensing and design basis calculations are annotated as “latest revision”. Submittal of the latest revision of such Calculation Packages to the USNRC and other regulatory authorities during the course of regulatory reviews is managed under the company’s Configuration Control system.

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

[5.1.2] B.T. Rearden and M.A. Jessee, Eds., *SCALE Code System*, ORNL/TM-2005/39, Version 6.2.1, Oak Ridge National Laboratory, Oak Ridge, Tennessee (2016). Available from Radiation Safety Information Computational Center as CCC-834.

[5.1.3] Not Used.

[5.1.4] HI-STAR 100 SAR, Latest Revision (Docket 71-9261), and HI-STORM FSAR, Latest Revision (Docket 72-1014), HI-STORM FW FSAR, Latest Revision (Docket 72-1032), and HI-STAR 180D, Latest Revision (Docket 71-9367).

[5.1.5] B.L. Broadhead, “Recommendations for Shielding Evaluations for Transport and Storage Packages,” NUREG/CR-6802 (ORNL/TM-2002/31), Oak Ridge National Laboratory, May 2003.

[5.2.1] Not Used.

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

[5.2.3] A. Luksic, "Spent Fuel Assembly Hardware: Characterization and 10CFR 61 Classification for Waste Disposal," PNL-6906-vol. 1, Pacific Northwest Laboratory, June 1989.

[5.3.1] Not Used.

[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.

[5.4.5] Holtec International Report HI-2177694, “The Radiation Source Term Calculations for HI-STAR 80”, Latest Revision. (Holtec Proprietary).

[5.4.6] Holtec International Report HI-2167211, “Shielding Analysis for the HI-STAR 80”, Latest Revision. (Holtec Proprietary).

Appendix 5.A

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

Appendix 5.B

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

Appendix 5.C

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

Appendix 5.D

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

APPENDIX 5.E

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

APPENDIX 5.F

[PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390]

Appendix Withheld in its Entirety

CHAPTER 6 CRITICALITY EVALUATION

6.0 INTRODUCTION

This chapter documents the criticality evaluation of the HI-STAR 80 Cask for the packaging and transportation of radioactive materials (spent nuclear fuel) in accordance with 10CFR71. The results of this evaluation demonstrate that an infinite number of HI-STAR 80 Packages with variations in internal and external moderation remain subcritical with subcriticality margin of at least 0.05Δk under all conditions. This corresponds to a criticality safety index (CSI) of zero (0.0) and demonstrates compliance with criticality requirements in USNRC Interim Staff Guidance (ISG) - 8, Rev. 3, 10 CFR 71.55 and 10 CFR 71.59 for normal and hypothetical accident conditions of transport.

In addition to demonstrating that the criticality safety acceptance criteria are satisfied, this chapter describes the HI-STAR 80 design structures and components important to criticality safety. It also provides limiting fuel characteristics. With the cask and fuel description, this chapter gives data in sufficient detail to allow the criticality evaluation of the package.

Finally, the analysis methods, models and acceptance criteria utilized in the safety evaluation documented in this chapter are based on those used in the licensing of the HI-STAR 180 in Docket #71-9325 [6.0.1], the HI-STAR 180D in Docket #71-9367 [6.0.2], and the HI-STAR 100 in Docket #71-9261 [6.0.3].

6.1 DESCRIPTION OF CRITICALITY DESIGN

6.1.1 Design Features

The containment system of the HI-STAR 80 is a cylindrical shell with a flat bottom and flat bolted lids at the top. Inside the containment system, fuel assemblies are placed in a basket structure to maintain their location.

The following fuel basket designs are available for use in the HI-STAR 80, as specified in Table 7.D.1:

- a 12-cell basket (F-12P), designed for spent undamaged PWR UO_2 fuel assemblies and fuel debris with a specified maximum enrichment. The following configurations are analyzed:

    - Configuration 1: Spent undamaged PWR UO_2 fuel assemblies are stored in all 12 cells of the basket. This configuration also bounds spent undamaged fuel assemblies in 10 cells with locations 4 and 9 empty, or 10 cells with locations 5 and 8 empty;

    - Configuration 2: As shown in Section 6.B.7, quivers (damaged fuel containers) with PWR UO_2 fuel debris are placed in one region (4 cells) at the periphery of the basket; Two basket cells at locations 4 and 9, or locations 5 and 8 are empty; Spent undamaged PWR UO_2 fuel assemblies are placed in the remaining positions.

- a 32-cell basket (F-32B), designed for spent undamaged BWR UO_2 fuel assemblies and fuel debris with a specified maximum enrichment and spent undamaged BWR MOX fuel assemblies with a specified composition. The following configurations are analyzed:

    - Configuration 1: Spent undamaged BWR fuel assemblies are stored in all 32 cells of the basket, with up to 4 BWR MOX assemblies loaded in fuel storage locations 6, 9, 24, and 27. This configuration also bounds spent undamaged fuel assemblies in 28 cells with locations 13, 14, 19, and 20 empty, or 24 cells with locations 12, 13, 14, 15, 18, 19, 20 and 21 empty, or 24 cells with locations 7, 8, 13, 14, 19, 20, 25 and 26 empty.

    - Configuration 2: As shown in Section 6.B.7, quivers with BWR UO_2 fuel debris are placed in one region (12 cells) at the periphery of the basket; Four basket cells at locations 13, 14, 19, and 20 are empty; Spent undamaged BWR UO_2 fuel assemblies are placed in the remaining positions. This configuration also bounds spent undamaged fuel assemblies in remaining cells with locations 12, 13, 14, 15, 18, 19, 20 and 21 empty, or remaining cells with locations 7, 8, 13, 14, 19, 20, 25 and 26 empty.

The partial loading configurations are bounded by the fully loaded configurations analyzed here, as discussed in Subsection 6.3.6.

For general details of these fuel baskets see the description and drawings in Section 1.3. Sketches showing the fuel basket details that are important for criticality safety are also presented in Subsection 6.3.1 of this chapter. The cell numbers for F-12P and F-32B baskets, discussed above, are graphically shown in Appendix 7.D, Figures 7.D.1 and 7.D.2, respectively.

A non-fuel waste basket (NFWB-1) is used in the HI-STAR 80 to transport core components such as fuel channels, control rods, neutron sources, temporary burnable absorbers, and various forms of metal scrap with induced radioactivity. However, the total weight of the fissile material to be transferred in the NFWB-1 basket is less than the permissible quantity per package in Table 1.2.3. Since an individual package containing the maximum permissible quantity of fissile material in Table 1.2.3 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 NFWB-1 basket is not required.

Criticality safety of the HI-STAR 80 relies on the following principal design features:

- The inherent geometry of the fuel basket design within the cask. F-12P basket design also contains flux traps for criticality control;

- The incorporation of permanent fixed neutron-absorbing material in the fuel basket structure. [
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- Administrative limits on the maximum average enrichment for PWR UO_2 fuel, the maximum planar-average enrichment for BWR UO_2 fuel, and the composition of the BWR MOX fuel; and

- The ability of the cask to prevent water inleakage under accident conditions. The cask is equipped with a double lid system. The additional lid provides additional assurance that water will not enter the containment system under accident conditions. The cask therefore remains dry and the reactivity is very low under any accident conditions. [
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Applicable codes, standards, and regulations, or pertinent sections thereof, include the following:

- U.S. Code of Federal Regulations, “Packaging and Transportation of Radioactive Materials,” Title 10, Part 71.

- NUREG-1617, “Standard Review Plan for Transportation Packages for Spent Nuclear Fuel” USNRC, Washington D.C., March 2000.

- U.S. Code of Federal Regulations, “Prevention of Criticality in Fuel Storage and Handling,"

Title 10, Part 50, Appendix A, General Design Criterion 62.

- USNRC Standard Review Plan, NUREG-0800, Section 9.1.2, "New and Spent Fuel Storage", Rev. 4, March 2007.

- USNRC Interim Staff Guidance 19 (ISG-19), Revision 0, "Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality of Spent Fuel under the Requirements of 10 CFR 71.55(e)".

- USNRC Interim Staff Guidance - 8 (ISG-8), Revision 3, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transportation and Storage Casks".

6.1.2 Summary Table of Criticality Evaluations

Confirmation of the criticality safety of the HI-STAR 80 package was accomplished with the three-dimensional Monte Carlo code MCNP5 [6.1.1]. K-factors for one-sided statistical tolerance limits with 95% probability at the 95% confidence level were obtained from the National Bureau of Standards (now NIST) Handbook 91 [6.1.2].

To assess the reactivity effects due to temperature and fuel density changes, CASMO-5, a two-dimensional transport theory code [6.1.3 - 6.1.4] for fuel assemblies was used. CASMO-5 was not used for quantitative information, but only to qualitatively indicate the direction and approximate magnitude of the reactivity effects.

Benchmark calculations were made to compare the primary code package (MCNP5) with experimental data, using critical experiments selected to encompass, insofar as practical, the design parameters of the HI-STAR 80 package. The most important parameters are (1) the enrichment, (2) cell spacing, and (3) the ^{10}B loading of the neutron absorber panels. The critical experiment benchmarking work is summarized in Appendix 6.A.

To assure the true reactivity will always be less than the calculated reactivity, the following conservative assumptions were made:

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The principal calculational results address the following conditions:

- A single package, under the conditions of 10 CFR 71.55(b), (d), and (e);
- An array of undamaged packages, under the conditions of 10 CFR 71.59(a)(1); and
- An array of damaged packages, under the conditions of 10 CFR 71.59(a)(2)

Results are summarized in Table 6.1.1 for the most reactive configuration and fuel condition in each basket. The table contains the maximum k_{eff} for each case. The results are conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For package arrays, an infinite number of packages are analyzed. It is noted that the results for the internally flooded single package and package arrays are statistically equivalent for each basket. This shows that the

physical separation between overpacks and the steel radiation shielding are each adequate to preclude any significant neutronic coupling between casks in an array configuration. In addition, the table shows the result for an unreflected, internally flooded cask for each basket. This configuration is used in many calculations and studies throughout this chapter, and is shown to yield results that are statistically equivalent to the results for the corresponding reflected package. Further analyses for the various conditions of flooding that support the conclusion that the fully flooded condition corresponds to the highest reactivity, and thus is most limiting, are presented in Subsection 6.3.4. These analyses also include cases with various internal and external moderator densities and various cask-to-cask spacings. The maximum k_{eff} value for all cases is below the limit of 0.95 recommended in NUREG-1617. The results therefore demonstrate that the HI-STAR 80 Package is in full compliance with 10CFR71 (71.55(b), (d), and (e) and 71.59(a)(1) and (a)(2)).

Additional results of the design basis criticality safety calculations for single unreflected, internally flooded casks (limiting cases) are listed in Tables 6.1.2 and 6.1.3, conservatively evaluated for the worst combination of manufacturing tolerances (as identified in Section 6.3), and including the calculational bias, uncertainties, and calculational statistics. For each of the basket design and fuel assembly class[1], Tables 6.1.2 and 6.1.3 list the bounding maximum k_{eff} value for each assembly class in the F-12P and F-32B baskets. The bounding fuel assembly is therefore defined as 15x15S3 fuel assembly for PWR fuel in F-12P basket and 10x10S5 fuel assembly for BWR fuel in F-32B basket, and the bounding configuration is determined as Configuration 1 for both F-12P basket and F-32B basket. Additional results and discussions for each of the candidate fuel assemblies are given in Section 6.2.

6.1.3 Criticality Safety Index

The calculations for package arrays are performed for infinite arrays of HI-STAR 80 Packages under flooded conditions and results are below the NUREG-1617 limit of 0.95, i.e. N is infinite. Therefore, the criticality safety index (CSI) is zero (0.0).

[1] The assembly classes for BWR and PWR fuel are defined in Section 6.2.

Table 6.1.1
SUMMARY OF THE CRITICALITY RESULTS
TO DEMONSTRATE COMPLIANCE WITH 10CFR71.55 AND 10CFR71.59

F-12P[2], Configuration 1				
Configuration	**% Internal Moderation**	**% External Moderation**	**Applicable Requirement**	**Maximum k_{eff}[1]**
Single Package, unreflected	100%	0%	n/a	0.9481
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	0.9485
Containment, fully reflected	100%	100%		0.9475
Single Package, Damaged	0%	100%	10CFR71.55 (e)	0.3415
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	0.3963
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	0.3480
F-32B[3], Configuration 1				
Configuration	**% Internal Moderation**	**% External Moderation**	**Applicable Requirement**	**Maximum k_{eff}[1]**
Single Package, unreflected	100%	0%	n/a	0.9424
Single Package, fully reflected	100%	100%	10CFR71.55 (b) and (d)	0.9428
Containment, fully reflected	100%	100%		0.9438
Single Package, Damaged	0%	100%	10CFR71.55 (e)	0.3906
Infinite Array of Undamaged Packages	0%	0%	10CFR71.59 (a)(1)	0.4407
Infinite Array of Damaged Packages	0%	100%	10CFR71.59 (a)(2)	0.3970

Note:

1 The maximum k_{eff} is equal to the sum of the calculated k_{eff}, three standard deviations, the code bias, the bias due to one missing rod, and the statistical combination of the code bias uncertainty and the uncertainty due to one missing rod. For all cases, the standard deviation is from 0.0001 to 0.0004. The combined reactivity biases and bias uncertainties for F-12P basket and F-32B basket are shown in Table 6.4.1.

2 The bounding fuel assembly class determined in Table 6.1.2 is used.

3 The bounding fuel assembly class determined in Table 6.1.3 is used.

Table 6.1.2

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE F-12P[1 2]

Fuel Assembly Class	**Maximum k_{eff}**	
	Configuration 1	**Configuration 2**
17x17S1	0.9460	0.9265
17x17S2	0.9297	0.9213
17x17S3	0.9422	0.9268
17x17S4	0.9370	0.9243
15x15S1	0.9462	0.9266
15x15S2	0.9388	0.9239
15x15S3	**0.9481**	**0.9284**

Note:

1. These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.
2. For all cases, the standard deviation is 0.0004.

Table 6.1.3

BOUNDING MAXIMUM k_{eff} VALUES FOR EACH ASSEMBLY CLASS IN THE F-32B[1 2]

Fuel Assembly Class	**Maximum k_{eff}**	
	Configuration 1	**Configuration 2**
8x8S1	0.9219	0.8729
8x8S2	0.9156	0.8704
8x8S3	0.9216	0.8707
8x8S4	0.9218	0.8718
9x9S1	0.9095	0.8660
9x9S2	0.9092	0.8657
10x10S1	0.9202	0.8714
10x10S2	0.9401	0.8816
10x10S3	0.9157	0.8693
10x10S4	0.9103	0.8670
10x10S5	**0.9424**	**0.8845**
10x10S6	0.9350	0.8782
10x10S7	0.9052	0.8645
11x11S1	0.9200	0.8717
11x11S2	0.9211	0.8723

Note:

1. These calculations are for single unreflected, fully flooded casks. However, comparable reactivities were obtained for fully reflected casks and for arrays of casks.
2. For all cases, the standard deviation is 0.0004.

6.2 FISSILE MATERIAL CONTENT

6.2.1 General

The HI-STAR 80 package contains up to 12 PWR fuel assemblies and 32 BWR fuel assemblies. The maximum enrichment including uncertainty of PWR UO_2 fuel and the maximum planar-average initial enrichment including uncertainty of BWR UO_2 fuel are 5.0 wt% ^{235}U. For BWR MOX assemblies, the total plutonium mass does not exceed 14 kg per fuel assembly (See Table 7.D.1). All fuel is in solid metal oxide form and is dry.

Due to the large number of minor variations in fuel assembly dimensions, the use of explicit dimensions in defining the authorized contents could limit the applicability of the HI-STAR 80 package. To resolve this limitation, a number of fuel assembly classes for both PWR and BWR fuel are evaluated with bounding fuel dimensions. The results of parametric studies justify using those bounding fuel dimensions for defining the authorized contents.

6.2.2 Fuel Parameters

Various classes of fuel assemblies are to be qualified for the HI-STAR 80. Each class of fuel assembly has some similar principal characteristics, such as array size, numbers and locations of fuel rods, and numbers and locations of guide tubes (PWR) or water rods (BWR), which are listed in Tables 7.D.2 and 7.D.3. However, fuel assemblies in the same class may differ in some of the details, such as fuel rod and guide tube/water rod dimensions. Previous studies [6.0.3] have shown that the bounding conditions correspond to:

- Maximum Active Length;
- Maximum Pellet OD;
- Maximum Fuel Rod Pitch;
- Maximum Clad ID;
- Minimum Clad OD;
- Minimum Guide Tube/Water Rod Thickness; and
- Maximum Channel Thickness (for BWR assemblies only).

To further demonstrate that the aforementioned characteristics are in fact bounding for the HI-STAR 80, parametric studies were performed on reference PWR and BWR assemblies determined in Subsection 6.1.2, namely PWR assembly type 15x15S3 and BWR assembly type 10x10S5. The results of these studies for Configuration 1 are shown in Tables 6.2.1 and 6.2.2, and verify the bounding parameters listed above. Consistent with previous work, the dimensions from the reference case are therefore used in all further analyses. Note that in the studies presented in Tables 6.2.1 and 6.2.2, PWR UO_2 fuel is with the maximum initial enrichment of 5.0 wt%, and BWR UO_2 fuel is with the maximum initial planar-average enrichment of 5.0 wt%. In addition, the fuel pellet

diameter and cladding inner diameter are changed together. This is to keep the cladding-to-pellet gap, which is conservatively flooded with pure water in all cases (see Paragraph 6.3.4.3), at a constant thickness, to ensure the studies evaluate the fuel parameters rather than the moderation conditions.

In addition to those dimensions, additional fuel assembly characteristics important to criticality control are discussed in the following paragraphs and the bounding fuel assembly characteristics are used in the HI-STAR 80 analysis. The assembly cross sections for each class are provided in Appendix 6.B, Section 6.B.5.

6.2.2.1 PWR Fuel Assemblies

Typically, PWR fuel assemblies are designed with solid fuel pellets throughout the entire active fuel length. However, some PWR assemblies contain annular fuel pellets in the top and bottom 6 to 8 inches of the active fuel length. This changes the fuel to water ratio in these areas, which could have an effect on reactivity. However, the top and bottom of the active length are areas with high neutron leakage, and changes in these areas typically have no significant effect on reactivity. Studies with the annular pellets at the top and bottom of the active length were performed in the HI-STORM FW FSAR [6.2.1] and confirm this conclusion. Nevertheless, to further demonstrate that the above conclusion is applicable to the HI-STAR 80, the calculations with about 8 inches of annular pellets at the top and bottom were performed for the reference 15x15S3 assembly class with various pellet Ids. The results of these studies for Configuration 1 are shown in Table 6.2.3, and confirm no significant reactivity effects, even if the annular region of the pellet is flooded with pure water. All calculations for PWR fuel assemblies are therefore performed with solid fuel pellets along the entire length of the active fuel region, and the results are directly applicable to those PWR assemblies with annular fuel pellets.

6.2.2.2 BWR Fuel Assemblies

BWR assembly classes 10x10S1, 10x10S3, 10x10S4, 10x10S5, 10x10S6, 10x10S7, 11x11S1 and 11x11S2 contain partial length rods. There are differences in location of those partial length rods within the assembly that influence how those rods affect reactivity: some partial length rods are completely surrounded by full length rods, whereas some partial length rods are on the periphery of the assembly or facing the water gap, where they may directly face only two full length rods (see Appendix 6.B, Section 6.B.5). To determine a bounding configuration for each assembly class, calculations are performed with the maximum initial planar-average enrichment of 5.0 wt% for all assembly classes that have partial length rods, and results for Configuration 1 are listed in Table 6.2.4 for the actual (real) assembly configuration and for the axial segments (assumed to be full length) with and without the partial length rods. The results show that the configurations with only the full length rods present, i.e. where the partial length rods are assumed completely absent from the assembly, is bounding for assembly classes 10x10S1, 10x10S3, 10x10S4 and 11x11S1. Consequently, assembly classes 10x10S1, 10x10S3, 10x10S4 and 11x11S1 are analyzed with the partial length rods absent. For assembly classes 10x10S5, 10x10S6 and 11x11S2 which have many partial length rods on the periphery or facing the water gap, calculations with different

assumptions for the length of the part-length rods show that reducing the length of the partial length rods reduces reactivity. This means that the reduction in the fuel amount is more dominating than the change in moderation for this configuration. Note that fuel assembly class 11x11S2 are specified with various partial length rod locations (see Appendix 6.B, Section 6.B.5). Calculations are performed for those variations to show that the results with all rods assumed full length are bounding. For fuel assembly classes 10x10S5, 10x10S6 and 11x11S2, all rods therefore are assumed full length. However, for assembly class 10x10S7, calculations with different assumptions show that the bounding case is the configuration with the actual partial length rods. Therefore, fuel assembly class 10x10S7 is analyzed with actual full length and part-length rods. Note that except for fuel assembly class 10x10S7, neither of the bounding case is the configuration with the actual partial length rods. However, assembly class 10x10S7 is bounded by the assembly class 10x10S5 with a large margin. The specification of the authorized contents has therefore no minimum requirement for the active fuel length of the partial length rods.

BWR assemblies are specified in Table 7.D.1 with a maximum planar-average enrichment. The analyses presented in this chapter use a uniform enrichment, equal to the maximum planar-average. Analyses presented in the HI-STAR 100 SAR ([6.0.3], Chapter 6, Appendix 6.B) show that this is a conservative approach, i.e. that a uniform enrichment bounds the distributed enrichments in terms of the maximum k_{eff}. To verify that this is applicable to the F-32B basket and confirm that this is also true for the higher enrichments analyzed here, additional calculations were performed for Configuration 1 and are presented in Table 6.2.2 in comparison with the results for the uniform enrichment for the reference 10x10S5 assembly class. Since the actual (as-built) enrichment distributions are not available, several bounding cases are analyzed. [

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] The results are also included in Table 6.2.2 and show that in all cases, the maximum k_{eff} calculated for the distributed enrichments are statistically equivalent to or below those for the uniform enrichments. Therefore, modeling BWR assemblies with distributed enrichments using a uniform enrichment equal to the planar-average value is acceptable and conservative. The assumed enrichment distributions are shown in Appendix 6.B, Section 6.B.6.

For BWR assembly class 11x11S1, rod pitch is fixed in the middle and top zones while various rod pitches are present in the bottom zone of the fuel assembly, and the maximum rod pitch in the bottom zone is larger than the fixed rod pitch in the middle and top zones. Calculations are performed for the case where the fixed rod pitch shown in the middle and top zone was also applied to the bottom zone, and for the case where the various rod pitches shown in the bottom zone were assumed in the whole fuel assembly. The results for Configuration 1 listed in Table 6.2.5 confirm

that using the fixed rod pitch in the middle and top zones along the entire active fuel length is bounding. This case is therefore used for 11x11S1 assembly class to determine the bounding BWR fuel assembly (See Table 6.1.3) in the HI-STAR 80 analysis. For BWR assembly classes 10x10S5, 10x10S6 and 11x11S2, various rod pitches are also present in the fuel assembly. Since previous studies [6.0.3] have shown that the bounding conditions correspond to the maximum fuel rod pitch, all rod pitches in those fuel assembly classes are assumed to be the maximum fuel rod pitch to determine the bounding BWR fuel assembly in the analysis.

6.2.3 MOX Assemblies

The HI-STAR 80 cask is to be qualified for a limited number of undamaged MOX assemblies per basket, in specific locations as defined in Appendix 7.D. This is a typical approach for MOX assemblies, predominantly to address possible thermal and shielding concerns for this assembly type, and the fact that there is only a limited population of MOX assemblies to be transported with this cask system. For the criticality safety analysis two different loading configurations are evaluated, one where the entire basket is considered to be filled with undamaged MOX assemblies, and one where the undamaged MOX assemblies are considered to be present only in the specific locations they are limited to in the qualified loading plans. The first configuration is analyzed to allow a direct comparison of the reactivity of the undamaged MOX assemblies with that of undamaged UO_2 assemblies, with the goal to demonstrate that the MOX assemblies are bounded by UO_2 assemblies with a substantial margin. The second configuration is then to show that due to that large margin, the reactivity of the actual configuration with the mixture of undamaged UO_2 and undamaged MOX assemblies is also still well below that of the uniform loading with undamaged UO_2 assemblies. The stated margins may be used to offset any uncertainties in the analyses that cannot be explicitly addressed. [

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For the first configuration with a uniform loading of undamaged MOX assemblies in all basket locations, calculations are performed for 10x10S2 BWR MOX fuel in the F-32B basket with bounding dimensions, and the results are compared to the results of the reference cases with 10x10S2 BWR UO_2 fuel. For the 10x10S2 MOX fuel assemblies, the heavy metal mass per assembly, total uranium mass per assembly, total plutonium mass per assembly, ^{235}U initial content, Pu-vector and Am-241 portion are all specified in Table 6.2.6. . [

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The reactivity of the MOX fuel, and the differences to the UO_2 fuel of 5.0 wt% enrichment are presented in Table 6.2.6 for the 10x10S2 MOX fuel assemblies in the F-32B basket, and show that

the UO_2 fuel bounds the MOX fuel with a significant margin. Consequently, the reactivities of all MOX fuel are well below the reactivity of the design basis BWR UO_2 fuel assembly class (10x10S5) presented in Table 6.1.3. Based on this comparison and the demonstrated margin, any basket location that is qualified using fresh UO_2 fuel with 5.0 wt% enrichment would therefore also be qualified to contain a MOX assembly that meets the requirements in Table 6.2.6.

The second configuration analyzed is the mixed loading pattern of spent undamaged BWR MOX and undamaged UO_2 fuel assemblies in the F-32B basket. The bounding assembly from the first configuration, namely the 10x10S2 MOX fuel, is used as the MOX fuel in this configuration. Calculations are performed for the following cases:

- Four 10x10S2 MOX assemblies are loaded in fuel storage locations 6, 9, 24 and 27 of the F-32B basket, 10x10S2 UO_2 assemblies are loaded in the remaining fuel storage locations. The reactivity of this loading pattern is compared with the uniform loading pattern of 10x10S2 UO_2 assemblies.
- Four 10x10S2 MOX assemblies are loaded in fuel storage locations 6, 9, 24 and 27 of the F-32B basket, the design basis BWR fuel assemblies, 10x10S5 UO_2 assemblies are loaded in the remaining fuel storage locations. The reactivity of this loading pattern is compared with the uniform loading pattern of the design basis 10x10S5 BWR UO_2 assemblies. [

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The results are presented in Table 6.2.7, and show that for both cases the mixed MOX and UO_2 loading patterns are bounded by the uniform loading pattern of UO_2 assemblies. Since these configurations are more dominated by the larger number of UO_2 assemblies than by the 4 MOX assemblies, the margin to the pure UO_2 loading condition is less than for the first configuration. However, the margin is still significant, and hence useful to address any possibly unaccounted uncertainties as discussed above.

Overall these evaluations give assurance that the qualified loading configurations for a mixture of MOX and UO_2 fuel meet the criticality safety requirements.

6.2.4 Fuel Debris in Quivers

The F-12P and F-32B baskets are designed to contain PWR and BWR UO_2 fuel debris loaded into quivers, respectively. The quiver can be loaded with damaged fuel rods or fuel rod pieces resulting from rod inspections. The specifications, number and permissible location of quivers are provided in Subsection 1.2.2 and Chapter 7. Because the entire height of either the F-12P or F-32B fuel basket contains the neutron absorber (Metamic-HT), the quivers are covered by the neutron absorber even if they were to move axially.

Fuel debris can include a large variety of configurations ranging from whole fuel assemblies with severe damage down to individual fuel pellets. To identify the configuration or configurations leading to the highest reactivity, a bounding approach is taken, which is based on the analysis of the regular arrays of bare fuel rods without cladding.

In modeling the fuel debris in the quivers, the following conservative considerations are applied:

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All calculations are performed for full cask models, containing the maximum permissible number of quivers. As an example of the fuel debris model used in the analyses, Figure 6.2.1 shows the F-32B basket cell with a quiver containing a 10x10 array of bare fuel rods.

The results are listed in Table 6.2.8 and Table 6.2.9 for F-12P and F-32B, respectively. The bounding condition is bolded in Tables 6.2.8 and 6.2.9 and used in all subsequent calculations of Configuration 2 which contains quivers.

In Paragraph 6.4.4.2 of HI-STORM 100 [6.2.2], additional studies for damaged fuel were performed to further show that the above approach using arrays of fuel rods is bounding. The studies considered conditions including

- Fuel assemblies that are undamaged except for various numbers of missing rods.
- Variations in the diameter of the bare fuel rods in the arrays.
- Consolidated fuel assemblies with cladded rods.
- Enrichment variations in BWR assemblies.

Results of those studies were shown in the HI-STORM 100 FSAR, Table 6.4.8 and 6.4.9 and Figure 6.4.13 and 6.4.14 (undamaged and consolidated assemblies); HI-STORM 100 FSAR Table 6.4.12 and 6.4.13 (bare fuel rod diameter); and HI-STORM 100 FSAR Subparagraph 6.4.4.2.3 and Table 6.4.8 (enrichment variations). In all cases the results of those evaluations are equivalent to, or bounded by those for the bare fuel rods arrays. Since the generic approach of modeling fuel debris is similar to HI-STORM 100, these evaluations are still applicable for HI-STAR 80.

Note that quivers are not qualified to be loaded with undamaged BWR MOX fuel assemblies in the same cask. In addition, MOX fuel assemblies are not allowed to be loaded inside the quivers.

Table 6.2.1

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Table 6.2.2

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Table 6.2.3

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Table 6.2.4

EFFECT OF PARTIAL LENGTH RODS IN THE BWR FUEL ASSEMBLY CLASSES [1 2]

Fuel Assembly Class	Full-length rods only	Full-length and part-length rods (real assembly)	Part-length rods extended to full-length
10x10S1	**0.9075**	0.9030	0.8982
10x10S3	**0.9030**	0.9013	0.8914
10x10S4	**0.8976**	0.8959	0.8929
10x10S5	0.9141	0.9291	**0.9297**
10x10S6	0.8902	0.9156	**0.9223**
10x10S7	0.8798	**0.8925**	0.8891
11x11S1	**0.9073**	0.9029	0.9013
11x11S2, Partial Length Rod Locations #1	0.8851	0.9000	**0.9084**
11x11S2, Partial Length Rod Locations #2	0.8902	0.9055	**0.9084**

Note:

1. All values are calculated k_{eff} values.
2. The standard deviation (σ) of the calculations is about 0.0004.

Table 6.2.5

EFFECT OF VARIATIONS IN ROD PITCH IN THE 11x11S1 FUEL ASSEMBLY CLASS

Description	**Calculated k_{eff}[1]**	**Difference**
11x11S1 (5.0 wt% ^{235}U)		
Fixed Rod Pitch present in Middle and Top Zones (Reference)	0.9073	Reference
Various Rod Pitches present in Bottom Zone	0.9036	-0.0037

Notes:

1. The standard deviation (σ) of the calculations is about 0.0004 for all calculations.

Table 6.2.6

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Table 6.2.7

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TABLE 6.2.8

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TABLE 6.2.9

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FIGURE 6.2.1 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

6.3 GENERAL CONSIDERATIONS

In compliance with the requirements of 10CFR71.31(a)(1), 10CFR71.33(a)(5), and 10CFR71.33(b), this section provides a description of the HI-STAR 80 package in sufficient detail to identify the package accurately and provide a sufficient basis for the evaluation of the package.

6.3.1 Model Configuration

Figures 6.3.1 through 6.3.4 show representative cross sections of the criticality models for the two baskets. Figures 6.3.1 and 6.3.2 show a single cell from the F-12P and F-32B basket, respectively. Figures 6.3.3 and 6.3.4 show the entire F-12P and F-32B basket, respectively. Figure 6.3.5 shows a sketch of the calculational model in the axial direction.

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The basket geometry can vary due to manufacturing tolerances and due to potential deflections of basket walls as the result of accident conditions. The basket tolerances are defined on the drawings in Chapter 1. . [

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] Based on the calculations, the conservative dimensional assumptions listed in Table 6.3.2 were determined for the basket designs. Because the reactivity effect (positive or negative) of the manufacturing tolerances is not assembly dependent, these dimensional assumptions were employed for all criticality analyses.

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Variations of other parameters, namely fuel density and water temperature in the cask, were analyzed using CASMO-5. The results are presented in Table 6.3.4, and show that the maximum fuel density and the minimum water temperature (corresponding to a maximum water density) are bounding. These conditions are therefore used in all further calculations.

Calculations documented in Chapter 2 show that the baskets stay within the applicable structural limits during all normal and accident conditions. Furthermore, the neutron poison material is an integral and non-removable part of the basket material, and its presence is therefore not affected by the accident conditions. Except for the potential deflection of the basket walls that is already considered in the criticality models, damage to the cask under accident conditions is limited to damage to the neutron absorber on the outside of the cask. However, this external absorber is

already neglected in the calculational models. Other parameters important to criticality safety are fuel type and enrichment, which are not affected by the hypothetical accident conditions. The calculational models of the cask and basket for the accident conditions are therefore identical to the models for normal conditions, and no separate models need to be developed for accident conditions.

As discussed in Chapter 1, the cask is designed so that water leakage under accident conditions is not considered credible. There are, however, differences between the normal and accident models in terms of internal and external water density and external reflections. The effect of these conditions is discussed in Subsection 6.3.4.

Additionally, studies are performed to evaluate the potential effect of fuel reconfiguration during accident conditions. These are presented in Subsection 6.3.5.

6.3.2 Material Properties

Composition of the various components of the principal designs of the HI-STAR 80 package is listed in Table 6.3.5. The nuclide identification number (ZAID), presented for each nuclide in Table 6.3.5, includes the atomic number, mass number and the cross-section evaluation identifier, which are consistent with the ZAIDs used in the benchmarking calculations documented in Appendix 6.A.

The HI-STAR 80 is designed such that the fixed neutron absorber will remain effective for a period greater than 40 years, and there are no credible means to lose it. A detailed physical description, historical applications, unique characteristics, service experience, and manufacturing quality assurance of the fixed neutron absorber are provided in Paragraph 1.2.1.6 and Chapter 2.

As specified in Table 8.1.3, the manufacturer's minimum B_4C content for the Metamic-HT fixed neutron absorber is 10 wt%. The continued efficacy of the fixed neutron absorber is assured by acceptance testing, documented in Paragraph 8.1.5.5, to validate the ^{10}B (poison) concentration in the fixed neutron absorber. In addition, based on calculations prepared for a similar cask model [6.2.1], the fraction of ^{10}B atoms destroyed during the service life in the fixed neutron absorber by neutron absorption is negligible (less than 10^{-6}). Therefore, there is no need to provide a surveillance or monitoring program to verify the continued efficacy of the neutron absorber.

The only materials affected by the accident conditions are the Holtite neutron absorber on the outside of the cask, and the impact limiters. None of these materials are considered in the criticality model. Therefore, material properties of the materials used in the criticality analyses are not affected by the accidents.

6.3.3 Computer Codes and Cross Section Libraries

MCNP5-1.51 and CASMO-5 Version 2.00.00 are used for the criticality analyses of the HI-STAR 80 Cask for the packaging and transportation of radioactive materials. Both codes were installed and validated on the Holtec International's computer following the documentations provided by the code developers.

The principal code for the criticality analysis is the general three-dimensional continuous energy Monte Carlo N-Particle code MCNP5 [6.1.1] developed at the Los Alamos National Laboratory. MCNP5 was selected because it has been extensively used and verified and has all of the necessary features for this analysis. MCNP5 design basis calculations used continuous energy cross-section data, based on ENDF/B-VII, as distributed with the code.

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CASMO-5 [6.1.3 - 6.1.4] was used for determining some incremental reactivity effects (see Subsection 6.3.1). [
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6.3.4 Demonstration of Maximum Reactivity

The basket designs are intended to safely accommodate fuel with enrichments indicated in Appendix 7.D. The calculations were based on the assumption that the HI-STAR 80 cask was fully flooded with water. The principal characteristics of fuel assemblies discussed in Subsection 6.2.2 is also important for the various studies presented in this subsection. The studies are only performed for the bounding BWR and PWR assembly types, and the results are then generally applicable to all assembly types. Note that this approach is consistent with that used for the HI-STAR 100 [6.0.3].

6.3.4.1 Internal and External Moderation

The regulations in 10CFR71.55 include the requirement that the package remains subcritical when assuming moderation to the most reactive credible extent. The regulations in 10CFR71.59 require

subcriticality for package arrays under different moderation conditions. Subparagraph 6.3.4.1.1 through Paragraph 6.3.4.4 present various studies to confirm or identify the most reactive configuration or moderation condition. Specifically, the following conditions are analyzed:

- Reduced internal and external water density for single packages (6.3.4.1.1) and package arrays (6.3.4.1.2);
- Variation in package to package distance in package arrays (6.3.4.1.2);
- Partial internal flooding of package (6.3.4.2);
- Flooding of pellet to cladding gap of the fuel rods (6.3.4.3); and
- Preferential flooding, i.e. uneven flooding inside the package (6.3.4.4).

The calculations that specifically demonstrate compliance with the individual requirements of 10CFR71.55 and 10CFR71.59 are presented in Sections 6.4 through 6.6.

Regarding the effect of low moderator density, it is noted that with a neutron absorber present (i.e., the neutron poison integral to the walls of the storage compartments), the phenomenon of a peak in reactivity at a hypothetical low moderator density (sometimes called "optimum" moderation) does not occur to any significant extent. In a definitive study, Cano, et al. [6.3.1] has demonstrated that the phenomenon of a peak in reactivity at low moderator densities does not occur when strong neutron absorbing material is present or in the absence of large water spaces between fuel assemblies. Nevertheless, calculations for a single reflected cask and for infinite arrays of casks were made to confirm that the phenomenon does not occur with low density water inside or outside the HI-STAR 80, and results are discussed in Subparagraph 6.3.4.1.1.

As discussed in Chapter 2, the cask is designed so that water inleakage under accident conditions is not considered credible. The main purpose of this design characteristic is to ensure that any potential reconfiguration of high burnup fuel under accident conditions is inconsequential from a criticality perspective. The calculations to demonstrate compliance with 10CFR71.55 and 10CFR71.59 under accident conditions are therefore performed with an internally dry cask. Nevertheless, the studies performed in the following subparagraphs that determine the bounding moderation conditions still conservatively consider internal water moderation under accident conditions.

6.3.4.1.1 Single Package Evaluation

The calculational model for a single package consists of the HI-STAR 80 Cask surrounded by a hexagonal box filled with water. The neutron absorber on the outside of the HI-STAR 80 is neglected, since it might be damaged under accident conditions, and since it is conservative to replace the neutron absorber (Holtite) with a neutron reflector (water). The minimum water thickness on each side of the cask is 30 cm, which effectively represents full water reflection. The outer surfaces of the surrounding box are conservatively set to be fully reflective, which effectively models a three dimensional array of casks with a minimum surface to surface distance of 60 cm. The calculations with internal and external moderators of various densities are shown in Table

6.3.7. For comparison purposes, a calculation for a single, unreflected cask (Case 1) is also included in Table 6.3.7. At 100% external moderator density, Case 2 corresponds to a single, fully-flooded cask, fully reflected by water. Figures 6.3.6 and 6.3.7 plot calculated k_{eff} values as a function of internal moderator density for 100% external moderator density (i.e., full water reflection) for F-12P and F-32B baskets, respectively.

Results listed in Table 6.3.7 and plotted in Figures 6.3.6 and 6.3.7 support the following conclusions:

- The calculated k_{eff} for a fully-flooded cask is independent of the external moderator (the small variations in the listed values are due to statistical uncertainties which are inherent to the calculational method (Monte Carlo)); and

- Reducing the internal moderation results in a monotonic reduction in reactivity, with no evidence of any optimum moderation. Thus, the fully flooded condition corresponds to the highest reactivity, and the phenomenon of optimum low-density moderation does not occur and is not applicable to the HI-STAR 80 package.

6.3.4.1.2 Evaluation of Package Arrays

In terms of reactivity, the normal conditions of transport (i.e., no internal or external moderation) are bounded by the hypothetical accident conditions of transport. Therefore, the calculations in this subparagraph evaluate arrays of HI-STAR 80 Packages under hypothetical accident conditions (i.e., internal and external moderation by water to the most reactive credible extent and no neutron shield present).

In accordance with 10CFR71.59 requirements, calculations were performed to simulate an infinite three-dimensional square array of internally fully-flooded (highest reactivity) casks with varying cask spacing and external moderation density. The maximum k_{eff} results of these calculations are listed in Table 6.3.8 and confirm that the individual casks in a square-pitched array are independent of external moderation and cask spacing.

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The calculations demonstrate that the thick steel wall of the overpack is more than sufficient to preclude neutron coupling between casks, consistent with the findings of Cano, et al [6.3.1]. Neglecting the Holtite neutron shielding in the calculational model provides further assurance of conservatism in the calculations.

6.3.4.2 Partial Flooding

To demonstrate that the HI-STAR 80 would remain subcritical if water were to leak into the containment system, as required by 10CFR71.55, calculations in this paragraph address partial flooding in the HI-STAR 80 and demonstrate that the fully flooded condition is the most reactive.

The reactivity changes during the flooding process were evaluated in both the vertical and horizontal positions. For these calculations, the cask is partially filled (at various levels) with full density (1.0 g/cm^3) water and the remainder of the cask is filled with steam consisting of ordinary water at partial density (0.0002 g/cm^3). Results of these calculations are shown in Table 6.3.12. In all cases, for both the F-12P and F-32B baskets, the reactivity increases monotonically as the water level rises, confirming that the most reactive condition is fully flooded. The fully flooded case therefore represents the bounding condition for all basket types.

6.3.4.3 Pellet-to-Clad Gap Flooding

The reactivity effect of flooding the fuel rod pellet-to-clad gap regions, in the fully flooded condition, has been investigated. Table 6.3.13 presents maximum k_{eff} values that demonstrate the positive reactivity effect associated with flooding the pellet-to-clad gap regions. These results confirm that it is conservative to assume that the pellet-to-clad gap regions are flooded. Therefore, for all cases that involve flooding, the pellet-to-clad gap regions are assumed to be flooded.

6.3.4.4 Preferential Flooding

Preferential flooding of the baskets themselves is not possible [

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6.3.4.5 Eccentric Positioning of Assemblies in Fuel Storage Cells

In this paragraph, studies are presented to determine the reactivity effect of eccentric positioning of fuel assemblies in the fuel storage cells, and the conditions with the highest maximum k_{eff} are identified.

To conservatively account for eccentric fuel positioning in the fuel storage cells, different configurations are analyzed, and the results are compared to determine the bounding configuration:

- Cell Center Configuration: All assemblies centered in their fuel storage cell;
- Basket Center Configuration: All assemblies in the basket are moved as closely to the center of the basket as permitted by the basket geometry; and
- Basket Periphery Configuration: All assemblies in the basket are moved furthest away from the basket center, and as closely to the periphery of the basket as possible.
- Displacement towards Specific Cells Configuration (for Configuration 2 only): All quivers are moved as closely to the center of the basket as permitted by the basket geometry, while all other assemblies are moved furthest away from the basket center, and as closely to the periphery of the basket as possible.

It should be noted that the eccentric configurations are hypothetical, since there is no known physical phenomenon that could move all assemblies within a basket consistently to the center or periphery. However, since the configurations listed above bound all credible configurations, they are conservatively used in the analyses.

The results are presented in Table 6.3.14. The table shows the maximum k_{eff} value for centered and eccentric configurations for each basket, and the difference in k_{eff} between the considered and reference positionings. The results show that for both the F-12P and F-32B baskets, the basket center configuration results in the highest reactivity for Configuration 1, while the cell center configuration results in the highest reactivity for Configuration 2 of the F-12P, and displacement towards specific cells configuration results in the highest reactivity for Configuration 2 of the F-32B. Therefore, all further calculations, including those that demonstrate compliance with 10CFR71 requirements, are performed with the bounding eccentric configurations unless otherwise stated.

6.3.5 Potential Fuel Reconfiguration

6.3.5.1 Potential Fuel Reconfiguration under Accident Conditions

The cask is designed to remain internally dry under any accident conditions. Therefore, any fuel reconfiguration under accident conditions would be of no consequences. Additionally, the evaluation of the fuel performance under accident conditions presented in Chapter 2 indicate that no fuel damage, and hence no fuel reconfiguration would be expected, even for high burnup fuel. Nevertheless, as a defense-in-depth, analyses are performed assuming coinciding fuel reconfiguration and flooding of the cask, as mentioned in Chapter 1, Section 1.4.

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These results show that even if there would be any damage and reconfiguration of the fuel assemblies from transport accident conditions, and even if the cask would be flooded during the accident, there would be no significant effect on the reactivity of the package.

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In summary, the evaluations show that even if fuel damage as a result of accident conditions is postulated, the maximum k_{eff} would not exceed the NUREG-1617 limit of 0.95.

6.3.5.2 Potential Fuel Reconfiguration under Normal Conditions

[

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] Based on this, if there would be any fuel damage under normal condition, the effect on the maximum k_{eff} would also be negligible, and the maximum k_{eff} would also remain well below the NUREG-1617 limit of 0.95.

6.3.6 Partial Loading

Each basket cell is completely surrounded by the basket walls containing neutron absorber material (B_4C). Under a partial loading situation, i.e. where one or more basket locations are not occupied with fuel, the amount of fissile material is obviously reduced. Also, under the bounding condition of a fully flooded cask, the amount of water is increased. This will result in an increased moderation of neutrons in the empty cell locations. This increased moderation will increase the effectiveness of the surrounding thermal neutron absorber. Described differently, the now empty cell locations will act as additional flux traps. Therefore, due to the reduced amount of fissile material, and the increased neutron absorption, the reactivity of the package under partial loading conditions will be reduced, and will always be bound by the fully loaded conditions. No further evaluations of this condition are therefore necessary.

6.3.7 Fuel Assemblies with Missing Rods

The design basis calculations are performed without any missing rod, while for fuel assemblies that are qualified for transportation, missing fuel rods are possible. To determine the reactivity effect of missing rods in fuel assemblies, studies are performed for both the F-12P and F-32B baskets using the bounding fuel assembly. [

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Therefore, for fuel assemblies that are qualified for fuel transportation, one missing fuel rod is acceptable. However, if there are more than one missing fuel rods in a fuel assembly, additional missing fuel rods must be replaced with dummy rods that displace a volume of water that is equal to, or larger than, that displaced by the original rods. For fuel assembly classes 10x10S1, 10x10S3, 10x10S4 and 11x11S1, any missing fuel rods at the locations of partial length fuel rods are acceptable, since the configuration with only the full length rods present is bounding for those assembly classes, as stated in Paragraph 6.2.2.2.

Table 6.3.1

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Table 6.3.2

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.3

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Table 6.3.4

CASMO-5 CALCULATIONS FOR EFFECT OF TOLERANCES AND TEMPERATURE

Changes in Parameters	**Δk Maximum Tolerance**		**Action/Modeling Assumption**
	F-12P, 15x15S3, 5.0 wt% ^{235}U	**F-32B, 10x10S5, 5.0 wt% ^{235}U**	
Maximum UO_2 Density ($10.80\ g/cm^3$) Decrease in UO_2 Density ($10.52\ g/cm^3$)	Ref. -0.0029	Ref. -0.0038	Assume max UO_2 stack density
Increase in Temperature 20°C 40°C 70°C 100°C	 Ref. -0.0033 -0.0101 -0.0189	 Ref. -0.0034 -0.0101 -0.0184	Assume 20°C
10% Void in Moderator 20°C with no void 20°C 100°C	 Ref. -0.0411 -0.0602	 Ref. -0.0249 -0.0431	Assume no void

Table 6.3.5

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Table 6.3.5 (continued)

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.5 (continued)

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Table 6.3.6

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Table 6.3.7

MAXIMUM REACTIVITIES WITH REDUCED WATER DENSITIES FOR CASK ARRAYS[1]

Case Number	Water Density		MCNP5 Results, Configuration 1					
			F-12P, 15x15S3, 5.0 wt% ^{235}U			F-32B, 10x10S5, 5.0 wt% ^{235}U		
	Internal	External	Max. k_{eff}	1 σ	EALF (eV)	Max. k_{eff}	1 σ	EALF (eV)
1	100%	single cask	0.9481	0.0004	0.3336	0.9424	0.0004	0.4283
2	100%	100%	0.9485	0.0004	0.3329	0.9428	0.0004	0.4283
3	100%	70%	0.9483	0.0004	0.3330	0.9426	0.0004	0.4273
4	100%	50%	0.9486	0.0004	0.3328	0.9436	0.0004	0.4285
5	100%	20%	0.9482	0.0004	0.3328	0.9436	0.0004	0.4276
6	100%	10%	0.9487	0.0004	0.3326	0.9435	0.0004	0.4280
7	100%	5%	0.9481	0.0004	0.3319	0.9423	0.0004	0.4282
8	100%	0%	0.9485	0.0004	0.3313	0.9436	0.0004	0.4286
9	70%	0%	0.8170	0.0004	0.7754	0.8264	0.0004	1.0638
10	50%	0%	0.6993	0.0004	2.2315	0.7136	0.0004	3.3524
11	20%	0%	0.4787	0.0003	95.091	0.5015	0.0003	175.81
12	10%	0%	0.4164	0.0002	1156	0.4503	0.0002	1839.8
13	5%	0%	0.3983	0.0002	5622.4	0.4397	0.0002	7118.3
14	10%	100%	0.3969	0.0002	1566.2	0.4359	0.0002	2324.1

Note:

1. This table is for an infinite hexagonal array of casks with 60 cm spacing between cask surfaces.

Table 6.3.8

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Table 6.3.9

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Table 6.3.10

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Table 6.3.11

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.12

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.13

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.14

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.15

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.16

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390.

Table 6.3.17

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.18

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Table 6.3.19

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Figure 6.3.1 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.2 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.3 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.4 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.5 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.6 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Figure 6.3.7 PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

6.4 SINGLE PACKAGE EVALUATION

6.4.1 Configuration

The calculations in this subsection demonstrate that a single HI-STAR 80 Package remains subcritical for all credible conditions of moderation, and that the package fulfills all requirements of 10CFR71.55.

In modeling the single package, the following considerations are applied:

- The bounding geometric and temperature assumptions identified in Tables 6.3.2 and 6.3.4 are used;
- The assemblies are in the eccentric configuration which results in the highest k_{eff} as demonstrated in Paragraph 6.3.4.5;
- The pellet to clad gap is assumed to be flooded (see Paragraph 6.3.4.3);
- The baskets are assumed to be loaded with fuel of the maximum permissible reactivity, i.e.
    - F-12P: The basket is loaded with fresh PWR UO_2 fuel using one of the configurations defined in Appendix 7.D and shown in Section 6.B.7. Specifically:
        - Configuration 1: All basket cells are occupied by the fresh undamaged PWR UO_2 fuel assemblies with an initial enrichment of 5.0 wt%.
        - Configuration 2: The fuel debris are limited to four basket cells, and modeled with an initial enrichment of 5.0 wt% ^{235}U. Two basket cells at locations 4 and 9, or locations 5 and 8 are empty. The rest of the basket cells are occupied by the fresh undamaged BWR UO_2 fuel assemblies with an initial enrichment of 5.0 wt%.
    - F-32B: The basket is loaded with fresh BWR UO_2 fuel using one of the configurations defined in Appendix 7.D and shown in Section 6.B.7. Specifically:
        - Configuration 1: All basket cells are occupied by the fresh undamaged fuel assemblies with a planar-average initial enrichment of 5.0 wt%. This also bounds BWR MOX fuel (See Subsection 6.2.3).
        - Configuration 2: The fuel debris are limited to twelve basket cells, and modeled with an initial enrichment of 5.0 wt% ^{235}U. Four basket cells at locations 13, 14, 19, and 20 are empty. The rest of the basket cells are occupied by the fresh undamaged fuel assemblies with the planar-average initial enrichment of 5.0 wt% ^{235}U.

Normal Conditions

The studies in Paragraphs 6.3.4.1 through 6.3.4.4 demonstrate that the moderation by water to the most reactive credible extent corresponds to the internally fully flooded condition of the basket, with the pellet-to-clad gap in the fuel rods also flooded with water. The external moderation has a statistically negligible effect.

Under normal condition, water is assumed to leak into the package, consistent with 10 CFR 71.55. Flooding with full density water is assumed, since this is the bounding condition as shown in Subsection 6.3.4.

To demonstrate compliance with 10CFR71.55 under normal conditions, the following calculations are performed for the HI-STAR 80 design:

- Single containment with full internal and external water moderation. [

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  ] This case addresses the requirement of 10CFR71.55 (b).
- Single cask with full internal and external water moderation. [
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  ]

To satisfy the requirements of 10CFR71.55 (b)(1), the calculations are performed

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Additional calculations (CASMO-5) at elevated temperatures confirm that the temperature coefficients of reactivity are negative as shown in Table 6.3.4. This confirms that the calculations are conservative.

Calculations with BWR MOX fuel confirm that fresh BWR UO_2 fuel with a planar-average enrichment of 5.0 wt% bounds BWR MOX fuel with a large margin, as presented in Subsection 6.2.3.

Accident Conditions

The analyses presented in Chapter 2 and Chapter 3 demonstrate that the damage resulting from the hypothetical accident conditions of transport are limited to a loss of the neutron shield material as a result of the hypothetical fire accident. Because the criticality analyses do not take credit for the neutron shield material (Holtite), this condition has no effect on the criticality analyses.

The HI-STAR 80 is designed for high burnup fuel (HBF), i.e. for fuel with burnups larger than 45 GWd/mtU. For fuel of this burnup, there are concerns that the fuel cladding could be damaged under accident conditions, with a potential effect on reactivity. Chapter 2 demonstrates that the cask remains leaktight under all credible accident conditions. Further, the second lid provides additional assurance that water will not leak into the containment as a result of an accident. The package therefore satisfies the intent of USNRC ISG 19, and flooding of the containment system under accident condition is not considered in the design basis analyses.

In summary, the hypothetical transport accidents have no adverse effect on the geometric form of the package contents important to criticality safety, and thus, are limited to the effects on internal and external moderation evaluated in Paragraph 6.3.4.1.

To demonstrate compliance with 10CFR71.55 under accident conditions, the following calculations are performed for the HI-STAR 80 design:

- Single cask, internally dry, with full external water moderation. [

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  ] This case addresses the requirement of 10CFR71.55 (e).

As additional assurance that the package remains subcritical under accident conditions, studies were performed for some credible damaged fuel configurations under accident conditions with a fully flooded containment boundary. These studies, presented in Subsection 6.3.5, show that even under the assumption of fuel damage and flooding, the package remains subcritical in the accident.

6.4.2 Results

In calculating the maximum reactivity, the analysis uses the following equation:

[

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Appendix 6.A presents the critical experiment benchmarking for fresh UO_2 and MOX fuel and the derivation of the corresponding bias and standard error of the bias (95% probability at the 95% confidence level).

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The maximum k_{eff} values for all these cases, calculated with 95% probability at the 95% confidence level, are listed in Table 6.4.2 for the F-12P basket and Table 6.4.3 for the F-32B basket. Overall, these results confirm that the effective multiplication factor (k_{eff}), including all biases and uncertainties at a 95-percent confidence level, does not exceed 0.95 under normal and accident conditions of transport.

Configuration 1 is selected for the evaluations of single package to show compliance with 10CFR71.55 in Section 6.4, and for the evaluations of package arrays to show compliance with 10CFR71.59 in the following Sections 6.5 and 6.6.

Table 6.4.1

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Table 6.4.2

HI-STAR 80 SINGLE PACKAGE WITH F-12P BASKET

Configuration	**% Internal Moderation**	**% External Moderation**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
Single Package, fully reflected	100%	100%	0.9485	0.0004	0.3329
Containment, fully reflected	100%	100%	0.9475	0.0004	0.3332
Single Package, Damaged	0%	100%	0.3415	0.0001	76913

Table 6.4.3

HI-STAR 80 SINGLE PACKAGE WITH F-32B BASKET

Configuration	% Internal Moderation	% External Moderation	Max. k_{eff}	1 σ	EALF (eV)
Single Package, fully reflected	100%	100%	0.9428	0.0004	0.4283
Containment, fully reflected	100%	100%	0.9438	0.0004	0.4273
Single Package, Damaged	0%	100%	0.3906	0.0001	70258

6.5 EVALUATION OF PACKAGE ARRAYS UNDER NORMAL CONDITIONS OF TRANSPORT

6.5.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator densities have a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under normal conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally and externally dry, is modeled. All other modeling assumptions are identical to the modeling assumptions for the single package under normal conditions. The analyses are performed for both baskets. This addresses the requirement of 10CFR71.59 (a) (1) and the determination of the criticality safety index according to 10CFR71.59 (b).

6.5.2 Results

The results are presented in Table 6.5.1, and show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95 for both baskets. Since an unlimited number of packages can be placed in an array, the value of N is infinite, and the CSI is therefore zero (0).

Table 6.5.1

HI-STAR 80 PACKAGE ARRAYS UNDER NORMAL CONDITIONS

Configuration	**% Internal Moderation**	**% External Moderation**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
F-12P	0%	0%	0.3963	0.0001	38765
F-32B	0%	0%	0.4407	0.0001	39203

6.6 PACKAGE ARRAYS UNDER HYPOTHETICAL ACCIDENT CONDITIONS

6.6.1 Configuration

Studies in Subsection 6.3.4 show that the spacing and external moderator density has a negligible effect on the reactivity of the package. Therefore, any external condition can be used to represent the most reactive configuration. To represent package arrays under accident conditions, a hexagonal array of touching casks, infinite in lateral and axial direction, internally dry with full external water reflection, is modeled. This model is consistent with the model for the single cask under accident condition, and recognizes the fact that water intrusion under accident condition is not considered credible. This calculation addresses the requirement of 10CFR71.59 (a)(2).

6.6.2 Results

The results are presented in Table 6.6.1, and show that the maximum k_{eff} is well below the NUREG-1617 limit of 0.95 for both baskets. Since an unlimited number of packages can be placed in an array, the value of N is infinite, and the CSI is therefore zero (0).

Table 6.6.1

HI-STAR 80 PACKAGE ARRAYS UNDER ACCIDENT CONDITIONS

Configuration	**% Internal Moderation**	**% External Moderation**	**Max. k_{eff}**	**1 σ**	**EALF (eV)**
F-12P	0%	100%	0.3480	0.0001	69512
F-32B	0%	100%	0.3970	0.0001	64463

6.7 FISSILE MATERIAL PACKAGES FOR AIR TRANSPORT

Not Applicable. The HI-STAR 80 package will not be transported by air.

6.8 BENCHMARK EVALUATIONS

Benchmark calculations have been made on selected critical experiments, chosen, insofar as possible, to bound the range of variables in the cask designs. The most important parameters are (1) the enrichment, (2) the cell spacing, and (3) the ^{10}B loading of the neutron absorber panels. Other parameters, within the normal range of cask and fuel designs, have a smaller effect, but are also included. Detailed benchmark calculations are presented in Appendix 6.A.

The benchmark calculations were performed with the same computer codes and cross-section data, described in Section 6.3, that were used to calculate the k_{eff} values for the cask. Further, all calculations were performed on the same computer hardware, specifically, personal computers under Microsoft Windows.

The calculated code bias and bias uncertainties applied in the analysis are determined in Appendix 6.A and also presented in Table 6.4.1.

CHAPTER 6 REFERENCES

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

[6.0.1] Holtec International Report HI-2073681, Safety Analysis Report HI-STAR 180 Cask System, USNRC Docket 71-9325, latest revision.

[6.0.2] Holtec International Report HI-2125175, Safety Analysis Report HI-STAR 180D Cask System, USNRC Docket 71-9367, latest revision.

[6.0.3] Holtec International Report HI-951251, Safety Analysis Report HI-STAR 100 Cask System, USNRC Docket 71-9261, latest revision.

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

[6.1.2] M.G. Natrella, "Experimental Statistics", National Bureau of Standards, Handbook 91, August 1963.

[6.1.3] "CASMO-5/CASMO5M A Fuel Assembly Burnup Program Methodology Manual", SSP-08/405, Rev. 1, Studsvik Scandpower, Inc.

[6.1.4] "CASMO-5 A Fuel Assembly Burnup Program, User's Manual," SSP-07/431, Rev. 4, Studsvik Scandpower, Inc..

[6.2.1] Holtec International Report HI-2114830, Final Safety Analysis Report on the HI-STORM FW System, USNRC Docket 72-1032, latest revision.

[6.2.2] Holtec International Report HI-2002444, HI-STORM 100 Final Safety Analysis Report, USNRC Docket 72-1014, latest revision.

[6.3.1] J.M. Cano, R. Caro, and J.M Martinez-Val, "Supercriticality Through Optimum Moderation in Nuclear Fuel Storage," *Nucl. Technol.*, 48, 251-260, (1980).

Appendix 6.A

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

Appendix 6.B

PROPRIETARY INFORMATION WITHHELD PER 10CFR2.390

CHAPTER 7: PACKAGE OPERATIONS

The text matter and data presented in this chapter in **bold** font (or as otherwise noted) are an integral part of the Certificate of Compliance (CoC) of the package and cannot be altered without NRC's approval through a license amendment. Moreover, essential elements and criteria in Section 7.0 through Section 7.3, essential elements and criteria in Appendix 7.A and the whole of Appendix 7.D have been identified as conditions of the CoC.

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7.0 INTRODUCTION

This chapter provides a summary description of the essential elements and minimum requirements necessary to prepare the HI-STAR 80 package for shipment and to ensure that it operates in a safe and reliable manner under normal and accident conditions of transport pursuant to the provisions of 10CFR71, as described in this SAR. The information presented in this chapter, along with the technical basis of the package design described in Chapters 2 through 6 will be used by Holtec International's Site Services organization to develop more detailed generic procedures for users of the HI-STAR 80 Package. Equipment specific operating details such as valve manipulation, onsite cask transporter handling methods etc., will be provided to individual users of the HI-STAR 80 package based on the specific ancillary equipment selected by the user and the configuration of the site. It is the user's responsibility to utilize the information provided in this chapter, (treating it as an inviolable set of operation elements that must be included in the detailed operating procedures). In addition, the user must consult the conditions of the NRC issued Certificate of Compliance (CoC), equipment-specific operating instructions, and the plant's working procedures and apply them to develop the site-specific written loading, unloading, and handling procedures to ensure that the package is operated in accordance with the CoC and all applicable government regulatory requirements. **The following generic criteria shall be used to qualify that the site specific operating procedures are acceptable for use:**

- **All heavy load handling instructions are in conformance with the guidance in industry standards, and Holtec's proprietary rigging manual.**
- **A careful technical evaluation of all potential modes of loss-of-load stability has been performed and accepted by Holtec International's site services organization.**
- **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 reviewed to incorporate all applicable lessons learned from prior cask handling and loading evolutions.**

- **Procedures contain provisions for classroom and hands-on training and for a Holtec approved personnel qualification process to insure that all operations personnel are adequately trained.**
- **The procedures are sufficiently detailed and articulated to enable craft labor to execute them in *literal compliance* with their content.**

The operations described in this chapter assume that the contents will be loaded into or unloaded from the HI-STAR cask submerged in a spent fuel pool. With some modifications, the information presented herein can be used to develop site-specific procedures for loading contents into or unloading contents from the HI-STAR cask within a hot cell or other remote handling facility.

US Department of Transportation (USDOT) transportation regulations in 49CFR applicable to the transport of the HI-STAR 80 package are only addressed in this chapter to the extent required to ensure compliance with 10CFR71 regulations and to provide a more complete package operation description. Applicable 49CFR regulations, including those explicitly called out in 10CFR 71.5, shall be complied with for package use in the US and/or for US package export and import. For transport outside US territory and under the approval or jurisdiction of one or more foreign competent authorities, other requirements such as the ADR, "European Agreement Concerning the International Carriage of Dangerous Goods by Road" and the RID, "European Agreement Concerning the International Carriage of Dangerous Goods by Rail" may be imposed in place of the 49CFR. It is the user's responsibility to comply with the latest revision of these transportation regulations as required by the applicable competent authority.

Users shall develop or modify existing programs and procedures to account for the transport operation of the HI-STAR 80. Written procedures are required and will be developed or modified to account for such items as handling and storage of systems, structures and components identified as *important-to-safety*, heavy load handling, specialized instrument calibration, special nuclear material accountability, fuel handling procedures, training, equipment and process qualifications. Users shall implement controls to ensure that the lifted weights do not exceed the cask lifting trunnion design limit. Users shall implement controls to monitor the time limit for the removal of the cask from the spent fuel pool to the commencement of cask draining to prevent boiling. Users shall also implement controls to ensure that the cask cannot be subjected to a fire event in excess of design limits during loading operations.

For the determination of Time-To-Boil time limits or the determination of cyclic vacuum drying time limits, thermal evaluations may implement Fluent 3D models that are the same or consistent with the models used for safety analysis. Alternatively, other demonstrably conservative and appropriately benchmarked models may be utilized.

The procedures in this chapter contain generic ALARA notes and warnings to alert users to radiological issues. Actions identified with these notes and warnings are not mandatory and shall be implemented based on a determination by radiation protection.

This Chapter covers the loading of HI-STAR 80 with authorized contents for "Load-and-Go" and transport service under 10CFR 71 without first deploying the system at an Independent Spent Fuel Storage Installation (ISFSI) under 10CFR 72.

Appendix 7.A provides general operational weights and illustrations of typical operations of the HI-STAR 80 Package. Additional general weight information may be provided in the drawing package referenced in the CoC.

Appendix 7.D provides content conditions of the HI-STAR 80 Package.

Fuel assembly selection and verification shall be performed by the user in accordance with written, approved procedures that ensure that only SNF assemblies authorized in the CoC are loaded into the HI-STAR 80 cask. Fuel handling shall be performed in accordance with written site-specific procedures.

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

Fuel assembly selection, and some aspects of assembly verification, are typically performed well in advance of the actual loading date, specifically with respect to the selection and verification of the assemblies to meet the definition of undamaged fuel in the CoC. A typical approach to show compliance with the CoC definition of undamaged fuel may include the following steps:

- **During reactor operation, the water chemistry is monitored. If no indications of fuel leakage is detected, all assemblies unloaded from the core are considered undamaged.**
- **If indication of leakage is found in the water during reactor operation, the population of the assemblies in the core that may have the leak may be narrowed down by a more detailed evaluation of the leaked isotopes, or by manipulating control blades in a BWR core.**
- **Once unloaded, further examination, such as sipping, may be performed to clearly identifying the leaking assembly or assemblies, out of the population identified.**
- **Once leaking assemblies are identified, they may simply be considered not meeting the CoC requirements and excluded from the selection, or further tests are performed to identify the extent of cladding damage.**
- **For channeled BWR assemblies, such further tests to identify the extent of the leak, and potentially qualify them as undamaged if the leak does not exceed the requirements in the CoC for undamaged assemblies, would require the removal of the channel.**

Fuel handling shall be performed in accordance with written site-specific procedures.

7.1 PACKAGE LOADING

Note: This section, including tables and figures, is an integral part of the Certificate of Compliance (CoC) of the package.

The HI-STAR 80 Package is used to load and transport spent fuel or non-fuel waste. The essential elements required to prepare the HI-STAR 80 Package for loading, to load the fuel (or non-fuel waste), to ready the cask for transport as a Transport Package are described below.

7.1.1 Preparation for Loading

1. If the HI-STAR 80 Packaging has previously been used to transport spent fuel or non-fuel waste, the HI-STAR 80 is received and the personnel barrier, if attached, is removed and security seals, if used, are inspected to verify there was no tampering and that they match the corresponding shipping documents.
2. The HI-STAR 80 Packaging is visually receipt inspected to verify that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. Any issues are identified to site management. Any road dirt is washed off and any foreign material is removed.
3. Radiological surveys are performed in accordance with 49CFR173.443 [7.1.2] and 10CFR20.1906 [7.1.3]. If necessary, the HI-STAR 80 Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties.
4. The impact limiters, if attached, are removed and a second visual inspection to verify that there are no outward visual indications of impaired physical condition is performed.
5. The cask is upended and the neutron shield relief devices are inspected to confirm that they are installed, intact, and not covered by tape or any other covering.
6. The cask lids are removed and damaged seals are removed and discarded.
7. The containment closure flange inner and outer lid sealing surfaces are inspected for damage that may compromise the performance of the seal. Any damage to the sealing surfaces is repaired by welding and/or polishing/machining damaged areas as necessary. If the cask sealing surface is weld repaired, the sealing surfaces are faced with corrosion resistant veneers.
8. The inner and outer closure lid bolts are inspected for distortion and damaged threads and any suspect bolts are replaced.
9. Any foreign material is removed from inside the cask and the basket panels are visually checked to verify they are not damaged.

7.1.2 Loading of Contents

7.1.2.1 Loading Operations

ALARA Note:
A bottom protective cover may be attached to the cask bottom or placed in the designated preparation area or spent fuel pool. This will help prevent embedding contaminated particles in the cask bottom surface and ease the decontamination effort. Waterproof tape placed over empty bolt holes, and bolt plugs may also reduce the time required for decontamination. Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

1. The cask containment closure flange sealing surfaces are covered with a protective cover or a protective funnel. Caps or plugs are installed on the neutron shielding enclosure pressure relief devices. The cask storage cavity is filled with either spent fuel pool water, clean borated water or clean demineralized water and the cask is lowered into the spent fuel pool for loading. The cask cavity may be filled by pumping water into the cask or by lowering the cask in the spent fuel pool and allowing water to overflow into the cask cavity. A protective sealed skirt is installed around the HI-STAR 80 cask and filled with water to provide supplementary cooling and to minimize contamination from accumulating on the outer surface of the cask.

2. Quivers may be loaded with contents, dried, backfilled and leak tested prior to loading into the cask. Prior to loading the quiver with spent fuel rods, the user identifies the fuel rods or fuel debris to be loaded and the content is independently verified that it meets the conditions of the CoC.

3. Prior to loading quivers into the cask, the user identifies the quivers to be loaded and the quivers are independently verified that they meets the conditions of the CoC and the operational requirements in Table 7.1.8.

4. Prior to loading the fuel, the user identifies the fuel and quivers to be loaded and the fuel is independently verified that it meets the conditions of the CoC and this chapter. The pre-selected assemblies are loaded into the cask and a visual verification of the assembly identification is performed. Any additional information required to be documented by Appendix 7.D for the shipping manifest must be recorded.

Attention:
1) MOX fuel may be stored in the F-32B Fuel Basket. The cell locations for the mixed loading MOX and UO_2 fuel assemblies are provided in Appendix 7.D. In summary, Table 7.D.6 specifies the cell locations that are allowed to contain MOX fuel. UO_2 fuel may be loaded in any cell location including the cell locations designated for MOX fuel. 2) As a strategy to optimize (i.e. decrease) the per assembly cooling time, empty cell locations are allowed in Appendix 7.D for both F-12P and F-32B Fuel Baskets. In summary, Table 7.D.4 and Table 7.D.5 include the identification of cell locations that shall be left empty in order for the corresponding assembly initial enrichments and post-irradiation cooling times to be applicable.

5. While still under water, the containment closure flange seal protection device is removed, and the containment closure flange inner lid sealing surface protective cover or funnel is removed and the sealing surfaces for the inner closure lid are inspected for signs of damage to determine if the sealing surface is clear of potential solid contamination and free from gross damage that might affect the seal performance. Any contamination or damage that would prevent a seal is remedied. Prior to placing the inner lid in the water, any damaged seals are removed and replaced and the sealing surfaces are inspected to verify they are free of damage and contamination that might affect seal performance. Any contamination or damage that would prevent a seal is remedied. New seals may be installed in the inner closure lid and the lid is then lowered into the water and installed on the cask. The lid is visually inspected to confirm it is properly seated. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to the start of draining operations. The Time- to-Boil clock begins when the inner lid is placed on the cask. If it appears that the Time-to-Boil limit will be exceeded prior to draining operations, the user shall take appropriate action to either replace the water in the cask cavity with an inert gas, circulate water through the cask cavity to reset the Time-to-Boil clock, or return the cask to the spent fuel pool and remove the lid to allow for natural water circulation. Inner closure lid bolts may be installed at any time after the inner closure lid is installed but before the cask is dried.

ALARA Note:
Activated debris may have settled on flat surfaces of the cask during loading. Cask surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce decontamination time, the cask surfaces should be kept wet until decontamination begins.

6. The lift attachment is engaged to the cask lifting trunnions and the cask is raised out of the spent fuel pool after being cleared by Radiation Protection. As the cask is raised out of the

spent fuel pool, the lift attachment and cask are sprayed with clean water to help remove contamination.

7. The accessible areas of the bottom of the cask and the cask bottom protective cover, if used, are decontaminated, the cask is placed in the designated preparation area and the lift attachment is removed. The top surfaces and accessible areas of the cask are decontaminated. The inner lid retainer ring is installed. Caps or plugs are removed from the neutron shielding enclosure pressure relief devices.

8. Dose rates are measured at the inner closure lid and around the cask body to confirm appropriate radiological control.

9. The vent orifice tool is installed, and the vent line is opened to prevent cask pressurization and temporary shielding (if used) is installed.

10. The inner closure lid bolts are torqued after the vent line is opened and before the cask cavity is drained. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The user may attach security seals to the outer closure lid bolts at this time.

ALARA Warning:
Personnel should remain clear of the drain lines any time water is being pumped or purged from the cask. Radiological crud, suspended in the water, may create a radiation hazard to workers. Dose rates will rise as water is drained from the cask. Continuous dose rate monitoring is recommended.
Caution:
Except as allowed by Table 7.1.6, an inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during loading operations.

11. The Forced Helium Dehydration (FHD) System is connected to the cask and used to remove moisture from the cask cavity. There is no time limit on FHD drying. As the water is drained from the cask, an inert gas is introduced into the cask to prevent oxidation of the fuel cladding. After the bulk water has been removed, the helium exiting the FHD demoisturizer is cooled to the temperature or dew point given in Table 7.1.2 and circulated through the duration given in Table 7.1.2 to ensure that the cask cavity is suitably dry.

12. Optionally, a vacuum drying system is connected to the cask and used to remove moisture from the cask cavity. The user performs a site-specific evaluation to determine whether cyclic vacuum drying and time limits are necessary to ensure the vacuum drying criteria is met. A protective sealed skirt may be installed around the HI-STAR 80 cask and filled with water to provide supplementary cooling during the vacuum drying process. Users shall refer to Table 7.1.2 and Table 7.1.3 for vacuum drying criteria for fuel and non-fuel waste contents. As the water is drained from the cask, an inert gas is introduced into the cask to

prevent oxidation of the fuel cladding (see Table 7.1.6 for air exposure conditions). (If the cask is loaded with a non-fuel waste, air may be used instead of an inert gas.) The cask cavity is vacuum dried. Once it is demonstrated that the cask cavity pressure meets the pressure criterion given in Table 7.1.2 for the duration given in Table 7.1.2, with the valve closed , it shall be considered dry.

13. The cask cavity is backfilled to the requirements in Table 7.1.4 or Table 7.1.5 as applicable and the port caps/plugs are closed.

14. With the inner closure lid inter-seal test port plug removed, the inner closure lid inter-seal space is dried. The inner closure lid inner seal is leak tested through its respective inter-seal test ports. Test requirements and acceptance criteria are provided in Chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals. Note that the leak testing of the inner closure lid main seal may be performed immediately after the lid bolts are installed and torqued such that if a leak is detected, the cask does not need to be reflooded.

15. The sealing surfaces and mating surfaces of the orifice port covers are inspected for signs of damage. Any damage that would prevent a seal is remedied and any old seals are removed. The space beneath the port covers are backfilled to the requirements in Table 7.1.4 or Table 7.1.5 as applicable. The port cover bolts are torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The vent and drain port cover plate inner seals are leak tested through their respective inter-seal test port to the required test requirements and acceptance criteria provided in Chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

7.1.2.2 Cask Closure

1. The test port plugs on the inter-seal test ports are installed and torqued. The containment closure flange outer sealing surface protective cover is removed. The sealing surfaces for the outer closure lid are inspected for signs of damage or particulate matter that might affect the seal performance. Any particulate matter or sealing surface damage that would prevent a seal is remedied. The user ensures that the inner closure lid inter-seal test port plug(s) are installed. The outer closure lid is installed. The outer closure lid bolts are installed and torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The user may attach security seals to the outer closure lid bolts at this time.

2. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4 or Table 7.1.5 as applicable.

3. The outer closure lid access port plug is closed.

4. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested in accordance with the test requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

5. The outer closure lid access port cover is installed with a seal and port cover bolts are torqued. The outer closure lid inter-seal test port plug(s) is installed and torqued.

6. Note that the cask closure steps may be performed prior to draining the cask for ALARA purposes.

7.1.3. Preparation for Transport

1. If more than twelve months have elapsed since the performance of the leakage tests described in Section 7.1.2.2, a periodic leakage test shall be performed as follows:

   a. If installed, the outer closure lid is removed and the inner closure lid inter-seal test port plug(s) and inner closure lid port cover inter-seal test port plugs are removed. The inner closure lid inner seal and vent and drain port cover plate inner seals are leak tested to the requirements and acceptance criteria listed in Chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

   b. The inner closure lid inter-seal test port plug(s) and inner closure lid port cover inter-seal test port plugs are installed with new seals.

   c. The sealing surfaces for the outer closure lid are inspected for signs of damage or particulate matter that might affect the seal performance. Any particulate matter or sealing surface damage that would prevent a seal is remedied. The outer closure lid is installed using new seals. The outer closure lid bolts are installed and torqued. Bolt torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively. The user may attach security seals to the outer closure lid bolts at this time.

   d. The inter-lid space is dried, evacuated and backfilled to the requirements in Table 7.1.4 or Table 7.1.5 as applicable.

   e. The outer closure lid access port plug, fitted with a new seal, is torqued to the requirements in Table 7.1.1. The outer closure lid inner-seal and outer closure lid access port plug seal are leak tested to the requirements and acceptance criteria in Chapter 8. Unacceptable leakage rates will require cleaning or repair of the sealing surfaces and replacement of the seals prior to retesting of the seals.

   f. The outer closure lid access port cover is installed with a seal and port cover bolts are torqued. The outer closure lid inter-seal test port plug(s) is installed with new seal and torqued.

2. The cask neutron shield pressure relief devices are visually verified to be undamaged.

ALARA Warning:
Dose rates around the unshielded bottom end of the cask may be higher than other locations around the cask. After the cask is downended on the transport frame, the bottom impact limiter should be installed promptly. Personnel should remain clear and exercise other appropriate ALARA controls when working around the bottom end of

the cask.

3. The cask is moved to the transport location, placed on the transport vehicle and downended.
4. A visual inspection for signs of impaired condition is performed. Any non-satisfactory conditions are remedied.
5. Contamination surveys are performed per 49CFR173.443. If necessary, the cask is further decontaminated to meet the survey requirements.
6. The impact limiter bolts/nuts are torqued. Bolt/Nut torque requirements and recommended tightening procedure are provided in Table 7.1.1 and Figure 7.1.1, respectively.
7. The tie-down system is installed, a cover is installed over at least one of the access tubes on the top impact limiter, and a security seal is installed on the top impact limiter. Security seal serial number(s) are recorded in the shipping documents.
8. Trunnion covers, custom tie-down devices or other blocking ancillary devices must be used to render accessible top and/or bottom trunnions inoperable (i.e. not accessible for lifting and handling). See Figure 7.A.1 or Figure 7.A.2 for requirements based on applicable transport configuration.
9. Final radiation surveys of the package surfaces per 10CFR71.47 [7.1.4] and 49CFR173.443 [7.1.2] are performed and if necessary, the HI-STAR 80 Packaging is further decontaminated to meet the survey requirements. Survey results are recorded in the shipping documents. For packages containing HBF, the final radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The final location of measurements and the measurements shall be recorded in the shipping documents.
10. The surface temperatures of the accessible areas of the package are measured to confirm temperatures are within 10CFR71.43 requirements, if the personnel barrier will not be used.
11. For packages containing HBF, surface temperatures are measured as required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The final location of measurements, ambient conditions (air temperature, date, time of day, and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements.
12. The personnel barrier is installed. The personnel barrier is optional if the package surface temperature and the dose rates without the personnel barrier are within 10CFR71.43 and 10CFR71.47 requirements, respectively; and no applicable 49CFR requirements are violated.

13. The assembled package is given a final inspection to verify that the following conditions for transport have been met (inspection steps may be performed in any order):
    a. Verify that required radiation survey results are properly documented on the shipping documentation.
    b. Perform a cask surface temperature check. The accessible surfaces of the Transport Package (impact limiters and personnel barrier) shall not exceed the exclusive use temperature limits of 49CFR173.442.
    c. Verify that all required leakage testing has been performed, the acceptance criteria have been met, and the results have been documented on the shipping documentation.
    d. Verify that the receiver has been notified of the impending shipment and that the receiver has the appropriate procedures and equipment available to safely receive and handle the Transport Package (10CFR20.1906(e)).
    e. Verify that the carrier has the written instructions and a list of appropriate contacts for notification of accidents or delays.
    f. Verify that the carrier has written instructions that the shipment is to be Exclusive Use in accordance with 49CFR173.441.
    g. Verify that route approvals and notification to appropriate agencies have been completed.
    h. Verify that the appropriate labels have been applied in accordance with 49CFR172.403 [7.1.1].
    i. Verify that the appropriate placards have been applied in accordance with 49CFR172.500.
    j. Verify that all required information is recorded on the shipping documentation including information required by Appendix 7.D.

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

Table 7.1.1

HI-STAR 80 Package Torque Requirements (Note 6)

Fastener (See Note 1)	**Recommended Torque (N-m), τ** (See Note 2)	**Minimum Total Bolt Preload** kN (See Note 7)	**Comments**
Inner Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	12,167	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Outer Closure Lid Bolts	1st Pass: Wrench Tight Intermediate Pass: 30% to 45% of final torque value Final Pass: See Note 3	4,056	See Figure 7.1.1 and Notes 4 and 5. Intermediate pass is final pass for empty but previously used packages
Outer Closure Lid Port Cover Bolts	See Note 3	34.9	None
Outer Closure Lid Access Port Plug	"Snug Tight"	N/A	Alternate torque may be permitted with Holtec approval
Top Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Bottom Impact Limiter Attachment Bolts/Nuts	"Snug Tight"	N/A	None
Orifice Port plug	"Snug Tight"	N/A	None
Vent Port Outer Cover Plate, Without NITS Seals	9.0	30.0	None
Drain Port Cover Plate, With NITS Seals	13.5	45.0	None
Spray Cooling Cap	"Snug Tight"	N/A	None
Spray Cooling Cover Plate Bolts	14.25	60.0	None

Notes continued on next page:

Table 7.1.1

HI-STAR 80 Package Torque Requirements (continued)

Notes:

1. Fasteners shall be cleaned and inspected for damage or excessive wear (replaced if necessary) and coated with a light layer of lubricant, such as Fel-Pro Chemical Products, N-5000, Nuclear Grade Lubricant.
2. For conversion from Newton-meter (N-m) to foot pounds (ft-lb) divide by 1.356.
3. The nominal bolt torque, τ, is given by the semi-empirical formula,

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

   where, K = Torque coefficient

   The torque coefficient, K, varies from 0.12 (extremely effective lubricant such as Bowman Anti-Seize) to 0.18 (commercial lubricant). The above formula is derived from Shigley, et. al.[1]. The above torque values assume a high quality lubricant (K=0.12). A higher value may be used based on the lubricant supplier's recommendation.

   P_B = Minimum Bolt Preload.

   d = Nominal bolt diameter (soft conversion between metric and US units is permitted)

   Fastener sizes are provided in the drawing package referenced in the CoC.
4. Detorquing shall be performed by turning the bolts counter-clockwise in 1/3 turn +/- 30 degrees increments per pass for three passes. The bolts may then be removed.
5. Values listed are for the minimum number of passes permitted. Additional intermediate passes are permitted.
6. For empty packages, alternate torque requirements may be used with Holtec approval.
7. To determine individual bolt preload required, divide the total shown by the number of bolts for the lid/cover.

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

Table 7.1.2

Cask Drying Method and Dryness Criteria

Fuel Burnup (MWD/MTU)	**Heat Load (kW)**	**Method of Moisture Removal**
All Fuel Assembly Burnups	Up to design basis cask heat load in Table 7.D.1 Q_{DB}	Forced Helium Dehydration
		Vacuum Drying (Note 3)
Recommended Dryness Criteria (Note 1 and 2)		
Forced Helium Dehydration	Temperature or dew point of gas exiting the FHD demoisturizer, T_{FHD}	≤ -5.0°C (22.9°F)
	Duration of gas circulation at T_{FHD}	≥ 30 minutes
Vacuum Drying (continuous and cyclic, for fuel only)	Cask cavity vacuum pressure, P_{VAC}	≤ 0.4kPa (3 Torr)
	Duration of isolated cask cavity at P_{VAC}	≥ 30 minutes
Vacuum Drying (continuous, for non-fuel waste only)	Cask cavity vacuum pressure, P_{VAC}	≤ 0.8 kpa (6 Torr)
	Duration of isolated cask cavity at P_{VAC}	≥ 2 hours

Notes:
1. Alternate dryness criteria following the guidance of NUREG 1617, NUREG 1536, PNL-6365 (Knoll, 1987) may be permitted with Holtec approval.
2. Users shall refer to Table 7.1.3 for additional cask drying criteria.
3. Time limits may be applicable.

Table 7.1.3

Criteria Applicable to Cask Drying Operations

Criterion	Specification
Fuel Cladding Temperature Limit	400°C (752°F) (High Burnup Fuel)
	570°C (1058°F) (Moderate Burnup Fuel)
Fuel Cladding Temperature Excursion During Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision
Thermal Cycling	According to the guidance contained in ISG-11 Revision 3 or latest revision

Table 7.1.4

Cask Backfill Requirements for Shipment of Fuel

Cask Space	**Reference Pressure or Pressure Range**
Cask Cavity Space (Note 1)	172.4 kPa (25 psia) to 200 kPa (29 psia) absolute pressure
Cask Cavity Space (For Q ≤ 43.5kW) (Notes 2 and 3)	20.0 kPa (2.9 psia) to 200 kPa (29 psia) absolute pressure
Cask Inter-Lid Space (Note 1)	0 kPa (0 psig) to 17.2 kPa (2.5 psig) gauge pressure
Orifice Port Space	atmospheric
Recommended Backfill Gas	
Type	Helium
Reference Purity	99.99% Nom.

Notes:

1. The reference pressure or pressure range is at a reference temperature of 21.1°C (70°F)
2. For Q ≤ 43.5 kW, following cask drying operations, the gas temperature inside the cask cavity will be higher than 21.1°C (70°F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the cask cavity pressure is within the pressure range is sufficient to establish the proper backfill conditions.
3. For Q≤43.5 kW, applicable heat load patterns are identified in Table 7.1.9.

Table 7.1.5

Cask Backfill Requirements for Shipment of Non-Fuel Waste

Cask Space	**Reference Pressure or Pressure Range**
Cask Cavity Space (Note 1)	20 kPa (2.9 psia) to 200 kPa (29 psia) absolute pressure
Cask Inter-Lid Space (Notes 1 and 3)	0 kPa (0 psig) to 17.2 kPa (2.5 psig) gauge pressure
Orifice Port Space	atmospheric
Recommended Backfill Gases	
Type:	**Reference Purity:**
Air	Not Applicable
Helium	99.99% Nominal

Notes:

1. The reference pressure is based on a reference cask space bulk temperature of ≥ 21.1°C (70°F)
2. Not used.
3. For ambient temperatures above 21.1°C (70°F), the gas temperature in the inter-lid cavity will be higher than 21.1°C (70°F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the inter-lid cavity pressure is sufficient to establish the proper backfill conditions. For ambient temperatures below 21.1°C (70°F), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1°C (70°F) using the ideal gas law. Use of pressure gauges to confirm that the inter-lid cavity pressure is between the adjusted limits is sufficient to establish the proper backfill conditions.

Table 7.1.6 (Sheet 1 of 3)

Air Exposure Conditions for Loading and Unloading

Attention: Prior to allowing air exposure under loading and/or unloading, the user's detailed operating procedures shall include a comprehensive, detailed flowchart reflecting the requirements of this table.

CONDITIONS FOR LOADING OPERATIONS:

For casks with fuel packages that will be vacuum dried, air may be used as the cover gas instead of an inert gas under the following conditions:	
A.	The user determines the applicability of the Air Exposure Threshold Time Limit (ATTL) according to Note 1 below.
B.	The user obtains a site-specific, cask heat load dependent evaluation to determine the ATTL (See Table 7.1.7).
C.	The user establishes the Reserve Time Limit (RTL) as indicated in Note 2 below and determines if air exposure of fuel is allowable
D.	The Air Exposure clock begins when fuel cladding is initially exposed to air during water draining process. The user may elect to conservatively start the Air Exposure clock at the start of the water draining process
E.	After the water draining process, the fuel package should be placed in a state of vacuum of less than 180 Torr in an expeditious manner (the standard vacuum system is capable of less than 3 Torr). To achieve this, the water draining operation must take place as expeditiously as practical and the start of vacuum drying must commence promptly after the water draining operation has concluded. (See Note 4). Typically, the time to dewater the cask is approximately 1 hour and time to achieve less than 180 Torr is approximately 1 hour.
F.	The Air Exposure clock stops when either the cask is refilled with water to cover the fuel cladding or when the cask is filled with an inert gas. The total air exposure time is cumulative for each fuel package. Refilling a cask with water does not reset the Air Exposure clock. (See Note 3).
G.	The cask shall be filled with inert gas after achieving the heat up phase of the first vacuum cycle (applicable to either continuous vacuum drying or cyclic vacuum drying). (See Note 4).Air shall not be reintroduced after the heat up phase of the first vacuum cycle.

Loading Notes:

1. The ATTL DOES NOT apply to fuel packages where ALL fuel assemblies are undamaged AND DO NOT have known or suspected cladding defects such as pin holes or hairline cracks. Fuel cladding integrity shall be verified by review of operational records or through testing for cladding defects through inspection of assemblies. Nevertheless, the cask must be filled with inert gas after achieving the heat up phase of the first vacuum cycle in condition G) above and consistent with note 4.
2. One hour is the minimum default RTL. The RTL is contingency time set aside to allow operations to cover fuel with inert gas or to cover fuel with water. A site-specific evaluation of operational steps shall be performed to determine if a longer RTL is necessary. To proceed with air exposure of fuel, the ATTL must be greater than the RTL.
3. If the ATTL is exceeded, cask must be filled with inert gas or water within the default RTL and prior to exceeding cladding temperature of 400ºC. For this purpose, a transient thermal evaluation may be performed under the cask specific heat load with the cask cavity under vacuum condition.
4. Any time fuel assemblies are exposed to air, fuel cladding temperature will increase; however, a cladding cutoff temperature of 380ºC is built into the vacuum drying process (applicable to both MBF or HBF as an air exposure condition). This cutoff temperature allows time for backfill of inert gas without exceeding the cladding temperature limit of 400ºC, a time which is dependent on cask heat load.

Table 7.1.6 (Sheet 2 of 3)

Air Exposure Conditions for Loading and Unloading

CONDITIONS FOR LOADING OPERATIONS:

Casks with fuel packages may be exposed to air during unloading under any one of the following conditions:	
A.	ALL fuel assemblies were initially loaded as undamaged AND verified NOT TO HAVE known or suspected cladding defects such as pin holes or hairline cracks at time of loading. Furthermore, the package, if shipped, was NOT SUBJECTED to non-routine conditions of transport (e.g. package drops). (Note 5 below is applicable)
B.	ALL fuel assemblies were initially loaded as undamaged AND verified NOT TO HAVE known or suspected cladding defects such as pin holes or hairline cracks at time of loading. Furthermore, it is determined by gas sampling during unloading that fuel cladding remains unbreached. (Note 5 below is applicable)
C.	Cumulative (loading and unloading) Air Exposure Threshold Time Limit (ATTL) is not exceeded. (See Notes 1, 2, 3 and 5): a. If an ATTL was initially implemented for loading the cask under Scenario 1 of Table 7.1.7, then ATTL unloading shall be restricted to the cumulative ATTL based on Scenario 3 of Table 7.1.7 (the actual exposure time used for loading must satisfy the ATTL for loading under Scenario 3). b. If an ATTL was NOT initially implemented for loading the cask under Scenario 1, then the user obtains a site-specific, cask heat load dependent evaluation to determine an ATTL for unloading based on Scenario 2 of Table 7.1.7. The cask heat load may be assumed the same as the heat load at time of loading OR the cask heat load at time of unloading may account for heat load reduction due to additional cooling time since the cask was initially loaded. c. The user establishes the Reserve Time Limit (RTL) as indicated in Note 3 below and determines if air exposure of fuel is allowable. d. The user obtains the Fuel Cladding Temperature Threshold Time Limit (FTTL) as indicated in Note 5 below and determines if air exposure of fuel is allowable. e. The Air Exposure clock and Cladding Heat-up clock begin when more than half the fasteners on any cask containment closure component are untorqued (or when any containment orifice is opened) AND no other means to prevent air ingress has been implemented. f. The Air Exposure clock and Cladding Heat-up clock stop when the cask is filled with water to cover the fuel cladding OR if the cask is refilled with inert gas. Refilling the cask with water does not reset the Air Exposure clock. (See Note 4)

Notes continued on next page.

Table 7.1.6 (Sheet 3 of 3)

Air Exposure Conditions for Loading and Unloading

CONDITIONS FOR UNLOADING OPERATIONS (continued)

Unloading Notes:

1. An ATTL DOES NOT APPLY to fuel packages where the cask cavity space pressure at time of cask opening is atmospheric or greater. In this case, the operation to introduce water into the cask cavity space shall commence as expeditiously as practical to place the cask cavity in a state of positive internal pressure until all fuel cladding is covered in water.
2. An ATTL applies to gas sampling IF gas sampling operations that do not prevent air ingress greater than trace amounts into the cask cavity.
3. One hour is the minimum default RTL that is set aside to allow time to cover fuel with inert gas or to cover fuel with water. A site-specific evaluation of operational steps shall be performed to determine if a longer RTL is necessary. To proceed with air exposure of fuel, the ATTL must be greater than the RTL.
4. If the ATTL is exceeded, the cask must be filled with inert gas or water within the default RTL and prior to exceeding the FTTL.
5. Any time fuel assemblies are exposed to air, fuel cladding temperature will increase; therefore, an FTTL shall be applied during unloading. The FTTL is determined based the thermal analysis methodology used in the safety case to limit fuel cladding temperature to 400ºC (applicable to both MBF or HBF as an air exposure condition). To proceed with air exposure of fuel, the FTTL must be greater than the RTL.

Table 7.1.7 (Sheet 1 of 2)

Air Exposure Time Limit for Loading and Unloading

Scenario 1: Air Exposure Threshold Time Limit for Loading Only
To compute permissible air exposure duration τ_{max} during loading only (vacuum drying operations) the following equation is applied: $$U := \int_0^{\tau_{max}} \frac{1}{t_{2.4}(y(x))} dx \leq 1$$ Where $t_{2.4}$ (hours) = 8760*2.97*10^{-13}*exp (26.6 kcal/mol*R*(T_f+273)) $t_{2.4}$ is a function of fuel temperature T_f which during vacuum drying operations is a function y(x) of time x in hours. Note: If air exposure is expected to take place during unloading then use the cumulative ATTL equation (Scenario 3).
Scenario 2: Air Exposure Threshold Time Limit for Unloading Only
To compute permissible air exposure duration τ_{max} during unloading operations only the following equation is applied: $$U := \int_0^{\tau_{max}} \frac{1}{t_{2.4}(y(x))} dx \leq 1$$ Where $t_{2.4}$ (hours) = 8760*2.97*10^{-13}*exp (26.6 kcal/mol*R*(T_f+273)) $t_{2.4}$ is a function of fuel temperature T_f which during unloading is a function y(x) of time x in hours. Note: If air exposure is expected to take place during loading then use the cumulative ATTL equation (Scenario 3).

Table 7.1.7 (Sheet 2 of 2)

Air Exposure Time Limit for Loading and Unloading

Scenario 3: Cumulative Air Exposure Threshold Time Limit for Loading and Unloading
To compute permissible air exposure duration, τL, during vacuum drying operations (loading) and for unloading operations, τUL, in the event that air exposure is expected to take place under both loading and unloading, the following equation is applied: $U = \int_0^{\tau L} \frac{1}{t_{2.4}(y(x))} dx + \int_0^{\tau UL} \frac{1}{t_{2.4}(y_1(x))} dx \leq 1$ Where $t_{2.4}$ (hours) = 8760*2.97*10^{-13}*exp (26.6 kcal/mol*R*(T_f+273)) $t_{2.4}$ is a function of fuel temperature T_f which during loading and unloading operations is a function y(x) and y_1(x) of time x in hours, respectively.   Attention: The ATTL for loading will be shorter than if determined separately via Scenario 1.

Table 7.1.8

Quiver Operational Requirements

Criterion	**Specification**
Condition of Fuel Rods	Either broken fuel rods or fuel debris or otherwise punctured fuel rods with nominal 3 mm or larger opening
Dryness	≤ 0.4 kPa (3 Torr)
Backfill Reference Pressure	20 kPa (2.9 psig) gauge pressure
Backfill Gas	99% Nom. purity Helium
Leaktightness	≤ $1x10^{-7}$ ref-cm^3/s air ($1x10^{-8}$ Pa-m^3/s air)

Notes:

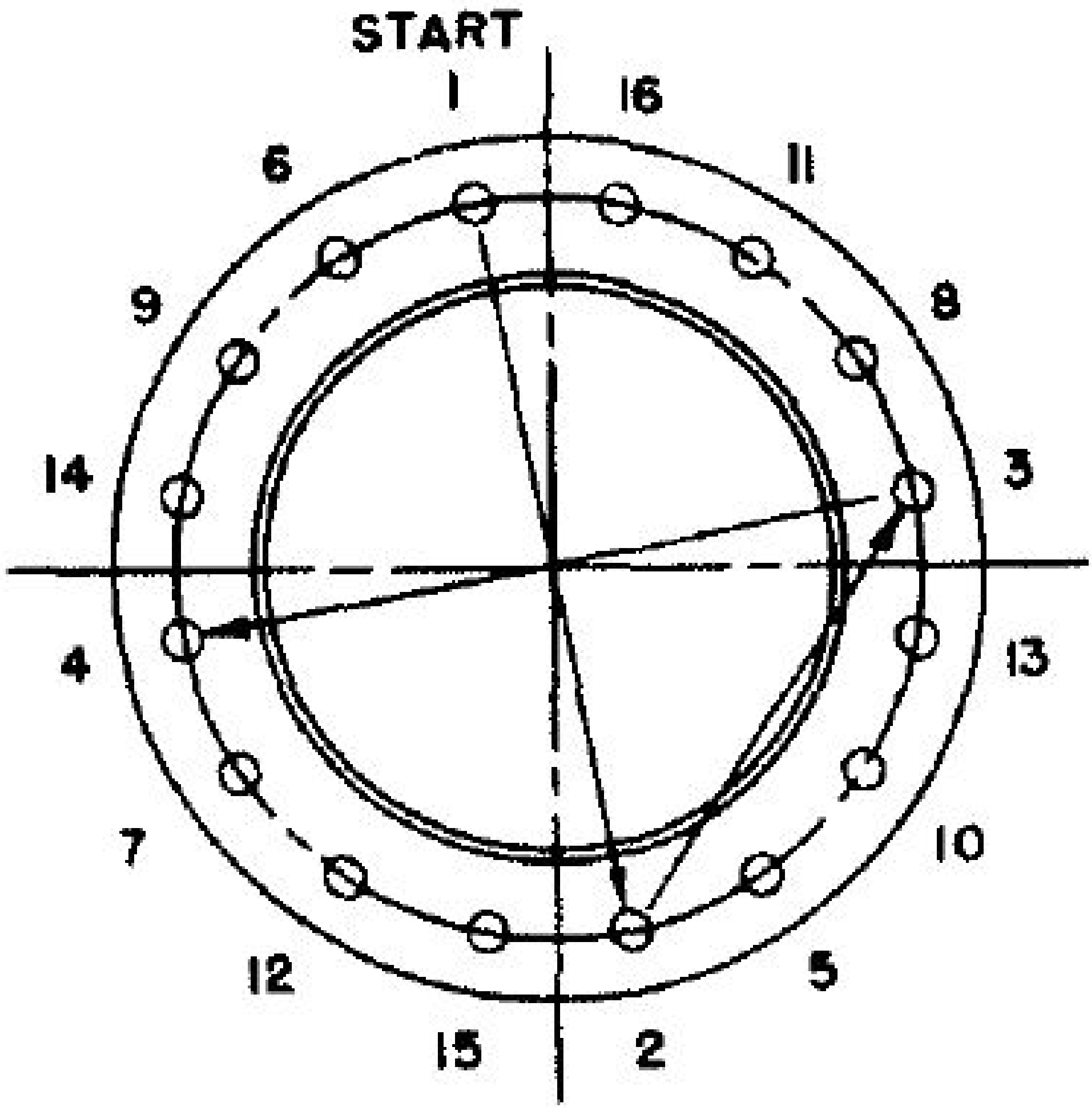
1. The reference pressure is based on a reference quiver space bulk temperature of ≥ 21.1°C (70°F).
2. For ambient temperatures above 21.1°C (70°F), the gas temperature in the quiver cavity will be higher than 21.1°C (70°F); therefore, direct measurement of the gas temperature is not required. Use of pressure gauges to confirm that the quiver cavity pressure is sufficient to establish the proper backfill conditions. For ambient temperatures below 21.1°C (70°F), the pressure range shown above may be adjusted based on the ratio between ambient temperature and 21.1°C (70°F) using the ideal gas law. Use of pressure gauges to confirm that the quiver cavity pressure is between the adjusted limits is sufficient to establish the proper backfill conditions

Table 7.1.9

Heat Load Patterns for Q ≤ 43.5 kW

Basket	Number of Fuel Assemblies	Decay Heat Limits	
F-12P (Note 1)	up to 12	Cell Locations 4, 5, 8, and 9	≤ 3.27 kW
		All Other Cell Locations	≤ 3.80 kW
		Total Cask Decay Heat	≤ 43.5 kW
	up to 10 (Note 3)	Cell Locations 4 and 9, or 5 and 8	≤ 3.70 kW
		Cell Locations 1, 2, 3, 6, 7, 10, 11, 12	≤ 4.35 kW
		Total Cask Decay Heat	≤ 42.2 kW
F-32B (Note 2)	up to 32	All Cell Locations	≤ 1.35 kW
		Total Cask Decay Heat	≤ 43.5 kW
	up to 28 (Note 4)	Cell Locations13, 14, 19, and 20	Empty
		All Other Cell Locations	≤ 1.54 kW
		Total Cask Decay Heat	≤ 43.12 kW
	up to 24	Cells Locations 13, 14, 19, and 20 Plus Cell Locations: 12, 15, 18, 21 OR 7, 8, 25, 26	Empty
		All Other Cell Locations	≤ 1.80 kW
		Total Cask Decay Heat	≤ 43.2 kW

Note 1: PWR cell locations are identified in Figure 7.D.1.
Note 2: BWR cell locations are identified in Figure 7.D.2.
Note 3: When quivers are loaded, decay heat limits in Figure 7.D.4 apply.
Note 4: When quivers are loaded, decay heat limits in Figures 7.D.7 and 7.D.8 apply.



Note: It is important that all bolted joints be tightened uniformly and in a diametrically staggered pattern as illustrated above. Due to the large diameter of the closure lids and other factors, the standard star pattern with added flexibility is permitted with Holtec approval. Tools designed to torque more than one bolt at a time (e.g. bolts 1 and 2 simultaneously) may be implemented and are recommended as good ALARA practice. Alternate patterns shall be approved by Holtec

FIGURE 7.1.1

RECOMMENDED BOLT TIGHTENING PROCEDURE

7.2. PACKAGE UNLOADING

Note: This section is an integral part of the Certificate of Compliance (CoC) of the package.

When the HI-STAR 80 Package needs to be unloaded, the essential elements required to prepare the package for fuel unloading, to cool the stored fuel assemblies in the cask, to flood the internal cavity, to remove the lids and bolts, to lower the cask into the spent fuel pool, to unload the spent fuel assemblies and quivers, and to recover and prepare the cask for additional load cycles are described below.

7.2.1 Receipt of Package from Carrier

1. The HI-STAR 80 Package is received from the carrier and inspected to verify that there are no outward visual indications of impaired physical conditions except for superficial marks and dents. Any issues are identified to site management.
2. The personnel barrier, if used, is removed and the security seal installed on the top impact limiter is inspected to verify there was no tampering and that it matches the corresponding shipping documents.
3. Radiological surveys are performed in accordance with 49CFR173.443 [7.1.2] and 10CFR20.1906 [7.1.3]. If necessary, the HI-STAR 80 Packaging is decontaminated to meet survey requirements and/or notifications are made to affected parties. For packages containing HBF, the radiation survey shall include the dose rate measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The location of measurements shall correspond to the same locations recorded for Subsection 7.1.3. The measurements shall be recorded in the shipping documents.
4. For packages containing HBF, surface temperature measurements shall include the surface temperature measurements required by the post-shipment fuel integrity acceptance test specified in Chapter 8, Subsection 8.1.8 of this SAR. The location of measurements shall correspond to the same locations recorded for Subsection 7.1.3. Ambient conditions (air temperature, date, time of day and description of daylight (sunny, cloudy, overcast, in-shade or night time)) and the measurements shall be recorded in the shipping documents. Package surfaces shall be dry at the time of temperature measurements.

ALARA Warning:
Dose rates around the unshielded bottom end of the HI-STAR 80 cask may be higher than other locations around the cask. After the impact limiters are removed, the cask should be upended promptly. Personnel should remain clear of the bottom of the unshielded cask and exercise other appropriate ALARA controls.

5. The impact limiters and tie-down system are removed.
6. The cask is visually inspected to verify there are no outward visual indications of impaired physical conditions and a radiation survey and a removable contamination survey are performed to establish appropriate radiological controls. Any issues are identified to site management.
7. The cask is upended and returned to the fuel building or other unloading area.

8. The cask is placed in the designated preparation area.

7.2.2 Removal of Contents

1. A protective skirt may be installed around the cask to provide cooling via water circulation and maintain a contamination free surface. Caps or plugs are installed on the neutron shielding enclosure pressure relief devices any time before the cask is placed in the spent fuel pool.

2. The outer lid access port cover is removed and a gas sample is drawn from the inter-lid space to determine radiological conditions.

3. The inter-lid space gas is handled in accordance with Radiation Protection directions and the outer closure lid is removed. Note that the outer lid may stay in place until the cask is backfilled with water for ALARA purposes.

4. The orifice port covers are removed to access the vent and drain ports.

ALARA Warning:
Gas sampling is performed to assess the condition of the fuel cladding. If a leak is discovered in the fuel cladding, the user's Radiation Control organization may require special actions to vent the cask cavity.
Caution: Fuel Exposure to Air Restriction
Except as allowed by Table 7.1.6, an inert gas must be used any time the fuel is not covered with water to prevent oxidation of the fuel cladding. The fuel cladding is not to be exposed to air at any time during unloading operations.

5. A temporary attachment is connected to the vent port to open the vent port tube cap/plug and a gas sample from inside the cask cavity is collected. A gas sample analysis is performed to assess the condition of the fuel assembly cladding for ALARA purposes. As necessary during preparation for lid removal, the gas inside the cask cavity is handled/vented to an approved location. A gas sampling may also be performed in order to assess whether the cladding of any fuel assembly that was initially loaded as undamaged AND unbreached has remained unbreached. Depending on cask cavity pressure, the cavity may require additional backfill or venting to equalize its pressure to atmospheric while maintaining an inert environment (see Table 7.1.6 for air exposure conditions). If the cask cavity pressure is sub atmospheric when a port is opened and no additional backfill is performed to equalize the pressure to atmospheric, then ambient air ingress prior to and during cask water refill shall be prevented by inline fluid devices, tools or other means to comply with the Caution statement on Fuel Exposure to Air Restrictions.

6. If the cask is to be unloaded under water, the cask is filled with water at a controlled rate to minimize thermal shock to the fuel assemblies and to avoid over-pressurizing the cask from the formation of steam. Spray cooling may be initiated at this time to cool and condense a portion of the generated steam. The effluent is directed to the spent fuel pool or other approved discharge point.

7. If the cask containing fuel is not immediately moved to the spent fuel pool, water is circulated through the cask to cool the contents and allow for establishment of a Time-To-Boil time limit. The user performs a site-specific Time-to-Boil evaluation to determine a time limitation to ensure that water boiling will not occur in the cask prior to placement of the cask in the spent fuel pool. The Time-to-Boil clock begins when the cask is filled with water. If it appears that the Time-to-Boil limit will be exceeded prior to placement of the cask in the spent fuel pool, the user shall take appropriate action to circulate water through the cask cavity to reset the Time-to-Boil clock.
8. Inner closure lid bolts may be removed at any time from after the internal cavity pressure is equalized until the time the inner closure lid is to be removed. In addition, the inner closure lid bolts and retainer ring are removed either before the cask is placed in the spent fuel pool or other fuel unloading area or after placement of the cask in one of these areas.

ALARA Note:
Wetting the components that enter the spent fuel pool may reduce the amount of decontamination work to be performed later.

9. The lift attachment is engaged to the lifting trunnions and the cask is placed in the spent fuel pool or other appropriate unloading area. The inner closure lid is removed.
10. All fuel assemblies and quivers are placed in spent fuel storage racks and the cask fuel cells are vacuumed when necessary to remove any assembly debris and crud.
11. Non-fuel Core Component Cassettes are unloaded and placed in designated storage racks. Non-fuel items, not utilizing Core Component Cassettes, are unloaded per plant procedures. The NFWB is vacuumed when necessary to remove any remaining debris and crud.
12. The fuel cells are inspected for any remaining items to be removed as appropriate.

ALARA Warning:
Activated debris may have settled on flat surfaces of the cask during fuel unloading. Surfaces suspected of carrying activated debris should be kept under water until a preliminary dose rate scan clears the cask for removal. To reduce contamination of the cask, the surfaces of the cask and lift yoke should be kept wet until decontamination can begin.

13. The cask is returned to the designated preparation area and any water is pumped back into the spent fuel pool, liquid radwaste system or other approved location as necessary. If applicable, the protective skirt is removed. Caps or plugs are removed from the neutron shielding enclosure pressure relief devices.
14. The cask is decontaminated as directed by site Radiation Protection personnel. Outer surfaces of the cask are decontaminated to remove surface contamination to the level necessary to allow for proper cask transport, loading, or storage as applicable.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

Note: This section is an integral part of the Certificate of Compliance (CoC) of the package.

7.3.1 Overview of Empty Package Transport

The essential elements and minimum requirements for preparing an empty package (previously used) for transport are similar to those required for transporting the loaded package with some differences. A survey for removable contamination is performed to verify that the removable contamination on the internal and external surfaces of the cask is ALARA and that the limits of 49CFR173.428 [7.1.2] and 10CFR71.87(i) [7.1.4] are met. At the user's discretion, impact limiters and/or a personnel barrier are installed. The procedures provided herein describe the installation of the impact limiters and the personnel barrier. These steps may be omitted, as appropriate.

7.3.2 Preparation for Empty Package Shipment

1. The containment closure flange inner closure lid sealing surface protector is removed from the cask, if necessary.
2. The cask is surveyed for contamination and verified to be empty and contain less than 15 grams of U-235 in accordance with 49CFR173.421(a)(5)
3. The inner closure lid and retaining ring are installed and the bolts are torqued. See Table 7.1.1 for torque requirements.
4. The orifice port covers are installed if necessary.
5. The containment flange outer closure lid sealing surface protector is removed, if necessary, the outer closure lid is installed, and the bolts are torqued. See Table 7.1.1 for torque requirements. If desired, a security seal may be attached to the outer closure lid bolts.
6. The outer closure lid access port plug and access port cover are installed if necessary.
7. The cask is downended and positioned on the transport equipment.
8. A final inspection of the cask is performed and includes the following:
   - A final survey for removable contamination on the accessible external surfaces of the cask in accordance with 49CFR173.443(a). If necessary, the cask is decontaminated to meet the survey requirements.
   - A radiation survey of the cask to confirm that the radiation levels on any external surface of the cask do not exceed the levels required by 49CFR173.421(a)(2). Any issues are identified to site management and the cask is decontaminated as directed by site radiation protection.

- A visual inspection of the cask to verify that there are no outward visual indications of impaired physical condition except for superficial marks and dents and that the empty package is securely closed in accordance with 49CFR173.428(b).
- Verification that the cask neutron shield pressure relief devices are installed, are intact and are not covered by tape or other covering.

9. If necessary, the impact limiters are installed and the impact limiter bolts/nuts are torqued. (See Table 7.1.1 for torque requirements.)
10. If desired, a security seal is installed on the top impact limiter.
11. Final radiation surveys of the empty package surfaces are performed per 10CFR71.47, and 49CFR173.428(a).
12. If desired, the personnel barrier and personnel barrier locks are installed and the personnel barrier keys are transferred to the carrier.
13. A final check to ensure that the empty package is ready for release is performed and includes the following checks:
    - Verification that the receiver has been notified of the impending shipment.
    - Verification that any labels previously applied in conformance with Subpart E of 49CFR172 [7.1.1] have been removed, obliterated, or covered and the "Empty" label prescribed in 49CFR172.450 [7.1.1] is affixed to the packaging in accordance with 49CFR173.428(e).
    - Verification that the empty package for shipment is prepared in accordance with 49CFR173.422.
    - Verification that all required information is recorded on the shipping documentation.
14. The empty package is then released for transport.

7.4 OTHER OPERATIONS

There are no other operations for the HI-STAR 80 Package with regard to provisions for any special operational controls (e.g., route, weather, shipping time restrictions, etc.). Essential operations and conditions are detailed in this chapter.

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 20 "Standards for Protection against Radiation".

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

APPENDIX 7.A

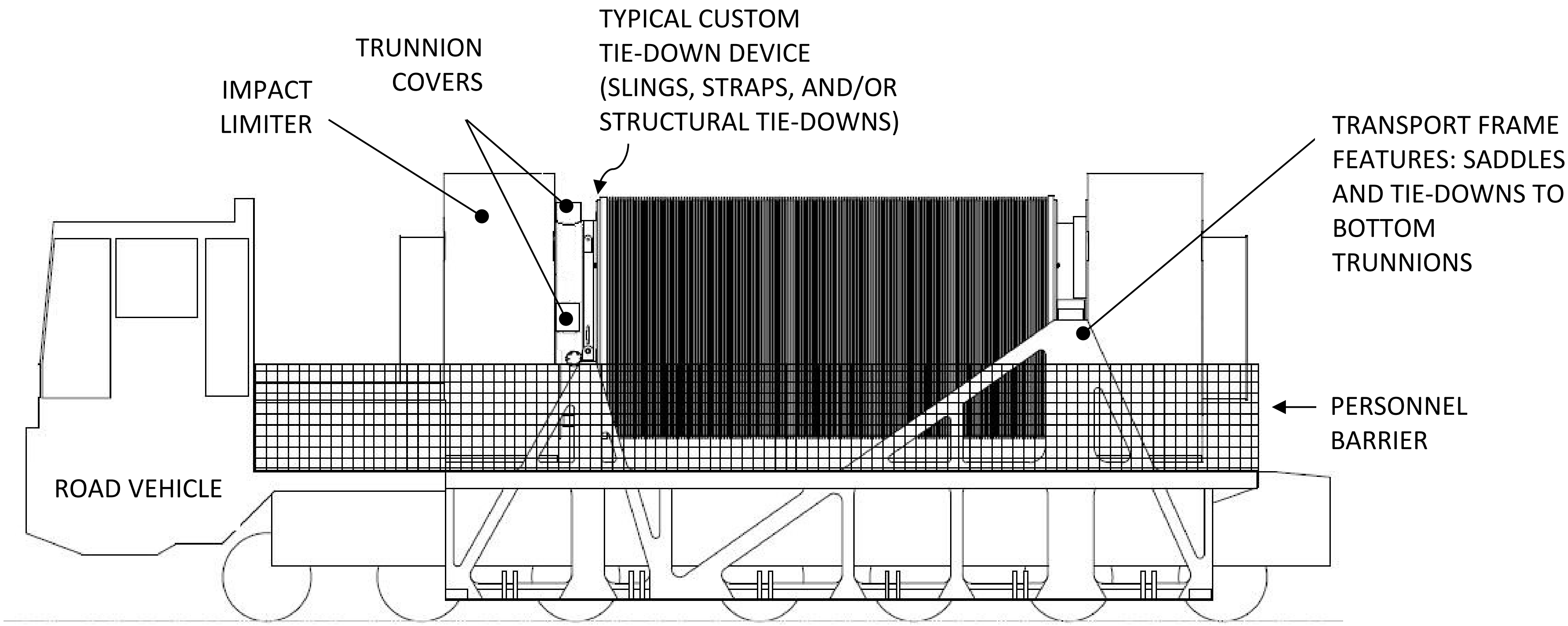
GENERAL WEIGHTS AND ILLUSTRATIONS OF TYPICAL LOADING OPERATIONS

Table 7.A.1: General Transport Weights of HI-STAR 80

Item	**Value** (kg)
Maximum Gross Transport Weight of HI-STAR 80 Package (with Impact Limiters, F-32B Fuel Basket w/ Fuel Assemblies, Spacers, no Personnel Barrier)	106,475
Nominal Empty Packaging Weight (with Impact Limiters, F-32B Fuel Basket, Spacers and no Personnel Barrier) – Note 2	94,795
Empty Cask (with F-32B Fuel Basket) – Note 2	81,250
Empty Cask (no basket or shims) – Note 2	77,472

Notes:

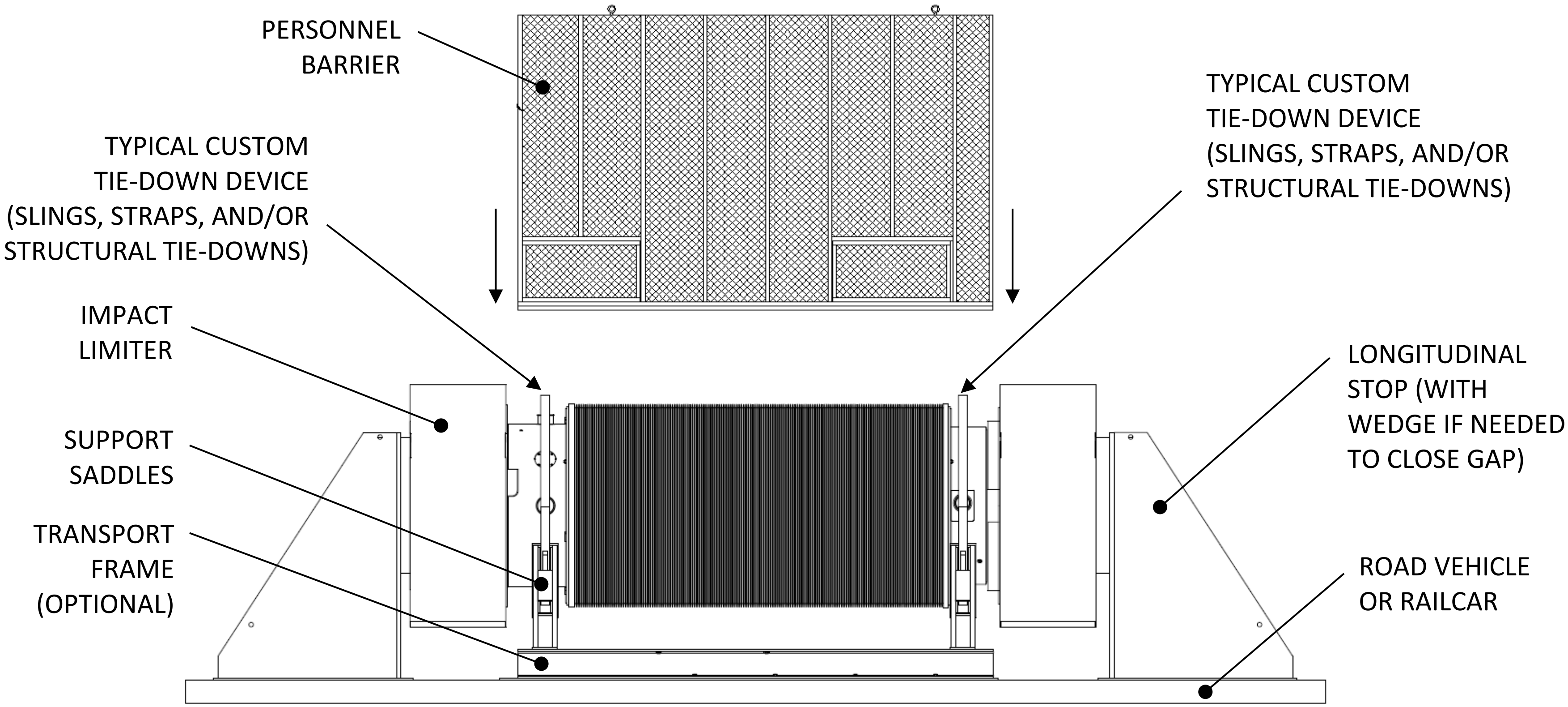
1. The Maximum Gross Transport Weight is a condition of the CoC.
2. Weight is representative based upon CAD models and provided for information only. Weights include cask lids and bolting. Lifting, handling and tie down evaluations shall be performed using bounding weights.



Notes:

1. This general arrangement may be utilized for transport outside the U.S. only. Trunnion covers (shown here) or other blocking ancillary device must be used to render all accessible top trunnions inoperable.
2. The width of the vehicle must be equal to or greater than 2.7 meters.
3. The essential elements of this general arrangement in notes 1 and 2 are conditions of the CoC.

FIGURE 7.A.1: GENERAL ARRANGEMENT OF HI-STAR 80 ON ROAD VEHICLE (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)



Notes:

1. This general arrangement may be utilized for transport within and outside the U.S. Custom tie-down devices (shown here) or trunnion covers (not shown) must render all accessible top and bottom trunnions inoperable.
2. The width of the vehicle or railcar must be equal to or greater than 2.7 meters.
3. The essential elements of this general arrangement in notes 1 and 2 are conditions of the CoC.

FIGURE 7.A.2: GENERAL ARRANGEMENT OF HI-STAR 80 FOR ROAD OR RAIL (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

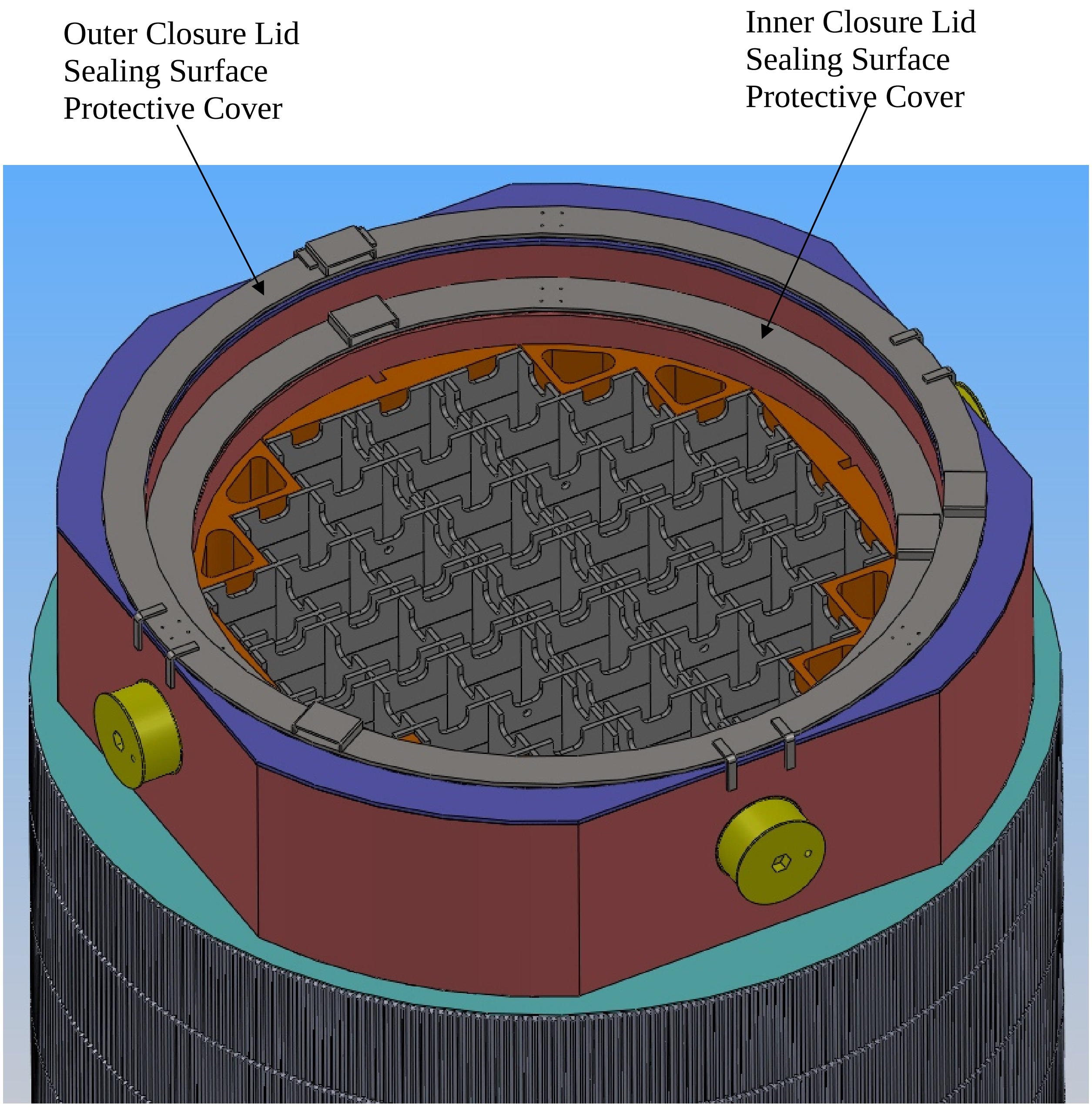


FIGURE 7.A.3: HI-STAR SHOWN WITH INNER AND OUTER CLOSURE LIDS REMOVED AND SEALING SURFACE PROTECTIVE COVERS INSTALLED ON THE CONTAINMENT CLOSURE FLANGE (SEALING SURFACE PROTECTORS SHOWN FOR EXAMPLE ONLY AND MAY VARY IN ACTUAL CONFIGURATION DETAILS)

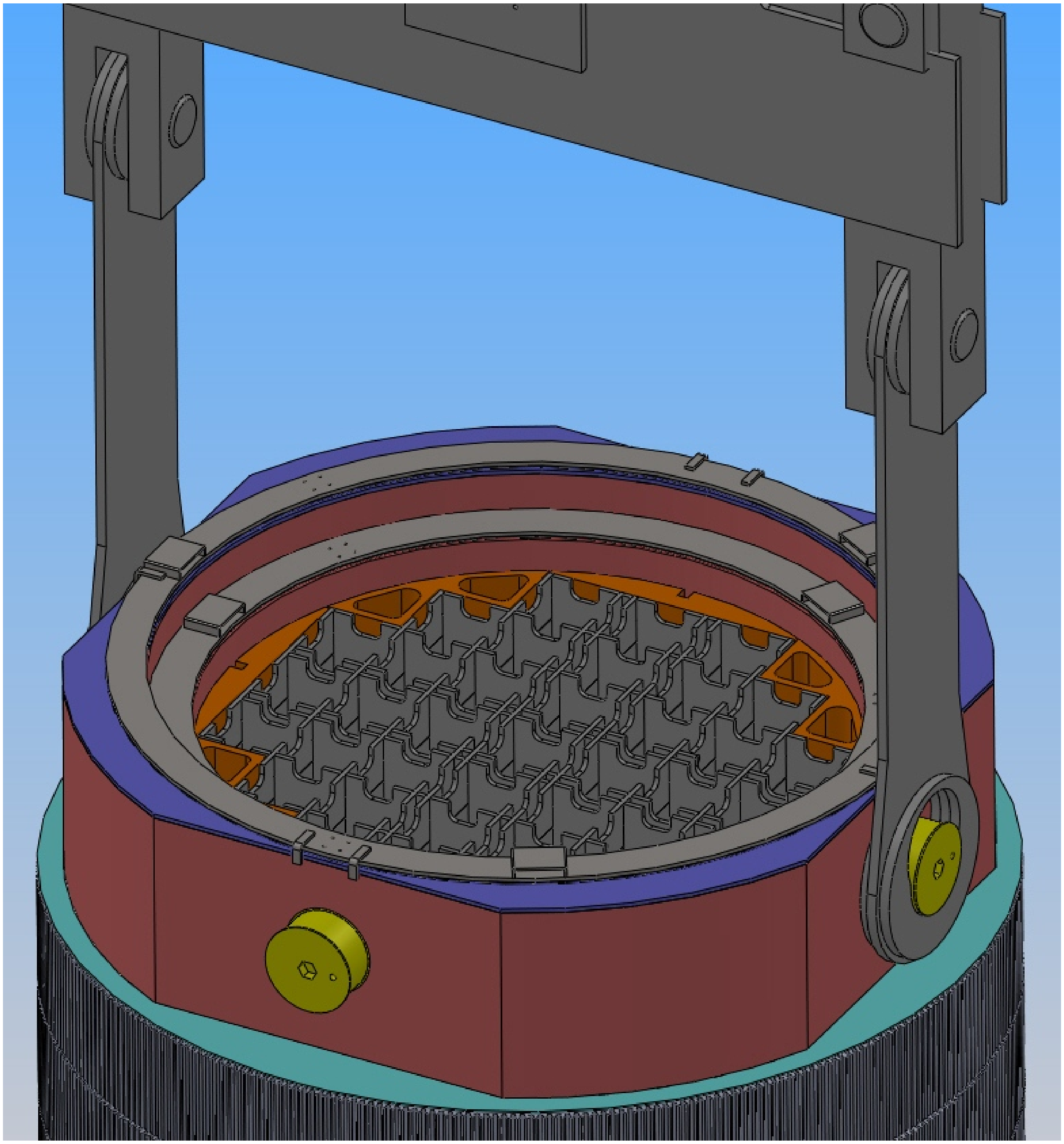


FIGURE 7.A.4: HI-STAR SHOWN BEING LOADED INTO THE SPENT FUEL POOL (LIFTING ATTACHMENTS ARE SHOWN FOR ILLUSTRATIVE PURPOSES ONLY, FINAL CONFIGURATION OF LIFT ATTACHMENTS WILL BE DETERMINED BASED ON PLANT SYSTEMS)

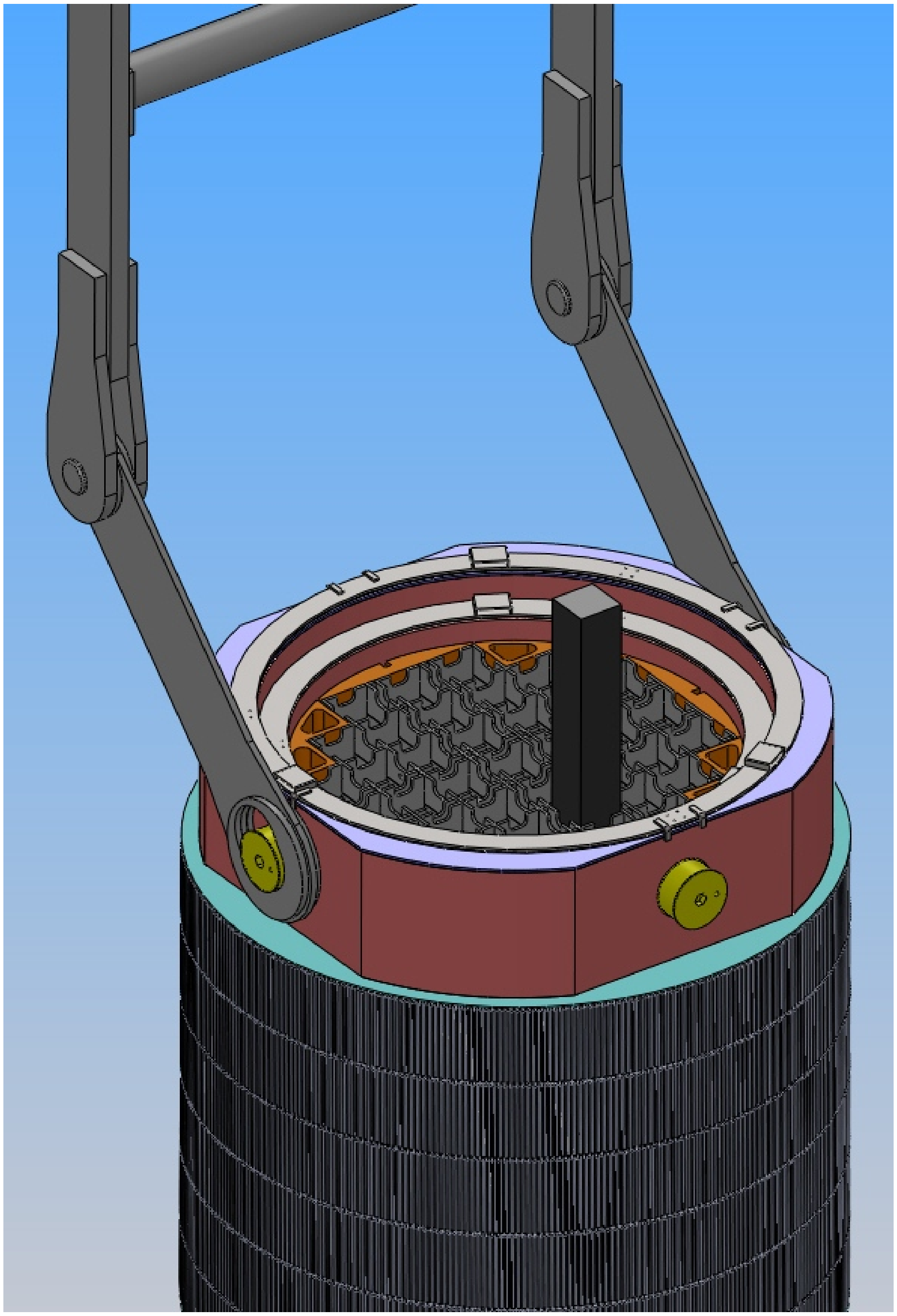


FIGURE 7.A.5: SPENT FUEL ASSEMBLY LOADING IN THE HI-STAR (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

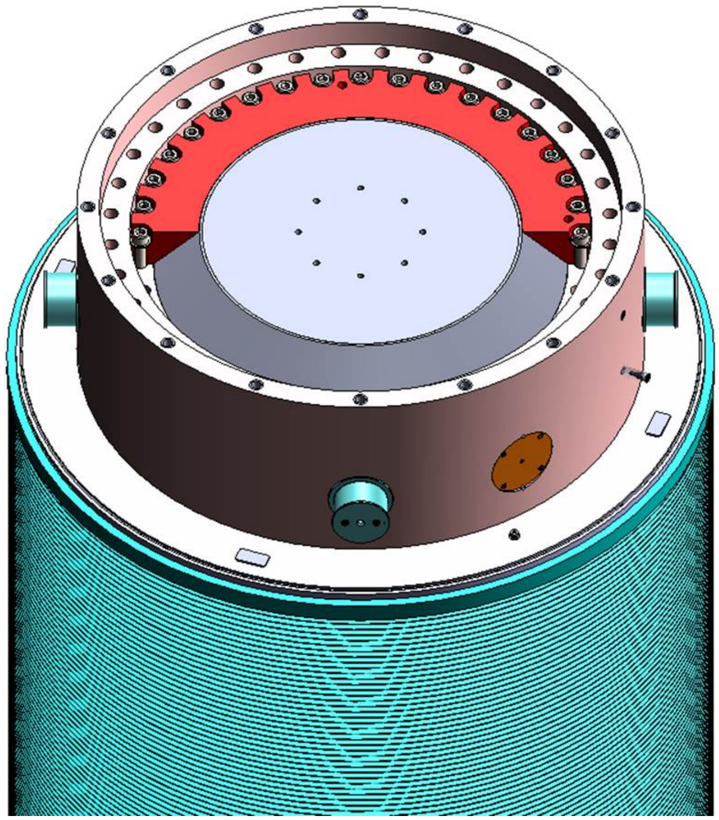


FIGURE 7.A.6: HI-STAR 80 INNER CLOSURE LID, BOLTS SHOWN WITH PARTIAL RETAINER RING (EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

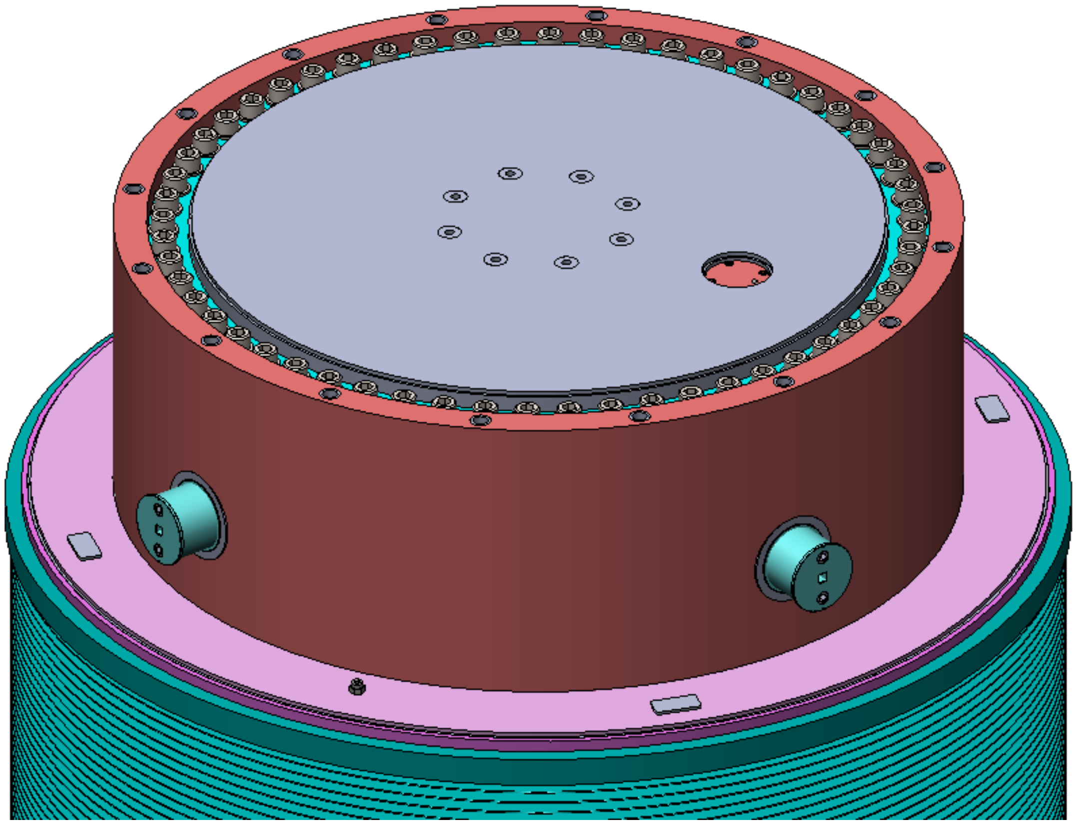


FIGURE 7.A.7: HI-STAR OUTER CLOSURE LID
(EXAMPLE ONLY, SHOWN FOR ILLUSTRATION ONLY)

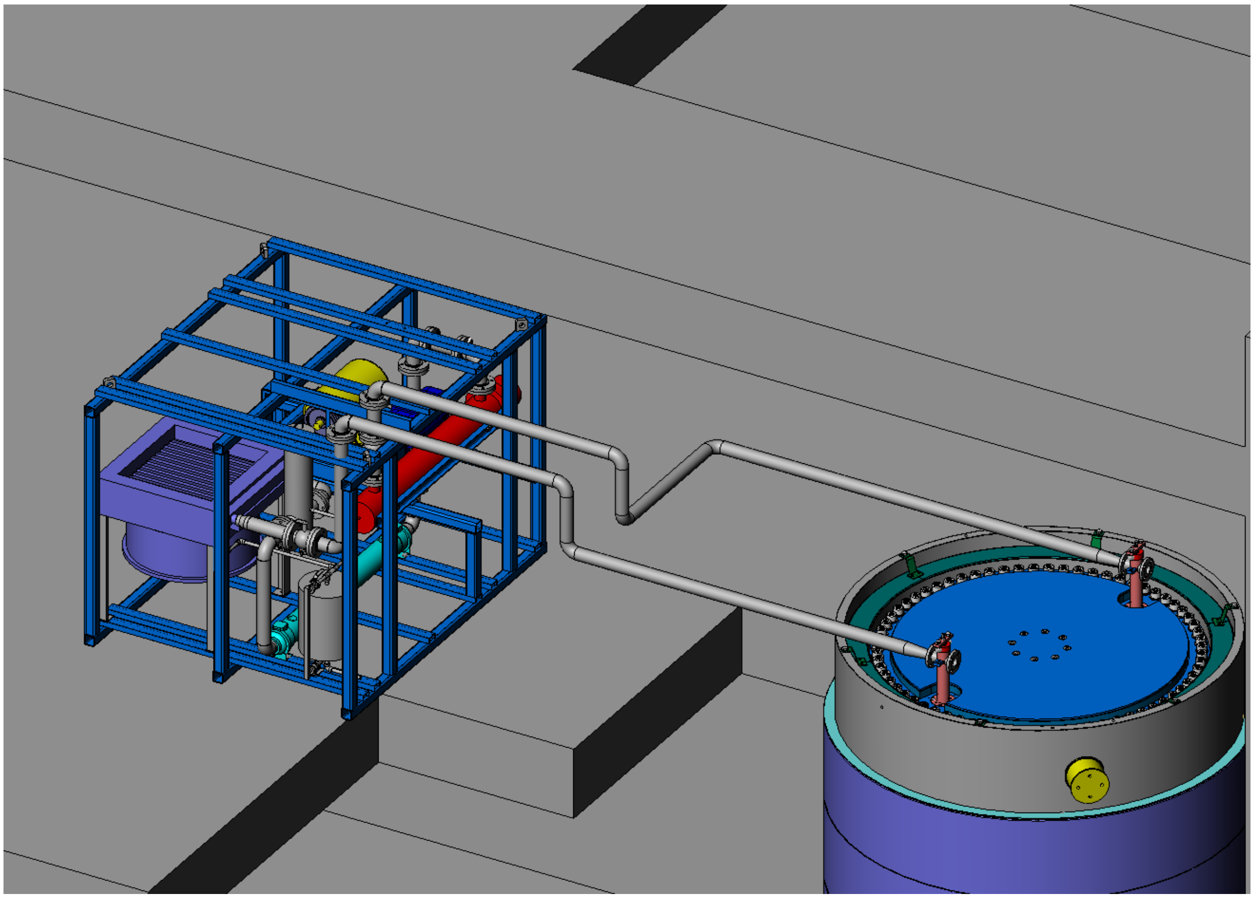


FIGURE 7.A.8: HI-STAR SHOWN DURING DEWATERING, DRYING AND BACKFILL OPERATIONS (EXAMPLE CONFIGURATION FOR ILLUSTRATION ONLY, ACTUAL CONFIGURATION IS DEPENDENT UPON PLANT SYSTEMS)

APPENDIX 7.B

Intentionally Not Used

APPENDIX 7.C

Intentionally Not Used

APPENDIX 7.D

CONTENT CONDITIONS OF THE HI-STAR 80 PACKAGE

Note: This Appendix, including tables and figures, is an integral part of the Certificate of Compliance (CoC) of the package.

Table 7.D.1
Fuel Assembly Limits

I. BASKET MODEL: F-12P

A. Allowable Contents

1. Uranium oxide, PWR undamaged fuel assemblies and Quivers meeting the criteria listed in Table 7.D.2 and meeting the following specifications (Note 1):

Condition/Description:	**Value:**
a. Cladding type:	ZR (Note 2)
b. Maximum initial enrichment:	5.0 wt% ^{235}U
c. Post-irradiation cooling time, average burnup, and minimum initial enrichment per assembly (Notes 7 and 8)	Assembly post-irradiation cooling time, average burnup, and minimum initial enrichment as specified in Table 7.D.4
d. Decay heat per assembly (Note 5 and 6):	
Up to 12 assemblies: • cell locations 4, 5, 8, 9 in Figure 7.D.1 • cell locations 1, 2, 3, 6, 7, 10, 11, 12 in Figure 7.D.1 • Total Cask Decay Heat	• ≤ 3.76 kW • ≤ 4.37kW • ≤ 50 kW
Up to 10 assemblies: • cell locations 4 and 9, OR 5 and 8 in Figure 7.D.1) • cell locations 1, 2, 3, 6, 7, 10, 11, 12 in Figure 7.D.1) • Total Cask Decay heat	• ≤ 4.25 kW • ≤ 5.00 kW • ≤ 48.5 kW
Up to 10 assemblies:	Per Configuration 2
e. Fuel assembly length:	≤ 4500 mm (nominal design for fuel including non-fuel hardware) ≤ 4200 mm (nominal design for quiver)

Table 7.D.1
Fuel Assembly Limits

f. Fuel assembly weight:	≤ 750 kg (nominal design) for all basket cell locations with up to 800 kg (nominal design) for any one cell basket location All fuel assembly weights include non-fuel hardware ≤ 449 kg (nominal design) for quiver
g. Maximum Pellet Density (g/cm^3)	10.96
h. Maximum Fuel Mass and Fuel Mass per unit length of active region	0.4976 MTU 0.1360 MTU/m
i. Maximum Co-59 Impurity (ppm) of the hardware regions of the assembly	300

B. Quantity per Basket: Two general loading configurations are allowed as follow:

Configuration 1: Up to 12 PWR fuel assemblies.

Configuration 2: Up to 10 PWR fuel assemblies of which up to 4 may be quivers, each containing up to 34 fuel rods. Decay heat loads are specified per cell location in Figures 7.D.3 and 7.D.4. (Note 9).

Note 1: Fuel assemblies containing CRAs, RCCAs, and CEAs may be loaded in only the four inner fuel storage locations (Cells 4, 5, 8, and 9 in Figure 7.D.1). The minimum cooling time for CRAs, RCCAs, and CEAs is 1 year. The CRAs, RCCAs, and CEAs must be operated in a fully withdrawn position with respect to the active fuel region during full power operations. The absorber material must be AgInCd (with mass fractions of approximately 0.8, 0.15, and 0.05 for Ag, In, and Cd, respectively).

Note 2: ZR Designates cladding material made of Zirconium or Zirconium alloys.

Note 3: Damaged fuel assemblies and fuel debris are not authorized contents. The only exception is the contents of quivers loaded into the appropriate basket cells (See Note 9).

Note 4: Fuel assemblies may contain irradiated stainless steel replacement rods, subject to the following restrictions. Fuel assemblies with up to 4 irradiated stainless steel replacement rods may only be loaded in fuel storage locations 4, 5, 8, or 9 (see Figure 7.D.1). Assemblies with an arbitrary number of irradiated Zircaloy rods or non irradiated stainless steel rods replacing fuel rods may be loaded in any storage location. One arbitrary fuel rod may be missing and not replaced by a dummy rod. Fuel assemblies with up to 25 irradiated stainless steel rods are permitted only for the Assembly Class 17x17S1, and with the following restrictions: 1) Only two assemblies within the F-12P

Table 7.D.1
Fuel Assembly Limits

may contain irradiated stainless steel rods, and 2) These two assemblies must be loaded into Cells 4, 5, 8, or 9 in Figure 7.D.1

Note 5: When complying with the maximum decay heat units in any basket cell location, decay heat from both the fuel assembly and any non-fuel hardware (i.e., CRAs, RCCAs, and CEAs) must be accounted, as applicable for the particular basket cell, to ensure the decay heat emitted by all contents in a basket cell does not exceed the limit, with a heat generation of 41.8 W for every CRA.

Note 6: The Maximum Decay Heat Load per Assembly is to be calculated considering the adjustments per Table 7.D.10.

Note 7: For assemblies with axial blankets, the enrichment(s) of those blankets are excluded from the comparison with the minimum enrichment.

Note 8: For assemblies with axial blankets, the assembly average burnup must be calculated without consideration for those blankets.

Note 9: Quivers are restricted to the cell locations specified in Figures 7.D.3 and 7.D.4. Quivers must be prepared for loading as specified in Section 7.1 of this SAR and meet the requirements specified in Table 7.1.8.

Table 7.D.1
Fuel Assembly Limits

II. BASKET MODEL: F-32B

A. Allowable Contents:
Uranium oxide and MOX, BWR undamaged fuel assemblies and Quivers meeting the criteria listed in Table 7.D.3, meeting the following specifications:

Condition/Description:	**Value:**
a. Cladding type:	ZR (Note 1)
b. Maximum planar-average initial enrichment: i. UO2 assemblies	 5.00 wt% ^{235}U
c. Initial maximum rod enrichment: i. UO2 assemblies ii. MOX rod in 10x10 MOX assemblies	 6.0 wt% ^{235}U 0.20 wt% ^{235}U
d. Post-irradiation cooling time, average burnup, and minimum initial enrichment per assembly: (Note 6)	Assembly post-irradiation cooling time, average burnup, and minimum initial enrichment as specified in Table 7.D.5 for UO_2 Fuel and Table 7.D.6 for MOX Fuel.
e. Decay heat per assembly (Note 4 and 5): i. up to 32 assemblies ii. up to 28 assemblies, See Table 7.D.5 for empty cell requirements. iii. up to 24 assemblies, See Table 7.D.5 for empty cell requirements. iv. Total cask decay heat	 ≤ 1.68 kW ≤ 1.92 kW, or per Configuration 2 ≤ 2.25 kW ≤ 54 kW
f. Fuel assembly length:	≤ 4500 mm (nominal design for fuel) ≤ 4411 mm (nominal design for quiver)
g. Fuel assembly weight:	≤ 360 kg (nominal design) all basket cells locations with up to 400 kg (nominal design) for cell numbers 6, 9, 24, and 27 only ≤ 232 kg (nominal design) for quiver
h. Heavy Metal mass (MOX assembly)	≤ 212 kg for 10x10 MOX fuel

Table 7.D.1
Fuel Assembly Limits

Condition/Description:	Value:
i. Pu-total mass per fuel assembly (MOX assembly)	≤ 14 kg for 10x10 MOX fuel
j. Pu Vector (wt%):	For 10x10 MOX fuel: Pu-238 ≥ 1.108 Pu-239 ≤ 62.970 Pu-240 ≥ 25.584 Pu-241 ≤ 6.222 Pu-242 ≥ 4.118
k. Max Pellet Density (g/cm^3)	10.96
l. Maximum Fuel Mass and Fuel Mass per unit length of active region for UO_2 fuel	0.2262 MTU 0.0574 MTU/m
m. Maximum Co-59 Impurity (ppm) of the hardware regions of the assembly	500

B. Quantity per Basket:

Configuration 1: Up to 32 BWR fuel assemblies, with up to 4 MOX assemblies loaded in fuel storage locations 6, 9, 24, and 27 (see Figure 7.D.2).

Configuration 2: Up to 28 BWR fuel assemblies of which up to 12 may be quivers, each containing up to 14 fuel rods. Decay heat loads are specified per cell location in Figures 7.D.5 through 7.D.8. (Note 7)

Note 1: ZR Designates cladding material made of Zirconium or Zirconium alloys.

Note 2: Damaged fuel assemblies and fuel debris are not authorized contents. The only exception is the contents of quivers loaded into the appropriate basket cells (See Note 7).

Note 3: Fuel assemblies may contain up to 4 irradiated stainless steel replacement rods. Fuel assemblies with irradiated stainless steel replacement rods may only be loaded in fuel storage locations 7, 8, 12, 13, 14, 15, 18, 19, 20, 21, 25, and 26 (see Figure 7.D.2). Assemblies with an arbitrary number of irradiated Zircaloy rods or not irradiated stainless steel rods replacing fuel rods can be loaded in any storage location. One arbitrary fuel rod may be missing and not replaced by a dummy rod.

Note 4: When complying with the maximum decay heat units in any basket cell location, decay heat from both the fuel assembly and any non-fuel hardware must be accounted, as applicable for the particular basket cell, to ensure the decay heat

Table 7.D.1
Fuel Assembly Limits

emitted by all contents in a basket cell does not exceed the limit.

Note 5: The Maximum Decay Heat Load per Assembly is to be calculated considering the adjustments per Table 7.D.10.

Note 6: For assemblies with axial blankets, the enrichment(s) of those blankets are excluded from the comparison with the minimum enrichment.

Note 7: Quivers are restricted to the cell locations specified in Figures 7.D.5 through 7.D.8. Quivers must be prepared for loading as specified in Section 7.1 of this SAR and meet the requirements specified in Table 7.1.8.

Table 7.D.2

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (1 of 2)

Fuel Assembly Array/Class	**17x17S1**	**17x17S2**	**17x17S3**	**17x17S4**	**15x15S1**	**15x15S2**	**15x15S3**
No. of Fuel Rod Locations	264	264	264	264	204	208	208
Fuel Clad O.D. (mm)	≥ 9.3555	≥ 9.405	≥ 9.0486	≥ 9.4743	≥ 10.5732	≥ 10.7613	≥ 10.4148
Fuel Clad I.D. (mm)	≤ 8.5749	≤ 8.4335	≤ 8.08	≤ 8.5446	≤ 9.7162	≤ 9.797	≤ 9.494
Fuel Pellet Dia. (mm)	≤ 8.383	≤ 8.3224	≤ 7.9184	≤ 8.3426	≤ 9.4536	≤ 9.6051	≤ 9.292
Fuel Rod Pitch (mm)	≤ 12.8876	≤ 12.726	≤ 12.726	≤ 12.8775	≤ 14.544	≤ 14.5743	≤ 14.5743
Active Fuel Length (mm)	≤ 3706.7	≤ 3694.58	≤ 3848.1	≤ 3848.1	≤ 3706.7	≤ 3848.1	≤ 3848.1
No. of Guide and/or Instrument Tubes	25 (Note 2)	25	25	25	21	17	17
Guide/Instrument Tube Thickness (mm)	≥ 0.4257	≥ 0.4653	≥ 0.396	≥ 0.495	≥ 0.4257	≥ 0.3564	≥ 0.3564

Table 7.D.2

PWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (2 of 2)

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. May include solid steel rods instead of guide tubes.

Table 7.D.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (1 of 5)

Fuel Assembly Array/Class	**8x8S1 (Note 3)**	**8x8S2 (Note 4)**	**8x8S3**	**8x8S4 (Note 5)**
No. of Fuel Rod Locations	63	64	64	60
Fuel Clad O.D. (mm)	≥ 11.6325	≥ 12.1275	≥ 11.6325	≥ 11.6325
Fuel Clad I.D. (mm)	≤ 10.7565	≤ 10.7565	≤ 10.7565	≤ 10.7565
Fuel Pellet Dia. (mm)	≤ 10.5444	≤ 10.5444	≤ 10.5444	≤ 10.5444
Fuel Rod Pitch (mm)	≤ 16.463	≤ 15.958	≤ 16.463	≤ 16.463
Active Fuel Length (mm)	≤ 3749.12	≤ 3749.12	≤ 3749.12	≤ 3749.12
No. of Water Rods (Note 2)	1	N/A	0	4
Water Rod/Box Thickness (mm)	≥ 0.6633	≥ 0.792	≥ 0.792	≥ 0.792
Channel Thickness (mm)	≤ 2.323	≤ 1.111	≤ 2.323	≤ 2.323

Table 7.D.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (2 of 5)

Fuel Assembly Array/Class	**9x9S1**	**9x9S2**
No. of Fuel Rod Locations	76	80
Fuel Clad O.D. (mm)	≥ 10.89	≥ 10.6326
Fuel Clad I.D. (mm)	≤ 9.7667	≤ 9.3425
Fuel Pellet Dia. (mm)	≤ 9.595	≤ 9.1506
Fuel Rod Pitch (mm)	≤ 14.5945	≤ 14.6753
Active Fuel Length (mm)	≤ 3694.58	≤ 3848.1
No. of Water Rods (Note 2)	5	1
Water Rod/Box Thickness (mm)	≥ 0.7425	≥ 0.495
Channel Thickness (mm)	≤ 2.323	≤ 2.5654

Table 7.D.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (3 of 5)

Fuel Assembly Array/Class	**10x10S1 (Note 6)**	**10x10S2 (Note 7)**	**10x10S3 (Note 8)**	**10x10S4 (Note 9)**	**10x10S5 (Note 10)**	**10x10S6 (Note 11)**	**10x10S7 (Note 12)**
No. of Fuel Rod Locations	92	92	91	91	96	96	96
Fuel Clad O.D. (mm)	≥ 10.1574	≥ 9.9	≥ 10.1772	≥ 9.9495	≥ 9.5238	≥ 9.7416	≥ 10.1574
Fuel Clad I.D. (mm)	≤ 9.1506	≤ 9.2516	≤ 9.1304	≤ 8.9284	≤ 9.0294	≤ 8.7163	≤ 9.1506
Fuel Pellet Dia. (mm)	≤ 8.9688	≤ 9.09	≤ 8.9587	≤ 8.7567	≤ 8.8577	≤ 8.5648	≤ 8.9688
Fuel Rod Pitch (mm)	≤ 13.0795	≤ 13.332	≤ 13.0795	≤ 13.0795	≤ 12.8775	≤ 13.13	≤ 13.0795
Active Fuel Length (mm)	≤ 3749.12	≤ 4040	≤ 3749.12	≤ 3749.12	≤ 3747.1	≤ 3757.2	≤ 3716.8
No. of Water Rods (Note 2)	2	8	N/A	N/A	N/A	N/A	1
Water Rod/Box Thickness (mm)	≥ 0.7524	≥ 0.495	≥ 0.792	≥ 0.71775	≥ 0.792	≥ 0.792	≥ 0.7524
Channel Thickness (mm)	≤ 3.0805	≤ 2.525	≤ 2.5654	≤ 2.323	≤ 1.414	≤ 1.414	≤ 2.3836

Table 7.D.3

BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (4 of 5)

Fuel Assembly Array/Class	**11x11S1 (Note 13)**	**11x11S2 (Note 15)**
No. of Fuel Rod Locations	112	109
Fuel Clad O.D. (mm)	≥ 9.306	≥ 9.405
Fuel Clad I.D. (mm)	≤ 8.3426	≤ 8.4436
Fuel Pellet Dia. (mm)	≤ 8.1911	≤ 8.2921
Fuel Rod Pitch (mm)	≤ 12.0695 (Note 14)	≤ 12.0695
Active Fuel Length (mm)	≤ 3787.5	≤ 3787.5
No. of Water Rods (Note 2)	N/A	3
Water Rod/Box Thickness (mm)	≥ 0.8415	≥ 0.792
Channel Thickness (mm)	≤ 2.5654	≤ 3.03

Table 7.D.3
BWR FUEL ASSEMBLY CHARACTERISTICS (Note 1) (5 of 5)

Notes:

1. All dimensions are design nominal values. Maximum and minimum dimensions are specified to bound variations in design nominal values among fuel assemblies within a given array/class.
2. These rods may also be sealed at both ends and contain Zr material in lieu of water.
3. Contains in total 63 fuel rods and 1 water rod.
4. Contains four rectangular water cross segments dividing the assembly into four quadrants.
5. Contains in total 60 fuel rods and 4 water rods.
6. Contains in total 92 fuel rods; 78 full length rods and 14 partial length rods; and two water rods replacing 8 fuel rods.
7. Contains in total 92 fuel rods and 8 water rods, and contain 92 MOX rods in the MOX fuel bundle, as specified in Table 6.2.6.
8. Contains in total 91 fuel rods; 79 full length rods and 12 partial length rods; and one square water box replacing 9 fuel rods.
9. Contains in total 91 fuel rods; 83 full length rods and 8 partial length rods, and one square water box replacing 9 fuel rods.
10. Contains either A) in total 96 fuel rods; all fuel rods are full length rods, or B) in total 96 fuel rods, 88 full length rods and 8 partial rods of only one length. All assemblies have four rectangular water cross segments dividing the assembly into four quadrants, and one diamond-shaped water box replacing the 4 center fuel rods.
11. Contains either A) in total 96 fuel rods; all fuel rods are full length rods, or B) in total 96 fuel rods, 84 full length rods and 12 partial rods of two lengths. All assemblies have four rectangular water cross segments dividing the assembly into four quadrants, and one diamond-shaped water box replacing the 4 center fuel rods.
12. Contains in total 96 fuel rods; 80 full length rods, 8 long partial length rods, 8 short partial length rods and one water rod replacing 4 fuel rods.
13. Contains in total 112 total fuel rods; 92 full length rods, 8 long partial length rods, 12 short partial length rods and one square water box replacing 9 fuel rods.
14. The results listed in Table 6.2.5 confirm that using the fixed rod pitch in the middle and top zones along the entire active fuel length is bounding. This value is therefore listed and used in the HI-STAR 80 analysis.
15. Contains in total 109 total fuel rods; 91 full length rods, 8 long partial length rods, 10 short partial length rods and 3 water rods replacing 12 fuel rods. The partial length rods locations can vary.

Table 7.D.4 (2 pages total)

Fuel Assembly Cooling, Average Burnup, and Initial Enrichment for the PWR Fuel in the F-12P Fuel Basket

UP TO 12 ASSEMBLIES PER BASKET							
Assembly Burnup (MWD/MTU)	Assembly Initial Enrichment (wt. % U-235)	Condition Set 1		Condition Set 2		Condition Set 3	
		Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)
≤ 10,000	≥ 3.0	1	≥ 6	n/a	n/a	n/a	n/a
	≥ 3.5	1	≥ 4	n/a	n/a	n/a	n/a
≤ 30,000	≥ 3.0	2	≥ 14	1	≥ 19	n/a	n/a
	≥ 3.5	2	≥ 12	1	≥ 17	n/a	n/a
≤ 40,000	≥ 3.5	4	≥ 13	3	≥ 17	2	≥ 21
	≥ 4.0	4	≥ 12	3	≥ 16	2	≥ 20
	≥ 4.5	4	≥ 12	3	≥ 16	2	≥ 20
	≥ 5.0	4	≥ 12	3	≥ 16	2	≥ 20
≤ 50,000	≥ 3.5	5	≥ 13	4	≥ 17	3	≥ 21
	≥ 4.0	5	≥ 12	4	≥ 16	3	≥ 20
	≥ 4.5	5	≥ 12	4	≥ 16	3	≥ 20
	≥ 5.0	5	≥ 12	4	≥ 16	3	≥ 20
≤ 55,000	≥ 4.0	5	≥ 16	4	≥ 20	3	≥ 24
	≥ 4.5	5	≥ 15	4	≥ 19	3	≥ 23
	≥ 5.0	5	≥ 15	4	≥ 19	3	≥ 23
≤ 60,000	≥ 4.5	5	≥ 18	4	≥ 22	n/a	n/a
	≥ 4.75	5	≥ 18	4	≥ 22	n/a	n/a
	≥ 5.0	5	≥ 18	4	≥ 22	n/a	n/a
≤ 65,000	≥ 4.75	5	≥ 21	4	≥ 25	n/a	n/a
	≥ 5.0	5	≥ 21	4	≥ 25	n/a	n/a
≤ 70,000	≥ 4.9	5	≥ 24	4	≥ 28	n/a	n/a

UP TO 10 ASSEMBLIES PER BASKET (CELLS 4 AND 9 OR 5 AND 8 ARE EMPTY CELLS)							
Assembly Burnup (MWD/MTU)	Assembly Initial Enrichment (wt. % U-235)	Condition Set 1		Condition Set 2		Condition Set 3	
		Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)
≤ 10,000	≥ 3.0	1	≥ 6	n/a	n/a	n/a	n/a
	≥ 3.5	1	≥ 4	n/a	n/a	n/a	n/a
≤ 30,000	≥ 3.0	2	≥ 14	1	≥ 19	n/a	n/a
	≥ 3.5	2	≥ 12	1	≥ 17	n/a	n/a
≤ 40,000	≥ 3.5	4	≥ 13	3	≥ 17	2	≥ 21
	≥ 4.0	4	≥ 12	3	≥ 16	2	≥ 20
	≥ 4.5	4	≥ 12	3	≥ 16	2	≥ 20
	≥ 5.0	4	≥ 12	3	≥ 16	2	≥ 20
≤ 50,000	≥ 3.5	5	≥ 13	4	≥ 17	3	≥ 21
	≥ 4.0	5	≥ 12	4	≥ 16	3	≥ 20
	≥ 4.5	5	≥ 12	4	≥ 16	3	≥ 20
	≥ 5.0	5	≥ 12	4	≥ 16	3	≥ 20
≤ 55,000	≥ 4.0	5	≥ 15	4	≥ 19	3	≥ 23
	≥ 4.5	5	≥ 14	4	≥ 18	3	≥ 22
	≥ 5.0	5	≥ 13	4	≥ 17	3	≥ 21
≤ 60,000	≥ 4.5	5	≥ 17	4	≥ 21	n/a	n/a
	≥ 4.75	5	≥ 16	4	≥ 20	n/a	n/a
	≥ 5.0	5	≥ 16	4	≥ 20	n/a	n/a
≤ 65,000	≥ 4.75	5	≥ 20	4	≥ 24	n/a	n/a
	≥ 5.0	5	≥ 19	4	≥ 23	n/a	n/a
≤ 70,000	≥ 4.9	5	≥ 24	4	≥ 28	n/a	n/a

Note 1: See Figure 7.D.1 for basket cell numbering.
Note 2: While cooling times less than 1 year have been technically justified, a minimum cooling time of 1 year applies per 10CFR71.4.
Note 3: Fuel irradiated for less than 1 cycle is qualified, using the cooling time specified for 1 cycle, with a burnup limit equal to the burnup limit for 1 cycle multiplied with the fraction of the cycle that the assembly was irradiated.
Note 4: Fuel irradiated with one or more cycles with a cycle length not equal to 1 year is qualified with a minimum cooling time that is determined by linear interpolation between the cooling time limits for the applicable burnup and enrichment limits, considering irradiation times instead of cycle numbers. For example, for an assembly irradiated for 3 cycles of 1.5 years each, the irradiation time is 4.5 years, and the minimum cooling time is then determined by linear interpolation between 4 years (4 cycles in the table) and 5 years (5 cycles in the table).

Table 7.D.5 (4 pages total)

Fuel Assembly Cooling, Average Burnup, and Initial Enrichment for the BWR UO_2 Fuel in the F-32B Fuel Basket

UP TO 32 ASSEMBLIES PER BASKET							
Assembly Burnup (MWD/MTU)	Assembly Initial Enrichment (wt. % U-235)	Condition Set 1		Condition Set 2		Condition Set 3	
		Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)
≤ 10,000	≥ 3.0	n/a	n/a	1	≥ 8	n/a	n/a
	≥ 3.5	n/a	n/a	1	≥ 6	n/a	n/a
≤ 20,000	≥ 3.0	3	≥ 11	2	≥ 13	1	≥ 17
	≥ 3.5	3	≥ 9	2	≥ 11	1	≥ 15
≤ 30,000	≥ 3.0	4	≥ 11	3	≥ 13	2	≥ 17
	≥ 3.5	4	≥ 9	3	≥ 11	2	≥ 15
≤ 50,000	≥ 3.0	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 3.5	5	≥ 17	4	≥ 19	3	≥ 23
	≥ 4.0	5	≥ 15	4	≥ 17	3	≥ 21
	≥ 4.5	5	≥ 14	4	≥ 16	3	≥ 20
	≥ 5.0	5	≥ 14	4	≥ 16	3	≥ 20
≤ 55,000	≥ 3.5	5	≥ 19	4	≥ 21	3	≥ 25
	≥ 4.0	5	≥ 19	4	≥ 21	3	≥ 25
	≥ 4.5	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 5.0	5	≥ 17	4	≥ 19	3	≥ 23
≤ 60,000	≥ 3.5	6	≥ 21	5	≥ 23	4	≥ 27
	≥ 4.0	6	≥ 20	5	≥ 22	4	≥ 26
	≥ 4.5	6	≥ 20	5	≥ 22	4	≥ 26
	≥ 4.75	6	≥ 19	5	≥ 21	4	≥ 25
	≥ 5.0	6	≥ 19	5	≥ 21	4	≥ 25
≤ 65,000	≥ 4.75	7	≥ 22	6	≥ 24	5	≥ 28
	≥ 5.0	7	≥ 22	6	≥ 24	5	≥ 28
≤ 70,000	≥ 4.9	7	≥ 31	6	≥ 32	5	≥ 34

UP TO 28 ASSEMBLIES PER BASKET (CELLS 13, 14, 19, AND 20 ARE EMPTY CELLS)							
Assembly Burnup (MWD/MTU)	Assembly Initial Enrichment (wt. % U-235)	Condition Set 1		Condition Set 2		Condition Set 3	
		Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)
≤ 10,000	≥ 3.0	n/a	n/a	1	≥ 8	n/a	n/a
	≥ 3.5	n/a	n/a	1	≥ 6	n/a	n/a
≤ 20,000	≥ 3.0	3	≥ 11	2	≥ 13	1	≥ 17
	≥ 3.5	3	≥ 9	2	≥ 11	1	≥ 15
≤ 30,000	≥ 3.0	4	≥ 11	3	≥ 13	2	≥ 17
	≥ 3.5	4	≥ 9	3	≥ 11	2	≥ 15
≤ 50,000	≥ 3.0	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 3.5	5	≥ 16	4	≥ 18	3	≥ 22
	≥ 4.0	5	≥ 15	4	≥ 17	3	≥ 21
	≥ 4.5	5	≥ 14	4	≥ 16	3	≥ 20
	≥ 5.0	5	≥ 14	4	≥ 16	3	≥ 20
≤ 55,000	≥ 3.5	5	≥ 19	4	≥ 21	3	≥ 25
	≥ 4.0	5	≥ 19	4	≥ 21	3	≥ 25
	≥ 4.5	5	≥ 17	4	≥ 19	3	≥ 23
	≥ 5.0	5	≥ 17	4	≥ 19	3	≥ 23
≤ 60,000	≥ 3.5	6	≥ 20	5	≥ 22	4	≥ 26
	≥ 4.0	6	≥ 19	5	≥ 21	4	≥ 25
	≥ 4.5	6	≥ 19	5	≥ 21	4	≥ 25
	≥ 4.75	6	≥ 18	5	≥ 20	4	≥ 24
	≥ 5.0	6	≥ 18	5	≥ 20	4	≥ 24
≤ 65,000	≥ 4.75	7	≥ 21	6	≥ 23	5	≥ 27
	≥ 5.0	7	≥ 21	6	≥ 23	5	≥ 27
≤ 70,000	≥ 4.9	7	≥ 27	6	≥ 30	5	≥ 33

UP TO 24 ASSEMBLIES PER BASKET (CELLS 12, 13, 14, 15, 18, 19, 20, AND 21 ARE EMPTY CELLS OR CELLS 7, 8, 13, 14, 19, 20, 25, AND 26 ARE EMPTY CELLS)							
Assembly Burnup (MWD/MTU)	Assembly Initial Enrichment (wt. % U-235)	Condition Set 1		Condition Set 2		Condition Set 3	
		Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time (months)
≤ 10,000	≥ 3.0	n/a	n/a	1	≥ 8	n/a	n/a
	≥ 3.5	n/a	n/a	1	≥ 6	n/a	n/a
≤ 20,000	≥ 3.0	3	≥ 11	2	≥ 13	1	≥ 17
	≥ 3.5	3	≥ 9	2	≥ 11	1	≥ 15
≤ 30,000	≥ 3.0	4	≥ 11	3	≥ 13	2	≥ 17
	≥ 3.5	4	≥ 9	3	≥ 11	2	≥ 15
≤ 50,000	≥ 3.0	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 3.5	5	≥ 16	4	≥ 18	3	≥ 22
	≥ 4.0	5	≥ 15	4	≥ 17	3	≥ 21
	≥ 4.5	5	≥ 14	4	≥ 16	3	≥ 20
	≥ 5.0	5	≥ 13	4	≥ 15	3	≥ 19
≤ 55,000	≥ 3.5	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 4.0	5	≥ 18	4	≥ 20	3	≥ 24
	≥ 4.5	5	≥ 17	4	≥ 19	3	≥ 23
	≥ 5.0	5	≥ 16	4	≥ 18	3	≥ 22
≤ 60,000	≥ 3.5	6	≥ 20	5	≥ 22	4	≥ 26
	≥ 4.0	6	≥ 19	5	≥ 21	4	≥ 25
	≥ 4.5	6	≥ 18	5	≥ 20	4	≥ 24
	≥ 4.75	6	≥ 17	5	≥ 19	4	≥ 23
	≥ 5.0	6	≥ 17	5	≥ 19	4	≥ 23
≤ 65,000	≥ 4.75	7	≥ 20	6	≥ 22	5	≥ 26
	≥ 5.0	7	≥ 19	6	≥ 21	5	≥ 25
≤ 70,000	≥ 4.9	7	≥ 28	6	≥ 29	5	≥ 33

Note 1: See Figure 7.D.2 for basket cell numbering.
Note 2: While cooling times less than 1 year have been technically justified, a minimum cooling time of 1 year applies per 10CFR71.4.
Note 3: Fuel irradiated for less than 1 cycle is qualified, using the cooling time specified for 1 cycle, with a burnup limit equal to the burnup limit for 1 cycle multiplied with the fraction of the cycle that the assembly was irradiated.
Note 4: Fuel irradiated with one or more cycles with a cycle length not equal to 1 year is qualified with a minimum cooling time that is determined by linear interpolation between the cooling time limits for the applicable burnup and enrichment limits, considering irradiation times instead of cycle numbers. For example, for an assembly irradiated for 3 cycles of 1.5 years each, the irradiation time is 4.5 years, and the minimum cooling time is then determined by linear interpolation between 4 years (4 cycles in the table) and 5 years (5 cycles in the table).

Table 7.D.6 (1 pages total)

Fuel Assembly Cooling, and Average Burnup for the BWR MOX Fuel in the F-32B Fuel Basket

UP TO 4 MOX ASSEMBLIES AND 28 UO2 ASSEMBLIES PER BASKET			
Assembly Burnup (MWD/MTU for UO2 Assembly) (MWD/MTIHM for MOX Assemblies)	Minimum Assembly Initial Enrichment for UO2 Assemblies (wt. % U-235)	Minimum Number of 1 year irradiation cycles	Post-irradiation Cooling Time for MOX and UO2 Assemblies (months)
MOX Assemblies			
≤ 50,000	n/a	9	≥ 22
≤ 55,000	n/a	9	≥ 26
≤ 60,000	n/a	11	≥ 30
≤ 65,000	n/a	12	≥ 35
UO2 Assemblies			
≤ 50,000	≥ 4.0	4	29

Note 1: MOX Assemblies must be loaded into Basket Cells 6, 9, 24, and 27. See Figure 7.D.2 for basket cell numbering.
Note 2: Fuel irradiated with one or more cycles with a cycle length not equal to 1 year is qualified considering irradiation times instead of cycle numbers.
Note 3: Cells 1, 4, 5, 10, 23, 28, 29, and 32 must be loaded with fuel assemblies and cannot be empty.

Table 7.D.7 (Page 1 of 1)

Intentionally Deleted

Table 7.D.8 (Page 1 of 1)

Non-Fuel Waste Basket Limits

I. Non-Fuel Waste Basket: NFWB-1

A. Allowable Contents

1. Reactor-Related Non-Fuel Waste ("Core Components") consisting of
   - fuel channels,
   - transition pieces,
   - spacer grids
   - core grid components
   - core spray components
   - control rods or control blades,
   - neutron monitors using fission chambers,
   - burnable absorbers

   in solid form, including any associated parts, or any mixture of those components, with or without stainless steel secondary packaging and meeting the following specifications:

a. Core Component Mass:	5000 kg (total mass of waste and cartridge container shall not exceed 5665 kg)
b. Total Cask Decay Heat:	≤ 2.0 kW
c. Source Strength Limits:	See Table 7.D.9 together with the applicable notes
d. Maximum permissible quantity of fissile materials (including SNM):	2 grams
e. Minimum Cooling Time:	1 year

Table 7.D.9 (Page 1 of 1)

Non-Fuel Waste Source Strength Limits (Note 1)

Energy Group (MeV) or Isotope	Mass Specific Source Strength Limit, photons/sec/kg	Total Activation Source Strength Limit, photons/sec
0.45-0.7	1.15E+14	5.75E+17
0.7-1.0	8.78E+12	4.39E+16
1.0-1.5 (excluding Co-60)	6.73E+11	3.37E+15
1.5-2.0	1.26E+11	6.31E+14
2.0-2.5	4.79E+10	2.40E+14
2.5-3.0	2.30E+10	1.15E+14
Co-60	9.13E+11	4.56E+15
Energy Group (MeV) or Isotope	Surface Specific Source Strength Limit, photons/sec/m^2	Total Contamination Source Strength Limit, photons/sec
0.45-0.7	1.64E+16	5.75E+17
0.7-1.0	1.40E+15	4.39E+16
1.0-1.5 (excluding Co-60)	1.32E+14	3.37E+15
1.5-2.0	2.99E+13	6.31E+14
2.0-2.5	1.22E+13	2.40E+14
2.5-3.0	5.83E+12	1.15E+14
Co-60	1.64E+14	4.56E+15

Note 1: For a given content of the NFWB, determine the actual source strength for each of the energy group and isotope limits specified in the table, and calculate the ratio of the actual value to the limit. When performing this evaluation,

- Only the mass of the activated material is to be considered when calculating the mass specific source strength. Any material added to the activated material for the purpose of handling or support is to be neglected.
- Only the mass of stainless steel, Inconel, zirconium alloys or aluminum alloys is to be considered when calculating the mass specific source strength. The mass of any other activated material is to be neglected, but the activation of the material is to be included.
- The evaluation is to be performed for each item in the NFWB-1, based on its activation and mass / surface area. Further, for each item, the evaluation must be representative of the activation and mass / surface area of its most activated / contaminated section. The highest sum of all ratios evaluated this way must be below 1.0.

Table 7.D.10 (Page 1 of 1)

ADJUSTMENTS FOR CALCULATION OF ASSEMBLY DECAY HEAT

1. Adjustments of assembly decay heat is to be performed by either adjusting the assembly burnup (1.A below), or by adjusting the calculated decay heat value (1.B below)

1.A Adjustments of assembly-average burnups to be used for calculating decay heat

- PWR Assemblies
  - With blankets:
    - For fuel assemblies with natural or depleted Uranium axial blankets, the average burnup is calculated excluding axial blankets
    - No adjustment needed.
  - With exposure to Axial Power Shaping Rods (APSRs)
    - Up to 15 GWd/mtU: add 2 GWd/mtU
    - Up to 30 GWd/mtU: add 1 GWd/mtU
    - Above 30 GWd/mtU: no adjustment needed
  - All other
    - Up to 15 GWd/mtU: add 1 GWd/mtU
    - Up to 30 GWd/mtU: add 0.5 GWd/mtU
    - Above 30 GWd/mtU: no adjustment needed
- BWR Assemblies
  - Up to 20 GWd/mtU: add 1 GWd/mtU
  - Up to 40 GWd/mtU: add 0.5 GWd/mtU
  - Above 40 GWd/mtU: no adjustment needed

1.B Adjustments of decay heat values

- PWR Assemblies
  - With blankets:
    - For fuel assemblies with natural or depleted Uranium axial blankets, the average burnup is calculated excluding axial blankets
    - No adjustment needed.
  - With exposure to Axial Power Shaping Rods (APSRs)
    - Up to 30 GWd/mtU: Multiply the resulting heat load with a factor of -1.66E-04 Bu^2 + 4.14E-03 Bu + 1.06E+00
      where Bu is the fuel assembly average burnup in GWd/mtU
    - Above 30 GWd/mtU: no adjustment needed
  - All other
    - Up to 30 GWd/mtU: Multiply the resulting heat load with a factor of 2.40E-05 Bu^2 - 2.82E-03 Bu + 1.07E+00
      where Bu is the fuel assembly average burnup in GWd/mtU

        - Above 30 GWd/mtU: no adjustment needed
- BWR Assemblies
    - Up to 40 GWd/mtU: Multiply the resulting heat load with a factor of -5.85E-06 Bu^3 + 6.00E-04 Bu^2 - 2.09E-02 Bu + 1.27E+00
      where Bu is the fuel assembly average burnup in GWd/mtU
    - Above 40 GWd/mtU: no adjustment needed

2. Additional adjustments of Decay Heat Values for Assemblies with Part Length Rods

For assemblies containing part-length rods, the decay heat value calculated on the basis of the assembly average burnup, with the adjustments specified above, shall be multiplied with the following factor before comparing the decay heat with the applicable limit.

Factor = n_{max} x al_{tot} / $\Sigma(n_i \times al_i)$

With

n_{max} = maximum number of fuel rods in any cross section
al_{tot} = total active length
n_i = number of fuel rods in cross section i
al_i = length of active region with number of rods ni
i = index of axial sections with different number of fuel rods. Summation performed over all sections

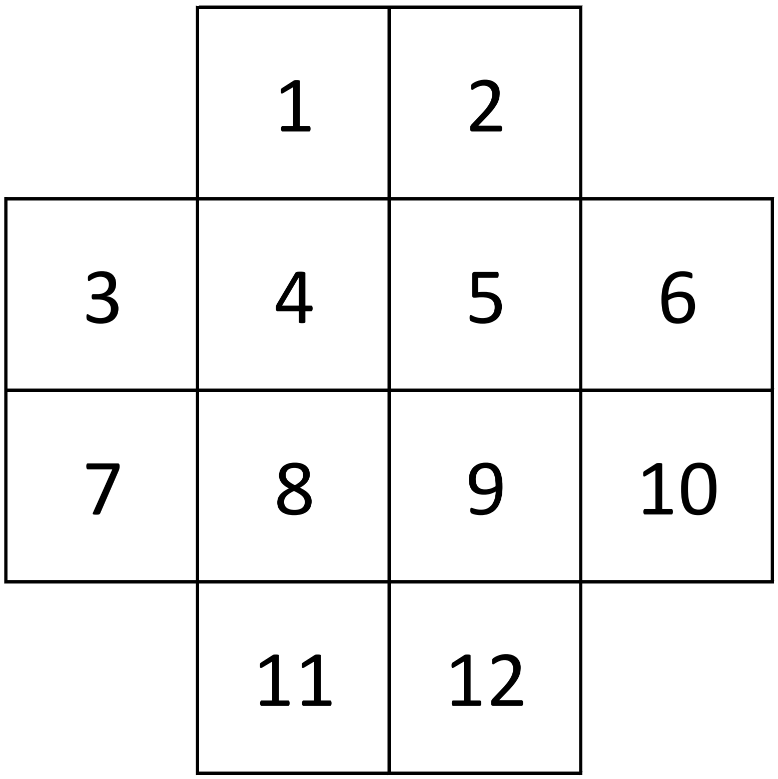


Figure 7.D.1

Cell Numbers for F-12P Basket

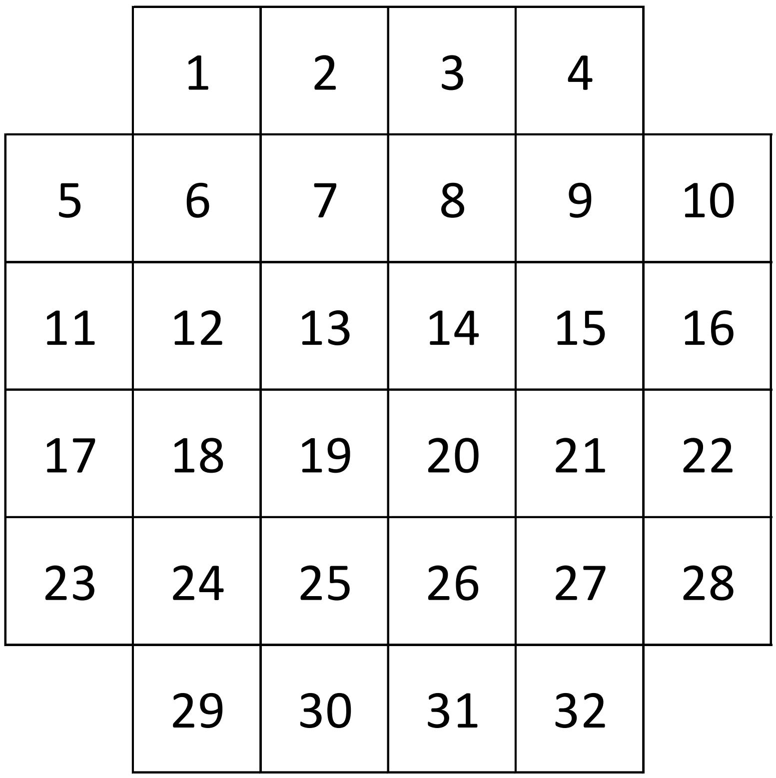


Figure 7.D.2

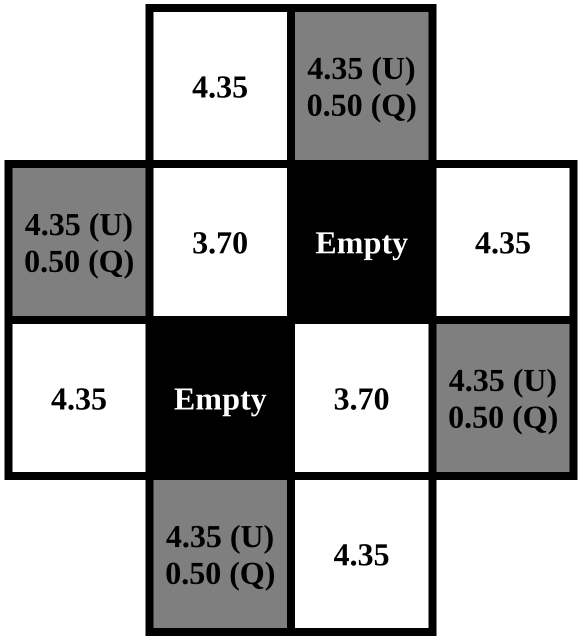
Cell Numbers for F-32B Basket

	5.00	5.00 (U) 0.50 (Q)	
5.00 (U) 0.50 (Q)	4.25	Empty	5.00
5.00	Empty	4.25	5.00 (U) 0.50 (Q)
	5.00 (U) 0.50 (Q)	5.00	

Notes:
1. See Figure 7.D.1 for cell location numbers.
2. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as “Empty” must remain empty regardless of the contents of the adjacent cell. Cell locations 4 and 9 may be empty instead of cells 5 and 8.

Figure 7.D.3

Loading Pattern for F-12P Configuration 2



Notes:

1. See Figure 7.D.1 for cell location numbers.
2. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as “Empty” must remain empty regardless of the contents of the adjacent cell. Cell locations 4 and 9 may be empty instead of cells 5 and 8.

Figure 7.D.4

Loading Pattern for F-12P Configuration 2

	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	
1.920 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.920 (U) 0.384 (Q)
1.920	1.920	Empty	Empty	1.920	1.920
1.920	1.920	Empty	Empty	1.920	1.920
1.920 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.920 (U) 0.384 (Q)
	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	

Notes:

1. See Figure 7.D.2 for cell location numbers.
2. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as "Empty" must remain empty regardless of the contents of the adjacent cell.

Figure 7.D.5

Loading Pattern for F-32B Configuration 2

	1.920 (U) 0.384 (Q)	1.920	1.920	1.920 (U) 0.384 (Q)	
1.920 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.920 (U) 0.384 (Q)
1.920	1.920	Empty	Empty	1.920	1.920
1.920	1.920	Empty	Empty	1.920	1.920
1.920 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.920 (U) 0.384 (Q)
	1.920 (U) 0.384 (Q)	1.920	1.920	1.920 (U) 0.384 (Q)	

Notes:
1. See Figure 7.D.2 for cell location numbers.
2. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as “Empty” must remain empty regardless of the contents of the adjacent cell.

Figure 7.D.6

Loading Pattern for F-32B Configuration 2

	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	
1.540 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.540 (U) 0.384 (Q)
1.540	1.540	Empty	Empty	1.540	1.540
1.540	1.540	Empty	Empty	1.540	1.540
1.540 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.540 (U) 0.384 (Q)
	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	0.384 (U) 0.384 (Q)	

Notes:
1. See Figure 7.D.2 for cell location numbers.
2. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as “Empty” must remain empty regardless of the contents of the adjacent cell.

Figure 7.D.7

Loading Pattern for F-32B Configuration 2

	1.540 (U) 0.384 (Q)	1.540	1.540	1.540 (U) 0.384 (Q)	
1.540 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.540 (U) 0.384 (Q)
1.540	1.540	Empty	Empty	1.540	1.540
1.540	1.540	Empty	Empty	1.540	1.540
1.540 (U) 0.384 (Q)	0.960	0.960	0.960	0.960	1.540 (U) 0.384 (Q)
	1.540 (U) 0.384 (Q)	1.540	1.540	1.540 (U) 0.384 (Q)	

Notes:

3. See Figure 7.D.2 for cell location numbers.
4. All Storage cell heat loads are in kW. Undamaged Fuel (U), or Quivers (Q) may be stored in grey shaded cells. Cells denoted as “Empty” must remain empty regardless of the contents of the adjacent cell.

Figure 7.D.8

Loading Pattern for F-32B Configuration 2

CHAPTER 8: ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

The text matter and data presented in this chapter in bold font (or as otherwise noted) are an integral part of the Certificate of Compliance (CoC) of the package and cannot be altered without NRC's approval through a license amendment. Moreover, essential elements of the acceptance tests in Section 8.1 and of the maintenance program in Section 8.2 have been identified as conditions of the CoC.

8.0 INTRODUCTION

This chapter identifies the acceptance tests and maintenance program to be conducted on the HI-STAR 80 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].

8.1 ACCEPTANCE TESTS

In this section the inspections and acceptance tests to be performed on the HI-STAR 80 Package prior to its use are summarized. These inspections and tests provide assurance that the HI-STAR 80 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 80 Package 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 fabrication sampling plan shall be made and controls shall be exercised to ensure that the packaging conforms to the dimensions and tolerances specified on the licensing and fabrication drawings. These dimensions are subject to independent confirmation and documentation in accordance with the Holtec QA program approved in NRC Docket No. 71-0784.

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

- **Visual inspections and measurements shall be made to ensure that the packaging effectiveness is not significantly reduced. Any *important-to-safety* component found to be under the minimum thickness requirement shall be repaired or replaced as required.**
- **Visual inspections shall be made to verify that neutron absorber panels, basket shims, fuel spacers, anti-rotation/alignment bars, and non-fuel waste basket (NFWB) are present as required by cask contents and basket design.**
- **The packaging shall be visually inspected to ensure it is conspicuously and durably marked with the proper markings/labels in accordance with 10CFR71.85(c).**
- **The packaging shall be inspected for cleanliness and preparation for shipping in accordance with written and approved procedures.**

The visual inspection and measurement results for the HI-STAR 80 Package shall become part of the final quality documentation package.

8.1.2 Weld Examination

The examination of HI-STAR 80 Package welds shall be performed in accordance with the drawing package referenced in the CoC and applicable codes and standards in Table 8.1.6, including alternatives as specified in Table 8.1.7. Weld examinations and repairs shall be performed as specified below. **All code and Metamic-HT weld inspections shall be performed in accordance with written and approved procedures by personnel qualified in accordance with SNT-TC-1A [8.1.2].** All required inspections, examinations, and tests shall become part of the 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. Weld overlays for cask sealing surfaces shall be VT and PT examined to insure that a leakage path between the containment space and the outside environment that may violate the specified cask leakage rate criterion is detected and eliminated. Although ASME Code Section III, Subsection NB does not require visual examination of welds, the welds will be visually examined to ensure conformance with the fabrication drawings (e.g. proper geometry, workmanship etc.).**

2. **ITS welds on the cask (excluding containment boundary welds), NFWB, Fuel Spacers and impact limiters shall be examined in accordance with ASME Code Section V, with acceptance criteria per ASME Code Section III, Subsection NF, Article NF-5300. These welds shall be repaired in accordance with ASME Code Section III, Article NF-4450 and examined after repair in the same manner as the original weld. These weld requirements are not applicable to NITS welds (e.g. seal welds).**

3. **Basket welds connecting Metamic-HT panels shall be examined and repaired in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for welding Metamic-HT with acceptance criteria per ASME Section V, Article 1, Paragraph T-150 (2007 Edition). The basket welds, made by the Friction Stir Weld process, are classified as Category C per NG-3351.3 and belonging to Type III (by virtue of being corner joint with a thru-thickness "stir zone") in Table NG-3352-1. These weld requirements are not applicable to welds identified as NITS on the drawing package referenced in the CoC.**

4. **Basket welds connecting Metamic-HT panels to Aluminum shims (F-12P and F-32B Baskets), and welds connecting Aluminum plates surrounding the shield blocks (F-32B Baskets) shall be examined in accordance with NDE specified in the drawing package and with written and approved procedures developed specifically for each application. Repaired welds shall be examined with the same method(s) as the original weld, using written and approved procedures developed for each application.**

5. **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 tested by combination of methods (including helium leak test, pressure test and NDE, as specified in this chapter and the licensing drawing package referenced in the CoC) to verify that it is free of cracks, pinholes, uncontrolled voids or other defects that could significantly reduce the effectiveness of the packaging.

8.1.3.1 Lifting Trunnions

Four top trunnions are provided for vertical lifting and handling of the cask. The top trunnions are required to be tested and inspected in accordance with ANSI N14.6 [8.1.3]. Two bottom trunnions are provided for rotation of the loaded or empty cask for downending/upending operations. Both top and bottom trunnions are rendered inoperable during package transport.

Each pair of opposite trunnions at the top of the cask constitutes a single load path for vertical lifting and handling. The pair of top trunnions aligned with the bottom trunnions shall be tested for vertical lifting in accordance with ANSI N14.6 at 300% of the maximum design service load (the full weight of the loaded cask at a minimum). The second pair of top trunnions shall be tested for vertical lifting in accordance with ANSI N14.6 at either 150% (for redundant lifting) or 300% (for single load path lifting) of the maximum design service load. Load tests may be performed in excess of the test loads specified above provided an engineering evaluation is performed to ensure trunnions or other cask components will not be damaged by the load test. The test load shall be applied for a minimum of 10 minutes. The accessible parts of the trunnions (areas outside the cask), and the local cask areas shall then be visually examined to verify no deformation, distortion, or cracking has occurred. Any evidence of deformation (other than minor localized surface deformation due to contact pressure between lifting device and the trunnions), distortion or cracking of the trunnion or adjacent cask areas shall require replacement of the trunnion and/or repair of the cask. Following any replacements and/or major repair, as defined in ANSI N14.6, the load testing shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria. Testing shall be performed in accordance with written and approved procedures. Certified material test reports verifying trunnion material mechanical properties meet ASME Code Section II requirements provide further verification of the trunnion load capabilities. Test results shall be documented and shall become part of the final quality documentation package.

8.1.3.2 Pressure Testing

Pressure testing of the HI-STAR 80 containment boundary (cavity space, inter-lid space and space between port closures as defined in the licensing drawing package referenced in the CoC) is required. Furthermore, all containment boundary closures must be pressure tested. The cask containment boundary shall be pressure tested at a test pressure of not less than 150% of cask cavity maximum normal operating pressure per 10CFR71.85(b), or at hydrostatic/pneumatic test pressures of 125%/110% of the cask cavity design

internal pressure in accordance with the ASME Code Section III, Subsection NB-6000; whichever is greater.

Pressure testing may be performed in various cask closure configurations as needed so that each containment boundary closure is pressure tested at least once. Containment boundary closures may be tested with single temporary test seal.

All pressure testing shall be performed in accordance with approved procedures written by qualified personnel in accordance with Holtec QA program. The written and approved test procedure shall clearly define the test equipment arrangement. SNT-TC-1A [8.1.2] is not applicable to this test; however, for quality assurance, trained and qualified personnel shall perform the test and the leakage verification in accordance with written procedures and document the results. The leakage verification shall be performed in accordance with written quality assurance program.

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

8.1.4 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5 [8.1.6] specified in this Chapter. Tables 8.1.1 and 8.1.2 specify the allowable leakage rate and test sensitivity as well as components to be tested for fabrication and pre-shipment leakage rate tests.

A pre-shipment leakage rate test of cask containment seals is performed following loading of authorized contents into the cask. This pre-shipment leakage rate test is valid for 1 year or until the tested component(s) is opened or respective containment fasteners are untorqued.

In case of an unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

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

Leakage rate testing procedures shall be approved by an ASNT Level III specialist. The written and approved test procedures shall clearly define the test equipment arrangement. Leakage rate testing shall be performed by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A [8.1.2]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

8.1.5 Component and Material Tests

8.1.5.1 Seals

The cask closure seals are conservatively specified in the drawing package referenced in the CoC to provide a high degree of assurance of containment under normal and accident conditions of transport. Seal tests under the most severe package service conditions including performance at pressure under high and low temperatures will not challenge the capabilities of these seals and thus are not required. Seal specifications are in accordance with the manufacturer recommendation.

8.1.5.2 Impact Testing

To provide protection against brittle fracture under cold conditions, fracture toughness test criteria of cask ferritic containment boundary components, including containment boundary welds, are specified in Table 8.1.8. Non-containment boundary ferritic steel package components are tested for fracture toughness in accordance with Table 8.1.9. Exemption from fracture toughness testing as allowed by ASME Code Section III, Subsections NB and NF may apply. Code alternatives listed in Table 8.1.7 may apply.

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

8.1.5.3 Impact Limiter Crush Material Testing

Verification of the transport impact limiter crush material crush strength is accomplished by performance of a crush test of sample blocks. The verification tests are performed by the crush material supplier or third-party testing facility in accordance with Holtec approved procedures. Impact limiter material crush strength is specified in Table 8.1.11.

The certified test results shall be retained by Holtec International as archive record for each batch of impact limiter crush material manufactured and used. Test results shall be documented and shall become part of the final quality documentation package.

8.1.5.4 Neutron Shielding Material

Manufacturing of Holtite neutron shielding material shall be conducted according to approved written procedures that shall ensure mix ratios and mixing methods are controlled in order to achieve proper material composition and distribution, and that emplacement is properly controlled. Table 8.1.10 provides Holtite reference properties. **Each manufactured lot of Holtite neutron shield material shall be tested to verify that boron carbide content, hydrogen density and bulk Holtite material density meet specified requirements**. **Boron carbide content shall be verified by spectrochemical and/or gravimetric analysis. A manufactured lot is defined as the total amount of material used to make any number of mixed batches comprised of constituent ingredients from the same lot/batch identification numbers supplied by the constituent manufacturer. Testing shall be performed in accordance with written and approved procedures.**

Holtec International shall maintain samples of each manufactured lot of neutron shielding material. Test results for each manufactured lot of neutron shield material shall become part of the final quality documentation package.

8.1.5.5 Neutron Absorber Material

The manufacturing of Metamic-HT is governed by a set of quality validated standard procedures contained in the Metamic-HT Manufacturing Manual [8.1.8]. The material properties and characteristics have been tested and documented in Ref. [8.1.10]. The manufactured Metamic-HT is subject to all quality assurance requirements under Holtec International's NRC approved quality program. The minimum guaranteed values (MGVs) of the final manufactured panels are set forth in Table 8.1.5. **Production testing requirements including acceptance criteria are provided in Table 8.1.3.**

The manufacturing processes for Metamic-HT are defined in the Metamic-HT Manufacturing Manual. Metamic-HT panels will be manufactured to Holtec's purchase specification [8.1.9] that incorporates all requirements set forth in Chapter 8 of this SAR, the drawing package referenced in the CoC and the fabrication drawings. The supplier of raw materials must be qualified under Holtec's quality program for important to safety materials and components or alternatively each lot of raw material shall be tested in accordance with Table 8.1.3 requirements. The manufacturing of Metamic-HT is subject to all quality assurance requirements under Holtec International's NRC approved quality program.

The tests conducted on Metamic-HT to establish the compliance of the manufactured panels with Holtec's Purchasing Specification are intended to ensure that *critical characteristics* of the final product will meet the minimum guaranteed values (MGVs) set forth in Table 8.1.5. The tests are performed at both the raw material and manufactured panels stages of production with the former serving as the insurer of the properties in the final product and the latter serving the confirmatory function. The testing is conducted for each lot of raw material and finished panels as prescribed in Table 8.1.3. A lot is defined as follows:

> "Lot" means a population of an item that shares identical attributes that are central to defining a critical performance or operational characteristic required of it. Thus, a lot of boron carbide powder procured to a certified Purchasing Specification used in the manufacturing of Metamic-HT is the bulk quantity of the powder that has the same particle size distribution. A lot of finished panels drawn from a powder mix and manufactured in an extrusion run have identical aluminum and boron carbide characteristics and the same extrusion conditions.

The following tests are performed (see Table 8.1.3):

(i) Testing and certification of powder material

- **All lots of aluminum and boron carbide powder shall be certified to meet particle size distribution and chemistry requirements in the Metamic-HT Manufacturing Manual.**
- **All lots of B_4C will be certified as containing Boron with the minimum**

isotopic B-10 per the boron carbide purchase specifications incorporated in the Metamic-HT Manufacturing Manual.

- **Homogenized mixtures of Al powder(s) and boron carbide powder(s) from traceable lots, prepared for sintering and billet forming operations, shall have the minimum boron carbide wt% verified by wet chemistry testing of one sample from each lot of blended powders. The mixing/blending of the batch shall be controlled via approved procedures.**

(ii) Testing of finished panels

The number of panels subject to testing shall be governed by Table 8.1.4. The panels that need to be tested per the statistical protocol of Table 8.1.4, hereafter referred to as test panels, shall be subject to the following evaluations:

- **The Metamic-HT panels shall be tested for all mechanical properties in Table 8.1.5 in accordance with Table 8.1.4 sampling plan.**
- **The thickness of each panel will be measured using the procedure set down in the Metamic-HT Manufacturing Manual. The average measured value must meet the minimum basket wall requirements specified in the Drawing Package referenced in the CoC.**
- **One coupon from a test panel drawn from cask manufactured lot shall be subject to neutron attenuation testing to quantify the boron carbide content for compliance with the minimum requirement in Table 8.1.3 using written procedures.**

(iii) Testing of Basket

- **Metamic-HT basket welds shall be tested/inspected as stated in Section 8.1.2 using written procedures.**

FSW Procedure Qualification, Welder Operator Qualification and Welded Coupon Test for welds connecting Metamic-HT basket panels:

A. Procedure qualification and welder operator qualification of the Friction Stir Welding (FSW) process shall meet the following requirements from ASME Section IX, 2013 Edition [8.1.1]:

- **The Procedure Qualification Record (PQR) shall meet the essential variable requirements of QW-267.**
- **The Weld Procedure Specification (WPS) shall meet the essential variable requirements of QW-267, QW-361.1(e) and QW-361.2.**
- **Welder operator performance qualifications shall meet the essential variable requirements of QW-361.2.**
- **Welder operator may be qualified by volumetric NDE of a test coupon; or a coupon from their initial production welding within the limitations of QW-304 and QW-305; or by bend tests taken from a test coupon.**

All welding by FSW process shall meet applicable requirements of ASME Section IX, 2013 Edition [8.1.1].

B. **Procedure qualification of the Friction Stir Welding process may be accomplished by tensile testing the appropriate number of coupons per ASME Section IX (2007). Verification of weld soundness is performed by visual examination, and radiography or bend testing per approved written procedures (bend testing emulates ASME Section IX). Bend test qualification of a representative weld sample emulating ASME Section IX paragraph QW 160 at a bend radius that produces at least 150% of the average tensile strain developed in the friction stir welded joint under the hypothetical free drop accident condition. The bend radius shall be recorded on the PQR. The bend test sample must meet the acceptance criteria of Section IX QW-163 and visual examination acceptance criteria of ASME Section III Subsection NG 5632 with any additional requirements per Holtec approved written procedure.**

FSW Procedure Qualification, Welder Operator Qualification and Welded Coupon Test for welds connecting Metamic-HT basket panels to Aluminum Shims are performed and qualified under Holtec QA validated program and procedures.

Visual Inspection of Metamic-HT Panels:

Each plate of neutron absorber shall be visually inspected for damage such as scratches, cracks, burrs, foreign material embedded in the surfaces, voids, and delamination. Panels are also visually inspected for contamination on the surface as specified in the Metamic-HT Manufacturing Manual. Panels not meeting the acceptance criteria will be reworked or rejected. Unless basket is fabricated at the same factory manufacturing Metamic-HT, all panels shall be inspected before being shipped to the cask manufacturing facility where they may be subject to receipt inspection prior to installation.

8.1.6 Shielding Tests

A shielding effectiveness test of each fabricated cask must be performed after loading with approved contents and prior to the first shipment as specified in the paragraph the follow.

A shielding effectiveness test of the assembled and loaded package shall be performed to verify the effectiveness of the shielding using written and approved procedures. Calibrated radiation detection equipment shall be used to take measurements at the surface of the HI-STAR package. Measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the shielding. The calculated values shall be representative of the loaded contents (e.g. fuel/NFW type, enrichment, burnup, cooling time, etc.). The test may be performed with the cask in the vertical or horizontal configurations, as long as the package configuration is appropriately taken into account. Measurements shall be documented and become part of the final quality documentation

package.

8.1.7 Thermal Tests

The first fabricated HI-STAR 80 cask shall be tested to confirm its heat dissipation capability.

A thermal test performed for a similar cask design may be used as proof of heat transfer capability in lieu of thermal testing of the HI-STAR 80. **In case of a proof with similar cask, an engineering evaluation between HI-STAR 80 and the previously-tested cask shall be documented** and become part of the final quality documentation package.

The test shall be conducted after fabrication is complete. A test cover plate shall be used to seal the cask cavity. The cavity will be heated with steam.

Twelve (12) calibrated thermocouples shall be installed on the external walls of the cask using four thermocouples, equally spaced circumferentially, at three different elevations. Three calibrated thermocouples shall be installed on the internal walls of the cask in locations to be determined by procedure. Additional temperature sensors shall be used to monitor ambient temperature, steam supply temperature, and condensate drain temperature. The thermocouples shall be attached to strip chart recorders or other similar mechanism to allow for continuous monitoring and recording of temperatures during the test. Instrumentation shall be installed to monitor cask cavity internal pressure.

After the thermocouples have been installed, dry steam will be introduced through an opening in the test cover plate previously installed on the cask and the test initiated. Temperatures of the thermocouples, plus ambient, steam supply, and condensate drain temperature shall be recorded at hourly intervals until thermal equilibrium is reached. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of potential ambient test conditions and incorporated into the test procedure. In general, thermal equilibrium is expected approximately 12 hours after the start of steam heating. Air will be purged from the cask cavity via venting during the heatup cycle. During the test, the steam condensate flowing out of the cask drain shall be collected and the mass of the condensate measured with a precision weighing instrument.

Once thermal equilibrium is established, the final ambient, steam supply, and condensate drain temperatures and temperatures at each of the thermocouples shall be recorded. The strip charts, hand-written logs, or other similar readout shall be marked to show the point when thermal equilibrium was established and final test measurements were recorded. The final test readings along with the hourly data inputs and strip charts (or other similar mechanism) shall become part of the quality records documentation package for the HI-STAR 80 Package.

The heat rejection capability of the cask at test conditions shall be computed using the following formula:

$$\mathbf{Q_{hm} = (h_1 - h_2)\, m_c}$$

Where: **Q_{hm} = Heat rejection rate of the cask (kW)**

h_1 = Enthalpy of steam entering the cask cavity (KJ/kg)

h_2 = Enthalpy of condensate leaving the cask cavity (KJ/kg)

m_c = Average rate of condensate flow measured during thermal equilibrium conditions (kg/s)

Based on the HI-STAR 80 cask thermal model, a design basis minimum heat rejection capacity (Q_{hd}) shall be computed at the measured test conditions (i.e., steam temperature in the cask cavity and ambient air temperature). The thermal test shall be considered acceptable if the measured heat rejection capability is greater than the design basis minimum heat rejection capacity ($Q_{hm} > Q_{hd}$).

If the acceptance criteria above are not met, then the HI-STAR 80 Package shall not be accepted until the root cause is determined, appropriate corrective actions are completed, and the cask is re-tested with acceptable results.

Testing shall be performed in accordance with written and approved procedures similar to the Holtec standard procedure used for the test performed on the HI-STAR 100 overpack and documented in Holtec Document DOC-5014-03 [8.1.7].

8.1.8 Miscellaneous Acceptance Tests

Post-Shipment Fuel Integrity Acceptance Test

For packages containing HBF, cask surface temperatures and cask surface dose rates shall be measured in accordance with the procedures in Chapter 7 as a practical means of monitoring the condition of the fuel assemblies. Fuel reconfiguration and significant fuel cladding damage is not expected after the transportation period of each shipment.

A total of six measurements of both temperature and dose rate shall be recorded before and after each shipment with the loaded cask configured horizontally with impact limiters and no personnel barrier. Three measurements are taken from each side of the package at least 45 degrees below the cask axial centerline (below the top cask trunnion, at or near the cask circumferential centerline and below the bottom cask trunnion).

The post-shipment surface temperature measurements should not exceed the pre-shipment surface temperature measurements by more than 5 degrees C when adjusted under the same ambient conditions. The temperature criteria may be adjusted to account for the difference in ambient conditions such as solar insolation.

The post-shipment surface dose rate measurements should not exceed the pre-shipment surface dose rate measurements by more than 10%.

Failed tests shall be reported to USNRC within one month of the post-shipment measurement and shall include a description of the package contents, any available engineering justification for failed test(s), and if applicable any special precautions that will be implemented prior to unloading the contents of the package. Package exhibiting tests results equal to or greater than twice the acceptance criteria shall not be unloaded without USNRC authorization.

No additional tests are required prior to using the packaging.

Table 8.1.1 (Sheet 1 of 2)
Containment System Performance Specifications (Notes 1, 2 and 4)

Design Attribute	Design Rating
F-12P Fuel Package	
Reference Helium Air Leakage Rate Acceptance Criterion (L_R)	2.0×10^{-5} ref-cm^3/s, He **(Note 3)**
Leakage Rate Test Sensitivity	1.0×10^{-5} ref-cm^3/s, He (½ of the leakage rate acceptance criterion per ANSI N14.5 [8.1.6])
F-32P Fuel Package	
Reference Helium Leakage Rate Acceptance Criterion (L_R)	5.0×10^{-6} ref-cm^3/s, He **(Note 3)**
Leakage Rate Test Sensitivity	2.5×10^{-6} ref-cm^3/s, He (½ of the leakage rate acceptance criterion per ANSI N14.5 [8.1.6])
Non-Fuel Waste Packages	
Reference Air Leakage Rate Acceptance Criterion (L_R)	5×10^{-7} (ref-cm^3/s air) **(Note 3)**
Leakage Rate Test Sensitivity	2.5×10^{-7} ref-cm^3/s air (½ of the leakage rate acceptance criterion per ANSI N14.5 [8.1.6])

Notes:

1. During leakage rate tests appropriate conversion factors will be employed using written and approved procedures to account for actual backfill/tracer gas.
2. The leakage rate acceptance criteria defined herein are applicable to Fabrication, Maintenance, Pre-shipment and Periodic leakage tests.

Table 8.1.1 (Sheet 2 of 2)
Containment System Performance Specifications

Notes (cont'd):

3. 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 leakage rate $L_{R,}$ is "No Detected Leakage" when tested using a test method with a sensitivity of at least $1x10^{-3}$ ref-cm^3/s, air. 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).
4. This table is a condition of the CoC.

Table 8.1.2 (Sheet 1 of 5)
Leakage Rate Tests For The HI-STAR 80 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5 [8.1.6], App. A)	Allowable Leakage Rate
Fabrication Leakage Rate Test (Note 1)	• Containment Shell and Cladding • Containment Lower Forging • Containment Upper Forging • Inner Closure Lid Retainer Ring • Outer Closure Lid • Inner Closure Lid Plug • Outer Closure Lid Test Plug • Vent/Drain Port Bronze Plug • Vent/Drain Port Bushing • Port Inner Cover Plate • Containment Shell Welds • Containment Shell to Containment Lower Forging Weld • Containment Shell to Containment Upper Forging Weld • Spray Cooling Cap • Spray Port Cooling Inner Cover Plate • Inner Closure Lid Test Port Plug • Inner Closure Lid Leak Test Port Primary Helical Thread Insert	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Test Port Plug Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Outer Containment Seal	A.5.4	Table 8.1.1
	• Spray Cooling Cap Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Test Plug Seal	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 2 of 5)
Leakage Rate Tests For The HI-STAR 80 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5 [8.1.6], App. A)	Allowable Leakage Rate
Fabrication Leakage Rate Test (Note 1) Con't.	• Spray Cooling Cover Plate Inner Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Bushing/Plug Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
Pre-Shipment Leakage Rate Test (Note 3)	• Inner Closure Lid Inner Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Inner Closure Lid Test Port Plug Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Spray Cooling Inner Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Vent/Drain Port Outer Containment Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Spray Cooling Cover Plate Inner Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Vent/Drain Port Bushing/Plug Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4 [or Per Note 3]	Table 8.1.1
	• Outer Closure Lid Test Plug Seal	A.5.4 [or Per Note 3]	Table 8.1.1

Table 8.1.2 (Sheet 3 of 5)
Leakage Rate Tests For The HI-STAR 80 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5[8.1.6], App. A)	Allowable Leakage Rate
Maintenance Leakage Rate Test (Note 1)	• Containment Shell and Cladding • Containment Lower Forging • Containment Upper Forging • Inner Closure Lid Retainer Ring • Outer Closure Lid • Inner Closure Lid Plug • Outer Closure Lid Test Plug • Vent/Drain Port Bronze Plug • Vent/Drain Port Bushing • Port Inner Cover Plate • Containment Shell Welds • Containment Shell to Containment Lower Forging Weld • Containment Shell to Containment Upper Forging Weld • Spray Cooling Cap • Spray Port Cooling Inner Cover Plate • Inner Closure Lid Test Port Plug • Inner Closure Lid Test Port Primary Helical Thread Insert	A.5.3	Table 8.1.1
	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Test Port Plug Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Outer Containment Seal	A.5.4	Table 8.1.1
	• Spray Cooling Cap Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Test Plug Seal	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 4 of 5)
Leakage Rate Tests For The HI-STAR 80 Containment System

Leakage Test	Components Tested	Type of Leakage Rate Test (from ANSI N14.5 [8.1.6], App. A)	Allowable Leakage Rate
Maintenance Leakage Rate Test (Note 1) Cont'd	• Spray Cooling Cover Plate Inner Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Bushing/Plug Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
Periodic Leakage Rate Test (Note 1)	• Inner Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Inner Closure Lid Test Port Plug Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Outer Containment Seal	A.5.4	Table 8.1.1
	• Spray Cooling Inner Seal	A.5.4	Table 8.1.1
	• Spray Cooling Cover Plate Inner Seal	A.5.4	Table 8.1.1
	• Vent/Drain Port Bushing/Plug Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Inner Seal	A.5.4	Table 8.1.1
	• Outer Closure Lid Test Plug Seal	A.5.4	Table 8.1.1

Table 8.1.2 (Sheet 5 of 5)
Leakage Rate Tests For The HI-STAR 80 Containment System

Notes:
1. For a Leakage Rate Acceptance Criterion, the summation of individual component leakage rates of the containment boundary of a package is not required.

2. For packages containing HBF, pre-shipment and periodic leakage rate testing shall be performed on all containment boundary closure components (double barrier for moderator exclusion function). For packages containing MBF or NFW, pre-shipment and periodic leakage rate testing shall be performed on either the inner or outer containment boundary closure seals (single barrier, non-moderator exclusion function).

3. For a pre-shipment test implementing the alternative pre-shipment leakage rate acceptance criterion specified in Note 3 of Table 8.1.1, alternative types of leak rate tests, e.g. A.5.1 or A.5.2, may be used as supported by ANSI N14.5.

4. This table is a condition of the CoC.

Table 8.1.3 (Sheet 1 of 2)
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
i.	B_4C powder (raw material) (see note 1)	Particle size distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchasing Specification [8.1.9]
		Purity	One sample per lot	To verify material supplier's data sheet	ASTM C-750
ii.	Al Powder (raw material)	Particle Size Distribution	One sample per lot	To verify material supplier's data sheet	Per Holtec's Purchasing Specification [8.1.9]
		Purity	One sample per lot	To verify material supplier's data sheet	Must be 99% (min.) pure aluminum
iii.	B_4C/Al Mix	B_4C Content (by the wet chemistry method)	One sample per mixed/blended powders lot	To ensure wt.% B_4C requirements compliance	The weight density of B_4C must lie in the range of 10 to 11% Nom.

Table 8.1.3 (Sheet 2 of 2)
Metamic-HT Production Testing Requirements

	Item Tested	Property Tested For	Frequency of Test	Purpose of Test	Acceptance Criterion
iv.	Finished Metamic-HT panel	Thickness and width, straightness, camber and bow	Holtec QA Program Sampling Plan	To ensure fabricability of the basket	Per Holtec's Purchasing Specification [8.1.9]
		Mechanical & Structural Properties in Table 8.1.5 (see Note 3)	Per Sampling Plan Table 8.1.4 (see note 2)	To ensure structural performance.	MGVs per Holtec's Purchasing Specification [8.1.9]
		B_4C content by areal density measurements (neutron attenuation method)	One sample from a panel from each Metamic-HT manufactured lot	To ensure criticality safety	The B_4C content by weight shall be ≥ 10 wt. %

Notes:
1. The B_4C testing requirements apply if the raw material supplier is not in Holtec's Approved Vendor List.
2. Sampling Plan is included in the Metamic-HT Manufacturing Manual [8.1.8].
3. All properties shall be measured at room temperature on extruded coupons.
4. This table is a condition of the CoC.

Table 8.1.4: Tier System for Metamic-HT Production Coupon Testing

Tier No.	Number of Extrusions Tested as a Percent of Number of Extrusions in the Lot	Number of Continuous Lots that Must Pass to Drop Down to the Next Tier
1	20	5
2	12.5	5
3	5	10
4	1	N/A

Note 1: If a coupon fails with respect to any MGV property, then it may be replaced by two coupons from the extrusion that produced the failed coupon. If both of the replacement coupons pass the failed MGV property, then the lot can be accepted. If either of the replacement coupons is unsuccessful in meeting the failed MGV property, then the entire lot is rejected. As an alternative to rejecting the entire lot, testing of the failed MGV value on all extrusions within the lot is permitted to isolate acceptable panels.

Note 2: Testing shall be moved up to the next tier if any MGV property fails in two consecutive lots.

Note 3: Tiering defined on the basis of sample size. Higher tier testing requires greater percentage of sample testing (i.e. moving up the Table).

Note 4: This table is a condition of the CoC.

Table 8.1.5: Minimum Guaranteed Values of Metamic-HT Primary Properties

Property (Note 1)	Temperature, °C	Property Value (Note 2)	Property Type
Yield strength, σ_y (ksi)	Ambient 200/300/350 450	19.5 15.0/13.8/10.0 7.7	Primary
Tensile strength, σ_u (ksi)	Ambient 200/300/350 450	28.2 18.8/15.6/11.9 8.1	Primary
Young's Modulus, E (Msi)	Ambient 200/300/350 450	11.8 10.8/8.8/6.9 3.8	Primary
Area Reduction (%)	Ambient 200/300/350 450	20 17.9/14.2/12.9 7.8	Primary

Note 1: All properties are critical characteristics.
Note 2: Properties can be interpolated, use 40°C for ambient when interpolating.

Table 8.1.6 (Sheet 1 of 2): ASME Code Boiler & Pressure Vessel Code and Other Standards Applicable to HI-STAR 80

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Methodology	Welding	Inspection	Testing
Containment System (pressure vessel except closure seals)	ASME Code Section III Subsection NB-2000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-3000	ASME Code Section III Subsection NB-4000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-5000 and Chapter 8 of this SAR	ASME Code Section III Subsection NB-6000 and Chapter 8 of this SAR
Fuel Basket	Chapter 8 of this SAR	Deflection limited to ensure subcriticality	Deflection Evaluation	Holtec Manufacturing Manual (Note 1) and Chapter 8 of this SAR.	Holtec Manufacturing Manual	Chapter 8 of this SAR
Lifting Trunnions	ASME Code Section II	NUREG-0612 [8.1.11] 10 CFR 71.45 Reg. Guide 3.61 [8.1.12]	NUREG-0612 10 CFR 71.45 Reg. Guide 3.61	Not Applicable	ANSI N14.6 and Chapter 8 of this SAR	ANSI N14.6 and Chapter 8 of this SAR
Trunnions Bushings	ASME Code Section II	ASME Code Section III Subsection NF-3000 for Class 1 supports (for balance of component)	ASME Code Section III Subsection NF-3000 for Class 1 supports (for balance of component)	Not Applicable	Chapter 8 of this SAR	Chapter 8 of this SAR
Outer Shield Cylinders	UNS designation per licensing drawing package	No gross failure leading to significant loss of shielding	Elastic-plastic with inclusion of strain rate effects, as appropriate	Not Applicable	Not Applicable	Chapter 8 of this SAR.
Gamma Shielding Components (metallic)	ASME Code Section II and/or ASTM	No gross failure leading to significant loss of shielding	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Chapter 8 of this SAR.

Table 8.1.6 (Sheet 2 of 2): ASME Code Boiler & Pressure Vessel Code and Other Standards Applicable to HI-STAR 80

Component ID	Material Procurement	Component Design Acceptance Criteria	Stress and Deformation Analysis Methodology	Welding	Inspection	Testing
Basket Shims (including Anti-Rotation/Alignment bar)	ASME Code Section II and/or ASTM	No gross yielding and no buckling	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Chapter 8 of this SAR
Neutron Shielding Material	Holtec Manufacturing Manual	Holtec Qualification Sourcebook	Not Applicable	Not Applicable	Holtec Manufacturing Manual	Chapter 8 of this SAR
Impact Limiter Backbone Structures	ASME Code Section II and/or ASTM	No gross yielding or buckling	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Chapter 8 of this SAR
NFWB	ASME Code Section II and/or ASTM	No gross yielding or buckling	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Not Applicable
Fuel Spacers	ASME Code Section II and/or ASTM	No gross yielding or buckling. No collapse.	ASME Code Section III Subsection NF-3000 for Class 3 supports	ASME Code Section IX and Chapter 8 of this SAR	ASME Code Section V and Chapter 8 of this SAR	Not Applicable

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

Table 8.1.7 (Sheet 1 of 3)
ASME Code Requirements and Alternatives for the HI-STAR 80 Package

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Containment System	NB-1000	Statement of requirements for Code stamping of components.	Cask containment boundary is designed, and will be fabricated in accordance with ASME Code, Section III, Subsection NB to the maximum practical extent, but Code stamping is not required.
Cask Containment System	NB-2000	Requires materials to be supplied by ASME-approved material supplier.	Holtec approved suppliers will supply materials with CMTRs per NB-2000.
Cask Containment System	NB-7000	Vessels are required to have overpressure protection.	No overpressure protection is provided. Function of cask vessel is as a radionuclide containment boundary under normal and hypothetical accident conditions. Cask is designed to withstand maximum internal pressure and maximum accident temperatures.
Cask Containment System	NB-8000	States requirements for name, stamping and reports per NCA-8000.	HI-STAR 80 Package to be marked and identified in accordance with 10CFR71. Code stamping is not required. QA data package prepared in accordance with Holtec's approved QA program.

Table 8.1.7 (Sheet 2 of 3)
ASME Code Requirements and Alternatives for the HI-STAR 80 Package

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask Containment System	NB-2330	Establish TNDT and test base metal, heat affected zone and weld metal at TNDT + 60ºF	Rather than testing to establish the RTNDT as defined in paragraph NB-2331, the guidance from Reg Guide 7.11 [8.1.4] is used for materials less than or equal to 4 inches thick and Reg Guide 7.12 [8.1.5] is used for materials from greater than 4 up to 12 inches thick. The provisions of Reg. Guides 7.11 is applicable for the containment shell material. Reg. Guide 7.11 for materials up to 4 inches thick does have a reference to SA203 material and requires the TNDT to be <-56.7ºC (-70ºF). Since the specified TNDT for the shell material, as reflected in Table 8.1.8, is lower, it is in compliance with NB-2330. Table 8.1.8 summarizes the specific impact testing requirements for the Containment Boundary components per Reg. Guides 7.11 and 7.12. Thicknesses of containment welds on the HI-STAR 80 are less than or equal to the containment shell weld thickness. Therefore the TNDT for the containment welds will be the same as the TNDT for the containment shell as reflected in Table 8.1.8. Drop weight testing is not required to determine the TNDT for the containment welds.

Table 8.1.7 (Sheet 3 of 3)
ASME Code Requirements and Alternatives for the HI-STAR 80 Package

Component	Code Section	Code Requirement	Alternative, Justification & Compensatory Measures
Cask • Containment System • Cask components welded to the containment system	NB-4622	All welds, including repair welds, shall be post-weld heat treated (PWHT).	Exemptions apply per NB-4622.7 and Table NB-4622.7(b)-1.
Cask Containment System	NB-5120	Perform radiographic examination after post-weld heat treatment (PWHT).	The NDE (radiographic examination) is not known to cause any defects in tested materials and shall be performed to provide assurance that the weld is free of defects. Radiography of pressure retention boundary welds after PWHT is not required. All welds (including repairs) will have passed radiographic examination prior to PWHT of the entire containment boundary. Confirmatory radiographic examination after PWHT is not necessary because PWHT is not known to introduce new weld defects in nickel steels.

Table 8.1.8 (Sheet 1 of 6): Fracture Toughness Test Criteria: Containment System

Item (Note 1)	Material	Thickness in. (mm)	Qualification to LST of -29°C (-20°F) (Note 5)		Qualification to LST of -40°C (-40°F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Weld Metal for NB Welds	As required	NA	$T_{NDT} \leq$ -67.78°C (-90°F) per Code Alternative in Table 8.1.7 of this SAR. Testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	Drop Test Not Required	$T_{NDT} \leq$ -78.9°C (-110°F) per Code Alternative in Table 2.2.13 of this SAR. Testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2430 and Article NB-2330	Drop Test Not Required
Containment Shell	SA-203 E/ SA-350 LF3	2 (51)	$T_{NDT} \leq$ -67.78°C (-90°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -67.78°C (-90°F) per R.G. 7.11	$T_{NDT} \leq$ -78.9°C (-110°F) with testing and acceptance criteria per ASME Section III, Subsection NB, Article NB-2330	$T_{NDT} \leq$ -78.9°C (-110°F) per R.G. 7.11
Containment Shell Cladding	Grades 30400/30403/30453/30480/30880/30883/30980/30983/31600/31603/31653/31680/31683	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Inner Closure Lid Retainer Ring	SA-182 FXM-19 (UNS 20910)	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Table 8.1.8 (Sheet 2 of 6): Fracture Toughness Test Criteria: Containment System

Item (Note 1)	Material	Thickness in. (mm)	Qualification to LST of -29⁰C (-20⁰F) (Note 5)		Qualification to LST of -40⁰C (-40⁰F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Outer Closure Lid Bolt	SA 564-630 (H1100)	1.42 (36)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 4) Test temperature ≤ -29ºC (-20ºF)	No requirements (per NB-2333)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 4) Test temperature ≤ -40ºC (-40ºF)	No requirements (per NB-2333)
Outer Closure Lid Threaded Bolt Hole Insert	UNS S21800/UNS N07750	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Outer Closure Lid	SA 965-F304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Table 8.1.8 (Sheet 3 of 6): Fracture Toughness Test Criteria: Containment System

Item	Material	Thickness in. (mm)	Qualification to LST of -29⁰C (-20⁰F) (Note 5)		Qualification to LST of -40⁰C (-40⁰F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Inner Closure Lid Plug	SA 965-F304/SA 182-F304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Inner Closure Lid Bolt	SA 564-630(H1100)	1.42 (36)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 4) Test temperature ≤ -29ºC (-20ºF)	No requirements (per NB-2333)	Cv (lateral expansion): minimum 25 mils (per Table NB-2333-1) for each of three specimens. (Note 4) Test temperature ≤ -40ºC (-40ºF)	No requirements (per NB-2333)
Inner Closure Threaded Bolt Helical Insert	UNS S21800/UNS N07750	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Table 8.1.8 (Sheet 4 of 6): Fracture Toughness Test Criteria: Containment System

Item (Note 1)	Material	Thickness in. (mm)	Qualification to LST of -29°C (-20°F) (Note 5)		Qualification to LST of -40°C (-40°F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Containment Upper Forging	SA 965-F304/SA 182-F304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Containment Lower Forging	SA 965-F304/SA 182-F304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Outer Closure Lid Test Plug	SA 193-B8/SA 193-B8S/SA 193-B8R	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Vent/Drain Port, Bronze Plug	SB 150 C62400/SB 505 C95400	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Vent/Drain Port, Bushing	SA 479-S21800	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Table 8.1.8 (Sheet 5 of 6): Fracture Toughness Test Criteria: Containment System

Item (Note 1)	Material	Thickness in. (mm)	Qualification to LST of -29⁰C (-20⁰F) (Note 5)		Qualification to LST of -40⁰C (-40⁰F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Spray Cooling Cap	SA 479-S21800	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Spray Port Cooling Inner Cover Plate	SA 240-304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Spray Cooling Cover Plate Bolt	SA 193-B7/SA 564-630 (H1100)	0.39 (10)	No requirements (exempt per Table NB-2333-1)	No requirements (exempt per NB-2311)	No requirements (exempt per Table NB-2333-1)	No requirements (exempt per NB-2311)
Inner Closure Lid Test Port Plug	SA 193-B8/SA 193-B8S/SA 193-B8R	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Inner Closure Lid Leak Test Port Primary Helical Thread Insert	UNS S21800/UNS N07750	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Table 8.1.8 (Sheet 6 of 6): Fracture Toughness Test Criteria: Containment System

Item (Note 1)	Material	Thickness in. (mm)	Qualification to LST of -29^{0}C (-20^{0}F) (Note 5)		Qualification to LST of -40^{0}C (-40^{0}F) (Note 5)	
			Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)	Charpy V-Notch Temperature (Note 2)	Drop Test Temperature (Note 3)
Port Inner Cover Plate	SA 240-304/SA 479-304	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)
Cover Plate Bolt	SA 193-B7/SA 564-630 (H1100)	0.39 (10)	No requirements (exempt per Table NB-2333-1)	No requirements (exempt per NB-2311)	No requirements (exempt per Table NB-2333-1)	No requirements (exempt per NB-2311)
Orifice Helical and Spray Cooling Thread Insert	UNS S21800/UNS N07750	-	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)	No requirements (exempt per NB-2311)

Notes:

1. Containment System components with exemption from brittle fracture testing in accordance with ASME Section III, Subsection NB-2300 may not be listed in this table. All Containment System components and base materials are provided in the drawing package referenced in the CoC.
2. Component material to be charpy impact tested in accordance with ASTM A370
3. Component material to be drop weight tested in accordance with ASTM E208-87a.
4. An additional Charpy absorbed energy requirement of 5 ft-lb at -29ºC (-20ºF) or at -40^{0}C (-40^{0}F), depending on the desired cask LST qualification, is imposed on the closure lid bolts.
5. The cask may be qualified to either to an LST of either -29^{0}C (-20^{0}F) or -40^{0}C (-40^{0}F).
6. This table is a condition of the CoC.

Table 8.1.9
Fracture Toughness Test Criteria: Ferritic Steel Parts for HI-STAR 80

Item (Notes 1, 2 and 3)	Material	Thickness in. (mm)	Charpy V-Notch Test Temperature	Remarks
Cask				
Lifting Trunnions	SA 564-630 (H1100)	8 1/8 (206)	Test at -40°C (-40°F)	Charpy absorbed energy is 35 ft.-lb. (average of 3 specimens and minimum of 30 ft.-lb. for any single specimen) Charpy (lateral expansion) is 15 mils
Intermediate Shell	SA-517 Gr. E, F or P	1 7/8 (48)	Test at -40°C (-40°F)	Charpy absorbed energy is 27 ft.-lb. (average of 3 specimens and minimum of 22 ft.-lb. for any single specimen) Charpy (lateral expansion) is 15 mils

Notes:

1. The drawing package referenced in the CoC may specify additional material options such as austenitic steels and non-ferrous materials that are not shown in this table and that are not subject to brittle fracture at the LST of the package.
2. Components may be exempt from impact testing as allowed by NF-2311 [8.1.1].
3. SA 516 GR. 70 plate may be normalized.
4. Charpy absorbed energy values are based on actual thickness and/or minimum specified yield strength per Figure NF 2331(a)-2.
5. Impact testing only applies to ferritic steel dose blocker parts located at the exterior boundary of the cask with the exception of the Intermediate Shell.
6. Components shall meet the acceptance standard applicable to either Charpy for Absorbed Energy or Charpy for Lateral Expansion.
7. This table is a condition of the CoC.

Table 8.1.10: [PROPRIETARY INFORMATION WITHHELD PER 10 CFR 2.390]

Table 8.1.11: Impact Limiter Crush Material (Aluminum Honeycomb) Crush Strength

Crush Material Type	Crush Strength (nominal), σ_c, psi (Target volumetric average value)
Type 1	2,400 ~ 2,900
Type 2	3,200 ~ 3,800
Type 3	450 ~ 550

Notes:

1. Like all manufactured materials, the crush strength of the Aluminum Honeycomb material are subject to slight variation. The crush strength of the procured material will be held to a tolerance band of about 20% (nominal crush strength ± 10%).

2. This table is a condition of the CoC.

Table 8.1.12: Emissivity of Metamic-HT Baskets

Component	Temperature, ºC	Emissivity Value (dimensionless), e
Metamic-HT Fuel Basket Panels (F-12P and F-32B Fuel Baskets)	150≤T≤500	0.9

8.2 MAINTENANCE PROGRAM

An ongoing maintenance program for the HI-STAR 80 Package will be prepared and issued prior to the delivery and first use of the HI-STAR 80 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 80 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 80 package is totally passive by design. There are no active components or systems required to assure the continued performance of its safety functions. As a result, only minimal maintenance will be required over its lifetime, and this maintenance would primarily result from weathering effects, and pre- and post-usage requirements for transportation. Typical of such maintenance would be the reapplication of corrosion inhibiting materials on accessible external surfaces, seal replacement, and leak testing following seal replacement. Such maintenance requires methods and procedures no more demanding than those currently in use at nuclear power plants.

A maintenance inspections and tests program schedule for the HI-STAR 80 Package is provided in Table 8.2.1.

8.2.1 Structural and Pressure Tests

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

8.2.2 Leakage Tests

Leakage rate tests on the cask containment system shall be performed per written and approved procedures in accordance with the requirements of Chapter 7 and the requirements of ANSI N14.5 [8.1.6] specified in this Chapter. Tables 8.1.1 and 8.1.2 specify the allowable leakage rates and test sensitivity as well as components to be tested for maintenance and periodic leakage rate tests.

If the pre-shipment leakage rate test (Section 8.1.4) expires, a periodic leakage rate test of the containment seals must be performed prior to transport. The periodic leakage rate test shall be performed at the frequency indicated in Table 8.2.1.

Maintenance leakage rate testing of containment seals is performed prior to returning a package to service following maintenance, repair (such as weld repair), or replacement of containment system components (such as containment seal replacement and/or removal of closure bolts/plugs/bushings). Only that portion of the containment system that is affected by the maintenance, repair or component replacement needs to be leak tested.

In case of unsatisfactory leakage rate, weld repair, seal surface repair/polishing and/or seal change and retest shall be performed until the test acceptance criterion is satisfied.

Periodic and maintenance leakage rate test results shall be documented in accordance with the user's quality assurance program.

Leakage rate testing procedures shall be approved by an ASNT Level III specialist. The written and approved test procedure shall clearly define the test equipment arrangement. Leakage rate testing shall be performed by personnel who are qualified and certified in accordance with the requirements of SNT-TC-1A [8.1.2]. Leakage rate testing shall be performed in accordance with a written quality assurance program.

8.2.3 Component and Material Tests

8.2.3.1 Relief Devices

The neutron shield relief devices shall be visually inspected for damage or indications of excessive corrosion prior to fuel loading of the HI-STAR 80 package. If the inspection determines an unacceptable condition, the neutron shield relief devices shall be replaced. Additionally, the neutron shield relief devices may be replaced periodically while the cask is in service if recommended by the manufacturer's O&M manual.

8.2.3.2 Shielding Materials

Periodic verification of the neutron shield integrity shall be performed as required by Table 8.2.1 prior to shipment using written and approved procedures. Calibrated radiation detection equipment shall be used to take measurements (with either loaded contents or a check source) at the surface of the package. At a minimum, measurements shall be taken at three cross sectional planes through the radial shield and at four points along each plane's circumference. The average measurement results from each sectional plane shall be compared to calculated values to assess the continued effectiveness of the neutron shield. The calculated values shall be representative of the loaded contents (i.e., fuel/NFW type, enrichment, burnup, cooling time, etc…) or the particular check source used for the measurements.

The test results shall be documented and maintained in accordance with the user's quality assurance program.

8.2.3.3 Packaging Surfaces

Accessible external surfaces of the packaging (including impact limiters) shall be visually inspected for damage prior to each fuel loading to ensure that the packaging effectiveness is not significantly reduced. Visual inspections of the cask and impact limiters shall be performed for external surface coating (if applicable) and component damage including surface denting, surface penetrations, weld cracking, chipped or missing coating. Where necessary and applicable, cask coatings shall be reapplied. **Damage shall be evaluated for impact on**

packaging safety and shall be repaired or replaced accordingly. Wear and tear from normal use will not impact cask safety. **Repairs or replacement in accordance with written and approved procedures, as set down in the O&M manual, shall be required if unacceptable conditions are identified.**

Prior to installation or replacement of a closure seal, the cask sealing surface shall be cleaned and visually inspected for scratches, pitting or roughness, and affected surface areas shall be polished smooth or repaired as necessary in accordance with written and approved procedures.

8.2.3.4 Packaging Fasteners

Cask and impact limiter fasteners shall be visually inspected for damage such as excessive wear, galling, or indentations on the threaded surfaces prior to installation. Threaded fasteners shall be examined in accordance with paragraph NB-2582, ASME Section III, Subsection NB. Fasteners without sufficient usable thread length meeting the requirements of NB-2582 shall be replaced. Damaged internal threads (including bushings, welded/helical inserts and other threaded components) may be repaired per standard industry practice. Any repair shall be evaluated to ensure ASME Code stress limits applicable to bolted closure joints are met. Any required material or manufacturing process testing would also be performed in accordance with ASME Section III, Subsection NB or Subsection NF as applicable.

Bolting of both Inner Closure Lid Assembly (Inner Lid and Retainer Ring) and Outer Closure Lid, and bolting of the Spray Cooling and Vent/Drain Port Cover Plates shall be replaced as guided by fatigue analysis per the provisions of Section III of the ASME Code. The maintenance program in Table 8.2.1 provides a bolt change out schedule to insure that the cumulative damage factor accumulated by a bolt shall be less than 1.0 with sufficient margin. One bolting cycle is the complete sequence of torquing and removal of bolts.

Inserts, plugs and bushings in the Containment Upper/Lower Forgings Vent/Drain ports and closure lids/cover plates bolt holes have a maximum service life limit based on bolting or torqueing/untorqueing cycles as determined by fatigue analysis per the provisions of Section III of the ASME Code. The bolting or torqueing cycles specified in Table 8.2.1 shall not be exceeded. One bolting or torqueing cycle is the complete sequence of torquing and removal of bolts or threaded device.

8.2.3.5 Cask Trunnions

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

the cask. The repair process shall involve removal of the trunnion from the cask and inspection of all surfaces of the trunnion for further defects that may require repair.

Trunnion inserts and bushings shall be visually inspected during repair or replacement of the trunnions, for damage such as excessive wear, galling, or excessive indentations on the bearing. The severity of damage shall be evaluated per standard industry practice. Damaged bushings shall be replaced accordingly. Any required material or manufacturing process testing for the Trunnions bushings is performed in accordance with the original codes and standards.

Following any replacements and/or repair, the load testing (Subsection 8.1.3) shall be re-performed and the components re-examined in accordance with the original procedure and acceptance criteria.

8.2.3.6 Closure Seals

The HI-STAR 80 Packaging may be equipped with elastomeric seals as specified in the drawing in the CoC. The closure seals are shipped from the factory pre-inspected and carefully packaged. Once installed and compressed, the seals should not be disturbed by removal of closure fasteners. **Removal of closure fasteners and closure lid or port cover pate may require the seals to be visually inspected to ensure it remained free of debris, and no tears or gouges occurred during lid removal. If seals are deemed acceptable they may be re-used until leakage testing indicates they can no longer meet the leakage criteria or are replaced based on the seal design life as recommended by the seal manufacturer.** Closure seals are specified for long-term use and do not require additional maintenance.

8.2.3.7 Fuel Basket

No additional tests are required for the HI-STAR 80 fuel basket. Long-term fuel basket integrity has been ensured by fuel basket design and by extensive material testing. The essential fuel basket predicates including the effects of creep and irradiation, lateral deflection, protection against crack propagation and tearing, and B-10 area density, in conjunction with the minimum guaranteed values (MGVs) provided in Table 8.1.5 ensure that the fuel basket will meet its performance requirements.

8.2.3.8 Fuel Spacers

Prior to loading into cask, fuel spacers shall be visually inspected for damage. If inspection determines an unacceptable condition, the fuel spacer shall be replaced in accordance with written and approved procedures.

8.2.4 Thermal Tests

Periodic thermal performance test shall be performed at the frequency provided in Table 8.2.1 prior to shipment to demonstrate that the thermal capabilities of the cask remain within its design basis.

This test may be performed after a HI-STAR 80 Package is loaded with spent nuclear fuel and prior to transport. **The in-service test is performed to verify a continued adequate rate of heat dissipation from the cask to the environment.** Acceptable performance under test conditions ensures that design basis fuel cladding temperature limits to which the HI-STAR 80 Package is qualified under design basis heat loads will not be exceeded during transport.

Prior to performing the test, thermal equilibrium of the HI-STAR 80 Package shall be verified by measuring the temperature at a defined point near the mid-plane of the HI-STAR 80 Package at one hour intervals using a calibrated thermocouple or surface pyrometer. Appropriate criteria defining when thermal equilibrium is achieved shall be determined based on a variety of ambient test conditions and incorporated into the test procedure.

After thermal equilibrium is established, **temperatures shall be measured and recorded using a calibrated thermocouple or surface pyrometer at a minimum of four equally spaced circumferential locations at the mid height of the active fuel.** The decay heat load and fuel cycle history of the fuel assemblies loaded in the HI-STAR 80 Package shall also be recorded.

The HI-STAR 80 Package is considered acceptable if the average measured surface to ambient temperature differential indicated in the procedure, when adjusted for environmental conditions, is not exceeded.

Final test data for the thermal test shall become part of the quality records documentation package.

8.2.5 Miscellaneous Tests

No additional tests are required for the HI-STAR 80 Packaging, packaging components, or packaging materials.

Table 8.2.1 (Sheet 1 of 2)
Maintenance Inspections and Tests Program Schedule

Task	Schedule
Cask surface visual inspection. (See Paragraph 8.2.3.3)	Prior to each fuel loading
Fuel Spacer Inspection (See Paragraph 8.2.3.8)	Prior to loading into cask.
Cask closure fasteners/bolts and Vent/Drain ports inserts/bushings visual inspection (See Paragraph 8.2.3.4)	Prior to installation
Cask trunnions visual inspection of surfaces outside cask (See Paragraph 8.2.3.5.)	Prior to each fuel loading
Cask trunnions (all surfaces), bushings and inserts (See Paragraph 8.2.3.5)	Following observed deformation, distortion, or cracking of trunnions or adjacent cask surfaces in accordance with Paragraph 8.2.3.5, or during repair or replacement of trunnions.
Impact limiter and impact limiters fasteners/bolts visual inspection (See Paragraph 8.2.3.3 and 8.2.3.4)	Prior to installation and/or prior to each transport
Neutron shield relief device visual inspection (See Paragraph 8.2.3.1)	Prior to each fuel loading
Periodic leakage rate test of containment system seals (See Subsection 8.2.2)	Annually or prior to off-site package transport if period from last test exceeds 1 year
Seal replacement for Inner and Outer Closure Lids, Spray Cooling Cap and Cover Plate, and Test Port Inner Plug and Outer Plug (inner seals) (See Paragraph 8.2.3.6)	If the seal is found to be damaged, or does not meet the maintenance leakage rate test or pre-shipment test criteria, or if required based on seal design life limitations as recommended by the manufacturer
Bolt replacement (*Service Life*) for Inner and Outer Closure Lids (See Paragraph 8.2.3.4)	Maximum allowable bolting cycles for SA 564-630 (H1100)/SB 637-N07718: 265
Bolt hole inserts replacement (*Service Life)* for Containment Upper Forging bolts (Inner and Outer Closure) (See Paragraph 8.2.3.4)	Maximum allowable cycles for UNS S21800/UNS N07750: 20,000
Replacement (Service Life) for Vent/Drain Ports Bronze Plug (See Paragraph 8.2.3.4)	Maximum allowable cycles for SB 150 C62400/SB 505 C95400: 2,400

Table 8.2.1 (Sheet 2 of 2)
Maintenance Inspections and Tests Program Schedule

Replacement (Service Life) for Vent/Drain Ports Bushing (See Paragraph 8.2.3.4)	Maximum allowable cycles for SA 479-S21800: 20,000
Replacement (Service Life) for Vent/Drain Ports Cover Plates Bolts (8.2.3.4)	Maximum allowable cycles for SA 193-B7/SA 564-630 (H1100)//SB 637-N07718: 588
Replacement (Service Life) for Spray Cooling Cap (8.2.3.4)	Maximum allowable cycles for SA 479-S21800: 20,000
Replacement (Service Life) for Spray Cooling Cover Plate Bolt (8.2.3.4)	Maximum allowable cycles for SA 193-B7/SA 564-630 (H1100)/SB 637-N07718: 588
Replacement (Service Life) for Inner Closure Lid Test Port Inner Plug (8.2.3.4)	Maximum allowable cycles for SA 193-B8/SA 193-B8S//SA 193-B8R: 20,000
Replacement (Service Life) for Inner Closure Lids Leak Test Ports Primary Helical Thread Inserts (8.2.3.4)	Maximum allowable cycles for UNS S21800/UNS N07750: 20,000
Orifice Helical and Spray Cooling, Thread Insert (Service Life) (See Paragraph 8.2.3.4)	Maximum allowable cycles for UNS S21800/UNS N07750: 20,000
Seal replacement for Vent/Drain Ports Bushing, Bronze Plug and Cover Plate (See Paragraph 8.2.3.6)	If the seal is found to be damaged, or does not meet the maintenance leakage rate test or pre-shipment test criteria, or if required based on seal design life limitations as recommended by the manufacturer
Neutron shield relief device replacement (See Paragraph 8.2.3.1)	As required by the manufacturer's O&M manual or due to unacceptable condition observed during inspection
Shielding Test (See Paragraph 8.2.3.2)	Within 5 years of the last shielding effective test prior to shipment or following major repairs and maintenance activities
Thermal Test (See Subsection 8.2.4)	Within 5 years of the last thermal performance test prior to shipment or following major repairs and maintenance activities
Maintenance Leakage Rate Test (See Subsection 8.2.2)	Following maintenance, repair or replacement of containment system components

Note: This table is a condition of the CoC.

CHAPTER 8 REFERENCES

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

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

[8.1.1] American Society of Mechanical Engineers, "Boiler and Pressure Vessel Code," Sections II, III, V, IX, and XI, 2010 Edition unless otherwise indicated (Section IX, 2013 for FSW only unless otherwise indicated).

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

[8.1.3] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials - Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kilograms) or More", ANSI N14.6, September 1993.

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

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

[8.1.6] American National Standards Institute, Institute for Nuclear Materials Management, "American National Standard for Radioactive Materials Leakage Tests on Packages for Shipment", ANSI N14.5, 2014.

[8.1.7] Holtec International Document DOC-5014-03, "Acceptance Testing of First HI-STAR Overpack (Thermal and He Leak Tests)", September 2006

[8.1.8] "Metamic-HT Manufacturing Manual", Latest Revision, Holtec International (Holtec Proprietary)

[8.1.9] "Metamic-HT Purchasing Specification", Holtec Document ID PS-11, Latest Revision, (Holtec Proprietary)

[8.1.10] "Metamic-HT Qualification Sourcebook", HI-2084122, Latest Revision, Holtec International (Privilege Intellectual Property)

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

[8.1.12] Regulatory Guide 3.61 (Task CE306-4) "Standard Format for a Topical Safety Report for a Spent Fuel Storage Cask", USNRC, February 1989.

[8.1.13] 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.