Docket No. 71-9235

NAC-STC

NAC Storage Transport Cask

SAFETY ANALYSIS REPORT

Volume 1 of 2

Amendment for
CONNECTICUT YANKEE ATOMIC POWER COMPANY

NAC INTERNATIONAL

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November 8, 2000

U.S. Nuclear Regulatory Commission
11555 Rockville Pike
Rockville, MD 20852-2738
Attention: Document Control Desk

Subject: Docket No. 71-9235

Request for Amendment of the NAC-STC Certificate of Compliance (No. 9235) to Incorporate the Connecticut Yankee (Haddam Neck) Nuclear Power Plant Spent Fuel and GTCC Waste as Approved Contents

References:

1. Request for Amendment of the Certificate of Compliance for the NAC International, Inc., Multi-Purpose Canister (MPC) System (Certificate No. 1025) to Incorporate the Connecticut Yankee (Haddam Neck) Nuclear Power Plant Spent Fuel as Approved Contents, NAC International, May 19, 2000
2. Certificate of Compliance No. 9235 for the Model No. NAC-STC, Revision 2, United States Nuclear Regulatory Commission, March 25, 1999
3. Letter, "NAC-STC Amendment Request," USNRC, October 20, 2000
4. Letter, "Planned NAC-STC Amendment Request to Incorporate Connecticut Yankee fuel and GTCC Waste," NAC International, October 30, 2000
5. Conference Call, USNRC and NAC International, October 30, 2000

NAC International (NAC) herewith requests that Reference 2 (Certificate of Compliance No. 9235 for the NAC-STC) be amended to incorporate Connecticut Yankee (CY) spent fuel and GTCC waste as approved contents. The CY-MPC canistered configuration is currently under review at the NRC per Reference 1. This proposed amendment for the CY-STC has been discussed with the Spent Fuel Project Office staff in References 3, 4 and 5.

This amendment request is in the form of a complete NAC-STC Safety Analysis Report (SAR) modified to incorporate the Revision STC-00A revised licensing drawings and changed pages for Connecticut Yankee. Revision bars on the pages indicate where changes have been incorporated. Pages with text flow changes are only indicated by the Revision STC-00A in the page header. Ten copies of the modified SAR are provided.

This submittal includes NAC Proprietary Information in the form of two calculation packages. Three copies of the NAC Proprietary Information are provided in appropriately marked separate packaging. The executed Proprietary Information Affidavit is enclosed. The NAC Proprietary Information included in this submittal is: NAC Calculation Packages No. 12414-2103, Revision 0, "CY-MPC/STC Balsa Impact Limiter Analysis," and EA790-2233, Revision 0, "Reduction of

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the Redwood & Balsa Test Data." These calculation packages are the bases for the impact limiter design documented in the SAR for the NAC-STC.

As described in Reference 4 and discussed in Reference 5, this amendment request is complete for the NRC to begin the technical review in accordance with the NRC's handling of other recent similar transport cask certification requests. Benchmarked validation of the cask drop evaluations will be provided in a separate submittal.

Implementation of the CY-MPC and CY-STC systems for spent fuel storage and transport is a critical path item for successful completion of the decommissioning of the Connecticut Yankee site. Therefore, NAC requests that the NRC complete the technical review and approval of this amendment request on a schedule that will support the CY decommissioning project.

If you have any comments or questions, please contact me at 678-328-1321.

Sincerely,

JS Hobbs/for

Thomas C. Thompson
Director, Licensing
Engineering & Design Services

Enclosures: Proprietary Information Affidavit
Three copies of two NAC Proprietary Calculation Packages
Ten copies of the NAC-STC SAR Amendment for Connecticut Yankee – Volumes 1 and 2

cc: T. Troutman, Bechtel
E. Glasbergen, Bechtel

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AFFIDAVIT

IN SUPPORT OF PROPRIETARY INFORMATION CONTAINED IN THE REQUEST FOR AN AMENDMENT OF THE NAC-STC CERTIFICATE OF COMPLIANCE TO INCORPORATE CONNECTICUT YANKEE FUEL AND GTCC WASTE AS APPROVED CONTENTS

State of Georgia, County of Gwinnett

James M. Viebrock (Affiant), Group Senior Vice President, Manufacturing & Projects, of NAC International, hereinafter referred to as NAC, at 655 Engineering Drive, Norcross, Georgia 30092, being duly sworn, deposes and says that:

1. Affiant is personally familiar with the trade secrets and privileged information contained in the NAC-STC Amendment Request being submitted to incorporate Connecticut Yankee fuel and GTCC waste as approved contents. Affiant requests that the Nuclear Regulatory Commission, pursuant to Chapter 10 of the Code of Federal Regulations, Part 2.790 (10 CFR 2.790) "Public Inspections, Exemptions, Request for Withholding," withhold the information contained within the calculations submitted as part of the subject amendment request, hereafter referred to as the Proprietary Material, from public disclosure.

2. This information has been and is held in confidence by NAC International Inc.

3. The information contained within the proprietary material is the result of design calculations including component design details and critical dimensions that were developed by NAC. This type of information is held in confidence based on the significant commercial investment of time and money expended in its development.

4. The Proprietary material being transmitted to the Nuclear Regulatory Commission in confidence includes NAC Calculations No. 12414-2103, "CY-MPC/STC Balsa Impact Limiter Analysis" and EA790-2233, "Reduction of the Redwood & Balsa Test Data."

5. The information that is being claimed as trade secrets and privileged information has not been and is not available in public sources.

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6. NAC has invested a considerable amount of time, engineering labor, and money in the development of the calculations. Public disclosure of this information would cause substantial harm to the competitive position of NAC. Others seeking to develop similar analysis would have to make similar investments to develop the information on their own as long as the information is not disclosed to the public.

James M. Viebrock
Group Senior Vice President
Manufacturing & Projects
NAC International

Subscribed and sworn to before me this 8th day of November 2000.

Yvonne Tombetti

Notary Public in and for the
County of Cobb
State of Georgia

My commission expires the 4th day of November, 2002

Notary Public, Cobb County, Georgia
My Commission Expires Nov. 4, 2002

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Revision STC-00A

August 2000

NAC-STC

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1.0 GENERAL INFORMATION

NAC International (NAC) has designed a Storable Transport Cask (NAC-STC) for spent nuclear fuel. The United States Nuclear Regulatory Commission (NRC) licenses the NAC-STC for the transport of spent nuclear fuel. This Safety Analysis Report (SAR) addresses the ability of the NAC-STC to satisfy the NRC transportation requirements for spent fuel, either directly loaded in the cask (uncanistered) or in a canister, and Greater Than Class C (GTCC) waste in a Transportable Storage Canister, as prescribed in 10 CFR 71.

The Transportable Storage Canister is a component of the NAC-MPC dry storage system. The NAC-MPC is provided in two configurations. The first is designed to store Yankee Class spent fuel and GTCC waste and is referred to as the Yankee-MPC. The second is designed to store Connecticut Yankee spent fuel and GTCC waste and is referred to as the CY-MPC.

This chapter presents a general introduction to the transport cask and a description of its design features. The terminology used throughout this report is summarized in Table 1-1.

The NAC-STC may be shipped by rail, barge, or heavy-haul vehicle. The NAC-STC is assigned a Transport Index of 20 based on the shielding evaluation summarized in Section 5.1.4. As shown in Chapter 6, the Transport Index based on nuclear criticality safety is zero, since an infinite number of packages with optimum moderation remain subcritical.

The NAC-STC has been designed to satisfy the international requirements of IAEA Safety Series No. 6, in addition to U.S. requirements prescribed in 10 CFR 71.

Table 1-1 Terminology

Cask Model	NAC-STC
NAC-STC Cask	This packaging consists of a spent-fuel storable transport cask body with dual closure lids and energy-absorbing impact limiters.
Packaging	The assembly of components necessary to ensure compliance with the packaging requirements of 10 CFR 71. Within this report, the packaging is denoted as the NAC-STC.
Package	The packaging with its radioactive contents (payload), as presented for transport (10 CFR 71.4). Within this report, the package is denoted as the NAC-STC, the NAC-STC cask or, simply, the cask.
Contents (Payload)	Twenty-six (26) pressurized water reactor (PWR) fuel assemblies in the directly loaded fuel (uncanistered) configuration or a sealed Transportable Storage Canister containing Yankee Class or Connecticut Yankee spent fuel or Greater Than Class C waste.
Containment System	The components of the packaging intended to retain the radioactive material during transport.
Cask Body	
- **Multiwall Body**	Construction of the cask body, which consists of concentric layers of the inner shell, gamma shielding, outer shell and neutron shielding materials.
- **Neutron Shield**	Consists of the stainless steel shell, gussets, and end plates, copper-stainless steel (Cu/SS) fins, and the solid NS-4-FR neutron shielding material.

Table 1-1 Terminology (continued)

NS-4-FR	A solid, synthetic polymer developed by BISCO Products, Inc. and supplied by Japan Atomic Power Company and its licensees. NS-4-FR is a borated hydrogenous material, which results in neutron absorption capabilities similar to borated water.
Lifting Trunnions	Four, high-strength stainless steel components welded to the top forging that are used in pairs for lifting and handling the cask.
Top Forging	
- Interlid Port	A penetration in the top forging that is used as (1) a drain for the interlid region and (2) a pressure test port for the outer lid seal.
- Pressure Port	A penetration in the top forging that houses a pressure transducer, which may be used to monitor the pressure in the interlid region during storage.
- Port Cover Assembly	Includes the port cover body, spacer, retainer, bolts and o-rings.
- Pressure Transducer	An instrument for measurement of pressure in a confined space.
- O-Ring	An o-ring seals the interfaces between separate cask components.
- PTFE	Blended Polytetrafluoroethylene (PTFE) is an o-ring material used as a sealing component between metallic surfaces.
- Interseal	Refers to the region between pairs of o-rings.

Table 1-1 Terminology (continued)

Bottom Inner Forging	The cup-shaped component that forms the bottom of the NAC-STC cavity.
Bottom Outer Forging	The ring-shaped component that forms the bottom outer region of the NAC-STC.
Bottom Plate	The plate welded to the bottom outer forging, which forms the bottom of the cask. The bottom plate encloses the neutron shielding material in the bottom of the cask.
Rotation Trunnion Recesses	Two stainless steel blocks, each provided with a deep machined groove suitable to accept the rear cask support. These recesses are welded onto the outer shell near the bottom of the cask.
Cask Cavity	The volume of space within the containment boundary.
Transportable Storage Canister (Canister)	The stainless steel cylindrical shell, bottom end plate, shield lid, and structural lid that holds the canistered fuel basket or Greater Than Class C Waste.
Canister Spacer	Structures that position the canister in the NAC-STC cavity during transport. The Yankee-MPC uses two spacers constructed of aluminum honeycomb material encased in a shell constructed of 6061-T6 aluminum alloy. The CY-MPC uses a single spacer constructed of concentric rings of stainless steel welded to a stainless steel base plate.

Table 1-1 Terminology (continued)

Fuel Basket	The structure located in the cask cavity or transportable storage canister to support the fuel assemblies.
- Support Disk	A circular stainless steel plate with square holes machined in a symmetrical pattern. The support disk is the primary lateral load-bearing component of the basket. Each square hole in the support disk is a location for a fuel tube.
- Heat Transfer Disk	A circular aluminum plate with square holes machined in a symmetrical pattern. The heat transfer disk enhances heat transfer in the fuel basket. Each square hole in the heat transfer disk is a location for a fuel tube.
- Fuel Tube	A stainless steel tube with a square cross-section and BORAL neutron poison material on its exterior surfaces.
- Threaded Rod	Aligns and supports the support disks and heat transfer disks in the fuel basket in the cask cavity.
- Spacer Nut	Installed on the threaded rod between the support disks to properly position and provide axial support for the support disks and heat transfer disks in the fuel basket in the cask cavity.
- Tie Rod	Aligns the support disks and heat transfer disks in the fuel basket structure located in the NAC-STC cask cavity or in the transportable storage canister.
- Split Spacer	Installed on the tie rod between the support disks to properly position and provide axial support for the support disks and the heat transfer disks.

Table 1-1 Terminology (continued)

Outer Lid	A secondary containment closure that is bolted to the top forging during transport.
- Outer Lid Bolts	Retain the outer lid.
Inner Lid	The primary containment closure for transport, located directly on top of the cask cavity inside the top forging.
- Drain Port	Located in the inner lid to permit draining of the cask cavity.
- Vent Port	Located in the inner lid to aid in draining and backfilling the cask cavity.
- Port Coverplates	The sealed covers that protect the vent and drain ports.
- Interseal Test Port	The test port between pairs of o-rings that permits testing of the containment seal. The test port is closed by a threaded plug with a metallic o-ring.
- Inner Lid Bolts	Retain the inner lid.
Quick Disconnect	The quick disconnect valved nipple used in the vent, drain, interlid, and inner lid interseal test port to close off the port. The drain port quick disconnect may be valved or unvalved.
Interlid Region	The space between the inner and outer lids.
Transport Impact Limiters (Upper and Lower)	Impact limiters designed for use exclusively during transport of the NAC-STC. They protect the cask by limiting impact loads during the1-foot free drop (normal conditions of transport) and the 30-foot free drop (hypothetical accident conditions).

Table 1-1 Terminology (continued)

Yankee-MPC Contents	Up to 36 intact Yankee Class PWR spent fuel assemblies and Yankee Class Reconfigured Fuel Assemblies to a maximum total contents weight of 30,600 pounds.
CY-MPC Contents	Up to 26 Connecticut Yankee PWR spent fuel assemblies (including fuel inserts), CY-MPC Reconfigured Fuel Assemblies and CY-MPC Damaged Fuel Cans containing Connecticut Yankee intact or damaged fuel to a maximum total contents weight of 35,100 pounds.
Yankee Class Spent Fuel	Fuel that includes United Nuclear Type A and Type B, Combustion Engineering Type A and Type B, Exxon-ANF Type A and Type B, Westinghouse Type A and Type B and failed fuel cages that are bound by the above fuel types.
Connecticut Yankee Spent Fuel	15 x 15 PWR fuel assemblies manufactured by Westinghouse, Gulf Nuclear/Gulf General Atomic, NUMEC and Babcock and Wilcox.
Connecticut Yankee Fuel Inserts	Reactor Control Cluster Assemblies or Flow Mixers that may be inserted in, and stored with, the Connecticut Yankee spent fuel.
Reconfigured Fuel Assembly	A stainless steel container having approximately the same external dimensions as a standard spent fuel assembly that ensures criticality control geometry and permits gaseous and liquid media to escape while preventing dispersal of gross particulates. The reconfigured fuel assembly may contain intact fuel rods, damaged fuel rods and fuel debris from any type of Yankee Class or Connecticut Yankee spent fuel assembly.
CY-MPC Damaged Fuel Can	A stainless steel container that confines a damaged Connecticut Yankee spent fuel assembly, which allows gaseous and liquid media to escape but minimizes the dispersal of gross particulate.

Table 1-1 Terminology (continued)

Intact Fuel Assembly	A fuel assembly without known or suspected cladding defects greater than pinhole leaks or hairline cracks.
Intact Fuel Rod	A fuel rod without known or suspected cladding defects greater than pinhole leaks or hairline cracks.
Damaged Fuel Assembly	A fuel assembly with known or suspected cladding defects greater than pinhole leaks or hairline cracks.
Damaged Fuel Rod	A fuel rod with known or suspected cladding defects greater than pinhole leaks or hairline cracks.
Fuel Debris	Fuel in the form of particles, loose pellets and fragmented rods or assemblies.
Greater Than Class C Waste (GTCC)	Irradiated and surface contaminated metal, usually stainless steel, whose disposal is controlled by 10 CFR 61 due to the presence of very long-lived isotopes, including ^{59}Ni, ^{94}Nb and ^{14}C. This waste results from reactor decommissioning.

1.1 Introduction

The NAC-STC is designed to safely transport spent fuel assemblies in two configurations and Greater Than Class C (GTCC) waste in a canistered configuration. The fuel assemblies may be placed directly into a fuel basket installed in the cask cavity (uncanistered) or sealed in a transportable storage canister (canistered).

The design basis spent fuels for the uncanistered (directly loaded) configuration are the Westinghouse 17 x 17 or 15 x 15 PWR fuel assemblies. These fuels bound smaller array Westinghouse and similar Babcock & Wilcox and Combustion Engineering PWR fuel assemblies.

There are two canistered fuel configurations. The first is designed to store up to 36 intact Yankee Class spent fuel and reconfigured fuel assemblies and is referred to as the Yankee-MPC. The second is designed to store up to 26 Connecticut Yankee fuel assemblies, reconfigured fuel assemblies and damaged fuel in CY-MPC damaged fuel cans, and is referred to as the CY-MPC.

Yankee Class fuel includes United Nuclear, Combustion Engineering, Exxon-ANF, and Westinghouse Type A and Type B fuel designs. The Type A and Type B fuel designs are complementary configurations that accommodate the use of a cruciform control blade in reactor operations.

Connecticut Yankee spent fuel includes 15 x 15 PWR fuel assemblies having a square cross-section. The fuel specifications that serve as the design basis for the CY-MPC are presented in Section 1.2.3. The Connecticut Yankee fuel consists of fuel assemblies manufactured by Westinghouse, Gulf Nuclear/Gulf General Atomic, NUMEC and Babcock & Wilcox.

The canister configurations also accommodate GTCC waste. The Yankee-MPC and CY-MPC canister and GTCC basket accommodates up to 24 fuel assembly sized containers of GTCC waste. The GTCC canister designs have the same external dimensions as the respective spent fuel canisters, but have different basket designs.

The NAC-STC, when loaded, has a maximum design weight of 260,000 pounds. The NAC-STC provides a radioactive material containment boundary for maximum safety during the handling

and transport operations required for spent-fuel shipment. The general configuration of the NAC-STC and the major cask dimensions are shown in Figure 1.1-1.

The transport containment boundary consists of the following components:

(1) Inner shell center section and upper and lower inner shell rings (transition sections)
(2) Bottom inner forging
(3) Top forging
(4) Inner lid and inner lid outer metallic o-ring
(5) Inner lid interseal test port threaded plug with metallic o-ring
(6) Vent port coverplate and the coverplate outer metallic o-ring
(7) Vent port coverplate interseal test hole threaded plug with metallic o-ring
(8) Drain port coverplate and the coverplate outer metallic o-ring
(9) Drain port coverplate interseal test hole threaded plug with metallic o-ring

The transportable storage canister provides the secondary containment boundary for transport of Reconfigured Fuel Assemblies (Section 1.2.1.2.8.4), as required by 10 CFR 71.63.

The NAC-STC is designed to meet 10 CFR 71 and IAEA Safety Series No. 6 licensing requirements for spent fuel transport packages. The transport licensing requirements include providing safe containment during the handling and transport of spent nuclear fuel. Certain design features of the NAC-STC that have been included for the sole purpose of satisfying storage licensing requirements also provide added safety for transport conditions. The design features of the NAC-STC include: inner and outer lids, redundant seals at each containment boundary penetration, cavity penetrations located in the inner lid, and a puncture-resistant outer shell and outer lid.

This Safety Analysis Report is written for transport cask licensing only. Design features related to storage cask licensing are included for clarity and for ease of review.

The NAC-STC closure design provides dual lids for transport and storage operations, as well as protection of the vent and drain ports that are located in the inner lid. This design permits performance of a periodic verification leak test on the containment seals prior to transport following extended storage. Both the inner and outer lids are installed during transport and storage.

The inner lid and its outer metallic o-ring are major components in the primary containment boundary. A second metallic o-ring of slightly smaller diameter provides an interseal region that permits leak-testing of the outer metallic o-ring. The metallic o-rings provide long-term sealing capability in an elevated temperature and radiation environment.

The vent and drain port coverplates, which protect the vent and drain ports located in the inner lid, are also part of the primary containment boundary of the cask. Each coverplate is sealed by two concentric metallic o-rings. Each of the outer metallic (primary containment) seals is fabrication verification leak tested after initial installation.

The outer lid provides a sealed secondary closure of the NAC-STC for transport and storage operations. During transport, the outer lid seal is provided by one metallic o-ring, which is replaced prior to transport operation. The outer lid protects the inner lid and the vent and drain ports from external puncture events.

There are two penetrations in the top forging: an interlid port, which serves primarily as a drain for the interlid region, and a pressure port, which may house a transducer that monitors the pressure in the interlid region during storage. During transport, the pressure port is closed by a threaded plug. The pressure port plug is covered by the transport port coverplate. The interlid and pressure port penetrations in the top forging are protected by SA-705, Type 630, 17-4 precipitation-hardened (PH) stainless steel port covers with two piston-type blended polytetrafluoroethylene (PTFE) o-rings.

The body of the NAC-STC is a smooth right-circular cylinder of multiwall construction, consisting of stainless steel inner and outer shells separated by lead gamma radiation shielding, which is poured in place. The center section of the inner shell is fabricated from Type 304 stainless steel. At each end of the inner shell center section, inner shell rings fabricated from Type XM-19 stainless steel provide the transition to the bottom inner forging and the top forging. The outer shell is also fabricated from Type 304 stainless steel. The inner and outer shells are welded to the Type 304 stainless steel top forging, which is a ring that is machined to mate with the inner and outer lids. The inner and outer shells are also welded to the Type 304 stainless steel bottom inner and outer forgings, respectively. The cask bottom consists of the two forgings and a plate with neutron shield material sandwiched between the bottom inner forging and the bottom plate. Neutron shield material is also placed in an annulus that surrounds the cask outer shell along the length of the cask cavity. The neutron shielding material is a solid synthetic

polymer (NS-4-FR) developed by BISCO Products, Inc. The neutron shield annulus is enclosed by Type 304 stainless steel shell and by end plates that are welded to the outer shell. Two pressure relief valves are provided in the bottom of the neutron shield annulus to relieve pressure in the neutron shield annulus due to a severe thermal accident condition (fire). Neutron shielding is also provided on the top of the cask by a layer of NS-4-FR enclosed in the inner lid.

Redundant lifting capability for the NAC-STC is provided by four lifting trunnions welded to the top forging at 90-degree intervals. Rotation trunnion recesses are located on the outer shell near the bottom of the cask to permit the NAC-STC to be rotated to the horizontal position and to provide longitudinal tiedown restraint in the aft direction. A Type 304 stainless steel shear ring is provided at the top end of the radial neutron shield to supply longitudinal restraint when the cask is positioned horizontally for transport in the front support structure.

For fuel assemblies loaded directly into the NAC-STC, a stainless steel basket locates and supports the 26 PWR fuel assemblies in the cask cavity. The basket design utilizes a series of high-strength stainless steel support disks to support the fuel assemblies in stainless steel tubes, which include BORAL neutron poison sheets (0.02 g/cm^2 ^{10}B minimum). Aluminum heat transfer disks are provided to enhance the thermal performance of the package. The heat transfer disks are also supported by the stainless steel basket.

For the Yankee-MPC canistered configuration, two aluminum honeycomb spacers, placed one above the canister and one below, locate the canister in the cask cavity so that the location of the center of gravity of the packaging is the same as it is for the uncanistered fuel packaging. The aluminum honeycomb is enclosed in a 6061-T6 aluminum alloy shell. In the CY-MPC canistered configuration, a single stainless steel spacer, placed below the canister, is used to position the canister so that the location of the center of gravity of the packaging is the same as it is for the uncanistered fuel packaging.

The canister shell, bottom and welded shield and structural lids are fabricated from stainless steel. The basket for the canistered configuration is similar in design to that used for directly loaded fuel. Two basket configurations are used for Connecticut Yankee fuel. A 26-assembly basket is used for all of the fuel types except Westinghouse Vantage 5H. Vantage 5H fuel must be installed in the 24-assembly basket, which may also hold other Connecticut Yankee fuel types. The construction of the two basket configurations is identical except that two fuel loading positions of the 26-assembly basket are blocked to form the 24-assembly basket.

The Yankee-MPC or CY-MPC canisters may contain one or more Reconfigured Fuel Assemblies. The Yankee Reconfigured Fuel Assembly is shown in Figure 1.2-2. It is designed to contain up to 64 Yankee Class fuel rods, or portions thereof, which are classified as failed, and to maintain the geometric positions of the rods. The external dimensions and the top end fitting of the Yankee Reconfigured Fuel Assembly are the same as those of a standard Yankee Class fuel assembly, allowing it to be handled in the same way as a standard assembly.

The CY-MPC Reconfigured Fuel Assembly is shown in Figure 1.2-3. It consists of a stainless steel 10 x 10 array of tubes attached to upper and lower end fittings that are similar to those used on standard fuel assemblies. The diameter of the tubes is sized to allow the insertion of individual damaged or bowed fuel rods. The design allows the release of gaseous products and liquids, but minimizes the dispersal of particulates.

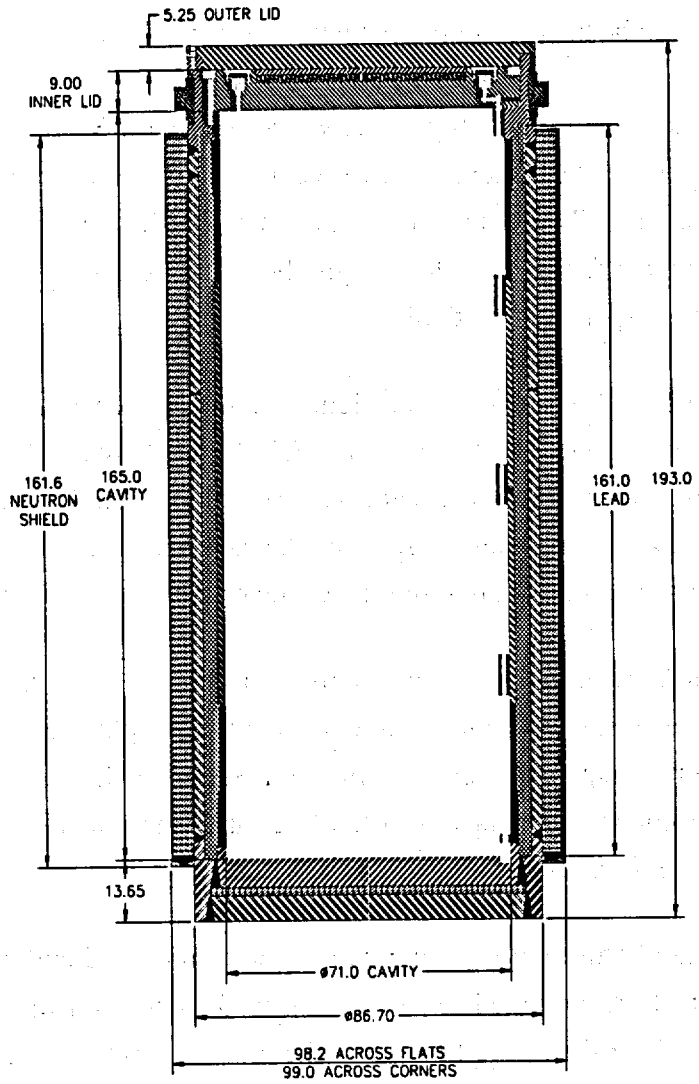
The CY-MPC Damaged Fuel Can is shown in Figure 1.2-4. It is designed to hold a complete fuel assembly, which may be intact or damaged. The CY-MPC Damaged Fuel Can has a square cross-section that is slightly larger than a standard Connecticut Yankee fuel assembly. The damaged fuel can is fabricated from stainless steel and has top and bottom closures that allow the release of gaseous products and liquids, but minimizes the dispersal of particulates.

Some of the Connecticut Yankee fuel assemblies will be stored with flow mixers or with reactor control cluster assemblies installed. Flow mixers are thimble plug assemblies used during reactor operation to maintain equal coolant flow in fuel assemblies that do not contain a reactor control cluster. Reactor control clusters were used to control the reactivity of the Connecticut Yankee reactor during operations and shutdown.

Impact limiters consisting of balsa wood, or a combination of redwood and balsa wood, encased in Type 304 stainless steel are provided to limit the g-loads acting on the cask during a drop accident load condition. The g-loads are limited by the crush strength of the wood contained in the impact limiters. The all balsa wood impact limiter (the balsa impact limiter), is designed for use with all the proposed contents. The redwood impact limiters may only be used with directly loaded fuel or the Yankee-MPC configurations.

Any number of NAC-STCs may be shipped at one time, with each cask on its own railcar. The NAC-STC may also be shipped in any number on board ships, barges, or special heavy-haul vehicles.

Figure 1.1-1 Major Cask Dimensions (in inches)



1.2 Package Description

This section presents a basic description of the NAC-STC and the contents that may be transported. An operational schematic of the cask is presented in Figure 1.2-1. Detailed dimensional drawings are provided in Section 1.3.2. The design characteristics of the NAC-STC are summarized in Table 1.2-1.

1.2.1 Packaging

1.2.1.1 Gross Weight

The maximum gross transport weight of the NAC-STC spent-fuel shipping cask is calculated to be 249,700 pounds for directly loaded fuel with the standard (redwood) impact limiters and is 254,589 pounds for CY-MPC canistered GTCC waste with the lightweight (balsa) impact limiters. When the NAC-STC is loaded on its railcar, the gross weight of the railcar (including cask, impact limiters, supports, and personnel barrier) will satisfy the requirements of the Association of American Railroads. The calculated component weights, detailed in Tables 2.2-1 through 2.2-5, are summarized as:

Component	Directly Loaded Fuel Weight (pounds)	Yankee-MPC Canistered Fuel Weight (pounds)	Yankee-MPC Canistered GTCC Waste Weight (pounds)	CY-MPC Canistered Fuel Weight (pounds)	CY-MPC Canistered GTCC Waste Weight (pounds)
Cask Body	175,970	175,970	175,970	175,970	175,970
Basket	16,350	--	--		
Fuel or GTCC Waste	39,650	30,600	12,340	35,100	20,230
Canister	--	14,600	14,600	16,666	16,666
Canister Basket	--	9,530	26,471	14,055	28,926
Spacers	--	860	860	1,374	1,374
Total (calculated)	**231,970**	**231,560**	**230,241**	**243,165**	**243,166**
With Standard (Redwood) Impact Limiters	249,700	249,290	247,971	--	--
With Lightweight (Balsa) Impact Limiters	243,393	242,983	241,664	254,588	254,589
Analysis Weight	**250,000**	**250,000**	**250,000**	**260,000**	**260,000**

The weight of the CY-MPC fuel basket is that of the 26-assembly basket. The weight of the 24-assembly basket is 13,451 pounds.

1.2.1.2 Material of Construction, Dimensions and Fabrication

The NAC-STC body is of cylindrical, multiwall construction. The materials of construction of the structural components of the cask body are Type 304, Type XM-19, and Type 17-4 PH stainless steel. The primary structural components of the cask are the inner and outer shells. Poured-in-place chemical copper lead fills the annulus between the inner and outer shells and serves as the primary gamma radiation shield. The top forging, which is a ring that forms the upper end of the cask, is welded to the inner and outer shells. The SA-336 Type 304 stainless steel inner lid is recessed in and bolted to the top forging. The SA-705, Type 630, H1150, 17-4 PH stainless steel outer lid is bolted into the end of the top forging. The vent and drain ports are recessed into the inner lid and are each protected by an SA-240, Type 304 stainless steel port coverplate. The interlid port and the pressure port are recessed in the top forging and are protected by SA-705, Type 630, 17-4 PH stainless steel port covers. At the lower end of the cask, the inner and outer shells are welded to the cask bottom, which consists of two forgings and a plate, a cup-shaped bottom inner forging that is the lower end of the cask cavity, a ring-shaped bottom outer forging that forms the exterior of the cask bottom and connects the outer shell to the bottom inner forging, and a bottom plate that is the bottom end of the cask. Neutron radiation shielding is provided by NS-4-FR, a poured-in-place solid synthetic neutron-absorbing polymer, which surrounds the outer shell along the cavity region and is enclosed by a shell and end plates that are welded to the outer shell. A layer of NS-4-FR is enclosed in the inner lid and in the cask bottom to provide neutron shielding at the ends of the cask during cask loading operations. Twenty-four explosively bonded copper and Type 304 stainless steel fins are located in the radial neutron shield to enhance the heat rejection capability of the NAC-STC and to support the neutron shield shell and end plates. The cask is passively cooled.

In the event of an accident during transport where impact force(s) may be applied to the cask, the NAC-STC is protected by energy-absorbing impact limiters that consist of balsa wood (the balsa impact limiter), or a combination of redwood and balsa wood (the redwood impact limiter), enclosed in a stainless steel shell. The cup-shaped impact limiters fit over each end of the cask and dissipate kinetic energy by crushing the wood at known force values, limiting the g-loads acting on the cask during an impact load condition.

The NAC-STC is provided with four lifting trunnions on the outside of the top forging at 90-degree intervals. The lifting trunnions are fabricated from SA-705, Type 630, 17-4 PH

stainless steel. Only two diametrically opposite trunnions are required to lift the NAC-STC. Two additional lifting trunnions are provided for those facilities that require redundant lifting. Two rotation trunnion recesses are located on the outer shell near the bottom of the cask. The NAC-STC safely transports spent fuel assemblies in two configurations. The fuel may be placed directly in a fuel basket installed in the cask cavity, or the fuel may be sealed in a transportable storage canister that is installed in the cask.

The NAC-STC directly loaded fuel basket has a capacity of 26 PWR fuel assemblies. The fuel basket design uses Type 17-4 PH stainless steel support disks to support the fuel assemblies in Type 304 stainless steel tubes. The support disks are spaced and retained by Type 17-4 PH stainless steel, square spacer nuts, which are assembled on six 1.625-inch diameter Type 17-4 PH threaded rods. Type 6061-T651 aluminum alloy heat transfer disks are supported by the stainless steel basket assembly to enhance heat rejection of the package.

The transportable storage canister is constructed of Type 304L stainless steel. The canister is closed with a shielding lid and a separate structural lid, both of which are welded in place. The shielding lid is constructed of Type 304 stainless steel, and the structural lid is constructed of Type 304L stainless steel. The canister contains a basket that provides support and geometry control for Yankee Class spent fuel, Connecticut Yankee spent fuel, Yankee Class GTCC waste or Connecticut Yankee GTCC waste. The spent fuel basket used in the canister is similar in design to the directly loaded fuel basket.

The materials of construction and detailed component and assembly dimensions for the NAC-STC are shown in the license drawings presented in Section 1.3.2. The major components are described in the following sections.

1.2.1.2.1 Cask Body

The outer shell, the center section of the inner shell, the top and bottom forgings, the bottom plate, and the inner lid of the NAC-STC are manufactured from Type 304 stainless steel. Type 304 stainless steel has well-documented mechanical properties and a long history of use in similar applications. It is a commonly welded material and is readily available throughout the world. Type 304 stainless steel possesses good strength and adequate toughness in the operating temperature range of the NAC-STC. The center section of the inner shell is 1.5 inches thick and has an inner diameter of 71.0 inches. Welded to the top and bottom of the inner shell center

section are the inner shell rings. The inner shell rings are manufactured from Type XM-19 high-strength stainless steel. The inner shell rings connect the bottom inner forging and the ring-shaped top forging to the center section of the inner shell. The inner shell rings are 2.0 inches thick at the end that is welded to the forgings and have a 3.0-inch-long taper down to a 1.5-inch thickness at the weld joint to the inner shell center section. The top and bottom inner shell rings reduce the stress concentration at the inner shell interface with the top and bottom forgings. Type XM-19 stainless steel has well-documented mechanical properties and is suitable for welding to the Type 304 stainless steel components.

Two forgings and a plate comprise the bottom of the cask body. The separate forgings are necessary to facilitate the pouring of the lead. These forgings are assembled with full-penetration welds and act as a single structural unit when fabrication is complete. The bottom components are differentiated here for clarity as the bottom inner forging, the bottom outer forging, and the bottom plate. The bottom inner forging is cup-shaped. The bottom of the cup is 6.2 inches thick. The side of the cup, which is welded to the bottom inner shell ring, is 2.0 inches thick.

The outer shell is concentric with the inner shell and is 2.65 inches thick. The outer shell is welded to the bottom outer forging, which is ring-shaped. The bottom outer forging is the outer ring portion of the cask bottom and is 3.9 inches thick in the radial direction at the location of the neutron shield material. The bottom outer forging is also welded to the outside diameters of the bottom inner forging and the bottom plate. The bottom plate is a 5.45-inch thick plate. A 2.0-inch thick, 78.9-inch diameter layer of NS-4-FR neutron shielding material is enclosed between the bottom inner forging and the bottom plate. Two rotation trunnion recesses are located approximately 180 degrees apart and are welded to the exterior of the outer shell just above the bottom of the neutron shield. Sixteen 1 - 8 UNC holes, equally spaced on a 76.0-inch diameter, are tapped into the bottom plate for attachment of the bottom transport impact limiter.

The upper inner shell ring and the upper end of the outer shell are welded to the ring-shaped top forging. On the inner diameter of the top forging is a recessed ledge. The inner lid is completely recessed into the top forging and mates with the ledge. The outer lid is bolted into the end of the top forging. Thirty-six outer lid bolts secure the outer lid to the top forging. The inner lid rests on a ledge in the top forging that is the sealing surface for the two metallic o-rings and the land for the 42 inner lid bolts. Two guide pins are installed in two of the inner lid bolt holes during cask loading and unloading operations and, along with alignment marks, assist in aligning and ensuring proper seating of the inner lid. Similar procedures are used to assist in the proper

alignment of the outer lid. Four lifting trunnions are welded to the top forging to permit cask lifting and handling with either a redundant or a nonredundant lifting yoke.

Radial gamma radiation shielding for the NAC-STC is provided by the inner shell, the outer shell, and the 3.7-inch thickness of American Society of Testing Materials (ASTM) B29 chemical copper lead located in the annulus between the inner and outer shells. The lead also serves as an elastic support for the outer shell during a puncture event and for the inner shell during a side impact event.

Radial neutron shielding for the NAC-STC is provided by NS-4-FR, which is a solid synthetic polymer originally developed by BISCO Products, Inc. and is now supplied by the Japan Atomic Power Company and its licensees. This solid neutron shielding material is selected to eliminate leakage and maintenance problems and to alleviate other concerns attendant with using a liquid neutron shield. NS-4-FR has a high-hydrogen content to provide for neutron attenuation, is doped with boron to minimize the number of secondary gamma's generated, is stable at elevated temperature service, and is fire retardant. A 5.5-inch-thick layer of NS-4-FR is installed in the annulus formed by the outer shell, the 0.250-inch-thick neutron shield shell, and the 0.472-inch (12 mm)-thick neutron shield end plates.

The inner shell, inner shell rings, top forging, bottom inner forging, and the inner lid establish a cask cavity that is 165.0 inches long and 71.0 inches in diameter.

The calculated weight of the cask body is 175,970 pounds. The overall length of the cask body is 193.0 inches, and the maximum outside diameter is 99.1 inches across the corners of the neutron shield shell.

1.2.1.2.2 Inner Lid and Bolts

The inner lid and its outer o-ring are the principle installed components of the NAC-STC containment boundary. The inner lid is 9.0 inches thick, 79.0 inches in diameter, and is fabricated from Type 304 stainless steel. The top portion of the inner lid is a 2.0-inch-thick, 67.5-inch-diameter layer of NS-4-FR neutron shielding material enclosed by a 1.0-inch-thick, Type 304 stainless steel coverplate that is welded in place. The 42 inner lid bolts are 1 1/2 - 8 UN socket head cap screws fabricated from SB-637, Grade N07718 nickel alloy steel bolt material. This bolt material has a coefficient of thermal expansion that is very similar to that of

the Type 304 stainless steel inner lid and top forging and, thus, alleviates differential thermal expansion effects.

The inner lid is recessed to a depth of 11.8 inches into the top forging to provide clearance for the outer lid. The inner lid bolt holes are located on a ledge machined into the inner lid, so that the bolt heads are below the top surface of the lid. The top surface of the inner lid has threaded holes for the attachment of a lid-lifting device. The bottom of the inner lid is sealed to the top forging of the cask body by two metallic o-rings. The outer metallic o-ring provides the primary containment seal for transport after storage, while the inner metallic o-ring provides the primary containment seal for transport immediately after loading.

Three ports are recessed into the inner lid: the vent port, the drain port, and the interseal test port. These ports are described in Section 1.2.1.2.4.

1.2.1.2.3 Outer Lid and Bolts

The outer lid, bolts and o-ring, when bolted to the top forging, provide a sealed secondary closure. The outer lid is 5.25 inches thick in the central region, 86.7 inches in diameter, and is fabricated from SA-705, Type 630, H1150, 17-4 PH stainless steel. The 36 outer lid bolts are 1-8 UNC socket head cap screws fabricated from SA-564, Type 630, H1150, 17-4 PH stainless steel. The bolt material is identical to that of the outer lid, alleviating any differential thermal expansion effects.

The outer lid is bolted to the top forging of the NAC-STC. The lid bolt holes are countersunk into the lid so that the bolt heads are below the top surface of the lid. The bottom surface of the outer lid is sealed to the top forging by one metallic o-ring. The outer lid o-ring is replaced prior to transport. The interlid port, located in the top forging, is used to test the seal of the o-ring in the outer lid. The top surface of the outer lid has threaded holes for the attachment of a lid-lifting device and for the attachment of the upper transport impact limiter.

1.2.1.2.4 Ports and Port Covers

The NAC-STC design includes five ports: three in the inner lid and two in the top forging. The vent, drain and interseal test ports are recessed in the inner lid and provide access to the cask containment. Recessed in the top forging are two noncontainment ports, the interlid port for

interlid region drainage and outer lid o-ring leak testing, and the pressure port, which is provided for monitoring of the pressure in the interlid region during storage.

The vent port is a 1.0-inch diameter penetration through the inner lid and is closed by a quick-disconnect valved nipple (quick disconnect). The quick disconnect is not considered to be a containment barrier. The vent port coverplate outer metallic o-ring is the containment boundary seal for transport after storage and for transport after loading. The vent port is used to access the cask cavity following the fuel loading to drain, dry, leak test and backfill it with inert gas prior to transport. The drain port is a 1.0-inch diameter penetration through the inner lid that is used to fill and drain the cask cavity. The drain port is also closed by a quick disconnect, which is not considered to be a containment barrier. The drain port coverplate outer metallic o-ring and the drain port interseal test port plug provide the containment boundary seal for transport after a period of spent fuel storage, while the inner o-ring provides the containment boundary when the cask is loaded for immediate shipment. Alignment marks on the top surface of the inner lid and the top forging assist in aligning the drain port in the lid and the drain tube in the cask cavity. The interseal test port is also closed by a quick disconnect, which is not considered to be a containment barrier. An interseal test port is provided with a 1/4-inch quick disconnect valved nipple to allow leak testing of the inner lid o-rings. The interseal test port is closed with a threaded plug having a metallic o-ring, which is part of the containment boundary for transport after a period of storage.

The pressure port, located in the top forging, houses the transducer that monitors the pressure in the interlid region during storage. The pressure transducer is removed during transport. The interlid port penetrates the top forging into the region between the inner and the outer lids and serves as a drain for the interlid region and as a port to pressurize the interlid region for seal testing purposes. The interlid port is closed by a quick disconnect. The basic geometry of the interlid and pressure ports and port covers is identical. Each port has a 4.5-inch diameter opening that is a minimum of 1.1 inches deep. Concentric with the port opening is a 2.93-inch diameter bore. This bore acts as a lead-in to the 2.875–inch diameter bore that serves as the sealing surface for the two piston-type Blended Polytetrafluoroethylene (PTFE) o-rings in the port cover.

Both of the port covers are fabricated from SA-705, Type 630, H1150, 17-4 PH stainless steel. The port covers resemble a cup-shape and have the geometrical appearance of a thick round end plate with a cylindrical body. The end plate of the port cover is 4.5 inches in diameter and 1.0 inch thick. The three 3/8 – 16 UNC port cover bolts, which are fabricated from SA-193, Grade

B6, Type 410 stainless steel, are countersunk flush with the top of the port cover. There are two piston-type PTFE o-rings on the cylindrical body of the port covers with a seal test port between the o-rings. A retainer is bolted to the open end of the cylindrical body of the port cover to retain the o-rings and the spacer between them after assembly. The port cover design permits the thick end plate to absorb an impact, while any deflection of the end plate results in the o-rings sliding in the bore of the port with the seal maintained.

The basic geometry of the inner lid vent port and coverplate, and the drain port and coverplate, are identical to each other. Each port has a 6.53-inch diameter opening in the inner lid that is 1.8 inches deep. Concentric with the port opening is a 2.8-inch deep, 3.25-inch diameter bore that houses the 1.0-inch diameter quick disconnect. For loading of the NAC-STC for storage, the primary containment boundary seal for the vent and drain ports is provided by the outer metallic o-ring located on the bottom face of the port coverplates and by its interseal test hole plug. For loading of the NAC-STC for immediate transport, the containment boundary is the inner o-ring of the drain port coverplate and the outer o-ring and interseal test plug of the vent port coverplate.

The 1.0-inch thick vent and drain port coverplates are fabricated from SA-240, Type 304 stainless steel. When installed, the port coverplates are recessed 0.8 inch below the top surface of the inner lid. The vent and drain port coverplates are sealed to the inner lid by the metallic o-rings on the bottom face of each port coverplate. The four 1/2 - 13 UNC port coverplate bolts are fabricated from SA-193, Grade B6, Type 410 stainless steel. The bolt holes are countersunk so that the bolt heads are flush with the top of the port coverplate.

1.2.1.2.5 Lifting Trunnions and Rotation Trunnion Recesses

The NAC-STC has four lifting trunnions that are fabricated from SA-705, Type 630, H1150, 17-4 PH stainless steel and are welded into 2.0-inch deep recesses in the top forging at 90-degree intervals around the cask circumference. Only two diametrically opposite lifting trunnions are required to lift the NAC-STC. The lifting trunnions are 5.5 inches in diameter and have a load-bearing width of 2.5 inches. The trunnions are machined to create a 0.38-inch thick end flange, which acts as a safety stop to ensure proper engagement and to prevent inadvertent disengagement of the lifting yoke.

There are two rotation trunnion recesses located near the bottom end of the NAC-STC. The rotation trunnion recesses are located approximately 18 inches above the bottom of the cask in line with two of the lifting trunnion, but 3.0 inches offset from the cask centerline to ensure that rotation of the cask occurs in the proper direction. Each recess is fabricated from SA-705, Type 630, 17-4 PH stainless steel and is groove-welded to the bottom outer forging. The recess is 6.0 inches square and 4.13 inches deep, with a full radius at the top of the recess that engages with the rotation support. The neutron shield shell is cut out to accommodate the rotation trunnion recesses.

1.2.1.2.6 Transport Impact Limiters

The NAC-STC is equipped with removable, cup-shaped impact limiters that are bolted over each end of the cask to ensure that the design impact loads for the cask are not exceeded for any of the defined normal operation or accident drop conditions. The NAC-STC transport impact limiters are provided in two configurations. The standard configuration is constructed of a combination of redwood and balsa wood and is referred to as the redwood impact limiter. The other configuration is constructed using only balsa wood and is referred to as the balsa impact limiter. Both configurations are completely enclosed in a stainless steel shell. The upper impact limiter has cutouts in its inside diameter for clearance with the lifting trunnions. The impact limiters absorb the energy of a cask drop by crushing the redwood and/or balsa wood. The force required to crush the impact limiter is determined by the amount and location of the wood and its grain direction. The upper and lower impact limiters are bolted over each end of the cask body by 16 equally spaced attachment rods and nuts. The lightweight impact limiters have a lower weight and improved crush characteristics compared to the standard impact limiters, which accommodates a higher cask contents weight and higher cask total weight. As shown in Section 1.2.1.1, the lightweight impact limiters must be used in the transport of the CY-MPC canister configurations. Either impact limiter design may be used with the directly loaded fuel or Yankee-MPC configurations. The two impact limiter configurations are similar in size and shape. However the redwood impact limiters have a total weight of 17,730 pounds, while the total weight of the balsa impact limiters is 11,423 pounds.

1.2.1.2.7 Directly Loaded Fuel Basket

The NAC-STC has one directly loaded fuel basket configuration and three (3) canistered fuel basket configurations. The canistered fuel basket configurations are described in Section

1.2.1.2.8. The directly loaded basket and the canistered baskets are constructed of stainless steel with aluminum heat transfer disks and are of similar design.

The directly loaded fuel basket design is a right-circular cylinder configuration with square fuel tubes laterally supported by a series of support disks, which are retained by square spacer nuts on threaded rods at six locations. The nuts are torqued at installation to provide a solid load path in compression between the support disks. The support disks are 0.5-inch thick, 70.86-inch diameter 17-4 PH stainless steel disks spaced 4.87 inches center-to-center with square holes for the fuel tubes. The top end weldment and the bottom end weldment are fabricated from Type 304 stainless steel, are geometrically similar to the support disks, and are 1.0-inch thick. The threaded rods have a 1-5/8 – 8 UN thread diameter and are fabricated from Type 17-4 PH stainless steel. The nuts are 2.5-inch square bars that are also fabricated from Type 17-4 PH stainless steel. The fuel tubes are fabricated from Type 304 stainless steel and provide support for the encased BORAL sheet on each of the four sides. The BORAL provides criticality control in the basket. No structural credit is taken for the stainless steel tubes as a contributor to the total structural strength of the basket and support of the fuel assemblies.

The NAC-STC directly loaded fuel basket accommodates 26 PWR fuel assemblies in an aligned configuration in 8.78-inch inside dimension square fuel tubes, which have 0.142-inch thick walls. The fuel tubes are supported in the basket assembly between the top and bottom weldment plates. The hole in the top weldment is 8.75 inches square. The hole in the bottom weldment is 8.65 inch square. The basket design traps the fuel tube between the top and bottom weldment preventing axial movement of the fuel tube. The minimum width of the support disk webs between the fuel tubes is 1.5 inches, but two webs have a width of 3.3 inches.

Twenty Type 6061-T651 aluminum alloy heat transfer disks, 0.625-inches thick, 70.65 inches in diameter, are supported by the threaded rods and spacer nuts, which also support and locate the stainless steel support disks. These aluminum disks are located at the center of the axial spacing between the stainless steel support disks and are sized to eliminate contact with the cask inner shell and basket threaded rods as a result of differential thermal expansion.

The NAC-STC has been designed to facilitate filling with water and subsequent draining. A 1.0-inch rounded notch is located at the bottom of each fuel tube, ensuring that there will be free flow between the inner tube regions and the disk regions. Water will naturally fill and drain between the basket disks and the cask body. Water will also flow between the disks in the gap

between each of the tubes and the disk that surrounds it. Each of the disks also has four 1-inch diameter holes to supplement the flow of water between the disks. Also, to facilitate flow to the drain line, the bottom plate is positioned by supports 1.5 inches above the bottom of the cask. These design features have been provided to ensure that there is a free flow of water in the cask basket that results in even filling and draining of the cask.

1.2.1.2.8 Transportable Storage Canister

There are two transportable storage canister configurations. One configuration is used for Yankee Class spent fuel and GTCC waste (Yankee-MPC). The other is used for Connecticut Yankee spent fuel and GTCC waste (CY-MPC). The canisters differ only in overall length and in the thickness of some components. The transportable storage canister consists of four (4) principle components. These are the canister, canister basket, shield lid and structural lid. The canister consists of an annular right-circular shell closed at one end by a bottom plate. The shell is constructed of 5/8-inch rolled Type 304L stainless steel plate. The edges of the rolled plates are joined with full penetration welds. The Type 304L stainless steel bottom plate is attached to the shell by also using a full penetration weld. The canister shell is constructed in accordance with ASME Code Section III, Subsection NB. The inside and outside diameter of the canister are 69.39 inches and 70.64 inches, respectively.

The overall external length of the Yankee-MPC canister is 122.5 inches, the inside depth is 121.5 inches and the bottom plate is 1.0-inch thick. The overall external length of the CY-MPC canister is 151.75 inches, the inside depth is 150.0 inches and the bottom plate is 1.75-inches thick.

After loading, the canister is closed by a shield lid and structural lid, each welded to the canister shell. Both the shield lid and structural lid welds are examined in accordance with ASME Code Section V.

The shield lid of both canister configurations is a 5-inch thick Type 304 stainless steel plate. It is joined to the canister shell using a partial penetration weld. The shield lid contains the drain and fill penetrations and provides gamma radiation protection to operators for the draining, drying and inerting operations attendant to sealing the canister. After the shield lid is welded in place, the shield lid weld is leak tested in accordance with ANSI N14.5-1997 to ensure that the required leaktightness is achieved.

The structural lid of both canister configurations is a 3-inch-thick Type 304L stainless steel plate. It is attached to the canister shell with a partial penetration weld. Removable lifting fixtures threaded in the structural lid are used to lift the loaded canister.

1.2.1.2.8.1 Canistered Fuel Baskets

There are three (3) canistered fuel basket configurations. The Yankee-MPC basket accomodates 36 spent fuel assemblies. The CY-MPC basket is provided in a 26 assembly and a 24 assembly configuration.

The Yankee-MPC Fuel Basket

The Yankee-MPC fuel basket is used to position up to 36 Yankee Class fuel assemblies within the canister and to maintain geometry control of the fuel during all of the transport (and storage) conditions.

The fuel basket design is a right-circular cylinder with square fuel tubes laterally supported by a series of support disks, which are retained by split spacers on tie rods at eight locations. The split spacers are installed to provide a solid load path in compression between the support disks. The support disks are 0.5-inch thick, 69.15-inch diameter 17-4 PH stainless steel disks spaced 4.4 inches center-to-center with square holes for the fuel tubes. The top end disk (top weldment) and the bottom end disk (bottom weldment) are fabricated from Type 304 stainless steel. They are geometrically similar to the support disks and are 0.5-inch thick. The tie rods have a 1-1/8-inch diameter and are fabricated from Type 304 stainless steel. The split spacers are 2.5 inches in diameter by 1.416 inches long with an additional 2.0 inch diameter by 0.539 inch long extension, and they are also fabricated from Type 304 stainless steel. The fuel tubes are fabricated from Type 304 stainless steel and provide support for encased BORAL sheet welded onto each of the four external sides. The BORAL provides criticality control in the basket. No structural credit is assumed for the stainless steel tubes as a contributor to the total structural strength of the basket and support of the fuel assemblies.

The canistered fuel basket accommodates fuel assemblies in an aligned configuration in 7.8-inch inside dimension square fuel tubes, which have composite 0.141-inch thick walls. The fuel tubes are supported in the basket assembly between the top and bottom weldment plates. The hole in the top weldment is 7.78 inches square. The hole in the bottom weldment is 6.0 inches square.

The top of the fuel tube has a flange surface, which extends to 8.65 inches square. The basket design traps the fuel tube between the top and bottom weldments, preventing axial movement of the fuel tube. The minimum width of the support disk webs between the fuel tubes is 0.75 inches.

Fourteen (14) Type 6061-T651 aluminum alloy heat transfer disks, 0.5-inches thick and 68.87 inches in diameter, are supported by the tie rods and split spacers, which also support and locate the stainless steel support disks. These aluminum disks are located at the center of the axial spacing between the stainless steel support disks and are sized to preclude contact with the cask inner shell and basket tie rods as a result of differential thermal expansion.

The canistered fuel basket has been designed to facilitate filling with water and subsequent draining. Each of the disks has three (3) 1.25-inch diameter holes to facilitate water flow between disks. Water will also flow between the disks in the gap between each of the tubes. To facilitate flow to the drain line, the bottom plate is positioned by supports 1.5 inches above the bottom of the cask. These design features have been provided to ensure that there is a free flow of water in the cask basket that results in even filling and draining of the cask.

As shown in Table 1.2-2, there are minor weight variations between Yankee Class fuel assembly types. Fuel assembly types may be mixed within the basket, provided that the contents weight limit of 30,600 pounds is not exceeded. Mixing fuel types within the weight limit can result in a basket containing 36 fuel assemblies, whereas loading a basket with only Westinghouse fuel would result in the basket containing 34 assemblies.

The CY-MPC Fuel Baskets

The CY-MPC fuel basket is provided in both a 26 and a 24 assembly configuration. The two configurations are identical except that the top weldment of the 24 assembly configurations has only 24 fuel tube penetrations (See Drawing 414-892). As described in Section 1.2.3.1, the 24 assembly basket is used for loading Zircaloy clad spent fuel with an enrichment above 3.93 wt % ^{235}U or stainless steel clad spent fuel with an enrichment above 4.03 wt % ^{235}U.

The CY-MPC fuel basket design is a right-circular cylinder with square fuel tubes laterally supported by a series of support disks, which are retained by split spacers on tie rods at six locations. The split spacers are installed to provide a solid load path in compression between the support disks. The support disks are 0.5-inch thick, 69.15-inch diameter 17-4 PH stainless steel

disks spaced 4.59 inches center-to-center with square holes for the fuel tubes. The top end disk (top weldment) and the bottom end disk (bottom weldment) are fabricated from Type 304 stainless steel. They are geometrically similar to the support disks and are 0.5-inch thick. The tie rods have a 1-5/8-inch diameter and are fabricated from Type 304 stainless steel. The split spacers are 2.88 inches in diameter by 1.485 inches long with an additional 2.5-inch diameter by 0.56-inch long extension, and they are also fabricated from Type 304 stainless steel. The fuel tubes are fabricated from Type 304 stainless steel and provide support for encased BORAL sheet welded onto each of the four external sides. The BORAL provides criticality control in the basket. No structural credit is assumed for the stainless steel tubes as a contributor to the total structural strength of the basket and support of the fuel assemblies.

Four fuel positions in each basket configuration are 9.1-inches square with the remaining (either 22 or 20 fuel positions) being 8.7-inches square. The larger fuel positions are designated "oversize" fuel positions and are intended to accommodate CY damaged fuel cans and fuel assemblies with dimensions that exceed the fuel design dimensions due to reactor events. The fuel tubes are supported in the basket assembly between the top and bottom weldment plates and have composite 0.14-inch thick walls. The fuel position holes in the bottom weldment are 8.57 inches square. The top of the fuel tube has a flange surface, which extends to 9.6 inches square, except that the flange surface of the oversize fuel tubes is 10.0 inches square. The basket design traps the fuel tube between the top and bottom weldments, preventing axial movement of the fuel tube. The minimum width of the support disk webs between the fuel tubes is 1.0 inches.

Twenty-seven (27) Type 6061-T651 aluminum alloy heat transfer disks, 0.5-inches thick and 68.87 inches in diameter, are supported by the tie rods and split spacers, which also support and locate the twenty-eight (28) stainless steel support disks. These aluminum disks are located at the center of the axial spacing between the stainless steel support disks and are sized to preclude contact with the cask inner shell and basket tie rods as a result of differential thermal expansion.

The canistered fuel basket has been designed to facilitate filling with water and subsequent draining. Each of the disks has three (3) 1.25-inch diameter holes to facilitate water flow between disks. Water will also flow between the disks in the gap between each of the tubes. To facilitate flow to the drain line, the bottom plate is positioned by supports 1.5 inches above the bottom of the cask. These design features have been provided to ensure that there is a free flow of water in the cask basket that results in even filling and draining of the cask.

As shown in Table 1.2-4, there are enrichment differences between Connecticut Yankee fuel types. The 24 assembly basket is used for loading Zircaloy clad spent fuel with an enrichment above 3.93 wt % ^{235}U or stainless steel clad spent fuel with an enrichment above 4.03 wt % ^{235}U.

1.2.1.2.8.2 Canistered GTCC Basket

There are two canistered GTCC basket configurations. The Yankee-MPC GTCC basket design is similar to the Yankee Class fuel basket in that the basket is a modified tube and disk design that positions and supports up to 24 Yankee Class GTCC waste containers. The CY-MPC GTCC basket design is nearly identical in that it is also a modified tube and disk design that provides 24 loading positions in tubes. The designs accommodate the geometry of the existing GTCC waste.

Yankee-MPC GTCC Basket

The Yankee-MPC GTCC basket is a right-circular cylinder with square tubes laterally supported by a series of eight support disks. The support disks are 1.0-inch thick, 68.98-inches diameter, Type 304 stainless steel disks that are spaced 15.60 inches center-to-center. The support disks are open in the center region to accommodate twenty-four 8.20-inch square tubes. The tubes are supported full length by 2.5-inch thick support walls all around the center region. The support disks are retained in position by welding to the support walls of the basket. The basket accommodates GTCC waste containers in an aligned configuration in 7.82-inch square inside dimension Type 304 stainless steel tubes, which have 0.25-inch-thick walls. The basket is a modified tube and disk design. The maximum loaded weight of a GTCC container is 514 pounds, so the maximum content weight is 12,340 pounds for 24 containers.

CY-MPC GTCC Basket

The CY-MPC GTCC basket is a right-circular cylinder with square tubes laterally supported by a series of nine support disks. The support disks are 1.0-inch thick, 69.15-inch diameter, Type 304 stainless steel disks that are spaced 17.0 inches center-to-center. The support disks are open in the center region to accommodate twenty-four 9.22-inch square tubes. The tubes are supported full length by a 2.25-inch thick support wall (the shield shell weldment) all around the center region. The support disks are retained in position by welding to the shield shell weldment of the basket. The basket accommodates GTCC waste containers in an aligned configuration in 8.72-inch square inside dimension Type 304 stainless steel tubes, which have 0.25-inch thick walls.

The maximum loaded weight of GTCC waste is 26,000 pounds for 24 containers. The maximum weight of a loaded container is 1,500 pounds.

1.2.1.2.8.3 Canister Transport Spacers

The Yankee-MPC fuel or GTCC waste canister is located in the NAC-STC cavity by two (2) aluminum honeycomb spacers. One spacer is installed below the canister and one above. The aluminum honeycomb is an engineered material having well-defined load-bearing and crush characteristics established by design and fabrication. The two (2) spacers have different lengths and are not interchangeable. The aluminum honeycomb is encased within a thin 6061-T6 aluminum alloy skin that precludes the entry of incidental water, contamination and foreign materials into the honeycomb structure. The spacers support the canister in all of the normal operations, but may deform during hypothetical accident events.

The bottom spacer is nominally 14 inches high and 69.0 inches in diameter. The top spacer is 28 inches high and 70.6 inches in diameter. Removable lifting lugs are used to install and remove the spacers.

The CY-MPC fuel or GTCC waste canister is located in the NAC-STC cavity by a single stainless steel spacer formed by a series of concentric rings welded to a stainless steel base plate. The spacer is installed below the canister. The spacers support the canister in all of the normal operations, but may deform during hypothetical accident events.

The bottom spacer is nominally 12.7 inches high and 70.6 inches in diameter. Removable lifting lugs are used to install and remove the spacer.

1.2.1.2.8.4 Reconfigured Fuel Assemblies

The reconfigured fuel assemblies are used with both the Yankee-MPC and CY-MPC configurations. The reconfigured fuel assembly is designed to confine fuel rods, or portions thereof, which are classified as failed fuel, and to maintain the geometric configuration of those fuel rods. The assemblies are designed to allow the draining of free water and the backfilling of the rods and surrounding region with helium. Since there is no significant remaining "gap activity" in the failed rods, pressure retention is not a concern.

The Yankee-MPC Reconfigured Fuel Assembly consists of a shell (square tube with end fittings) and a basket assembly that supports 64 tubes in an 8 x 8 array, which hold the failed rods. The shell, basket assembly and tubes are stainless steel. The spent fuel rods are confined in the fuel tubes, which are closed with end plugs. The shell is closed with top and bottom end fittings. The tube end plugs and the shell end fittings have drilled holes to permit draining, drying and helium backfilling. The Yankee-MPC Reconfigured Fuel Assembly is shown in Figure 1.2-2.

The CY-MPC Reconfigured Fuel Assembly consists of a 10 x 10 array of stainless steel tubes attached to upper and lower end fittings that are similar to those used on standard fuel assemblies. The tubes are designed to hold individual fuel rods that have been removed from fuel assemblies. The diameter of the tubes is sized to allow the insertion of individual damaged or bowed fuel rods. The cross-section dimension restricts loading to one of the four "oversize fuel" basket positions described in Section 1.2.1.2.8.1. The CY-MPC reconfigured fuel assembly is shown in Figure 1.2-3.

1.2.1.2.8.5 CY-MPC Damaged Fuel Cans

The damaged fuel can is designed to hold a complete fuel assembly, which may be intact or damaged. Damaged fuel includes fuel assemblies that have one or more individual fuel rods that are classified as failed. The damaged fuel can has a square cross-section that is slightly larger than a standard Connecticut Yankee fuel assembly. Consequently, loading of the damaged fuel can is restricted to one of the four corner "oversize fuel" basket positions. The damaged fuel can is fabricated from stainless steel and has top and bottom closures that allow the release of gaseous products and liquids but minimizes the dispersal of particulates. The CY-MPC damaged fuel can is shown in Figure 1.2-4.

1.2.1.3 Heat Dissipation

The NAC-STC design basis decay heat dissipation capability is:

Directly Loaded Fuel	22.1 kW
Canistered Yankee Class Fuel	12.5 kW
Canistered Yankee Class GTCC	2.9 kW
Canistered Connecticut Yankee Fuel	17 kW
Canistered Connecticut Yankee GTCC	5 kW

The use of aluminum heat transfer disks in the basket and the use of 24 explosively bonded copper/stainless steel fins extending through the NS-4-FR solid neutron shield aid in the heat transfer capability of the NAC-STC. The heat dissipation features of the NAC-STC are entirely passive. No active or support cooling mechanisms are required during transport. A detailed discussion of the thermal characteristics of the NAC-STC is provided in Chapter 3.

The directly loaded basket accommodates 26 PWR fuel assemblies with a maximum decay heat load of 0.85 kilowatts per assembly.

The Yankee-MPC configuration accommodates up to 36 assemblies, depending on assembly type. The maximum canistered fuel assembly decay heat load is 0.347 kilowatts per assembly for a canister of 36 assemblies and 0.264 kilowatts per assembly for a canister of 34 stainless steel-clad assemblies. The basket may also contain one or more Yankee-MPC Reconfigured Fuel Assemblies with a maximum heat load of 0.102 kW per assembly.

The CY-MPC configuration accommodates up to 26 assemblies, depending on assembly type. The maximum canistered fuel assembly decay heat load is 0.654 kilowatts per assembly for a canister of 26 assemblies. The basket may also contain one or more CY-MPC Reconfigured Fuel Assemblies with a maximum heat load of 0.321 kW per assembly or CY-MPC Damaged Fuel Cans with a maximum heat load of 0.654 kW per can.

1.2.1.4 Coolants

There are no coolants utilized within the NAC-STC. An inert helium gas atmosphere is used to backfill the cask cavity during transport.

1.2.1.5 Shielding

A 3.7-inch thickness of chemical copper lead and a 4.4-inch total thickness of stainless steel are maintained between the cask contents and the exterior radial surface of the NAC-STC for the attenuation of gamma radiation. Additional radial shielding is provided to reduce the gamma radiation contribution above the radial neutron shield by a 0.47-inch stainless steel ring attached to the top weldment. A thickness of 5.5 inches of solid, borated neutron shielding material (NS-4-FR), which extends beyond the full length of the active fuel region, is provided for radial neutron shielding. The inner and outer lids provide a total thickness of 12.25 inches of stainless

steel on the top end of the cask to attenuate gamma radiation from the fuel and assembly hardware. A 2.0-inch-thick disk of solid, borated NS-4-FR is provided in the inner lid for neutron shielding on the top end of the cask. When transporting canistered fuel, the canister shield and structural lids provide an additional total thickness of eight inches of steel that provides significant attenuation of gamma radiation at the top end of the cask. The canister shell also provides an additional 0.62 inches of stainless steel shielding in the top radial direction. The cask provides 11.65 inches of stainless steel gamma radiation shielding material and 2.0 inches of solid, borated NS-4-FR neutron shielding material. The bottom of the canister provides an additional one inch of stainless steel shielding at the bottom in the axial direction of the cask. A detailed description of the NAC-STC shielding design, as well as the shielding analysis, is provided in Chapter 5.

1.2.1.6 Protrusions

There are no outer protrusions on the NAC-STC other than the four external lifting trunnions that are welded to the top forging near the upper end of the cask. The lifting trunnions are within the envelope protected by the impact limiters. The inner lid and all of the port covers are recessed into the cask body and do not protrude above the cask surface. The outer lid forms a smooth surface with its recessed bolts.

1.2.2 Operational Features

The NAC-STC is designed for ease of operation. The cask is designed to be easily loaded, unloaded, and handled at a nuclear facility. The configuration and surface finish of the cask exterior surfaces have been designed to facilitate and minimize cask decontamination efforts. The inner lids of the cask, the outer lids of the cask, and the port covers are all one-piece components designed to reduce handling times and to maintain personnel dose rates as low as reasonably achievable (ALARA). Quick-disconnect fittings are provided in the vent and drain ports, the inner lid interseal test port and in the interlid port for improved handling operations. All operational features are shown on the license drawings provided in Section 1.3.2. An operational schematic for the NAC-STC is shown in Figure 1.2-1. Operating procedures are provided in Chapter 7 for both canistered and directly loaded (uncanistered) fuel operations.

1.2.3 Contents of Packaging

Shipments in the NAC-STC shall not exceed the following limits:

1. The maximum content weight of the NAC-STC shall not exceed 67,200 pounds.

2. The limits specified in Tables 1.2-2 through 1.2-4 for the design basis fuels shall not be exceeded.

3. The total decay heat of the cavity contents shall not exceed 22.1 kilowatts for directly loaded fuel, 12.5 kilowatts for Yankee Class canistered fuel and 17 kilowatts for Connecticut Yankee canistered fuel.

4. The total weight of the Zircaloy and/or stainless steel clad fuel assemblies in the Yankee-MPC and CY-MPC configurations shall not exceed 30,600 pounds and 35,100 pounds, respectively.

5. The total weight of the Yankee-MPC and CY-MPC GTCC canistered waste shall not exceed 12,340 pounds and 20,230 pounds, respectively.

6. Any number of NAC-STC casks may be shipped at one time on a railcar, a ship, a barge, or a heavy-haul vehicle.

7. Radiation levels shall not exceed the requirements of 10 CFR 71.47, 10 CFR 71.51, and IAEA Safety Standard Series No. ST-1, Common Provision B3.

8. Surface contamination levels shall not exceed the requirements of 10 CFR 71.87(i)(1) and IAEA Safety Standard Series No. ST-1, Common Provision B4.

1.2.3.1 Design Basis Spent Fuel

The NAC-STC is designed to safely transport spent fuel assemblies in two configurations. The fuel assemblies may be directly loaded into a fuel basket installed in the cask cavity (uncanistered) or sealed in a transportable storage canister (canistered). The design basis fuel

assemblies for the uncanistered configuration are the Westinghouse 17 x 17 or 15 x 15 PWR fuel assemblies. These assemblies bound smaller array Westinghouse, and similar Babcock & Wilcox, and Combustion Engineering PWR fuel assemblies. The key parameters of the design basis directly loaded spent fuel assemblies are provided in Table 1.2-2. The NAC-STC can transport 26 directly loaded PWR fuel assemblies.

In the Yankee-MPC configuration, the NAC-STC can transport up to 36 Yankee Class fuel assemblies, including Yankee-MPC Reconfigured Fuel Assemblies, provided that any spent fuel assembly with fuel rods removed shall have each of the empty fuel rod positions filled with a solid rod fabricated from Zircaloy or stainless steel. The key parameters of the design basis Yankee-MPC spent fuel assemblies are provided in Table 1.2-3. The NAC-STC can also transport up to 24 containers of Yankee Class GTCC waste.

In the CY-MPC configuration, the NAC-STC can transport up to 26 Connecticut Yankee fuel assemblies, including CY-MPC Reconfigured Fuel Assemblies and CY-MPC Damaged Fuel Cans. CY-MPC Reconfigured Fuel Assemblies and Damaged Fuel Cans must be loaded in one of the four "oversize fuel" loading positions in the CY-MPC fuel basket. The NAC-STC can also transport up to 24 containers of Connecticut Yankee GTCC waste.

1.2.3.2 Greater Than Class C Waste

Greater Than Class C (GTCC) waste is defined in 10 CFR 61.55(a)(3) and (4) by the concentration of long-lived radionuclides, i.e., ^{14}C, ^{59}Ni, and ^{94}Nb, and/or short-lived radionuclides, i.e., ^{3}H, ^{60}Co, and ^{63}Ni. The disposal of GTCC waste is controlled by 10 CFR 61. GTCC waste consists of radiation activated and surface contaminated steel, and/or plasma cutting debris (dross). Stainless steel core baffle structure, which is located adjacent to the reactor vessel in a high neutron flux field, is the major component of GTCC waste.

Yankee Class GTCC Waste

The core baffle structure is plasma cut underwater into pieces of a size that are loaded into containers that have the same external dimensions as a "Yankee Class" fuel assembly. Dross (fines and debris) is generated by the underwater plasma cutting of the core baffle structure. The dross is solid particulate debris, varying in size from approximately 8 microns to over 850 microns and having a density approximately 24 percent lower than the parent material. The dross material does not generate, nor release, radioactive gases.

Dross material is collected from the spent fuel pool in buckets, in non-metallic sock filters, or by vacuuming and is discharged directly into a GTCC container. No credit is taken for the sock filters in retaining the dross material. The GTCC containers have 80 micron perforated plates that screen the drain holes in the top and bottom end fittings. Based on an experimental study of plasma cutting debris particle size, the 80 micron perforated plates in the GTCC containers retain in excess of 95 percent of the dross material. Up to 24 GTCC containers, having a total weight of 12,340 pounds, can be placed in the GTCC basket/canister. The reference volume for the design basis GTCC is 43,147 inches^3.

The principal isotopic constituents of typical Yankee Class GTCC waste are presented in Table 1.2-5. The radionuclide composition of the waste was determined based on radiochemical assay of samples and dose rate measurements of the waste containers. The isotopes that primarily contribute to the radiological source term are ^{54}Mn, ^{55}Fe, ^{60}Co, and ^{63}Ni. The source terms applied in the evaluation of the GTCC waste are presented in Section 5.2.

Any contents, such as residual water or filter media, that are subject to the production of radiolytically generated combustible gases will be limited so that the quantity of any individual combustible gas will not exceed 4% by volume within any volume of a canister containing GTCC waste. A determination of the combustible gas generation within a sealed canister will be made prior to transport to demonstrate that the 4% limit will not be exceeded from the time the canister is sealed through a period equal to twice the expected shipment duration. Furthermore, the GTCC waste will be evaluated prior to loading to ensure that none of the activated material or filter media contents produce chemical or galvanic corrosion reactions with the stainless steel canister.

Table 1.2-5 provides the detailed inventory of radionuclides in the core baffle and dross material. Activation and surface contamination data is provided for 21 GTCC containers (15 core baffle containers and 6 dross containers). The total activity for these 21 containers is shown to be bounded by the design basis evaluation of 24 containers.

Connecticut Yankee GTCC Waste

The Connecticut Yankee GTCC waste consists of sections of the core baffle, core barrel, core support plate and miscellaneous related hardware associated with these components. The major components were hydrolaser cut underwater into pieces of a size that are loaded into containers that have the same external dimensions as a Connecticut Yankee fuel assembly. Any dross material (fines and debris) generated by the cutting operations will be disposed of as low level radioactive waste.

The GTCC containers have 80 micron perforated plates that screen the drain holes in the top and bottom end fittings to allow water draining and vacuum drying. Up to 24 GTCC containers, having a total weight of 20,230 pounds, can be placed in the GTCC basket/canister. The four central containers may weigh up to 1,500 pounds each. The remaining 20 containers may weigh up to 1,000 pounds each.

The principle isotopic constituents of the Connecticut Yankee GTCC waste, resulting from activation and surface contamination, are presented in Table 1.2-6. The radionuclide composition of the waste was determined based on radiochemical assay of samples and dose rate measurements of the waste containers. The isotopes that primarily contribute to the radiological source term are ^{54}Mn, ^{55}Fe, ^{60}Co, and ^{63}Ni. The source terms applied in the evaluation of the GTCC waste are presented in Section 5.2.

The GTCC waste is solid and the waste containers have screened openings in the top and bottom that permit water draining and vacuum drying. Consequently, no hydrogen generation as a result of residual water occurs.

Figure 1.2-1 Operational Schematic for the NAC-STC

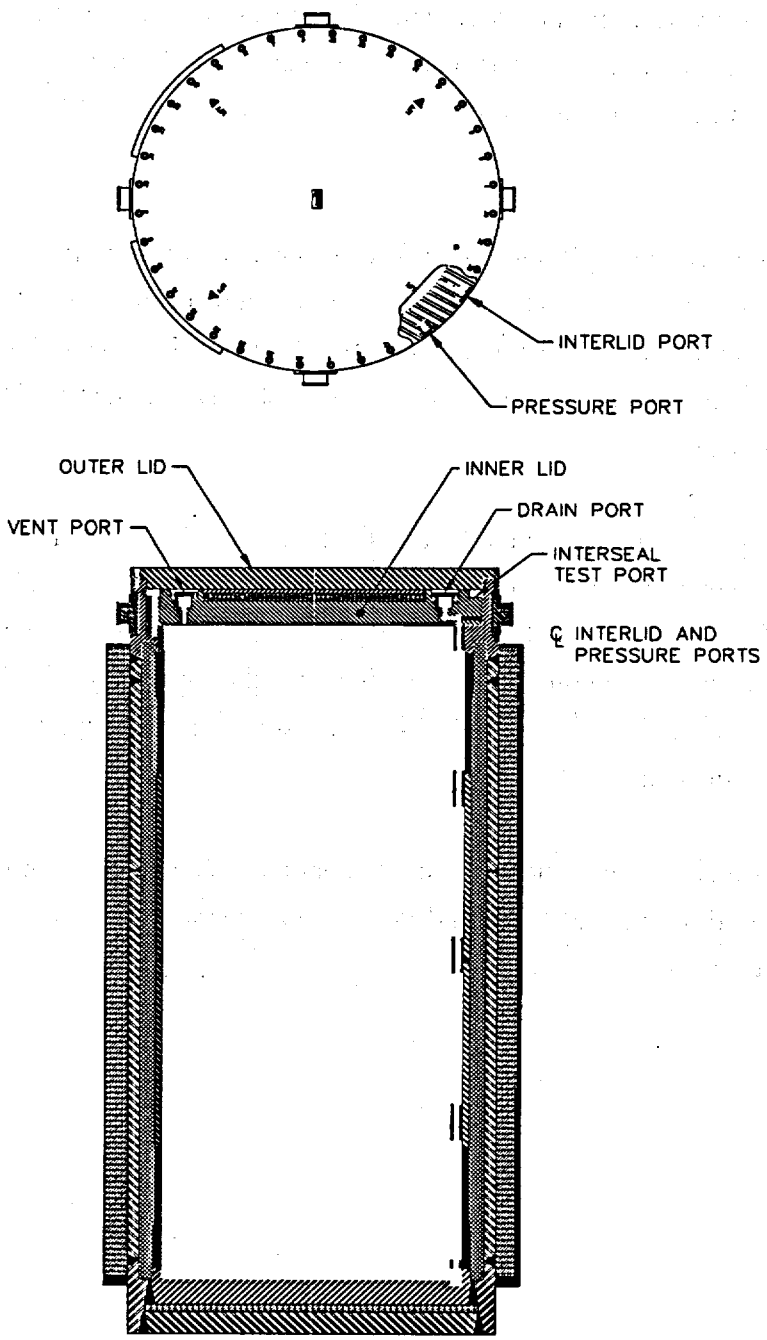


Figure 1.2-2 Yankee-MPC Reconfigured Fuel Assembly

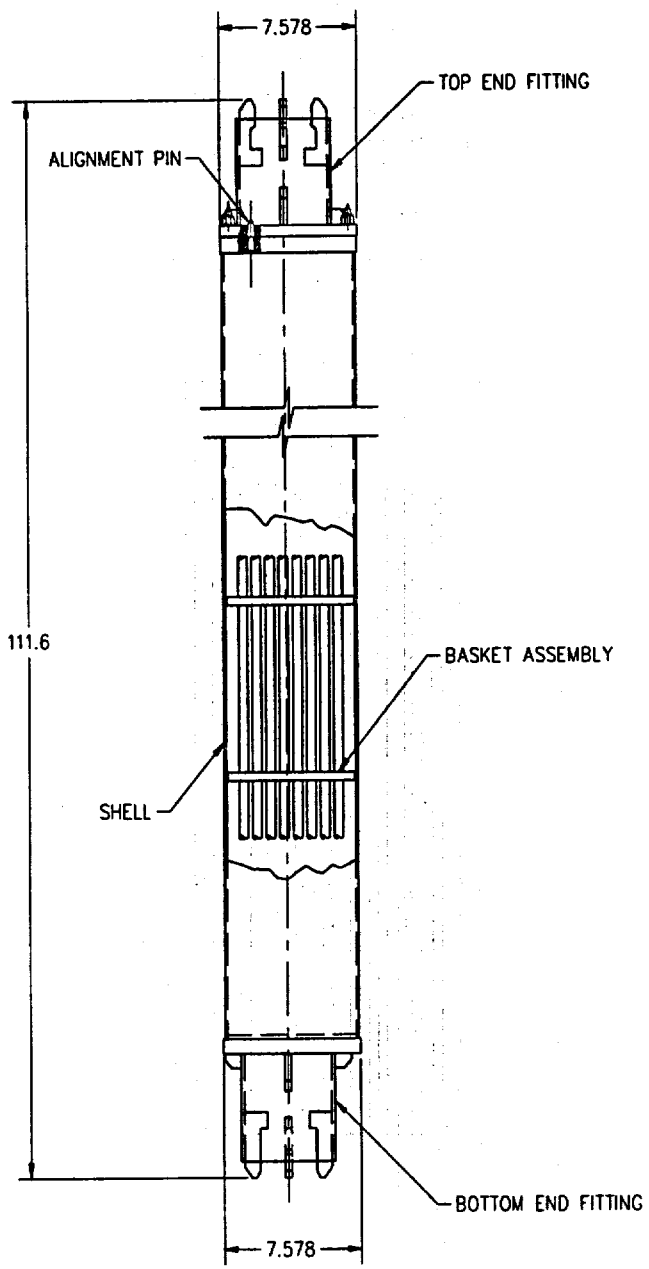


Figure 1.2-3 CY-MPC Reconfigured Fuel Assembly

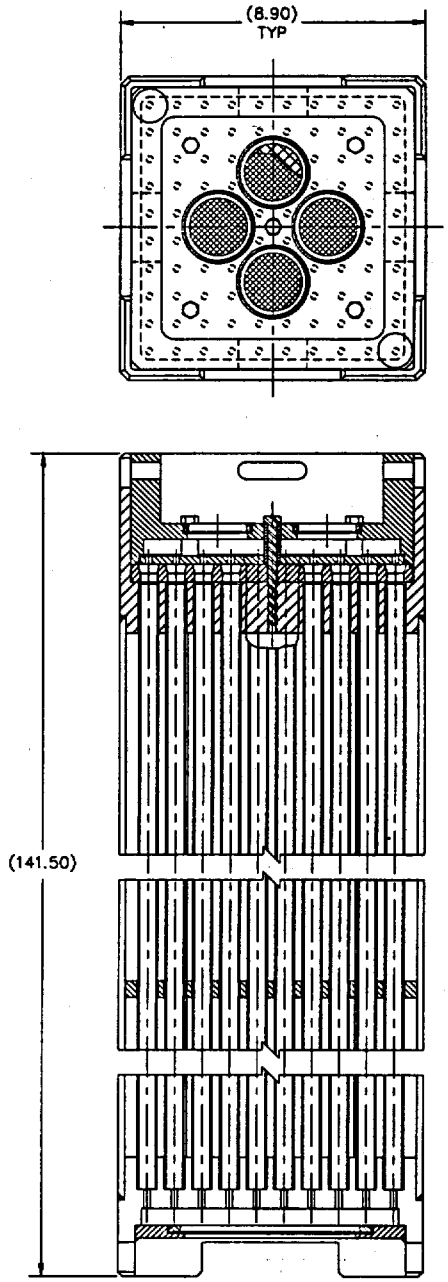


Figure 1.2-4 CY-MPC Damaged Fuel Can

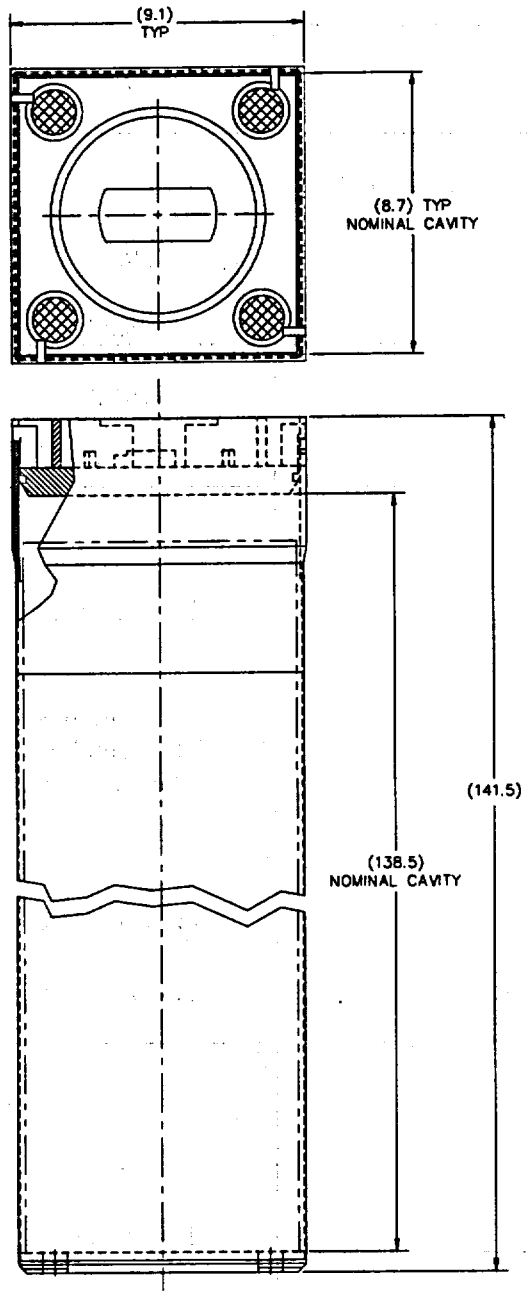


Table 1.2-1 Design Characteristics of the NAC-STC

Design Characteristic	Dimension[1]	Material
Cask Overall Length (without impact limiters)	193.0	
Cask Maximum Cross-Section Diameter		
- Across Corners	99.05	
- Across Flats	98.20	
Cask Cavity Length	165.0	
Cask Cavity Diameter	71.0	
Cask Capacity		
- Directly Loaded	26 assemblies	PWR Fuel Assemblies
Yankee Class		
- Canistered Fuel	36 assemblies	Yankee Class (zircaloy clad)
- Canistered Fuel	34 assemblies	Yankee Class (stainless clad)
- Canistered GTCC Waste	24 containers	Yankee GTCC Waste
Connecticut Yankee (CY)		
- Canistered Fuel	26 assemblies	CY fuel except Vantage 5
- Canistered Fuel	24 assemblies	CY fuel including Vantage 5 fuel
- Canistered GTCC Waste	24 containers	CY GTCC Waste
Cask Cavity Atmosphere		
- Backfill Gas	---	Helium
- Backfill Pressure	1.0 atm. abs.	
Cask Interlid and Interseal Regions		
- Backfill Gas	---	Helium
- Backfill Pressure	1.0 atm. abs.	

[1] Dimensions in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristic	Dimension[1]	Material
Inner Shell - Thickness	1.5	Type 304 Stainless Steel
Inner Shell Ring		Type XM-19 Stainless Steel
- Shell Region Thickness	1.5	
- Transition Region Thickness	2.0	
Gamma Shield - Thickness		Chemical Copper Lead
- Shell Region Thickness	3.70	
- Transition Region Thickness	3.20 (min)	
Outer Shell - Thickness	2.65	Type 304 Stainless Steel
Top Forging - Radial Thickness at cavity diameter	7.85	Type 304 Stainless Steel
Bottom Thickness (Total)	13.65	
- Bottom Inner Forging	6.20	Type 304 Stainless Steel
- Bottom Outer Forging (Radial at bottom neutron shield)	3.9	Type 304 Stainless Steel
- Bottom Plate	5.45	Type 304 Stainless Steel
- Neutron Shielding Material	2.00	NS-4-FR, Solid Synthetic Polymer

[1] Dimensions in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristic	Dimension[1]	Material
Neutron Shield - Thickness		
- Neutron Shielding Material	5.50	NS-4-FR, Solid Synthetic Polymer
- Shell	0.25	Type 304 Stainless Steel
- End Plates	0.472	Type 304 Stainless Steel
Lifting Trunnion - Diameter	5.50	Type 17-4 PH Stainless Steel
Rotation Trunnion Recess - Thickness	5.75	Type 17-4 PH Stainless Steel
Inner Lid - Thickness (Total)	9.0	
- Rim and Central Region	6.0	Type 304 Stainless Steel
- Neutron Shielding Material	2.0	NS-4-FR, Solid Synthetic Polymer
- Coverplate	1.0	Type 304 Stainless Steel
- Bolts (42)	1-1/2 - 8 UN	SB-637, GR N07718, Nickel Alloy

[1] Dimension in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristic	Dimension[1]	Material
Outer Lid		
- Body Thickness	5.25	Type 17-4 PH Stainless Steel
- Bolts (36)	1 - 8 UNC	SA-564, Type 630 17-4PH Stainless Steel
Inner Lid Port Coverplate		
- Body Thickness	1.00	Type 304 Stainless Steel
- Bolts (4)	1/2 - 13 UNC	SA-193, Grade B6, Type 410, Stainless Steel
Port Cover		
- Body Thickness	1.01	Type 17-4 PH Stainless Steel
- Bolts (3)	3/8 - 16 UNC	SA-193, GR B6, Type 410 Stainless Steel
Canister Spacers		
- Yankee-MPC Top Spacer	28.0 x 70.6 (dia)	Aluminum Honeycomb with 6061-T6 Aluminum Outer Shell
- Yankee-MPC Bottom Spacer	14.0 x 68.9 (dia)	Aluminum Honeycomb with 6061-T6 Aluminum Outer Shell
- CY-MPC Bottom Spacer	12.7 x 70.6 (dia)	ASTM A240, Type 304 Stainless Steel

[1] Dimension in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristics	Dimension[1]	Material
Fuel Basket (Directly Loaded)		
- End Weldments (Plate)	1.0 x 70.86 dia.	Type 304 Stainless Steel
- Support Disks	0.5 x 70.86 dia.	Type 17-4 PH Stainless Steel
- Heat Transfer Disks	0.625 x 70.65 dia.	Type 6061-T651 aluminum alloy
- Tube	8.78 x 8.78 x 0.048	Type 304 Stainless Steel encasing BORAL
- Spacer Nuts	2.5 Square	Type 17-4 PH Stainless Steel
- Threaded Rod (6)	1-5/8 - 8 UN	Type 17-4 PH Stainless Steel
Canister		
- Shell (Plate)	5/8	Type 304L Stainless Steel
- Shield Lid (Plate)	5	Type 304L Stainless Steel
- Structural Lid (Plate)	3	Type 304 Stainless Steel
- Shell Bottom (Plate)		
- Yankee-MPC	1.0	Type 304L Stainless Steel
- CY-MPC	1.75	Type 304L Stainless Steel

[1] Dimensions in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristics	Dimension[1]	Material
Yankee-MPC Canister Fuel Basket		
- End Weldments	0.5 x 68.98 dia.	Type 304 Stainless Steel
- Support Disks	0.5 x 69.15 dia.	Type 17-4 PH Stainless Steel
- Heat Transfer Disks	0.5 x 68.87 dia.	Type 6061-T651 Aluminum Alloy
- Tube	7.80 x 7.80 x 0.048	Type 304 Stainless Steel encasing BORAL
- Spacers	2.5 dia.	Type 304 Stainless Steel
- Tie Rods (8)	1-1/8 dia.	Type 304 Stainless Steel
Yankee-MPC Canister GTCC Basket		
- Support Walls	2.5 x 111.3	Type 304 Stainless Steel
- Support Disks	1.0 x 68.98 dia.	Type 304 Stainless Steel
- Tube	8.32 x 8.32 x 0.25	Type 304 Stainless Steel
CY-MPC Canister Fuel Basket		
- End Weldments	0.5 x 68.98 dia.	Type 304 Stainless Steel
- Support Disks	0.5 x 69.15 dia.	Type 17-4 PH Stainless Steel
- Heat Transfer Disks	0.5 x 68.87 dia.	Type 6061-T651 Aluminum Alloy
- Tube	8.72 x 8.72 x 0.048	Type 304 Stainless Steel encasing BORAL
- Oversized Tube	9.12 x 9.12 x 0.048	Type 304 Stainless Steel encasing BORAL
- Spacers	2.88 dia.	Type 304 Stainless Steel
- Tie Rods (8)	1-5/8 dia.	Type 304 Stainless Steel

[1] Dimensions in inches unless otherwise noted.

Table 1.2-1 Design Characteristics of the NAC-STC (continued)

Design Characteristics	Dimension[1]	Material
CY-MPC Canister GTCC Basket		
- Support Walls	2.25 x 141.5	Type 304 Stainless Steel
- Support Disks	1.0 x 69.15 dia.	Type 304 Stainless Steel
- Tube (Inside Dimension)	8.72 x 8.72 x 0.25	Type 304 Stainless Steel
Seals (O-Rings)		
- Inner Lid		
- Inner	0.25 dia. x 72.251 dia.	Type 321 Stainless Steel
- Outer	0.25 dia. x 73.497 dia.	Type 321 Stainless Steel
- Port Coverplates		
- Inner	0.125 dia. x 3.875 dia.	Type 321 Stainless Steel
- Outer	0.125 dia. x 4.500 dia.	Type 321 Stainless Steel
- Outer Lid	0.250 dia. x 82.060 dia.	Type 321 Stainless Steel
- Port Covers		
- Primary	0.103 dia. x 2.675 dia.	PTFE
- Secondary	0.103 dia. x 2.675 dia.	PTFE

[1] Dimensions in inches unless otherwise noted.

Table 1.2-2 NAC-STC Design Basis Directly Loaded Fuel Characteristics

Parameter	Westinghouse PWR Fuel[1]	
	17 x 17	15 x 15
Maximum Number of Assemblies	26	26
Maximum Assembly Weight, lbs	1467	1440
Maximum Assembly Length, in	160	160
Active Fuel Length, in	144	144
Fuel Rod Cladding	Zircaloy-4	Zircaloy-4
Maximum Uranium, kgU	464	469
Maximum Initial ^{235}U, wt %	4.2	4.2
Minimum Initial ^{235}U, wt %	3.7	3.7
Maximum Burnup, MWD/MTU	40,000	40,000
Maximum Assembly Decay Heat, kW	0.85	0.85
Maximum Cask Decay Heat, kW	22.1	22.1
Minimum Cool Time, yr	6.5[2]	6.5[2]

1 Conservatively assumed maximum assembly weight is 1,525 pounds. Actual assembly weights are provided for information only. These assemblies are the design basis fuel assemblies for the structural, thermal and shielding evaluations. The design basis fuel for the criticality evaluation is the Westinghouse 17x17OFA. Physical properties for the OFA assembly are provided in Table 6.2-1.

2 The NAC-STC has also been designed to accommodate directly loaded PWR assemblies with a minimum cool time of 10 years and a burnup of 45,000 MWD/MTU.

Table 1.2-3 NAC-STC Design Basis Yankee Class Fuel Characteristics

Parameter	Yankee Class Fuel[1,2]				
	United Nuclear Type A	Combustion[3] Type A	Westinghouse Type B	Exxon Type A	Yankee RFA
Maximum Number of Assemblies	36	36	34	36	36
Maximum Assembly Weight, lbs	850	850	900	850	850
Maximum Assembly Length, in	111.25	111.79	111.25	111.56	111.79
Active Fuel Length, in	91	91	92	91	91
Fuel Rod Cladding	Zircaloy	Zircaloy	Stainless Steel	Zircaloy	Zircaloy
Maximum Uranium, kgU	245.6	239.4	286.9	239.4	70.0
Maximum Initial ^{235}U, wt %	4.0	3.9	4.94	4.0	4.0
Minimum Initial ^{235}U, wt %	4.0	3.7[3]	4.94	3.5	3.5
Maximum Burnup, MWD/MTU	32,000	36,000	32,000	36,000	36,000
Maximum Assembly Decay Heat, kW	0.272	0.347	0.273	0.331	0.097
Maximum Cask Decay Heat, kW	9.8	12.5	9.3	11.9[4]	3.5
Minimum Cool Time, yr	11.0	8.1	19.0	9.0[4]	8.0

1 The Yankee Class Fuel includes United Nuclear Type A and Type B, Combustion Engineering Type A and Type B, Exxon-ANF Type A and Type B and Westinghouse Type A and Type B. The United Nuclear Type A is the most reactive assembly and is used as the design basis fuel for criticality analyses. The Combustion Type A is the design basis fuel for shielding and thermal evaluations. The Westinghouse Type B fuel is the design basis fuel for structural weight considerations. The Yankee Class design basis fuels bound a Yankee Class Reconfigured Fuel Assembly.

2 The maximum number of mixed Type Yankee Class fuel assemblies is limited to 36 or to 30,600 lbs, total loaded assembly weight.

3 The NAC-STC can also accommodate canistered Combustion Engineering 3.5 wt % enriched fuel having a minimum cool time of 7 years and a burnup of 32,000 MWD/MTU.

4 The limit corresponds to Exxon assemblies with Zircaloy in-core hardware. Exxon assemblies with steel in-core hardware are limited by a minimum cool time of 16 years and a maximum decay heat of 9.7 kW.

Table 1.2-4 NAC-STC Design Basis Connecticut Yankee Fuel Characteristics

Parameter	Connecticut Yankee Fuel[1,2,3]				
	Westinghouse	Babcock and Wilcox	Westinghouse Vantage 5H	CY-MPC RFA[4]	CY-MPC DFC[5]
Maximum Number of Assemblies	26	26	24	4	4
Maximum Assembly Weight, lbs	1,350	1,230	1,230	1,500	1,500
Maximum Assembly Length, in	137.1	137.1	137.1	141.5	141.5
Active Fuel Length, in	121.8	121.1	120.6	121.8	121.8
Fuel Rod Cladding	Stainless Steel	Zircaloy	Zircaloy	Either	Either
Maximum Uranium, kgU	432	395	390	212	432
Maximum Initial ^{235}U, wt %	4.01	4.61	4.61	4.61	4.61
Minimum Initial ^{235}U, wt %	3.00	2.95	2.95	2.95	2.95
Maximum Burnup, MWD/MTU	38,000	43,000	43,000	43,000	43,000
Maximum Assembly Decay Heat, kW	0.6545	0.6545	0.6545	0.321	0.6545
Maximum Cask Decay Heat, kW	17	17	17	17	17
Minimum Cool Time, years	10	10	10	10	10

1 Connecticut Yankee spent fuel includes Westinghouse, Babcock and Wilcox, Gulf General Atomic and NUMEC designs. The Westinghouse Vantage 5H design is the most reactive and is used as the design basis fuel for criticality analyses. The Westinghouse stainless steel design is the design basis fuel for shielding, thermal and structural evaluations.
2 Intact fuel assemblies may have a reactor control cluster installed.
3 Intact fuel assemblies may have a flow mixer installed. Assemblies with flow mixers installed must be loaded into one of the eight interior fuel loading positions in the basket.
4 Reconfigured Fuel Assemblies (RFA) must be loaded in one of the 4 oversize fuel loading positions.
5. Damaged Fuel Cans (DFC) must be loaded in one of the 4 oversize fuel loading positions.

Table 1.2-5 Isotopic Constituents of Yankee GTCC Waste

Isotope	Baffle Activity (Ci)		Average Dross Activity (Ci)		Total Activity (Ci)		Total Activity (Ci)[1]	
	Activation	Surface	Activation	Surface	15 Baffle	6 Dross	Total-21	24 Design Basis
Tritium	4.52E+01	1.68E-04	5.59E+00	2.07E-05	4.52E+01	5.59E+00	5.08E+01	--
Carbon-14	4.90E+01	1.42E-03	6.06E+00	1.76E-04	4.90E+01	6.06E+00	5.50E+01	--
Manganese-54	7.72E+01	1.62E-03	9.57E+00	2.01E-04	7.72E+01	9.57E+00	8.68E+01	1.00E+02
Iron-55	7.07E+04	9.09E-01	8.75E+03	1.13E-01	7.07E+04	8.75E+03	7.94E+04	8.75E+04
Cobalt-60	1.02E+05	2.01E+00	1.26E+04	2.49E-01	1.02E+05	1.26E+04	1.14E+05	1.25E+05
Nickel-63	2.79E+04	6.64E-01	3.45E+03	8.22E-02	2.79E+04	3.45E+03	3.13E+04	3.35E+04
Technetium-99	1.36E-01	1.76E-04	1.68E-02	2.18E-05	1.36E-01	1.69E-02	1.53E-01	--
Cesium-134	0.00	5.32E-03	0.00	6.59E-04	5.32E-03	6.59E-04	5.98E-03	--
Cesium-137	0.00	2.49E-01	0.00	3.09E-02	2.49E-01	3.09E-02	2.80E-01	--
Cerium-144	0.00	1.05E-03	0.00	1.30E-04	1.05E-03	1.30E-04	1.18E-03	--
Plutonium-238	0.00	2.61E-03	0.00	3.23E-04	2.61E-03	3.23E-04	2.93E-03	--
Plutonium-239/240	0.00	6.65E-03	0.00	8.24E-04	6.65E-03	8.24E-04	7.48E-03	--
Plutonium-241	0.00	2.09E-01	0.00	2.59E-02	2.09E-01	2.59E-02	2.35E-01	--
Americium-241	0.00	3.94E-03	0.00	4.88E-04	3.94E-03	4.88E-04	4.43E-03	--
Curium-242	0.00	1.89E-07	0.00	2.35E-08	1.89E-07	2.35E-08	2.13E-07	--
Curium-243/244	0.00	1.48E-03	0.00	1.84E-04	1.48E-03	1.84E-04	1.67E-03	--
Ruthenium-106	0.00	1.82E-03	0.00	2.25E-04	1.82E-03	2.25E-04	2.04E-03	--
Strontium-89	0.00	3.81E-13	0.00	4.72E-14	3.81E-13	4.72E-14	4.29E-13	--
Strontium-90	0.00	2.20E-01	0.00	2.72E-02	2.20E-01	2.72E-02	2.47E-01	--
Iodine-129LLD	0.00	1.12E-04	0.00	1.38E-05	1.12E-04	1.38E-05	1.25E-04	--
Antimony-125	0.00	1.40E-02	0.00	1.73E-03	1.40E-02	1.73E-03	1.57E-02	--
Silver-110m	0.00	1.07E-04	0.00	1.33E-05	1.07E-04	1.33E-05	1.20E-04	--
Cobalt-57	0.00	3.96E-05	0.00	4.90E-06	3.96E-05	4.90E-06	4.45E-05	--
Niobium-94	6.63E-01	0.00	8.21E-02	0.00	6.63E-01	8.21E-02	7.45E-01	--
Nickel-59	1.52E+02	0.00	1.88E+01	0.00	1.52E+02	1.88E+01	1.71E+02	--
Zinc-65	6.78E-01	0.00	8.39E-02	0.00	6.78E-01	8.39E-02	7.62E-01	--

1. Isotopes except Manganese, Iron, Cobalt and Nickel are limited to a total of 500 curies per canister. The total Plutonium content must be less than 20 to exempt the canister from the requirements of 10 CFR 71.63.

Table 1.2-6 Isotopic Constituents of Connecticut Yankee GTCC Waste

Isotope	GTCC Activity[1]	
	Curies/gram	Estimated Curies
Carbon-14	1.17E-05	1.13E+02
Manganese-54	5.10E-06	4.90E+01
Iron-55	1.07E-02	1.03E+05
Cobalt-60	2.04E-02	1.96E+05
Nickel-63	4.39E-05	4.22E+02
Technetium-99	7.46E-03	7.18E+04
Niobium-94	1.65E-07	1.59E+00
Nickel-59	2.96E-08	2.85E-01
Total		3.71E+05

1. The GTCC activity is based on the activity of the Core Baffle component and a GTCC contents weight of 21,200 lbs.

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1.3 Appendices

1.3.1 Quality Assurance

The U.S. NRC has assigned Approval Number 18 to the NAC International Quality Assurance program, which satisfies the provisions of Subpart H of 10 CFR 71.

The Quality Assurance program provides control over all activities designated important to safety that are applicable to the design, fabrication, assembly, testing, maintenance, repair, modification and use of the packaging for transportation of radioactive materials. The program applies controls to the various activities in a graded approach, such that the effort expended on an activity is consistent with its importance to safety. The program is consistent in approach and method with Regulatory Guide 7.10.

In accordance with the requirements of 10 CFR 71.37(a), the approved Quality Assurance program has been applied to the design and analysis of the packaging, and will be applied to the packaging fabrication, assembly, testing, maintenance, repair, and modification. An equivalent U.S. NRC-approved program maintained by a Registered User shall be applied to the use of the packaging.

1.3.2 License Drawings

This section contains the license drawings pertinent to the NAC-STC and for the Yankee Class Reconfigured Fuel Assembly. The List of Drawings is presented in the Table of Contents for Chapter 1.

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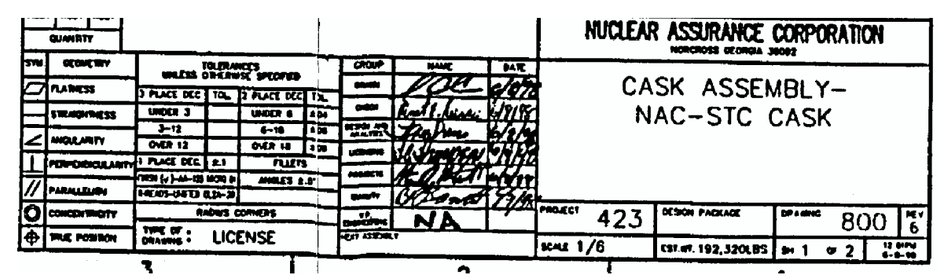

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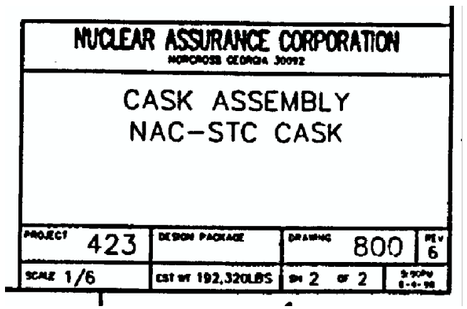

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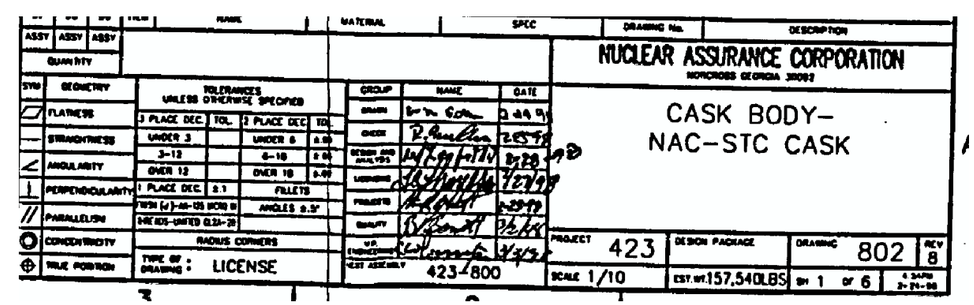

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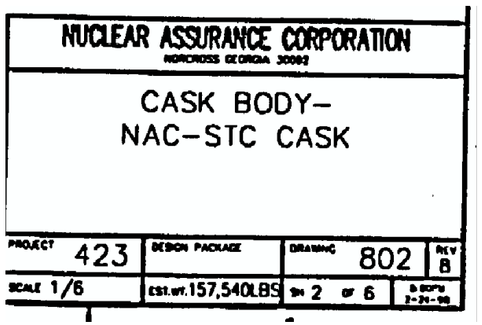

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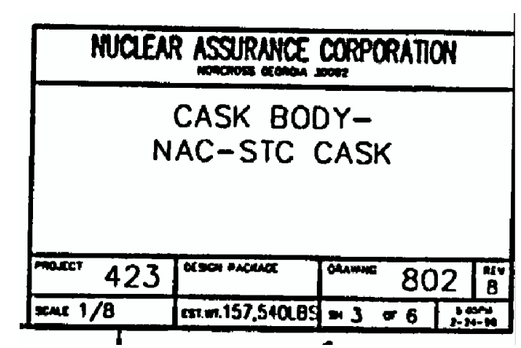

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PROJECT 423	DESIGN PACKAGE	DRAWING 802	REV B
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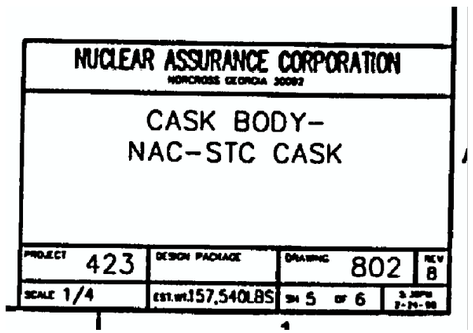

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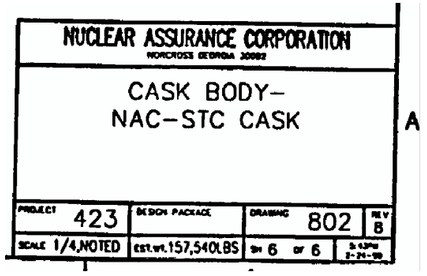

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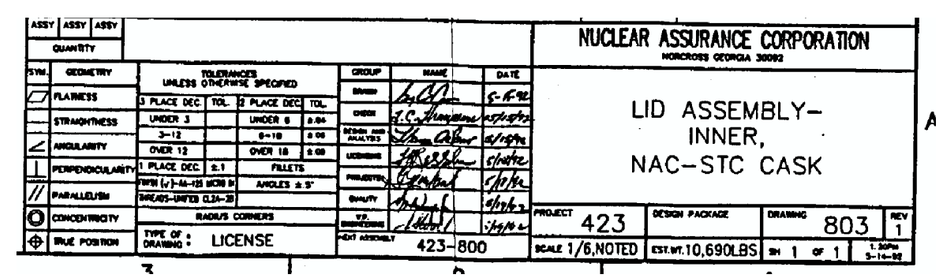

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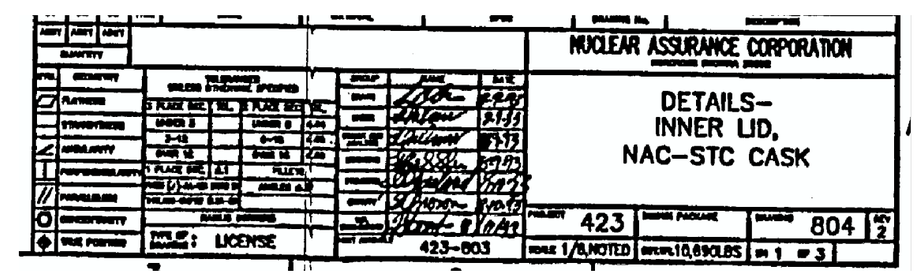

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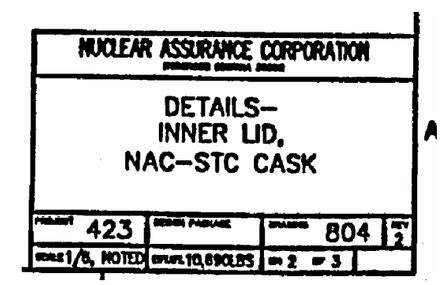

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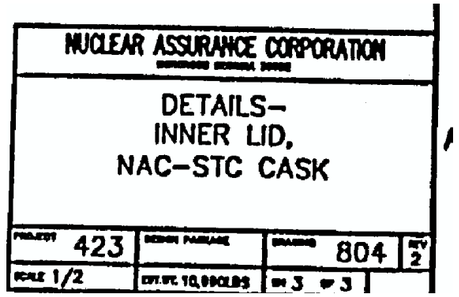

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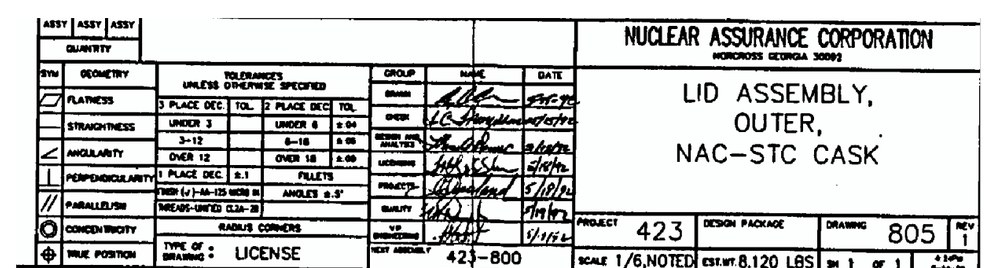

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QUANTITY			
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	FLATNESS	3 PLACE DEC. / TOL.	2 PLACE DEC / TOL.
	STRAIGHTNESS	UNDER 3	UNDER 6 / ±.04
		3-12	6-18 / ±.06
	ANGULARITY	OVER 12	OVER 18 / ±.09
	PERPENDICULARITY	1 PLACE DEC. / ±.1	FILLETS
	PARALLELISM	FINISH (√)-AA-125 MICRO IN	ANGLES ±.5°
		THREADS-UNIFIED CL2A-2B	
	CONCENTRICITY	RADIUS CORNERS	
	TRUE POSITION	TYPE OF DRAWING: LICENSE	

GROUP	NAME	DATE
DRAWN		5-7-92
CHECK		
DESIGN AND ANALYSIS		5/15/92
LICENSING		5/19/92
PROJECTS		5/18/92
QUALITY		5/19/92
V.P. ENGINEERING		5/19/92
NEXT ASSEMBLY	423-803	

NUCLEAR ASSURANCE CORPORATION
NORCROSS GEORGIA 30092

PORT COVERPLATE ASSY.
INNER LID,
NAC-STC CASK

PROJECT 423	DESIGN PACKAGE	DRAWING 806	REV 1
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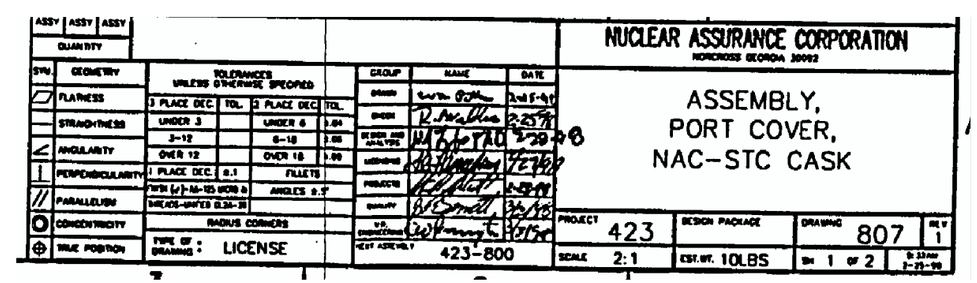

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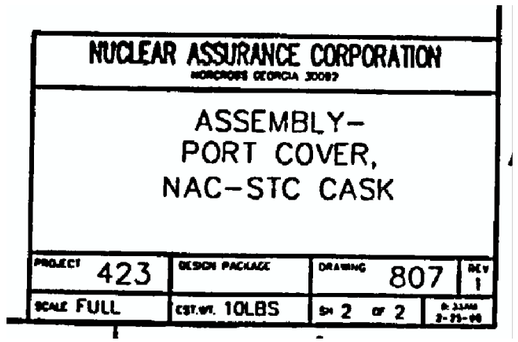

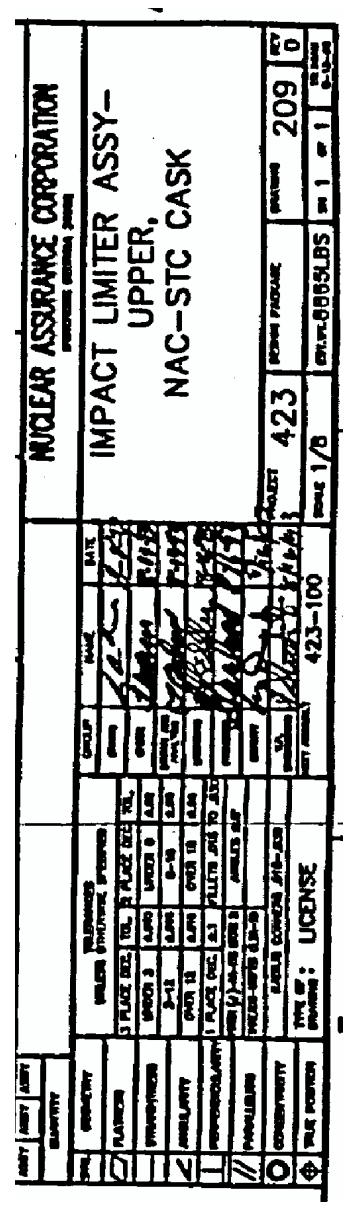

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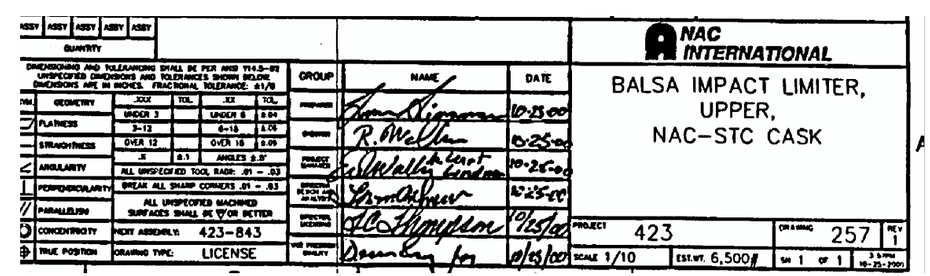

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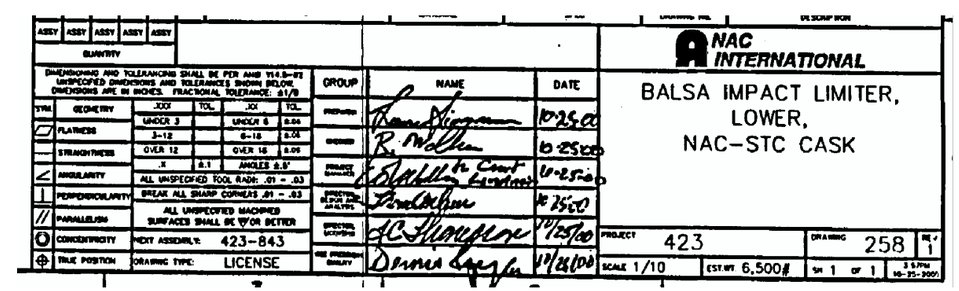

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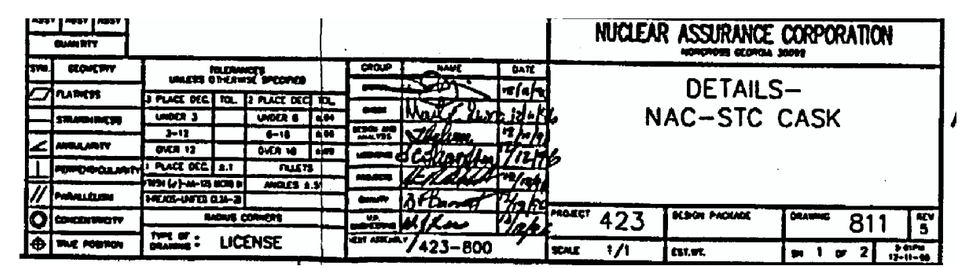

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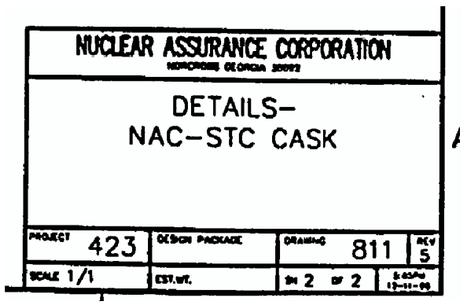

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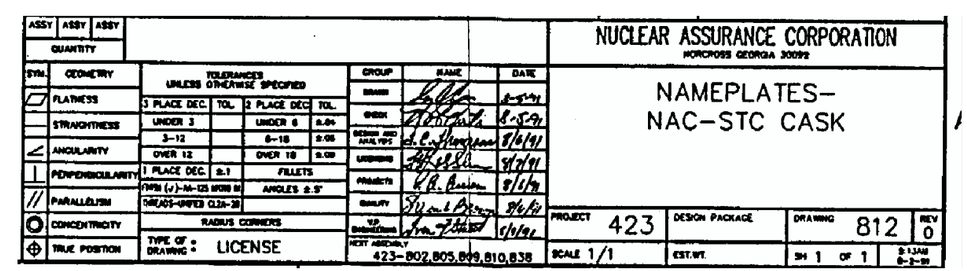

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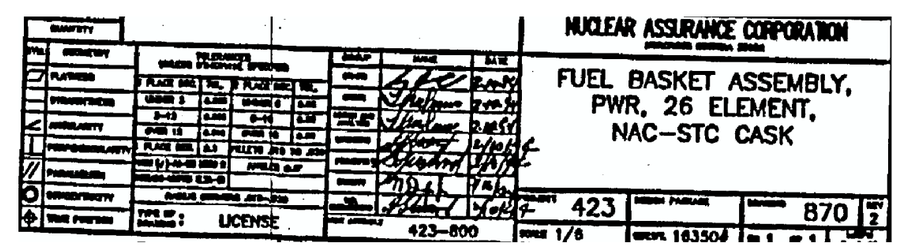

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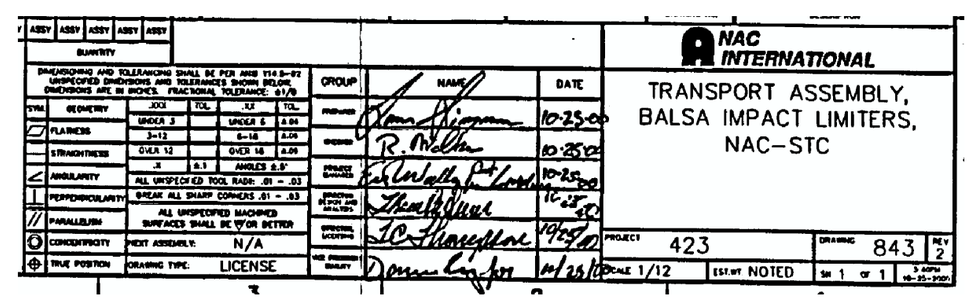

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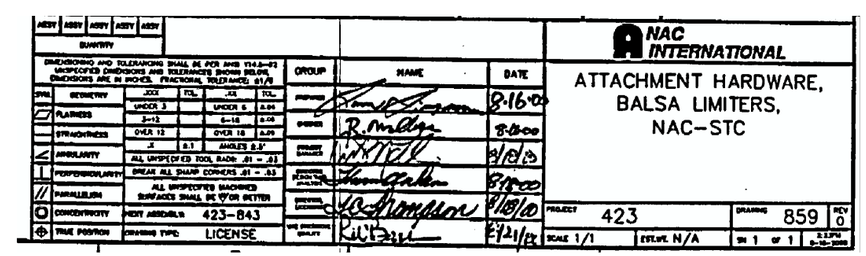

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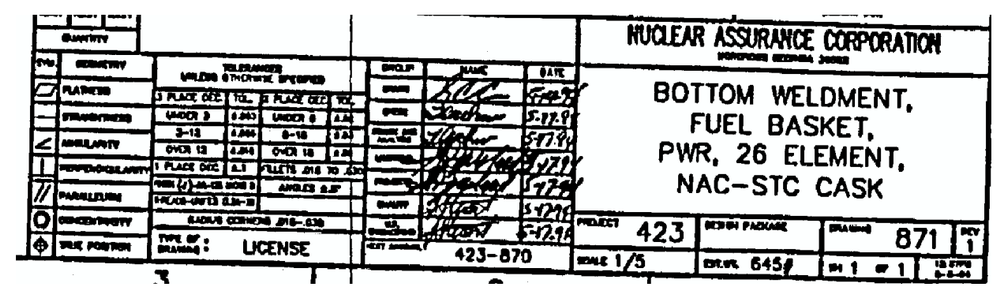

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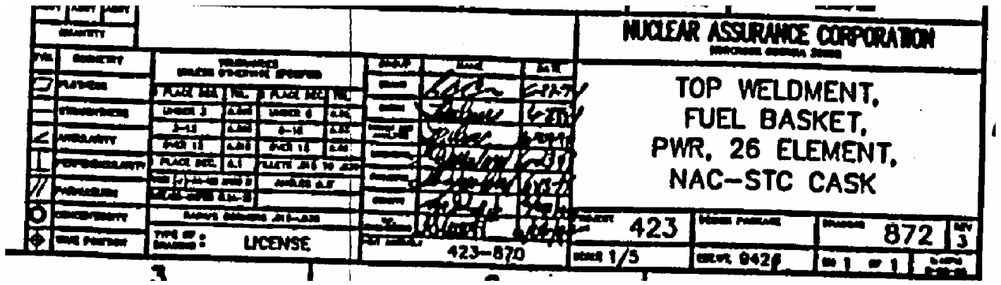

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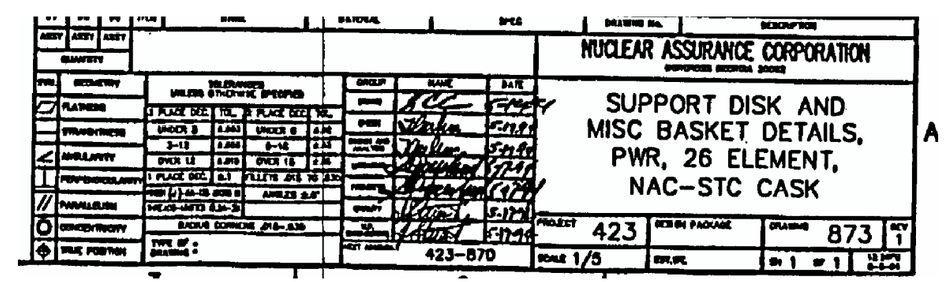

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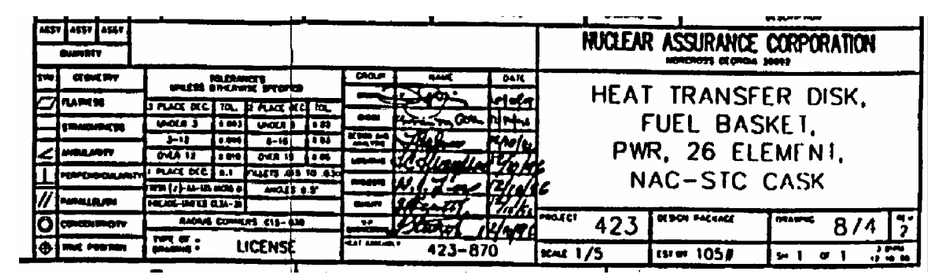

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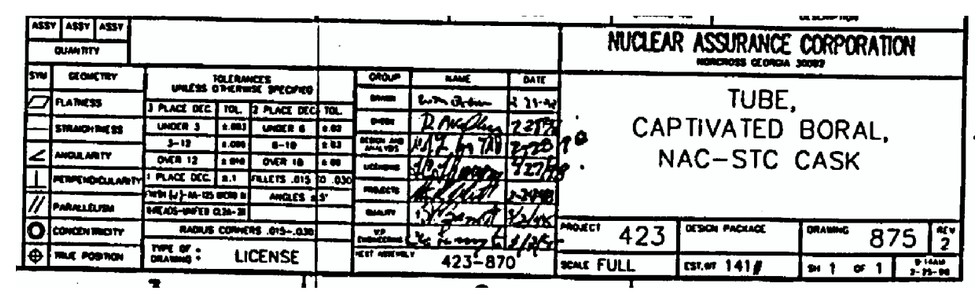

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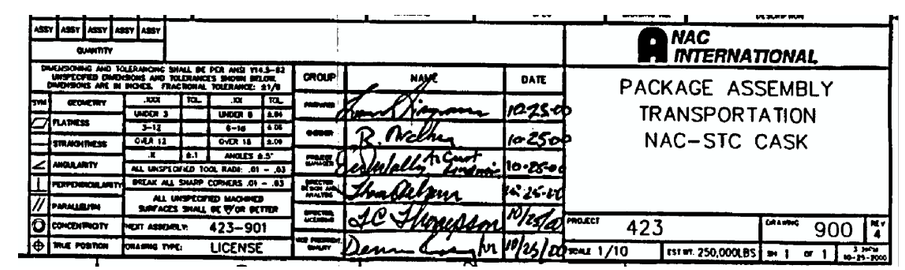

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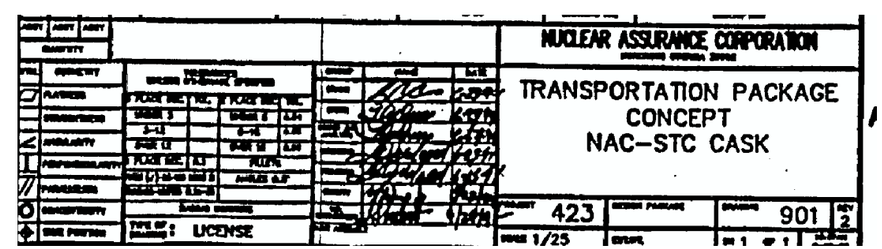

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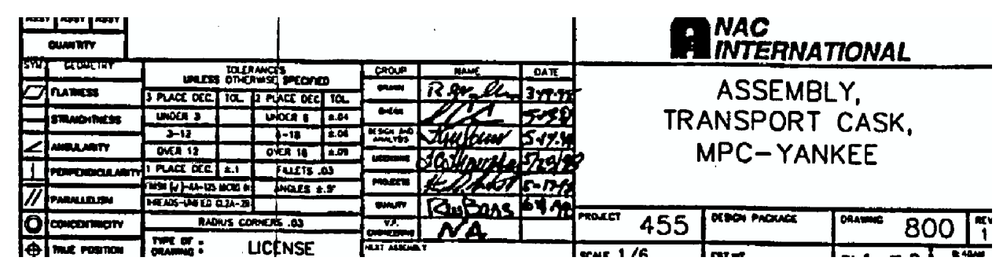

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

ASSEMBLY,
TRANSPORT CASK,
MPC–YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 800	REV 1
SCALE 1/6	EST. WT.	SH 2 OF 2	8:41AM 3-19-98

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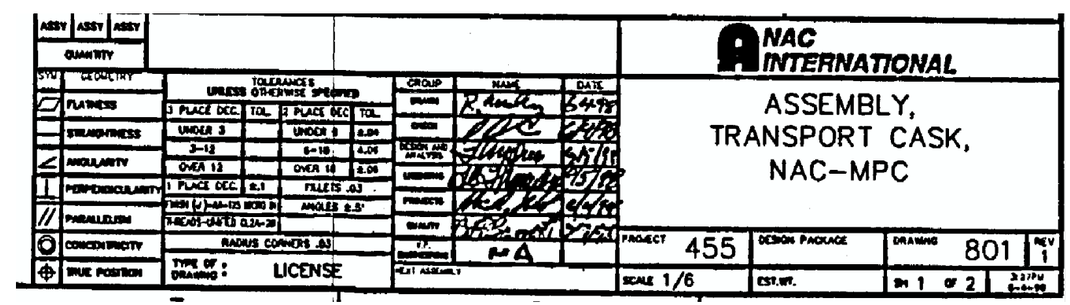

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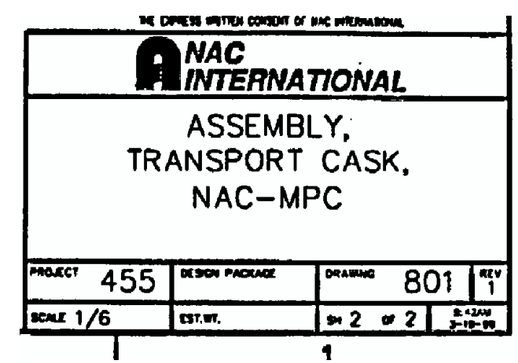


FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

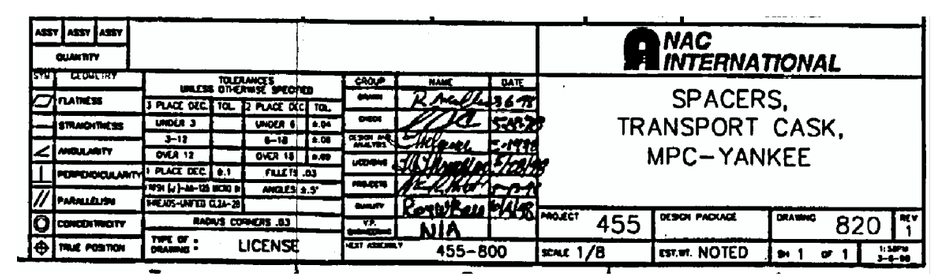
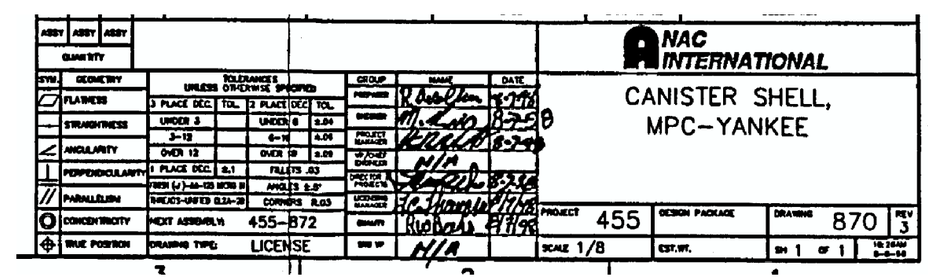


FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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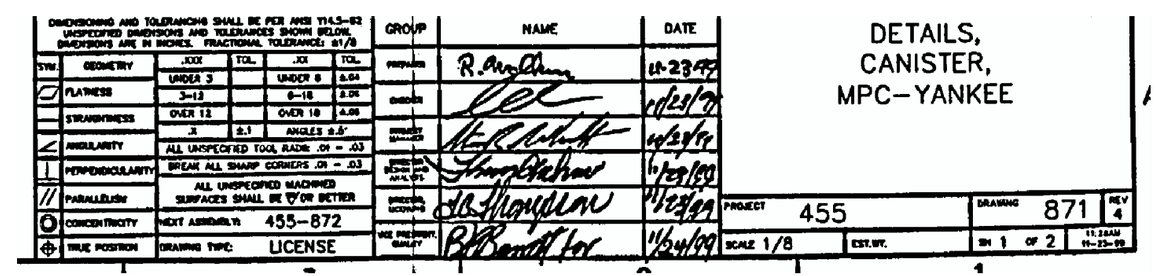


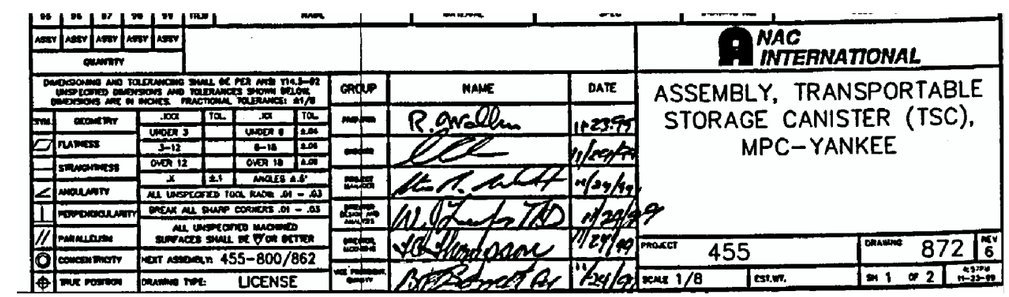
FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

DETAILS,
CANISTER,
MPC–YANKEE

PROJECT 455		DRAWING 871	REV 4
SCALE 1/8	EST. WT.	SH 2 OF 2	11:27 AM 11-23-99

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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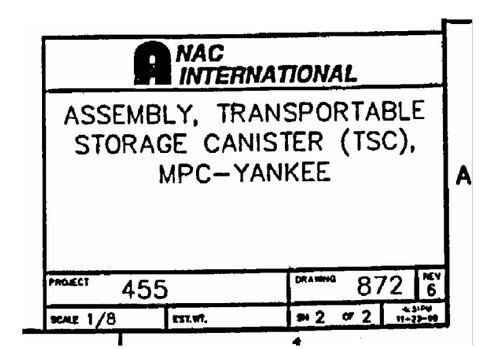

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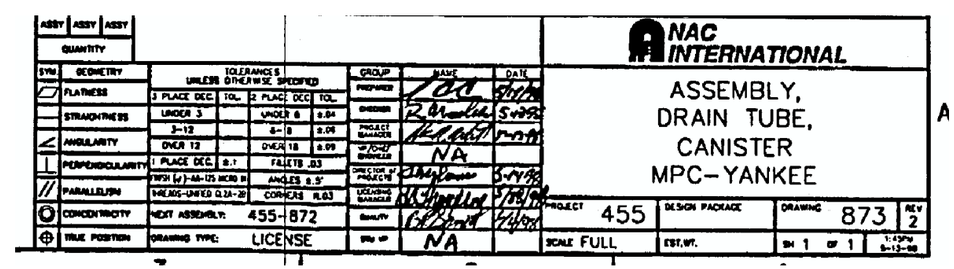

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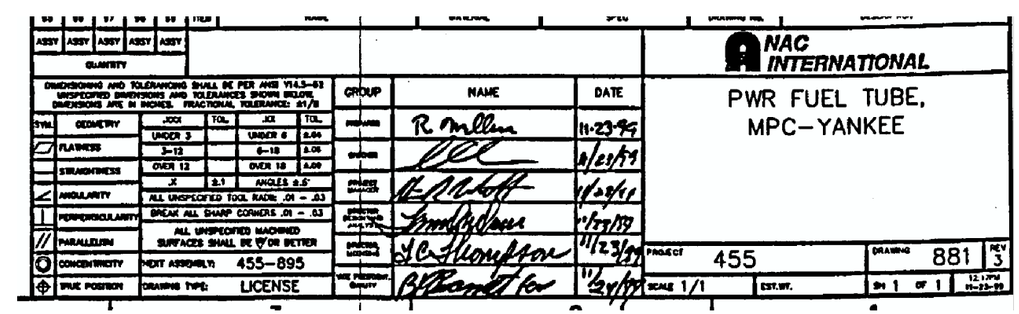

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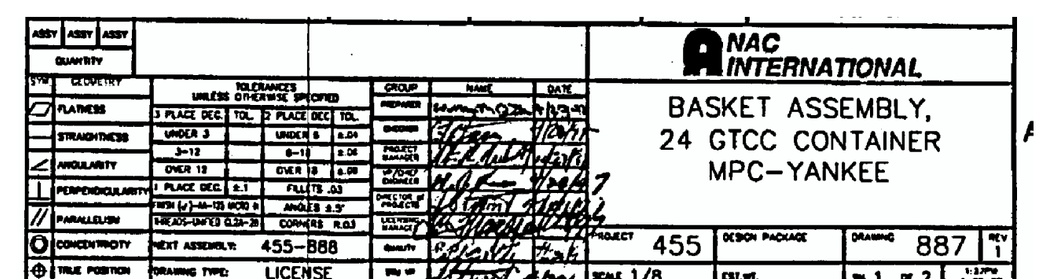


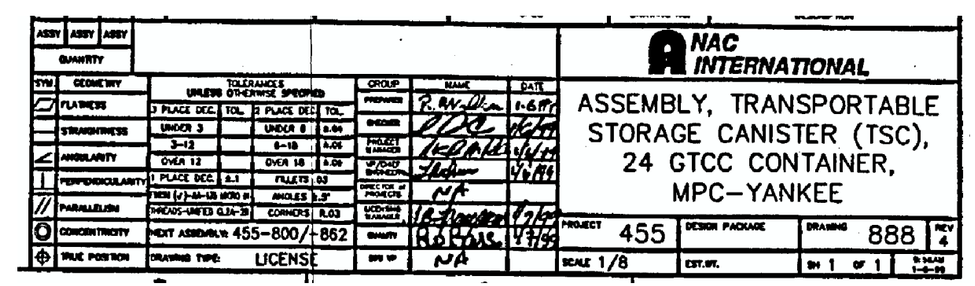
FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

BASKET ASSEMBLY,
24 GTCC CONTAINER,
MPC-YANKEE

PROJECT 455	DESIGN PACKAGE	DRAWING 887	REV 1
SCALE 1/8	EST. WT.	SH 2 OF 2	10:49AM 4-28-97

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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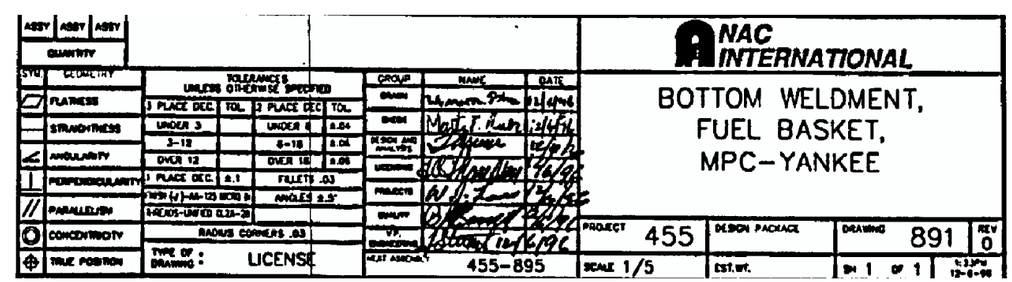

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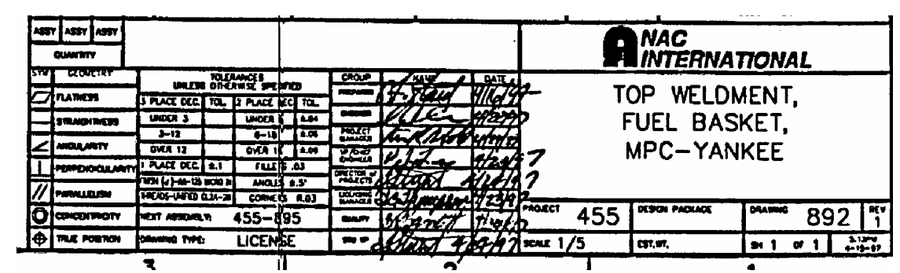

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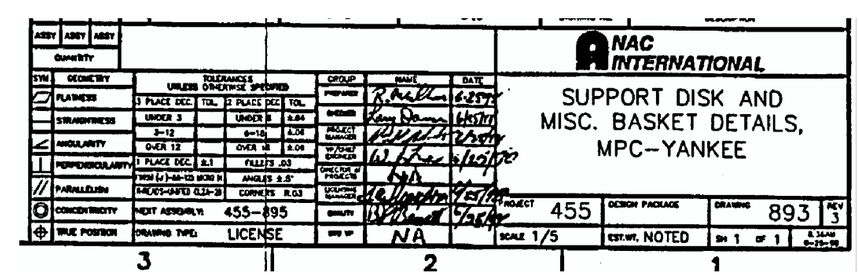

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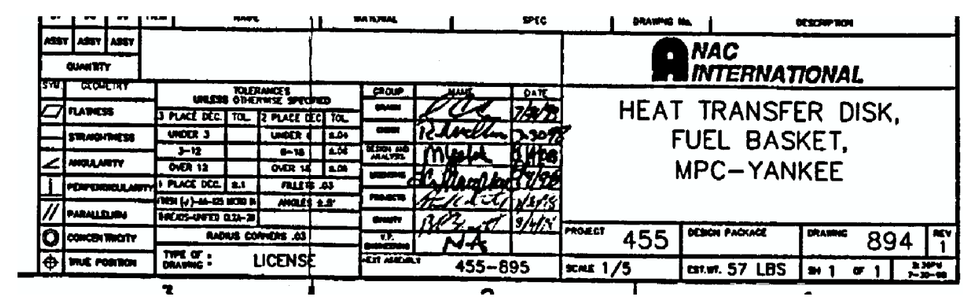

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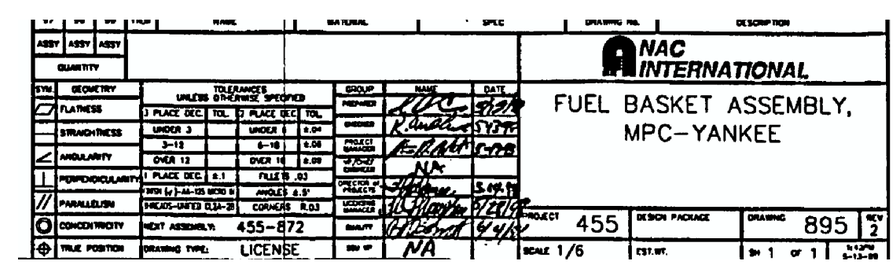

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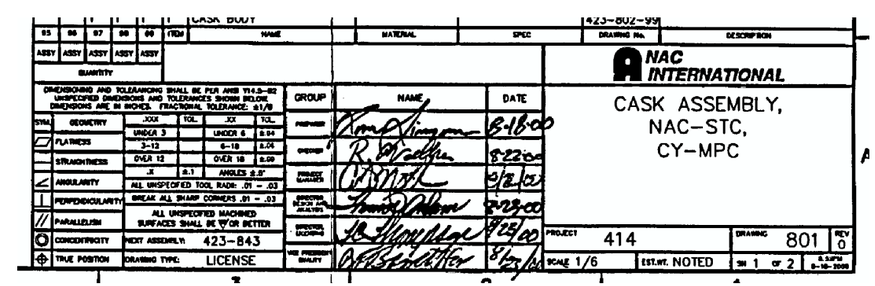

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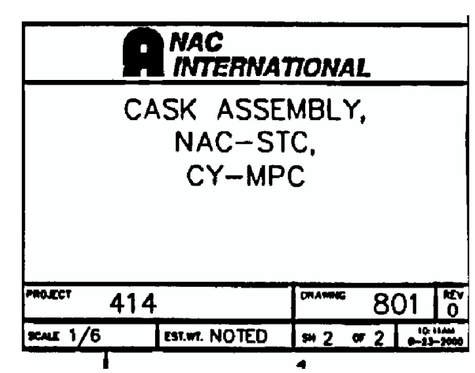

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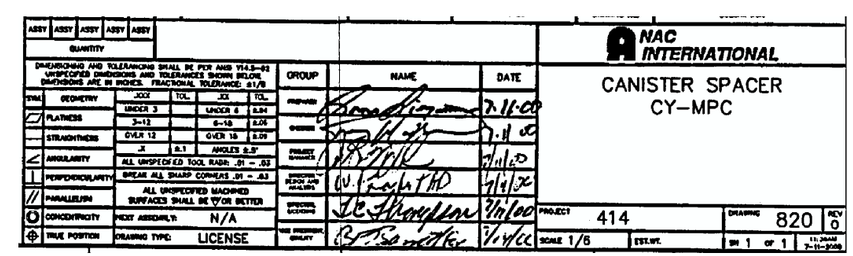

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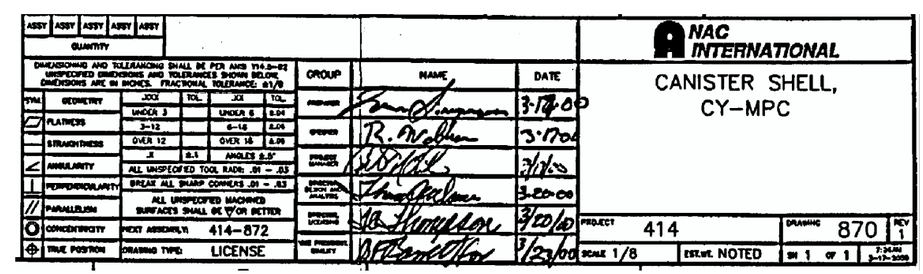

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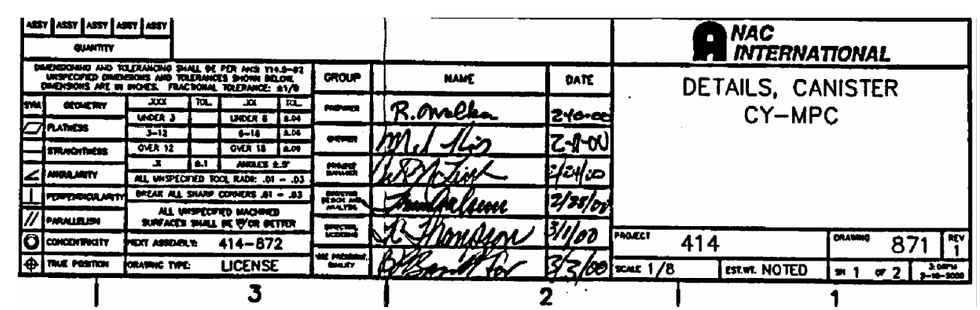

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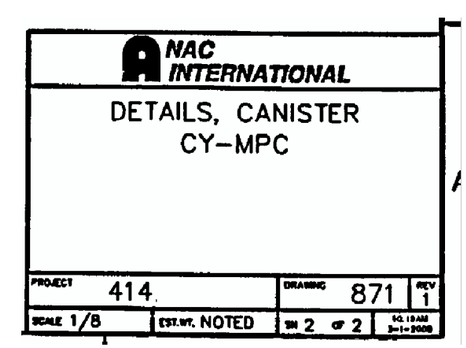

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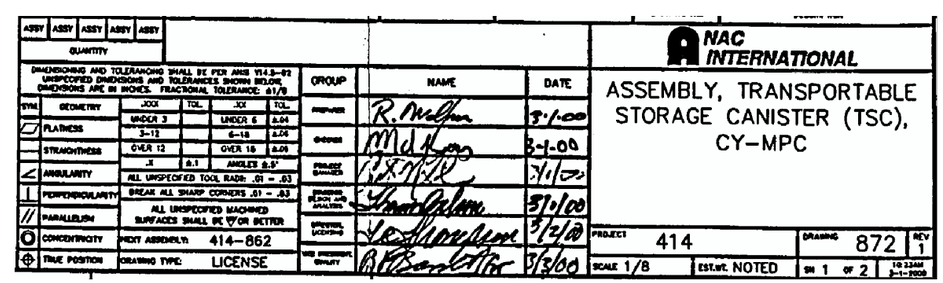

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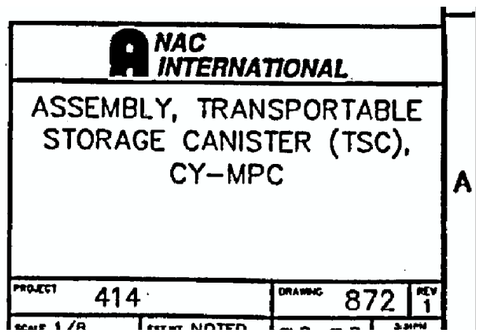

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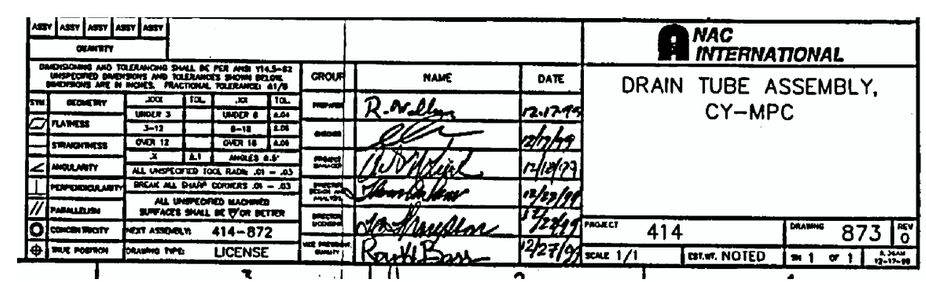

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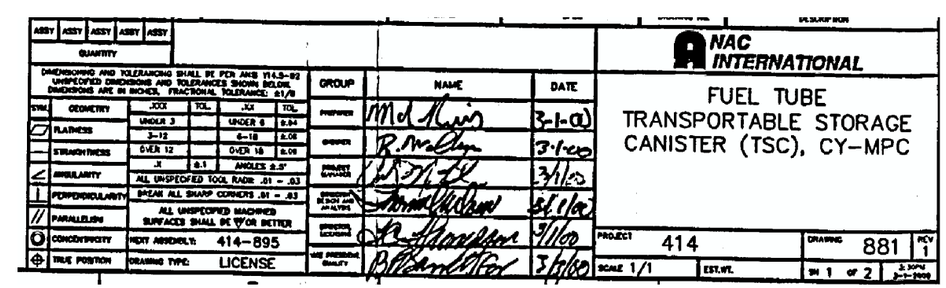

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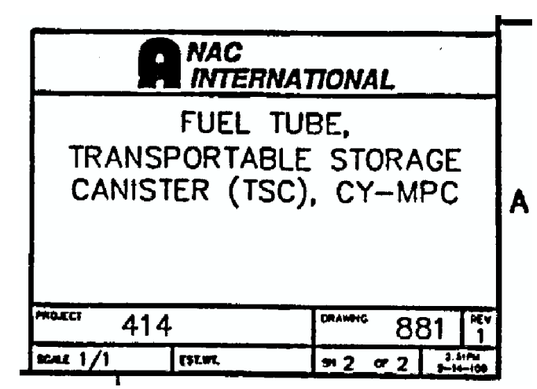

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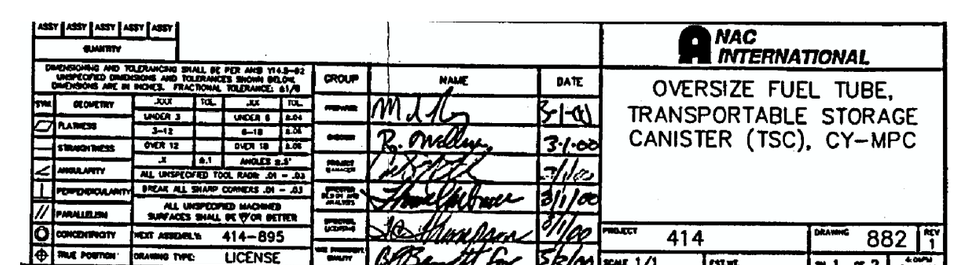

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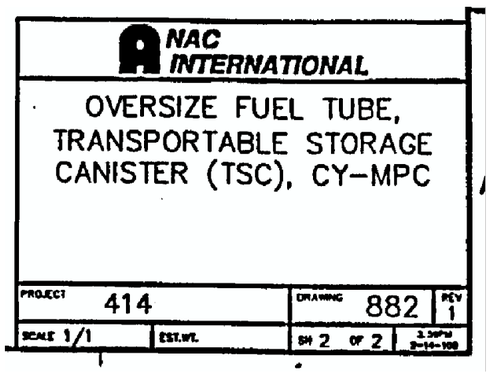

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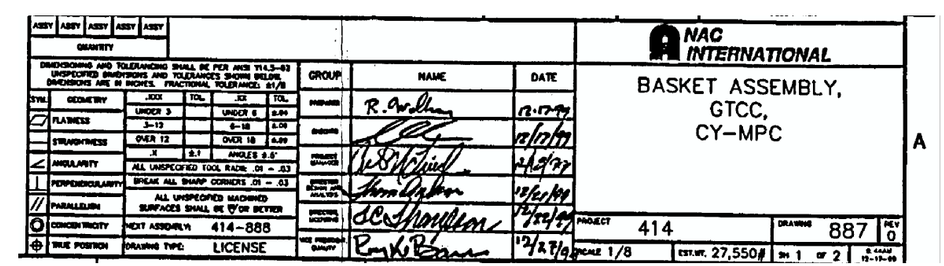


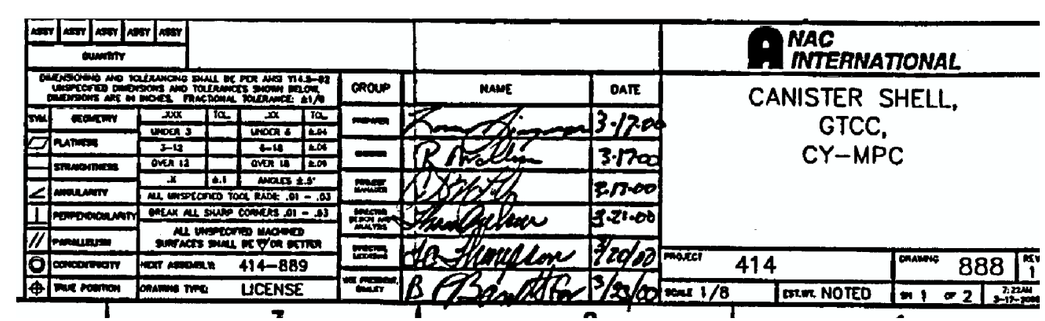
FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

BASKET ASSEMBLY,
GTCC,
CY-MPC

PROJECT 414		DRAWING 887	REV 0
SCALE 1/8	EST.WT. NOTED	SH 2 OF 2	9:47AM 12-17-99

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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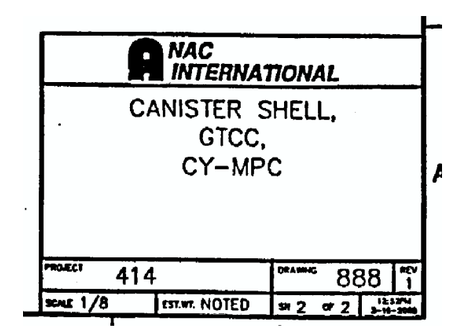

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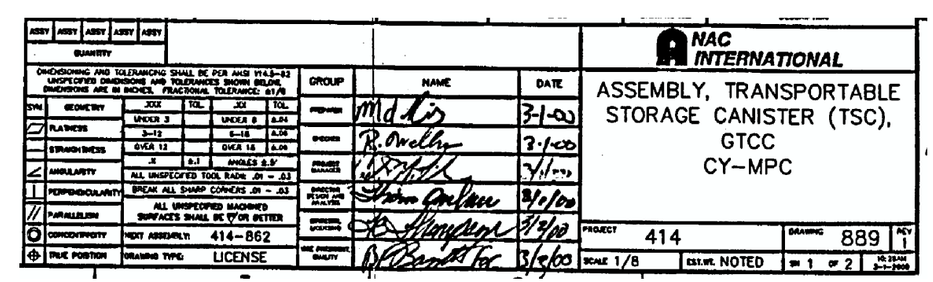

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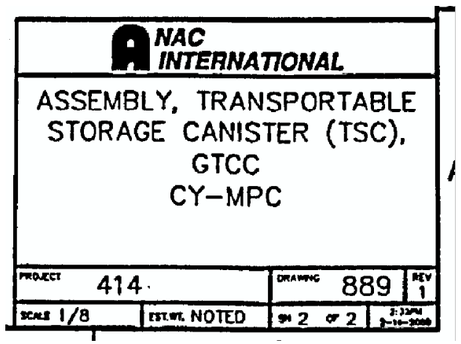

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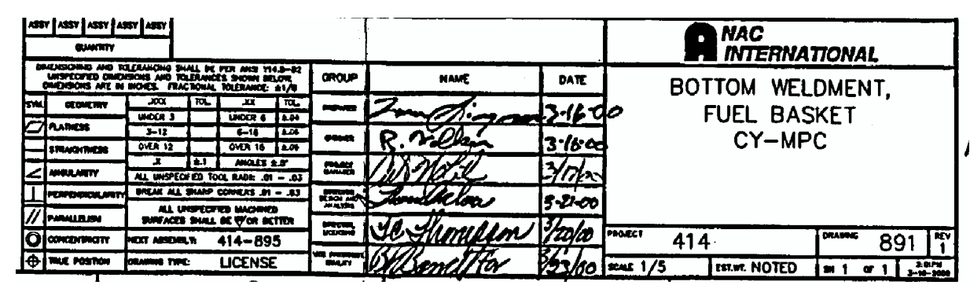

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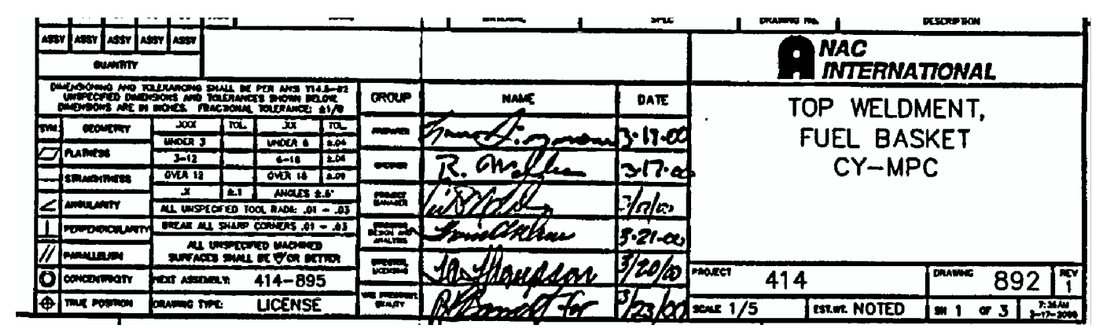


ASSY	ASSY	ASSY	ASSY	ASSY
QUANTITY				

DIMENSIONING AND TOLERANCING SHALL BE PER ANSI Y14.5-82
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM.	GEOMETRY	.XXX	TOL.	.XX	TOL.
	FLATNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.04
	STRAIGHTNESS	OVER 12		OVER 18	±.09
∠	ANGULARITY	.X	±.1	ANGLES ±.5°	
⊥	PERPENDICULARITY	ALL UNSPECIFIED TOOL RADII .01 - .03			
//	PARALLELISM	BREAK ALL SHARP CORNERS .01 - .03			
◎	CONCENTRICITY	ALL UNSPECIFIED MACHINED SURFACES SHALL BE 125 RMS OR BETTER			
⌖	TRUE POSITION	NEXT ASSEMBLY: 414-895			
		DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARED	[illegible]	3-17-00
CHECKED	R. Moffen	3-17-00
STRUCT. DYNAMICS	[illegible]	3/21/00
CRITICAL DESIGN AND ANALYSIS	[illegible]	3-21-00
DRAWING LICENSING	[illegible]	3/20/00
NAC PROJECT QUALITY	[illegible] for	3/23/00

DRAWING NO. | DESCRIPTION

NAC INTERNATIONAL

TOP WELDMENT,
FUEL BASKET
CY-MPC

PROJECT	414	DRAWING	892	REV 1
SCALE 1/5	EST.wt. NOTED	SH 1 OF 3	7:36 AM 3-17-2000	

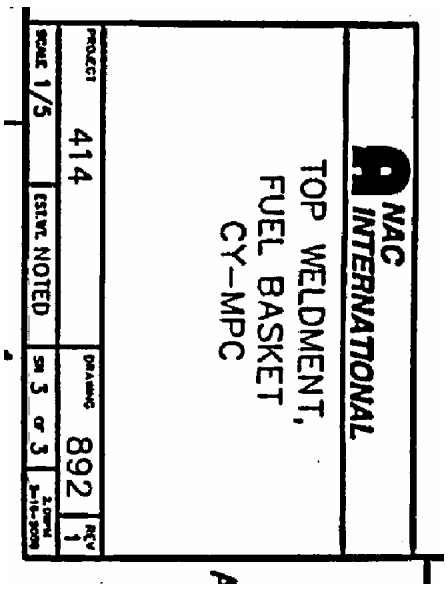
FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

TOP WELDMENT,
FUEL BASKET
CY-MPC

PROJECT 414		DRAWING 892	REV 1
SCALE 1/5	EST.WT. NOTED	SH 2 OF 3	

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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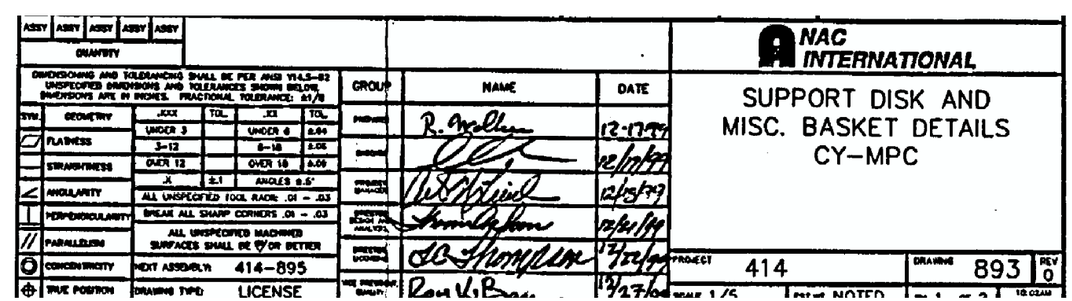

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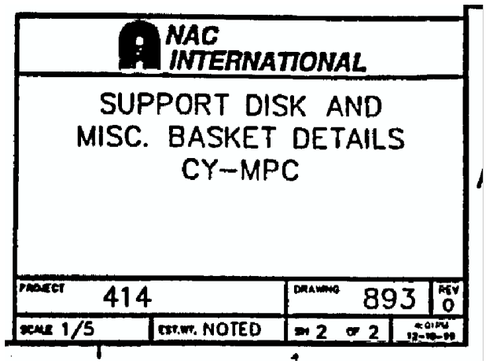

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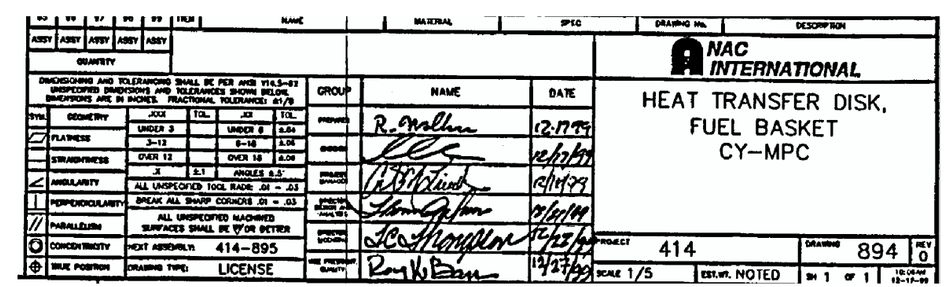

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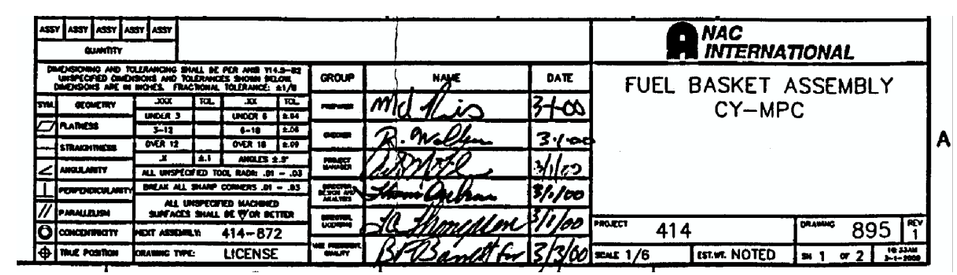


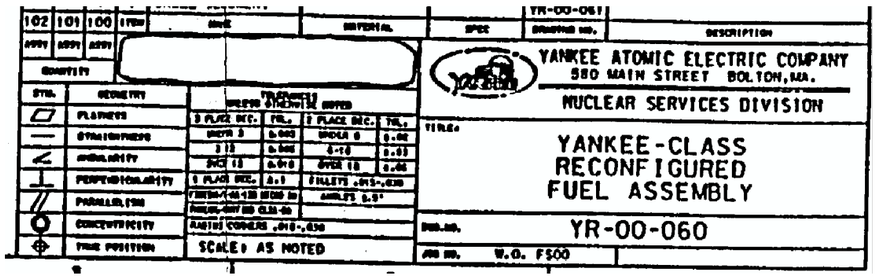
FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

FUEL BASKET ASSEMBLY
CY-MPC

PROJECT 414		DRAWING 895	REV 1
SCALE 1/6	EST.WT. NOTED	SH 2 OF 2	10:33AM 3-11-2009

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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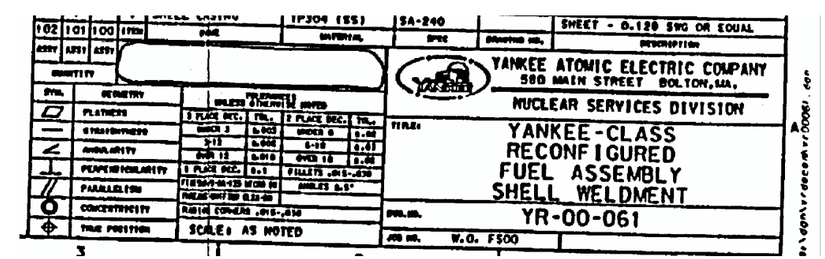
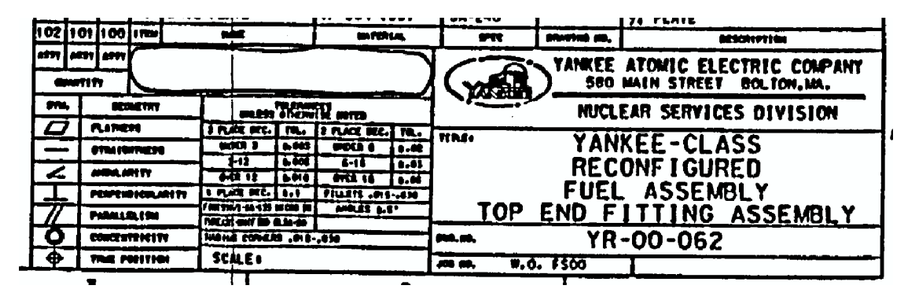


FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION



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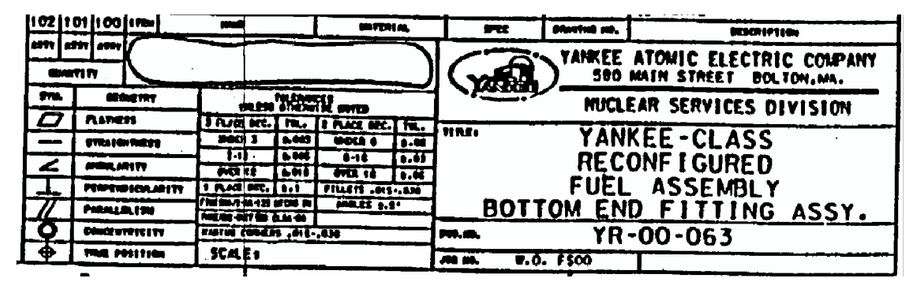

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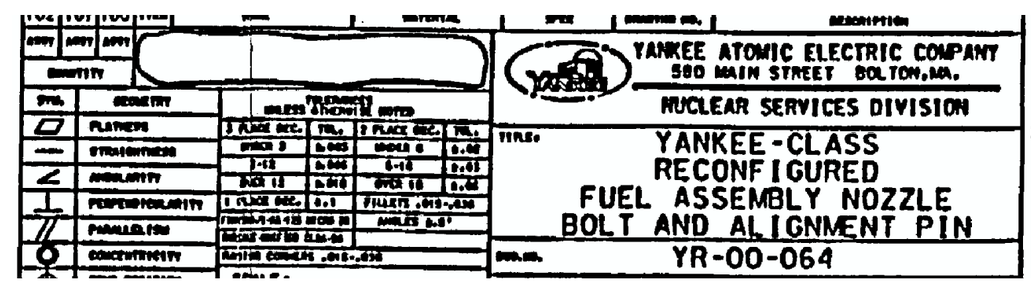

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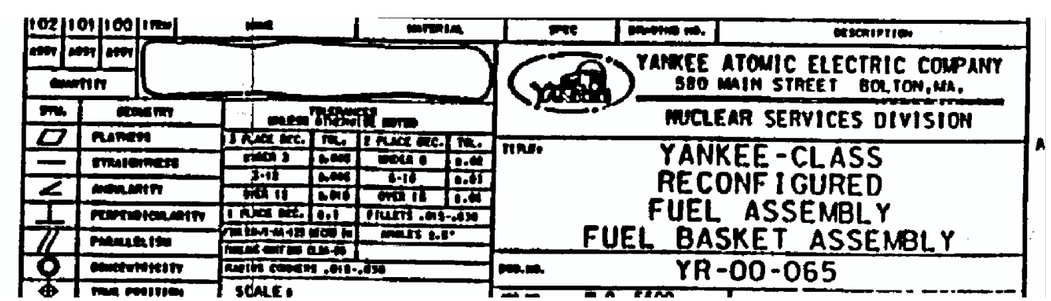

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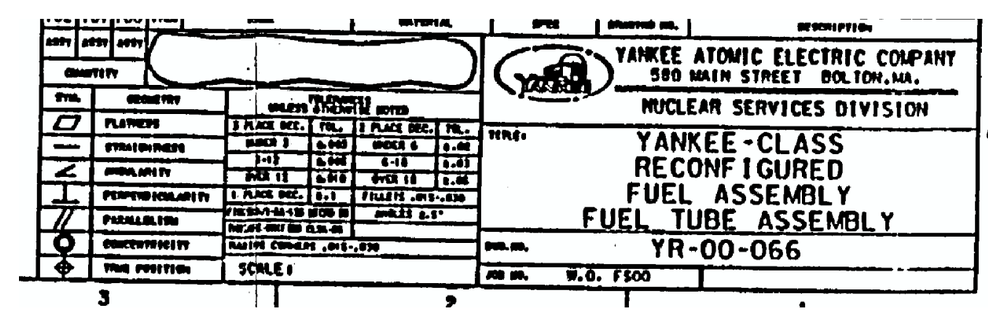

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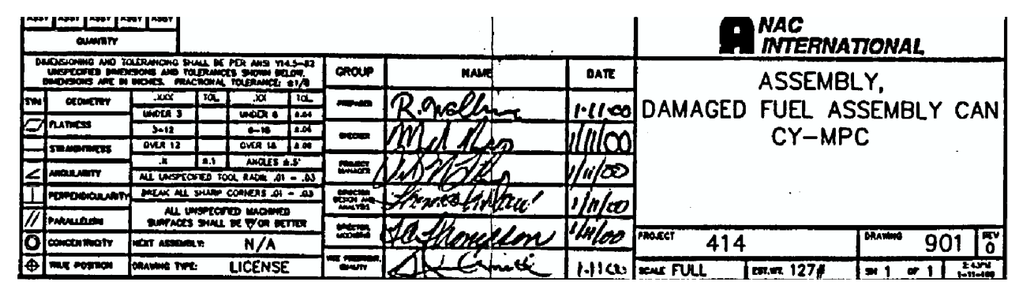

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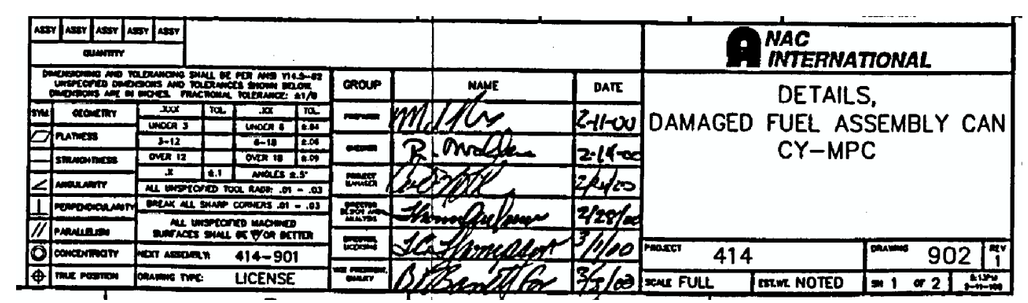

ASSY	ASSY	ASSY	ASSY	ASSY
QUANTITY				

DIMENSIONING AND TOLERANCING SHALL BE PER ANSI Y14.5-82
UNSPECIFIED DIMENSIONS AND TOLERANCES SHOWN BELOW.
DIMENSIONS ARE IN INCHES. FRACTIONAL TOLERANCE: ±1/8

SYM	GEOMETRY	.XXX	TOL.	.XX	TOL.
▱	FLATNESS	UNDER 3		UNDER 6	±.04
		3-12		6-18	±.06
—	STRAIGHTNESS	OVER 12		OVER 18	±.09
∠	ANGULARITY	.X	±.1	ANGLES ±.5°	
		ALL UNSPECIFIED TOOL RADII: .01 - .03			
⊥	PERPENDICULARITY	BREAK ALL SHARP CORNERS .01 - .03			
//	PARALLELISM	ALL UNSPECIFIED MACHINED SURFACES SHALL BE ▽ OR BETTER			
◎	CONCENTRICITY	NEXT ASSEMBLY: 414-901			
⌖	TRUE POSITION	DRAWING TYPE: LICENSE			

GROUP	NAME	DATE
PREPARED	M. Miller	2-11-00
CHECKED	R. Moulden	2-14-00
PROJECT MANAGER	[illegible]	2/4/00
SUPERVISOR DESIGN AND ANALYSIS	[illegible]	2/28/00
SUPERVISOR DESIGNING	[illegible]	3/1/00
VICE PRESIDENT QUALITY	[illegible]	3/7/00

NAC INTERNATIONAL

DETAILS,
DAMAGED FUEL ASSEMBLY CAN
CY-MPC

PROJECT	DRAWING	REV
414	902	1
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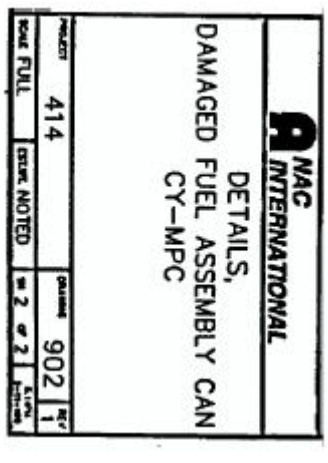

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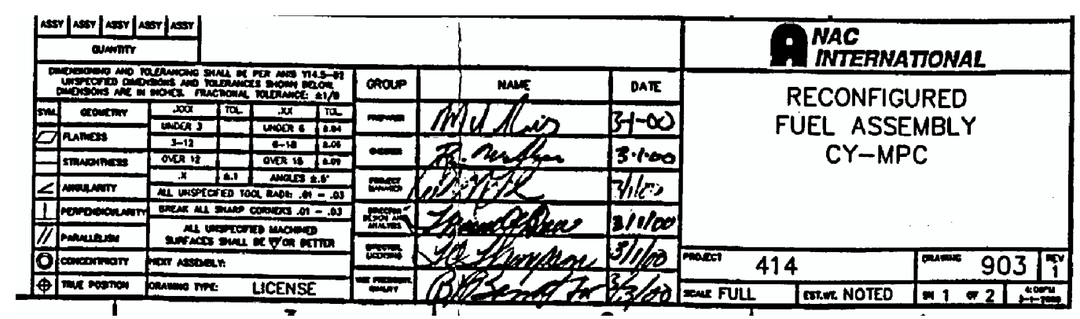

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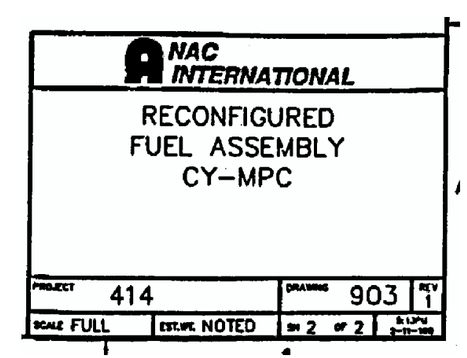

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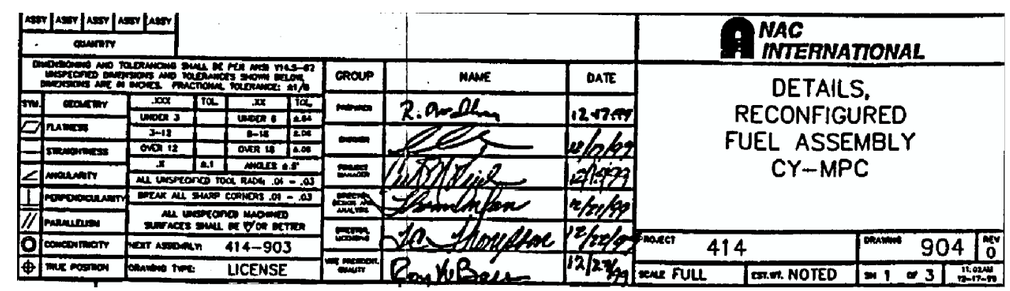

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

DETAILS,
RECONFIGURED
FUEL ASSEMBLY
CY–MPC

PROJECT 414		DRAWING 904	REV 0
SCALE FULL	EST.WT. NOTED	SH 2 OF 3	11:01 AM 12-27-99

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

NAC INTERNATIONAL

DETAILS,
RECONFIGURED
FUEL ASSEMBLY
CY–MPC

PROJECT 414		DRAWING 904	REV 0
SCALE FULL	EST.WT. NOTED	SH 3 OF 3	

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2.0 STRUCTURAL EVALUATION

The structural analyses of the NAC-STC spent fuel transportation and storage cask demonstrate that the package satisfies the requirements of Part 71 of Title 10, Chapter 1 of the Code of Federal Regulations—specifically, Subpart E, "Package Approval Standards," and Subpart F, "Package and Special Form Tests." It is also designed to satisfy the requirements of IAEA Safety Series No. 6. It is shown that containment is not breached under any of the normal conditions of transport or the hypothetical accident conditions.

The structural analyses presented herein utilize current state-of-the-art methods for calculating stresses in large structures subject to steady state and transient loadings. The evaluation of the structural characteristics of the containment boundary will be based on a conservative interpretation of the requirements of Section III of the "ASME Boiler and Pressure Vessel Code, Nuclear Power Plant Components." The "ASME Boiler and Pressure Vessel Code" is the recognized standard for pressure vessel analysis, mechanical properties of materials, and allowable stress values.

This section of the Safety Analysis Report demonstrates that the NAC-STC design is capable of meeting the rigors of transport, while carrying spent nuclear fuel in the directly loaded or canistered configurations or Greater Than Class C waste in the canistered configuration. It documents the results of the analyses, which were performed to provide assurance that the NAC-STC design also satisfies the statutory requirements for licensing.

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2.1 Structural Design

2.1.1 Discussion

The NAC-STC is a cylindrical, multiwall cask designed to safely transport directly loaded or canistered spent nuclear fuel or canistered Greater Than Class C (GTCC) waste. The cask accommodates up to 26 directly loaded design basis PWR fuel assemblies. In the canistered fuel or waste configurations, the NAC-STC transports the Multi-Purpose Canister (MPC) of the NAC-MPC system, which is designed for the long-term storage and transport of spent fuel. The NAC-MPC is provided in several configurations to provide efficient storage and transport of both spent fuel and GTCC waste. The NAC-MPC canister system designed for Yankee Class fuel is designated the Yankee-MPC and holds up to 36 Yankee Class fuel assemblies. Using a modified internal basket, the same size canister also holds up to 24 containers of Yankee GTCC waste. The NAC-MPC canister system designed for Connecticut Yankee is designated the CY-MPC and holds up to 26 Connecticut Yankee fuel assemblies or, using a modified internal basket, up to 24 containers of Connecticut Yankee GTCC waste. The Yankee-MPC and CY-MPC canisters have the same external diameter, but have different overall lengths. The CY-MPC canister system has a higher allowable contents weight than the directly loaded or Yankee-MPC system. To accommodate the higher contents weight, an all balsa wood impact limiter is used with the CY-MPC configuration. The all balsa wood impact limiter is referred to as the "balsa impact limiter." The balsa impact limiter has performance characteristics comparable to the redwood and balsa wood impact limiters ("redwood impact limiter"), but weighs significantly less. As noted in Section 2.2, the balsa impact limiters can be used with any NAC-STC configuration. However, the redwood impact limiters are used only with the directly loaded and Yankee-MPC configurations.

The primary components of the NAC-STC are: (1) the cask body—inner shell, outer shell, lead shell, and bottom; (2) the inner lid, bolts, and metallic o-rings; (3) the outer lid, bolts, and metallic o-ring; (4) the port covers, port coverplates, bolts, and o-rings; (5) the neutron shield; (6) the trunnions; (7) the transport impact limiters—upper and lower; and (8) the fuel basket. The NAC-STC primary containment boundary for storage and transport after storage consists of: (1) inner shell center section and upper and lower inner shell rings (transition sections); (2) bottom inner forging; (3) top forging; (4) inner lid and inner lid outer metallic o-ring; (5) inner lid interseal test port and its threaded plug with metallic o-ring; (6) vent port coverplate and vent port coverplate outer metallic o-ring; (7) vent port coverplate interseal test threaded plug with

metallic o-ring; (8) drain port coverplate and drain port coverplate outer metallic o-ring; and (9) drain port coverplate interseal test threaded plug with metallic o-ring. A detailed discussion of the containment boundary is presented in Chapter 4. As described in Section 7.1.3, for loading of the NAC-STC for immediate shipment, the containment boundary for the inner lid and drain port coverplate are the inner metallic o-rings, rather than the outer o-rings and interseal test plugs. The geometry and the materials of fabrication of the cask components are described in Section 1.2.1 and are shown on the license drawings presented in Section 1.3.2.

The NAC-STC is designed to satisfy the requirements of 10 CFR 71 for the transport of radioactive materials (and the requirements of 10 CFR 72 for the storage of radioactive materials) and the requirements of IAEA Safety Series No. 6. The cask body holds and protects the cask cavity contents for the normal conditions of transport, as well as for the hypothetical accident conditions. The lead located between the inner and outer shells provides the primary gamma radiation shielding for the cask in the radial direction. The cask bottom connects the inner and outer shells, providing for the bottom end closure, as well as both gamma and neutron radiation shielding in the axial direction.

The inner lid, bolts, and metallic o-rings are the primary closure components of the NAC-STC for transport conditions. The outer lid and metallic o-ring provide a secondary closure boundary.

The vent port and the drain port are located in the inner lid and are each protected by a port coverplate. The primary containment boundary at the vent port and at the drain port is the port coverplate and its outer metallic o-ring. The o-ring is located in the bottom surface of the port coverplate. A second metallic o-ring is also located in the bottom surface of the port coverplate, inside of, and concentric with, the primary containment, outer metallic o-ring. The seals of the metallic o-rings are tested by pressurizing the annulus between them with helium and using a "sniffer" probe to detect helium leakage at the outer circumference of the inner lid and port coverplates.

The forty-two 1 1/2 - 8 UN inner lid bolts are preloaded by an installation torque to restrain rotation of the edge of the inner lid and to maintain a containment seal for the critical load condition. This condition is a uniformly distributed pressure resulting from the impact of the basket and cavity contents on the inner surface during a top end or top corner impact. The critical design load condition for the inner lid bolts, as listed in Table 2.7.1.6-2, Section 2.7.1.6,

is a 54.7 g top corner impact (10 CFR 71 Hypothetical Accident Condition). The critical design load condition for the inner lid is the top end impact, Section 2.7.1.6.

The outer lid is bolted to the top forging by the thirty-six 1 - 8 UNC outer lid bolts, which are installed to a specified torque. The torque provides a total bolt preload that exceeds the maximum applied bolt load for the critical load condition, preventing any lid and o-ring movement that might result in a loss of secondary seal integrity. The critical design load condition for the outer lid bolts, as listed in Table 2.7.1.6-4, Section 2.7.1.6, is a 51.3g side impact (10 CFR 71 Hypothetical Accident Condition). The critical design load condition for the outer lid is the pin puncture accident condition. The NAC-STC outer lid bolts are loaded by the interlid region pressure, the o-ring compression force, and by either the impact limiter crush force during a top end or top corner impact, or by a concentrated center load during a pin puncture impact. The outer lid seal is provided by a metallic o-ring, which is tested by pressurizing the interlid region.

In addition to the main closure, the secondary closure boundary of the NAC-STC also includes the two ports located in the top forging—the interlid port and the pressure port. Each of these ports is protected and sealed by a recessed, bolted port cover with two piston-type (bore seal) PTFE o-rings. The port covers are installed with new o-rings just prior to transport (a slightly different port cover is installed during storage operation). The seal at each port cover is verified by pressure-testing the annulus between the two PTFE o-rings.

The neutron shielding material, NS-4-FR, is a solid synthetic polymer that absorbs the neutron radiation emitted by the cask contents. In addition to the radial neutron shielding along the cask length, neutron shielding is provided in the axial direction at each end of the cask by circular layers of NS-4-FR enclosed in the inner lid and in the cask bottom.

Four external trunnions are welded to the top forging of the NAC-STC at 90-degree intervals around the circumference of the cask. These trunnions are provided for lifting and handling the cask. Either a redundant (four trunnions) or a nonredundant (two trunnions) lifting system may be used. However, each pair of opposing trunnions are conservatively designed to satisfy the heavy lifting requirements of NUREG-0612 for a nonredundant lift, as well as the requirements of 10 CFR 71.45(a) and paragraph 506 of IAEA Safety Series No. 6. Two rotation trunnion recesses are welded to the bottom outer forging near the bottom of the cask. The neutron shield is cut out to accommodate the placement of the rotation trunnion recesses, which are used to

attach the bottom of the cask to the transport vehicle and to rotate the cask from the vertical lifting position to the horizontal position and vice-versa.

As discussed above, two transport impact limiter configurations are used with the NAC-STC cask to limit the impact loads that may act on the cask. The impact limiters absorb the energy of a cask drop impact through the crushing of the wood in the limiters. A balsa impact limiter design must be used when the NAC-STC is transporting spent fuel or GTCC waste in the CY-MPC canister configuration. When transporting directly loaded fuel or the Yankee-MPC canister, either the redwood or balsa impact limiter configuration may be used.

The NAC-STC fuel basket is constructed of stainless steel and has a capacity of 26 PWR fuel assemblies. The fuel basket has a cylindrical shape with a series of support disks that provide lateral support for the square, stainless steel fuel tubes, which encase BORAL poison plates on each of the four sides. The support disks are separated and supported at 4.87-inch intervals by a threaded rod and spacer nuts at six locations. Aluminum heat transfer disks are located in the central region of the fuel basket and are supported by the six threaded rods and spacer nuts. The stainless steel support disks have adequate strength at the basket temperatures that occur during the transport and/or storage of 26 design-basis PWR fuel assemblies.

For the Yankee Class fuel and GTCC waste, the Yankee-MPC transportable storage canister (canister) serves as the enclosure of the spent fuel assemblies and GTCC waste. The Yankee-MPC canister has a capacity of up to 36 Yankee Class spent fuel elements or up to 24 containers of GTCC waste. Similarly, the CY-MPC canister serves as the enclosure for the Connecticut Yankee spent fuel and GTCC waste. The CY-MPC canister has a capacity of up to 26 Connecticut Yankee spent fuel assemblies or up to 24 containers of GTCC waste. The canister consists of a cylindrical shell with a welded bottom plate, a fuel or GTCC basket, a shield lid and a structural lid. The canister provides leak tight containment of the spent fuel or waste that it holds. This leak tight level of containment is maintained in all of the design basis normal conditions of transport and hypothetical accident conditions. Consequently, it qualifies as the separate inner container required by 10 CFR 71.63(b) for failed or damaged fuel that may be in the canister. The canister is evaluated for normal conditions of transport in Sections 2.6.13 and for hypothetical accident conditions in Section 2.7.11 in the transport configuration.

2.1.2 Design Criteria

2.1.2.1 Discussion

The load conditions that must be considered for the design of a spent-fuel transport cask are defined in 10 CFR 71 and in Regulatory Guide 7.8. Additionally, the NAC-STC is designed for the load conditions defined in 10 CFR 72 for dry storage casks. The stresses in the containment vessel, the noncontainment structure, and the closure bolts of the NAC-STC satisfy the stress limits defined in "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Regulatory Guide 7.6. These limits are essentially the same as those in the "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Subsection NB for Class 1 Components.

The NAC-STC is analyzed as a pressure vessel whose containment boundary is not breached during any loading condition. The cask design provides well-defined load paths that are analyzed using straight-forward, proven structural analysis methods. The structural analysis of the NAC-STC is a linear elastic analysis. In those cases where loadings are open to analytical interpretation, bounding load condition analyses are performed to bracket the actual load condition.

Each normal condition of transport and each hypothetical accident condition will have a combination of various loading types. These load type combinations will define the total load criteria for each condition. The loading types that must be considered will include thermal, external and/or internal pressure, bolt preload, inertia, and cask drop impacts. The NAC-STC is analyzed for normal conditions of transport in Section 2.6 and for hypothetical accident conditions in Section 2.7.

The total stresses in the cask components are calculated as the combination of stresses that result from each of the various load types (thermal, pressure, mechanical) that are part of a given load condition. For those load conditions and components that are analyzed using classical hand-calculational methods, the total stress components are obtained by summation of the individual stress components for each type of load that is a part of the load condition. This summation is appropriate because the individual and total stress components are linear, elastic stresses.

2.1.2.2 Allowable Stress Limits - Ductile Failure

2.1.2.2.1 Containment Structures

Regulatory Guide 7.6 and "ASME Boiler and Pressure Vessel Code," Section III, Subsection NB are used to establish the allowable stress limits for the NAC-STC primary containment boundary for both normal conditions of transport and hypothetical accident conditions. Material property data used in calculating the allowable stress limits corresponds to the design stress intensities (S_m), yield strengths (S_y), and ultimate strengths (S_u), presented in Section 2.3. The NAC-STC primary containment boundary for storage and transport after storage includes: 1) the 6.2-inch thick cup-shaped bottom inner forging (Type 304 stainless steel); 2) the 71.0-inch inside diameter, 1.50-inch thick inner shell (Type XM-19 and Type 304 stainless steel), to which the bottom inner forging is welded; 3) the top forging (Type 304 stainless steel), to which the upper end of the inner shell is welded; 4) the 9.0-inch thick inner lid (Type 304 stainless steel) and its outer metallic o-ring (as well as its interseal test port, threaded plug and metallic o-ring), and 5) the vent and drain port coverplates, outer metallic o-rings and the port coverplate interseal test threaded plugs and metallic o-rings. When loaded for immediate shipment, the containment boundary includes the inner metallic o-rings of the inner lid and drain port cover plate, rather than the outer o-ring and interseal test port. The inner lid is installed and retained using 42 bolts (SB-637, Grade N07718 nickel alloy steel).

A summary of the allowable stress criteria used for containment structures and bolting materials is presented in Table 2.1.2-1. These criteria are consistent with Regulatory Guide 7.6 and applicable parts of Subsection NB-3000 and Appendix F of the "ASME Boiler and Pressure Vessel Code." Analysis section locations on the cask are identified in Section 2.10.2.4.2 to aid in the evaluations of the various load conditions.

For the canistered fuel configuration, the NAC-STC primary containment boundary is unchanged. However, the TSC is designed as a confinement/containment boundary to satisfy 10 CFR 72 spent fuel storage requirements and provides a second containment boundary for the transport of Reconfigured Fuel Assemblies in accordance with the requirements of 10 CFR 71.63. A summary of the allowable stress criteria used for containment structures and bolting materials, including the Yankee-MPC and CY-MPC canisters, is presented in Table 2.1.2-1.

2.1.2.2.2 Noncontainment Structures

Noncontainment structures include all structural members other than the primary containment boundary components, but exclude the lifting trunnions, the rotation trunnion recesses, the lead and the impact limiters. Noncontainment structural members are shown to satisfy essentially the same structural criteria as the containment structure, even though Regulatory Guide 7.6 applies only to containment structures. Allowable stresses for the noncontainment structures and noncontainment bolting materials are presented in Table 2.1.2-2.

The allowable stresses for the lifting and handling components of the NAC-STC are based on the requirements of 10 CFR 71.45(a): material yield strength with a load factor of 3.0. The lifting and handling components of the NAC-STC also satisfy the structural requirements of NUREG-0612: the allowable stress is the material yield strength with a load factor of 6.0 or the material ultimate strength with a load factor of 10.0, depending on which load condition is more critical.

The lead (gamma shielding material) is not stress-limited because its deformation is considered, where appropriate, in the various cask analyses.

The impact limiters are not stress- or deformation-limited. While performing their intended function during a free drop impact, the impact limiter(s) crushes, and thus, absorbs the energy of the impact. Crushing of the impact limiter(s) limits the impact forces that are applied to the cask.

In the canistered configuration, the Transportable Storage Canister provides containment of the spent fuel with a double welded closure. The canister contains a structurally sound, criticality safe, and thermally efficient basket that is a noncontainment structure. The basket provides the structural support to the fuel and maintains the spent fuel in a subcritical configuration during all of the normal conditions of transport and hypothetical accident conditions.

The allowable stresses for noncontainment structures, noncontainment bolting materials, and fuel/waste basket structures are presented in Table 2.1.2-2.

Table 2.1.2-1 Allowable Stress Limits for Containment Structures

	ALLOWABLE STRESS INTENSITY		BOLT MATERIAL ALLOWABLE STRESS INTENSITY*	
Stress Intensity Category	**Normal Conditions**	**Accident Conditions**	**Normal Conditions**	**Accident Conditions**
Primary Membrane	1.0 S_m	Lesser of: 2.4 S_m and 0.7 S_u	$2.0(S_m)_{BM}$	Lesser of: 1.0 S_y and 0.7 S_u
Primary Membrane + Primary Bending	1.5 S_m	Lesser of: 3.6 S_m and 1.0 S_u	$3.0(S_m)_{BM}$	1.0 S_y
Range of Primary + Secondary	3.0 S_m	N/A		
Pure Shear	0.6 S_m	0.42S_u		
Bearing	1.0 S_y or 1.5S_y**	1.0 S_u		
Peak		Per Section 2.1.3.2		
Buckling		Per Section 2.1.3.4		

* Neglecting stress concentrations.

** Distance to edge > distance over which the bearing load is applied.

S_u = Material Ultimate Strength.
S_y = Material Yield Strength.
S_m = Material Design Stress Intensity.
= Lesser of: $S_u/3$ and $2S_y/3$.
$(S_m)_{BM}$ = $S_y/3$.for Bolt Material.

Table 2.1.2-2 Allowable Stress Limits for Noncontainment Structures

	ALLOWABLE STRESS INTENSITY		BOLT MATERIAL ALLOWABLE STRESS INTENSITY*		BASKET MATERIAL ALLOWABLE STRESS**	
Stress Intensity Category	**Normal Conditions**	**Accident Conditions**	**Normal Conditions**	**Accident Conditions**	**Normal Conditions**	**Accident Conditions**
Primary Membrane	1.0 S_m	0.7 S_u	2.0$(S_m)_{BM}$	S_u	1.0 S_m	0.7 S_u
Primary Membrane + Primary Bending	1.5 S_m	1.0 S_u	3.0$(S_m)_{BM}$	1.0 S_y	1.5 S_m	1.0 S_u
Range of Primary + Secondary	3.0 S_m	N/A			3.0 S_m	N/A
Pure Shear	0.6S_m	0.42 S_u			0.6 S_m	0.42 S_u
Bearing	1.0 S_y or 1.5 S_y***	1.0 S_u			1.0 S_y	1.0 S_u
Peak	Per Section 2.1.3.2				Per Section 2.6.12.8	
Buckling					Per Section 2.7.8.3	

* Neglecting stress concentrations.

** ASME Code, Section III, Subsection NG.

*** Distance to edge > distance over which the bearing load is applied.

S_u = Material Ultimate Strength.
S_y = Material Yield Strength.
S_m = Material Design Stress Intensity.
= Lesser of: $S_u/3$ and $2S_y/3$.
$(S_m)_{BM}$ = $S_y/3$ for Bolt Material.

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2.1.3 Miscellaneous Structural Failure Modes

2.1.3.1 Brittle Fracture

The primary structural material of the NAC-STC is Type 304 stainless steel. The outer shell, the inner shell, the top forging, the bottom forgings, the inner lid, and the vent and drain port coverplates are fabricated from Type 304 stainless steel. The inner shell rings at each end of the inner shell are fabricated from Type XM-19 stainless steel. For the canistered fuel or GTCC waste configurations: the canister and the structural lid are Type 304L stainless steel; the fuel and GTCC waste tubes, the tie rods, and the top and bottom weldments are Type 304 stainless steel; and the support disks are Type 17-4 PH precipitation—hardened stainless steel. Because Type 304, Type 304L, and Type XM-19 stainless steel are austenitic stainless steel, they do not undergo a ductile-to-brittle transition in the temperature range of interest for a spent-fuel transport and/or storage cask. Therefore, brittle fracture is not a concern.

Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of Four Inches (0.1 m)," which identifies fracture toughness criteria, references the criteria contained in NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick." The inner lid bolts are SB-637, Grade N07718 nickel alloy steel bolting material. According to Section 5 of NUREG/CR-1815, bolts are generally not considered fracture-critical components because multiple load paths exist and because bolted systems are designed to be redundant. Therefore, brittle fracture evaluation of the bolts is not required. Conservatively, for purposes of comparison, the nil-ductility transition temperature (NDTT) of the inner lid bolts will be calculated and compared with the requirements of NUREG/CR-1815. Although this method of analysis is not applicable to bolts, it is presented to demonstrate that the bolt material possesses a level of resistance to brittle fracture that is comparable to the other cask component materials. Using the most restrictive requirements of Section 6.2.1.1 of ASTM A-320, the minimum impact energy absorption for high alloy steel bolting material is 20 foot-pounds at -150°F. The Charpy impact measurement may be transformed into a fracture toughness value by using the empirical relation developed in Section 4.2 of NUREG/CR-1815, as follows:

$$K_{ID} = \left[5E(C_v)\right]^{0.5}$$

$$= 56{,}214 \text{ psi-(in)}^{0.5}$$

where:

K_{ID} = Dynamic Fracture Toughness, psi-(in)$^{0.5}$
E = Modulus of Elasticity, psi
= 31.6×10^6 psi at -150°F
C_v = Charpy impact measurement, ft-lbs
= 20 ft-lbs

The dynamic fracture toughness is translated to an equivalent NDTT by using the Pellini reference curve given as Figure 2 in NUREG/CR-1815. By interpolation, the temperature relative to NDTT is found as:

$$(T - NDTT) = 32°F$$

Accordingly, the nil-ductility transition temperature is:

$$NDTT = -150 - (+32)$$
$$= -182°F$$

For Category I fracture critical components and in section thickness at 1.5 inches (bolt diameter), Figure 3 of NUREG/CR-1815 gives the minimum offset, "A," as approximately 60°F. Thus, the required NDTT value is:

$$T_{NDT} = LST - A$$
$$= -40 - 60$$
$$= -100°F$$

where:

T_{NDT} = required maximum NDTT per NUREG/CR-1815
LST = Lowest Service Temperature
= -40°F (Regulatory Guide 7.8)
A = 60°F (Figure 3, NUREG/CR-1815)

The SB-637, Grade N07718 nickel alloy steel, inner lid bolts can be expected to experience a ductile-to-brittle transition at a temperature of -182°F, whereas the criterion of NUREG/CR-1815 prescribes an NDTT of -100°F. The 82°F margin between criteria requirements and material capability provides conservative assurance that brittle fracture failures will not occur in the nickel alloy steel inner lid bolts.

The outer lid, the outer lid bolts, the port covers, the lifting trunnions, the rotation trunnion recesses, and the fuel basket support disks, threaded rods and spacer nuts are SA-705, SA-693 or SA-564, Type 630, H1150, 17-4 PH stainless steel.

The Transportable Storage Canister (TSC) is fabricated from Type 304L stainless steel. The TSC fuel basket tubes, axial tie rods, and top and bottom weldments, are Type 304 stainless steel. The TSC fuel basket support plate is Type 17-4 PH stainless steel. All of the components of the GTCC basket assembly are Type 304 stainless steel.

Conservatively, for purposes of demonstrating its comparable brittle fracture resistance, the NDTT of the material will be calculated and compared with the requirements of NUREG/CR-1815.

The typical minimum impact energy absorption requirement for Type 17-4 PH, precipitation-hardened stainless steel is 48 foot-pounds at -110°F. This value is obtained from Table 14, Product Data Bulletin No. S-22, "ARMCO 17-4 PH PRECIPITATION-HARDENING STAINLESS STEEL," ARMCO, Inc. The Charpy impact measurement may be transformed into a fracture toughness value by using the empirical relation developed in Section 4.2 of NUREG/CR-1815, as follows:

$$K_{ID} = \left[5E(C_v)\right]^{0.5}$$
$$= 82{,}994 \text{ psi-(in)}^{0.5}$$

where:

K_{ID} = Dynamic Fracture Toughness, psi-(in)$^{0.5}$

E = Modulus of Elasticity, psi
= 28.7×10^6 psi at -110°F

C_v = Charpy Impact Measurement, ft-lbs
= 48 ft-lbs

The dynamic fracture toughness is translated to an equivalent NDTT by using the Pellini reference curve given as Figure 2 in NUREG/CR-1815. By interpolation, the temperature relative to NDTT is found as:

$$(T - NDTT) = 65°F$$

Accordingly, the nil-ductility transition temperature is:

$$\begin{aligned} NDTT &= -110 - (+65) \\ &= -175°F \end{aligned}$$

For Category I fracture critical components and in section thickness of 4.0 inches, Figure 3 of NUREG/CR-1815 gives the minimum offset, "A," as approximately 100°F. Thus, the required NDTT value is:

$$\begin{aligned} T_{NDT} &= LST - A \\ &= -40 - 100 \\ &= -140°F \end{aligned}$$

where:

T_{NDT} = Required Maximum NDTT per NUREG/CR-1815
LST = Lowest Service Temperature
= -40°F (Regulatory Guide 7.8)
A = 100°F (Figure 3, NUREG/CR-1815)

The Type 17-4 PH stainless steel components can be expected to experience a ductile-to-brittle transition at a temperature of -175°F, whereas the criterion of NUREG/CR-1815 requires a maximum NDTT of -140°F. The calculated margin of 35°F between criteria requirements and material capability provides conservative assurance that brittle fracture failures will not occur in these high-strength stainless steel components.

2.1.3.2 Fatigue - Normal Operation

The fatigue stress limitations of Regulatory Guide 7.6 are used for the analysis of those components that are, by definition, a part of the primary containment vessel. Paragraph C.3 of Regulatory Guide 7.6 defines the "high cycle" fatigue stress limit for any point in the containment vessel under normal conditions of transport as a limit on the maximum stress intensity range. That limit is equal to twice the allowable alternating stress at 10^6 cycles (S_a) as tabulated in the mechanical properties of materials, Section 2.3, as adjusted by the ratio of the modulus of elasticity used in the development of the material fatigue curve divided by the material's modulus of elasticity at the applicable temperature for the load combination being evaluated. At analysis locations where a structural discontinuity exists, the calculated peak stress intensity range includes appropriate stress concentration effects.

Paragraph C.7 of Regulatory Guide 7.6 defines the "low cycle" fatigue stress limit for any point in the containment vessel for the cask's entire life--initial state, fabrication state, normal conditions of transport, and hypothetical accident--as a limit on the maximum stress intensity range. That limit is equal to twice the allowable alternating stress at 10 cycles (S_a) as tabulated in the mechanical properties of materials, Section 2.3. S_a has been adjusted by the ratio of the material's modulus of elasticity (at the applicable temperature for the load combination being evaluated) to the modulus of elasticity used in the development of the material fatigue curve. At analysis locations where a structural discontinuity exists, the calculated peak stress intensity range includes appropriate stress concentration effects.

A normal operating cycle for transport consists of: 1) loading an empty cask at ambient temperature with contents of maximum heat load, 2) transporting the contents to a destination, and 3) unloading the contents and letting the cask return to ambient temperature. The anticipated number of normal operating cycles is not expected to exceed 240 cycles (12 cycles per year x 20 years).

The fatigue criteria is always satisfied as long as the allowable alternating stress intensity range is greater than the allowable primary plus secondary stress intensity range multiplied by the appropriate stress concentration factor. Subsection NB-3222.2 of the "ASME Boiler and Pressure Vessel Code" defines the allowable primary plus secondary stress intensity range as 3.0 (S_m), where S_m is the design stress intensity.

2.1.3.2.1 Cask Body and Inner Lid

For the Type 304 stainless steel cask body at 360°F, conservatively high for stress concentration areas, S_m = 19.4 ksi (Section 0) and 3.0 S_m = 58.2 ksi. The maximum stress concentration in the cask body occurs at two different locations: (1) the intersection of the outer shell and the bottom of the cask; and (2) the holes for the inner lid bolts. At the outer shell/cask bottom intersection, radius r = 0.5 inch, thickness t = 2.65 inches, so d = 5.30 inches (2 x 2.65), effective width of cask bottom D = 10.40 inches [(2)(2.65 + 2.55)], bottom thickness m = 13.65 inches; then, D/d = 1.96, m/d = 2.58, and the stress concentration factor is K_t = 3.35 (Peterson, Figure 192). At an inner lid bolt hole, hole radius r = 0.75 inch, edge distance c = 2.155 inches; then, r/c = 0.35 and the stress concentration factor is K_t = 3.33 (Peterson, Figure 87). Using a stress concentration factor of 3.35, the maximum allowable peak stress intensity range is $(SI)_{pr}$ = (3.35)(58.2) = 195.0 ksi and the peak stress intensity amplitude is $(SI)_{pa} = (SI)_{pr}/2$ = 97.5 ksi. From the "ASME Boiler and Pressure Code," Appendix I, Figure I-9.2.1, the peak stress intensity amplitude is ratioed to incorporate the modulus of elasticity at 360°F, alternating stress intensity $(SI)_a$ = (97.5)(28.3/26.7) = 103.3 ksi. The allowable number of cycles associated with an $(SI)_a$ = 103.3 ksi is 1400 cycles. This number of allowable cycles considerably exceeds the number of normal operating cycles that the NAC-STC will incur during its lifetime.

For the Type XM-19 stainless steel inner shell rings at each end of the inner shell at 360°F, conservatively high for stress concentration areas, S_m = 31.0 ksi (Section 3.3) and 3.0 S_m = 93.0 ksi. The maximum stress concentration in the inner shell rings (Type XM-19 stainless steel) occurs at the location of the transitions in the outer diameter. The larger inner shell thickness H = 2.00 inches, smaller inner shell thickness h = 1.50, radius to taper r = 0.50 inch, length of taper = 3.00 inches; then H/h = 1.33, r/h = 0.33, and the stress concentration factor is K_t = 1.87 (Peterson, Figure 72a). Conservatively, using a stress concentration factor of 2.0, the maximum allowable peak stress intensity range is $(SI)_{pr}$ = (2.0)(93.0) = 186.0 ksi and the peak stress intensity amplitude is $(SI)_{pa} = (SI)_{pr}/2$ = 93.0 ksi. From the "ASME Boiler and Pressure Vessel Code," Appendix I, Figure I-9.2.1, the peak stress intensity amplitude is ratioed to incorporate the modulus of elasticity at 300°F, alternating stress intensity $(SI)_a$ = (93.0)(28.3/26.8) = 98.2 ksi.

The allowable number of cycles associated with an $(SI)_a$ = 98.2 ksi is 2000 cycles. This number of allowable cycles considerably exceeds the number of normal operating cycles that the NAC-STC will incur during its lifetime.

2.1.3.2.2 Outer Lid

Using a similar method of evaluation for the outer lid (SA-705, Type 630, H1150, 17-4 PH stainless steel) at 200°F, conservatively high for stress concentration areas, S_m = 45.0 ksi (Table 2.3.3-1) and 3.0 S_m = 135.0 ksi. The maximum stress concentration in the outer lid occurs at the bolt hole locations. At the outer lid bolt hole locations, the bolt hole diameter is d = 1.0 inch and the bolt hole pitch is w = 7.30 inches (36 holes on a 83.70-inch bolt circle). Then, d/w = 0.137 and the stress concentration factor is k_t = 3.07 (Peterson, Figure 86). Using a stress concentration factor of 3.07, the maximum allowable peak stress intensity range is $(SI)_{pr}$ = (3.07)(135.0) = 414.5 ksi and the peak stress intensity amplitude is $(SI)_{pa} = (SI)_{pr}/2 \doteq 207.2$ ksi. From the "ASME Boiler and Pressure Vessel Code," Section III, Appendix I, Figure I-9.2.1, the peak stress intensity amplitude is ratioed to incorporate the modulus of elasticity at 200°F, $(SI)_a$ = (207.2)(28.3/27.8) = 211.0 ksi. The allowable number of cycles associated with an $(SI)_a$ = 211.0 ksi is 190 cycles. Since this allowable number of cycles is excessively restrictive for the lifetime of a spent fuel transport cask, the grossly conservative evaluation methodology will be revised to use the maximum calculated stress in the outer lid. Since the maximum calculated stress in the outer lid is 19,647 psi (Table 2.7.1.6-1) for a 56.1 g, 30-foot drop top end impact accident load condition, it is very conservative to use this stress value in a normal operating condition fatigue analysis of the outer lid. The maximum peak stress intensity range for the outer lid is $(SI)_{pr}$ = (3.07)(19.6) = 60.2 ksi and the peak stress intensity amplitude is $(SI)_{pa} = (SI)_{pr}/2$ = 30.1 ksi. From the "ASME Boiler and Pressure Vessel Code," Section III, Appendix I, Figure I-9.2.1, the peak stress intensity amplitude is ratioed to incorporate the modulus of elasticity at 200°F, $(SI)_a$ = (30.1)(28.3/27.8) = 30.6 ksi. The allowable number of cycles associated with an $(SI)_a$ = 30.6 ksi is 90,000 cycles. This number of allowable cycles far exceeds the number of Normal Conditions of Transport loading cycles that the NAC-STC will incur during its lifetime of spent fuel transport.

2.1.3.2.3 Bolts

Stress concentration occurs in the inner lid bolts, the outer lid bolts, the port cover bolts, and the port coverplate bolts. The maximum cyclic stress in these bolts is due to the installation preload and thermally induced loads. From Shigley, the preload torque is calculated as:

$$T = \left[\left(\frac{d_m}{2d}\right)\left(\frac{\tan\lambda + \mu\sec\alpha}{1 - \mu\tan\lambda\sec\alpha}\right) + 0.625\mu\right](F)(d)$$

where:

F = preload force

d = bolt diameter

d_m = mean diameter of threads

α = one-half the thread angle

μ = coefficient of friction

$\tan\lambda = \dfrac{1}{\pi d_m N}$

N = number of threads per inch

2.1.3.2.3.1 Inner Lid Bolts

The maximum installation torque for each SB-637, Grade N07718 nickel alloy inner lid bolt is 2,740 foot-pounds (2,540 ± 200), or 32,880 inch-pounds; thus, T = 32,880 inch-pounds. The nominal inner lid bolt thread diameter is 1.5 inches; thus, d = 1.5 inches. In Section 2.6.7.5.4.1, the maximum normal tensile stress (preload + thermal) in each inner lid bolt is calculated as 86.3 ksi.

From the "ASME Boiler and Pressure Vessel Code," Section III, NB-3232.3(c), the fatigue strength reduction factor is assumed to be 4.0. In addition, the modulus of elasticity at 200°F is 28.3×10^6 psi (SB-637, Grade N07718 nickel alloy steel). Since the "ASME Boiler and Pressure Vessel Code," Section III, Figure I-9.4 is based on a modulus of elasticity of 30.0×10^6 psi, the equivalent stress range is:

$$S_{range} = (86{,}306)(4.0)(30.0 \times 10^6/28.3 \times 10^6)$$

$$= 365{,}962 \text{ psi}$$

The alternating stress is one-half of the stress range, or S_a = 183,817 psi. Using Figure I-9.4, Section III, "ASME Boiler and Pressure Vessel Code," the allowable number of normal operating cycles is 301 cycles (one cycle consists of one application and removal of preload). Assuming a maximum of 12 cycles per year for the bolts, a 25.1-year life is projected. Operational procedures will specify replacement of an entire set of these bolts every 240 cycles (20 years), ensuring a fatigue failure margin of safety of + 0.26.

2.1.3.2.3.2 Outer Lid Bolts

The allowable number of normal operating cycles for the outer lid bolts is calculated similarly to that for the inner lid bolts.

The maximum installation torque (T) for an outer lid bolt is 600 foot-pounds, or 7,200 inch-pounds; thus, T = 7,200 inch-pounds. The nominal thread diameter of an outer lid bolt is 1.0 inch; thus, d = 1.0 inch. In Section 2.6.7.5.4.2, the maximum tensile stress in each outer lid bolt is calculated to be 60,743 psi.

Again, assuming a fatigue strength reduction factor of 4.0 and ratioing for the modulus of elasticity at 200°F, 27.6×10^6 psi (SA-564, Type 630, H1150, 17-4 PH stainless steel), the equivalent stress range is S_{range} = 264,100 psi. Then, the alternating stress is S_a =132,050 psi and the allowable number of normal operating cycles is 573 cycles (Figure I-9.1, Appendix I, "ASME Boiler and Pressure Vessel Code"), which is significantly greater than the 240 cycles of normal transport loads that the NAC-STC is expected to incur during its lifetime.

2.1.3.2.3.3 Port Cover Bolts

The allowable number of normal operating cycles for the port cover bolts is calculated similarly to that for the inner lid bolts. The installation torque for a bolt for the port cover is 140 inch-pounds; thus, T = 140 inch-pounds. The nominal thread diameter of a bolt for the port cover is 0.375 inch; thus, d = 0.375 inch. The calculated tensile force and stress in the port cover bolts are 1,875 pounds and 30,242 psi, respectively. Assuming a fatigue strength reduction factor of

4.0 and ratioing for the modulus of elasticity at 200°F, 28.5 x 10^6 psi (SA-193, Grade B6 High Alloy Steel Bolting Material), the equivalent stress range is S_{range} = 127,335 psi. Then, the alternating stress is S_a = 63,667 psi and the allowable number of normal operating cycles for the bolts for the port cover is 1650 cycles (Figure I-9.4, Appendix I, "ASME Boiler and Pressure Vessel Code"), which is greater than the 240 cycles of normal transport loads that the NAC-STC is expected to incur during its lifetime.

2.1.3.2.3.4 Port Coverplate Bolts

The allowable number of normal operating cycles for the port coverplate bolts is calculated similarly to that for the inner lid bolts. The installation torque for a port coverplate bolt is 300 inch-pounds; thus, T = 300 inch-pounds. The nominal thread diameter of a bolt for the port coverplate is 0.5 inch; thus, D = 0.50 inch. The calculated tensile force and stress in the port coverplate bolts are 4,110 pounds and 28,964 psi, respectively. Again, assuming a fatigue strength reduction factor of 4.0 and ratioing for the modulus of elasticity at 200°F, 28.5 x 10^6 psi (SA-193, Grade B6 High Alloy Steel Bolting Material), the equivalent stress range is S_{range} = 121,954 psi. Then, the alternating stress is S_a = 60,977 psi and the allowable number of normal operating cycles for the bolts for the port coverplate is 1,700 cycles (Figure I-9.4, Appendix I, "ASME Boiler and Pressure Vessel Code"), which is greater than the 240 cycles of normal transport loads that the NAC-STC is expected to incur during its lifetime.

2.1.3.2.4 Normal Over-the-Rail Vibration

Fatigue concerns associated with normal over-the-rail vibration are addressed in Section 2.6.5.

2.1.3.3 Extreme Total Stress Intensity Range

Paragraph C.7 of Regulatory Guide 7.6 defines the "low cycle" fatigue stress limit for any point in the containment vessel for the cask's entire life—initial state, fabrication state, normal transport conditions and hypothetical accident--as a limit on the maximum stress intensity range. That limit is equal to twice the allowable alternating stress at 10 cycles (S_a) as tabulated in the mechanical properties of materials, Section 2.3. S_a has been adjusted by the ratio of the material's modulus of elasticity (at the applicable temperature for the load combination being evaluated) to the modulus of elasticity used in the development of the material fatigue curve. At

analysis locations where a structural discontinuity exits, the calculated peak stress intensity range includes appropriate stress concentration effects.

To conservatively evaluate the stress state in relation to the requirements of Paragraph C.7 of Regulatory Guide 7.6, the worst-case thermal/secondary stress intensity is used. The detailed evaluation of the extreme total stress intensity range for the NAC-STC is performed in Section 2.7.3.3.

2.1.3.4 Inner Shell Buckling Design Criteria

Code Case N-284 (Metal Containment Shell Buckling Design Methods) of the "ASME Boiler and Pressure Vessel Code" is used to analyze the NAC-STC inner shell for structural stability. Structural stability ensures that the inner shell does not buckle during cask fabrication, normal operations, or hypothetical accident conditions. The buckling evaluation requirements of Regulatory Guide 7.6, Paragraph C.5, are shown to be satisfied by the results of the interaction equation calculations of Code Case N-284.

2.1.3.4.1 Code Case N-284

The "ASME Boiler and Pressure Vessel Code" sets forth service limits that are analogous to load conditions found in 10 CFR 71. As stated in Regulatory Guide 7.6, the normal transport conditions correspond to Level A Service Limits, and the hypothetical accident conditions correspond to Level D Service Limits. Service conditions A and D allowable stresses are used in performing the buckling assessment of the inner shell. Level A (normal transport) conditions use a buckling safety factor of 2.0, and Level D (accident) conditions use a buckling safety factor of 1.34. Code Case N-284 addresses both elastic and inelastic buckling.

Interaction equations are used to combine hoop compressive, axial compressive, and in-plane shear loadings. Also, Appendix F of the "ASME Boiler and Pressure Vessel Code," (for Level D Service Loadings) specifically identifies the use of "A Code Case for Metal Containment Shell Buckling" as an acceptable means of addressing buckling issues (paragraph F-1331.5(c)).

Buckling of the inner shell, which is the primary component of containment, is evaluated in the following manner:

1. Determine the theoretical elastic buckling stresses using classical theory.

2. Apply the appropriate factors of safety and interaction equations to elastic and inelastic buckling cases and establish the worst-case compressive and in-plane shear stresses.

3. Calculate and apply capacity reduction factors, which account for differences between classical theory and predicted instability stress for fabricated shells.

4. Calculate plasticity reduction factors and apply them in cases where elastically determined buckling stresses are above the proportional limit.

2.1.3.4.2 Theoretical Elastic Buckling Stresses

Inner shell geometric parameters and material properties are used to follow the elastic buckling evaluation. The theoretical elastic buckling stresses for the inner shell are calculated using the equations of Code Case N-284, the inner shell geometric parameters, and the material yield strength and elastic modulus.

The equations from Code Case N-284 are:

$$S_{\phi eL} = C_{\phi} \frac{Et}{R}$$

$$S_{\theta eL} = S_{reL} = C_{\theta} \frac{Et}{R}$$

$$S_{heL} = C_{\theta h} \frac{Et}{R}$$

$$S_{\phi\theta eL} = C_{\phi\theta} \frac{Et}{R}$$

These elastic buckling stress formulas are for cylindrical shells that are unstiffened.

2.1.3.4.3 Capacity Reduction Factors

Capacity reduction factors, as stated earlier, compensate for differences between classically determined and predicted instability stresses for fabricated shells. The capacity reduction factors were determined using methods described in Section-1500 of Code Case N-284. For the NAC-STC inner shell geometry, the capacity reduction factors are determined by the following expressions:

1. Axial Compression: $\alpha_{\phi L} = [1.0 \times 10^{-5}(S_y)] - 0.033$

2. Hoop Compression: $\alpha_{\theta L} = 0.8$

3. Shear: $\alpha_{\phi\theta L} = 0.8$

In order to directly use the capacity reduction factors, the tolerance requirements of NE-4220 of the "ASME Boiler and Pressure Vessel Code," Subsection NE, must be satisfied. NE-4221.1 and NE-4221.2 set forth the "maximum difference in cross-sectional diameters" and "maximum deviation from true theoretical form for external pressure."

2.1.3.4.4 Plasticity Reduction Factors

Plasticity reduction factors account for nonlinear material behavior, occurring when buckling stresses exceed the proportional limit of the material. Plasticity reduction factors chosen are dependent upon the magnitude of the applied compressive or in-plane shear stress, S_i. Because values for S_i are not directly calculated, the equations used to determine the reduction factors (Section-1600 of Code Case N-284) are presented:

1. Axial Compression

$$\eta_\phi = 1.0; \text{ if } \left|(S_\phi)(FS)/(Sy)\right| < 0.55$$

$$\eta_\phi = 0.18/(1 - [0.45\, S_y/(S_\phi)(FS)]);$$

$$\text{if } 0.55 < [(S_\phi)(FS)/S_y] \leq 0.738$$

$$\eta_\phi = 1.31 - [1.15(S_\phi)(FS)/S_y]; \text{ if } 0.738 < [(S_\phi)(FS)/S_y] < 1.0$$

2. Hoop Compression

$\eta_\theta = 1.0$; if $[(S_\theta)(FS)/S_y] < 0.67$

$\eta_\theta = 2.53 - 2.29[(S_\theta)(FS)/S_y]$; if $0.67 < [(S_\theta)(FS)/S_y] < 1.0$

3. Shear

$\eta_{\phi\theta} = 1.0$; if $[(S_{\phi\theta})(FS)/S_y] \leq 0.48$

$\eta_{\phi\theta} = 0.1/(1 - [0.43S_y/(S_{\phi\theta})(FS)])$;

if $0.48 < [(S_{\phi\theta})(FS)/S_y] \leq 0.6$

2.1.3.4.5 Upper Bound Magnitudes for Compressive Stresses and In-Plane Shear Stresses

From Section-1600 of Code Case N-284, as an upper limit, the compressive stresses, S_i ($i = \phi$ or θ), must be less than the yield strength, S_y, divided by the appropriate factor of safety ($S_i < S_y/FS$). Similarly, for shear, $S_{\phi\theta}$ must be less than, or equal to, 0.6 S_y divided by the appropriate factor of safety ($S_{\phi\theta} < 0.6\ S_y/FS$). As stated in Section 2.1.3.4.1, there is a factor of safety of 2.0 for normal transport and a factor of safety of 1.34 for hypothetical accident conditions. Under no circumstances can the values for the upper bound magnitudes of compressive stresses and in-plane shear stresses be exceeded. However, satisfying these limits alone is not sufficient to demonstrate that buckling will not occur. As stated in Section 2.1.3.4.1, the interaction equations must also be satisfied.

2.1.3.4.6 Interaction Equations

Elastic and inelastic interaction equations must be satisfied for all states of compressive and in-plane shear stress. The interaction equations for cylindrical shells are directly available from paragraph 1713.1.1 and paragraph 1713.2.1 of Code Case N-284. Once a stress state is established for a specific shell, plasticity reduction factors can be determined and all appropriate interaction equations checked. Elastic interaction equations must be satisfied and, if any of the uniaxial critical stress values exceed the proportional limit of the fabricated material, the inelastic interaction equations must also be satisfied.

2.1.3.5 Creep Considerations at Elevated Temperatures

Structural components of the NAC-STC cask and fuel basket are fabricated from stainless steel, which does not experience creep below temperatures of 700°F. The fuel basket is the package structural component exposed to the highest temperatures, which remain below 700°F. Therefore, the potential of creep is eliminated from the package, satisfying design considerations relative to the creep failure mode.

2.1.3.6 Impact Limiter Deformation Limits

The NAC-STC impact limiter(s) is intended to crush and thus absorb energy during a free drop accident condition impact. The geometry of the impact limiter and the crush characteristics of the energy-absorbing material are designed to limit the impact forces that are applied to the cask.

The NAC-STC impact limiter(s) limit the deceleration experienced by the cask body to approximately 55.0 g for all impact conditions. The impact force is a function of the crush strength of the energy-absorbing material in the impact limiter and the area of crush. The impact limiter must provide a sufficient depth of energy-absorbing material so that all of the impact energy is absorbed (cask is stopped) before the limiter is crushed to solid "stacked" height (approximately 30 percent of the initial depth).

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2.2 Weights and Centers of Gravity

This section provides the weights and centers of gravity for five transport configurations and two impact limiter configurations. The transport configurations are directly loaded fuel, canistered fuel and GTCC waste using the Yankee-MPC configuration and canistered fuel and GTCC waste using the CY-MPC configuration. There are two impact limiter designs. The redwood design shown in Drawings 423-209 and 423-210 may be used for the directly loaded fuel and the Yankee-MPC configurations. The balsa wood design shown in Drawings 423-257 and 423-258 may be used for the directly loaded fuel and Yankee-MPC configurations, but must be used for the CY-MPC configurations.

The calculated weights of the major components of the NAC-STC directly loaded fuel configuration are tabulated in Table 2.2-1. The table also presents a summary of the weights and center of gravity locations of the NAC-STC for the three cask configurations most likely to occur - empty, under-the-hook loaded with fuel, and loaded with fuel/ready for transport. In Table 2.2-1, the "empty" weight includes the cask basket, but excludes any fuel or water in the cask cavity. The term "loaded with fuel" refers to the directly loaded cask with 26 design basis fuel assemblies in the basket. "Under-the-hook loaded with fuel" describes the directly loaded NAC-STC with water in the cavity, without the outer lid in place, and with the yoke. "Loaded with fuel/ready for transport" describes the directly loaded NAC-STC with helium in the cavity and the upper and lower impact limiters installed on the cask. The axial locations of the centers of gravity are measured from the bottom outer surface of the cask body. The centers of gravity are on the axial centerline of the cask because it is essentially symmetric about that axis.

The design weight of the NAC-STC directly loaded fuel configuration "loaded with fuel/ready for transport" is 250,000 pounds. This design weight is used in all normal transport, hypothetical accident, and lifting/handling analyses for the directly loaded fuel configuration.

The calculated weights of the major components of the Yankee-MPC canistered fuel and GTCC waste configurations of the NAC-STC are tabulated in Tables 2.2-2 and 2.2-3, respectively. The tables also present a summary of the weights and center of gravity locations of the NAC-STC for the three Yankee-MPC cask configurations most likely to occur – empty, under the hook loaded with fuel, and loaded with fuel/ready for transport. In Tables 2.2-2 and 2.2-3, the "empty" weight excludes the transportable storage canister but includes the canister spacer weight. The term "loaded with fuel" refers to the loaded Yankee-MPC canister in the cask, with the noted

number of design basis fuel assemblies in the basket. "Under-the-hook loaded with fuel" describes the loaded NAC-STC without the outer lid in place, and with the yoke. "Loaded with fuel/ready for transport" describes the loaded NAC-STC with helium in the cavity and the upper and lower impact limiters installed on the cask. The axial locations of the centers of gravity are measured from the bottom outer surface of the cask body. The centers of gravity are on the axial centerline of the cask because it is essentially symmetric about that axis. Table 2.2-3 provides similar information for the Yankee-MPC GTCC waste configuration. The design weight of the NAC-STC "loaded with fuel/ready for transport" in the Yankee-MPC configuration is also 250,000 pounds. This design weight is used in all normal transport, hypothetical accident, and lifting/handling analyses.

Similarly, The calculated weights of the major components of the CY-MPC canistered fuel and GTCC waste configurations of the NAC-STC are tabulated in Tables 2.2-4 and 2.2-5, respectively. The tables also present a summary of the weights and center of gravity locations of the NAC-STC for the three CY-MPC cask configurations most likely to occur – empty, under the hook loaded with fuel, and loaded with fuel/ready for transport. The "empty" weight excludes the transportable storage canister but includes the canister spacer weight. The term "loaded with fuel" refers to the loaded CY-MPC canister in the cask, with the noted number of design basis fuel assemblies in the basket. "Under-the-hook loaded with fuel" describes the loaded NAC-STC without the outer lid in place, and with the yoke. "Loaded with fuel/ready for transport" describes the loaded NAC-STC with helium in the cavity and the upper and lower impact limiters installed on the cask. The axial locations of the centers of gravity are measured from the bottom outer surface of the cask body. The centers of gravity are on the axial centerline of the cask because it is essentially symmetric about that axis. Table 2.2-5 provides similar information for the CY-MPC GTCC waste configuration. The design weight of the NAC-STC "loaded with fuel/ready for transport" in the CY-MPC configuration is 260,000 pounds. This design weight is used in all normal transport, hypothetical accident, and lifting/handling analyses.

Table 2.2-1 NAC-STC Calculated Weights and Centers of Gravity for Directly Loaded Fuel

Component	Calculated Weight (lbs)	Center of Gravity* (in)	Calculated Weight (lbs)	Center of Gravity* (in)
Impact Limiter Configuration	**Redwood**		**Balsa**	
Body Assembly	157,160		157,160	
Outer Lid	8,120		8,120	
Inner Lid	10,690		10,690	
TOTAL	175,970	96.8	175,970	96.8
Fuel (26 PWR Assemblies @ 1,525 lbs)	39,650	93.3	39,650	93.3
Fuel Basket	16,350	93.3	16,350	93.3
Water In Cavity	16,430	96.2	16,430	96.2
Yoke	2,150	N/A	2,150	N/A
Transport Impact Limiters				
Top	8,865	203.6	5,787	203.6
Bottom	8,865	-10.5	5,636	-10.5
TOTAL WEIGHT				
Empty	192,320	96.8	192,320	96.8
Under-the-Hook Loaded with Fuel	242,430	96.0	242,430	96.0
Loaded with Fuel/Ready for Transport	249,700	96.0	243,393	96.0
Design - Loaded with Fuel/ Ready for Transport	250,000	96.0	250,000	96.0

* Measured from bottom outer surface of cask body.

Table 2.2-2 NAC-STC Calculated Weights and Centers of Gravity for Yankee-MPC Canistered Fuel

Component	Calculated Weight (lbs)	Center of Gravity* (in)	Calculated Weight (lbs)	Center of Gravity* (in)
Impact Limiter Configuration	**Redwood**		**Balsa**	
Body Assembly	157,160		157,160	
Outer Lid	8,120		8,120	
Inner Lid	10,690		10,690	
TOTAL	175,970	96.8	175,970	96.8
Fuel (34 W PWR Assemblies @ 900 lbs)	30,600	N/A	30,600	N/A
or (36 CE or UN Assemblies @ 850 lbs)	30,600	N/A	30,600	N/A
Fuel Basket	9,530	N/A	9,530	N/A
Canister w/Lids	14,600	N/A	14,600	N/A
Spacers				
Top	510	N/A	510	N/A
Bottom	350	N/A	350	N/A
TOTAL WEIGHT OF CONTENTS (Canistered Fuel Basket Configuration)	55,590	N/A	55,590	N/A
Yoke	2,150	N/A	2,150	N/A
Transport Impact Limiters				
Top	8,865	203.6	5,787	203.6
Bottom	8,865	-10.5	5,636	-10.5
TOTAL WEIGHT OF NAC-STC				
Empty	176,830	N/A	176,830	N/A
Under-the-Hook Loaded with Fuel	233,710	N/A	233,710	N/A
Loaded with Fuel/Ready for Transport	249,290	96.0	242,983	96.0
Design - Loaded with Fuel/ Ready for Transport	250,000	96.0	250,000	96.0

* Measured from bottom outer surface of cask body.

Table 2.2-3 NAC-STC Calculated Weights and Centers of Gravity for Canistered Yankee-MPC GTCC Waste

Component	Calculated Weight (lbs)	Center of Gravity* (in)	Calculated Weight (lbs)	Center of Gravity* (in)
Impact Limiter Configuration	**Redwood**		**Balsa**	
Body Assembly	157,160		157,160	
Outer Lid	8,120		8,120	
Inner Lid	10,690		10,690	
TOTAL	175,970	96.8	175,970	96.8
GTCC Waste (24 Tubes Full @ 514 lbs)	12,340	N/A	12,340	N/A
Basket - GTCC Waste	26,471		26,471	
Canister w/Lids	14,600	N/A	14,600	N/A
Spacers				
Top	510	N/A	510	N/A
Bottom	350	N/A	350	N/A
Yoke	2,150	N/A	2,150	N/A
Transport Impact Limiters				
Top	8,865	203.6	5,787	203.6
Bottom	8,865	-10.5	5,636	-10.5
TOTAL WEIGHT				
STC Empty with spacers	176,830	N/A	176,830	N/A
Under-the-Hook Loaded with GTCC Waste	232,391	N/A	232,391	N/A
Loaded with GTCC Waste, Ready for Transport	247,971	N/A	241,664	N/A
Design - Loaded with Fuel or GTCC Waste, Ready for Transport	250,000	96.0	250,000	96.0

* Measured from bottom outer surface of cask body.

Table 2.2-4 NAC-STC Calculated Weights and Centers of Gravity for CY-MPC Canistered Fuel

Component	Calculated Weight 24 Fuel Assemblies (lbs)	Calculated Weight 26 Fuel Assemblies (lbs)	Center of Gravity[1] (in)
Transport cask body assembly	157,160	157,160	-
Outer lid	8,120	8,120	-
Inner lid	10,690	10,690	-
TOTAL	175,970	175,970	96.8
Fuel	32,400	35,100	N/A
Fuel basket	13,843	14,055	-
Canister with lids	16,666	16,666	N/A
Spacer	1,374	1,374	-
TOTAL WEIGHT OF CONTENTS	64,283	67,195	N/A
Yoke	2,150	2,150	N/A
Transport impact limiters[2]	-	-	-
Top	5,787	5,787	205.6
Bottom	5,636	5,636	-15.1
TOTAL WEIGHT of the NAC-STC with the CY-MPC			
Under-the-hook loaded with fuel	242,403	245,315	N/A
Loaded with fuel/ready for transport	251,676	254,588	98.9
Design - Loaded with Fuel - Ready for Transport	260,000	260,000	98.9

1. Measured from bottom outer surface of cask body.
2. Redwood impact limiters cannot be used for the transport of the CY-MPC canister.

Table 2.2-5 NAC-STC Calculated Weights and Centers of Gravity for Canistered CY-MPC GTCC Waste

Component	Calculated weight (lb)	Center of gravity[1] (in.)
Transport cask body assembly	157,160	-
Outer lid	8,120	-
Inner lid	10,690	-
TOTAL	175,970	96.8
24 GTCC Containers	20,230	-
GTCC basket	28,926	-
Canister with lids	16,666	-
Spacer	1,374	-
TOTAL WEIGHT OF CONTENTS	67,196	N/A
Yoke	2,150	N/A
Transport impact limiters[2]	-	-
Top	5,787	205.6
Bottom	5,636	-15.1
TOTAL WEIGHT of the NAC-STC with the CY-MPC	-	-
Under-the-hook loaded with waste	245,316	96.4
Loaded with waste/ready for transport	254,589	99.0
Design - Loaded with waste - Ready for Transport	260,000	99.0

1. Measured from bottom outer surface of cask body.
2. Redwood impact limiters cannot be used for the transport of the CY-MPC canister.

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2.3 Mechanical Properties of Materials

2.3.1 Discussion

The structural analyses of the NAC-STC for the normal conditions of transport and the hypothetical accident load conditions use the mechanical properties of the component materials at the appropriate temperature. The mechanical properties at the applicable temperature are also used in calculating the allowable stresses in each component analysis.

The NAC-STC is fabricated from several different materials. Most of the cask body—the center section of the inner shell, the outer shell, the cask bottom, the top forging, and the neutron shield shell—is Type 304 stainless steel. The 31-inch long inner shell rings at each end of the inner shell are Type XM-19 high-strength stainless steel. The remainder of the cask body consists of chemical lead gamma radiation shielding and borated NS-4-FR solid neutron radiation shielding (The radial neutron shield region also contains explosively-bonded copper/Type 304 stainless steel heat transfer "fins."). The inner lid is Type 304 stainless steel. The outer lid, the outer lid bolts, the port covers, the lifting trunnions, and the rotation trunnion recesses are SA-705 or SA-564, Type 630, H1150 17-4 PH stainless steel. The inner lid bolts are SB-637, Grade N07718 nickel alloy bolting material. The bolts for the port covers and port coverplates are SA-193, Grade B6 (Type 410) stainless steel. The fuel basket is an assembly of SA-693 or SA-564, Type 630, H1150 17-4 PH stainless steel support disks, threaded rods and spacer nuts, Type 304 stainless steel top and bottom end plates, and fuel tubes. Fuel basket heat transfer disks are Type 6061-T651 aluminum alloy. The impact limiters are redwood and balsa or are all balsa encased in thin stainless steel shells. For the canistered configuration of the NAC-STC, the canister and its structural lid are Type 304L stainless steel. The remaining components of the canister and baskets (fuel and GTCC waste) are Type 304 stainless steel with the exception of the support disks, which are 17-4 PH stainless steel, and the heat transfer disks, which are 6061-T651 aluminum alloy. The top and bottom cavity spacers are 5056 aluminum honeycomb encased in thin 6061-T6 aluminum alloy shells for the Yankee-MPC configuration. A single Type 304 stainless steel bottom spacer is used for the CY-MPC configuration.

The "ASME Boiler and Pressure Vessel Code," Section III, Appendix I, and Standard Handbook for Mechanical Engineers (Baumeister) are the sources of the mechanical properties of Type 304 stainless steel; Type XM-19 stainless steel; SA-705 and SA-564, Type 630, H1150 17-4 PH

stainless steel; SB-637, Grade N07718 nickel alloy steel bolting material; SA-193, Grade B6 (Type 410) stainless steel, Type 6061-T6 aluminum alloy, and Type 6061-T651 aluminum alloy.

The effects of temperature variations on the mechanical properties are included. The coefficients of thermal expansion presented in this section represent the mean value for the temperature range from 70°F to the indicated temperature.

2.3.2 Austenitic Stainless Steels

The primary structural components of the NAC-STC body, excluding: (1) the inner shell rings (transition sections of the inner shell); (2) the outer lid; (3) the lifting trunnions; and (4) the rotation trunnion recesses, are fabricated from Type 304 stainless steel. In addition to the cask body components fabricated from Type 304 stainless steel, the fuel tubes and fuel basket top and bottom weldment plates are fabricated from the same material. This material is selected because it is strong, ductile, and highly resistant to corrosion and brittle fracture. Type XM-19 stainless steel is selected for the inner shell rings at the ends of the inner shell because the high strength of Type XM-19 stainless steel provides additional resistance to shear buckling in those sections of the inner shell.

The mechanical properties of SA-240 (plate), Type 304 stainless steel are tabulated in Table 2.3.2-1. The mechanical properties of SA-336 (forging), Type 304 stainless steel are tabulated in Table 2.3.2-2. The mechanical properties of SA-240 (plate), Type XM-19 stainless steel are tabulated in Table 2.3.2-3.

The primary structural components of the Yankee-MPC and CY-MPC canisters and baskets, excluding the support disks and heat transfer disks, are fabricated from Type 304 and Type 304L stainless steels. This material is selected because it is strong, ductile, and highly resistant to corrosion and brittle fractures. The associated mechanical properties of the Type 304 and 304L stainless steels are tabulated in Tables 2.3.2-1, 2.3.2-2 and 2.3.2-4.

Table 2.3.2-1 Mechanical Properties of SA 240, Type 304 Stainless Steel

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	75.0	75.0	75.0	71.0	66.0	64.4	63.5	63.1
Yield Strength[2] (ksi)	30.0	30.0	30.0	25.0	22.5	20.7	19.4	17.3
Design Stress Intensity[3] (ksi)	20.0	20.0	20.0	20.0	20.0	18.7	17.5	15.6
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.31							
Density (lbm/in^3)	497 lbm/ft^3 (0.288 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-3.2.
2 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-2.2.
3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.2.
4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.
5 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1.
6 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.
7 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table NF-1.

Table 2.3.2-2 Mechanical Properties of SA 336, Type 304 Stainless Steel

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	70.0	70.0	70.0	66.2.0	61.5	60.0	59.3	58.9
Yield Strength[2] (ksi)	30.0	30.0	30.0	25.0	22.5	20.7	19.4	17.3
Design Stress Intensity[3] (ksi)	20.0	20.0	20.0	20.0	20.0	18.7	17.5	15.6
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.31							
Density[8] (lbm/in^3)	497 lbm/ft^3 (0.288 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-3.2.
2 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-2.2.
3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.2.
4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.
5 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1.
6 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.
7 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table NF-1.
8 "Nuclear Materials Handbook," Volume 1, Design Data, Property Code 3304.

Table 2.3.2-3 Mechanical Properties of Type XM-19 Stainless Steel

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	100.0	100.0	100.0	99.5	94.3	90.7	89.1	85.7
Yield Strength[2] (ksi)	55.0	55.0	55.0	47.0	43.4	40.8	38.8	35.8
Design Stress Intensity[3] (ksi)	33.3	33.3	33.3	33.2	31.4	30.2	29.7	28.5
Modulus of Elasticity[4] (ksi)	28.3E+3	28.3E+3	28.3E+3	27.0E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	708.0	708.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.3	28.3	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.31							
Density[8] (lbm/in^3)	497 lbm/ft^3 (0.288 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-3.1.
2 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-2.1.
3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.1.
4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.
5 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1.
6 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.
7 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table NF-1.
8 "Nuclear Materials Handbook," Volume 1, Design Data, Property Code 3304.

Table 2.3.2-4 Mechanical Properties of SA-240, Type 304L Stainless Steel

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength[1] (ksi)	70.0	70.0	70.0	66.2	60.9	58.5	57.8	55.9
Yield Strength[2] (ksi)	25.0	25.0	25.0	21.4	19.2	17.5	16.4	14.7
Design Stress Intensity[3] (ksi)	16.7	16.7	16.7	16.7	16.7	15.8	14.8	13.3
Modulus of Elasticity[4] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Alternating Stress[5] @ 10 cycles (ksi)	718.0	718.0	708.0	690.5	675.5	663.0	645.5	610.4
Alternating Stress[5] @ 10^6 cycles (ksi)	28.7	28.7	28.3	27.6	27.0	26.5	25.8	24.4
Coefficient of Thermal Expansion[6] (in/in/°F)	8.13E-6	8.19E-6	8.46E-6	8.79E-6	9.00E-6	9.19E-6	9.37E-6	9.76E-6
Poisson's Ratio[7]	0.31							
Density[8] (lbm/in^3)	503 lbm/ft^3 (0.291 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table U.
2 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table Y-1.
3 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table 2A.
4 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table TM-1.
5 "ASME Boiler and Pressure Vessel Code," Section III, Appendix I, Table I-9.1.
6 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table TE-1.
7 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table NF-1.
8 "ASME Boiler and Pressure Vessel Code," Section II, Part D, Table NF-2.

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2.3.3 Precipitation-Hardened Stainless Steel

SA-705, SA-693 or SA-564, Type 630, H1150 17-4 PH stainless steel is selected for the NAC-STC outer lid, outer lid bolts, port covers, lifting trunnions, rotation trunnion recesses, and fuel basket structural components because of its high strength combined with good corrosion and brittle fracture resistance. The 17-4 PH or the Type 630, as it is identified in the ASME Code, is a ferritic steel with 17 percent chromium and four percent nickel as compared to Type 304 austenitic steel, which has 18 percent chromium and eight percent nickel. Both materials are referred to as stainless steel by the metals industry and throughout this document. The mechanical properties of this precipitation-hardened stainless steel are tabulated in Table 2.3.3-1.

Table 2.3.3-1 Mechanical Properties of SA-705, SA-693 and SA-564, Type 630, H1150, 17-4 PH Stainless Steel

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+650
Ultimate Strength[1] (ksi)	135.0	135.0	135.0	135.0	135.0	131.4	128.5	125.7[2]
Yield Strength[3] (ksi)	105.0	105.0	105.0	97.1	93.0	89.5	87.0	83.6
Design Stress Intensity[4] (ksi)	45.0	45.0	45.0	45.0	45.0	43.8	42.8	41.9
Modulus of Elasticity[5] (ksi)	28.7E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	25.1E+3
Alternating Stress[6] @ 10 cycles (ksi)	401.8	401.8	396.2	386.4	378.0	371.0	361.2	341.6
Alternating Stress[6] @ 10^6 cycles (ksi)	19.1	19.1	18.9	18.4	18.0	17.7	17.2	16.3
Coefficient of Thermal Expansion[7] (in/in/°F)	5.88E-6	5.88E-6	5.89E-6	5.90E-6	5.90E-6	5.91E-6	5.91E-6	5.93E-6
Poisson's Ratio	0.287							
Density (lbm/in^3)	487 lbm/ft^3 (0.282 lbm/in^3)							

1. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-3.1.
2. Obtained by ratioing from the Design Stress Intensity values.
3. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-2.1.
4. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.1.
5. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.
6. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1.
7. "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.

2.3.4 Bolting Materials

The bolting materials for the NAC-STC are selected to provide high strength, good resistance to corrosion and brittle fracture, and coefficients of thermal expansion that are similar to those of the components being joined.

The outer lid bolts are SA-564, Type 630, H1150, 17-4 PH stainless steel with mechanical properties as tabulated in Table 2.3.3-1. The mechanical properties for the inner lid bolt material--SB-637, Grade N07718 nickel alloy bolting material—are tabulated in Table 2.3.4-1. The mechanical properties for the port cover bolts, port coverplate bolts, and fuel/basket spacer bolts material—SA-193, Grade B6 (Type 410) stainless steel--are tabulated in Table 2.3.4-2.

Table 2.3.4-1 Mechanical Properties of SB-637, Grade N07718 Nickel Alloy Steel Bolting Material

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength (ksi)	185.0[1]	185.0[1]	185.0[1]	177.6[5]	173.5[5]	170.6[5]	168.7[5]	165.0[5]
Yield Strength (ksi)	150.0[1]	150.0[1]	150.0[1]	144.0[5]	140.7[5]	138.3[5]	136.8[5]	133.8[5]
Design Stress Intensity[1] (ksi)	50.0	50.0	50.0	48.0	46.9	46.1	45.6	44.6
Modulus of Elasticity[2] (ksi)	29.6E+3	29.5E+3	29.0E+3	28.3E+3	27.8E+3	27.6E+3	27.1E+3	26.1E+3
Coefficient of Thermal Expansion[3] (in/in/°F)	6.87E-6	6.90E-6	7.15E-6	7.22E-6	7.33E-6	7.45E-6	7.57E-6	7.82E-6
Alternating Stress[4] @ 10^6 cycles (ksi)	13.3	13.7	13.1	12.7	12.5	12.4	12.2	11.7
Poisson's Ratio	0.32							
Density (lbm/in^3)	489 lbm/ft^3 (0.283 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.3.

2 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.

3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.

4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1, Figure I-9.4.

5 Obtained by ratioing from the design stress intensity values.

Table 2.3.4-2 Mechanical Properties of SA-193, Grade B6, High Alloy Steel Bolting Material

Property (units)	Temperature (°F)							
	-40	-20	+70	+200	+300	+400	+500	+750
Ultimate Strength (ksi)	110.0[1]	110.0[1]	110.0[1]	104.9[2]	101.5[2]	98.3[2]	95.6[2]	89.4[2]
Yield Strength (ksi)	85.0[1]	85.0[1]	85.0[1]	81.2[2]	78.4[2]	76.0[2]	73.9[2]	69.1[2]
Design Stress Intensity[1] (ksi)	28.3	28.3	28.3	27.0	26.1	25.3	24.6	23.0
Modulus of Elasticity[5] (ksi)	28.8E+3	28.7E+3	28.3E+3	27.6E+3	27.0E+3	26.5E+3	25.8E+3	24.4E+3
Coefficient of Thermal Expansion[4] (in/in/°F)	5.73E-6	5.76E-6	5.92E-6	6.15E-6	6.30E-6	6.40E-6	6.48E-6	6.64E-6
Alternating Stress[5] @ 10 cycles (ksi)	1104.4	1100.0	1085.0	1058.0	1035.0	1015.0	989.0	935.3
Alternating Stress[5] @ 10^6 cycles (ksi)	13.0	12.9	12.7	12.4	12.2	11.9	11.6	11.0
Poisson's Ratio	0.32							
Density (lbm/in^3)	489 lbm/ft^3 (0.283 lbm/in^3)							

1 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-1.3.
2 Tabulated value is calculated by ratioing from the Design Stress Intensity.
3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.
4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.
5 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-9.1, Figure I-9.4.

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2.3.5 Aluminum Alloys

SB-209, Type 6061-T651, aluminum alloy is selected to fabricate the fuel basket heat transfer disks. These disks are not safety related structural load path components and are attached to the fuel basket solely to enhance heat transfer performance of the fuel support structures. The Type 6061-T651 material is selected for high thermal conductivity relative to material weight in addition to being an ASME approved material.

The mechanical properties of SB-209, Type 6061-T651 and Type 6061-T6 aluminum alloy are tabulated in Table 2.3.5-1. These material properties are provided for information and are not intended as documentation for the structural performance of the NAC-STC package. Influence of time and temperature on these properties not identified in the ASME material information is from MIL-HDBK-5F.

The mechanical properties of Type 6061-T651 aluminum alloy for the heat transfer disk in the canistered fuel basket are tabulated in Table 2.3.5-1. There are no heat transfer disks in the canistered GTCC waste basket.

Table 2.3.5-1 Mechanical Properties of 6061-T651 and 6061-T6 Aluminum Alloy

Property (units)	Temperature (°F)						
	+70	+100	+200	+300	+400	+500	+600
Ultimate Strength[1,2] (ksi)	42.0	40.7	38.2	31.5	17.2	6.7	3.4
Yield Strength[1,2] (ksi)	35.0	33.9	32.2	26.9	14.0	5.3	2.5
Design Stress[1] Intensity[1] (ksi)	10.5	10.5	10.5	8.4	4.4	N/A	N/A
Modulus of Elasticity[3] (ksi)	10.0E+3	9.9E+3	9.6E+3	9.2E+3	8.7E+3	8.13E+3[5]	7.0E+3[5]
Coefficient of Thermal Expansion[4] (in/in/°F)	—	12.6E-6	12.9E-6	13.22E-6	13.52E-6	13.7E-6[6]	14.3E-6[6]
Poisson's Ratio	0.33						
Density (lbm/in^3)	0.102						

1 "ASME Boiler and Pressure Vessel Code," Section III Division 1, Appendix I, Table I-8.4.

2 Strength at elevated temperatures calculated using the following relationships from MIL-HDBK-5F, Figures 3.6.2.2.1(a) and 3.6.2.2.1(b);

$$S_{uTemp} = (\%)(S_{u70}),\ S_{yTemp} = (\%)(S_{u70})$$

	% Value @ Room Temperature					
Temp°F	100	200	300	400	500	600
S_u	97	91	75	41	16	8
S_y	97	92	77	40	15	7

3 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-6.0.

4 "ASME Boiler and Pressure Vessel Code," Section III, Division 1, Appendix I, Table I-5.0.

5 MIL-HDBK-5F, Figure 3.6.2.2.4.

6 MIL-HDBK-5F, Figure 3.6.2.0.

2.3.6 Shielding Material

Gamma radiation shielding for the NAC-STC is provided by the steel cask body and lids and by lead in the cask wall. The primary radial gamma radiation shielding for the cask is provided by a cylinder of chemical lead, which fills the annulus between the inner shell and the outer shell. There is no concern that the lead will experience large deformation or volume change, since it is completely enclosed and is essentially incompressible.

Neutron radiation shielding for the NAC-STC is provided by a solid synthetic polymer, NS-4-FR, located in each end of the cask and around the outside of the outer shell. The solid neutron shield material eliminates leakage and maintenance concerns associated with liquid neutron shields. The NS-4-FR neutron shielding function requires no strength and none is assumed for the structural evaluations.

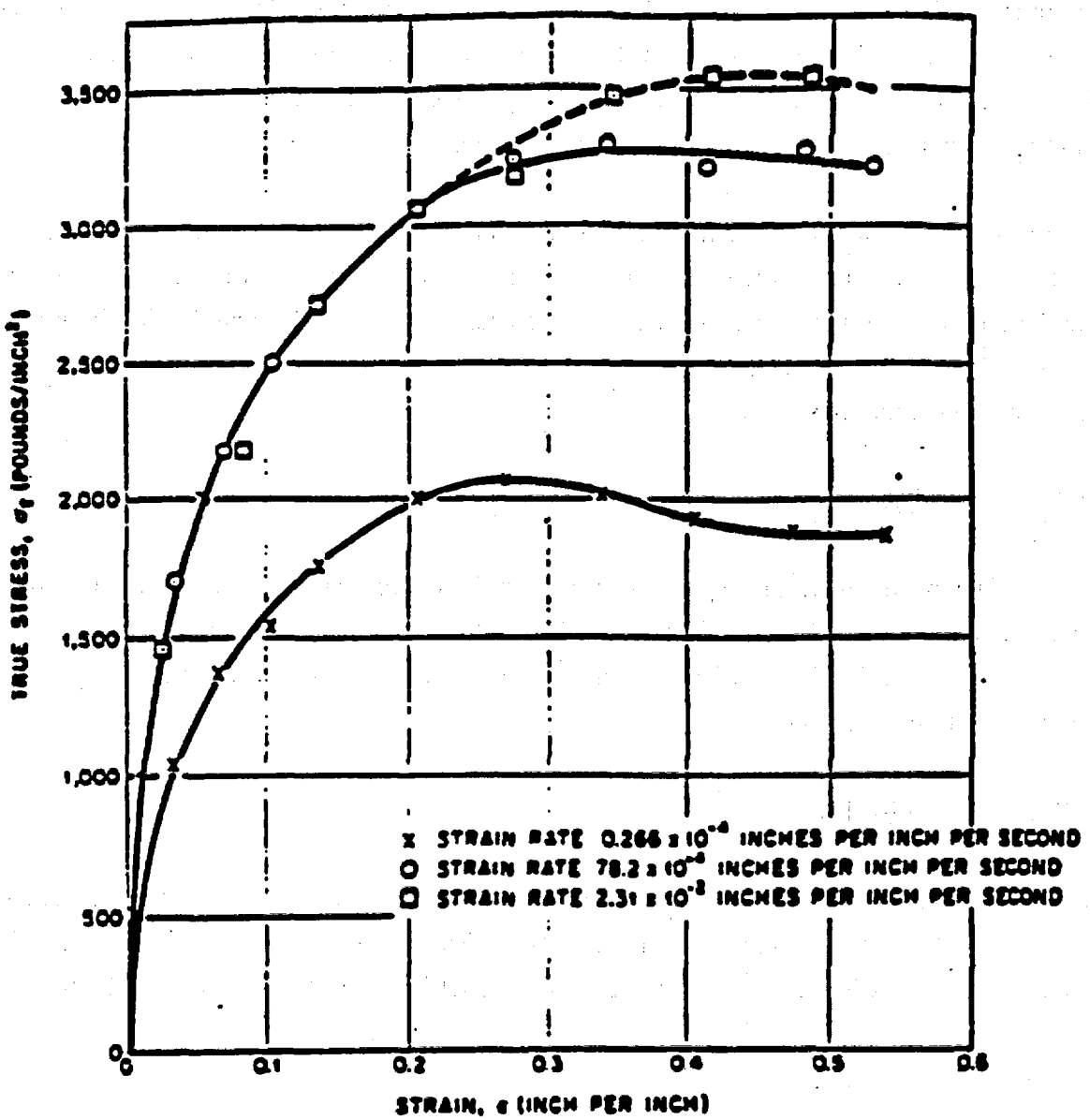
2.3.6.1 Chemical Copper Lead

The coefficient of thermal expansion for lead is of particular significance because it is approximately twice that of stainless steel. The static mechanical properties of chemical copper lead are tabulated in Table 2.3.6-1, and the stress-strain curve for chemical copper lead is presented in Figure 2.3.6-1.

2.3.6.2 NS-4-FR

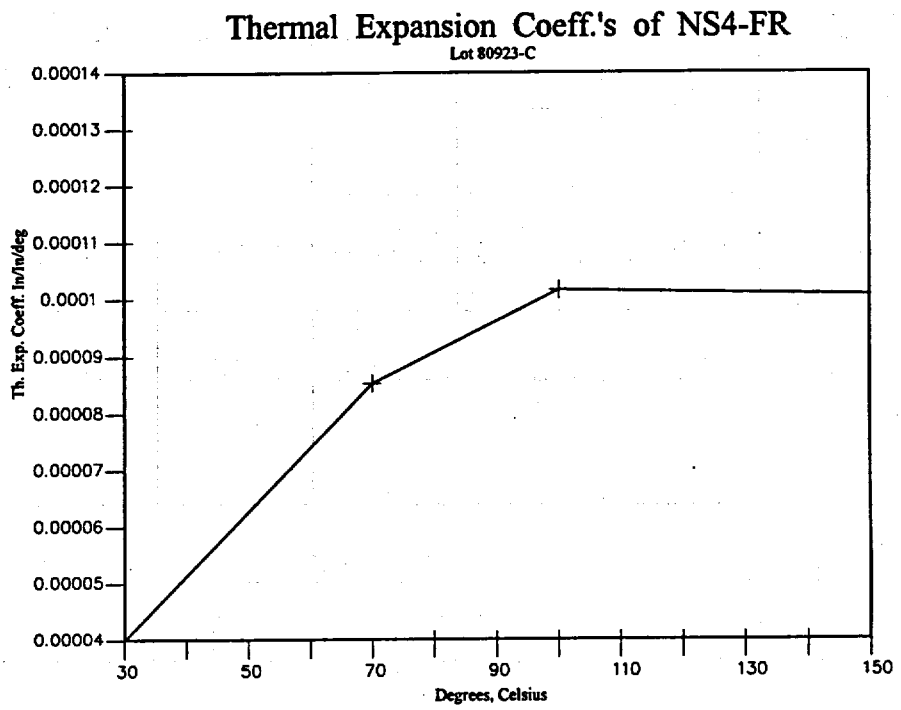
The NS-4-FR neutron shielding material was developed by BISCO Products, Inc. and is now supplied by the Japan Atomic Power Company. The mechanical properties of NS-4-FR are tabulated in Table 2.3.6-2. The thermal expansion coefficient is shown in Figure 2.3.6-2.

Figure 2.3.6-1 Quasi-Static True Stress-Strain Curves for Chemical Copper Lead in Compression



Reference: Evans

Figure 2.3.6-2 Neutron Shield Thermal Expansion Coefficient



Note: BISCO Products Data

Table 2.3.6-1 Static Mechanical Properties of Chemical Copper Lead

Property (units)	Temperature (°F)					
	-40	-20	+70	+200	+300	+600
Ultimate Strength[1,2] (ksi)	700	680	640	490	380	20
Modulus of Elasticity[3] (ksi)	2.45E+3	2.42E+3	2.28E+3	2.06E+3	1.94E+3	1.5E+3
Coefficient of Thermal Expansion[3] (in/in/°F)	15.6E-6	15.7E-6	16.1E-6	16.6E-6	17.2E-6	20.2E-6
Poisson's Ratio	0.40					
Density (lbm/in^3)	708 lbm/ft^3 (0.41 lbm/in^3)					

1 Tietz.
2 Gallagher.
3 NUREG/CR-0481, pages 42, 56 and 66.
4 Baumeister, page 6-10.

Table 2.3.6-2 Mechanical Properties of NS-4-FR

Property[1] (units)	Value
Compressive Modulus (ksi)	561
Coefficient of Thermal Expansion (in/in/°F)	Refer to Figure 2.3.6-2
Density (lbm/in^3)	0.0607

[1] BISCO Products Data.

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2.3.7 Impact Limiter Materials

The transport impact limiters for the NAC-STC are fabricated in two configurations. The first is the redwood and balsa wood impact limiter, referred to as the "redwood impact limiter," that may be used with the directly loaded fuel or Yankee-MPC contents. The second is an all balsa wood impact limiter, referred to as the "balsa impact limiter," that must be used with the CY-MPC contents and may also be used for the directly loaded and Yankee-MPC configurations. The balsa impact limiter weighs significantly less than the redwood impact limiter.

Both impact limiter configurations absorb the energy of a cask drop impact by crushing the redwood and/or balsa in the impact limiter.

The force-deformation curves for the NAC-STC upper and lower redwood impact limiters for end, corner, 75-degree oblique, and side impact orientations are presented in Figures 2.10.7-5 through 2.10.7-11. Figures 2.6.7.4.1-3 through 2.6.7.4.1-5 present the crush stress-strain curves for the wood material used in the redwood impact limiters.

The deformation and acceleration time history curves for the balsa impact limiters for end, corner and side drop orientations are presented in Section 2.10.3.1.

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2.3.8 Spacer Materials

Spacers are installed in the NAC-STC cask cavity for the transport of the Yankee-MPC and CY-MPC canisters containing either spent fuel or GTCC waste. The spacers are designed to locate the canister axially in the cavity so that the package center of gravity is located in the same position as that of the directly loaded fuel configuration of the cask. Removable lifting lugs are used to install and remove the spacer.

Two spacers (top and bottom) are used in the transport of the Yankee-MPC. Both spacers are fabricated from aluminum honeycomb encased in aluminum alloy shells.

The required aluminum honeycomb material properties are:

nominal density = 4.5 pcf;
crush strength = 320 psi;
compressive strength = 700 psi (typical) and 500 psi (minimum).

The CY-MPC canister is longer than the Yankee-MPC canister and a single stainless steel spacer, installed below the canister, is used. The CY-MPC spacer is formed by a series of concentric rings welded to a stainless steel base plate and is nominally 12.7 inches high and 70.6 inches in diameter.

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2.4 General Standards for All Packages

This section demonstrates that the general requirements found in 10 CFR 71.43 are addressed in the design and analysis of the NAC-STC, a spent-fuel transport and storage packaging. A packaging is defined as the assembly of components necessary to ensure compliance with 10 CFR 71 for the transportation of radioactive contents. The package consists of the packaging with its radioactive contents.

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2.4.1 Minimum Package Size

The minimum transverse dimension of the NAC-STC package is 98.2 inches (249.4 cm), and the minimum longitudinal dimension is 192.96 inches (490.1 cm). Both dimensions are greater than 10 centimeters; therefore, the requirements of 10 CFR 71.43(a) are satisfied.

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2.4.2 Tamperproof Feature

One numbered, crimped wire seal is looped through a hole in the end flange of the lifting trunnion and through a similar hole in an adjacent corner of the upper impact limiter as a tamper indicator. It is necessary to remove the upper impact limiter in order to attain access to the NAC-STC closure assembly (outer lid with bolts and inner lid with bolts); thus, a severed seal will indicate purposeful tampering. This satisfies the Tamperproof Feature requirement of 10 CFR 71.43(b).

The vent port and drain port are protected by bolted coverplates and are located in the inner lid, where access can only be attained by removal of the outer lid. The interlid and pressure ports, which are located in the top forging, are protected by bolted port covers. The port cover bolts are drilled for the installation of lockwire and are crimp sealed with a numbered wireseal device. This satisfies the requirements of 10 CFR 71.43(b). Additionally, a special tool is required to remove these port covers.

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2.4.3 Positive Closure

Inadvertent opening of the inner lid, outer lid, port coverplates, or port covers from the combined effects of shock, vibration, thermal expansion, internal loads and/or external loads cannot occur because of the large preload applied to the lid bolts. Loosening of these bolts is resisted by friction from the large clamping forces produced by the applied bolt preload torque. A cask operations procedure is followed, ensuring that each bolt is torqued. The operating procedure states that bolt torquing is a quality assurance "hold point," requiring verification and witnessing signatures. It is necessary to deliberately loosen the bolts with a wrench to facilitate inadvertent opening. Evidence of attempted unauthorized operation of the cask closure is provided by tamper-indicating features (Section 2.4.2). Therefore, the NAC-STC containment system cannot be opened unintentionally and evidence of attempted unauthorized operation is provided; the requirements of 10 CFR 71.43(c) and (e) are satisfied.

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2.4.4 Chemical and Galvanic Reactions

The materials used in the fabrication and operation of the NAC-STC cask—including coatings, lubricants, and cleaning agents—have been evaluated to determine whether chemical, galvanic, or other reactions among the materials, contents, and environments can occur. All phases of operation—loading, unloading, handling, storage, and transportation—have been considered, in conjunction with the procedures described in Chapter 7, for the environments that may be encountered under normal, off-normal, or accident conditions. Based on the evaluation, there are no potential reactions that could adversely affect the overall integrity of the cask, the fuel basket, the transportable storage canister (when used), or the structural integrity and retrievability of the fuel from the cask. The evaluation conforms to the guidelines of NRC Bulletin 96-04, "Chemical, Galvanic, or Other Reactions in spent Fuel Storage and Transportation Casks," dated July 5, 1996, and demonstrates that the NAC-STC cask meets the requirements of 10 CFR 71.43(d).

This section and Section 7.6 of the Operating Procedures describe the loading and closing of the transportable storage canisters. At the time of transport of the Yankee-MPC or CY-MPC canisters, the canisters will have been previously loaded and closed in accordance with the requirements of the NAC-MPC Safety Analysis Report for the NAC Multi-Purpose Canister System, Docket Number 72-1025. Since loading of the canisters in the NAC-STC is expected to be performed in a dry environment, there are no chemical, galvanic or corrosion reactions that occur between the stainless steel components of the NAC-STC and the stainless steel NAC-MPC canister. Once the canister is installed in the NAC-STC, the cask cavity atmosphere is inerted with dry helium, further reducing the potential for adverse reactions to occur within the cavity.

2.4.4.1 Component Operating Environment

Most of the component materials of the NAC-STC are exposed to one, or more, of three typical operating environments for casks: 1) a sealed internal cavity containing air, steam, helium, and spent fuel or other radioactive material; 2) an open internal cavity containing pool water (demineralized water - BWR, or borated water with a pH of 4.5 - PWR) and spent fuel or other radioactive material; 3) a sealed internal cavity containing helium, but with the cask in external surroundings, including air, rain water/snow/ice, and marine (salty) water/air. The spent fuel assemblies consist of Zircaloy or stainless steel clad fuel and other fuel assembly components of stainless steel.

Some of the cask components are completely enclosed and are exposed to an unchanging environment that is permanently sealed. These components include shielding materials and the energy-absorbing materials (impact limiters) that are only exposed to the temperature effects of the operating environments. The sealed shielding material regions are typically evacuated and backfilled with helium, while the impact limiter shells are leak tested following fabrication.

Each of the categories of cask component materials is evaluated for potential reactions in each of the operating environments to which those materials are exposed. These environments may occur during fuel loading or unloading, handling, storage or transport, including normal, off-normal, and accident conditions. Two of the operating environments to which the cask component materials are exposed do not provide the conditions necessary for a reaction (corrosion), since both moisture and oxygen must be present for corrosion to occur. The first of these environments is the sealed cavity, backfilled with helium. Helium displaces the oxygen in the cavity effectively precluding corrosion. Galvanic corrosion (i.e., between dissimilar metals that are in contact) could occur, but only if there is water present at the point of contact and the metals are in electrical contact with each other (i.e., mechanically held together). NAC's cask operating procedures provide two helium backfill cycles in series separated by a vacuum-drying cycle for the cask cavity during the preparation of the cask for storage or transport. Therefore, the cask cavity is effectively dry and galvanic corrosion is precluded. The second of these environments are those materials that are completely enclosed (permanently sealed) within another material, e.g., the primary shield materials—lead, NS-4-FR, or the criticality control material—borated aluminum, or the energy-absorbing materials - wood. For the metals, any oxygen that is trapped in the sealed region will be oxidized by the metals until thermodynamic equilibrium is reached, i.e., a thin oxide layer would develop on the lead or aluminum. In a similar manner for the NS-4-FR and the elastomers o-rings, any oxygen that is present will be captured by the hydrogen in the organic material until thermodynamic equilibrium is reached. Since the quantity of oxygen present, if any, is very small, equilibrium is reached very quickly and active corrosion in sealed regions does not occur.

2.4.4.2 Component Material Categories

The component materials evaluated are categorized based on similarity of physical and chemical properties and/or on similarity of component functions. The categories of materials that are considered are: 1) stainless/nickel alloy steels; 2) nonferrous metals; 3) shielding materials; 4)

criticality control materials; 5) energy absorbing materials; 6) cellular foams and insulation's; 7) lubricants and greases; and 8) seals. These categories are evaluated based on the environment to which they could be exposed during operation or use of the cask. The material categories and exposure environments are summarized in Table 2.4-1.

The cask component materials are not reactive among themselves, with the cask's contents, nor with the cask's operating environments during any phase of normal, off-normal, or accident condition loading, unloading, handling, storage or transportation operations. Therefore, since no reactions will occur, no gases or other corrosion byproducts will be generated.

2.4.4.2.1 Stainless/Nickel Alloy Steels

No reaction of the cask component steels (stainless or nickel alloy) is expected in any environment, except for the marine environment, where chloride-containing salt spray might initiate pitting of the steels if the chlorides are allowed to concentrate and stay wet for extended periods of time (weeks). Only the external cask surface could be so exposed. The corrosion rate will, however, be so low that no detectable corrosion products or gases will be generated. Additionally, the NAC-STC has smooth external surfaces, and ridges and crevices have been limited to minimize the collection of such materials as salts.

Galvanic corrosion between the stainless steels, Inconel, and the nickel alloy steels will not occur because there is no effective electrochemical potential difference between these metals. No coatings are applied to the stainless, or nickel alloy steels.

There is a significant electrochemical potential difference between austenitic (300 series) stainless steel and aluminum, copper, and lead. If they are in electrical contact with the austenitic stainless steel, these nonferrous materials could be expected to exhibit corrosion driven by electrochemical EMF when immersed in water. Boiling Water Reactor (BWR) pool water is demineralized water and is not sufficiently conductive to promote detectable corrosion for these metal couples, but Pressurized Water Reactor (PWR) pool water does provide a conductive potential. Because the copper and lead are not directly exposed to water, a reactive environment is not present and no reaction occurs. The only aluminum components that will be in contact with stainless steel and exposed to the pool water are in the fuel baskets. Generally poor electrical contact exists between the stainless steel and the aluminum and then only for the relatively short time that the fuel basket is submersed in water. Galvanic corrosion stops when

the electrolyte (water) is removed. Therefore, significant galvanically-driven corrosion does not occur. Copper and lead are in contact with stainless steel, but only in the completely enclosed (permanently sealed) gamma or neutron shield regions, where no water is present, so no reaction with stainless steel occurs.

There is no potential for a reaction between stainless steel and any silicone products, fluorocarbon elastomers, dry film lubricants, blended polytetrafluroethylene (PTFE), or ethylene glycol.

Based on the foregoing discussion, there are no significant potential reactions associated with the stainless steel cask components.

2.4.4.2.2 Nonferrous Metals

The nonferrous metals used in the NAC-STC are copper, aluminum, and aluminum bronze. As discussed in the previous section, these nonferrous metals do not produce any significant reaction in contact with stainless steel. Copper fins embedded in the neutron shield (NS-4-FR) region do not react with the NS-4-FR because there is no electrochemical driving potential between the materials.

The only aluminum components exposed to pool water are the heat transfer disks in the fuel baskets. Designer and Nuclear Regulatory Commission safety evaluations and tests of operating dry spent fuel storage systems have concluded that combustible gases, primarily hydrogen, may be produced by a chemical reaction and/or radiolysis when aluminum or aluminum flame-sprayed components are submersed in spent fuel pool water. The evaluations further concluded that it is possible, at higher temperatures (above 150°F - 160°F), for the aluminum/water reaction to produce a hydrogen concentration in the cask or canister that approaches or exceeds the Lower Flammability Limit (LFL) for hydrogen of four percent. NRC Inspection Reports No. 50-266/96005 and 50-301/96005 dated July 01, 1996, for the Point Beach Nuclear Plant concluded that hydrogen generation by radiolysis was insignificant relative to other sources.

Thus, it is reasonable to conclude that combustible gases, primarily hydrogen, may be produced during loading or unloading operations of the NAC-STC as a result of a chemical reaction between the 6061-T651 aluminum heat transfer disks in the fuel basket and the spent fuel pool

water. The generation of combustible gases stops when the water is removed from the cask or canister and the aluminum surfaces are dry. Also, a galvanic reaction may occur at the contact surfaces between the aluminum disks and the stainless steel tie rods and spacers in the presence of an electrolyte, like the pool water. The galvanic reaction ceases when the electrolyte is removed. The effects of radiolysis are considered insignificant.

The accumulation of combustible gases is only a concern during canistered fuel loading. For direct loading of fuel into the NAC-STC with the bolted closure, there is no ignition source for any combustible gases and the cask is vented to a radioactive waste handling system in operations prior to removal of the water from the cask cavity.

During canister closure operations, a cavity is created inside the canister beneath the shield lid by the drain-down of 50 gallons of water so that the shield lid to canister shell weld can be performed. The cavity beneath the shield lid is approximately 70 inches in diameter and 3 inches deep. Although there is some clearance between the inside diameter of the canister shell and the outside diameter of the shield lid, it is possible that gases released from a chemical reaction inside the canister could accumulate beneath the shield lid. A bare aluminum surface will oxidize when exposed to air, will react chemically in an aqueous solution, and may react galvanically when in contact with stainless steel in the presence of an aqueous solution.

The natural reaction of aluminum in water proceeds as shown below and results in hydrogen being generated:

$$2\ Al + 3\ H_20 \Rightarrow Al_2O_3 + 3\ H_2$$

Aluminum oxide (Al_2O_3) is the dull light gray film that develops on the surface of bare aluminum when it reacts with the oxygen in air or water. The formation of the film is a self limiting reaction as the aluminum metal is isolated from the oxygen source and, thus, acts as a barrier to further oxidation. The oxide film is stable in pH neutral (passive) solutions, but is soluble in borated PWR spent fuel pool water. The oxide film dissolves at a rate dependent upon the pH of the water, the exposure time of the aluminum in the water, and the temperatures of the aluminum and water.

PWR spent fuel pool water is a boric acid and demineralized water solution. The pH, water chemistry and water temperature vary from spent fuel pool to spent fuel pool. Since the reaction

rate is largely dependent upon these variables, it may vary considerably from pool to pool. Thus, an accurate calculation of a combustible gas (hydrogen) generation rate that could be considered representative of spent fuel pools, in general, is very difficult.

For directly loaded fuel, there is no ignition source for any hydrogen gas that might be generated, as the NAC-STC cask is a bolted closure. For the canistered configurations, which are closed by welding the loading and unloading procedures (Section 7.6) incorporate continuous monitoring to preclude welding operations if a concentration of hydrogen gas above 2.4% is detected. If a hydrogen gas concentration exceeding 2.4% is detected, the vacuum system is connected to the vent port and operated for a sufficient period of time to remove at least five times the air volume of the space beneath the shield lid. The system draws ambient air through the gap between the shield lid and the canister shell, thus, drawing out/diluting the hydrogen gas concentration. During welding, the hydrogen gas concentration is continuously monitored using a detector moving ahead of the weld head. The welding operation is stopped if a concentration above 2.4% is detected. Once the root pass weld is completed, there is no further likelihood of a combustible gas burn because the ignition source is isolated from the hydrogen gas source. Once welding has been completed, the cask or canister is drained, vacuum dried and back-filled with helium. These steps ensure safe loading and/or unloading of the NAC-MPC transportable storage canister configurations.

Galvanic corrosion may result when two dissimilar metals are in direct contact with each other in the presence of an electrolytic solution. Each metal has some tendency to ionize, or release electrons. A voltage, or electromotive force (emf), associated with this release of electrons is generated between two dissimilar metals in an electrolytic solution. The emf between aluminum and stainless steel is small and the amount of corrosion is directly proportional to the emf. Loading operations generally take less than 24 hours, after which the electrolyte (water) is drained and the cask or canister is dried and back-filled with helium, effectively halting any galvanic reaction.

Neither the potential chemical or galvanic reactions will have a significant detrimental effect on the ability of the aluminum heat transfer disks to perform their function for all normal and accident conditions associated with transport and dry storage.

2.4.4.2.3 Shielding Materials

The primary shielding materials used in the NAC-STC—lead and NS-4-FR—are completely enclosed and sealed in stainless steel. As previously described, there are no potential reactions of these materials with the stainless steel or with the copper fins.

Therefore, there are no potential reactions associated with the cask shielding materials.

2.4.4.2.4 Criticality Control Material

The criticality control material is a sheet consisting of boron carbide mixed in an aluminum alloy. This material is effectively a sheet of aluminum that is in contact with the aluminum alloy fuel tubes and is exposed to the cask cavity environment. This material is protected by an oxide layer that formed shortly after fabrication. The existing oxide layer effectively precludes further oxidation of the aluminum. Consequently, there are no potential reactions associated with the aluminum-based criticality control material.

2.4.4.2.5 Energy Absorbing Material

The NAC-STC utilizes redwood and balsa wood for energy absorption in the impact limiters. The wood is completely enclosed (sealed) in stainless steel and there are no potential reactions between the wood and the stainless steel shells. The wood is coated with a preservative prior to installation in the impact limiter shell and blocks of wood may be glued together with an epoxy adhesive. These are standard applications of preservatives and adhesives, so no post-application reactions will occur.

There are no potential reactions associated with the energy absorbing material.

2.4.4.2.6 Cellular Foam and Insulation

The NAC-STC utilizes layers of expansion foam and strips of insulation in the solid neutron shield regions. The expansion foam permits thermal expansion of the solid neutron shield material during normal operation, and the insulation protects the expansion foam during final closure welding of the neutron shield shell to the end plate. The foam and the insulation are non-

flammable, non-toxic, and non-corrosive silicone products that are used in the casks in a standard design application.

There are no potential reactions associated with the silicone expansion foam or insulation.

2.4.4.2.7 Lubricant and Grease

The dry film lubricants used with the NAC-STC meet the performance and general compositional requirements of the nuclear power industry. NEVER-SEEZ® lubricant is used primarily on rotating bearing surfaces. Neolube® is used primarily on threaded/mechanical connection surfaces. In addition, Dow Corning High Vacuum Grease is used as an adherent/lubricant to lubricate and retain the o-ring seals in their grooves. None of these lubricants contain elements or compounds prohibited by the NRC. NEVER-SEEZ® is a superior, high temperature, anti-seize and extreme pressure lubricant that contains flake particles of pure nickel, graphite and other additives in a special grease carrier. It is used on the trunnion surfaces of the NAC casks. Neolube® is 99% pure furnace graphite particles in isopropanol. It has excellent radiation resistance and high chemical purity. It dries as a thin, non-corrosive film with excellent adhesion, does not migrate, and is non-freezable. Dow Corning High Vacuum Grease is a stiff, nonmelting, nonoxidizing, non gumming silicone lubricating material that is insoluble in most solutions. There are no potential reactions associated with these lubricants or grease.

2.4.4.2.8 Seals

The NAC-STC utilizes seals formed from silicone rubber, blended polytetrafluroethylene (PTFE), and Viton. Viton is a silicon elastomer. Elastomer o-rings are used for transport cask applications because of their excellent short-term sealing capabilities, ease of handling, and more economical cost. All of the seal and gasket materials have stable, non-reactive compositions. There are no potential reactions associated with the NAC-STC seal materials.

2.4.4.3 General Effects of Identified Reactions

No significant potential galvanic or other reactions have been identified for the NAC-STC. The only potential chemical reaction identified for the NAC-STC is that of aluminum with the spent fuel pool water. As discussed in Section 2.4.4.2.2, it is possible at higher temperatures (above 150-160°F) that a flammable concentration of hydrogen might be generated by the

aluminum/water reaction and accumulate beneath the canister shield lid during the canister closure operations. The danger of potential ignition of the hydrogen is precluded by the operating controls and procedures presented in Chapter 7. Therefore, no adverse conditions can result during any phase of cask operations for normal, off-normal, or accident conditions.

2.4.4.4 Adequacy of the Cask Operating Procedures

Based on the results of this evaluation which resulted in only one identified reaction, aluminum in pool water, it is concluded that the NAC-STC operating controls and procedures presented in Chapter 7 are adequate to minimize the occurrence of hazardous conditions.

2.4.4.5 Effects of Reaction Products

No significant potential chemical, galvanic, or other reactions have been identified for the NAC-STC. Therefore, the overall integrity of the cask and the structural integrity and retrievability of the spent fuel is not adversely affected for any cask operations throughout the design basis life of the cask. Based on the evaluation, there will be no change in the cask or fuel cladding thermal properties, and there will be no binding of mechanical surfaces, no change in basket clearances, and no degradation of any safety components either directly or indirectly, since there are no significant reactions identified.

Table 2.4-1 Summary of NAC-STC Materials Categories and Operating Environments

ITEM	MATERIAL	ENVIRONMENT
Stainless Steels/Alloys	304, 304L, XM-19, 17-4PH, Ni Alloy, 410	Sealed Internal Open Internal/ External
Nonferrous Metals	ASTM B152 Cu, 6061-T651 Aluminum Alloy	Sealed Internal Open Internal/External
Shielding Materials	NS-4-FR, Chemical Copper Lead	Enclosed
Criticality Control Materials	Boroncarbide Aluminum 1100	Enclosed
Energy Absorbing Materials	Balsa Wood, Redwood	Enclosed
Cellular Foam/Insulation	Silicone (HT-810 & 800), Silicone Caulk (Dow Corning)	Enclosed
Lubricants & Greases	Never-Seeze® Neolube® High Vacuum Grease® by Dow Corning	Sealed Internal Open Internal
Seals & Gaskets	Silicone Rubber, PTFE, Viton	Sealed Internal Open Internal/ External

2.4.5 Cask Design

The NAC-STC is designed to meet the applicable sections of 10 CFR 71. Criticality, shielding, thermal, radiological and structural requirements of 10 CFR 71 are analytically shown to be satisfied. Conclusions drawn from the structural analyses are supported by quarter-scale model drop tests. The NAC-STC is an exclusive use package designed for transport in a 100°F environment such that personnel barrier temperatures do not exceed 180°F; thus, meeting the requirements of 10 CFR 71.43(g).

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2.4.6 Continuous Venting

The neutron shield is the only vented component of the NAC-STC. It contains a solid synthetic polymer (NS-4-FR), which has been shown by manufacturers' testing to give off small amounts of water vapor at the temperatures that occur during the thermal (fire) accident. To prevent a pressure build up in the neutron shield (under hypothetical fire accident conditions), two relief valves are provided in the bottom end plate. These relief valves are provided to minimize recovery from an over pressure condition. The relief valves do not provide a safety function. No venting of the neutron shield occurs during normal operations conditions; thus, the requirements of 10 CFR 71.43(h) are met.

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2.5 Lifting and Tiedown Standards

2.5.1 Lifting Devices

The NAC-STC has three types of lifting devices: (1) four lifting trunnions; (2) outer lid hoist-eyes; and (3) inner lid hoist-eyes. These lifting devices are designed to satisfy the requirements of 10 CFR 71.45(a). These lifting devices are also designed to meet the requirements of NUREG-0612, "Control of Heavy Loads at Nuclear Power Plants." NUREG-0612 defines specific design criteria to ensure the safe handling of heavy loads in critical regions of nuclear power plants. The design criteria in NUREG-0612 equals, or exceeds, that of 10 CFR 71.

The NAC-STC is equipped with four lifting trunnions located on the top forging near the top of the cask, and spaced at 90-degree intervals. A single two-arm yoke (nonredundant), or a combination of two yokes (redundant) may be used to lift and handle the cask. Each lifting yoke is attached to two diametrically opposite lifting trunnions. An overhead crane lifts the cask by these yokes. No transport impact limiter is attached to the cask during lifting and handling. The lower impact limiter could be attached for protection during handling, but the upper impact limiter cannot be used while the lifting yoke is in place. The inner and outer lid hoist-eyes are used for lifting the lids during installation or removal. The cask is rotated from the horizontal to the vertical position and vice-versa on the two rotation trunnion recesses. The rotation trunnion recesses also support the cask in the rear cask support during transport.

2.5.1.1 Lifting Trunnion Analysis

The NAC-STC has four lifting trunnions spaced at 90-degree intervals and located on the top forging near the top of the cask, which allow either a nonredundant, two-arm yoke or a redundant, four-arm yoke to lift and handle the cask. The NAC-STC lifting trunnions are designed to meet the requirements of NUREG-0612 for a nonredundant lifting system; that is, a two-trunnion lift. A redundant four-trunnion lift is less critical. Two lifting trunnions are capable of supporting a maximum load, which is defined as six times the design loaded lift weight of the cask without producing stresses anywhere in the cask in excess of the material yield strength. Any dynamic load effects are negligible when considered in combination with the large applied load factors. Additionally, the lifting trunnions are designed so that failure will not impair the ability of the cask to meet its other safety requirements.

The weight of the NAC-STC is conservatively assumed to be 260,000 pounds for the lifting analysis. The loads on each lifting trunnion for a nonredundant lift are as follows:

$$F_y = \text{yield stress limit} = \frac{260{,}000 \times 6}{2} = 780{,}000 \text{ lb}$$

$$F_u = \text{ultimate stress limit} = \frac{260{,}000 \times 10}{2} = 1{,}300{,}000 \text{ lb}$$

The properties of the materials used in the lifting trunnion analysis are as follows at the conservatively high temperature of 250°F:

1. Trunnions — SA-705, Type 630
   $S_y = 95.0$ ksi
   $S_u = 135.0$ ksi

2. Top Forging — SA-336, Type 304
   $S_y = 23.75$ ksi
   $S_u = 63.8$ ksi

3. Filler Material — AWS E309
   $S_y = 30$ ksi
   $S_u = 80$ ksi

2.5.1.1.1 Lifting Trunnion Shank

The diameter of the lifting trunnion shank is 5.5 inches. Figure 2.5.1-1 shows the lifting trunnion geometry. The shear and bending stresses at the base of the shank (through Point E in Figure 2.5.1-1) are calculated as:

(Yield Strength Criteria)

Shear Stress:

$$S_{sy} = \frac{F_y}{A}$$

$$= 32{,}828 \text{ psi}$$

where:

$F_y = 780{,}000$ lb

$A = (\pi)(2.75)^2$
$= 23.76 \text{ in}^2$

Bending Stress: $S_{by} = \dfrac{M_y}{S}$

$= 39{,}804$ psi*

where:

$M_y = (780{,}000)(2.5/3)$

$= 650{,}000$ in-lb

Section Modulus: $S = \dfrac{\pi R^3}{4} \text{ in}^3$

$= 16.33 \text{ in}^3$

where:

$R = 2.75$ in

The combined stress is calculated as:

$$S_{ey} = \left((S_{by})^2 + 3(S_{sy})^2\right)^{0.5}$$

$= 69{,}407$ psi*

The margin of safety is:

$$(MS)_y = \frac{95.0}{69.4} - 1 = +0.37^*$$

(Ultimate Strength Criteria)

* Note: Bending stress does not fully develop on the cylindrical cross-section because the location of the applied load is less than one diameter away from the section being analyzed. The load is assumed to be developed as a triangular distribution. The maximum pressure occurs at the base of the trunnion. This analysis is considered to be very conservative.

Shear Stress: $S_{su} = \frac{F_u}{A}$

$= 54{,}714$ psi

where:

$A = (\pi)(2.75)^2$
$= 23.76 \text{ in}^2$
$F_u = 1{,}300{,}000$ lb

Bending Stress: $S_{bu} = \frac{M_u}{S}$

$= 66{,}349$ psi*

where:

$M_u = (1{,}300{,}000)(1.25)$

$= 1{,}083{,}333$ in-lb

$S = 16.33 \text{ in}^3$

The combined stress is calculated as:

$$S_{eu} = \left((S_{bu})^2 + 3(S_{su})^2\right)^{0.5}$$

$= 115{,}680$ psi

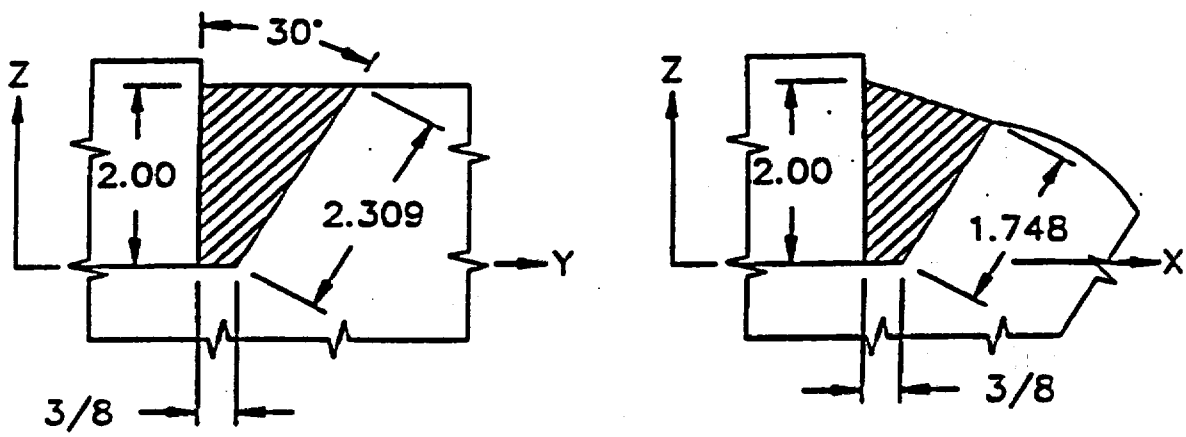
The margin of safety is:

$$(MS)_u = \frac{135.0}{115.7} - 1 = +0.17^*$$

* Note: Bending stress does not fully develop on the cylindrical cross-section because the location of the applied load is less than one diameter away from the section being analyzed. The load is assumed to be developed as a triangular distribution. The maximum pressure occurs at the base of the trunnion. This analysis is considered to be very conservative.

2.5.1.1.2 Trunnion Base Weld

The lifting trunnions are welded to the top forging of the cask body, as shown in Figures 2.5.1-1 and 2.5.1-2. The weld geometries at points A and B (Figure 2.5.1-1 and Figure 2.5.1-2, respectively) are shown below. Two postulated failures in the analysis of the welded connection are: (1) at the trunnion/weld interface; and (2) at the weld/forging interface. They are evaluated in Section 2.5.1.1.2.1 and Section 2.5.1.1.2.2, respectively. The sections through the trunnion weld are:



Point A (Dimensions in inches) Point B

2.5.1.1.2.1 Trunnion/Weld Interface

The depth of the weld at the trunnion/weld interface is 2.0 inches, as shown in the weld geometries above. The weld analyses using the yield stress and ultimate yield criteria are as follows:

(Yield Criteria Analyses)

The force and moment on the weld due to the yield design load, F_y, are:

$$F_{wy} = F_y$$

$$= 780{,}000 \text{ lb}$$

$$M_{wy} = F_y\left(\frac{2.50}{3} + 2.50 - \frac{2.00}{2}\right)$$

$= 1{,}820{,}000$ in-lb

The stresses in the weld at points A or C are calculated as:

$$S_y = \frac{780{,}000}{(\pi)(10.00)(2.0)}$$

$= 12{,}414$ psi (compression or tension)

$$S_z = \frac{1{,}820{,}500}{(\pi)(5.0)^2(2.0)}$$

$= 11{,}586$ psi (shear)

The Von Mises stress is:

$$S_{max} = \left((S_y)^2 + 3(S_z)^2\right)^{0.5}$$

$= 23{,}597$ psi

Conservatively taking the weld as the critical component, the margin of safety is:

$$(MS)_y = \frac{30.0}{23.6} - 1 = +0.27 \quad \text{(Point A or C)}$$

The stresses in the weld at points B or D are calculated as:

$$S_y = \frac{780{,}000}{(\pi)(10.00)(2.0)}$$

$= 12{,}414$ psi

Taking the weld as the critical component, the yield shear strength is 0.6(30) = 18 ksi. The margin of safety is:

$$(MS)_y = \frac{18}{12.4} - 1 = \underline{+0.45} \quad \text{(Point B or D)}$$

(Ultimate Criteria Analyses)

The force and moment on the weld due to the ultimate design load, F_u, are:

$$F_{wu} = F_u = 1{,}300{,}000 \text{ lb}$$

$$M_{wy} = F_u\left(\frac{2.50}{3} + 2.50 - \frac{2.00}{2}\right)$$

$$= 3{,}033{,}333 \text{ in-lb}$$

The stresses in the weld at points A or C are:

$$S_y = \frac{1{,}300{,}000}{\pi(10.00)(2.0)}$$

$$= 20{,}690 \text{ psi (compression or tension)}$$

$$S_z = \frac{3{,}033{,}333}{\pi(5.0)^2\,(2.0)}$$

$$= 19{,}311 \text{ psi (shear)}$$

The Von Mises stress is:

$$S_{max} = \left((S_y)^2 + 3(S_z)^2\right)^{0.5}$$

$$= 39{,}330 \text{ psi}$$

Conservatively taking the weld as the critical component, the margin of safety is:

$$(MS)_u = \frac{80.0}{39.3} - 1 = +1.03 \quad \text{(Points A or C)}$$

The stresses at points B or D are calculated as:

$$S_y = \frac{1{,}300{,}000}{(\pi)(10.00)(2.0)}$$

= 20,690 psi

Taking the weld as the critical component and taking the ultimate shear strength as 0.42(80) = 33.6 ksi, the margin of safety is:

$$(MS)_u = \frac{33.6}{20.7} - 1 = +0.62 \quad \text{(Points B or D)}$$

2.5.1.1.2.2 Weld/Forging Interface

The weld/forging interface consists of the 3/8-inch root around the trunnion and surface on the 60-degree truncated cone. The weld/forging interface varies from a maximum at point A to a minimum at point B (see weld sections shown in Section 2.5.1.1.2). It is conservatively assumed that the minimum weld section at point B exists uniformly around the trunnion. In order to simplify the weld-to-forging analysis another conservative assumption is used, taking the critical section as the surface of the cylinder concentric with the trunnion and its surface passing through the intersection of the weld/forging interface and the cask surface (see the weld section at point B shown in Section 2.5.1.1.2). The weld/forging interface at the root of the weld is also neglected.

The radius of the assumed critical section of the weld/forging interface is 5 + 0.375 + (1.748)(sin 30°) = 6.249 inches, and the height is (1.748) (cos 30°) = 1.514 inches.

(Yield Strength Criteria)

The stresses between the weld and the forging at points A and C are calculated as:

$$S_y = \frac{780{,}000}{(2)(\pi)(6.249)(1.514)}$$

= 13,121 psi

$$S_z = \frac{1{,}820{,}000}{(\pi)(6.249)^2(1.514)}$$

= 9,799 psi

The Von Mises stress is:

$$S_{max} = \left((S_y)^2 + 3(S_z)^2\right)^{0.5}$$

$$= 21{,}453 \text{ psi}$$

The yield strength of the forging of 23.75 ksi at a conservatively high temperature of 250°F governs. The margin of safety is calculated as:

$$(MS)_y = \frac{23.75}{21.5} - 1 = +0.10$$

(Ultimate Strength Criteria)

The stresses between the weld and the forging at points A and C are calculated as:

$$S_y = \frac{1{,}300{,}000}{(2)(\pi)(6.240)(1.514)}$$

$$= 21{,}900 \text{ psi}$$

$$S_z = \frac{3{,}033{,}333}{(\pi)(6.249)^2(1.514)}$$

$$= 16{,}331 \text{ psi}$$

The Von Mises stress is:

$$S_{max} = \left((S_y)^2 + 3(S_z)^2\right)^{0.5}$$

$$= 35{,}773 \text{ psi}$$

The margin of safety for the forging is:

$$(MS)_u = \frac{63.8}{35.8} - 1 = +0.78$$

2.5.1.1.3 Trunnion Base

The trunnion base plate is analyzed as a flat circular plate with a fixed outer edge and a trunnion fixed at its center using the equations provided in Young, page 435, Case 21b. The trunnion moment at the midpoint of the embedded thickness of the trunnion base plate for the design lifting load is:

$$M_{tbp} = 2.75\ F_{DL}$$

(Yield Strength Criteria)

The trunnion moment for the Yield Strength Criteria evaluation is:

$$(M_{tbp})_y = 2.75\ F_y$$
$$= 2.145 \times 10^6 \text{ in-lb}$$

where:

$$F_y = 780{,}000 \text{ lb}$$

The maximum bending stress in the trunnion base plate is:

$$S_r = \frac{\beta (M_{tbp})_y}{at^2}$$
$$= 65{,}036 \text{ psi}$$

where:

$a = 5.00$ in
$b = 2.75$ in
$b/a = 0.55$
$\beta = 0.9475$
$t = 2.50$ in

Then, the margin of safety is:

$$(M.S.)_y = \frac{S_y}{S_r} - 1 = +0.46$$

where:

S_y = 95.0 ksi at 250°F

(Ultimate Strength Criteria)

The trunnion moment for the Ultimate Strength Criteria evaluation is:

$$(M_{tbp})_u = 2.75\ F_u$$
$$= 3.575 \times 10^6 \text{ in-lb}$$

where:

F_u = 1,300,000 lb

The maximum bending stress in the trunnion base plate is:

$$S_r = \frac{\beta (M_{tbp})_y}{at^2}$$
$$= 108{,}394 \text{ psi}$$

where:

a = 5.00 in
b = 2.75 in
b/a = 0.55
β = 0.9475
t = 2.50 in

Then, the margin of safety is:

$$(M.S.)_u = \frac{S_u}{S_r} - 1 = +0.25$$

where:

S_u = 135.0 ksi at 250°F

Therefore, the trunnion base plate is structurally adequate for the trunnion design loading conditions.

2.5.1.1.4 Overload in the Lifting Trunnions

According to 10 CFR 71.45(a), any lifting attachment that is a structural part of a cask must be designed so that failure of any lifting device under excessive load would not impair the ability of the cask to meet other requirements of 10 CFR 71. The ultimate shear capacities of the different parts of the lifting trunnion are calculated and compared. To show that the cask will meet the other requirements of 10 CFR 71, the failure should not occur in the shell of the cask before failure of the other parts.

2.5.1.1.4.1 Shank Failure

Lifting trunnion shank (Ultimate Shear Strength):

$$F_{tr} = (\pi)(d^2/4)(0.42S_u)$$
$$= 1{,}347{,}095 \text{ lb}$$

where:

$d = 5.5$ in

$S_u = 135{,}000$ psi

2.5.1.1.4.2 Weld/Trunnion Interface Failure

The ultimate shear strength of the weld/trunnion interface is governed by the shear strength of the weld and is calculated as:

$$F_u = (\pi)(10.00)(2.0)(0.42S_u)$$
$$= 2{,}111{,}150 \text{ lb}$$

where:

S_u = ultimate tensile strength of the weld
= 80,000 psi

2.5.1.1.4.3 Weld/Forging Interface Failure

The width of the weld/forging interface is taken as the mean of the interface widths at points A and B; that is, (2.309 + 1.748)/2 = 2.028 inches. The mean radii to the center of the interfaces at points A and B are calculated as:

$$R_A = 5.0 + 0.375 + (0.5)(2.0 \tan 30°)$$
$$= 5.95$$
$$R_B = 5.0 + 0.375 + (0.5)(1.748 \sin 30°)$$
$$= 5.812$$

$$R_{ave} = 5.881 \text{ inches}$$

The ultimate shear strength of the weld/forging interface is:

$$F_u = (A_w)(0.42S_u)$$
$$= 2{,}335{,}539 \text{ lb}$$

where:

S_u = ultimate strength of the forging
= 63,800 psi

$$A_w = (2\pi)(5.881)(2.028) + (\pi)(5.375^2 - 5.0^2)$$
$$= 87.16 \text{ in}^2$$

The maximum ultimate shear capacities are:

	Capacity
Lifting Trunnion Shaft	1,347,095 lb
Weld/trunnion interface	2,111,150 lb
Weld/forging interface	2,335,539 lb

Thus, the lifting trunnion shank will fail in shear before the weld or the forging, ensuring that failure caused by excessive overload on the lifting trunnions will not impair the ability of the cask to meet the other requirements of 10 CFR 71.

2.5.1.2 Lid Lifting Device

The inner lid and the outer lid of the NAC-STC will each be lifted using a wire-rope sling that is load-rated for not less than the weight of each individual lid. The sling will be attached to each of the lids using hoist-eyes that are threaded into four equidistant holes on the lids. These holes will be clearly marked by engraved black painted letters on the top surface of each lid. The four slings will attach to a strongback at two points, centered 22.5 inches apart, two slings at each point.

2.5.1.2.1 Outer Lid Lifting

The outer lid lifting system uses four 1-8 UNC threaded holes located on a 76.00 inch bolt circle. The four holes are equally spaced. Helical thread inserts are used to increase the wear endurance. The outer lid material is SA-705, Type 630, H1150, 17-4 PH stainless steel.

The outer lid weight (W_o) is 8,120 pounds, as documented in Table 2.2-1.

From the requirements of 10 CFR 71.45(a), a load factor of 3 is used in the stress qualification of a lifting device:

$$P_y = (3.0)(W_o)$$
$$= 24{,}360 \text{ lb}$$

The inclined angle (θ) of the sling for an outer lid lifting condition is illustrated in Figure 2.5.1-3. The sling length is 68.0 inches. The vertical distance from the hoist eye to the strongback is 60.48 inches, for the outer lid.

$$\sin\theta = 60.48/68.00$$
$$\theta = 62.80 \text{ degrees}$$

The lifting force F_n, and its components F_x and F_y, on each sling, are calculated as:

$$F_y = P_y/4 = 6{,}090 \text{ lb}$$
$$F_n = F_y/\sin\theta = 6{,}847 \text{ lb}$$
$$F_x = (F_n)(\cos\theta) = 3{,}130 \text{ lb}$$

Hoist Eye Stress Evaluation

Hoist Eye Specifications – American Drill Bushing Company, Part 23106 or equivalent)

Thread: 1-8 UNC-2A x 1.54 long
Material: SA-540, Grade B22 Low Alloy Steel
$S_y = 3\ S_m = 100.2$ ksi at 200°F
$A_t = 0.606\ in^2$
$I = 0.0252\ in^4$
$C = 0.4233$ in

The tensile and bending stresses on the critical section of the hoist eye are determined:

d = moments are = 0.74 inch
$M_z = (F_x)(d) = 2{,}727$ inch-lb
$S_a = F_y/A_t + (M_z)(c)/I = 59{,}035$ psi

The shear stress is:

$S_s = F_x/A_t = 6{,}081$ psi

The principal stresses are:

$s_1, s_2 = S_a/2 \pm [(S_a/2)^2 + S_s^2]^{0.5}$
$= +59{,}655$ and -620 psi

The stress intensity is:

S.I. = 60,275 psi

The resulting margin of safety is:

$MS = (S_y/S.I.) - 1 = +0.66$

Hoist Eye Thread Engagement Evaluation

The hoist eyes used for the outer and inner lids are identical, therefore the evaluation of the inner lid hoist eye length of thread engagement follows the same approach presented earlier for the outer lid hoist eye.

P_y = 32,070 lb
F_y = $P_y/4$ = 8017.5 lb
t = F_y/A_s = 3873 psi, where A_s = 2.07 in^2 as calculated in Section 2.5.1.2.1

MS = (0.577 S_y/t) - 1 = + Large

Inner Lid Thread Engagement Evaluation

The inner lid material is SA-336, Type 304 stainless steel. Allowable shear stress = 0.577 S_y = 14.43 ksi at 200°F (Table 2.3.2-2). The evaluation of the inner lid thread engagement follows the same approach presented earlier for the outer lid, since both inner and outer lids have 1 1/8 - 8 UNC internal threads for use with a 1-8 UNC helical coil insert. Therefore, the resultant shear stress and margin of safety for the inner lid is:

t = $F_y/(A_s)$(Length) = 8017.5/(2.67)(1.25) = 2396 psi

MS = (0.577 S_y/t) - 1 = (14,425/2396) - 1 = + Large

2.5.1.3 Canister Lifting

This section presents the canister lift evaluation for the Yankee-MPC (Section 2.5.1.3.1) and the CY-MPC (Section 2.5.1.3.2).

2.5.1.3.1 Yankee-MPC Canister Lifting

The adequacy of the canister lifting devices is demonstrated by considering each of the hoist rings, the canister structural lid, and the weld that joins the structural lid to the canister shell. Lifting of the canister employs redundant 3-legged lifting slings for single failure proof lifting in accordance with NUREG-0612.

When considering a three-point lifting configuration, the load-bearing members of the canister maintain a factor of safety greater than three based on material yield strength. Additionally, the

load-bearing members of the canister maintain a factor of safety greater than five based on material ultimate strength. The hoist rings are designed with a 5 to 1 safety factor based on ultimate. Therefore, the lifting requirements are satisfied. Each lifting device in a three-point lift would experience the following load, F, when lifting the canister (the total load is based on the dead weight of the loaded canister with a dynamic load factor of 10%):

$$F = \frac{54{,}730 \times 1.1}{3} = 20{,}068 \text{ lb}$$

The hoist rings used to lift the canister have a rated load capacity of 24,000 pounds with a 5 to 1 safety factor based on material ultimate strength (American Drill Bushing Co.). The length of the hoist ring bolt is 2.50 inches. The following calculation (using formula from Machinery's Handbook) demonstrates that a thread engagement length of at least 2.20 inches is required.

Definition of Terms

D = basic major diameter of bolt threads = 1.5 inches
n = number of threads per inch = 6
A_t = tensile area of the bolt thread (in^2)
L_e = minimum thread engagement length for mating materials with equal tensile strengths (in.)
$K_n max$ = maximum minor diameter of lid (internal) thread = 1.35 inches
$E_s min$ = minimum pitch diameter of bolt (external) threads = 1.3812 inches
A_s = shear area of bolt threads (in^2)
A_n = shear area of lid threads (in^2)
$D_s min$ = minimum major diameter of bolt (external) threads = 1.4794 inches
$E_n max$ = maximum pitch diameter of lid (internal) threads = 1.402 inches
Q = length of thread engagement required to prevent shearing when the mating thread materials are different tensile strengths (in.)
J = scale factor for calculation of Q
H = height of sharp "V" thread = 0.1443 inches

Hoist ring material	= 4140 High strength alloy steel
Tensile strength of 4140	= 180,000 psi
Hoist ring thread	= 1-1/2 - 6 UNC
Structural lid material	= Type 304 L stainless steel
Temperature of structural lid	= 250°F (Maximum calculated temperature = 209°F, Table 3.4-1)
Tapped hole in structural lid	= 1-1/2 - 6 UNC

For steels up to 100,000 psi tensile strength, the tensile area of the bolt thread is given by:

$$A_t = \pi\left(\frac{Esmin}{2} - \frac{3H}{16}\right)^2$$

$$A_t = 1.3835 \text{ in}^2$$

For mating materials having equal tensile strengths, the minimum length of thread engagement is given by:

$$L_e = \frac{2A_t}{3.1416K_n max\left[\frac{1}{2} + 0.57735n\left(E_s min - K_n max\right)\right]}$$

$$L_e = 1.073 \text{ inches}$$

For mating materials of differing tensile strengths:

$$J = \frac{A_s \text{ x tensile strength of bolt thread material}}{A_n \text{ x tensile strength of lid thread material}}$$

The shear areas are calculated as follows:

$$A_s = 3.1416nL_eK_n max\left[\frac{1}{2n} + 0.57735\left(E_s min - K_n max\right)\right]$$

$$A_s = 2.769 \text{ in}^2$$

$$A_n = 3.1416 n L_e D_s min\left[\frac{1}{2n} + 0.57735\left(D_s min - E_n max\right)\right]$$

$$A_n = 3.830 \text{ in}^2$$

At a temperature of 250°F, the ultimate strength of Type 304L stainless steel is 63,550 psi.

$$J = \frac{A_s x\left(S_u\right)_{bolt}}{A_n x\left(S_u\right)_{lid}}$$

$$= 2.048$$

The length of thread engagement necessary to prevent shearing is:

$$Q = JL_e$$

$$Q = (2.048)(1.073) = 2.20 \text{ in.} < 2.50 \text{ in.}$$

Therefore, the required length of thread engagement is 2.20 inches, which is less than the hoist ring thread length of 2.5 inches.

The structural adequacy of the canister structural lid and weld was evaluated using a finite element representation of the upper portion of the canister using the ANSYS program. As shown in Figure 2.5.1-5, the model represents one-half (180° section) of the upper 50-inches of the canister (including the structural and shield lids). The lids and shell in the model are comprised of SOLID45 elements. CONTAC52 elements are used to model the interaction between the structural lid and the canister shell and between the shield lid and the canister shell, just below the respective lid weld joints. The size of the CONTAC52 gaps was determined from nominal dimensions of contacting components. COMBIN40 elements are used between the structural and shield lids in the axial direction and between the shield lid and the backing ring. These gaps are assigned small gap sizes of 1E-8 inches. All gap/spring elements are assigned a stiffness of 1E8 lb/inch.

To enforce symmetry at the boundary of the model (in the x-y plane), all nodes on the x-y symmetry plane were restrained perpendicular to the symmetry plane (UZ). In addition, the nodes in the x-z plane at the bottom of the model were restrained in the axial direction.

Load-bearing members of a lifting device must be capable of lifting three (3) times the combined weight of the shipping container with which it will be used, plus the weight of intervening components of the lifting device without exceeding the tensile yield strength of their materials of construction. In addition, the lifting components must be capable of lifting five (5) times that combined weight without exceeding the ultimate tensile strength of the materials. NUREG-0612 also requires that the lifting loads must be based on the combined maximum static and dynamic loads that could be imparted on the handling device based on characteristics of the crane that will be used. A dynamic load factor of 10% has been applied.

To simulate the lifting of the canister by a three-point lifting device (the lifting configuration is actually two independent 3-point lifting devices), point loads equal to one-third of the total canister and contents weight plus a dynamic loading factor of 10% were applied to the model.

Because the model represents a half section of the canister, only two point loads were applied 120° apart as shown in Figure 2.5.1-5. Because of the symmetry conditions of the model, the force applied to the node on the symmetry plane was one-half of the value applied at the other location.

The maximum stress intensity generated in the canister model from the applied lifting forces was 3,753 psi, which occurs in the structural lid where the lifting loads were applied (see Figure 2.5.1-6).

As stated previously, the maximum stress intensity in the canister lifting model occurs in the structural lid that is constructed of Type 304L stainless steel. The yield strength (S_y) of Type 304L stainless steel at 250°F is 20,300 psi. The ultimate strength (S_u) of Type 304L stainless steel at 250°F is 63,550 psi.

The factor of safety (FS) for the canister lift based on yield strength is:

$$FS = \frac{S_y}{S_{INT}} = \frac{20{,}300 \text{ psi}}{3{,}753 \text{ psi}} = 5.40 > 3$$

The factor of safety for the canister lift based on ultimate strength is:

$$FS = \frac{S_u}{S_{INT}} = \frac{63{,}550 \text{ psi}}{3{,}753 \text{ psi}} = 16.93 > 5$$

2.5.1.3.2 CY-MPC Canister Lifting

The adequacy of the CY-MPC canister lifting devices is demonstrated using the same methodology as is used for the Yankee-MPC analysis. Lifting of the canister employs redundant three-legged lifting slings for single failure proof lifting in accordance with NUREG-0612.

When considering a three-point lifting configuration, the load-bearing members of the canister maintain a factor of safety greater than three based on material yield strength. Additionally, the load-bearing members of the canister maintain a factor of safety greater than five based on material ultimate strength. The hoist rings are designed with a 5 to 1 safety factor based on material ultimate strength. Therefore, the lifting requirements are satisfied.

Each lifting device in a three-point lift would experience the following load, F, when lifting the canister (the total load is based on the dead weight of the loaded canister with a dynamic load factor of 10%):

$$F = \frac{66{,}000 \text{ lb} \times 1.1}{3} = 24{,}200 \text{ lb}$$

The hoist rings used to lift the canister have a rated load capacity of 30,000 pounds with a 5 to 1 safety factor based on material ultimate strength. The length of the hoist ring bolt is 2.0 inches. The following calculation (using a formula from Machinery's Handbook) demonstrates that a thread engagement length of 2.0 inches is satisfactory.

Definition of Terms

D	=	basic major diameter of bolt threads = 2.0 inches
n	=	number of threads per inch = 4 1/2
A_t	=	tensile area of the bolt thread (in^2) = 2.5 in^2
L_e	=	minimum thread engagement length for mating materials with equal tensile strengths (in.)
$K_n$max	=	maximum minor diameter of lid (internal) thread = 1.795 inches
$E_s$min	=	minimum pitch diameter of bolt (external) threads = 1.8433 inches

A_s	=	shear area of bolt threads (in^2)
A_n	=	shear area of lid threads (in^2)
$D_s min$	=	minimum major diameter of bolt (external) threads = 1.9751 inches
$E_n max$	=	maximum pitch diameter of lid (internal) threads = 1.8681 inches
Q	=	length of thread engagement required to prevent shearing when the mating thread materials are different tensile strengths (in.)
J	=	scale factor for calculation of Q

Hoist ring material	= 4140 High strength alloy steel
Tensile strength of 4140	= 180,000 psi
Hoist ring thread	= 2 - 4 1/2 UNC
Structural lid material	= Type 304 L stainless steel
Temperature of structural lid	= 250°F
Tapped hole in structural lid	= 2 - 4 1/2 UNC

For mating materials having equal tensile strengths, the minimum length of thread engagement is given by:

$$L_e = \frac{2A_t}{3.1416 K_n \max\left[\frac{1}{2} + 0.57735 n\left(E_s \min - K_n \max\right)\right]}$$

$L_e = 0.554$ inches

For mating materials of differing tensile strengths:

$$J = \frac{A_s \text{ x tensile strength of bolt thread material}}{A_n \text{ x tensile strength of lid thread material}}$$

The shear areas are calculated as follows:

$$A_s = 3.1416 n L_e K_n \max\left[\frac{1}{2n} + 0.57735\left(E_s \min - K_n \max\right)\right]$$

$A_s = 1.954\ in^2$

$$A_n = 3.1416 n L_e D_s \min\left[\frac{1}{2n} + 0.57735\left(D_s \min - E_n \max\right)\right]$$

$A_n = 2.674\ in^2$

At a temperature of 250°F, the ultimate strength of Type 304L stainless steel is 63,550 psi.

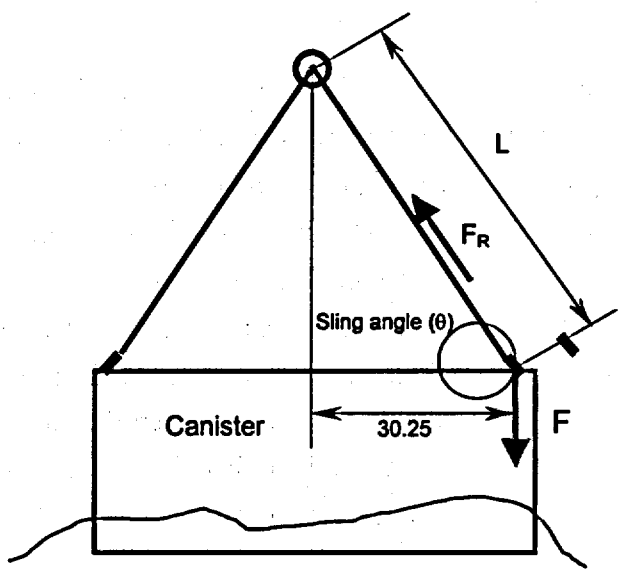
$$J = \frac{A_s x (S_u)_{bolt}}{A_n x (S_u)_{lid}} = 1.461$$

The length of thread engagement necessary to prevent shearing is:

$$Q = JL_e$$
$$Q = (1.461)(0.554) = 0.81 \text{ in.} < 2.0 \text{ in.}$$

Therefore, the required length of thread engagement is 0.81 inches, which is less than the hoist ring thread length of 2.0 inches.

The hoist rings are rated at 30,000 lbs with a safety factor of 5.



The relation between the tension in the sling and thus the load on the swivel hoist ring (F_R) is:

$$F_R = \frac{F}{\sin\theta}$$

Where

F_R = the load on the swivel hoist ring
F = the handling load on the hoist ring (66,000 lb × 1.1/3)

F_R is limited to 30,000 lb, the load rating (with a 5:1 safety factor) of the swivel hoist ring. The minimum sling angle (θ_{min}) is then determined as:

$$\theta_{min} = \sin^{-1}\frac{F}{F_R} = \sin^{-1}\frac{24{,}200}{30{,}000} = 53.8°$$

For a slight additional margin, the minimum sling angle is set at 60°, requiring a minimum sling length (L) of:

$$L = \frac{30.25}{\cos\theta} = 60.5 \text{ in}$$

Therefore, the minimum allowable distance from the master link of the sling to the top of the canister is $60.5 \sin 60° = 52.4$ inches.

The structural adequacy of the canister structural lid and weld is evaluated using a finite element representation of the upper portion of the canister using the ANSYS program. As shown in Figure 2.5.1-5, the model represents one-half (180° section) of the upper 50-in. of the canister (including the structural and shield lids). The lids and shell are modeled using SOLID45 elements. CONTAC52 elements are used to model the interaction between the structural lid and the canister shell and between the shield lid and the canister shell, just below the respective lid weld joints. The size of the CONTAC52 gaps is determined from nominal dimensions of contacting components. COMBIN40 elements are used between the structural and shield lids in the axial direction and between the shield lid and the backing ring. These gaps are assigned small gap sizes of 1E-8 inches. All gap/spring elements are assigned a stiffness of 1E8 lbs/in.

To enforce symmetry at the boundary of the model (in the x-y plane), all nodes on the x-y symmetry plane are restrained perpendicular to the symmetry plane (UZ). In addition, the nodes in the x-z plane at the bottom of the model are restrained in the axial direction.

Load-bearing members of a lifting device must be capable of lifting three (3) times the combined weight of the shipping container with which it will be used, plus the weight of intervening components of the lifting device without exceeding the tensile yield strength of their materials of construction. In addition, the lifting components must be capable of lifting five (5) times that

combined weight without exceeding the ultimate tensile strength of the materials. NUREG-0612 also requires that the lifting loads must be based on the combined maximum static and dynamic loads that could be imparted on the handling device based on characteristics of the crane that will be used. A dynamic load factor of 10% has been applied.

To simulate the lifting of the canister by a three-point lifting device (the lifting configuration is actually two independent three-point lifting devices), point loads equal to one-third of the total canister and contents weight plus a dynamic loading factor of 10% are applied to the model. Because the model represents a half section of the canister, only two point loads are applied 120° apart as shown in Figure 2.5.1-5. Because of the symmetry conditions of the model, the force applied to the node on the symmetry plane is one-half of the value applied at the other location. A temperature of 250°F is conservatively used to determine allowable stresses.

The maximum stress intensity generated in the canister model from the applied lifting forces is 4,482 psi, which occurs in the structural lid where the lifting loads are applied (Figure 2.5.1-7).

The maximum stress intensity in the canister lifting model occurs in the structural lid that is constructed of Type 304L stainless steel. The yield strength (S_y) of Type 304L stainless steel at 250°F is 20,300 psi. The ultimate strength (S_u) of Type 304L stainless steel at 250°F is 63,550 psi.

The factor of safety (FS) for the canister lift based on yield strength is:

$$FS = \frac{S_y}{S_{INT}} = \frac{20{,}300 \text{ psi}}{4{,}482 \text{ psi}} = 4.53 > 3$$

The factor of safety for the canister lift based on ultimate strength is:

$$FS = \frac{S_u}{S_{INT}} = \frac{63{,}550}{4{,}482} = 14.18 > 5$$

2.5.1.3.3 Shield Lid

The shield lid lifting system uses three 1 1/4 -7 UNC-2B threaded holes located on a 60.5 inch bolt circle. The three holes are equally spaced. The shield lid material is Type 304 stainless steel. The weight of the shield lid is 5,390 pounds.

The shield lid is lifted using a wire-rope sling that is load-rated for not less than the weight of the shield lid. The sling is attached to the lid using hoist-eyes that are threaded into the shield lid.

2.5.1.3.4 Structural Lid

The structural lid lifting system uses six 1 1/4 -7 UNC-2B threaded holes located on a 60.5 inch bolt circle. The six holes are equally spaced. The structural lid material is Type 304L stainless steel. The weight of the structural lid is 3,230 pounds.

The structural lid is lifted using a wire-rope sling that is load-rated for not less than the weight of the structural lid. The sling is attached to the lid using three equally spaced hoist-eyes that are threaded into the structural lid.

2.5.1.3.5 Empty Canister and Basket

The empty canister and basket lifting system uses eight hoist eyes threaded into holes located in the top nuts as part of the basket assembly. The holes are on a 62.5-inch bolt circle. The top nut material is Type 304 stainless steel. The weight of the empty canister and basket is 15,510 pounds.

The empty canister and basket are lifted using two wire-rope slings that are each load-rated for not less than the weight of the empty canister and basket assembly. The primary sling is attached to the basket using four equally spaced hoist-eyes that are threaded into the top nuts. The secondary (redundant) sling uses four equally spaced hoist eyes that are threaded into the remaining four top nuts.

Figure 2.5.1-1 Lifting Trunnion Geometry

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

Figure 2.5.1-2 Trunnion Weld Geometry

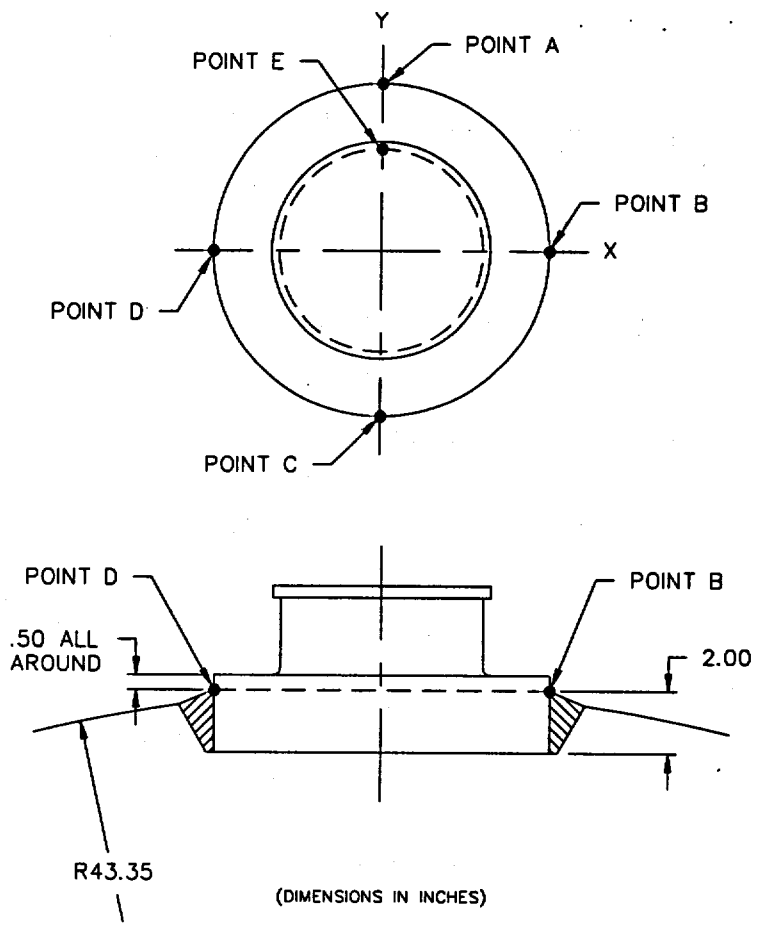


Figure 2.5.1-3 Sling Inclination Angle for Outer Lid Lifting

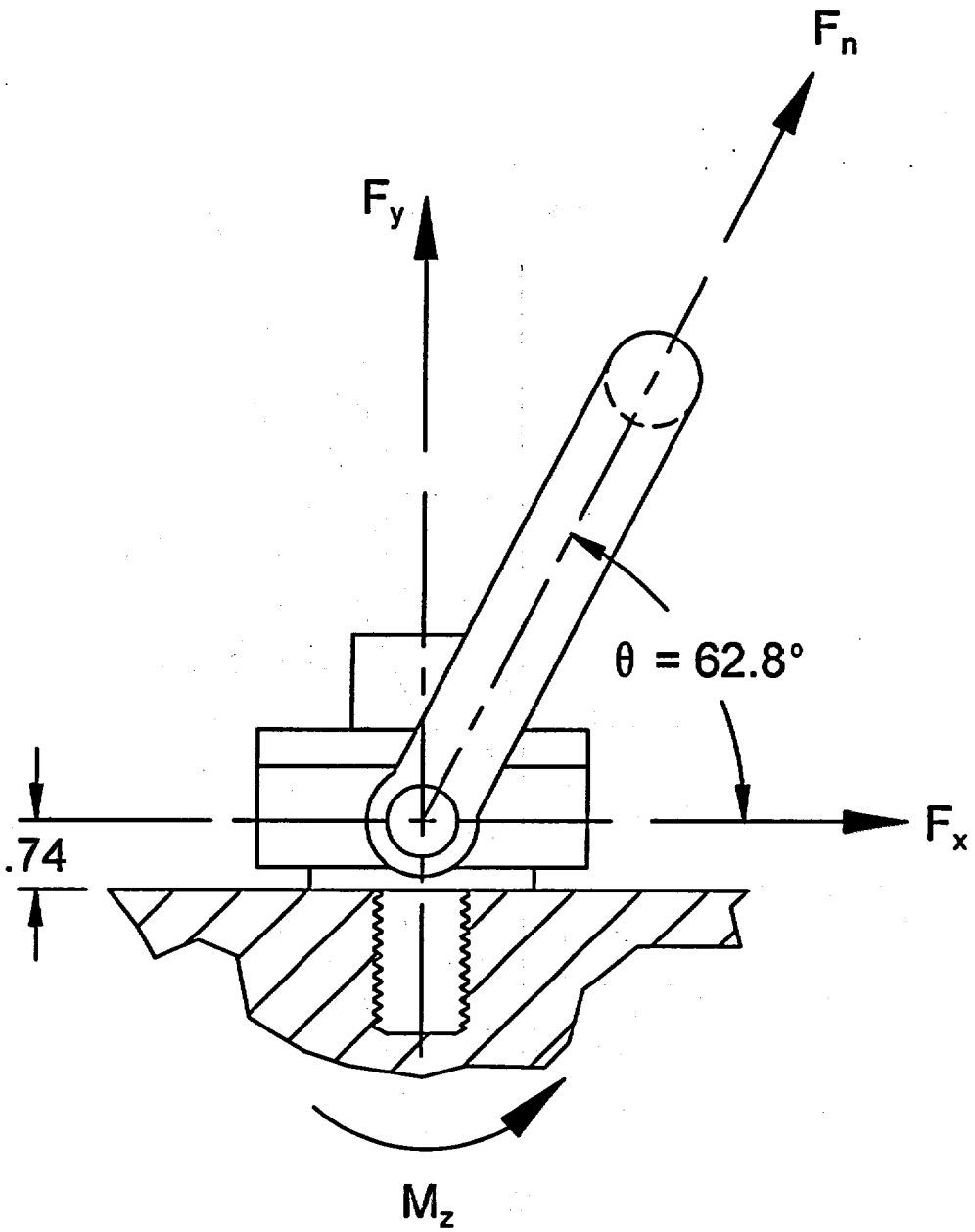


Figure 2.5.1-4 Sling Inclination Angle for Inner Lid Lifting

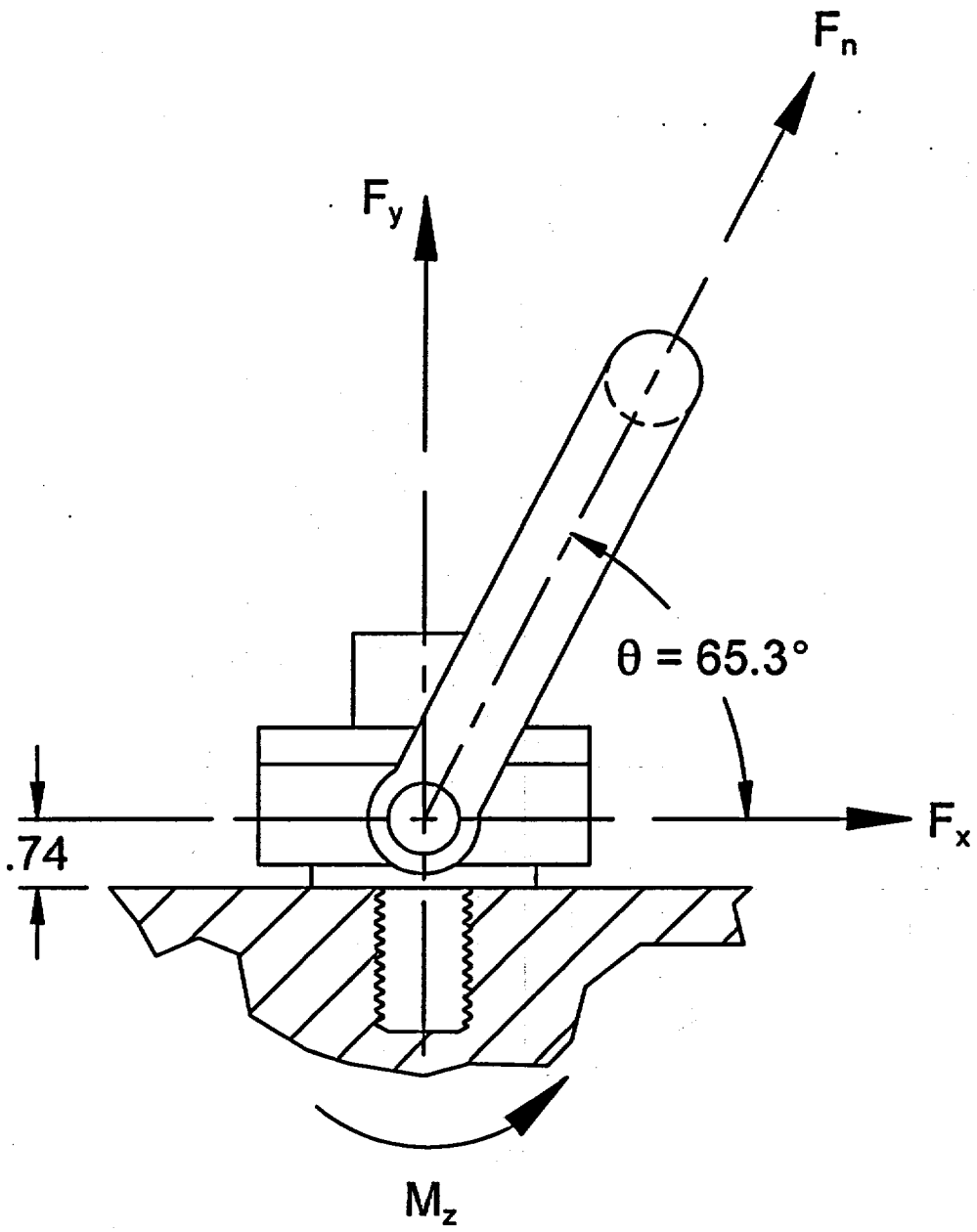


Figure 2.5.1-5 Canister Lift Finite Element Model

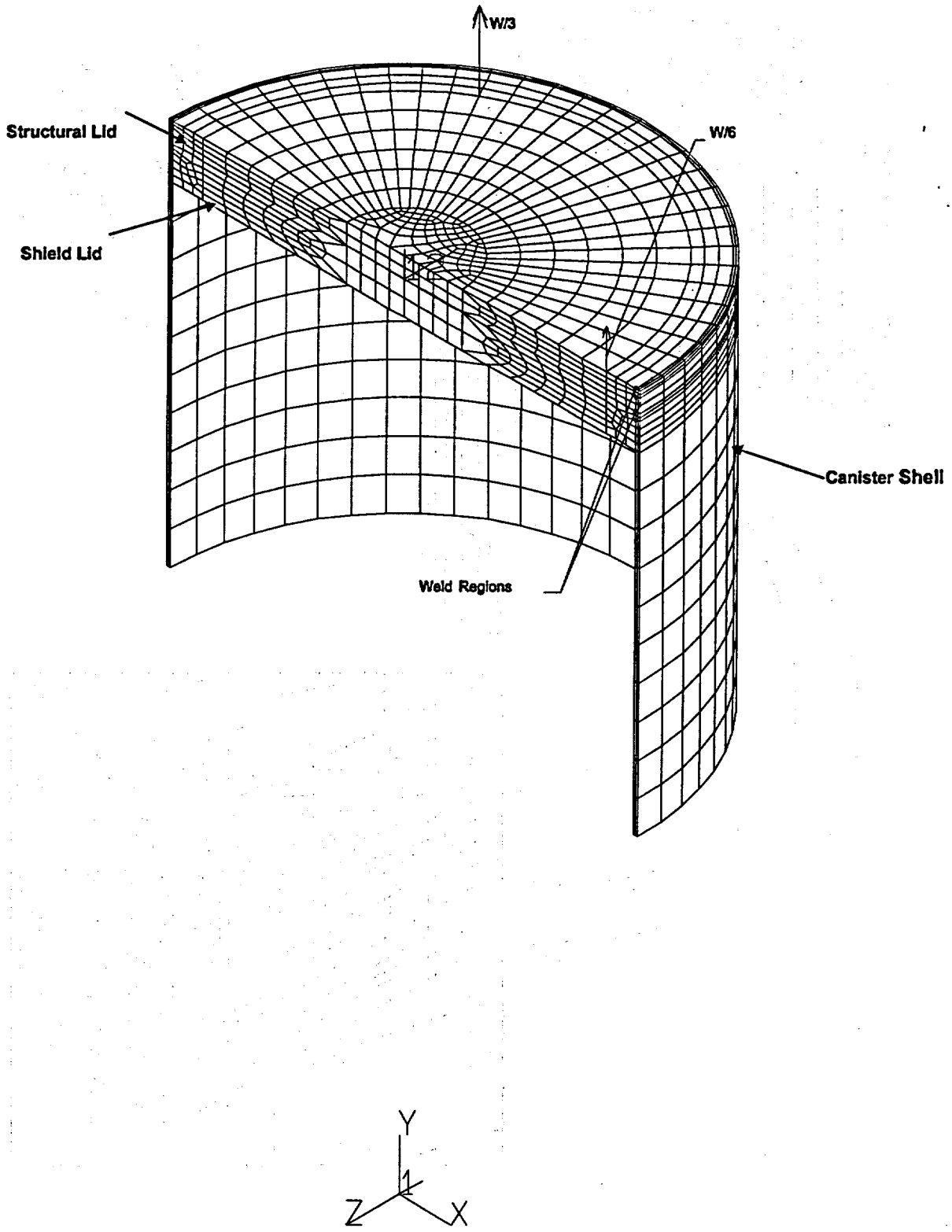


Figure 2.5.1-6 Yankee-MPC Canister Lift Model Stress Intensity Contours (psi)

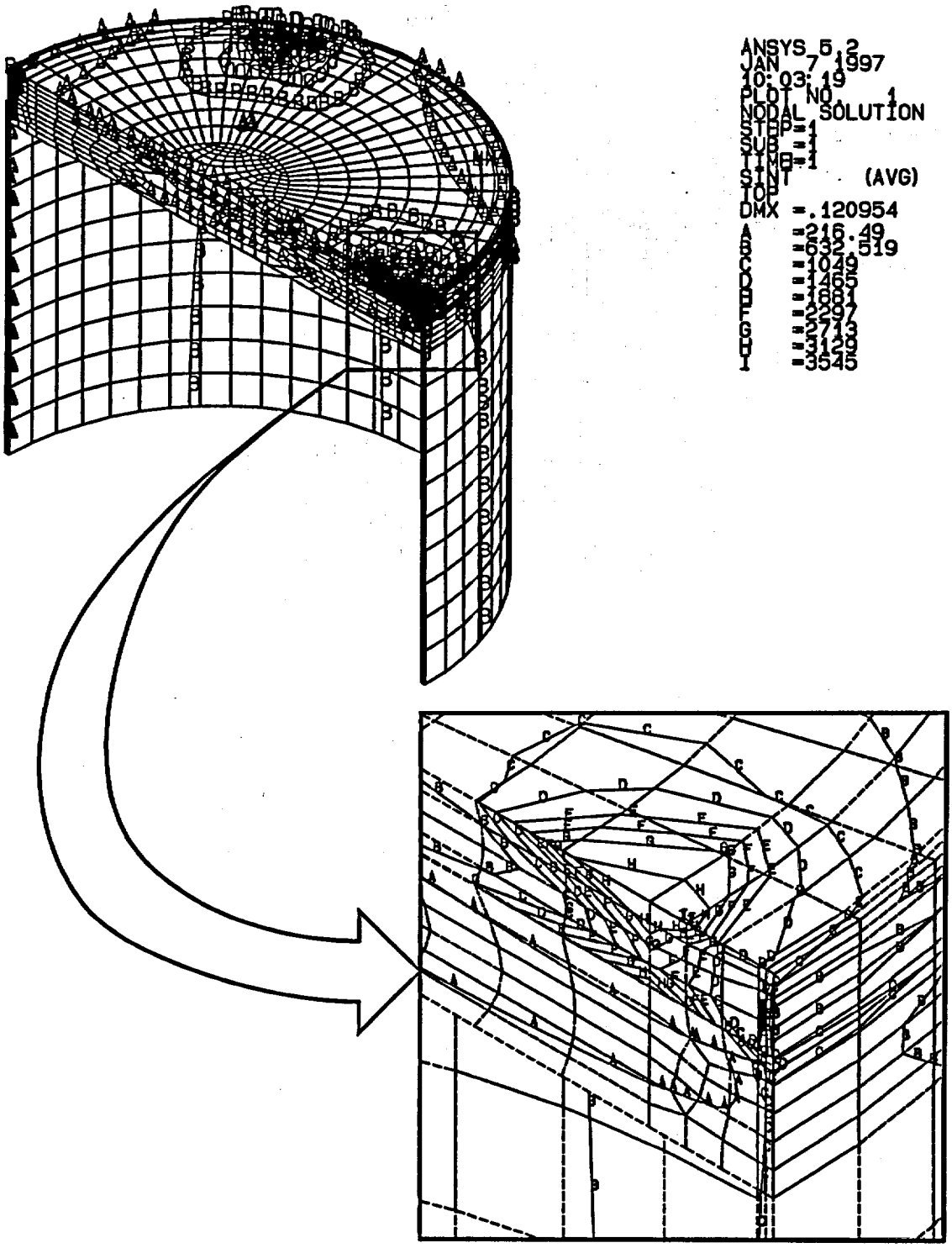
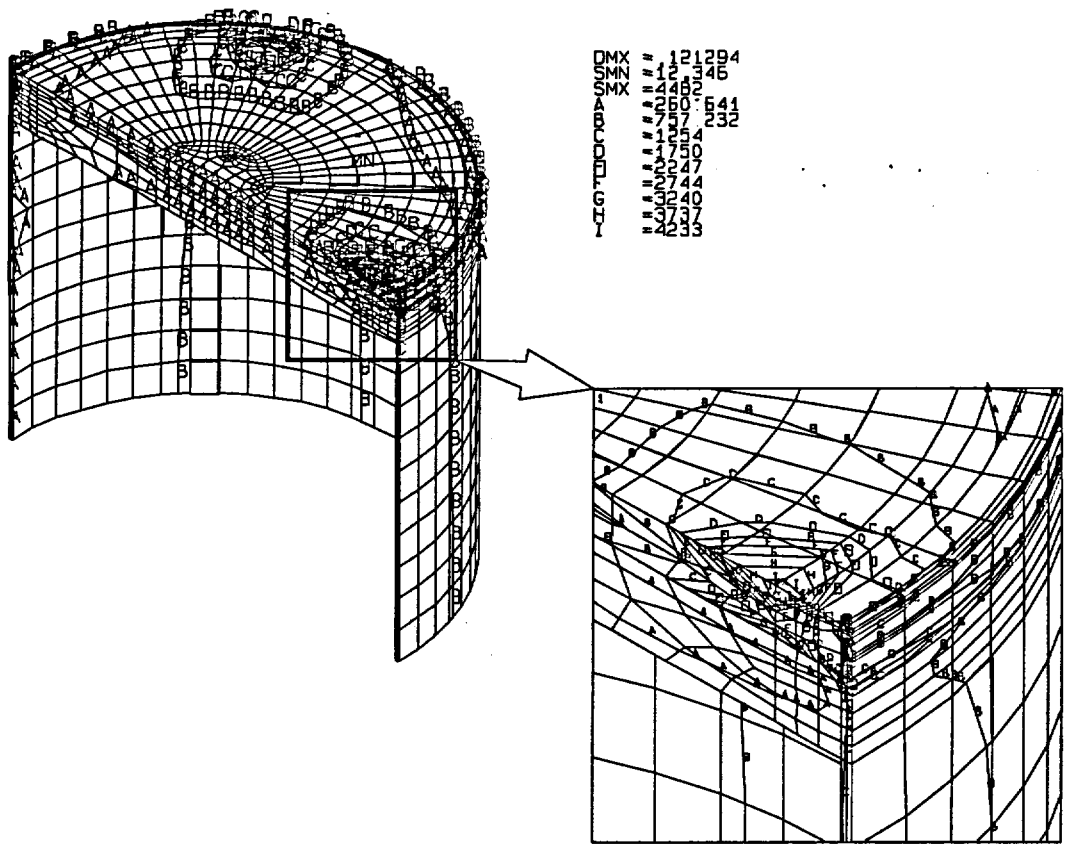


Figure 2.5.1-7 CY-MPC Canister Lift Model Stress Intensity Contours (psi)



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2.5.2 Tiedown Devices

The NAC-STC is tied down to the transport vehicle using the following: (a) rotation trunnion recesses near the bottom at point j (Figure 2.5.2-1); and (b) two 46-degree saddle supports, hold-down straps and a shear ring near the top end at point j (Figure 2.5.2-1). Longitudinal force towards the bottom of the cask is resisted by the supports at the rotation trunnion recesses. A shear ring welded to the outer shell resists the longitudinal force towards the top end of the cask. A 0.50-inch gap is provided between the shear ring and the saddle support to accommodate any thermal expansion of the cask.

The tiedown components of the NAC-STC are designed to satisfy the requirements of 10 CFR 71.45(b) and the AAR Field Manual, Rule 88, since rail is the most likely mode of transport. In accordance with 10 CFR 71.45(b), the structural components of the cask that are used for tiedown must be capable of withstanding certain specified forces, without generating stress in any material of the package in excess of its yield strength. These forces are comprised of a static force applied to the center of gravity of the package having a vertical component of 2 times the weight of the package with its contents, a horizontal component along the direction in which the vehicle travels of 10 times the weight of the package with its contents, and a transverse horizontal component of 5 times the weight of the package with its contents. In accordance with Rule 88 of the AAR Field Manual, the tiedowns for rail shipment of radioactive material containers must be capable of withstanding, without generating stress in any material of the tiedown in excess of its yield strength, a static force applied to the package center of gravity having components of 4.0 vertical, 7.5 longitudinal, and 1.8 transverse, times the weight of the package with its contents. The weight of the NAC-STC, loaded and ready for shipment, is 250,000 pounds in the directly loaded and Yankee-MPC configurations, and is 260,000 pounds in the CY-MPC configuration. The CY-MPC configuration weight is bounding. The calculational methodology and results for the cask tiedown evaluation using the 250,000 weight are presented in Sections 2.5.2.1, 2.5.2.2 and 2.5.2.3. The revised stress margins for the 260,000 pound weight are shown in Section 2.5.2.4.

2.5.2.1 Discussion and Loads

The resultant force on the shear ring is assumed to act at the centroid of the contact area between the shear ring and the saddle support. Referring to Figure 2.5.2-1, the distance of the centroid

from the center of the cask is determined. Calculate the centroid for $\theta = 60°$ and subtract the contribution of the 14 degree arc.

For $\theta = 60°$:

$$\bar{y} = \left(A_{o\bar{y}o} - A_{i\bar{y}i}\right)/(Ao - Ai)$$

$$\bar{y} = \left[\sin\theta\left(R_o^3 - R_i^3\right)\right]/\left[3\theta\left(R_o^2 - R_i^2\right)\right]$$

$$\bar{y}_{60} = 36.505 \text{ in (for } \theta = 60°)$$

where:

$A_o = \theta R_o^2$

$A_i = \theta R_i^2$

$\bar{y}_o = (2R_o \sin\theta)/3\,\theta$

$\bar{y}_i = (2R_i \sin\theta)/3\,\theta$

$\theta_{60} = 60° = \pi/3$ radians

$R_o = 44.925$ in

$R_i = 43.35$ in

Next, the centroid of the 14-degree arc is determined:

$$\bar{y}_{14} = [2 \sin\theta_1(R_o^3 - R_i^3)]/[3\theta_1(R_o^2 - R_i^2)]$$

$$= 43.704 \text{ in (for } \theta_1 = 14°)$$

where:

$\theta_{14} = 14° = 14\pi/180$ radians

The distance of the centroid from the center of the cask of the actual bearing area between θ = 14° and θ = 60° is calculated as:

$$\bar{y}_{act} = \frac{\bar{y}_{60} A_{60} - \bar{y}_{14} A_{14}}{A_{60} - A_{14}}$$

$$= \frac{\bar{y}_{60}[\theta_{60}(R_o^2 - R_i^2)] - \bar{y}_{14}[\theta_{14}(R_o^2 - R_i^2)]}{\theta_{60}(R_o^2 - R_i^2) - \theta_{14}(R_o^2 - R_i^2)}$$

$$= 34.31 \text{ in (for } \theta \text{ between } 14° \text{ and } 60°)$$

where:

A_{60} = $\theta_{60}(R_o^2 - R_i^2)$, area of 60 degree bearing area
A_{14} = $\theta_{14}(R_o^2 - R_i^2)$, area of 14 degree non-bearing area
$\bar{y}_{60}$ = centroid of 60 degree bearing area from cask axis
$\bar{y}_{14}$ = centroid of 14 degree non-bearing area from cask axis

There are three loading cases for the tiedown components--vertical, longitudinal, and lateral loads. The reaction forces for each loading case are determined by the equations of equilibrium.

2.5.2.1.1 Vertical Load Per 10 CFR 71.45(b)

Downward Direction

$$F_y = -2W = (-2)(250{,}000) = -500{,}000 \text{ lb}$$

Summing moments M_z about point j:

$$SM_z = (-500{,}000)(80.90) + (2R_{iy})(159.55) = 0$$

$$R_{iy} = +126{,}763 \text{ lb}$$

Summing vertical forces:

$$2R_{iy} + R_{jy} - 500{,}000 = 0$$

$R_{jy} = +246{,}474$ lb

Note: $R_{ix} = R_{jx} = 0$ because of the gap provided at the shear ring.

Upward Direction

$F_y = +2W = (+2)(250{,}000) = +500{,}000$ lb

Similarly, summing moments M_z about point j:

$R_{iy} = -126{,}763$ lb

$R_{jy} = -246{,}474$ lb

Note that the support saddle cannot carry any upward load. Hence, the negative R_{jy} is resisted by a tiedown strap.

2.5.2.1.2 Longitudinal Load Per 10 CFR 71.45(b)

Forward Direction

$F_x = +10W = (+10)(250{,}000) = +2{,}500{,}000$ lb

Summing horizontal forces:

$2{,}500{,}000 + R_{jx} = 0$

$R_{jx} = -2{,}500{,}000$ lb

Summing moments about j:

$(+2{,}500{,}000)(34.31) + (2R_{iy})(159.55) = 0$

$R_{iy} = -268{,}803$ lb

Summing vertical forces:

$$R_{jy} - (2)(268{,}803) = 0$$

$$R_{jy} = 537{,}606 \text{ lb}$$

Aft Direction

$$F_x = -10W = (-10)(250{,}000) = -2{,}500{,}000 \text{ lb}$$

Summing horizontal forces:

$$-2{,}500{,}000 + 2R_{ix} = 0$$

$$R_{ix} = +1{,}250{,}000 \text{ lb}$$

Summing moments about j:

$$(-2{,}500{,}000)(34.31) + (2)(1{,}250{,}000)(34.31 + 3) + (2R_{iy})(159.55) = 0$$

$$R_{iy} = -23{,}504 \text{ lb}$$

Summing vertical forces:

$$R_{jy} - (2)(23{,}504) = 0$$

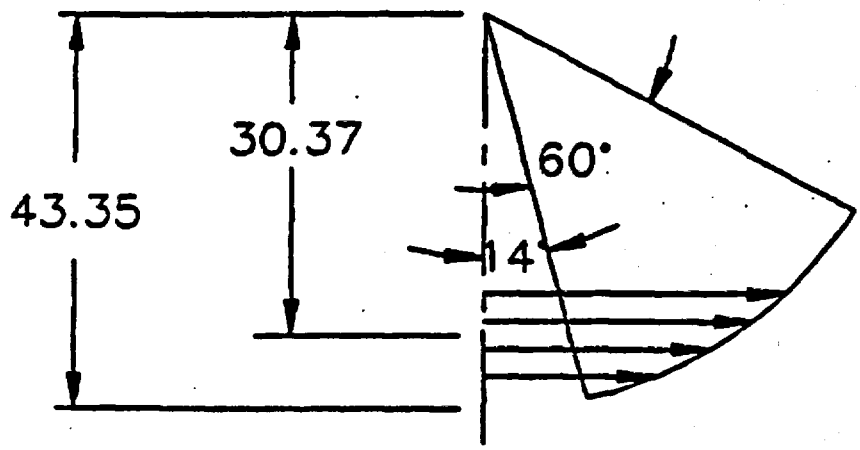
$$R_{jy} = 47{,}008 \text{ lb}$$

2.5.2.1.3 Lateral Load Per 10 CFR 71.45(b)

$$F_z = 5W = (5)(250{,}000) = 1{,}250{,}000 \text{ lb}$$

To find the reactions resisting the above load, it is necessary to find the location of the bearing pressure between the support saddle and the cask surface. The contact surface is one-half of the saddle, as shown below. Assume that the horizontal bearing pressure at any point is proportional to the sine function of the angular distance of the point from the lowest point in the saddle. The

distance from the center of the cask to the resultant of the bearing force between the cask and the saddle is calculated as:



Bearing Distribution of Cask in Saddle

For the 60 degree arc:

$$\bar{y} = \frac{A_1\bar{y}_1 - A_2\bar{y}_2}{A_1 - A_2}$$

$$= 30.562 \text{ in (for } \theta = 60°)$$

where:

$$A_1 = (\theta_1/2)(43.35)^2 = 983.959 \text{ in}^2$$

$$A_2 = (43.35)^2(\sin\theta_1)(\cos\theta_1)/2 = 406.864 \text{ in}^2$$

$$\bar{y}_1 = (2)(43.35)(\sin 60°)/(3)(\pi/3) = 23.90 \text{ in}$$

$$\bar{y}_2 = (2/3)(43.35 \cos 60°) = 14.45 \text{ in}$$

$$\theta_1 = 60° = \pi/3 \text{ radians}$$

For the 14 degree arc:

$$\bar{y}' = \frac{A_1'\bar{y}_1' - A_2'\bar{y}_2'}{A_1' - A_2'}$$

$= 42.56$ in, centroidal location of the 14° arc from cask axis

where:

$A_1' = (\theta_2/2)(43.35)^2 = 229.59 \text{ in}^2$

$A_2' = (43.35)^2(\sin\theta_2)(\cos\theta_2)/2 = 220.56 \text{ in}^2$

$\theta_2 = 14° = (14/180)(\pi)$ radians

$$\bar{y}_1' = \frac{(2)(43.35)(\sin\theta_2)}{3\theta_2} = 28.613 \text{ in}$$

$\bar{y}_2' = (2/3)(43.35)(\cos\theta_2) = 28.042$ in

The centroidal location of the resultant force acting laterally on the support saddle between the 14 degree and 60 degree angular distance from the vertical is:

$$\bar{y}_{act} = \frac{(30.562)(983.959 - 406.864) - (42.56)(229.59 - 220.56)}{(983.959 - 406.864) - (229.59 - 220.56)}$$

$= 30.37$ in

Call the location of this centroid: point k.

The horizontal distance from the center of the cask to the support point is 47.01 inches (Figure 2.5.2-2).

Summing moments about the vertical line through k (Figure 2.5.2-2):

$$(1{,}250{,}000)(80.90) + R'_{iz}(159.55) = 0$$

$$R'_{iz} = -633{,}814 \text{ lb}$$

Summing forces along the Z-axis:

$$1{,}250{,}000 - 633{,}814 + R_{jz} = 0$$

$$R_{jz} = -616{,}186 \text{ lb}$$

Summing forces along the Y-axis:

$$R_{iy} = -R'_{iy}$$

Summing moments about the longitudinal axis of the cask:

$$(616{,}186)(30.37) - (633{,}814)(3) - \left(-R'_{iy}\right)(47.01 + 47.01) = 0$$

$$-R'_{iy} = 178{,}814 \text{ lb}$$

$$R_{iy} = -178{,}814 \text{ lb}$$

Opposite Lateral Load

$$F_z = -5W = (-5)(250{,}000) = -1{,}250{,}000 \text{ lb}$$

The reactions for this case are opposite to the previous case.

2.5.2.1.4 Vertical Load Per AAR Field Manual, Rule 88

Downward Direction

$$F_y = (-4W) = (-4)(250{,}000) = -1{,}000{,}000 \text{ lb}$$

Summing moments M_z about point j:

$$\Sigma M_z = (-1{,}000{,}000)(80.90) + (2R_{iy})(159.55) = 0$$

$$R_{iy} = +253{,}525 \text{ lb}$$

Summing vertical forces:

$$2R_{iy} + R_{jy} - 1{,}000{,}000 = 0$$

$$R_{jy} = 492{,}950 \text{ lb}$$

Note: $R_{ix} = R_{jx} = 0$ because of the gap provided at the shear ring.

Upward Direction

$$F_y = +4W = (+4)(250{,}000) = +1{,}000{,}000 \text{ lb}$$

Similarly, summing moments M_z about point j:

$$R_{iy} = -253{,}525 \text{ lb}$$

$$R_{jy} = -492{,}950 \text{ lb}$$

Note that the support saddle cannot carry any upward load. Hence, the negative R_{jy} is resisted by a tiedown strap.

2.5.2.1.5 Longitudinal Load Per AAR Field Manual, Rule 88

Forward Direction

$$F_x = +7.5W = (+7.5)(250{,}000) = +1{,}875{,}000 \text{ lb}$$

Summing horizontal forces:

$$1{,}875{,}000 + R_{jx} = 0$$

$$R_{jx} = -1{,}875{,}000 \text{ lb}$$

Summing moments about j:

$$(1{,}875{,}000)(34.31) + 2R_{iy}(159.55) = 0$$

$R = -201{,}602$ lb

Summing vertical forces:

$R_{jy} - (-2)(201{,}602) = 0$

$R_{jy} = 403{,}204$ lb

Aft Direction

$F_x = -7.5W = (-7.5)(250{,}000) = -1{,}875{,}000$ lb

Summing horizontal forces:

$-1{,}875{,}000 + 2R_{ix} = 0$

$R_{ix} = +937{,}500$ lb

Summing moments about j:

$(-1{,}875{,}000)(34.31) + (2)(937{,}500)(34.31 + 3) + (2R_{iy})(159.55) = 0$

$R_{iy} = -17{,}628$ lb

Summing vertical forces:

$R_{jy} - (2)(17{,}628) = 0$

$R_{jy} = 35{,}256$ lb

2.5.2.1.6 Lateral Load Per AAR Field Manual, Rule 88

$F_z = 1.8W = (1.8)(250{,}000) = 450{,}000$ lb

Summing moments about the vertical line through k (Figure 2.5.2-2):

$$(450{,}000)(80.90) + (R'_{iz})(159.55) = 0$$

$$R'_{iz} = -228{,}173 \text{ lb}$$

Summing forces along the Z-axis:

$$450{,}000 - 228{,}173 + R_{jz} = 0$$

$$R_{jz} = -221{,}827 \text{ lb}$$

Summing forces along the Y-axis:

$$R_{iy} = -R'_{iy}$$

Summing moments about the longitudinal axis of the cask:

$$(221{,}827)(30.37) - (228{,}173)(3) - (R'_{iy})(47.01 + 47.01) = 0$$

$$R'_{iy} = 64{,}373 \text{ lb}$$

$$R_{iy} = -64{,}373 \text{ lb}$$

Opposite Lateral Load

$$F_z = -1.8W = (-1.8)(250{,}000) = -450{,}000 \text{ lb}$$

The reactions for this case are opposite to the previous case.

2.5.2.1.7 Loads Summary

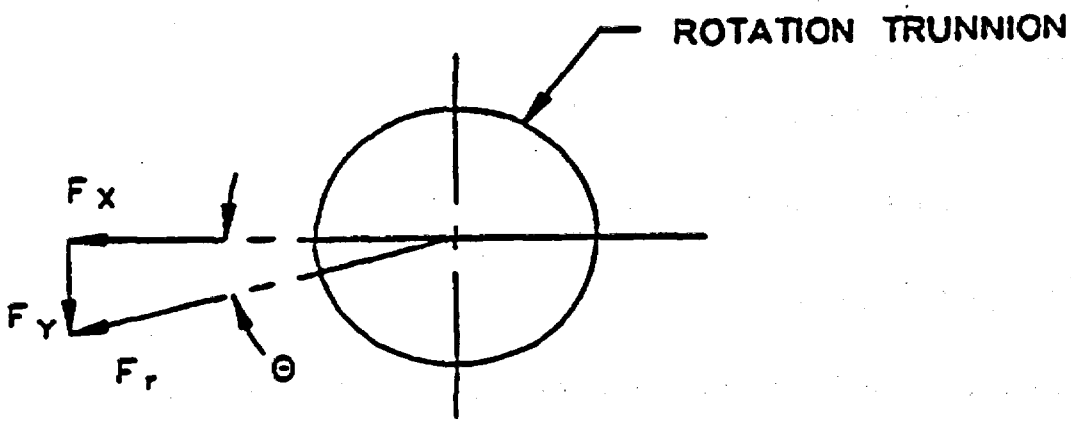
The results of all the loading cases are summarized in Tables 2.5.2-1 and 2.5.2-2.

2.5.2.2 Rear Support

The NAC-STC rear tiedown attachment is at the rotation trunnion recesses. There are two rotation trunnion recesses, which are slots located 18.15 inches above the bottom of the cask, and spaced at approximately 180-degree positions in line with two of the lifting trunnions. Each slot is a machined part, which is welded all around to the cask outer shell. The neutron shield tank shell is cut out to provide access to the slots. The geometry details of the shield tank cut-outs and the rotation trunnion slots are shown in the detailed drawings in Section 1.3.2.

2.5.2.2.1 Loads

The rotation trunnion recesses are analyzed for the cask tiedown load condition defined in 10 CFR 71.45(b) and Rule 88 of the Field Manual of the AAR. The condition used for this analysis assumes that the cask is supported horizontally on a railcar and is subjected to the more limiting of either (1) a 10g longitudinal shock load simultaneously with a 2g vertical shock load and a 5g lateral shock load or (2) a 7.5g longitudinal shock load, a 4g vertical shock load, and a 1.8g lateral shock load. The direct lateral load is transferred to the cask through bearing on the large trunnion slot base. Any dynamic load effects are negligible when considered in combination with the large applied load factors. The critical loads on the rotation trunnions are derived in Section 2.5.2.1 and are summarized in Tables 2.5.2-1 and 2.5.2-2. From these tables, it is apparent that the load conditions specified in 10 CFR 71.45(b) produce the more critical loads on the rotation trunnion.



Resultant Load Determination

$$F_r = \sqrt{(F_x)^2 + (F_y)^2}$$

$$= 1{,}292{,}592 \text{ lb}$$

where:

F_x = 1,250,000 lb

F_y = -329,081 lb (Table 2.5.2-1)

then

$$q = \arctan(329{,}081/1{,}250{,}000)$$

$$= 14.75°$$

2.5.2.2.2 Material Properties at 300°F

The yield strength of each material at 300°F, a conservatively high normal conditions temperature, is the allowable stress:

Type 304 stainless steel forging:

S_y = 22.5 ksi

S_u = 61.5 ksi

SA-705, Type 630, 17-4 PH Stainless Steel

S_y = 93.0 ksi

S_u = 135.0 ksi

AWS E309 filler material:

S_y = 61.0 ksi

S_u = 80.0 ksi

The bearing stress ratio is taken from MIL-HDBK-5C where the bearing yield stress for the 17-4 PH, H1150 stainless steels at ambient temperature is specified as 152 ksi. It is assumed that the ratio of bearing stress to yield stress remains constant up to 300°F:

$$S_{bry} = (93.0/105)(152) = 135 \text{ ksi}$$

The shear strength (yield strength criteria) for the different materials are:

Forging: $S_{sy} = 0.6S_y = 13{,}500$ psi

Trunnion: $S_{sy} = 0.6S_y = 55{,}800$ psi

Filler Material: $S_{sy} = 0.65y = 36{,}600$ psi

2.5.2.2.3 Stress Analysis

(Bearing Stress in Trunnion Slot)

$$F_r = 1{,}292{,}592 \text{ lb}$$

Length of engagement for 6.00-in diameter pin = 3.88 inches

$$A_{br} = (6.00)(3.88) = 23.28 \text{ in}^2$$

$$S_{br} = \frac{F_r}{A_{br}} = 55{,}524 \text{ psi}$$

$$MS = \frac{S_{bry}}{S_{br}} - 1 = +1.43$$

(Stress in Weld at Interface with Rotation Trunnion Recess)

Assume the entire load transferred to the cask outer shell through the weld at the base of the trunnion.

FIGURE WITHHELD UNDER 10 CFR 2.390

Section Through Weld at Base of Pocket

Effective thickness of weld:

te = [(1.50)2 + (1.375)2]o.5 = 2.035 inches (Section B-B, 3 Sides)

Section properties of weld group:

Area (Aw) = (19.035)(11.07) - (15.50)(7.00)
= 102.22 in^2

$$\bar{x} = \frac{(11.07\ (19.035)2/2 - (7.00)(15.50)(1.50 + 15.50/2)}{102.22}$$

=9.801 in

$$I_x = \frac{(19.035)(11.07)^3}{12} - \frac{(15.50)(7.00)^3}{12}$$
$$= 1709 \text{ in}^4$$

$$I_y = \frac{(11.07)(19.035)^3}{12} + (11.07)(19.035)\left(\frac{19.035}{2} - 9.801\right)^2$$
$$- \frac{(7.00)(15.50)^3}{12} - (7.00)(15.50)(9.25 - 9.801)^2$$
$$= 4174 \text{ in}^4$$

$b = 17.27$ in

$h = 9.035$ in

$t_a = 1.50$ in

$t_b = 2.035$ in

From Table 2.5.2-1, the loads for Case II are the highest combination loads on the weld group:

$F_x = 1{,}250{,}000$ lb

$F_y = 329{,}081$ lb

$F_r = (F_x^2 + F_y^2)^{0.5} = 1{,}292{,}592$ lb

$e_x = 9.801 - 6.0 = 3.801$ in

$e_z = 5.8 - 4.13/2 = 3.735$ in

$M_x = F_y (e_z) = 1{,}229{,}118$ in-lb

$M_y = F_x (e_z) = 4{,}668{,}750$ in-lb

$M_z = F_y (e_x) = 1{,}250{,}837$ in-lb

Component stresses on the effective thickness weld group are:

$$S_{AC} = \frac{M_y c_x}{I_y} = \frac{(4{,}668{,}750)(9.801)}{(4174)}$$

= 10,963 psi (Bending Stress at Points A and C)

$$S_{BC} = \frac{M_x c_y}{I_x} = \frac{(1{,}229{,}118)(5.535)}{1709}$$

= 3981 psi (Bending Stress at Points B and C)

$$S_s = \frac{F_R}{A_W} = \frac{1{,}292{,}592}{102.22}$$

= 12,645 psi (Resultant Direct Shear Stress)

$$(S_{ST})_A = \frac{M_Z^*}{2bht_A} = \frac{1{,}250{,}837}{(2)(17.27)(9.035)(1.50)}$$

= 2672 psi (Torsional Shear Stress at Point A)

$$(S_{ST})_B = \frac{M_Z^*}{2bht_B} = \frac{1{,}250{,}837}{(2)(17.27)(9.035)(2.035)}$$

= 1970 psi (Torsional Shear Stress at Point B)

* Seely, Table 14.

The von Mises equivalent stresses at Points A, B, and C are:

$$S_{EA} = \left[S_{AC}^2 + 3(S_S + (S_{ST})_A)^2\right]^{0.5} = 28{,}706 \text{ psi}$$

$$S_{EB} = \left[S_{BC}^2 + 3(S_S + (S_{ST})_B)^2\right]^{0.5} = 25{,}625 \text{ psi}$$

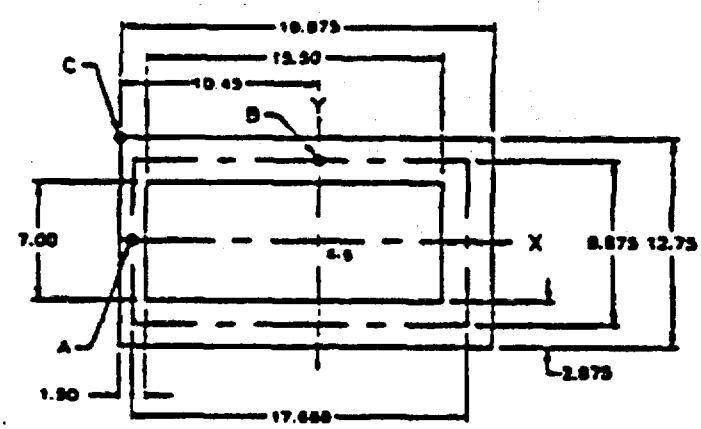
$$S_{EC} = \left[(S_{AC} + S_{BC})^2 + 3S_S^2\right]^{0.5} = 26{,}432 \text{ psi}$$

The minimum margin of safety in the weld material at the rotation trunnion recess/weld interface is based on the lower yield strength of the E309 weld filler metal, $S_y = 61.0$ ksi:

$$MS = \frac{61{,}000}{28{,}706} - 1 = \underline{+1.125}$$

(Stress at Cask Body/Rotation Trunnion Recess Weld Interface)

The rotation trunnion recess is welded to the cask body, which is made of Type 304 stainless steel. The strength of Type 304 stainless steel is less than the AWS E309 filler material. The stress at the weld/cask interface is analyzed below. The weld/cask interface is shown.



Section Through Weld/Cask Interface

Section properties of Weld/Cask Interface:

$$\text{Area } (A_w) = (19.875)(12.75) - (15.50)(7.00)$$
$$= 144.91 \text{ in}^2$$

$$b = 17.688 \text{ in}$$

$$h = 9.875 \text{ in}$$

$$t_A = 1.50 \text{ in}$$

$$t_B = 2.875 \text{ in}$$

$$\bar{x} = \frac{(12.75)(19.875)^2/2 - (7.00)(15.50)(1.50 + 15.50/2)}{144.91}$$
$$= 10.45 \text{ in}$$

$$I_x = \frac{(19.875)(12.75)^3}{12} - \frac{(15.50)(7.00)^3}{12}$$
$$= 2990 \text{ in}^4$$

$$I_y = I_y = \frac{(12.75)(19.875)^3}{12} + (12.75)(19.875)(10.45)^2$$

$$- \frac{(7.00)(15.50)^3}{12} - (7.00)(15.50)(10.45 - 9.25)^2$$

$$= 6080 \text{ in}^4$$

Loads on weld/cask interface:

From Table 2.5.2-1, inspection of the load combinations indicates that Case II is most critical for the rotation trunnion recess:

F_x = 1,250,000 lb

F_y = -329,081 lb

$F_R = (F_x^2 + F_y^2)^{0.5}$ = 1,292,592 lb

e_x = 10.45 - 6.0 = 4.45 in

e_z = 5.8 - 4.13/2 = 3.735 in

$M_x = F_y (e_z)$ = 1,229,118 in-lb

$M_y = F_x (e_z)$ = 4,668,750 in-lb

$M_z = F_y (e_x)$ = 1,464,410 in-lb

Component stresses in the weld/cask interface are:

$$S_{AC} = \frac{M_y c_x}{I_y} = \frac{(4{,}668{,}750)(10.45)}{6080}$$

= 8024 psi (Bending Stress at Points A and C)

$$S_{BC} = \frac{M_x c_y}{I_x} = \frac{(1{,}229{,}118)(6.375)}{2990}$$

= 2621 psi (Bending Stress at Points B and C)

$$S_S = \frac{F_R}{A_W} = \frac{1{,}292{,}592}{144.91}$$

= 8920 psi (Resultant Direct Shear Stress)

$$(S_{ST})_A = \frac{M_z^*}{2bht_A} = \frac{1{,}464{,}410}{(2)(17.688)(9.875)(1.50)}$$

$$= 2{,}795 \text{ psi (Torsional Shear Stress at Point A)}$$

$$(S_{ST})_B = \frac{M_z^*}{2bht_B} = \frac{1{,}464{,}410}{(2)(17.688)(9.875)(2.875)}$$

$$= 1{,}458 \text{ psi (Torsional Shear Stress at Point B)}$$

The von Mises equivalent stresses at Points A, B, and C are:

$$S_{EA} = \left[S_{AC}^2 + 3(S_S + (S_{ST})_A)^2\right]^{0.5} = 21{,}819 \text{ psi}$$

$$S_{EB} = \left[S_{BC}^2 + 3(S_S + (S_{ST})_B)^2\right]^{0.5} = 18{,}165 \text{ psi}$$

$$S_{EC} = \left[(S_{AC} + S_{BC})^2 + 3S_S^2\right]^{0.5} = 18{,}762 \text{ psi}$$

The minimum margin of safety at the weld/cask interface is based on the lower yield strength material, the Type 304 stainless steel cask body forgings with $S_y = 22.5$ ksi:

$$MS = \frac{22{,}500}{21{,}819} - 1 = +0.03$$

The positive margins of safety show that the rotation trunnion recesses satisfy the requirements of 10 CFR 71.45(b).

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* Seely, Table 14.

2.5.2.2.4 Overload - Tiedowns

According to 10 CFR 71.45(b)(3), each tiedown device that is a structural part of a package must be designed so that failure of the device under excessive load would not impair the ability of the package to meet the other requirements of 10 CFR 71. For this reason, the shear capacity of the rotation trunnion recesses, welds, and the outer shell are compared.

The weld attaching the rotation trunnion to the outer shell and the lower forging is shown in Section 2.5.2.2.3. The shear capacities of the rotation trunnions, welds, and the outer shell are calculated below.

Weld

The effective shear area of the weld is 98.25 square inches, as previously calculated. The filler material used to weld the rotation trunnion to the cask body is AWS E309 with an ultimate tensile strength of 80.0 ksi. The ultimate shear capacity of the weld is:

$$F_w = (98.25)(0.42)(80{,}000)$$

$$= 3{,}301{,}200 \text{ lb}$$

Cask Body

The area of the interface between the weld and the cask body is 139.22 square inches. The cask body has a tensile strength of 61.5 ksi, which is lower than the tensile strength of 80.0 ksi for the filler material. The cask body, therefore, is the critical part at the interface region. The ultimate shear capacity of the cask body at the interfacing area with the weld is:

$$F_{cb} = (139.22)(0.42)(61{,}500)$$

$$= 3{,}596{,}052 \text{ lb}$$

The maximum shear capacities of the weld and the cask body at the interface are summarized as follows:

Weld = 3,301,200 lb
Cask Body = 3,596,052 lb

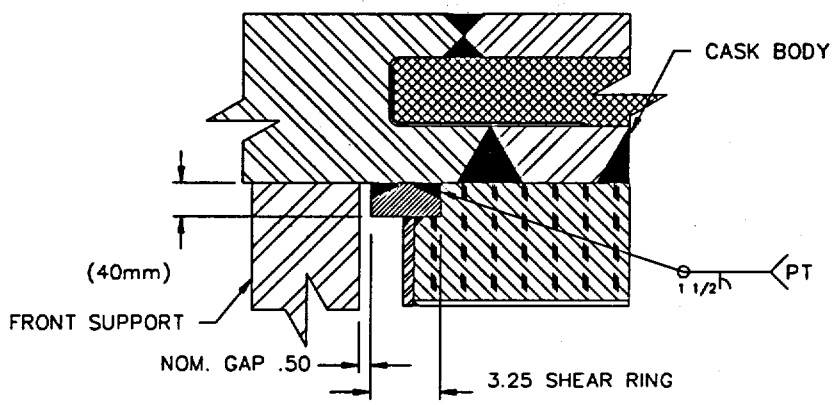
Thus, the weld will fail in shear before the cask body, ensuring that failure caused by excessive overload on the rotation trunnions will not impair the ability of the package to meet the other requirements of 10 CFR 71.

2.5.2.3 Front Support

2.5.2.3.1 Discussion

The longitudinal force toward the top end of the cask is resisted by a shear ring welded to the cask outer shell. The shear ring is located at the juncture of the neutron shield shell top plate and the outer shell.

2.5.2.3.2 Shear Ring



Shear Ring Geometry

The shear ring geometry bears on the shipping frame along two 58-degree arcs (Figure 2.5.2-1). The load on the shear ring is:

R_{jx} = 2,500,000 lb (Section 2.5.2.1.2)

Assuming that 1.575 inches (40 mm) of the ring thickness is in direct bearing against the side of the support frame, the bearing pressure is:

$S_{brg} = 2{,}500{,}000/(0.64)(\pi)(43.35)(1.575)$

$= 18{,}211$ psi

The allowable bearing on the surface of Type 304 stainless steel is:

$(S_{brg})_{Allow}$ = 23,750 psi at the conservatively high temperature of 260°F

The margin of safety for bearing is:

$$MS = \frac{23{,}750}{18{,}211} - 1 = +0.30$$

The shear stress across the weld is:

$S_s = R_{jx}/A_w = 2{,}500{,}000/267.8 = 9{,}335$ psi

where:

$A_w = (\pi)(86.7)(116/360)(1.5)(2) + (0.75)(1.5)(4) = 267.8\ in^2$

The margin of safety at the conservatively high temperature of 250°F is:

$$MS = \frac{(0.6)(20{,}000)}{9{,}335} - 1 = +0.29$$

where:

S_m = 20,000 psi at the conservatively high temperature of 250°F.
(Actual calculated temperature is 211°F)

2.5.2.4 <u>Tiedown Evaluation for the CY-MPC Configuration with Balsa Impact Limiters.</u>

The shipping weight for the CY-MPC fuel configuration is 260,000 pounds, which is a 4% increase in shipping weight over the directly loaded and Yankee-MPC configurations. The methodology of Section 2.5.2.1 is used, applying an increase in the calculated stresses by 4% to determine the margins of safety for the higher CY-MPC weight. This evaluation uses the stress results and figures of Sections 2.5.2.2.3 and 2.5.2.2.4.

From Section 2.5.2.2.3, the stress in the weld at interface with the rotation trunnion recess is evaluated. The corresponding margin for the 260,000-pound shipping weight is:

M.S.=135/(1.04 x 55.52)-1 = + 1.34

From Section 2.5.2.2.3, the minimum margin of safety in the weld material at the rotation trunnion recess/weld interface is calculated based on the lower yield strength of the E309 weld material. The corresponding margin of safety for the 260,000 pound shipping weight is:

M.S.=61/(1.04 x 28.7)-1 = + 1.04

The margin of safety for the weld/cask interface (Cask Body/Rotation Trunnion Recess Weld Interface) is evaluated using the allowable stress at 250°F, which is higher than the calculated outer cask radial surface temperature at the trunnion recess location (~220°F). The bounding stress is the von Mises equivalent stress at Point A of 21,819 psi. The margin of safety is:

M.S.= 23.75/(1.04 x 21.8)-1 = + 0.05

As shown in Section 2.5.2.2.4, the weld fails in shear before the cask body, thereby ensuring that the cask body retains integrity. Since this result is based on material properties, the increase in the weight will not alter the conclusion of 2.5.2.2.4.

From Section 2.5.2.3.2, the shear ring for the front support is evaluated. The margin of safety for the bearing stress for the 260,000-pound weight is:

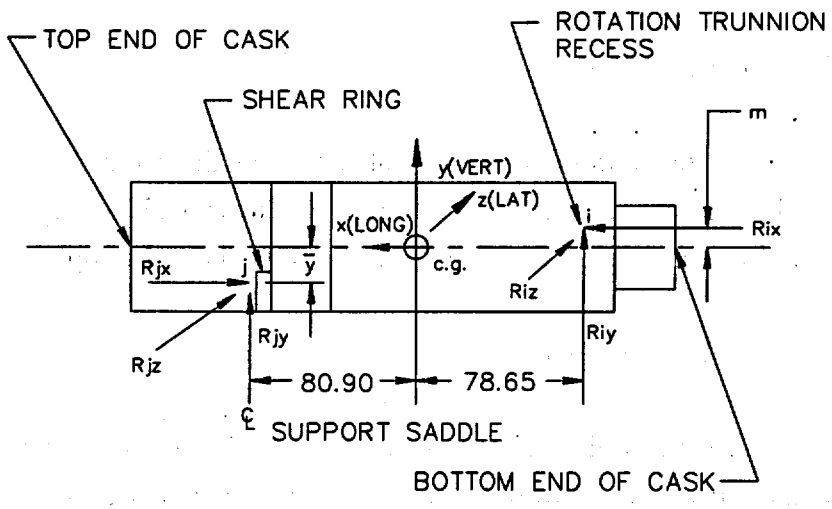
M.S.=23.75/(1.04 x 18.21)-1 = + 0.25

Similarly, the margin of safety for the shear stress across the weld is:

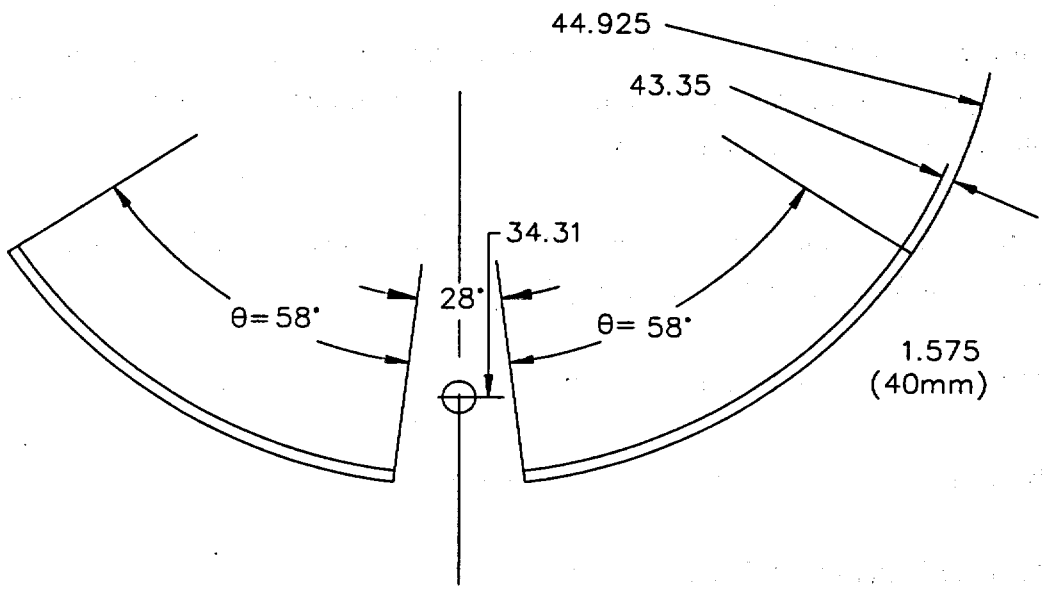
M.S.=.6(20)/(1.04 x 9.34)-1 = + 0.24

Based on these results, the NAC STC tie down system for the CY-MPC 260,000 pound transport weight satisfies the requirements of 10 CFR 71.45(b) and the AAR Field Manual, Rule 88.

Figure 2.5.2-1 Front Support and Tiedown Geometry



Free Body Diagram



Shear Ring Geometry

Figure 2.5.2-2 Free Body Diagram of Cask Subjected to Lateral Load

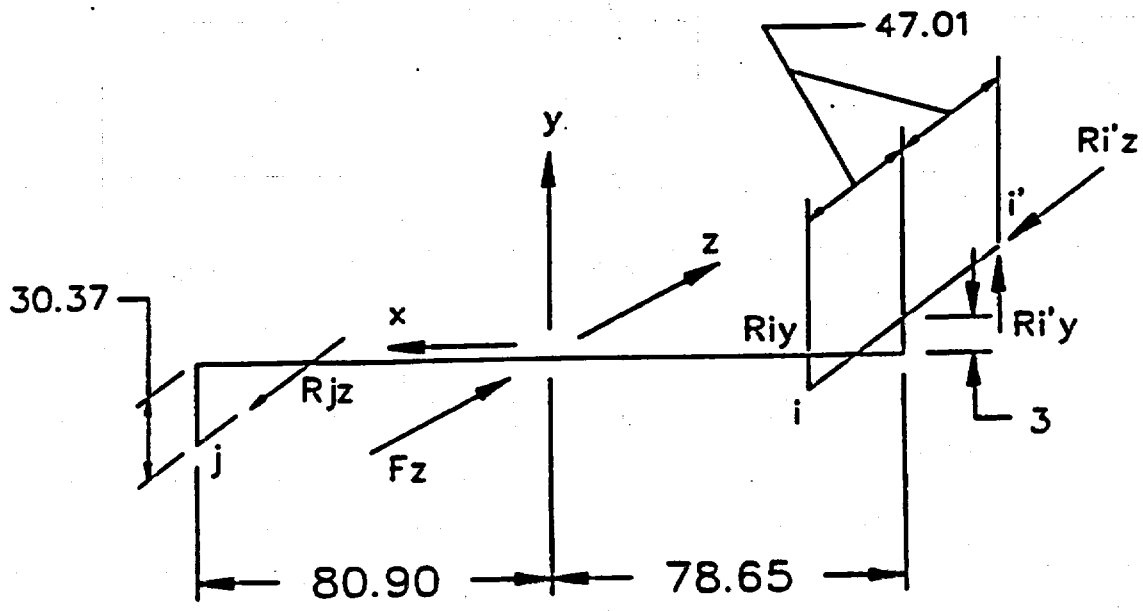


Table 2.5.2-1 Reactions Caused By Tiedown Devices From 10 CFR 71.45(b) Loads

Load Case	Load (lb)	Reactions (lb)					
		R_{jx}	R_{jy}	R_{jz}	R_{ix}	R_{iy}	R_{iz}
A1	F_y = -500,000	0	246,474	0	0	126,763	0
A2	F_y = 500,000	0	-246,474	0	0	-126,763	0
B1	F_x = 2,500,000	-2,500,000	537,606	0	0	-268,803	0
B2	F_x = -2,500,000	0	47,008	0	1,250,000	-23,504	0
C1	F_z = 1,250,000	0	0	-616,186	0	-178,814	0
C2	F_z = -1,250,000	0	0	616,186	0	178,814	633,814
Combined reactions:							
Case I. $A_1 + B_1 + C_1$		-2,500,000	784,080	-616,186	0	-320,854	0
Case II. $A_2 + B_2 + C_1$		0	-199,466	-616,186	1,250,000	-329,081	0
Case III. $A_2 + B_1 + C_1$		-2,500,000	291,132	-616,186	0	-574,380	0
Case IV. $A_2 + B_2 + C_2$		0	-199,466	616,186	1,250,000	28,547	633,814

Table 2.5.2-2 Reactions Caused By Tiedown Devices from AAR Field Manual, Rule 88 Loads

Load Case	Load (lb)	Reactions (lb)					
		R_{jx}	R_{jy}	R_{jz}	R_{ix}	R_{iy}	R_{iz}
A1	F_y =-1,000,000	0	492,950	0	0	253,525	0
A2	F_y =1,000,000	0	-492,950	0	0	-253,525	0
B1	F_x =1,875,000	1,875,000	403,204	0	0	-201,602	0
B2	F_x =-1,875,000	0	35,256	0	937,500	-17,628	0
C1	F_z =450,000	0	0	-221,827	0	-64,373	0
C2	F_z =-450,000	0	0	221,827	0	64,373	228,173
Combined reactions:							
Case I. $A_1 + B_1 + C_1$		1,875,000	896,154	-221,827	0	-12,450	0
Case II. $A_2 + B_2 + C_1$		0	-457,694	-221,827	937,500	-335,526	0
Case III. $A_2 + B_1 + C_1$		1,875,000	-89,746	-221,827	0	-519,500	0
Case IV. $A_2 + B_2 + C_2$		0	-457,694	221,827	937,500	-206,780	228,173

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2.6 Normal Conditions of Transport

The 10 CFR 71.71 requires that the NAC-STC be structurally adequate for the following normal conditions of transport: (1) heat, (2) cold, (3) reduced external pressure, (4) increased external pressure, (5) vibration, (6) water spray, (7) free drop, (8) corner drop, (9) compression, and (10) penetration. In the free drop analyses, the cask impact orientation evaluated is the orientation that inflicts the maximum damage to the cask. The 10 CFR 71.71 requires that the evaluation of the cask for the normal conditions of transport be at the most unfavorable ambient temperature in the range from -20°F to +100°F. In this section, the NAC-STC is evaluated for structural integrity for the normal conditions of transport in three configurations - with directly loaded fuel, with the Yankee-MPC and with the CY-MPC. The Yankee-MPC and CY-MPC configurations include spent fuel and Greater Than Class C (GTCC) waste.

NAC-STC

Two- and three-dimensional structural analyses of the cask discussed in this section and summarized in the tables presented in Section 2.10.4 are not influenced by the localized changes to the closure system, fuel basket or revised heat transfer analysis. Therefore, cask structural analyses have not been revised. The SAR has been revised to include evaluations of alternate configurations of the cask contents, i.e., (1) fuel assemblies contained in a canister; and (2) cans of GTCC waste contained in a canister.

Revised heat transfer analyses are presented in Chapter 3. Section 2.10.10 presents a comparison of temperature gradients obtained from the different heat transfer analyses and evaluation of conservative margins of safety identified using original temperature distributions in the cask structural qualification. It is concluded from this evaluation that the detailed finite element analyses performed for normal and accident condition loads using the original temperature distributions are conservative; therefore, the original analyses have not been revised.

Temperature distributions for both normal and accident conditions are revised as a result of improvements in the modeling of the boundary conditions used in the heat transfer analyses. These boundary condition improvements better reflect actual conditions than those originally modeled in the cask thermal analyses. The most significant revisions to the boundary conditions included modeling the gap between the basket and inner shell, and consideration of an adiabatic surface for the area of the cask covered by the impact limiter. Additional enhancements are made

to the heat transfer analysis resulting from revising the basket to an all stainless steel structural design. Additional discussion of these enhancements is presented in Chapter 3.

These enhancements resulted in reduced thermal gradients and the associated secondary stresses applicable to the normal condition structural qualification throughout the cask and increased the maximum component temperature in the regions of the cask influenced by the insulating effect of the impact limiter (Section 2.10.10). Based on the fact that these changes in temperature do not create higher stresses in the cask and that the resulting influence to the stress qualification is limited to reducing the temperature dependent material allowable stress, revisions to the structural qualification of the cask for normal conditions are limited to changes in the material allowable stresses and the margins of safety in the stress summary tables in Section 2.10.4.

Yankee-MPC

The Yankee-MPC configuration has the same design weight of 250,000 pounds as the NAC-STC directly loaded configuration. Due to the reduced length of the Yankee Class spent fuel and the load concentration of the canister lids, a separate three-dimensional finite element model is used to evaluate the stresses in the cask body for the normal conditions of transport.

CY-MPC

The CY-MPC configuration has a design weight of 260,000 pounds versus the 250,000 pound design weight of the NAC-STC directly loaded and Yankee-MPC configurations. In conjunction with the higher design weight, the CY-MPC configuration employs a balsa impact limiter design. The balsa impact limiters are significantly lighter than the standard redwood/balsa impact limiter design. A single three-dimensional model is employed to evaluate the stresses in the cask body for normal conditions of transport.

2.6.1 Heat

The NAC-STC body and closure lids are analyzed for structural adequacy in accordance with the requirements of 10 CFR 71.71(c)(1) Heat (normal condition of transport). The cask is loaded, ready for shipment and supported in the horizontal position with an ambient temperature environment of 100°F, an assumed internal pressure of 50 psig, maximum decay heat load, maximum solar insolation, and still air.

2.6.1.1 Heat Condition for the NAC-STC Cask in the Directly Loaded Fuel and Yankee-MPC Configurations

The stress analysis of the cask is performed using both the two-dimensional and the three-dimensional finite element models and the ANSYS computer program. For the two-dimensional analysis, the cask is modeled as an axisymmetric structure using ANSYS STIF42 isoparametric elements. The individual loading conditions of thermal heat, internal pressure, and bolt preload are analyzed using a two-dimensional axisymmetric model, because both the cask structure and the loads are axisymmetric. By contrast, the individual gravity loading condition, and the combined loading conditions must be analyzed using the three-dimensional finite element model, since the gravity loading condition is not axisymmetric. The ANSYS computer program is described in Section 2.10.1.1. The finite element model descriptions are provided in Section 2.10.2.1. The temperature-dependent material properties considered in the analysis are documented in Section 2.3.

For the heat condition, the cask is structurally loaded due to closure lid bolt preload, internal pressure, thermal heat, and gravity. The following four categories of load are considered on the cask:

1. Closure lid bolt preload – For the NAC-STC directly loaded and the Yankee-MPC configurations, the required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as explained in Section 2.10.2.2.3. The bolts are modeled as beam (ANSYS STIF3) elements.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. For analysis purposes, a conservatively assumed internal pressure of 50 psig is applied on the interior surfaces of the cask cavity in the outward normal direction. The 50 psig is conservative, based on the calculated maximum normal operating cavity pressure (MNOP) of 1.8 atmospheres absolute (12 psig) for fuel loaded directly into the cask cavity. The calculated MNOP in the cask cavity for canistered fuel is 1.77 atmospheres absolute (11.31 psig). The cavity pressure is even less for the canistered GTCC waste because no fuel rod fill-gas is present. The pressure loading region includes the lid and upper body forging mating surfaces outward to the inner lid seal centerline.

3. Thermal - The heat transfer analyses performed for maximum normal operating conditions determine the cask temperature distribution for the heat condition. The heat condition considers the cask to be subjected to an ambient temperature of 100°F, with maximum decay heat load (for directly loaded fuel) and maximum solar insolation, in still air. The maximum decay heat load for Yankee Class canistered fuel is 12.5 kW and is 2.9 kW for Yankee GTCC waste. The directly loaded fuel configuration is considered to bound the temperatures associated with the Yankee-MPC configurations. For The cask temperature distribution, obtained for this heat condition, is used as an input to the ANSYS analysis to determine the stresses in the cask. The ANSYS analysis determines the stresses resulting from the thermal expansion of the cask from its initial, 70°F, condition to its normal transport temperature condition. These stresses include the effects of the differential thermal growth within the components, which result from the temperature difference across the walls of the cask. The cask temperature distribution is also used in the ANSYS structural analysis to determine the values of the temperature-dependent material properties.

4. Gravity - The mechanical loads consist of gravity acting on the cask structure and its contents. The cask is assumed to be loaded and resting in the horizontal position on the front and rear cask supports. Mechanical loads resulting from a 1 g application of the total weight (250,000 lbs for the NAC-STC directly loaded and Yankee-MPC configurations) of the cask structure and contents are imposed on the model. The design weight of the empty cask (194,000 lbs) is imposed on the mass of the cask model.

   The weight of the cavity contents (56,000 lbs) for directly loaded fuel is imposed on the model as a contents pressure on the contact surface of the cask cavity (Section 2.10.2.2.1

for the contents pressure calculation). The weight of the cavity contents for the Yankee-MPC canistered fuel configuration is 55,590 pounds, including the top and bottom cask cavity spacers. For the Yankee GTCC waste configuration, the weight of the cavity contents is 54,271 pounds, including the cask cavity spacers. Fabrication stresses are considered to be negligible as demonstrated in Section 2.6.11.

For the two-dimensional NAC-STC directly loaded contents analyses, axisymmetric boundary conditions are applied to the two-dimensional finite element model because axisymmetry exists in the cask geometry and in the loading conditions considered. In addition, a longitudinal support is imposed on an outside corner node at one end of the cask to prevent rigid body motion. If the cask system is in equilibrium, then the reaction force at this support will be zero for the two-dimensional model.

For the three-dimensional finite element models, symmetric boundary conditions are applied to the model by restraining the nodes on the symmetry plane to prevent translations in the direction normal to the symmetry plane. Additional restraints are applied to simulate the orientation and method of support of the cask. The cask is considered to be loaded and resting in the horizontal position on a front saddle and a rear tiedown support. Therefore, nodes at the centerline of the front saddle on the cask outer radius are radially restrained, and one node at the rear tiedown is laterally and longitudinally restrained. When the cask system is in equilibrium, then the sum of the reaction forces at the restraints will be equal to the half-cask weight in the lateral direction and zero in the longitudinal direction. An examination of the magnitude of the reaction forces provides a check of the validity of the finite element evaluation for the heat condition.

The allowable stress limit criteria, for containment and noncontainment structures, are provided in Section 2.1.2. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum transport temperature within a given component to determine the allowable stress throughout that component. Note that higher component temperatures result in lower allowable stresses. Table 2.10.2-5 documents the allowable stress values determined for each component, for the temperature distribution (Condition 1) corresponding to the heat condition.

The stresses throughout the cask body are calculated for the individual and combined loading conditions for directly loaded fuel, which envelope the canistered fuel and the canistered waste configurations. The individual loading conditions are: (1) 50 psig internal pressure (including

bolt preload), (2) gravity, and (3) thermal heat (100°F) loads. Stress results for the individual loading case of 50 psig internal pressure (including bolt preload) are documented in Table 2.10.4-1. Stress results for the individual gravity cases are documented in Table 2.10.4-3. Stress results for the individual thermal loading cases are documented in Table 2.10.4-5. These are the nodal stress summaries obtained from the finite element analysis results. As described in Section 2.10.2.4.2 and Section 2.10.4, the nodal stresses are documented on the representative section cuts.

The combined loading conditions are: (1) gravity, with bolt preload and 50 psig internal pressure and (2) gravity, with bolt preload, 50 psig internal pressure, and thermal loading. Stress results for the combined loading conditions discussed above are documented in Tables 2.10.4-21 through 2.10.4-28.

These tables document the primary, primary plus secondary, primary membrane (P_m), primary membrane plus primary bending ($P_m + P_b$), primary plus secondary membrane and bending (S_n), and critical P_m, $P_m + P_b$, and S_n stresses in accordance with the criteria presented in Regulatory Guide 7.6. As described in Sections 2.10.2.3 and 2.10.2.4, procedures have been implemented to document the nodal and sectional stresses, as well as to determine the critical stress summary for all cask components.

For the individual loading condition of internal pressure, the maximum calculated membrane stress intensity is 1.1 ksi and the maximum calculated membrane plus bending stress intensity is 1.1 ksi, except that in areas affected by bolt preload, the maximum calculated membrane stress intensity is 7.5 ksi and the maximum calculated membrane plus bending stress intensity is 14.7 ksi. For the individual gravity loading condition, the maximum calculated primary membrane stress intensity is 8.9 ksi, the maximum calculated primary membrane plus primary bending stress intensity is 9.8 ksi, and the maximum calculated primary plus secondary membrane plus bending stress is 24.3 ksi.

As shown in Tables 2.10.4-26 and 2.10.4-27, the margins of safety for primary stresses are all positive for the heat condition. The most critically stressed component in the system is the inner lid. The minimum margin of safety in the inner lid for primary stresses for the heat condition is found to be $\underline{+1.2}$, as documented in Table 2.10.4-26. The locations of the most critical sections for each cask component are provided in the critical stress summary tables.

Regulatory Guide 7.6 requires that the range of primary plus secondary stress intensities between any two normal conditions of transport be less than 3.0 S_m. Therefore, it is necessary to evaluate the range of primary plus secondary stresses between all of the recognized normal conditions of transport: including the heat, cold, 1-foot end drop, 1-foot side drop, and 1-foot corner drop conditions. A simple, straightforward, and very conservative method of showing compliance with the 3.0 S_m criteria is to establish an allowable stress limit criteria of 1.5 S_m for the range of primary plus secondary stress intensities between each normal condition and the ambient condition. If each normal condition meets the 1.5 S_m allowable stress intensity range criteria at all locations within the cask when paired with the ambient condition, then all pairs of normal conditions will meet the 3.0 S_m stress intensity range criteria.

Table 2.10.4-28 documents the range of primary plus secondary stress intensity between the heat condition and the unloaded, ambient condition. The maximum calculated primary plus secondary stress intensity is shown to be 24.3 ksi, which is less than 1.5 S_m. In conjunction with the 1.5 S_m criteria for the stress intensity range between the ambient condition and each of the other normal conditions, it is therefore concluded that the NAC-STC meets the 3.0 S_m criteria for the primary plus secondary stress intensity range for the heat condition. For the fatigue evaluation of the NAC-STC, Section 2.1.3.2 documents that the requirements of Regulatory Guide 7.6 are satisfied by the 3.0 S_m criteria for the extreme total stress intensity range limit.

The documentation of the adequacy of the NAC-STC in satisfying the buckling criteria for the stresses of the heat condition is presented in Section 2.10.5.

Since the margins of safety are all positive, the NAC-STC, therefore, satisfies the requirements of 10 CFR 71.71(c)(1) for the heat (normal transport) condition for the directly loaded fuel, the canistered fuel configuration and the canistered GTCC waste configuration.

2.6.1.2 Heat Condition for the NAC-STC Cask in the CY-MPC Configuration

The three-dimensional model and analyses used in the 1-foot side drop evaluation for the CY-MPC configuration are also used for the evaluation of the heat condition. The NAC-STC cask with the CY-MPC canistered configuration is modeled as a three-dimensional structure using ANSYS STIF45 isoparametric elements. A detailed description of the three-dimensional finite element model of the NAC-STC cask body for the canistered configurations is provided in Section 2.10.2.1.3. Since some of the loading contributions for the heat condition are

axisymmetric, and the NAC-STC cask body is the same geometry for all fuel configurations, results of the two-dimensional model and analyses are combined with the results of the three-dimensional model of the CY-MPC fuel configuration.

Four categories of loads are considered in this evaluation: closure lid bolt preload, internal pressure, thermal expansion, and gravity loading:

1. Closure lid bolt preload – The required total bolt preloads on the inner and outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as described in Section 2.10.2.2.3. The stresses corresponding to the bolt preload with a 50 psig internal pressure for the directly load configuration are reported in Table 2.10.4-1 (for the two dimensional axisymmetric model), and the maximum stress intensity is 1.9 ksi (Location U). To account for the preload and internal pressure for the CY-MPC configuration, the 1.9 ksi is added to the stress intensity due to the 1g lateral load.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. A pressure of 50 psig, which envelops the calculated pressure of 38.1 psig for this configuration, is effectively used by adding the 1.9 ksi (reported above for the bolt preload) to the stress intensity due to the 1 g lateral load.

3. Thermal - The ANSYS analysis determines the stresses arising from the thermal expansion of the cask from its initial 70°F condition, including the effects of the differential thermal growth within the components, which is a result of the temperature difference across the walls of the cask. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties. The heat transfer analysis performed for maximum normal operating conditions determine the cask temperature distribution for the heat condition. The heat condition corresponds to a 100°F ambient temperature, a maximum decay heat load (17 kW), and full solar insolation.

   To bound the stresses arising from thermal expansion, the maximum gradient is used in the heat condition evaluation. The maximum temperature gradient is actually associated with the cold condition of –40°F with maximum decay heat and no solar insolation. To ensure that the minimum stress allowable is used, the allowables are taken at the

maximum temperature of the inner shell (331°F) for the heat condition described above. The temperature distribution for the canistered GTCC waste is considered to be enveloped by the 17 kW design basis heat load. Individual thermal cases are not evaluated, since the design basis heat load of 22.1 kW for the directly loaded fuel envelops the 17 kW basis heat load for the CY-MPC configuration.

4. Gravity loads - The mechanical loads consist of gravity acting on the cask structure and its contents. The cask is assumed to be loaded and resting in the horizontal position on the front and rear cask supports. Mechanical loads resulting from a 1g application of the total weight (260,000 lbs) of the cask structure and contents are imposed on the model.

These loading conditions are identical to the 1-foot side drop evaluated in 2.6.7.2.2 for the CY-MPC configuration except the 1-foot drop condition employed 20g instead of 1g for the gravity load. To determine the maximum primary stress intensity for the heat condition, the stress intensity due to the 20g loading (in Tables 2.6.7.1-3 and 2.6.7.1-4) can be factored by 1/20 and then added to the stress intensity associated with the 50 psig pressure + bolt preload (1.9 ksi).

The maximum primary stress intensities reported for the P_m and $P_m + P_b$ for the 1-foot side drop are 11.5 ksi and 20.9 ksi, respectively. Factoring these by 1/20 and adding the result to 1.9 ksi for the pressure + bolt preload, result in maximum stress intensities of 2.5 ksi and 2.9 ksi, respectively, for P_m and $P_m + P_b$. Using the minimum allowables of 19.6 ksi for P_m and 29.4 ksi for $P_m + P_b$, reported in Tables 2.6.7.1-3 and Table 2.6.7.1-4, the minimum margin for the cask body for the primary stress intensity P_m and $P_m + P_b$ are +6.8 and +9.1, respectively. It is concluded that the CY-MPC configuration satisfies the primary stress limits for the heat condition.

Using the methodology to evaluate the range of primary plus secondary stress intensities described in 2.6.1.1, the allowable stress intensity of 1.5 S_m of 29.4 ksi should be compared to bounding primary plus secondary stress intensity. This value is obtained by adding the maximum thermal stress intensity of 8.1 ksi to 2.9 ksi to obtain 11.0 ksi. Since 11.0 < 29.4 ksi, it is concluded that the CY-MPC configuration meets the 3.0 S_m criteria for the primary plus secondary stress intensity range for the heat condition.

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2.6.2 Cold

The NAC-STC body and closure lids are analyzed for structural adequacy in accordance with the requirements of 10 CFR 71.71(c)(2) Cold (normal condition of transport). The cask is loaded and ready for shipment in the horizontal position, with an ambient temperature environment of -40°F, an assumed internal pressure of 12 psig, no decay heat load, no solar insolation, and in still air and shade.

2.6.2.1 Cold Condition for the NAC-STC Cask in the Directly Loaded Fuel and Yankee-MPC Configurations

The stress analysis of the cask is performed using both the two-dimensional and the three-dimensional finite element models and the ANSYS computer program. For the NAC-STC directly loaded configuration two-dimensional analysis, the cask is modeled as an axisymmetric structure using ANSYS STIF42 isoparametric elements. The individual loading conditions of thermal cold, internal pressure, and bolt preload are analyzed using a two-dimensional axisymmetric model because both the cask structure and the load are axisymmetric. By contrast, the individual gravity loading condition and the combined loading conditions must be analyzed using three-dimensional finite element models, since the gravity loading condition is not axisymmetric. The ANSYS computer program is described in Section 2.10.1.1. The finite element model descriptions are provided in Section 2.10.2.1. The temperature-dependent material properties considered in the analysis are documented in Section 2.3.

For the cold condition, the cask is structurally loaded due to closure lid bolt preload, internal pressure, thermal cold, and gravity. The following four categories of load are considered on the cask:

1. Closure lid bolt preload – For the NAC-STC directly loaded and the Yankee-MPC configurations, the required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as explained in Section 2.10.2.2.3. The bolts are modeled as beam (ANSYS STIF3) elements.

2. Internal pressure - The cask internal pressure is temperature dependent and its maximum value is evaluated in Section 3.4.4. For analysis purposes for the cold condition, an internal pressure of 12 psig is applied on the interior surfaces of the cask cavity in the

outward normal direction. The calculated cavity pressure is -0.8 psia at -40°F for directly loaded fuel. Since the cask cavity is backfilled with helium to 1 atmosphere absolute (0 psig) at an ambient temperature, the cavity pressure at -40°F will be less than 12 psig for both the canistered fuel and the canistered GTCC waste configurations. The pressure loading region includes the lid and upper body forging mating surfaces outward to the inner lid seal centerline.

3. Thermal - The cold condition considers the cask to be subjected to an ambient temperature of -40°F, with no decay heat load and no solar insolation, in still air and shade. This cask temperature distribution calculated for the cold condition is used as an input to the ANSYS analysis to determine the stresses. The ANSYS analysis determines the stresses resulting from the thermal expansion or contraction of the cask from its initial 70°F condition to its normal transport temperature condition. These stresses include the effects of the differential thermal growth within the components, which result from the temperature difference across the walls of the cask. The cask temperature distribution is also used in the ANSYS structural analysis to determine the values of the temperature dependent material properties such as modulus of elasticity, density, and Poisson's ratio.

4. Gravity - The mechanical loads consist of gravity acting on the cask structure and its contents. The cask is assumed to be loaded and resting in the horizontal position on the front and rear cask supports. Mechanical loads resulting from a 1g application of the total weight (250,000 lbs for the directly loaded and Yankee-MPC configurations) of the cask structure and contents are imposed on the model. The weight of the empty cask (194,000 lbs) is imposed on the model as a deceleration on the mass of the cask model. The weight of the cavity contents (56,000 lbs) for directly loaded fuel is imposed on the model as a contents pressure on the contact surface of the cask cavity (see Section 2.10.2.2.1 for the contents pressure calculation). The weight of the cavity contents for the Yankee-MPC canistered fuel configuration is 55,590 pounds, including the top and bottom cask cavity spacers. For the canistered GTCC waste configuration, the weight of the cavity contents is 54,271 pounds. These weights include the cask cavity spacers.

Fabrication stresses are considered to be negligible as demonstrated in Section 2.6.11.

For the two-dimensional analyses, axisymmetric boundary conditions are applied to the two-dimensional finite element model because axisymmetry exists in the cask geometry and in the

loading conditions considered. In addition, a longitudinal support is imposed on an outside corner node at one end of the cask to prevent rigid body motion. If the cask system is in equilibrium, then the reaction force at this support will be zero for the two-dimensional model.

For the three-dimensional finite element models, symmetric boundary conditions are applied to the model by restraining the nodes on the symmetry plane to prevent translations in the direction normal to the symmetry plane. Additional restraints are applied to simulate the orientation and method of support of the cask. The cask is considered to be loaded and resting in the horizontal position on a front saddle and a rear tiedown support. Therefore, nodes at the centerline of the front saddle on the cask outer radius are radially restrained, and one node at the rear tiedown is laterally and longitudinally restrained. When the cask system is in equilibrium, then the sum of the reaction forces at the restraints will be equal to the half-cask weight (125,000 lbs) in the lateral direction and zero in the longitudinal direction. An examination of the magnitude of the reaction forces provides a check of the validity of the finite element evaluation for the cold condition.

For the NAC-STC directly loaded two-dimensional finite element analyses, all of the reaction forces are essentially zero. For the three-dimensional analysis, the reaction resultant in the cask lateral direction is 124,200 pounds. Compared to the half-cask design weight of 125,000 pounds, the unbalanced force of 800 pounds is negligible.

The allowable stress limit criteria for containment and noncontainment structures are provided in Section 2.1.2. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum transport temperature within a given component to determine the allowable stress throughout that component. Note that higher component temperatures result in lower allowable stresses.

The stresses throughout the cask body have been calculated for the individual and combined loading conditions for directly loaded fuel, which envelope the canistered fuel and canistered GTCC waste configurations. The individual loading conditions are: (1) 12 psig internal pressure (including bolt preload); (2) gravity; and (3) thermal cold (-40°F) loads. Stress results for the individual loading case of 12 psig internal pressure (including bolt preload) are documented in Table 2.10.4-2.

Stress results for the individual gravity cases are documented in Table 2.10.4-4. Stress results for the individual thermal loading cases are documented in Table 2.10.4-7. These are the nodal

stress summaries obtained from the finite element analysis results. As described in Section 2.10.2.4.2 and Section 2.10.4, the nodal stresses are documented on the representative section cuts.

The combined loading conditions are: (1) gravity, bolt preload, and 12 psig internal pressure and (2) gravity, bolt preload, 12 psig internal pressure, and thermal loading. Stress results for the combined loading conditions discussed above are documented in Tables 2.10.4-29 through 2.10.4-36.

These tables document the primary, primary plus secondary, primary membrane (P_m), primary membrane plus primary bending ($P_m + P_b$), primary plus secondary membrane and bending (S_n), and critical P_m, $P_m + P_b$, and S_n stresses in accordance with the criteria presented in Regulatory Guide 7.6. As described in Section 2.10.2.3 and 2.10.2.4, procedures have been implemented to document the nodal and sectional stresses, as well as to determine the critical stress summary for all cask components.

For the individual loading condition of internal pressure plus bolt preload, the maximum calculated membrane stress intensity is 0.3 ksi and the maximum calculated membrane plus bending stress intensity is 0.4 ksi in areas affected by bolt preload, the maximum calculated membrane stress intensity is 7.8 ksi, and the maximum calculated membrane plus bending stress intensity is 14.9 ksi. For the individual gravity loading condition, the maximum calculated membrane stress intensity is 3.9 ksi and the maximum membrane plus bending stress intensity is 4.2 ksi. For the individual thermal loading condition, the maximum calculated membrane stress intensity is 3.8 ksi and the maximum calculated membrane plus bending stress intensity is 4.0 ksi. For the combined loading condition, the maximum calculated primary membrane stress intensity is 9.2 ksi, the maximum calculated primary membrane plus primary bending stress intensity is 9.8 ksi, and the maximum calculated primary plus secondary membrane plus bending stress intensity is 15.4 ksi.

In order to determine the effect of cask temperature on stress levels, several studies were made, which compared the stress results between the heat and cold condition analyses for the directly loaded fuel configuration. The comparison of gravity stresses between the heat and cold conditions shows that there is only a minimal difference, indicating that cask stresses are essentially independent of the temperature conditions considered in these analyses. The maximum membrane plus bending stress intensity due to gravity for the heat condition, is 4.3 ksi, and the maximum membrane plus bending stress intensity due to gravity for the cold condition is

4.2 ksi. The difference in gravity stresses between the heat and the cold cases is, therefore, less than 2.3 percent.

A comparison of primary stress intensities, which consider internal pressure, bolt preload, and gravity loadings for the heat and the cold cases for the directly loaded fuel configuration shows that a negligible difference in stress exists. The maximum primary membrane plus primary bending stress intensity for the heat condition is 9.8 ksi; the maximum primary membrane plus primary bending stress intensity for the cold condition is 9.8 ksi. Therefore, the maximum primary membrane plus primary bending stress intensities are essentially the same for the heat and the cold conditions.

A final comparison of primary plus secondary stress intensities, which consider internal pressure, bolt preload, gravity, and thermal loadings for the heat and the cold cases for the directly loaded fuel configuration, shows that a difference in the stress intensities does exist as a result of the thermal expansion or contraction of the cask and the effect of temperature dependent material properties. The maximum primary plus secondary stress intensity for the heat condition is 24.3 ksi, and the maximum primary plus secondary stress intensity for the cold condition is 15.4 ksi. The difference in primary plus secondary stress intensities between the heat and the cold cases is, therefore, 36.6 percent. Based on these comparisons, it is concluded that for loadings, which do not include thermal stress effects, cask stresses are essentially independent of the temperature condition. Furthermore, note that the primary and the primary plus secondary stress intensities are greater for the heat condition than for the cold condition; also, note that allowable stress is a function of temperature, with higher component temperatures resulting in lower allowables.

Therefore, it is concluded that temperature condition 1 (corresponding to the heat condition, i.e., 100°F ambient temperature with maximum decay heat load and maximum solar insolation) is the most critical temperature condition. For this reason, the side, corner, and oblique drop analyses are performed for temperature condition 1. Additional parametric studies are performed for some drop cases in order to verify this conclusion.

As shown in Tables 2.10.4-34 and 2.10.4-35, the margins of safety are all positive for the cold condition. The most critically stressed component in the cask for the cold condition is the top forging. The minimum margin of safety for the cold condition is found to be <u>+1.2</u>, as documented in Table 2.10.4-34. The locations of the most critical sections for each cask component are provided in the critical stress summary tables.

Regulatory Guide 7.6 requires that the range of primary plus secondary stresses between any two normal conditions of transport be less than 3.0 S_m. Therefore, it is necessary to evaluate the range of primary plus secondary stress intensities between all of the normal conditions of transport: heat, cold, 1-foot end drop, 1-foot side drop, and 1-foot corner drop. A simple, straightforward, and very conservative method of showing compliance with the 3.0 S_m criteria is to establish an allowable stress limit criteria of 1.5 S_m for the range of primary plus secondary stress intensities between each normal condition and the ambient condition. If each normal condition meets the 1.5 S_m allowable stress intensity range criteria at all locations within the cask, when paired with the ambient condition, then all pairs of normal conditions will meet the 3.0 S_m stress intensity range criteria.

Table 2.10.4-36 documents the range of primary plus secondary stress intensity between the cold condition and the unloaded, ambient condition. Although the allowable stress is 3.0 S_m, as documented in this table, the maximum stress intensity range is shown to be 15.4 ksi, which is less than 1.5 S_m. In conjunction with the 1.5 S_m criteria for the stress intensity range between the ambient condition and each of the other normal conditions, it is, therefore, concluded that the NAC-STC meets the 3.0 S_m criteria for the stress intensity range.

For the fatigue evaluation of the NAC-STC, Section 2.1.3.2 documents that the requirements of Regulatory Guide 7.6 are satisfied by the 3.0 S_m criteria for the extreme total stress intensity range limit.

The documentation of the NAC-STC adequacy in satisfying the buckling criteria for the stresses of the cold condition is presented in Section 2.10.5.

Since the margins of safety are all positive, the NAC-STC, therefore, satisfies the requirements of 10 CFR 71.71(c)(2) for the cold (normal transport) condition for the directly loaded fuel, the canistered fuel configuration, and the canistered GTCC waste configuration.

2.6.2.2 Cold Condition for the NAC-STC Cask in the CY-MPC Configuration

The three-dimensional model and analyses used in the 1-foot side drop evaluation are also used for the evaluation of the cold condition. The NAC-STC cask with the CY-MPC canistered configuration is modeled as a three-dimensional structure using ANSYS STIF45 isoparametric elements. A detailed description of the three-dimensional finite element model of the NAC-STC cask body for the canistered configurations is provided in Section 2.10.2.1.3. Since some of the

loading contributions for the cold condition are axisymmetric, and the NAC-STC cask body is the same geometry for all fuel configurations, results of the two-dimensional model and analyses are combined with the results of the three-dimensional model of the CY-MPC fuel configuration.

Four categories of loads are considered in this evaluation: closure lid bolt preload, internal pressure, thermal expansion, gravity loading:

1. Closure lid bolt preload – The required total bolt preloads on the inner lid and outer lid bolts are 4.51 x10^6 pounds and 6.02 x 10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the blot shafts, as described in Section 2.10.2.2.3. The stresses corresponding to the bolt preload with a 12 psig internal pressure for the directly load configuration are reported in Table 2.10.4-2 (for the two-dimensional axisymmetric model), and the maximum stress intensity is 2.2 ksi (Location U). To account for the preload and internal pressure for the CY-MPC configuration, the 2.2 ksi is added to the stress intensity due to the 1g lateral load.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. For analysis purpose for the cold condition, an internal pressure of 12 psig is used, which envelop a backfill pressure of 0 psig. The 12 psig is effectively used by adding the 2.2 ksi (reported above for the bolt preload) to the stress intensity due to the 1g lateral load.

3. Thermal - The cold transfer analysis performed for maximum normal operating conditions determines the cask temperature distribution for the cold condition. The bounding cold load for the NAC-STC is for the directly loaded fuel of 22.1 kW, which is larger than the CY-MPC configuration 17 kW design cold load. The cold condition corresponds to a - 40°F ambient temperature, no decay heat and no solar insolation.

   To bound the stresses arising from thermal expansion, the maximum stress intensity of 7 ksi for the directly loaded fuel (Table 2.10.4-6, location R1) is added to maximum stress intensity of the other loading conditions for the cold condition of the CY-MPC configuration. This stress intensity bounds the actual cold condition described above. To ensure that the minimum stress allowable is used, the allowables are taken at the maximum temperature of the inner shell (331°F) for the cold condition described above. The temperature distribution for the canistered GTCC waste is considered to be enveloped by the 17 kW design basis cold load.

4. Gravity loads - The mechanical loads consist of gravity acting on the cask structure and it contents. The cask is assumed to be loaded and resting in the horizontal position on the front and rear cask supports. Mechanical loads resulting from a 1g application of the total weight (260,000 lbs) of the cask structure and contents are imposed on the model.

These loading conditions are identical to the 1 foot side drop evaluated in 2.6.7.2.2 for the CY-MPC configuration except the 1 foot drop condition employed 20g instead of 1g for the gravity load. Descriptions of the three-dimensional finite element model are contained in 2.6.7.2.2 and 2.10.2.1.3. To determine the maximum primary stress intensity for the cold condition, the stress intensity due to the 20g loading (in Tables 2.6.7.1-2 and 2.6.7.1-3) can be factored by 1/20 and then added to the stress intensity associated with the 50 psig pressure + bolt preload (2.2 ksi). The maximum primary stress intensity reported for P_m and $P_m + P_b$ for the 1-foot side drop are 11.5 ksi and 20.9 ksi, respectively. Factoring these by 1/20 and adding the result to 2.2 ksi for the pressure + bolt preload, results in 2.8 ksi and 3.2 ksi, respectively, for P_m and $P_m + P_b$. Using the minimum allowables of 19.6 ksi for P_m and 29.4 ksi for $P_m + P_b$, reported in Tables 2.6.7.1-4 and 2.6.7.1-5, the minimum margins of safeties for the cask body for the primary stress intensity P_m and $P_m + P_b$ are +6.0 and +8.2, respectively. It is concluded that the CY-MPC configuration satisfies the primary stress limits for the cold condition.

Using the methodology to evaluate the range of $P_m + P_b$ stress intensities described in 2.6.1.1, the allowable stress intensity of 1.5 S_m of 29.4 ksi should be compared to the bounding $P_m + P_b$ stress intensity. This value is obtained by adding the maximum thermal stress intensity of 7 ksi to 3.2 ksi to obtain 10.2 ksi. Since 10.2 < 29.4 ksi, it is concluded that the CY-MPC configuration meets the 3.0 S_m criteria for the $P_m + P_b$ stress intensity range for the cold condition.

2.6.3 Reduced External Pressure

The drop in atmospheric pressure to 3.5 psia, as specified in 10 CFR 71.71(c)(3), effectively results in an additional internal pressure in the cask of 11.2 psig. This additional pressure has a negligible effect on the NAC-STC because, in Section 2.6.1, the cask is analyzed for a normal transport conditions internal pressure of 50.0 psig. Since the maximum normal operating pressure, considering 3 percent fuel failure, is 12 psig for directly loaded fuel, 11.3 psig, which is bounding for the canistered fuel configurations, and near 0 psig for the canistered GTCC waste configuration (Section 3.4.4), the total effective internal pressure considering the drop in atmospheric pressure becomes 15.5 psig maximum. The maximum stress in the cask for the 50.0 psig internal pressure is 1,200 psi, Table 2.10.4-1. Thus, the requirements of 10 CFR 71.71(c)(3) are satisfied.

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2.6.4 Increased External Pressure

An increased external pressure of 20 psia (5.3 psig external pressure), as specified in 10 CFR 71.71(c)(4), has a negligible effect on the NAC-STC because of the thick outer shell and end closures of the cask. Conservatively, applying a 20-psi external pressure to the neutron shield shell produces hoop stresses of only 4,151 psi. This stress is negligible. Additionally, Section 2.6.7 addresses many different loading cases, which exceed these prescribed external pressure requirements. Therefore, the requirements of 10 CFR 71.71(c)(4) are satisfied.

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2.6.5 Vibration

The effect of vibrations normally incident to transportation is considered to be negligible for the NAC-STC. This conclusion is based on the following factors:

1. The natural frequency of the cask is conservatively calculated as 74 Hertz. This is much higher than 33 Hertz, which is normally the accepted minimum natural frequency of a rigid body.

2. The calculated stresses due to vibrations normally incident to transportation are much smaller than the calculated stresses for the normal transport 1-foot drop event.

The following analysis documents the second factor mentioned above.

The normal transport 1-foot side drop, discussed in Section 2.6.7.2, results in an impact deceleration equal to 18.12g. This impact force produces a 4,797 psi maximum stress intensity in the inner shell and a 5,620 psi maximum stress intensity in the outer shell of the NAC-STC for the directly loaded fuel configuration. For the canistered fuel configuration, the maximum inner shell and outer shell stress intensities are 22.9 ksi and 18.2 ksi, respectively, for an impact deceleration of 20g (Table 2.6.7.2-2). The shell stresses for the GTCC waste canister configuration will be lower than those for the fuel canister configuration due to the lower weight of the GTCC canister, although the impact deceleration may be slightly higher.

As a conservative worst case, it is assumed that the normal transport vibration acceleration is equal to the equivalent acceleration, which will produce the normal vertical loading imposed on the tiedown devices by 10 CFR 71.45(b)(1). This regulation specifies a load factor of 2.0 to be applied to the package weight; therefore, it is assumed that the tiedown devices and the cask must resist an imposed 2.0g vibration acceleration.

The maximum stress intensity range for normal transport vibration is obtained by multiplying the stress from the 1-foot side drop impact by the ratio of acceleration values from vibration to those for the drop impact. Thus the stress intensities in the outer shell (the critical component) are S_{max} = (2/18.12)(5620) = 620 psi and S_{min} = - (2/18.12)(5620) = - 620 psi, and the maximum stress intensity range is S_n = 1240 psi for the directly loaded fuel configuration. For both of the canistered fuel configurations, the inner shell (the critical component) stress intensity for normal transport vibration is estimated by ratioing from the 1-foot drop analysis as S_{max} = (2/20)(22.9) =

2.29 ksi psi. The allowable alternating stress intensity for austenitic stainless steel is determined as the 10^{11} cycle value from the "ASME Boiler and Pressure Vessel Code," Table I-9.2.2, ratioed for the effect of the 300°F temperature. This value is S_e = 12,975 psi; therefore, the margin of safety for the critical component of the NAC-STC in the directly loaded fuel configuration for normal transport vibration is:

$$MS = (S_e/S_{alt}) - 1 = (12{,}975/620) - 1 = +\text{Large}$$

where:

$$S_{alt} = 0.5\ S_n$$

The margin of safety for the inner shell for the canistered fuel configurations of the NAC-STC is:

$$MS = (12{,}975/2290) - 1 = +\text{Large}$$

During normal transport, the rotation trunnions serve as the rear tiedown for the NAC-STC. The rotation trunnion is the critical tiedown component for all three load axes; the front of the cask is supported in a cradle and restrained vertically by a band attached to the cradle. From Section 2.5.3, the critical component on the rotation trunnion is the attachment weld between the trunnion and the cask outer shell, which has an applied shear stress of 22.7 ksi. This applied shear stress is produced by the 10.2 g resultant from the combined longitudinal and vertical shock (10.0 g longitudinal and 2 g vertical) tiedown load components.

The same method is used to determine the maximum stress intensity range as is used for the cask, except that the ratio of the normal transport vibration acceleration to the resultant acceleration for the combined longitudinal and vertical shock was used. The allowable alternating stress for the weld is the same as that for the cask. The alternating shear stresses are S_{max} = (2/10.2)(22,700) = 4,451 psi and S_{min} = - (2/10.2)(22,700) = - 4,451 psi, and the maximum stress intensity range is S_n = 8,902 psi. The margin of safety for the rotation trunnion as a rear tiedown device for normal transport vibration is:

$$M.S. = (S_e/S_{alt}) - 1 = (12{,}975/8{,}902) - 1 = +\text{Large}$$

where:

$$S_{alt} = 0.5\ S_n$$

The NAC-STC satisfies the requirements for normal vibration incident to transportation as required by 10 CFR 71.71(c)(5).

2.6.6 Water Spray

Water causes negligible corrosion of the stainless steel materials used to fabricate the NAC-STC; the cask contents are protected in the sealed cavity. A water spray as specified in 10 CFR 71.71(c)(6) has no adverse effect on this package. The cask surface temperature during the water spray is between 100°F and -40°F. Consequently, the induced thermal stress in the cask components is less than the thermal stresses that occur during the extreme ambient temperature conditions for normal operation. Therefore, the requirements of 10 CFR 71.71(c)(6) are satisfied.

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2.6.7 Free Drop (1 Foot)

The free drop scenario outlined by 10 CFR 71.71(c)(7) requires the NAC-STC to be structurally adequate for a 1-foot drop (normal transport conditions) onto a flat, essentially unyielding horizontal surface in the orientation that inflicts the maximum damage to the cask. The following subsections evaluate the cask body, the impact limiters, the closure lid and bolts, the neutron shield shell, and the upper ring components; for the end, side, and corner drop orientations.

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2.6.7.1 One-Foot End Drop

The NAC-STC is structurally evaluated for the normal condition of transport 1-foot end drop in accordance with the requirements of 10 CFR 71.71. In this event, the NAC-STC (equipped with an impact limiter over each end) falls through a distance of one foot onto a flat, unyielding, horizontal surface. The cask strikes the surface in a vertical position; consequently, an end impact on the bottom end or top end of the cask occurs. The types of loading involved in an end drop event are closure lid bolt preload, internal pressure, thermal, impact load, and inertial body load. There are six credible end impact conditions to be considered, according to Regulatory Guide 7.8:

1. Top end drop with 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.
2. Top end drop with -20°F ambient temperature, maximum decay heat load, and no solar insolation.
3. Top end drop with -20°F ambient temperature, no decay heat load, and no solar insolation.
4. Bottom end drop with 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.
5. Bottom end drop with -20°F ambient temperature, maximum decay heat load, and no solar insolation.
6. Bottom end drop with -20°F ambient temperature, no decay heat load, and no solar insolation.

During an impact event, the cask body will experience a vertical deceleration. Considering the cask as a free body, the impact limiter will apply the load to the cask end to produce the deceleration. Since the deceleration represents an amplification factor for the inertial loading of the cask, the equivalent static method is adopted to perform the impact evaluations. The analyses consider the behavior of the cask to be linearly elastic. Additionally, the fabrication stresses are considered to be negligible (Section 2.6.11).

2.6.7.1.1 One-Foot End Drop Evaluation of the NAC-STC Cask in the Directly Loaded and Yankee-MPC Canistered Fuel Configurations

The NAC-STC cask is modeled as an axisymmetric structure using ANSYS STIF42 isoparametric elements. A detailed description of the two-dimensional finite element model of the NAC-STC is provided in Section 2.10.2.1.1.

Five categories of load—closure lid bolt preload, internal pressure, thermal, impact, and inertial body loads—are considered on the cask:

1. Closure lid bolt preload - The required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively, as calculated in Section 2.6.7.5. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as explained in Section 2.6.7.5. The bolts are modeled as beam (ANSYS STIF3) elements.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. Pressures of 50 psig and 12 psig are applied on the interior surfaces of the cask cavity for the hot ambient and cold ambient cases, respectively. These pressures envelope the calculated pressures for cask configurations—directly loaded fuel (12 psig), canistered fuel (11.3 psig), and canistered GTCC waste (< 11.3 psig).

3. Thermal - The thermal conditions described in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following three combinations of ambient temperature, heat load, and solar insolation for directly loaded fuel:

   Condition 1. 100°F ambient temperature, with maximum decay heat load, and maximum solar insolation.

   Condition 2. -20°F ambient temperature, with maximum decay heat load, and no insolation.

   Condition 3. -40°F ambient temperature, with no decay heat load, and no insolation.

   The cask temperature distributions calculated for each of the three temperature conditions discussed above are used as inputs to the ANSYS analyses for the directly loaded fuel

configuration. The ANSYS analysis determines the stresses arising from the thermal expansion of the cask from its initial 70°F condition, including the effects of the differential thermal growth within the components, which is a result of the temperature difference across the walls of the cask. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties.

Additional heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following two conditions for the canistered fuel configuration:

Condition 4. 100°F ambient temperature, maximum decay heat load (12.5 kW).

Condition 5. -40°F ambient temperature, maximum decay heat load (12.5 kW), and no solar insolation.

Due to the lower heat load (lower decay heat per inch of length), the temperature distribution for canistered fuel is enveloped by that for the directly loaded fuel configuration. The temperature distribution for the canistered GTCC waste (maximum decay heat = 2.9 kW) is also similarly enveloped.

4. Impact loads - The impact loads are induced by the impact limiter acting on the cask end during an end drop condition. The impact loads are determined from the energy absorbing characteristics of the impact limiters, as described in Section 2.6.7.4. The impact load is expressed in terms of the design cask weight (loaded or empty), multiplied by appropriate deceleration factors (g), for details see Section 2.6.7.4.

The impact limiter load is considered to be uniformly applied over the end surface of the finite element model of the cask. The calculation of impact pressure loads is documented in Section 2.10.2.2.2. The following is a summary of the impact pressures applied to the exterior surface of the impacting end, for the different loading scenarios, with the corresponding design deceleration (g) values for the directly loaded fuel configuration.

LOADING CONDITION	IMPACT PRESSURE FOR 1 g	DECELERATION (g)
Top end impact with basket and fuel	42.35 psi	20.0
Top end impact with basket, no fuel	35.86 psi	20.0
Bottom end impact with basket and fuel	42.35 psi	20.0
Bottom end impact with basket, no fuel	35.74 psi	20.0

For the end impact, with directly loaded fuel and basket, a uniform pressure of 847 psi (42.35 psi x [20 g/1 g]) is applied on the exterior surface of the end of the finite element model of the cask. This pressure value is calculated by dividing the total impact load ([20 g/1 g][250,000 lbs] = 5.0 x 10^6 lbs]) by the impact area ([π][43.35]^2 = 5903.8 in^2), which is the surface area of the end of the cask.

It should be noted that the design weight of the cask is 250,000 pounds, which includes the weight of the empty cask (194,000 lbs), plus the weight of the cavity contents (56,000 lbs) for the directly loaded fuel configuration. For those load conditions for which the cask contains no fuel, the basket (design weight 17,000 lbs) is still considered to be in the cask, resulting in a weight of 211,000 pounds for the empty cask with basket. The weights of the cavity contents for the canistered fuel and the canistered GTCC waste configurations are 55,590 pounds and 54,271 pounds, respectively, with the empty cask weight being 194,000 pounds; thus, the weights of the alternate configurations are enveloped by those of the directly loaded fuel configuration.

5. Inertial body load - The inertial effects, which occur during the end impact, are represented by equivalent static forces, in accordance with D'Alembert's principle. Inertial body load includes the weight of the empty cask (194,000 lbs) and the weight of the cavity contents (56,000 lbs) for the directly loaded fuel configuration, which envelopes that of the canistered fuel or the canistered GTCC waste.

Inertial loads resulting from the weight of the empty cask are imposed by applying an appropriate deceleration factor to the cask mass. The applied decelerations are determined by considering the crush strength and the geometry of the impact limiter, as explained in Section 2.6.7.4.

The inertial load resulting from the 56,000-pound contents design weight is represented as an equivalent static pressure load uniformly applied on the interior surface of the impacting end of the cask. For the load case with no fuel in the cavity, the design weight of the basket (17,000 lbs) is considered to be in the cask; the weight of the basket is represented in the ANSYS finite element model in the same manner as that of the contents.

The following is a summary of the inertial body load for a 1-g deceleration and the design decelerations for the different loading scenarios. The calculations of content pressures are documented in Section 2.10.2.2.1.

LOADING CONDITION	IMPACT PRESSURE FOR 1 g	DECELERATION (g)
Top end impact with basket and fuel	14.14 psi	20.0
Top end impact with basket, no fuel	4.29 psi	20.0
Bottom end impact with basket and fuel	14.14 psi	20.0
Bottom end impact with basket, no fuel	4.29 psi	20.0

In the ANSYS analyses, the inertial body loads are considered together with the impact loads. The results of the two simultaneous loadings are documented as "impact loads."

For an end drop (either top or bottom end) load condition, the NAC-STC cask body is loaded by the weight of the cavity contents on the interior of the inner bottom forging or on the interior of the inner lid and by the impact limiter crushing force on the exterior of the bottom plate or on the exterior of the outer lid. The calculated weight of the cavity contents for the directly loaded fuel configuration of the NAC-STC has been shown to be greater than that of the canistered fuel or GTCC waste configurations. Therefore, the cavity contents loads and the impact limiter loads on the cask for the directly loaded fuel configuration envelope those of the canistered configurations. Then, the detailed finite element stress analysis of the directly loaded fuel configuration for the end drop load conditions bounds similar analyses for the canistered configurations. No additional evaluation of the canistered configurations is required for the end drop load conditions.

The stresses throughout the cask body are calculated for individual and combined loading conditions for the directly loaded fuel configuration, which is the critical configuration. The

individual primary loading conditions are: (1) internal pressure (50 psig or 12 psig); (2) thermal heat (100°F); (3) thermal cold (-20°F); (4) top end impact (impact load only); and (5) bottom end impact (impact load only). The combined loading conditions are: (1) the 1-foot top end impact with bolt preload and 50 psig internal pressure; (2) 1-foot top end impact with bolt preload and 12 psig internal pressure; (3) 1-foot top end impact (without contents) with bolt preload and 12 psig internal pressure; (4) 1-foot bottom end impact with bolt preload and 50 psig internal pressure; (5) 1-foot bottom end impact with bolt preload and 12 psig internal pressure; and (6) 1-foot bottom end impact (without contents) with bolt preload and 12 psig internal pressure.

Because axisymmetry exists in the cask geometry and in the end-drop loading conditions, axisymmetric boundary conditions are represented in the formulation of the isoparametric elements. A longitudinal support is imposed on the corner node located in the non-impacting end of the cask, to prevent rigid body motion. When the cask system is in equilibrium (i.e., the inertial body loads match the impact loads exactly), then the reaction force at this support will be zero. An examination of the magnitude of the reaction forces provides a check of the validity of the finite element evaluation for the 1-foot end drop condition. The reaction at the longitudinal support is 920 pounds/radian for the 20 g 1-foot end drop load condition. This means that the unbalanced force of the cask model system is only $(920)(2\pi)/20 = 289$ pounds. Compared to the cask design weight of 250,000 pounds, the unbalanced force is negligible, amounting to only 0.12 percent of the design weight of the cask.

The allowable stress limit criteria, for containment and noncontainment structures, are provided in Section 2.1.2. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum operating temperature within a given component to determine the allowable stress throughout that component. Note that higher temperatures result in lower allowable stresses. A different set of cask component allowable stresses is determined for each of the temperature conditions. Table 2.10.2-5 documents the allowable stress values determined for each component, for the 100°F ambient temperature condition.

The stress results for the 1-foot top end drop loading cases for the NAC-STC with the directly loaded fuel configuration of the cavity contents are presented as follows. Stress results for the individual loading cases of internal pressure are documented in Tables 2.10.4-1 and 2.10.4-2. Stress results for the two thermal cases are provided in Tables 2.10.4-5 and 2.10.4-6. Stress results for the individual 1-foot top and bottom end drop impact loading cases are documented in Table 2.10.4-8 and 2.10.4-9. These are nodal stress summaries obtained from the finite element

analysis results. As described in Section 2.10.4, the nodal stresses are documented on the representative section cuts. Stress results for the 1-foot top and bottom end drop combined loading conditions discussed above are documented in Tables 2.10.4-37 through 2.10.4-64. These tables document the primary, primary plus secondary, primary membrane (P_m), primary membrane plus primary bending ($P_m + P_b$), primary plus secondary membrane plus bending (S_n), and critical P_m, $P_m + P_b$, and S_n stresses in accordance with the criteria presented in Regulatory Guide 7.6. As described in Sections 2.10.2.3 and 2.10.2.4, procedures have been implemented to document the nodal and sectional stresses, as well as to determine the critical (maximum) stress summary for all cask components.

For the 1-foot top end drop impact loading case, the maximum calculated membrane plus bending stress intensity is 19.3 ksi. By comparison, for the combined loading case, including impact, bolt preload, and internal pressure, the maximum calculated primary membrane plus bending stress intensity is 20.7 ksi. The maximum stress intensities due to impact alone are equal to 93 percent of the maximum primary stress intensities due to the combined loading. Therefore, it is concluded that the impact stresses are the governing factor for the 1-foot end drop condition.

For the 1-foot top end drop scenario, ANSYS analyses were performed at the three different temperature conditions outlined above for the directly loaded fuel configuration of the cask. The results from these three analyses show that the maximum $P_m + P_b$ stress intensities are 20.7 ksi, 20.0 ksi, and 18.0 ksi. These three stress results are essentially identical, with the difference between them being less than 13 percent. Since the allowable stress for a component is a function of the component temperature, with higher temperatures resulting in lower allowable stresses, the allowable stress will be lowest for temperature condition 1 because the highest component temperatures occur for that condition. As a result, the margins of safety are smallest for the analysis for temperature condition 1. The minimum margins of safety for the three temperature conditions are + 0.4, + 0.5, + 0.7, respectively. Therefore, it is concluded that the stress results from temperature condition 1 are the most critical for the top end drop accident conditions.

A similar set of ANSYS analyses was performed for the 1-foot bottom end drop case. The maximum $P_m + P_b$ stress intensities for the 1-foot bottom end drop are 13.8 ksi, 14.0 ksi, and 14.1 ksi. The maximum $P_m + P_b$ stress intensities for the bottom end drop are all lower than those for the top end drop. Hence, the top end drop condition is the most critical of the two.

As shown in Tables 2.10.4-37 through 2.10.4-64, the margins of safety for the primary stress intensity category are positive for all of the 1-foot end drop conditions. The most critically stressed component in the system is the inner lid for the top end drop. The minimum margin of safety for $P_m + P_b$ stress intensity for the top end drop condition is found to be +0.4, as documented in Table 2.10.4-43. The minimum margin of safety for $P_m + P_b$ stress intensity for the bottom end drop condition is found to be +1.1, as documented in Table 2.10.4-60. The locations of the most critical sections for each cask component are provided in the critical stress summary tables.

Regulatory Guide 7.6 requires that the range of primary plus secondary stress intensities between any two normal conditions of transport be less than 3.0 S_m. Therefore, it is necessary to evaluate the range of primary plus secondary stress intensities between all of the normal conditions of transport including: heat, cold, 1-foot end drop, 1-foot side drop, and 1-foot corner drop conditions. A simple, straightforward, and very conservative method of showing compliance with the 3.0 S_m criterion is to establish an allowable stress limit criterion of 1.5 S_m for the range of primary plus secondary stress intensities between each normal condition and the ambient condition. If the 1.5 S_m allowable stress limit criterion is satisfied at all locations within the cask, then all pairs of normal conditions will satisfy the 3.0 S_m stress range criterion.

Tables 2.10.4-44 and 2.10.4-64 document the range of primary plus secondary stress intensities between the 1-foot end drop condition and the unloaded, ambient condition for the top and bottom end drops, respectively. The maximum primary plus secondary stress intensity range (S_n) for the top end drop is 21.6 ksi, which is less than 1.5 S_m. The maximum primary plus secondary stress intensity range (S_n) for the bottom end drop is 15.9 ksi, which is also less than 1.5 S_m. In conjunction with the 1.5 S_m criterion for the stress range between the ambient condition and each of the other normal conditions, it is, therefore, concluded that the NAC-STC satisfies the 3.0 S_m criterion for the primary plus secondary stress intensity range for the 1-foot end drop load conditions.

The fatigue evaluation of the NAC-STC in Section 2.1.3.2 documents that the requirements of Regulatory Guide 7.6 are satisfied, since the 3.0 S_m criterion for the primary plus secondary stress intensity range is satisfied for the 1-foot end drop condition.

The documentation of the adequacy of the NAC-STC to satisfy the buckling criteria for the stresses of the 1-foot end drop condition is presented in Section 2.10.5.

Since all of the margins of safety for the 1-foot end drop condition are positive, the NAC-STC with the directly loaded fuel configuration satisfies the requirements of 10 CFR 71.71 for the normal condition of transport 1-foot end drop condition.

The weight of the directly loaded fuel configuration of the NAC-STC envelopes the weight of the Yankee-MPC canistered fuel and canistered GTCC waste configurations for the 1-foot end drop condition. Consequently, the requirements of 10 CFR 71.71 are also met for the Yankee-MPC configuration.

2.6.7.1.2 One-Foot End Drop Evaluation of NAC-STC in the CY-MPC Configuration

The NAC-STC cask with the CY-MPC canistered configuration is modeled as a three dimensional structure using ANSYS STIF45 isoparametric elements. A detailed description of the three-dimensional finite element model of the NAC-STC cask body for the canistered configurations is provided in Section 2.10.2.1.3. While the loading is axisymmetric, the three-dimensional model employed in this evaluation is also used for the 1-foot side drop orientation.

Five categories of loads are considered in this evaluation: closure lid bolt preload, internal pressure, thermal expansion, impact and inertial loading:

1. Closure lid bolt preload - The required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. The stresses corresponding to the bolt preload with a 50 psig internal pressure for the directly loaded configuration are reported in Table 2.10.4-1, and the maximum stress intensity is 1.9 ksi (Location U). To account for the preload and internal pressure for the CY-MPC configuration, the 1.9 ksi is added to the stresses due to the 1-foot end drop.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. A pressure of 50 psig , which envelopes the calculated pressure of 38.1 psig for this configuration, is effectively used by adding the 1.9 ksi (reported above for the bolt preload) to the stresses due to the 1-foot end drop.

3. Thermal - The ANSYS analysis determines the stresses arising from the thermal expansion of the cask from its initial 70°F condition, including the effects of the differential thermal growth within the components, which is a result of the temperature difference across the walls of the cask. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties. Heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following two conditions for the canistered fuel configuration (an analysis for the third condition is not required):

   1. 100°F ambient temperature, maximum decay heat load (17 kW).
   2. -40°F ambient temperature, maximum decay heat load (17 kW), and no solar insolation.
   3. -40°F ambient temperature, no decay heat load, and no solar insolation.

   To bound the stresses arising from thermal expansion, the maximum stress intensity (8.1 ksi, Location G5) from Table 2.10.4-5 is added to the maximum stress intensity in the end drop evaluation. The maximum thermal stress intensity is associated with Thermal Condition 1. To ensure that the minimum stress allowable is used, the allowables are taken at the maximum temperature of the inner shell (331°F) for Thermal Condition 1. The temperature distribution for the canistered GTCC waste is considered to be enveloped by the 17 kW design basis heat load. Individual thermal cases are not evaluated since the design basis heat load of 22.1 kW for the directly loaded fuel envelops the 17 kW basis heat load for the CY-MPC configuration.

4. Impact loads - The impact loads are induced by the impact limiter acting on the cask end during an end drop condition. The impact loads are determined from the energy absorbing characteristics of the impact limiters, and the impact load is expressed in terms of the design cask weight (loaded or empty), multiplied by appropriate deceleration factors (g).

   Instead of representing the impact load as a pressure applied to the ends of the cask body, the impact limiter load is actually represented by the contact force generated by the gap elements connected at the ends of the cask. (Figure 2.6.7.2-3). It should be noted that the design weight of the cask is 260,000 pounds, which bounds the weight of the empty cask (187,400 lbs), plus the weight of the cavity contents (67,196 lbs) for the CY-MPC fuel

configuration. The weight of the cavity contents for the canistered fuel configuration equals that of the canistered GTCC waste configuration.

5. Inertial body load - The inertial effects, which occur during the end impact, are represented by equivalent static forces, in accordance with D'Alembert's principle. Inertial body load includes the weight of the empty cask (194,000 lbs). Inertial loads resulting from the weight of the empty cask are imposed by applying a 20g deceleration factor to the cask mass. The applied decelerations are determined by considering the crush strength and the geometry of the impact limiter, as explained in Section 2.6.7.4.

   The inertial load resulting from the contents design weight is represented as an equivalent static pressure load uniformly applied on the interior surface of the impacting end of the cask. The pressure corresponds to 20 times the contents weight. For the bottom end drop, the pressures are applied to the bottom of the cask cavity, and for the top end drop, the pressures are applied to the inner surface of the inner lid.

Maximum stress values are obtained for the sections shown in Figure 2.6.7.2-1 by linearizing the stresses along the indicated sections. Components and nodes associated with these sections are shown in Table 2.6.7.1-1. A maximum stress intensity for the load case of "Bolt Preload + 50 psi Internal Pressure" obtained from Table 2.10.4-1 is added to the stress intensity for impact load to obtain a stress intensity associated with the combined loading of bolt preload, pressure, thermal expansion, impact and inertial loadings.

The summary of the maximum membrane stresses (P_m) and membrane plus bending ($P_m + P_b$) are presented in Tables 2.6.7.1-2 through 2.6.7.1-5 for the top end drop and the bottom end drop. All margins of safety for the 1-foot end drop condition are positive. Therefore, the NAC-STC cask with the CY-MPC fuel configuration satisfies the requirements of 10 CFR 71.71 for the normal condition of transport 1-foot end drop condition.

Using the methodology to evaluate the range of primary plus secondary stress intensities described in 2.6.1.1, the allowable stress intensity of 1.5 S_m of 29.4 ksi should be compared to the bounding primary plus secondary stress intensity. The maximum stress intensity in Table 2.6.7.1-5 (23.2 ksi) corresponds to Section 9, which includes the 1.9 ksi stress for pressure + bolt preload. The largest thermal stress intensity for the corresponding location in Table 2.10.4-5 is 1.8 ksi (Section B5). This results in a primary plus secondary stress intensity of 25.0 ksi. The

next largest stress intensity in Table 2.6.7.1-5 is 10.3 ksi at Section 10. Adding this value to the maximum thermal stress intensity of 8.1 ksi results in a primary plus secondary stress intensity of 18.4 ksi. These two combinations of stresses bound all other possible primary plus secondary stresses for the end drop condition. Since 25.0 < 29.4 ksi, it is concluded that the CY-MPC configuration meets the 3.0 S_m criteria for the primary plus secondary stress intensity range for the heat condition.

Table 2.6.7.1-1 Section Locations for Stress Evaluation (Maximums)

Section No.[1]	Component Name and Material	Inside Node	Section Location (in.)						
			X	Y	Z	Outside Node	X	Y	Z
1	Transition Shell – XM-19	197	35.5	146.1	0.0	165	37	146.1	0.0
2[2]	Inner Shell – 304	196	35.5	142.0	0.0	164	37	142.0	0.0
3	Inner Shell – 304	189	35.5	94.2	0.0	157	37	94.2	0.0
4	Bottom Forging – 304	130	35.5	14.5	0.0	123	38	14.5	0.0
5	Outer Shell – 304	280	40.7	14.5	0.0	328	43	14.5	0.0
6	Outer Shell – 304	300	40.7	103.2	0.0	358	43	103.2	0.0
7	Top Forging – 304	271	35.5	173.2	0.0	265	37.5	173.2	0.0
8	Top Forging – 304	317	40.7	173.2	0.0	435	43.4	173.2	0.0
9	Bottom Plate – 304	1	0.5	0.0	0.0	6	0.5	5.45	0.0
10	Bottom Forging – 304	10	0.5	7.45	0.0	16	0.5	13.65	0.0
11	Bottom Plate – 304	22	35.5	0.0	0.0	32	35.5	5.45	0.0
12	Bottom Forging – 304	52	35.5	7.45	0.0	62	35.5	13.65	0.0
13	Inner Lid – 304	484	0.5	178.68	0.0	786	0.5	187.65	0.0
14	Outer Lid – 17-4	510	0.5	187.68	0.0	499	0.5	192.96	0.0
15	Inner Lid – 304	485	35.5	178.68	0.0	796	35.5	187.65	0.0
16	Outer Lid – 17-4	497	35.5	187.68	0.0	495	35.5	192.96	0.0

1. Sections are shown in Figure 2.6.7.2-1.
2. This section is at the boundary of transition shell and inner shell. Allowables for 304 Stainless Steel are used for evaluation.

Table 2.6.7.1-2 CY-MPC Critical P_m Stress Summary; 1-ft Top End Drop

Section No.	P_m Stresses (ksi)						Principal Stresses (ksi)			S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) S_m	Margin of Safety
	S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	S1	S2	S3					
1	0.0	-1.6	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	1.6	1.9	3.5	31.0	7.9
2	0.0	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	1.6	1.9	3.5	19.6	4.6
3	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	19.6	5.3
4	0.0	-0.5	0.2	-0.1	0.0	0.0	0.2	0.0	-0.5	0.7	1.9	2.6	19.6	6.5
5	0.0	-0.2	0.2	0.0	0.0	0.0	0.2	0.0	-0.2	0.4	1.9	2.3	19.6	7.5
6	0.0	-1.3	0.3	0.0	0.0	0.0	0.3	0.0	-1.3	1.5	1.9	3.4	19.6	4.8
7	-0.2	-1.3	-0.2	0.0	0.0	0.0	-0.1	-0.2	-1.3	1.2	1.9	3.1	19.6	5.3
8	-0.1	-2.0	-0.1	-0.2	0.0	0.0	0.0	-0.1	-2.1	2.0	1.9	3.9	19.6	4.0
9	0.0	0.0	-0.4	0.0	0.0	0.0	0.0	-0.1	-0.4	0.4	1.9	2.3	19.6	7.5
10	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3	1.9	2.2	19.6	7.9
11	-0.2	0.0	-0.2	-0.1	0.0	0.0	0.0	-0.2	-0.2	0.2	1.9	2.1	19.6	8.3
12	0.2	-0.3	0.1	-0.1	0.0	0.0	0.2	0.1	-0.3	0.5	1.9	2.4	19.6	7.2
13	-0.2	-2.5	-0.3	0.4	0.0	0.0	-0.1	-0.3	-2.5	2.4	1.9	4.3	19.6	3.6
14	-0.5	-7.3	-1.0	0.3	-0.1	0.0	-0.5	-1.0	-7.3	6.8	1.9	8.7	19.6	1.3
15	0.0	-1.1	-0.1	0.0	-0.1	0.0	0.0	-0.1	-1.1	1.1	1.9	3.0	19.6	5.5
16	0.0	-1.4	0.0	-0.2	-0.1	0.0	0.0	0.0	-1.4	1.5	1.9	3.4	19.6	4.8

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

Table 2.6.7.1-3 CY-MPC Critical $P_m + P_b$ Stress Summary; 1-ft Top End Drop

Section No.	$P_m + P_b$ Stresses (ksi)						Principal Stresses (ksi)			S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) $1.5S_m$	Margin of Safety
	S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	S1	S2	S3					
1	0.0	-1.6	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	1.6	1.9	3.5	46.5	11.3
2	0.0	-1.6	0.0	0.0	0.0	0.0	0.0	0.0	-1.6	1.6	1.9	3.6	29.4	7.2
3	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	29.4	8.5
4	0.0	-1.3	0.0	0.0	0.0	0.0	0.0	0.0	-1.3	1.3	1.9	3.2	29.4	8.2
5	0.0	-0.8	0.0	-0.1	0.0	0.0	0.0	0.0	-0.8	0.8	1.9	2.7	29.4	9.9
6	0.0	-1.3	0.3	0.0	0.0	0.0	0.3	0.0	-1.3	1.6	1.9	3.5	29.4	7.4
7	-0.3	-2.2	-0.5	0.0	0.0	-0.1	-0.3	-0.5	-2.2	1.9	1.9	3.8	29.4	6.7
8	0.0	-3.4	-0.4	-0.1	0.0	0.0	0.0	-0.4	-3.4	3.4	1.9	5.3	29.4	4.6
9	-0.3	0.0	-2.0	0.0	0.0	-0.1	-0.1	-0.3	-2.0	2.0	1.9	3.9	29.4	6.5
10	0.3	0.1	2.4	0.0	0.0	0.1	2.4	0.3	0.1	2.4	1.9	3.3	29.4	7.9
11	-0.6	0.0	-0.1	-0.1	0.0	0.0	0.0	-0.1	-0.6	0.6	1.9	2.5	29.4	10.8
12	0.9	0.1	0.2	0.0	0.0	0.1	0.9	0.2	0.1	0.8	1.9	2.7	29.4	9.9
13	2.8	-0.9	4.6	0.4	0.0	0.1	4.6	2.8	-0.9	5.5	1.9	7.4	29.4	3.0
14	0.5	-6.6	0.9	0.4	0.3	0.0	0.9	0.5	-6.6	7.5	1.9	9.4	29.4	2.1
15	-0.1	-1.0	0.7	0.2	0.0	0.0	0.7	0.0	-1.1	1.8	1.9	3.7	29.4	7.0
16	2.0	-1.3	1.6	0.0	-0.1	-0.1	2.0	1.6	-1.3	3.3	1.9	5.2	29.4	4.7

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

Table 2.6.7.1-4 CY-MPC Critical P_m Stress Summary; 1-ft Bottom End Drop

Section No.	P_m Stresses (ksi)						Principal Stresses (ksi)			S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) S_m	Margin of Safety
	S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	S1	S2	S3					
1	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	31.0	9.0
2	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	19.6	5.3
3	0.0	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	1.5	1.9	3.4	19.6	4.8
4	-0.2	-1.6	-0.4	-0.1	0.0	0.0	-0.2	-0.4	-1.6	1.4	1.9	3.3	19.6	4.9
5	0.0	-2.5	-0.3	0.3	0.0	0.0	0.0	-0.3	-2.5	2.6	1.9	4.5	19.6	3.4
6	0.0	-1.4	0.3	0.0	0.0	0.0	0.2	0.0	-1.4	1.6	1.9	3.5	19.6	4.6
7	0.0	-0.8	0.4	0.1	0.0	0.0	0.4	0.0	-0.8	1.1	1.9	3.0	19.6	5.5
8	0.0	-0.6	0.4	-0.2	0.0	0.0	0.4	0.0	-0.6	1.0	1.9	2.9	19.6	5.8
9	-0.3	-7.3	-2.1	-0.5	0.1	-0.1	-0.2	-2.1	-7.3	7.1	1.9	9.0	19.6	1.2
10	0.0	-1.3	0.6	0.0	0.0	0.0	0.6	0.1	-1.3	1.9	1.9	3.8	19.6	4.2
11	-0.3	-1.9	-0.4	0.0	0.3	0.0	-0.3	-0.3	-1.29	1.6	1.9	3.5	19.6	4.6
12	0.4	-0.7	0.4	0.1	0.0	0.0	0.4	0.4	-0.7	1.1	1.9	3.0	19.6	5.5
13	-0.1	-0.2	-0.1	0.1	0.0	0.0	-0.1	-0.1	-0.3	0.2	1.9	2.1	19.6	8.3
14	-0.1	-0.9	-0.2	0.1	0.0	0.0	-0.1	-0.2	-0.9	0.8	1.9	2.7	19.6	6.3
15	-0.1	-0.3	-0.1	0.2	0.0	0.0	0.0	-0.1	-0.4	0.4	1.9	2.3	19.6	7.5
16	0.0	-0.1	0.0	0.1	0.0	0.0	0.0	0.0	-0.1	0.1	1.9	2.0	19.6	8.8

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

Table 2.6.7.1-5 CY-MPC Critical $P_m + P_b$ Stress Summary; 1-ft Bottom End Drop

Section No.	$P_m + P_b$ Stresses (ksi)						Principal Stresses (ksi)			S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) $1.5S_m$	Margin of Safety
	S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	S1	S2	S3					
1	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	46.5	14.0
2	0.0	-1.2	0.0	0.0	0.0	0.0	0.0	0.0	-1.2	1.2	1.9	3.1	29.4	8.5
3	0.0	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	-1.5	1.5	1.9	3.4	29.4	7.6
4	-0.4	-2.6	-0.8	-0.1	0.0	-0.1	-0.4	-0.8	-2.6	2.2	1.9	3.1	29.4	8.5
5	0.1	-4.6	-0.8	0.1	0.0	0.0	0.1	-0.8	-4.6	0.8	1.9	2.7	29.4	9.9
6	0.0	-1.4	0.2	0.0	0.0	0.0	0.2	0.0	-1.4	1.6	1.9	3.5	29.4	7.4
7	0.0	-1.0	0.3	0.0	0.0	0.0	0.3	0.0	-1.0	1.3	1.9	3.2	29.4	8.2
8	0.0	-1.2	0.2	0.1	0.0	0.0	0.2	0.0	-1.3	1.5	1.9	3.4	29.4	7.7
9	-0.5	-21.6	-12.6	-1.2	0.4	-0.8	-0.4	-12.7	-21.7	21.3	1.9	23.2	29.4	0.27
10	1.1	-0.2	8.2	0.0	0.0	0.4	8.2	1.1	-0.2	8.4	1.9	10.3	29.4	1.9
11	1.5	-1.3	1.4	-0.3	0.2	-0.1	1.6	1.3	-1.3	2.9	1.9	4.8	29.4	5.1
12	1.3	-0.6	0.9	0.2	0.0	0.0	1.3	0.9	-0.6	1.9	1.9	3.8	29.4	6.7
13	1.5	-0.4	2.4	0.1	0.0	0.0	2.4	1.5	-0.4	2.8	1.9	4.7	29.4	5.3
14	0.8	-0.9	1.4	0.1	0.1	0.0	1.4	0.8	-0.9	2.3	1.9	4.2	29.4	6.0
15	-0.2	-0.4	0.5	0.2	0.0	0.0	0.5	0.0	-0.5	1.1	1.9	3.0	29.4	8.8
16	-0.1	-0.1	0.4	0.1	0.0	0.0	0.4	0.0	-0.2	0.5	1.9	2.4	29.4	11.3

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

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2.6.7.2 One-Foot Side Drop

The NAC-STC is structurally evaluated for the normal conditions of transport 1-foot side drop in accordance with the requirements of 10 CFR 71.71. In this event, the NAC-STC (equipped with an impact limiter over each end) falls through a distance of 1 foot onto a flat, unyielding, horizontal surface. The cask strikes the surface in a horizontal position; consequently, a side impact on the cask occurs. The types of loading involved in a side drop accident are closure lid bolt preload, internal pressure, thermal, impact load, and inertial body load. There are three credible side impact conditions to be considered, according to Regulatory Guide 7.8:

1. Side drop with 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.
2. Side drop with -20°F ambient temperature, maximum decay heat load, and no solar insolation.
3. Side drop with -20°F ambient temperature, no decay heat load, and no solar insolation.

During a side drop impact event, the cask body experiences a lateral deceleration. Considering the cask as a free body, the impact limiters apply the load to the side of the cask (in the impact limiter contact area) to produce the deceleration. Since the deceleration represents an amplification factor for the inertial loading of the cask, the equivalent static method is adopted to perform the impact evaluations. The analyses consider the behavior of the cask to be linearly elastic. Additionally, fabrication stresses are considered to be negligible (Section 2.6.11).

2.6.7.2.1 One-Foot Side Drop Evaluation of the NAC-STC Cask in the Directly Loaded and Yankee-MPC Canistered Fuel Configurations

The finite element analysis method is utilized to perform the side drop stress evaluations for the NAC-STC. The 1-foot side drop condition is analyzed using a three-dimensional structural model to accurately represent the non-axisymmetric loads involved in the side drop case. One-half of the cask is modeled as a three-dimensional structure with one plane of symmetry. The ANSYS STIF45 three-dimensional solid element is the primary element type used in the model.

In order to reduce the overall problem of size to satisfy the limitations of the ANSYS program and the computer hardware, two three-dimensional models have been constructed for the directly loaded fuel configuration—the top fine mesh model and the bottom fine mesh model. A single

three-dimensional finite element model is constructed and used for the Yankee-MPC canistered fuel configuration of the NAC-STC. A detailed description of the three-dimensional finite element models of the NAC-STC is presented in Section 2.10.2.1.2 for each of the fuel configurations. The top fine mesh model contains a fine mesh region at the upper half of the cask with a relatively coarse mesh at the bottom end; the bottom fine mesh model contains a fine mesh region at the bottom end of the cask with relatively coarse mesh at the top end. Nevertheless, both models are complete representations of the cask, since the entire cask is modeled. Both models are used in the side drop analyses to obtain the detailed stresses at each end of the cask. The stress results from the fine mesh portion of each model are then combined to provide a final stress summary for the NAC-STC for the 1-foot side drop condition for the directly loaded fuel configuration. For the canistered fuel configuration, the stress results are obtained from the single finite element model of the NAC-STC for the Yankee-MPC configuration.

Five categories of load—closure lid bolt preload, internal pressure, thermal, impact, and body inertia—are considered on the cask:

1. Closure lid bolt preload - The required total bolt preloads on the inner lid and outer lid are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as explained in Section 2.10.2.2.3. The bolts are modeled as beam (ANSYS STIF4) elements.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. Pressures of 50 psig and 12 psig are applied on the interior surfaces of the cask cavity for the hot ambient and cold ambient cases, respectively. These pressures envelope the calculated pressures for all cask configurations—directly loaded fuel (12 psig), canistered fuel (11.3 psig), and canistered GTCC waste (< 11.3 psig).

3. Thermal - The heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following three combinations of ambient temperature, heat load, and solar insolation for directly loaded fuel:

   Condition 1. 100°F ambient temperature, with maximum decay heat load and maximum solar insolation.

   Condition 2. -20°F ambient temperature, with maximum decay heat load, and no solar insolation.

Condition 3. -20°F ambient temperature, with no decay heat load, and no solar insolation.

The cask temperature distributions calculated for each of the three thermal conditions are used as inputs to the ANSYS structural analyses. The ANSYS analyses determine the stresses induced by the thermal expansion of the cask from its initial 70°F condition. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties, such as modulus of elasticity, density, and Poisson's ratio.

Additional heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following two conditions for the canistered fuel configuration:

Condition 4. 100°F ambient temperature, maximum decay heat load (12.5 kW) and maximum solar insolation.

Condition 5. -40°F ambient temperature, maximum decay heat load (12.5 kW), and no solar insolation.

Due to the lower heat load (lower decay heat per inch of length), the temperature distribution for canistered fuel is enveloped by that for the directly loaded fuel configuration. The temperature distribution for the canistered GTCC waste (maximum decay heat = 2.9 kW) is also similarly enveloped.

4. Impact loads - The impact loads are induced by the impact limiters acting on the cask during a side drop condition. The impact loads are determined from the energy absorbing characteristics of the impact limiters, as described in Section 2.6.7.4. The impact load is expressed in terms of the design cask weight (loaded or empty), multiplied by appropriate deceleration factors (g). The 1-foot side drop evaluations conservatively consider a deceleration factor of 20 g based on the calculated deceleration value of 18.12 g, as documented in Section 2.6.7.4, Table 2.6.7.4.1-3.

The impact limiter load is applied to the finite element model as a distributed pressure over the contact areas between the impact limiters and the cask. The contact area is

defined based on the "crush" geometry of the impact limiter. The distribution of impact pressure is considered to be uniform in the longitudinal direction and is considered to vary in the circumferential direction. A cosine-shaped impact pressure distribution is selected for application in the circumferential direction. The cosine-shaped impact pressure distribution is peaked at the cask cross-section centerline and spread over a 79.4-degree arc on either side of that centerline in the circumferential direction, as shown in Figure 2.10.2-32. The 79.4-degree arc is based on the impact limiter geometry following a side drop crush test. The assumption of a "peaked" pressure distribution is a conservative, classical, stress analysis procedure. Since the center of gravity of the loaded cask is located within 1 inch of the longitudinal middle plane of the cask, the impact load is considered to be evenly divided between the two impact limiters. The impact contact area for a side drop accident consists of the 12.03-inch overlapping region between the impact limiter and the cask at each end of the cask.

The calculation to determine the impact pressure applied to the finite element model is documented in Section 2.10.2.2.2. That calculation is based on a 1-g deceleration condition. The following is a summary of the lateral impact pressures for the eight circumferential sectors for the directly loaded fuel configuration:

ARC (deg)	LATERAL IMPACT PRESSURE FOR 1 g (psi)	DECELERATION (g)
0 - 8.3	163.22	20
8.3 - 17.0	158.67	20
17.0 - 26.2	149.06	20
26.2 - 35.8	133.98	20
35.8 - 45.9	113.17	20
45.9 - 56.5	86.69	20
56.5 - 67.7	54.99	20
67.7 - 79.4	18.96	20

The impact pressures used in the 1-foot side drop analyses are determined by multiplying the pressure values summarized previously by the 1-foot side drop deceleration factor (20 g).

It should be noted that the design weight of the cask is 250,000 pounds, which includes the weight of the empty cask (194,000 lbs), plus the weight of the cavity contents (56,000 lbs) for the directly loaded fuel configuration. For those load conditions in which the cask contains no fuel, the basket (design weight = 17,000 lbs) is still considered to be in the cask, resulting in a weight of 211,000 pounds for the empty cask with basket. The weights of the cavity contents for the canistered fuel and the canistered GTCC waste configurations are 55,590 pounds and 54,271 pounds, respectively, with the empty cask weight being 194,000 pounds; thus, the weights of the alternate configurations are less than those of the directly loaded fuel configuration. Since the package weight for design analysis is the same, 250,000 pounds, for the NAC-STC directly loaded and Yankee-MPC configurations, the calculated lateral impact limited pressure distribution for the directly loaded fuel configuration is also applied to the ANSYS model for the Yankee-MPC configuration.

The inertial body load effects, which occur during the side impact, are represented by equivalent static forces in accordance with D'Alembert's principle. Inertial body load includes the weight of the empty cask (194,000 lbs) and the weight of the cavity contents (56,000 lbs) for the directly loaded fuel configuration, which envelopes that of the canistered fuel or the canistered GTCC waste (refer to previous paragraph).

5. Inertial body load - Inertia loads resulting from the weight of the empty cask are imposed by applying an appropriate deceleration factor to the cask mass. The applied deceleration is 20 g and is applied as explained in the discussion of impact loads.

The inertial load resulting from the 56,000-pound contents design weight is represented as an equivalent static pressure applied on the interior surface of the cask for the directly loaded fuel configuration. Specifically, the equivalent static pressure is applied with a uniform distribution along the cavity length, and with a cosine-shaped distribution in the circumferential direction. The calculation of the contents pressure, as documented in Section 2.10.2.2.1 uses the identical method as that used in the determination of the impact pressures. The following is a summary of the contents pressures for a 1-g deceleration for the eight circumferential sectors for the directly loaded fuel configuration:

ARC (deg)	LATERAL IMPACT PRESSURE FOR 1 g (psi)	DECELERATION (g)
0 - 8.3	6.51	20
8.3 - 17.0	6.33	20
17.0 - 26.2	5.95	20
26.2 - 35.8	5.34	20
35.8 - 45.9	4.51	20
45.9 - 56.5	3.46	20
56.5 - 67.7	2.19	20
67.7 - 79.4	0.76	20

Similarly, inertial load pressures are calculated for the Yankee-MPC canistered fuel configuration. As shown in Figure 2.6.7.2-2, a portion of the inertial load resulting from the 56,000 pound contents design weight is applied on the interior surface of the cask as a uniform distribution along a length of the cavity equal to the length of the canister below the shield and structural lids. The portion of the contents' inertial loading representing the shield and structural lids is distributed along a length of the cavity equal to the thickness of the two lids (8 inches). The axial location of the inertial pressures on the cask cavity represents the actual location of the canister and the lids in the cask. In the circumferential direction, the inertial pressure is applied as a cosine-shaped distribution representing the canister contact region with the cask inner shell over a 60° arc for the 1-foot side drop case (a 90° arc is used for the 30-foot side drop case). Due to the use of an identical canister and the reduced weight of the basket structure plus contents, the canistered Yankee GTCC waste configuration is enveloped by the canistered fuel configuration.

The contents pressures considered in the 1-foot side drop analyses are determined by multiplying the pressure values above by the deceleration factor of 20 g.

In the ANSYS analyses, the inertial body loads are considered together with the impact loads. The results of the two simultaneous loadings are documented as "impact loads."

The stresses throughout the cask body are calculated for individual and combined loading conditions for the directly loaded fuel configuration. The individual loading conditions are: (1) internal pressure (50 psig or 12 psig) plus bolt preload; (2) thermal heat (100°F); (3) thermal cold

(-20°F); and (4) 1-foot side impact (impact load only). The combined loading condition is the 1-foot side impact with bolt preload and 50 psig internal pressure. This is the most critical combined loading condition for the directly loaded fuel configuration based on the discussion in Section 2.7.1.2. Several parametric studies were performed to compare the stress results at the various temperature conditions. The stresses throughout the cask body are calculated for the combined loading condition: 1-foot side impact with bolt preload, 50 psig internal pressure, and 100°F ambient temperature.

The finite element model has one plane of symmetry in the cask geometry and in the side drop loading conditions. Symmetric boundary conditions are applied to the cask finite element model by restraining the nodes on the symmetry plane to prevent translations in the direction normal to the symmetry plane. In addition, two nodes at the outer cask radius on the top and bottom ends of the cask, opposite the points of impact, are restrained laterally (in the drop direction) and the node at the top is restrained in the longitudinal direction to prevent rigid body motion. When the cask system is in equilibrium (i.e., the inertial body loads match the impact loads exactly), then the reaction forces at these supports will be zero. An examination of the magnitude of the reaction forces provides a check of the validity of the finite element evaluation for the 1-foot side drop condition. The sum of reactions in the cask lateral direction for the bottom model is 3,442 pounds for the application of a 20-g load. This means that the unbalanced force of the cask model system is only 3,442/20 = 172.1 pounds. Compared to one-half of the design weight of the cask, 125,000 pounds, the unbalanced force is negligible, amounting to only 0.1 percent of the design weight of the cask. A similar check done for the top model indicates that the unbalanced force is 0.5 percent of the design weight, which is also negligible.

The allowable stress limit criteria for containment and noncontainment structures are provided in Section 2.1.2. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum operating temperature within a given component to determine the allowable stress throughout that component. Note that higher temperatures result in lower allowable stresses. A different set of component allowable stresses is determined for each temperature condition. Table 2.10.2-5 documents the allowable stress values determined for each component for temperature condition 1 (100°F ambient).

The stress results for the 1-foot side drop loading cases for the NAC-STC with the directly loaded fuel configuration of the cavity contents are presented as follows. Stress results for the individual internal pressure loading conditions are documented in Tables 2.10.4-1 and 2.10.4-2.

Stress results for the two thermal loading conditions are documented in Tables 2.10.4-5 and 2.10.4-6. Stress results for the individual 1-foot side impact loading condition are documented in Table 2.10.4-10. These are the nodal stress summaries obtained from the finite element analysis results. As described in Section 2.10.2.4.2, the nodal stresses are documented on the representative section cuts. Stress results for the combined loading condition are documented in Tables 2.10.4-65 through 2.10.4-83. These tables document: (1) the primary stresses for the 0-degree circumferential location; (2) the primary plus secondary stresses for the 0-degree circumferential location; (3) the primary membrane (P_m) stresses for the 0-, 45.9-, 91.7- and 180-degree circumferential locations; (4) the primary membrane plus primary bending ($P_m + P_b$) stresses for the 0-, 45.9-, 91.7- and 180-degree circumferential locations; (5) the primary plus secondary membrane plus bending (S_n) stresses on the 0-, 45.9-, 91.7-, and 180-degree circumferential locations; and (6) the critical P_m, $P_m + P_b$, and S_n stresses. The stress results on the 0-, 45.9-, 91.7- and 180-degree circumferential locations document the stress variation in the circumferential direction. The circumferential locations are illustrated in Figure 2.10.2-8. As described in Sections 2.10.2.3 and 2.10.2.4, procedures have been implemented to document the nodal and sectional stresses, as well as to determine the critical stress summary for all cask components.

Each of the stress summary tables for the directly loaded fuel configuration are prepared by considering the stress results of two analysis runs, the first run using the top fine mesh model and the second run using the bottom fine mesh model. The stress results from the fine mesh portion of each model are used to form the nodal and sectional stress summaries. For the critical stress summaries, stresses for the top forging, inner lid and outer lid are determined from the top fine mesh model results; stresses for the bottom plate and bottom forging are calculated from the bottom fine mesh model results; stresses for the inner shell, the transition sections, and the outer shell are determined as the larger of the stress results from the two models. In order to justify the use of stress results from both models for the side drop evaluation, comparisons are made on the combined loading (impact plus internal pressure) stress results from the two models at the middle section of the cask (Sections L and M in Figure 2.10.2-34, axial location of 96.15 inches from cask bottom). On the 0-degree and 45-degree circumferential locations, the stress results from both models show good agreement, with less than a 9 percent difference. On the 90-degree and 180-degree circumferential locations, where stresses are lower, the stress results from both models are still reasonably comparable, with less than a 13 percent difference. An additional check is performed for sections J and K (axial location of 54.90 inches) and sections N and O (axial location of 137.40 inches), which are about 40 inches away from the center of the cask

(Figure 2.10.2-34). The stress results from both models also show good agreement, with less than 10 percent difference for the 0-, 45.9- and 90-degree circumferential locations. Therefore, it is concluded that the combined stress results from the top fine mesh model and the bottom fine mesh model for the 1-foot side drop condition are valid and conservative.

It is worthwhile to mention that the most critical stress for the impact loading condition and that for the primary loading condition are essentially identical for the directly loaded fuel configuration, with a maximum difference of 5 percent. Therefore, it is concluded that the impact stresses are the governing factor for the 1-foot side drop condition.

As shown in the critical P_m and $P_m + P_b$ stress summaries (Tables 2.10.4-70 and 2.10.4-71) for the directly loaded fuel configuration, the critical stresses for most of the cask components occur on the 0-degree circumferential location, which contains the line of impact. It is also observed that for the cask inner shell, the maximum calculated stresses are located on the circumferential locations in the 67.7-degree region. This is because the maximum shearing stresses are located near the 67.7-degree circumferential location.

Similarly, the stress results for the canistered fuel configuration of the NAC-STC for the 100°F ambient temperature combined load condition are presented in Figure 2.6.7.2-1 and Tables 2.6.7.2-1 and 2.6.7.2-2. Only the inner and outer shells and their attachment regions to the top and bottom forgings are evaluated for the canistered fuel configuration because the canistered contents loading on the cask cavity does not significantly change the stresses in the end components of the cask from those for the directly loaded fuel configuration.

As shown in Tables 2.10.4-70 and 2.10.4-71, the margins of safety for the primary stress intensity category are positive for the 1-foot side drop condition. The most critically stressed component in the system is the top forging. The minimum margin of safety is found to be $\underline{+0.6}$, as documented in Table 2.10.4-70, for the directly loaded fuel configuration. The locations of the most critical sections for each cask component are provided in the critical stress summary tables. For the canistered fuel configuration, Tables 2.6.7.2-1 and 2.6.7.2-2 show that margins of safety are positive with the minimum margin of safety, +0.3, located on the inner shell near the bottom.

Regulatory Guide 7.6 requires that the range of primary plus secondary stresses between any two normal conditions of transport be less than 3.0 S_m. Therefore, it is necessary to evaluate the

range of primary plus secondary stress intensities between all of the normal conditions of transport, including the heat, cold, 1-foot end, 1-foot side, and 1-foot corner drop conditions. A simple, straightforward, and very conservative method of showing compliance with the 3.0 S_m criterion is to establish an allowable stress limit criterion of 1.5 S_m for the range of primary plus secondary stresses between each normal condition and the ambient condition. If each normal condition meets the 1.5 S_m allowable stress limit criterion at all locations within the cask when compared to the ambient condition, then all pairs of normal conditions will meet the 3.0 S_m stress range criterion.

Table 2.10.4-72 documents the range of primary plus secondary stress intensities between the 1-foot side drop condition and the unloaded, ambient condition for the directly loaded fuel configuration. The maximum S_n stress intensity range for the directly loaded fuel configuration 1-foot side drop is shown to be 26.9 ksi, which is less than 1.5 S_m. In conjunction with the 1.5 S_m criterion for the stress range between the ambient condition and each of the other normal condition, it is, therefore, concluded that the NAC-STC satisfies the 3.0 S_m criterion for the S_n stress range for the 1-foot side drop load condition. The maximum S_n stress intensity range for the canistered fuel configuration 1-foot side drop occurs at Section No. 4 (Figure 2.6.7.2-1) and is estimated by adding the principal stresses in Table 2.6.7.2-2 to those at Point F1 in Table 2.10.4-5, thermal heat condition for directly loaded fuel. The calculated value is S_n = 23.2 ksi, which is less than 1.5 S_m and satisfies the 3.0 S_m criterion.

For the fatigue evaluation of the NAC-STC, Section 2.1.3.2 documents that the requirements of Regulatory Guide 7.6 are satisfied by the 3.0 S_m criteria for the extreme total stress intensity range limit. The documentation of the NAC-STC adequacy in satisfying the buckling criteria for the stresses of the 1-foot side drop condition is presented in Section 2.10.5. The NAC-STC maintains its containment capability and, therefore, satisfies the requirements of 10 CFR 71.71 for the normal conditions of transport 1-foot side drop.

During the side drop, the bearing load on the cask cavity wall created by the fuel basket support plates in the directly loaded fuel configuration is a maximum for the normal condition loads. Considering the total cavity design weight of 56,000 pounds being supported by the 31 stainless steel support disks and the contact area being limited to a 90-degree arch length, the bearing stress is:

$S_{br\text{-}1g}$ = 56,000/(0.5 x 31 x 3.14 x 71.0 x 0.25)
= 64.8 psi

For the 18.1 g 1-foot drop the maximum bearing stress in the cavity wall is:

$S_{br\text{-}18.1g}$ = (18.1)(64.8) = 1,170 psi

Using an allowable based on the maximum inner shell temperature, 1.5 S_y = 32.94 ksi at 331°F, the margin of safety is:

MS = 32.94/1.17 - 1 = +Large

The bearing stress on the cask cavity wall for the Yankee-MPC fuel configuration is lower than that for the directly loaded fuel configuration because the support disk loads bear directly on the canister shell, which increases the bearing region on the cask cavity wall and reduces the bearing stresses. This condition is also true for the Yankee-MPC GTCC waste configuration.

2.6.7.2.2 <u>One-Foot Side Drop Evaluation for the CY-MPC Configuration</u>

The NAC-STC cask with the CY-MPC canistered configuration is modeled as a three-dimensional structure using ANSYS STIF45 isoparametric elements. A detailed description of the three-dimensional finite element model of the NAC-STC cask body for the canistered configurations is provided in Section 2.10.2.1.3. The model used in this evaluation is also used for the 1-foot end drop evaluation.

Five categories of loads are considered in this evaluation: closure lid bolt preload, internal pressure, thermal expansion, impact and inertial loading:

1. Closure lid bolt preload - The required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51 x 10^6 pounds and 6.02 x 10^5 pounds, respectively. The principal stresses corresponding to the bolt preload with a 50 psig internal pressure for the directly loaded configuration are reported in Table 2.10.4-1 and the maximum stress intensity is 1.9 ksi (Location U3). To account for the preload and internal pressure for the CY configuration, the 1.9 ksi is added to the stresses due to the 1-foot end drop.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. A pressure of 50 psig, which enveloped the calculated pressure of 38.1 psig for this configuration, is effectively used by adding the 1.9 ksi (reported above for the bolt preload) to the stresses due to the 1-foot end drop.
3. Thermal - The ANSYS analysis determines the stresses arising from the thermal expansion of the cask from its initial 70°F condition, including the effects of the differential thermal growth within the components, which is a result of the temperature difference across the walls of the cask. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties. Heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following two conditions for the canistered fuel configuration (an analysis for the third condition is not required):

   1. 100°F ambient temperature, maximum decay heat load (17 kW).
   2. -40°F ambient temperature, maximum decay heat load (17 kW), and no solar insolation.
   3. -40°F ambient temperature, no decay heat load, and no solar insolation.

   To bound the stresses arising from thermal expansion, the maximum stress intensity (8.1 ksi, location G5) from Table 2.10.4-5, is added to the maximum stress intensity in the side drop evaluation. The maximum thermal stress intensity is associated with Thermal Condition 1. To ensure that the minimum stress allowable is used, the allowables are taken at the maximum temperature of the inner shell (331°F) for Thermal Condition 1. The temperature distribution for the canistered CY GTCC waste is considered to be enveloped by the 17 kW design basis heat load. Individual thermal cases are not evaluated since the design basis heat load of 22.1 kW for the directly loaded fuel envelops the 17 kW basis heat load for the CY-MPC configuration.

4. Impact loads - The impact loads are induced by the impact limiter acting on the sides of the cask top end forging and bottom end forging during a side drop condition. The impact loads are determined from the energy absorbing characteristics of the impact limiters, and the impact load is expressed in terms of the design cask weight (loaded or empty), multiplied by appropriate deceleration factors (g).

   Instead of representing the impact load as a pressure applied to the sides of the cask body, the impact limiter load is represented by the contact force generated by the gap elements

connected at the sides for the top end forging and the bottom end forging (Similar to that shown for the side drop case shown in Figure 2.6.7.2-3). Details of the gap elements used to represent the impact limiter are also presented in Section 2.10.2.1.3. It should be noted that the design weight of the cask is 260,000 pounds, which bounds the weight of the empty cask (187,400 lbs), plus the weight of the cavity contents (67,196 lbs) for the directly loaded fuel configuration. The weight of the cavity contents for the canistered fuel equals that of the canistered GTCC waste configuration.

5. Inertial body load - The inertial effects, which occur during the end impact, are represented by equivalent static forces, in accordance with D'Alembert's principle. Inertial loads resulting from the weight of the empty cask are imposed by applying a 20g deceleration factor to the cask mass. The weight of the CY-MPC fuel, basket and canister factored by a 20g acceleration is represented by a surface pressure load. The pressure load for the canister lid and canister body with fuel is applied to the cask body using a cosine-shaped pressure distribution of a half angle of 30°. The total pressure applied to the cask is equal to the total impact load of the contents (i.e., weight multiplied by g-load). The weight of the spacer is applied to the appropriate region at the bottom of the canister.

Maximum stress values are obtained for the sections shown in Figure 2.6.7.2-1 by linearizing the stresses along the indicated sections. Components and nodes associated with these sections are shown in Table 2.6.7.1-1. A maximum stress intensity for the load case of "Bolt Preload + 50 psi Internal Pressure" obtained from Table 2.10.4-1 is added to the stress intensity for impact load to obtain a stress intensity associated with the combined loading of bolt preload, pressure, thermal expansion, impact and inertial loadings.

The summary of the maximum membrane stresses (P_m) and membrane plus bending (P_m+P_b) are presented in Tables 2.6.7.2-3 and 2.6.7.2-4. All margins of safety for the 1-foot side drop condition are positive. Therefore, the NAC-STC cask with the CY-MPC fuel configuration satisfies the requirements of 10 CFR 71.71 for the normal condition of transport 1-foot side drop condition.

Using the methodology to evaluate the range of primary plus secondary stress intensities described in 2.6.1.1, the allowable stress intensity of 1.5 S_m or 29.4 ksi should be compared to bounding primary plus secondary stress intensity. This value is obtained by adding the maximum thermal stress intensity of 8.1 ksi to 20.9 ksi (Table 2.6.7.2-4, Section 4, where the 20.9 ksi value

includes the pressure + bolt preload) to obtain 29.0 ksi. Since 29.0 < 29.4 ksi, it is concluded that the CY-MPC configuration meets the 3.0 S_m criteria for the primary plus secondary stress intensity range for the heat condition.

Figure 2.6.7.2-1 Section Locations for Stress Evaluation (Canister Configurations)

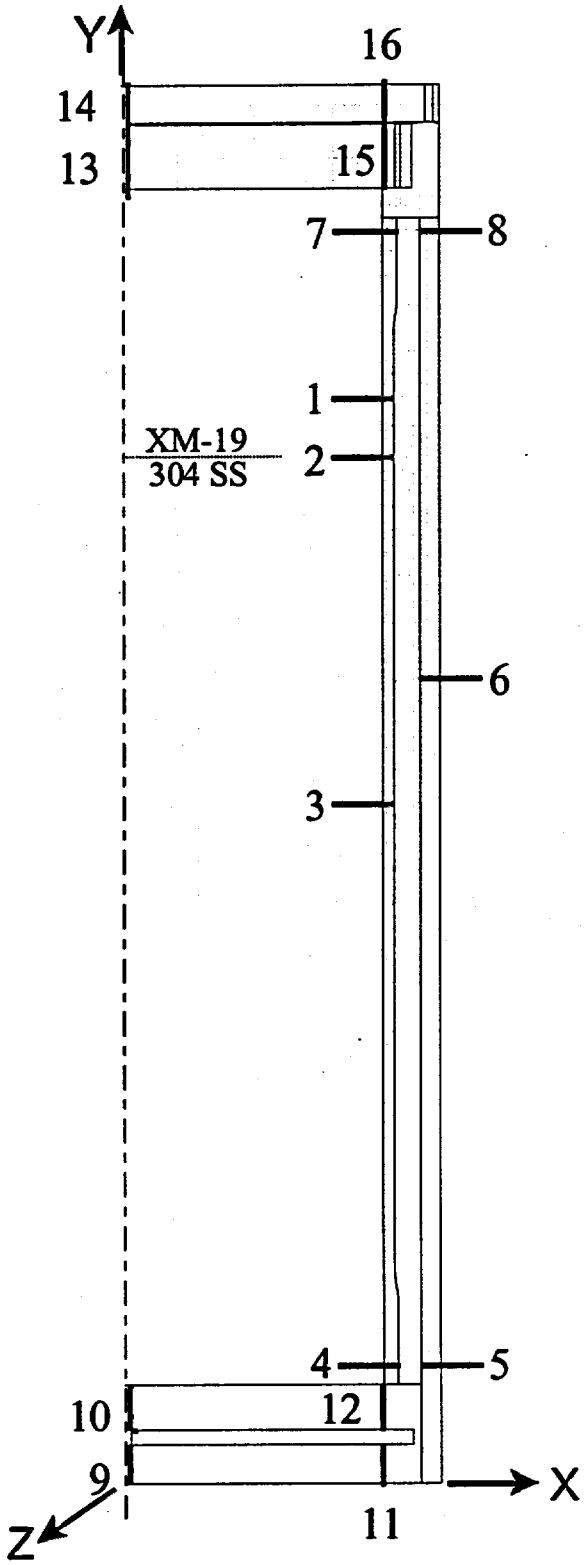

Figure 2.6.7.2-2 Yankee-MPC Model with Pressure Distribution Applied (Side Drop Case)

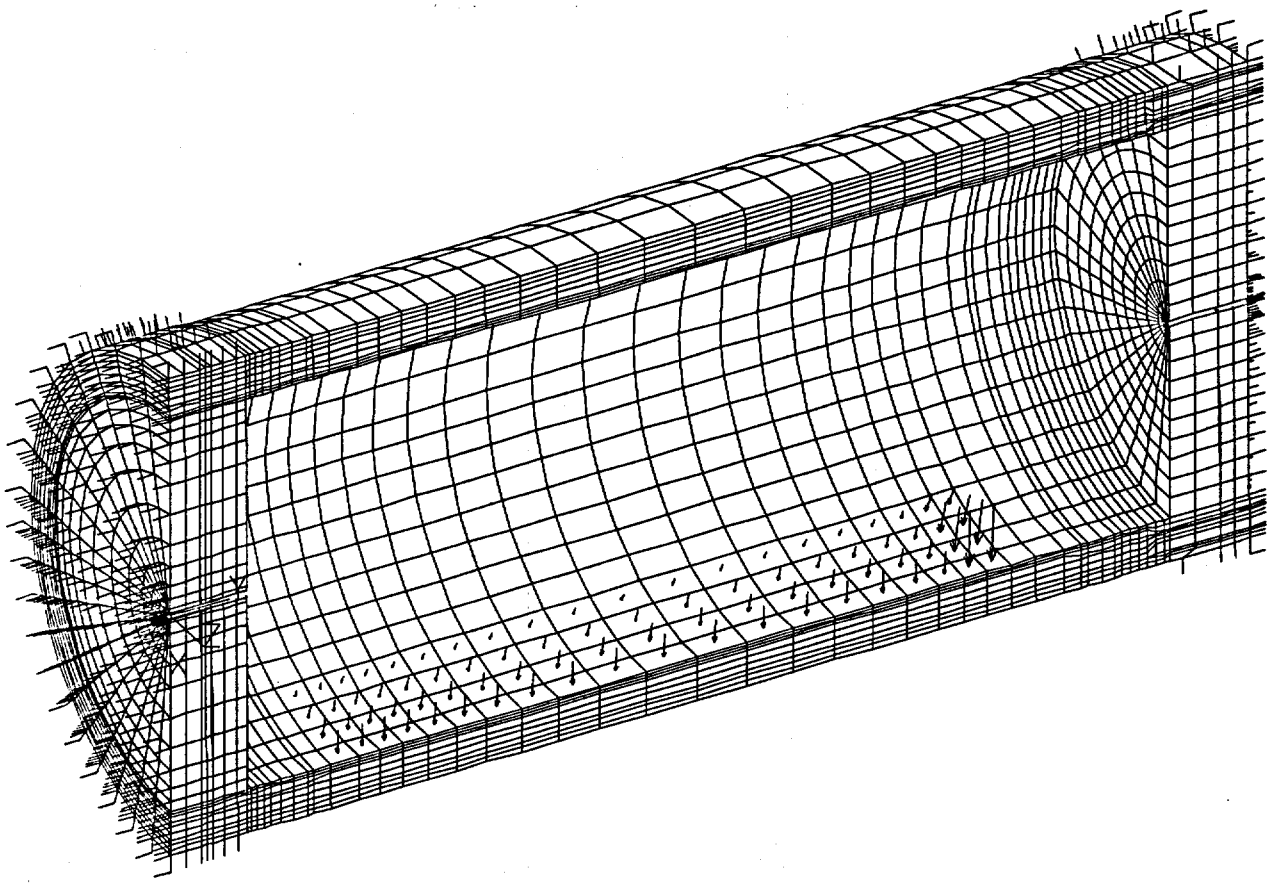

Figure 2.6.7.2-3 CY-MPC Model with Pressure Distribution Applied (Side Drop Case)

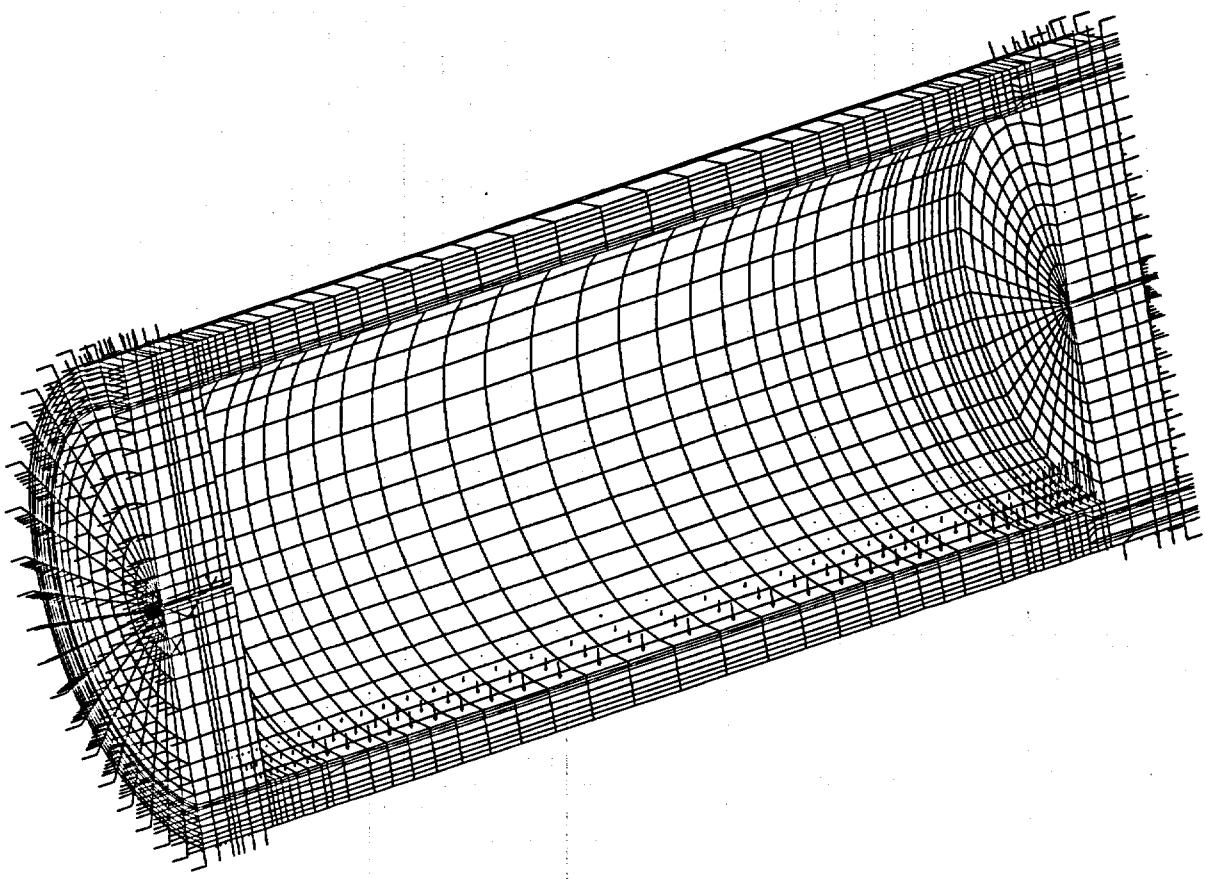

Table 2.6.7.2-1 Yankee-MPC Critical P_m Stress Summary; 1-ft. Side Drop; Drop Orientation = 90° (ksi)

Sec. No.	P_m Stresses						Principal Stresses			S.I.			Allow. Stress* S_m	Margin of Safety
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	S1	S2	S3	S.I. Impact	Bolt Preload + Pressure**	S.I. Total		
1	-1.2	3.7	5.8	-0.1	-0.7	0.6	6.1	3.5	-1.3	7.4	1.9	9.3	31.3	2.4
2	-0.8	4.8	5.3	0.2	-0.5	0.4	5.6	4.6	-0.9	6.5	1.9	8.4	19.9	1.4
3	-0.5	7.9	2.2	0.0	0.0	0.2	7.9	2.2	-0.5	8.5	1.9	10.4	19.9	0.9
4	-0.2	-5.2	-6.3	1.3	0.3	-0.4	0.1	-5.4	-6.4	6.6	1.9	8.5	19.9	1.3
5	-0.8	-1.1	-4.6	1.5	0.3	-0.4	1.6	-1.9	-4.7	6.3	1.9	8.2	19.9	1.4
6	-0.3	8.6	2.0	0.0	0.0	0.4	8.6	2.1	-0.4	9.0	1.9	10.9	19.9	0.8
7	0.0	-3.8	-4.3	-0.7	-0.2	-0.3	0.2	-3.8	-4.4	4.6	1.9	6.5	19.9	2.1
8	0.0	2.3	-0.8	-0.8	-0.3	-0.1	2.5	-0.2	-1.6	4.1	1.9	6.0	19.9	2.3

* Allowable at 311°F (maximum temperature for inner shell).
** Based on internal pressure of 50 psi.

Table 2.6.7.2-2 Yankee-MPC Critical $P_m + P_b$ Stress Summary; 1-ft. Side Drop; Drop Orientation = 90° (ksi)

Sec. No.	P_m Stresses						Principal Stresses			S.I.			Allow. Stress* S_m	Margin of Safety
	S_x	S_y	S_z	S_{xy}	S_{yz}	S_{xz}	S1	S2	S3	S.I. Impact	Bolt Preload + Pressure**	S.I. Total		
1	-1.5	12.7	16.9	-0.1	-0.3	1.3	17.0	12.7	-1.5	18.6	1.9	20.5	46.9	1.3
2	-0.9	11.7	16.6	0.1	-0.3	1.2	16.7	11.7	-0.9	17.6	1.9	19.5	29.8	0.5
3	-0.6	12.7	15.2	0.0	0.0	1.1	15.2	12.7	-0.6	15.9	1.9	17.8	29.8	0.7
4	-0.3	-20.3	-10.2	1.7	0.0	-0.7	0.5	-10.3	-20.4	21.0	1.9	22.9	29.8	0.3
5	1.2	-14.1	-7.8	0.4	0.0	-0.6	1.2	-7.9	-14.1	15.3	1.9	17.2	29.8	0.7
6	-0.3	13.9	15.8	0.0	0.0	1.3	15.9	13.9	-0.4	16.3	1.9	18.2	29.8	0.6
7	0.3	-9.6	-5.0	-1.0	0.1	-0.3	0.4	-5.0	-9.7	10.1	1.9	12.0	29.8	1.5
8	-0.5	7.4	-1.1	-1.0	-0.6	-0.0	7.6	-0.6	-1.2	8.8	1.9	10.7	29.8	1.8

* Allowable at 311°F (maximum temperature for inner shell).
** Based on internal pressure of 50 psi.

Table 2.6.7.2-3 CY-MPC Critical P_m Stress Summary; 1-ft Side Drop

Section No.	P_m Stresses (ksi) S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	Principal Stresses (ksi) S1	S2	S3	S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) S_m	Margin of Safety
1	-0.6	3.1	2.6	0.0	-0.5	0.1	3.4	2.3	-0.6	4.0	1.9	5.9	31.0	4.3
2	-0.5	4.0	2.2	0.0	-0.4	0.1	4.1	2.1	-0.5	4.6	1.9	6.5	19.6	2.0
3	-0.5	8.0	1.8	0.0	0.0	0.1	8.0	1.8	-0.6	8.6	1.9	10.5	19.6	0.87
4	-0.2	-3.7	-5.9	1.8	0.4	-0.5	0.6	-4.2	-6.1	6.7	1.9	8.6	19.6	1.28
5	1.0	1.8	-4.4	1.8	0.2	-0.5	3.2	-0.4	-4.5	7.7	1.9	9.6	19.6	1.0
6	-0.3	9.2	2.0	0.0	0.0	0.4	9.2	2.0	-0.4	9.6	1.9	11.5	19.6	0.70
7	-0.4	-4.8	-3.2	-1.8	-0.6	-0.2	0.2	-3.1	-5.5	5.7	1.9	7.6	19.6	1.6
8	0.0	3.8	0.0	-0.8	-0.3	0.1	4.0	0.0	-0.2	4.2	1.9	6.1	19.6	2.2

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

Table 2.6.7.2-4 CY-MPC Critical $P_m + P_b$ Stress Summary; 1-ft Side Drop

Section No.	$P_m + P_b$ Stresses (ksi) S_X	S_Y	S_Z	S_{XY}	S_{YZ}	S_{XZ}	Principal Stresses (ksi) S1	S2	S3	S.I. Impact (ksi)	S.I. Bolt Preload + Pressure** (ksi)	S.I. Total (ksi)	Allowable Stress* (ksi) $1.5S_m$	Margin of Safety
1	-0.6	6.1	10.8	0.0	-0.3	0.7	10.9	6.1	-0.6	11.5	1.9	13.4	46.5	2.5
2	-0.5	6.8	10.9	0.0	-0.2	0.6	10.9	6.8	-0.5	11.4	1.9	13.3	29.4	1.2
3	-0.6	12.5	14.0	0.0	0.0	1.0	14.1	12.5	-0.6	14.7	1.9	16.6	29.4	0.77
4	0.7	-20.7	-10.4	2.1	0.0	-0.8	0.9	-10.5	-21.0	19.0	1.9	20.9	29.4	0.41
5	1.3	-11.5	-8.2	0.4	-0.3	-0.7	1.4	-8.2	-11.5	12.8	1.9	14.7	29.4	1.0
6	-0.2	14.2	15.0	0.0	0.0	1.3	15.1	14.2	-0.4	15.5	1.9	17.4	29.4	0.70
7	0.6	-10.5	-3.0	-2.3	0.1	-0.2	1.0	-3.0	-11.0	12.0	1.9	13.9	29.4	1.1
8	-0.5	7.0	-0.6	-1.1	-0.9	0.1	7.2	-0.6	-0.7	8.0	1.9	9.9	29.4	2.0

* Allowable at 331°F (maximum temperature for inner shell).

** Based on internal pressure of 50 psi.

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2.6.7.3 One-Foot Corner Drop

This section presents the one-foot corner drop evaluation for the NAC-STC cask in the directly loaded, Yankee-MPC and CY-MPC configurations.

2.6.7.3.1 NAC-STC Cask One-Foot Corner Drop Evaluation for the Directly Loaded and Yankee-MPC Configurations

The NAC-STC in the directly loaded fuel configuration is structurally evaluated for the normal conditions of transport 1-foot corner drop in accordance with the requirements of 10 CFR 71.71. In this event, the NAC-STC (equipped with an impact limiter over each end) falls through a distance of 1 foot onto a flat, unyielding, horizontal surface. The cask strikes the surface on its top or bottom corner. The cask center of gravity is considered to be directly above the initial point of impact for the corner drop condition. For the NAC-STC, the orientation angle is 24 degrees for the corner drop.

Similar to the evaluation of the 1-foot end drop and side drop conditions, as presented in Sections 2.6.7.1 and 2.6.7.2, the 1-foot corner drop condition for the directly loaded fuel configuration is evaluated using finite element analysis (FEA), as shown in this Section. Based on the summary of finite element models and results (Sections 2.6.7.1 through 2.6.7.3) and the impact limiter analysis (Section 2.6.7.4), a comparison of the g-loads and finite element analysis stress results for the 1-foot end, side and corner drop conditions is shown below:

1-foot Drop Load Condition	Actual g-Load (Calculated)	g-load used in FEA	FEA Stress Results Minimum Margin of Safety
End	19.6	20	+ 0.4
Side	18.1	20	+ 0.6
Corner	5.3	20	+ 0.4

As shown, a very conservative g-load (20 g) is used in the analysis for the corner drop conditions, and the minimum margin of safety for the corner drop condition is similar to those of the end and side drop conditions. Therefore, it is concluded that the corner drop condition stresses for the directly loaded fuel configuration are bounded by the end drop and side drop condition stresses. The same conclusion can be reached for the 30-foot drop conditions using this comparison method. Since the calculated weight of the cavity contents for the directly loaded fuel

configuration has been shown to be greater than that of the Yankee-MPC fuel or GTCC waste configurations, and the center of gravity of the loaded cask is the same for both the directly loaded fuel configuration and canistered fuel configuration, it is also concluded that the corner drop condition stresses for the canistered fuel or GTCC waste configurations are bounded by the end drop and side drop condition stresses. Therefore, no additional evaluation of the 1-foot corner drop condition is required for the canistered fuel or GTCC waste configuration.

The types of loading involved in a corner drop accident are closure lid bolt preload, internal pressure, thermal, impact load, and inertial body load. There are six credible corner impact conditions to be considered, according to Regulatory Guide 7.8:

1. Top corner drop with 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.

2. Top corner drop with -20°F ambient temperature, maximum decay heat load, and no solar insolation.

3. Top corner drop with -20°F ambient temperature, no decay heat load, and no solar insolation.

4. Bottom corner drop with 100°F ambient temperature, maximum decay heat load, and maximum solar insolation.

5. Bottom corner drop with -20°F ambient temperature, maximum decay heat load, and no solar insolation.

6. Bottom corner drop with -20°F ambient temperature, no decay heat load, and no solar insolation.

The finite element analysis method is utilized to perform the corner drop stress evaluations for the NAC-STC. The corner drop conditions are analyzed using a three-dimensional finite element model to accurately represent the non-axisymmetric loads involved in the corner drop case. One-half of the cask is modeled as a three-dimensional structure with one plane of symmetry. The ANSYS STIF45 3-D solid element is the primary element type used in the model. Two models have been constructed—a top fine mesh model and a bottom fine mesh model. Each

model is a complete representation of the cask. There is a fine mesh region at the impacting end of the cask with a relatively coarse mesh at the opposite end of the cask. The maximum stresses occur at the impacting end of the cask; therefore, the fine element mesh density is used in this region to provide accurate results. The stresses calculated using the coarse element mesh at the non-impacting end of the model are an accurate representation of the stresses present there; however, the maximum stresses occur in that end of the cask for the load condition, in which it is the impacting end of the cask. The detailed descriptions of the three-dimensional finite element models of the NAC-STC are described in Section 2.10.2.1.2.

During a corner impact event, the impact limiter will apply the load to the cask impacting corner to produce the deceleration. Since the deceleration represents an amplification factor for the inertial loading of the cask, the equivalent static method is adopted to perform the impact evaluations. Additionally, the fabrication stresses are considered to be negligible (Section 2.6.11).

Five categories of load—closure lid bolt preload, internal pressure, thermal, impact, and body inertia—are considered on the cask:

1. Closure lid bolt preload - The required total bolt preloads on the inner lid bolts and the outer lid bolts are 4.51×10^6 pounds and 6.02×10^5 pounds, respectively. Bolt preload is applied to the model by imposing initial strains to the bolt shafts, as explained in Section 2.10.2.2.3. The bolts are modeled as beam (ANSYS STIF4) elements.

2. Internal pressure - The cask internal pressure is temperature dependent and is evaluated in Section 3.4.4. Pressures of 50 psig and 12 psig are applied on the interior surfaces of the cask cavity for the hot ambient and cold ambient cases, respectively. These pressures envelope the calculated pressures for all cask configurations—directly loaded fuel (12 psig), canistered fuel (11.3 psig), and canistered GTCC waste (< 11.3 psig).

3. Thermal - The heat transfer analyses performed in Sections 3.4.2 and 3.4.3 determine the cask temperature distributions for the following three combinations of ambient temperature, heat load, and solar insolation for directly loaded fuel:

   Condition 1: 100°F ambient temperature, with maximum decay heat load, and maximum solar insolation.

Condition 2: -20°F ambient temperature, with maximum decay heat load and no solar insolation.

Condition 3: -20°F ambient temperature, with no decay heat load, and no solar insolation.

The cask temperature distributions calculated for each of these three thermal conditions are used as inputs to the ANSYS structural analyses for the directly loaded fuel configuration. The ANSYS analysis determines the stresses induced by the thermal expansion of the cask from its initial 70°F condition. The cask temperature distributions are also used in the ANSYS structural analyses to determine the values of the temperature-dependent material properties, such as modulus of elasticity, density, and Poisson's ratio.

4. Impact loads - The impact loads are produced by the impact limiter acting on the cask end during a corner drop condition. The impact loads are determined from the energy absorbing characteristics of the impact limiters, as described in Section 2.6.7.4. The impact load is expressed in terms of the design cask weight (loaded or empty), multiplied by an appropriate deceleration factor (g). A design deceleration factor of 20 g is used for both top and bottom corner drops. This compares to the actual deceleration factor of 5.3 g, as documented in Section 2.6.7.4, Table 2.6.7.4.1-3.

The impact loads for the corner drop analyses have lateral and longitudinal components, which are calculated from the total impact load. The lateral load component is applied along the circumferential direction using a cosine-shaped distribution similar to that used in the side drop analysis (over a 0° to 79.4° arc on each side of the impact centerline). The longitudinal load component is applied using an uniform distribution on the end surface of the impacting end of the cask, over the same 0- to 79.4-degree arc on each side of the impact centerline.

Section 2.10.2.2.2 documents the calculation of the impact pressures for the NAC-STC design weight of 250,000 pounds and an impact limiter contact length of 24.06 inches (12.03 inches at each end). For the corner drop, the impact energy is absorbed by only one impact limiter; hence, the corner drop lateral impact pressures may be calculated by

multiplying the lateral impact pressures calculated for the side drop by 2 (the impact limiter contact length is only 12.03 inches) and by the sine of the drop angle (24° for the NAC-STC corner drop). For example, the corner drop lateral impact pressures for the elements located between the 0- and 8.29-degree circumferential planes is:

$$Press_1 = (163.22)(2)(\sin 24°) = 132.78 \text{ psi for 1 g}$$
$$Press_{20} = (132.78)(20 \text{ g}/1 \text{ g}) = 2655.6 \text{ psi for 20 g}$$

The following is a summary of the lateral impact pressures for the directly loaded fuel configuration of the NAC-STC, for the elements at the different circumferential locations, for a 1-g deceleration:

ARC (deg)	LATERAL IMPACT PRESSURE FOR 1 g (psi)	DECELERATION (g)
0 - 8.3	132.78	20
8.3 - 17.0	129.07	20
17.0 - 26.2	121.26	20
26.2 - 35.8	108.99	20
35.8 - 45.9	92.06	20
45.9 - 56.5	70.52	20
56.5 - 67.7	44.73	20
67.7 - 79.4	15.42	20

The longitudinal impact pressure may be calculated as the total impact load multiplied by the cosine of the drop angle and divided by twice the cask end area within the 0 to 79.4-degree arc. Therefore:

$$\text{Weight} = 250{,}000 \text{ lbs}$$
$$\text{Area} = (79.4/360)(2)(\pi)(43.35)^2 = 2{,}604 \text{ in}^2$$
$$Press_1 = (250{,}000)(\cos 24°)/2604 = 87.70 \text{ psi for 1 g}$$
$$Press_{20} = (87.70)(20 \text{ g}/1 \text{ g}) = 1754.0 \text{ psi for 20 g}$$

It should be noted that the design weight of the cask is 250,000 pounds, which includes the weight of the empty cask (194,000 lbs), plus the weight of the cavity contents (56,000 lbs).

5. Inertial body load - The inertial effects, which occur during the corner impact, are represented by equivalent static forces, in accordance with D'Alembert's principle. The inertial body load includes the weight of the empty cask (194,000 lbs) and the weight of the cavity contents (56,000 lbs).

Inertial loads resulting from the weight of the empty cask are imposed by applying an appropriate deceleration factor to the cask mass. The lateral and longitudinal components of inertial loading are determined in the same manner as they are for the impact loading.

The inertial load resulting from the 56,000-pound contents weight is represented as an equivalent static pressure load with the lateral and longitudinal components of the inertial load applied on the interior surface of the cask. The lateral load component is distributed to the cask model using the same circumferential cosine distribution as is used for the side drop load condition (over an arc from 0° to 79.4°). The longitudinal load component is distributed uniformly over the cask cavity end over the same 0-degree to 79.4-degree arc. The lateral load component may be determined by ratioing the side drop contents pressure values calculated in Section 2.10.2.2.1 by the deceleration (g) factor and multiplying by the sine of the drop orientation angle. The longitudinal load component is calculated by ratioing the end drop contents pressure by the deceleration (g) factor and multiplying by the cosine of the drop orientation angle. The design deceleration factor is 20 g for both the top and bottom 1-foot corner drops.

Section 2.10.2.2.1 contains the side drop contents pressures for a total contents weight of 56,000 pounds. The corner drop lateral contents pressure for the elements located between the 0- and 8.29-degree circumferential planes is, therefore:

$$Press_1 = (6.51)(\sin 24°) = 2.65 \text{ psi for 1 g}$$
$$Press_{20} = (2.65)(20 \text{ g}/1 \text{ g}) = 53.0 \text{ psi for 20 g}$$

The following is a summary of the applied lateral contents pressures for the corner drop for the directly loaded fuel configuration of the NAC-STC, for the elements at the circumferential locations, for a 1-g deceleration.

ARC (deg)	LATERAL IMPACT PRESSURE FOR 1 g (psi)	DECELERATION (g)
0 - 8.3	2.65	20
8.3 - 17.0	2.57	20
17.0 - 26.2	2.42	20
26.2 - 35.8	2.17	20
35.8 - 45.9	1.83	20
45.9 - 56.5	1.41	20
56.5 - 67.7	0.89	20
67.7 - 79.4	0.31	20

The longitudinal contents pressure is calculated from the longitudinal component of the total contents weight and the area over which it acts. Therefore:

Weight = 56,000 lbs

Area $= (\pi)(35.5)^2 = 3959 \text{ in}^2$

$Press_1 = (56{,}000)(\cos 24°)/3959 = 12.92$ psi for 1 g

$Press_{20} = (12.92)(20 \text{ g}/1 \text{ g}) = 258.4$ psi for 20 g

In the ANSYS analyses, the inertial body loads are considered together with the impact loads. The results of the two simultaneous loadings are documented as "impact loads."

The stresses throughout the cask body are calculated for individual and combined loading conditions. The individual loading conditions are: (1) internal pressure (including bolt preload); (2) top corner impact (impact load only); and (3) bottom corner impact (impact load only). Stress results for the individual loading cases of internal pressure (including bolt preload) are documented in Tables 2.10.4-1 through 2.10.4-2. The combined loading conditions are: (1) the 1-foot top corner impact with bolt preload and 50 psig internal pressure and (2) 1-foot bottom corner impact with bolt preload and 50 psig internal pressure.

The finite element model has one plane of symmetry in the cask geometry and in the corner drop loading conditions. Symmetric boundary conditions are applied to the cask finite element model

by restraining the nodes on the symmetry plane to prevent translations in the direction normal to the symmetry plane. In addition, two nodes at the outer cask radius on the top and bottom ends of the cask, opposite the point of impact, are restrained laterally; a longitudinal restraint is applied at one of the above nodes opposite to the end of impact, i.e., a bottom corner drop is axially restrained at the top node. These lateral and axial restraints are only to prevent rigid body motion; there should be no significant reaction forces associated with these restraints. When the cask system is in equilibrium (i.e., the inertial body loads match the impact loads exactly), then the reaction forces at these restraints will be zero. However, it is difficult to balance the impact limiter pressure resultant with the contents pressure and inertial body load resultant. An eccentricity between the two resultants induces a moment on the cask model. Therefore, non-zero reactions are found at the restraints. The reaction forces cause very high localized stresses (or stress singularities) in the model at the restraints. These stresses are unrealistic and do not really exist in the cask. The stress singularity effect is minimized by distributing the reaction forces over the nodes in the top and bottom regions of the model. For the bottom corner drop, the reactions at the restraints are 222.6 pounds laterally and zero pounds longitudinally for the application of a 20 g deceleration. This means that the unbalanced force of the cask model system is only 222.6/20 = 11.1 pounds. Compared to the half-cask design weight (125,000 lbs), the unbalanced force is negligible, amounting to only 0.009 percent of the design weight of the cask. For the top corner drop, the reactions at the restraints are 186.0 pounds laterally and zero longitudinally for the application of a 20 g deceleration. This means that the unbalanced force of the cask model system is only 186.0/20 = 9.3 pounds. Compared to the half-cask design weight (125,000 lbs), the unbalanced force is negligible, amounting to only 0.007 percent of the design weight of the cask. The allowable stress limit criteria for containment and noncontainment structures are provided in Section 2.1.2. These criteria are used to determine the allowable stresses for each cask component, conservatively using the maximum transport temperature within a given component to determine the allowable stress throughout that component. Note that higher component temperatures result in lower allowable stresses. Table 2.10.2-5 documents the allowable stress values determined for each component, for condition 1 temperatures.

The stress results for the 1-foot corner drop load conditions for the directly loaded fuel configuration of the NAC-STC are described as follows. Stress results for the individual 1-foot top and bottom corner drop impact loading cases are documented in Tables 2.10.4-11 and 2.10.4-12. These are the nodal stress summaries obtained from the finite element analysis

results. As described in Section 2.10.2.4.2 and Section 2.10.4, the nodal stresses are documented on the representative section cuts.

Stress results for the combined loading conditions discussed above are documented in Tables 2.10.4.8-84 through 2.10.4-111. All of the corner drop analyses are performed at temperature condition 1. Results from Sections 2.7.1.1 and 2.7.1.2 both indicate that the stresses associated with temperature condition 1 yield the smallest margins of safety due to the effect of higher temperatures upon the allowable stresses.

The stress result tables document the primary, primary plus secondary, primary membrane (P_m), primary membrane plus primary bending ($P_m + P_b$), primary plus secondary membrane plus bending (S_n), and critical P_m, $P_m + P_b$, and S_n stresses in accordance with the criteria presented in Regulatory Guide 7.6. As described in Sections 2.10.2.3 and 2.10.2.4, procedures have been implemented to document the nodal and sectional stresses, as well as to determine the critical stress summary for all cask components. The P_m and $P_m + P_b$ stresses documented in Tables 2.10.4-86 through 2.10.4-111 are stress results on the 0-, 45.9-, 91.7-, and 180-degree circumferential locations. They indicate that the stress variations in the circumferential direction are similar between the top and bottom corner drops. Furthermore, it is observed that the maximum calculated stresses are located on the circumferential locations in the 45.9- to 56.5-degree region. This is because the maximum shearing stresses are located near the 56.5-degree circumferential location. This shear stress is in the axial/circumferential location. It results from the cantilever support at the impact limiter pressure locations and is compounded by the uneven distribution of impact limiter and contents pressure loading.

For the individual impact loading cases, the maximum calculated membrane stress intensity for the top corner drop is 12.1 ksi. The maximum calculated membrane plus bending stress intensity is 24.4 ksi. By comparison, for the combined loading case, including impact, bolt preload, and internal pressure, the maximum calculated P_m stress intensity is 12.1 ksi and the maximum calculated $P_m + P_b$ stress intensity is 23.9 ksi. The maximum stress intensity for the impact loading condition and that for the primary loading condition are essentially identical, with a maximum difference of 2 percent. Therefore it is concluded that the impact stresses are the governing load condition for the 1-foot corner drop event.

The top corner drop cases result in higher maximum stress intensities than the bottom corner drop cases. As shown in Tables 2.10.4-89, 2.10.4-90, 2.10.4-103 and 2.10.4-104, the margins of

safety for the primary stress intensity category are positive for all of the 1-foot corner drop conditions. The most critically stressed component in the top corner drop is the top forging. In the bottom corner drop, the bottom forging is the most critically stressed component. The minimum margin of safety for the top corner drop condition is ±0.4, as documented in Table 2.10.4-90. The minimum margin of safety for the bottom corner drop condition is ±0.8, as documented in Table 2.10.4-104. The locations of the most critical sections for each cask component are provided in the critical stress summary tables.

Regulatory Guide 7.6 requires that the range of primary plus secondary stress intensities between any two normal conditions of transport be less than 3.0 S_m. Therefore, it is necessary to evaluate the range of primary plus secondary stress intensities between all of the normal transport conditions (heat, cold, 1-foot end drop, 1-foot side drop, and 1-foot corner drop conditions). A simple, straightforward, and very conservative method of showing compliance with the 3.0 S_m criterion is to establish an allowable stress limit criterion of 1.5 S_m for the range of primary plus secondary stress intensities between each normal condition and the ambient condition. If each normal condition meets the 1.5 S_m allowable stress limit criterion at all locations within the cask, then all pairs of normal conditions meet the 3.0 S_m stress range criterion.

Table 2.10.4-105 presents the critical component primary plus secondary stress intensity calculations for the 1-foot bottom corner drop condition; the maximum calculated primary plus secondary stress intensity is 13.4 ksi, which is less than 1.5 S_m.

Table 2.10.4-91 presents the critical component primary plus secondary stress intensity calculations for the 1-foot top corner drop. The maximum calculated primary plus secondary stress intensity for the 1-foot top corner drop for all cask components except the inner lid (component number 7) is 25.2 ksi, which is less than 1.5 S_m. Therefore, all cask components, except the inner lid, meet the conservative 1.5 S_m criterion for the 1-foot top corner drop. The maximum primary plus secondary stress intensity for the inner lid, for the 1-foot top corner drop is |-30.8| ksi, which is equal to 1.54 S_m. Therefore, the inner lid must be evaluated in a more detailed manner to determine its compliance with the 3.0 S_m criterion for the extreme total stress intensity range. An examination of the maximum critical primary plus secondary (S_n) stress intensity on the inner lid, for each of the normal transport conditions (heat, cold, 1-foot end drop, 1-foot side drop, and 1-foot corner drop), indicates that the two maximum S_n stress intensities on the inner lid for the normal transport conditions are |-30.8| ksi for the 1-foot top corner drop, as documented in Table 2.10.4-91, and |24.8| ksi for the 1-foot side drop condition, as documented

in Table 2.10.4-72. Therefore, the primary plus secondary stress intensity range for the inner lid is 30.8 + 24.8 = 55.6 ksi, which is less than 3.0 S_m (60 ksi). Thus, the inner lid also meets the 3.0 S_m criteria for extreme primary plus secondary stress intensity range limit.

It is important to note that this method of determining the maximum critical S_n stress intensity range on the inner lid is still very conservative, since the range calculation is being made between the maximum critical S_n stress intensities, which occur anywhere within the inner lid. A rigorous range calculation, using stress components on a section by section basis within the inner lid, would result in an even lower S_n stress intensity range (and hence a greater margin of safety) than that indicated by the above method.

For the fatigue evaluation of the NAC-STC, Section 2.1.3.2 documents that the requirements of Regulatory Guide 7.6 are satisfied by the 3.0 S_m criteria for the extreme total stress intensity range limit.

The documentation of the adequacy of the NAC-STC to satisfy the buckling criteria for the stresses of the 1-foot corner drop condition is presented in Section 2.10.5.

The NAC-STC satisfies all of the regulatory requirements for the normal conditions of transport 1-foot corner drop for the directly loaded fuel configuration.

2.6.7.3.2 NAC-STC Cask One-Foot Corner Drop Evaluation for the CY-MPC Configuration

The loaded canister weight for the CY-MPC configuration is 67,196 pounds as compared to the 56,000 pound content (fuel and basket) weight for the directly loaded fuel. This represents a 20% increase in contents weight. In comparing the total cask weight, the CY-MPC is only 4% heavier than the total cask weight for the directly loaded fuel. The comparison of the accelerations in 2.6.7.3.1 shows that the acceleration used in the corner evaluation was 3.8 (380%) times the actual acceleration imposed by the redwood impact limiters and 2.2 (220%) times that for the balsa impact limiters. The percentage increase of the accelerations used in the analysis above that of the impact limiter data is significantly larger than the percentage increase in the CY-MPC contents weight above that of the directly loaded fuel contents weight or the total cask weight. Additionally the heat loads responsible for the thermal stresses are larger for the directly loaded fuel than for the CY-MPC configuration. Therefore the corner drop evaluation performed for the directly loaded fuel bounds the corner drop condition for the CY-MPC configuration.

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2.6.7.4 Impact Limiters

Removable transport impact limiters are included in the NAC-STC design to ensure that the design impact loads on the cask are not exceeded for any of the defined impact load conditions. The defined loading conditions include the cask falling 1 foot or 30 feet and landing either on its side, impacting both impact limiters simultaneously, or vertically on one impact limiter at either end. As discussed in Section 2.10.7, the oblique impact events are bounded by the end and/or side drop events, as there is no "slap down" effect exhibited by the cask. Consequently, oblique drops and oblique drop angles are not evaluated.

Two impact limiter configurations are used. The first configuration, described in Section 2.6.7.4.1, incorporates redwood and balsa wood (redwood impact limiter) encased in a stainless steel shell. These impact limiters may be used only with the directly loaded fuel and Yankee-MPC canistered fuel and GTCC waste cask contents. The second configuration, described in Section 2.6.7.4.2, incorporates only balsa wood (balsa impact limiter), which is encased in a stainless steel shell. This configuration may be used with the directly loaded fuel, Yankee-MPC fuel or GTCC waste or the CY-MPC fuel or GTCC waste cask contents.

The balsa impact limiters weigh significantly less than the redwood impact limiters. In addition, the all balsa wood design eliminates reliance on "heart" redwood. Heart (center of the tree) redwood is increasingly difficult to obtain and may be unavailable in the future.

2.6.7.4.1 Redwood Impact Limiter Evaluation

The package geometry, package weight, contents weight, and package center of gravity location are the parameters that control the impact limiter design. The impact limiter evaluation presented in this section is for the package (loaded NAC-STC cask with impact limiters, as described on the drawings in Section 1.3.2) with a total weight of 250,000 pounds, a center of gravity located 96.01 inches above the bottom outer surface of the cask body, and a cavity contents weight of 56,000 pounds. This evaluation envelops the NAC-STC cask directly loaded fuel and the Yankee-MPC canistered fuel and GTCC waste configurations. The package geometry is identical for all of the configurations, as is the package center of gravity location. Axial spacers have been designed for the cask cavity to locate the Yankee-MPC canister loaded with fuel or GTCC waste such that the package center of gravity location is identical to that of the directly loaded fuel configuration. The differences in the contents weight and the associated

package weight for each of the contents configurations—56,000 pounds and 249,700 pounds for directly loaded fuel, 55,590 pounds and 249,290 pounds for the Yankee-MPC fuel, and 54,271 pounds and 247,971 pounds for the Yankee-MPC GTCC waste—have no significant effect on the impact limiter design or performance. Therefore, the impact limiter analysis in this section, the cask drop analyses in Sections 2.6.7 and 2.7.1, and the scale model tests and results in Section 2.10.6 are applicable for the directly loaded and the Yankee-MPC canistered configurations of the NAC-STC.

Assumptions

The following assumptions form the basis for the transport impact limiter analysis:

1. The cask impacts on an unyielding surface.

2. The impact limiter remains in position on the cask during all impact events (The qualification of the impact limiter attachment is presented in Section 2.6.7.4.7.).

Load Conditions

The transport impact limiters described and analyzed in the following paragraphs decelerate the cask by applying a force in the direction opposite the motion of the cask. The deceleration force is generated by crushing the redwood and balsa wood materials of the impact limiter between the cask and the unyielding surface. The energy absorbed during crushing is the net force, the vector sum of the cask weight (downward) and the deceleration force (upward), multiplied by the distance crushed. The amount of energy an impact limiter can absorb is calculated for various cask impact orientations, from vertical (0°) to horizontal (90°).

The specific loading conditions for the transport impact limiters are defined by 10 CFR 71.71(c)(7), 10 CFR 71.73(c)(1) and Regulatory Guide 7.8, as follows:

1. A 1-foot drop of the cask impacting at any angle from vertical (flat end) to corner (cask center of gravity is directly above the point of impact).

2. A 1-foot drop of the cask in a horizontal orientation.

3. A 30-foot drop of the cask in an end, a side, or an oblique orientation.

Based on these loading conditions, the NAC-STC impact limiters are primarily designed for the 30-foot cask drops, but with consideration of the 1-foot flat end drop. The maximum impact forces and the maximum crush depth for the 1-foot and 30-foot cask drops are obtained from the RBCUBED analyses of the impact limiters. RBCUBED is a proprietary NAC computer program that performs impact limiter analyses (Section 2.10.1.2).

2.6.7.4.1.1 Redwood Impact Limiter Description

Figures 2.6.7.4.1-1 and 2.6.7.4.1-2 show the locations on the cask and the primary dimensions of the transport impact limiters. Figure 2.6.7.4.1-2 shows the cross-section of an impact limiter. Except for the pockets for the lifting trunnions in the upper limiter, the upper and lower impact limiters are identical.

Each transport impact limiter consists of redwood and balsa wood, which are the energy-absorbing materials. The wood is enclosed in a thin stainless steel shell to maintain the wood orientation for a side impact.

To adequately specify the redwood crush strength, density, and their relationship to each other, NAC conducted compression tests of specimens taken from redwood purchased from a commercial supplier for the fabrication of scale model impact limiters. A total of 60 parallel-to-the-grain direction specimens from separate redwood boards and 59 perpendicular-to-the-grain direction specimens from those redwood boards (one specimen was accidentally destroyed) were tested. A density versus crush strength (at 0.4 in/in strain) plot of the test data results was constructed for each of the two crush directions. A strain value of 0.4 in/in was selected for use throughout this evaluation of redwood crush strength because it is a representative location of significant strain on the apparent plateau of the stress-strain curves for all of the redwood specimens. Based on the density versus crush strength parallel-to-the-grain direction plot, the 13 specimens with the highest densities and the two specimens with the lowest densities were discarded from the data base because they showed a significant scatter in crush strength values and inconsistent force-deflection plots, when compared with the specimens that were within the density criteria. Thus, an acceptable range of density for redwood was established, 23.5 ± 3.5 pounds per cubic foot, and only redwood with a density within this acceptable range will be used in the NAC-STC impact limiters. For the remaining 45 parallel-to-the-grain direction and 44 perpendicular-to-the-grain direction "statistical" specimens, the force and deflection test data was converted to stress-strain data by dividing the measured force by the cross-sectional area of the

specimen and by dividing the deflection by the length of the specimen. A "least squares" straight line fit was calculated for each of the crush direction data sets to establish the design relationship between density and crush strength. An average crush stress-strain curve for the parallel-to-the-grain direction was calculated by summing and averaging the test data values for the appropriate 45 statistical specimens. Similarly, an average crush stress-strain curve for the perpendicular-to-the-grain direction was calculated for the appropriate 44 statistical specimens. Figures 2.6.7.4.1-3 and 2.6.7.4.1-4 show the average, the design maximum, and the design minimum crush stress-strain curves for redwood in the parallel and perpendicular-to-the-grain directions, respectively.

The cold (-20°F) crush stress-strain curve for redwood in the parallel-to-the-grain direction was conservatively obtained from the nominal room-temperature crush stress-strain curve by ratioing based on the -40°F temperature effect shown in Figure 8 of NUREG/CR-0322. The design maximum crush stress-strain curve for redwood in the parallel-to-the-grain direction is determined by ratioing the cold crush stress-strain curve by 1.10 to account for the positive fabrication tolerance on the average crush strength of the redwood. Similarly, the design minimum crush stress-strain curve for redwood in the parallel-to-the-grain direction obtained by ratioing the nominal, room-temperature crush stress-strain curve based on the +230°F temperature effect shown in Figure 8 of NUREG/CR-0322 and on a factor of 0.90 to account for the negative fabrication tolerance. The design maximum and minimum crush stress-strain curves for redwood in the parallel-to-the-grain direction are used as the basis for the bounding impact limiter analyses in the RBCUBED program. Based on Figure 9 of NUREG/CR-0322, a dynamic crush load factor of 1.06 is appropriate for redwood. Since the design maximum and minimum crush stress-strain curves for redwood are based on quasi-static test results, but are then used directly in the RBCUBED program as dynamic crush stress-strain data, the 1.06 dynamic load factor is accounted for by reducing the specified static crush strength of the redwood to be used for the NAC-STC impact limiters. For each crush direction data set, the room-temperature average dynamic crush stress at 0.4 inch/inch strain is divided by 1.06 to obtain the average static crush stress at 0.4 inch/inch strain.

The average static crush stress ± 10 percent is used in conjunction with the "least squares" straight line for the data set to read off the equivalent density limits. The average of the density limits is the density value specified for each 30-degree pie-shaped section of redwood in the impact limiters.

The curve for the crush strength in the perpendicular-to-the-grain direction (Figure 2.6.7.4.1-4) was obtained from the compression tests of 44 specimens of redwood that were matched with the specimens used for the parallel-to-the-grain direction compression tests (one perpendicular-to-the-grain direction specimen was accidentally destroyed). The same procedure as outlined above was followed to establish the design maximum and minimum crush stress-strain curves for redwood in the perpendicular-to-the-grain direction, which are also used as the basis for the bounding impact limiter analyses.

The redwood material to be used for the NAC-STC impact limiters must satisfy density, crush strength (converted from the force-deflection curve) and moisture content specifications. The density of any single redwood board shall be 23.5 ± 3.5 pounds per cubic foot. The density of any 15-degree or 30-degree pie-shaped section of redwood shall be 22.3 ± 1.2 pounds per cubic foot. Each 15-degree pie-shaped section of redwood in the side segment of the impact limiter shall have an average dynamic crush strength in the parallel-to-the-grain direction of 6,240 ± 620 psi at 0.4 inch/inch strain and 70°F. Each 30-degree pie-shaped section of redwood in the end segment of the impact limiter shall have an average dynamic crush strength in the perpendicular-to-the-grain direction of 1,260 ± 130 psi at 0.4 inch/inch strain and 70°F. The dynamic load factor of 1.06 for redwood, previously discussed, is included in the design specification of the redwood to be used in the NAC-STC impact limiters as a reduction in the density specified for any 15-degree or 30-degree pie-shaped section. The moisture content of any single board shall be greater than 5 percent, but less than 15 percent. The average moisture content for the lot of redwood shall be less than 12 percent.

The balsa wood to be used in the NAC-STC impact limiters shall meet the specifications of MIL-S-7998A: (1) density between 7 and 10 pounds per cubic foot and (2) moisture content between 5 and 15 percent for any one piece with an average of not more than 12 percent for any lot of balsa wood. The average crush strength of the balsa wood in the parallel-to-the-grain direction at room temperature is 1,550 psi based on Figure 16 of JPL Technical Report No. 32-944 for a density of 10 pounds per cubic foot. The room-temperature crush stress-strain curve for balsa wood (Figure 2.6.7.4.1-5) is determined based on Figure 6 of JPL Technical Report No. 32-1295. The -40°F cold and the +230°F hot crush stress-strain curves are obtained by ratioing based on Figure 15 of JPL Technical Report No. 32-944. To account for crush strength fabrication tolerances, the -40°F cold case comparison stresses are factored by 1.10 and the +230°F hot case compression stresses are factored by 0.90. The resulting design maximum and minimum crush stress-strain curves for balsa wood are also presented in Figure 2.6.7.4.1-5.

The variation of crush strength of redwood and balsa wood as a function of the angle between the impact direction and the grain direction of the wood is shown in Figure 2.6.7.4.1-6 (Ref. Baumeister, page 6-157).

The outside diameter of the NAC-STC transport impact limiters is 124.0 inches and the height is 44.0 inches. The overlap between the cask body and the impact limiters is 12.0 inches. Sixteen 1.0-inch diameter retaining rods attach each impact limiter to the end of the cask. The attachments are described in detail in Section 2.6.7.4.1.4.

The height of the redwood in the end section of the impact limiter is 30.0 inches. A ring of balsa wood forms a part of the end section of the impact limiter. The ring has an inside diameter of 99.2 inches, an outside diameter of 123.75 inches, and a height of 21.6 inches. The bottom region of the impact limiter is a 1.5-inch thick layer of balsa wood, which absorbs most of the kinetic energy in a 1-foot drop end impact, and limits the initial impact force to a value acceptable for normal transport conditions. The low crush strength is necessary because the impact area is considerably greater in a flat end impact than in any other drop orientation. The redwood and the balsa wood ring absorb the majority of the energy in a corner impact and all of the energy in a side impact.

The different segments and sections comprising the impact limiters are bonded to each other with DAP-Weldwood resorcinol adhesive.

For each of the impact load conditions in this analysis, the impact limiters remain in position on the cask and absorb the energy of the impact; thus, they limit the impact loads to the calculated values tabulated in Tables 2.6.7.4.1-1 and 2.6.7.4.1-2 and summarized in Table 2.6.7.4.1-3.

2.6.7.4.1.2 Method of Analysis – Redwood Impact Limiter

The primary areas of analytical evaluation that are required in an impact limiter analysis are: (1) crush depth; (2) maximum crush force; and (3) attachment to the cask. The crush depth and maximum crush force are dependent on the crush strength of the crushable material, the area engaged in crushing, the geometry of the impact limiter, and the energy to be dissipated.

Deceleration forces for the NAC-STC redwood and balsa wood impact limiters are directly related to the area crushing and the crush strength of the limiter materials. The area engaged in crushing can be best explained by examining an end drop impact. The cask and the unyielding surface are rigid and undeformable compared to the redwood and balsa wood materials. The redwood and balsa wood materials are trapped in place between the cask and the impacted surface over the end area of the cask.

The layer of balsa wood located in the end of the impact limiters is designed to absorb the potential energy of the cask for a 1-foot drop impact. The higher crush strength redwood structurally restrains or "backs" the lower crush strength balsa wood, even if just the cask backs the higher crush strength redwood. The redwood in the NAC-STC impact limiters absorbs the kinetic energy of the cask in a 30-foot drop impact.

During an end impact, a force imbalance is established in the impact limiter between the layer of balsa wood at the bottom end and the redwood during crushing. The lower crush strength balsa wood at the bottom will crush until lock-up occurs. When lock-up occurs, the crush strength of the balsa wood increases and exceeds that of the redwood and crushing now begins in the redwood beneath the cask.

The cask has kinetic energy gained while falling prior to the impact limiter contacting the unyielding surface (Section 2.10.7 gives a more complete description of the kinetic energy gain). Some kinetic energy was dissipated in crushing the balsa wood at the bottom of the impact limiter. The remaining energy will be absorbed by crushing the higher strength redwood between the cask and the impacted surface. The cask "backs" the higher crush strength redwood; therefore, the maximum force is easily compared with the average maximum force from the quasi-static test as adjusted to reflect the dynamic crush strength of the redwood (For an explanation of the term "dynamic" as applied to quasi-static tests, refer to Section 2.10.6.4.1).

From Figure 2.10.6-12, the measured quasi-static compression force in an end impact orientation is higher than the RBCUBED calculated values. This is a result of shearing across the grain of the redwood. Shearing acts in a plane surrounding the shear area. In an end impact crush, the plane is a thin ring with a diameter equal to the diameter of the cask. Since the crush force is proportional to the backed area, which depends on the square of the cask diameter, shearing becomes a much less significant part of the maximum force for the full-scale impact limiter.

The sequence of crushing and the backed area concept are initiated as the lower crush strength balsa wood is crushed to stack height completely to the outer edge of the impact limiter. Higher crush strength redwood beneath the cask in the "backed" region is then crushed, while the redwood on the "other side" of the shear plane in the "unbacked" region is essentially uncrushed.

The combination of the accurate prediction of measured impact limiter crush forces and the visual evidence in the sectioned eighth-scale impact limiter after the quasi-static test shows that only the backed-up area of the redwood is crushed.

The cask orientation for a corner impact is defined by the angle from vertical of the cask's longitudinal axis when the cask center of gravity is vertically aligned with the impact point on the limiter. This angle is approximately 24 degrees for the top and the bottom impact limiters for the NAC-STC.

The NAC proprietary computer program, RBCUBED, is used to analyze an impact limiter for an impact event to determine the dynamics of the event, the forces generated during that event, and the depth of crush (Section 2.10.1.2).

The RBCUBED computer program is run for various combinations of redwood and balsa wood in impact limiter designs until satisfactory results are obtained. Then, two runs are made for each impact orientation. One run is made using the cold maximum crush strength stress-strain values of redwood and balsa wood plus 10 percent fabrication tolerance to determine the maximum impact limiter crush force on the cask. A second run, using the hot minimum crush strength values of redwood and balsa wood minus 10 percent fabrication tolerance is also made to determine the maximum crush depth of the impact limiter.

2.6.7.4.1.3 Redwood Impact Limiter Evaluation Results

The data in Tables 2.6.7.4.1-1 and 2.6.7.4.1-2 give the results of the impact limiter design analyses for 1-foot drops and for 30-foot drops, respectively. The calculated g-loads in the tables are based on the cold crush strength of -40°F plus 10 percent fabrication tolerance and on the hot crush strength at 230°F minus the 10 percent fabrication tolerance of redwood and balsa wood. The design cask weight of 250,000 pounds is used.

The calculated (RBCUBED) and measured (quasi-static, adjusted for dynamic crush strength) force-deflection curves for the NAC-STC impact limiters for all drop orientations are presented in Section 2.10.7. To verify the results, the area under the curves is calculated by the trapezoidal method. This area represents the energy dissipated for each of the cases; i.e., $E_{max} = 9.02 \times 10^7$ inch-pounds for the upper impact limiter at maximum strength and $E_{min} = 8.997 \times 10^7$ inch-pounds for the upper impact limiter for the minimum crush strength condition. The potential energy to be dissipated is the cask weight (250,000 lbs) multiplied by the distance the cask drops (360 in); i.e., $E_p = (360)(250{,}000) = 9.0 \times 10^7$ inch-pounds. The calculated and actual values compare within 0.22 percent, which indicates that the proper amount of potential energy is dissipated in the RBCUBED analysis. Another check is made by multiplying the total crush area (the maximum area backed by the cask) by the crush strength of the impact limiters to determine the reacting force. This hand-calculated value of the reaction force compares within 1.08 percent of the RBCUBED calculated value for the lower impact limiter and within 1.93 percent for the upper impact limiter. These results verify both the energy absorption and the reaction force calculations of RBCUBED for the impact limiters.

With both impact limiters at their minimum allowable crush strength (maximum crush depth case), clearance is maintained between the neutron shield and the unyielding surface for the 1-foot and 30-foot side impacts.

An evaluation of the displacements obtained from the RBCUBED runs is as follows:

1. The RBCUBED run for the 30-foot side drop assumes that the cask is a rigid element and does not include the trunnions; therefore, the displacement from the 30-foot drop must be analyzed by referring to Figure 2.6.7.4.1-2, as follows:

   The depth of crushable redwood around the side of the cask is 18.28 inches. The height of the lifting trunnion is 3.38 inches, leaving a height of 14.9 inches of crushable redwood outside of the lifting trunnions. The RBCUBED run for a 30-foot side drop calculates a crush depth of 10 inches for the maximum crush strength condition and 14.7 inches for the minimum crush strength condition. For the maximum crush strength condition, the compression ratio of the redwood at the trunnion location is 10.0/14.9 = 0.67, corresponding to a stress of 13,850 psi in the redwood. The compression ratio of the redwood away from the trunnion location is 10.0/18.28 = 0.55, corresponding to a crush stress of 8,850 psi. The increase in crush stress due to the presence of the trunnion is,

therefore, 13,850 – 8,850 = 5,000 psi. The area of the trunnion covered by the impact limiter is 20.0 square inches. The increase in the deceleration force due to the presence of the trunnion is (20.0)(5000) = 100,000 pounds. The total deceleration force at the trunnion location increases from 1.35×10^7 pounds to 1.36×10^7 pounds, producing a deceleration increase of 0.3 g (0.5 percent) from 54.1 g to 54.4 g.

For the minimum crush strength condition, the compression ratio of the redwood at the trunnion location is 14.7/14.9 = 0.98, corresponding to a stress of 18,900 psi in the redwood. The compression ratio of the redwood away from the trunnion location is 14.7/18.28 = 0.80, corresponding to a stress of 11,400 psi in the redwood. The increase in deceleration force due to the presence of a trunnion is (20.0)(18,900 - 11,400) = 150,000 pounds. The total deceleration force increases from 1.24×10^7 pounds to 1.255×10^7 pounds, producing a deceleration increase of 0.5 g (1.0 percent) from 49.7 g to 50.2 g. Thus, it can be concluded that a side impact of the cask over a lifting trunnion has a minimal effect on the deceleration force and may be ignored.

2. The 30-foot flat top end drop of the NAC-STC produces a deformation of 17.7 inches in the redwood for the minimum crush strength condition with a compression ratio of 17.7/30 = 59 percent. This corresponds to a stress of 2,440 psi in the redwood. Similarly, the deformation of the redwood for the maximum crush strength condition is 12.5 inches, with a compression ratio of 12.5/20 = 42 percent. This corresponds to 1,810 psi. Both stress values are well below lock-up stresses, which start at a compression ratio of 69 percent.

3. For a 30-foot corner drop on the upper impact limiter, the maximum impact force occurs with the crushable material at hot condition. For this condition, the crush distance is 31.6 inches. The NAC-STC impact limiter depth in the 24-degree corner impact orientation is 35.1 inches. The maximum compression ratio of the impact limiter is 31.6/35.1 = 90 percent for the upper impact limiter for the minimum crush strength condition. Thus, lock-up occurs, but only in a very local region. The calculated average compression stress is 1,783 psi. Similarly, the crush depth for the maximum crush strength condition is 26.6 inches (75.8 percent) with a calculated average compression stress of 1,937 psi.

The cask analysis for these impact conditions is based on the maximum deceleration (g) derived from the RBCUBED results. The critical condition for maximum deceleration from any 1-foot

drop is for the maximum crush strength condition. This results from the higher crush strength of the redwood and balsa wood in the cold condition. No lock-up occurs in the redwood and balsa wood for the minimum crush strength condition for a 1-foot drop. The critical deceleration condition for a bottom end impact is the maximum crush strength (cold) condition; the critical deceleration condition for a top end impact is the minimum crush strength (hot) condition, where lock-up in the redwood occurs because of the high compression ratio. The critical deceleration condition for the bottom and top corner impacts is the minimum crush strength (hot) condition, where local lock-up in the redwood and balsa wood occurs. The critical deceleration condition for a side drop is the maximum crush strength (cold) condition.

The calculated g-load factors (deceleration values) for the NAC-STC, as determined by the RBCUBED analyses, are summarized in Table 2.6.7.4.1-3. Table 2.6.7.4.1-4 provides a comparison of the deceleration g-loads for the 30-foot cask drop conditions, including the deceleration values determined by the RBCUBED analyses, those measured in the eighth-scale quasi-static tests, those measured in the 30-foot drop tests, and the values used in the stress qualifications of the cask and fuel basket design. The comparison demonstrates that the g-loads measured in the 30-foot drop tests are lower than the g-loads for which the cask and fuel basket were designed for all of the drop orientations. The table also indicates that the g-load values used for design are all greater than or equal to the g-load values predicted by RBCUBED for the corresponding drop orientations.

2.6.7.4.1.4 Redwood Impact Limiter Attachment Analysis

A three-part design criteria applies to the method of attachment of the impact limiters to the cask body. These three criteria are as follows:

1. The impact limiters must remain attached to the cask body during normal handling and transport. Satisfaction of this criterion ensures that the limiters will be in a proper position to perform their impact limiting function in the event of a free drop (normal or accident).

2. In a free drop (normal or accident), the limiter(s) making initial contact with the unyielding surface must remain in position on the end(s) of the cask for the full duration of the initial impact. Satisfaction of this criterion ensures that the limiter(s) will be able to properly perform their impact limiting function.

3. In a free drop (normal or accident) involving an initial impact on a single impact limiter, the limiter on the opposite end of the cask must remain attached to the cask during the initial impact. Satisfaction of this criterion ensures that the limiter will be in a proper position to perform its impact limiting function in a subsequent secondary impact following the initial impact.

These criteria are satisfied as described by the discussion presented below.

Redwood Impact Limiter Attachment During Normal Handling and Transport

Attachment of the redwood and balsa impact limiters to the cask body during normal handling and transport is ensured by demonstrating that the attachment hardware does not yield under normal handling and transport conditions. The worst case loading associated with normal handling and transport is a 7.5-g load corresponding to the peak longitudinal shock loading expected as the result of rail transport (as specified by the Field Manual of the AAR). The design load, P, on the attachment is:

$$P = (7.5)(8{,}865)$$
$$= 66{,}490 \text{ lbs}$$

where 8,865 pounds is the design weight of each impact limiter.

Analysis of Retaining Rods

There are 16 retaining rods, each 1-inch in diameter, equally spaced on a 76.0-inch diameter bolt circle. The attachment geometry is shown in Figure 2.6.7.4.1-7. The retaining rods are SA-276, Type 304 stainless steel, with a yield strength of 25.0 ksi at 200°F.

The load on each retaining rods due to a longitudinal shock load of 7.5 g is given as:

$$P = \frac{66{,}490}{16} = 4{,}156 \text{ lbs per retaining rod}$$

The tensile stress in the retaining rods, which has a tensile area of 0.606 in^2 in the threaded region, is calculated as:

$$S_t = \frac{P}{A} = 6{,}857 \text{ psi}$$

$$MS = \frac{25{,}000}{6{,}857} - 1 = +\text{Large}$$

Analysis of Retaining Rod Anchorage

The detail of the anchorage of the retaining rod to the impact limiter is shown in Figure 2.6.7.4.1-8. The nut of the retaining rod is bearing on a washer that has a diameter of 5.0 inches and a thickness of 0.50 inch. The washer is bearing on the bearing plate portion of the impact limiter shell, which bears on the redwood material.

The load on each of the 16 retaining rods due to the normal transportation acceleration is 4,156 pounds. The bearing area between the bearing plate and the redwood material is calculated as:

$$A = (\pi/4)(5.0^2 - 3.0^2) = 12.57 \text{ in}^2$$

The bearing pressure is:

$$p = 4156/12.57 = 331 \text{ psi}$$

The perpendicular-to-the-grain compressive stress in the redwood at 40 percent strain is 1,260 psi. The margin of safety for compression of the redwood is:

$$MS = 1260/331 - 1 = +\text{Large}$$

The washer is made of Type 304 stainless steel. It has a 1.09-inch diameter hole in the center. It is analyzed by assuming that it is simply supported along a circle having a diameter equal to the average of the diameters of the washer and the edge of the hole in the bearing plate ([5.0 + 3.00]/2 = 4.0 inches). The load of 4,156 pounds is distributed along the edge of the nut having an average diameter of 1.625 inches. From Roark, page 220, Case 15:

$$S_{max} = \frac{3W}{2\pi m t^2}\left[\frac{2a^2(m+1)}{a^2-b^2}\ln\frac{c}{d} + (m-1)\frac{c^2-d^2}{a^2-b^2}\right] = 22{,}368 \text{ psi}$$

where:

a = 2.50 in
b = 0.545 in
c = 2.00 in
d = 0.8125 in
t = 0.50 in
ν = 0.275
m = 3.636
W = 4,156 lbs

The yield strength of Type 304 stainless steel is 25.0 ksi at 200°F. The margin of safety is:

$$MS = 25.0/22.4 - 1 = +0.11$$

The positive margins of safety show that the attachment of the impact limiters is adequate during normal conditions of transport.

Evaluation of Redwood Impact Limiter Attachment for Vibration

During normal transport conditions, the impact limiter attachment may be subjected to vibration induced from the combination of component natural frequency and a dynamic load forcing function dependent on the transport media. Design of the impact limiter attachment eliminates the potential for the postulated vibration loading loosening the impact limiter attachment. Lock nuts are installed in back of each of the retaining rod attachment nuts to prevent them from becoming loose. Locking wires installed between sets of two retaining rods eliminate rotation of the impact limiter retaining rods relative to their anchorage. The combination of these two design features eliminates the potential for the impact limiter attachment from becoming loose as a result of postulated vibration loading during transport.

Response of the Impacted Limiter(s) During Initial Impact of Package with Ground

The second criterion applicable to the impact limiter attachments requires that the impact limiter(s) making initial contact with the unyielding surface must remain in position on the end(s) of the cask for the full duration of the initial impact. To satisfy this criterion, attachment hardware (mounting plate and bolts) may fail during an impact event, as long as the impact limiter(s) being crushed remains in position on the end of the cask and does not separate from the

cask. The ability of the impact limiter to remain in position during an impact is demonstrated with reference to several static compression tests, during which the only attachment mechanism was a strip of duct tape. All of the compression tests were performed using eighth-scale models of the impact limiters. Analytic evaluations are also presented to further justify that the impact limiters will remain in position during the impact.

2.6.7.4.1.5 Dynamic Free Drop Test Results

As presented in Section 2.10.6 a series of 30-foot free drop tests were performed using a quarter-scale model of the NAC-STC. Drop orientations included an end drop, a center of gravity over struck corner drop, a side drop and an oblique drop with a subsequent secondary impact. Based on the results of the initial drop tests, the impact limiter attachment design was modified to ensure that the impact limiters remain attached to the cask throughout the impact event. Subsequent drop testing has verified the modified attachment design. Based on the above considerations, it is concluded that the impact limiters will remain in position on the cask body for the full duration of the free drop impact event.

2.6.7.4.1.6 Redwood Impact Limiter Static Crush Test Results

A series of quasi-static crush tests have been performed on eighth-scale models of the impact limiters for the NAC-STC. The impact orientations tested were end (axial), side, and corner (center of gravity over corner). The purpose of the quasi-static crush tests was to document the force-deformation and energy absorption characteristics of the redwood and balsa wood used in the impact limiter. Additionally, the tests demonstrated that the impact limiters need not be mechanically attached to the cask body in order to remain in position to absorb the energy of crushing. No attachments (other than a strip of duct tape) between the model impact limiters and the test fixtures were used for the quasi-static crush tests. Once crushing of the impact limiter is initiated, its cup-shaped geometry causes it to maintain its position on the fixture, which is identical to an eighth-scale model cask body. The NAC-STC impact limiters are retained on the cask body by the attachment bolts and by the geometry of the impact limiter. As crushing occurs, the forces acting between the cask body and the unyielding surface act to keep the impact limiter in place.

Analytic Evaluations

Although the results from the above discussed test programs are considered to be the primary proof that the initially impacted impact limiter will remain in position during the impact event and properly perform its impact limiting function, analytic studies are used to confirm the test observations. Analytic assessments presented in this evaluation indicate that no failure of the attachment hardware can be expected to occur, but if an attachment failure does occur, separation of the cask and impact limiter does not occur. As shown, a significant resistance to the applied separation moment exists due to a combination of crushing of the limiter at the cask interface and due to frictional resistance that exists there. This total resistance is shown to be greater than the applied separation moment and is approximately 25 times greater than that provided by the attachment hardware alone.

Additionally, it is noted that the maximum applied separation moment occurs early in the impact when crush depths are small. As crush depths increase, the moment arm and the separation moment decrease to zero. The maximum separation moments occur early in the impact event when the package still possesses a significant downward velocity (87 percent of the initial impact velocity). Thus, the cask "drives" into the limiter and physically "traps" the limiter between the cask body and the ground. Additionally, the duration of the impact is very short (approximately 0.04 to 0.06 seconds) and minimal rotation (approximately 1 degree) of the package occurs during the impact.

The remainder of this section presents a detailed analytic study of the center of gravity over top corner impact event. This near vertical orientation, coupled with the fact that little energy will be converted into rotational energy of the entire package (that is, the center of gravity is over the impacted corner), makes this particular orientation a representative worst case regarding the development of significant separation moments. The available impact limiter analysis program results associated with the corner drop are summarized in Figure 2.6.7.4.1-9. The crush depths, crush forces and package velocities presented in the summary figure are directly available from the impact limiter analysis program, RBCUBED, and the separation moment is calculated based on the geometry (that is, the crush footprint) existing at the particular position of interest. Of note, the velocity of the package is still 527 inches/second (just slightly less than the initial impact velocity) when the maximum separation moment of 3.59×10^5 inch-pounds is developed.

Capability of Redwood Impact Limiter Attachment Hardware

Figure 2.6.7.4.1-10 presents a free body diagram for the upper impact limiter during a top down center of gravity over corner impact. With point "A" being the pivot point of the impact limiter on the cask and conservatively assuming only 2 of the farthest attachment rods are actively resisting the separation moment, taking moments about point "A" yields the following:

$$2(F_i)(81.35) = \text{separation moment}$$

$$F_i = (3.59 \times 10^5/81.35)/2$$

$$= 2{,}206 \text{ lbs}$$

where:

Separation Moment = 3.59×10^5 in-lbs (Figure 2.6.7.4.1-10)

The tensile stress in the retaining rod is:

$$S_t = 2{,}206/0.606 = 3641 \text{ psi}$$

The margin of safety is:

$$MS = 25.0/3.641 - 1 = +\text{Large}$$

The stress in the circular plate is calculated by ratioing the stress obtained in Section 2.6.7.4.1.4: $S_b = (2{,}206/4156)(22.4) = 11.9$ ksi. The margin of safety is:

$$MS = 25.0/11.9 - 1 = +1.1$$

The compressive stress in the redwood material is calculated as:

$$f = 2{,}206/5.62$$

$$= 392 \text{ psi}$$

The margin of safety against compression of the redwood is:

$$MS = 1{,}260/392 - 1 = +2.21$$

2.6.7.4.1.7 Resistance to Separation Following Attachment Hardware Failure

If the attachments do somehow fail, the cask tends to wedge itself into the impact limiter as shown in the free body diagram presented as Figure 2.6.7.4.1-11. From that figure:

$$f_{max} = \text{force required to crush redwood}$$
$$= 86.7\ S_c\ (\text{projected area x crush strength}) = (86.7)(6240)$$
$$= 541{,}000\ \text{lbs/in}$$

where:

$$S_c = \text{crush strength of redwood used in the impact limiter}$$
$$= 6{,}240\ \text{psi (at 0.4 in/in strain - Section 2.6.7.4.1.1)}$$

From moment equilibrium:

$$F_i x_i = (6)(6f_{max}) = 36f_{max}$$
$$= 1.95 \times 10^7\ \text{in-lbs}$$

A significant frictional resistance to separation of the impact limiter also exists. Selecting a coefficient of friction of approximately 0.5, the frictional resistance to the separation moment is:

$$M_f = F_f d$$
$$= 8.96 \times 10^7\ \text{in-lbs}$$

where:

$$F_f = \text{friction force}$$
$$= (0.5)(6f_{max}) = 3f_{max}$$
$$= 1{,}623{,}000\ \text{lbs}$$

and with the centroid of a 180-degree arc (that is, the arc over which f_{max} acts) being located at 63.7 percent of its radius:

$$d = (0.637)(86.7)$$
$$= 55.23 \text{ in}$$

The total resistance to separation, therefore, becomes:

$$M_t = 1.95 \times 10^7 + 8.96 \times 10^7$$
$$= 10.91 \times 10^7 \text{ in-lbs}$$

This total resistance to separation exceeds the maximum applied separation moment of 3.59×10^5 inch-pounds (Figure 2.6.7.4.1-9). Separation of the limiter from the cask body will not occur. As discussed in Section 2.6.7.4.1.5, this particular center of gravity over corner case was tested. Test results are consistent with the preceding analysis in that the cask did tend to wedge itself into the impact limiter, and that physical separation did not occur.

2.6.7.4.1.8 Response of Secondary Impact Limiter During Initial Impact of Package

The final criterion to be satisfied is that for a free drop (normal or accident) involving an initial impact on a single impact limiter, the limiter on the opposite end of the cask (secondary limiter) must remain attached to the cask during the initial impact. This ensures that the secondary limiter will be in position to absorb the secondary impact and it remains in position for the full duration of the secondary impact and performs its impact limiting function. Attachment is ensured by demonstrating that the attachment hardware (mounting plate and retaining rods) does not fail during the initial impact.

Drop Scenario

During a free drop of the cask (normal or accident) involving an initial impact on a single impact limiter, i.e., flat end, center of gravity over corner, or any oblique drop, the ground exerts an upward force on the impact limiter being impacted.

This force decelerates the impacted impact limiter. The impact limiter, in turn, exerts an upward force on the cask body, thus decelerating the cask body. The cask body, likewise, exerts an upward force on the secondary impact limiter, decelerating that impact limiter. This scenario is repeated during a rebound of the whole package; the ground exerts an upward force on the

impacted impact limiter, the impacted impact limiter exerts an upward force on the cask body, which in turn exerts an upward force on the secondary impact limiter, accelerating the whole package upwards. When the entire package is in the air, its components (the initially impacted impact limiter, the cask body, and the secondary impact limiter) move with the same acceleration and velocity, involving no other force acting among them. Thus, it is evident that during a free drop impact on the first impact limiter, no separation force exists between the cask body and the second impact limiter. This ensures that the second impact limiter stays in position to absorb the second impact. For further evidence that the secondary impact limiter will stay attached to the cask body, the resistance to separation between the cask body and the second impact limiter is calculated in the sections below.

Analysis of the Mounting Plate

The stress in the mounting plate of the impact limiter due to a longitudinal loading of 7.5 g is calculated as 22.4 ksi in Section 2.6.7.4.1.4. The yield and ultimate strengths of Type 304 stainless steel at 200°F are 25.0 ksi and 71.0 ksi, respectively. The maximum g-load that the attachment plate can support without exceeding its yield strength is:

$$F_y = (25.0/22.4)(7.5\ g)$$

$$= 8.4\ g$$

The g-load it can support without exceeding its ultimate strength is:

$$F_u = (71.0/22.4)(7.5\ g)$$

$$= 23.8\ g$$

Analysis of the Retaining Rods

The tensile stress in the retaining rod due to a 7.5 g longitudinal loading applied to the impact limiter is calculated in Section 2.6.7.4.1.4 as 6,857 psi. The yield and ultimate strengths of SA-276, Type 304 stainless steel at 200°F are 25.0 ksi and 71.0 ksi, respectively. The maximum g-load that the retaining rods can support without exceeding their yield strength is calculated as:

$$F_y = (25.0/6.857)(7.5\ g)$$

$$= 27.3\ g$$

The g-load that the retaining rods can support without exceeding their ultimate strength is calculated as:

$$F_u = (71.0/6.857)(7.5\ g)$$
$$= 77.7\ g$$

The maximum stress in the Type 304 stainless steel washer supporting the nut of the retaining rod is 22.4 ksi due to a normal transportation acceleration of 7.5 g. The yield stress of the plate material is 25.0 ksi at 200°F. The maximum g-load that the circular plate can support without exceeding it yield strength is calculated as:

$$a = (25.0/22.4)(7.5\ g)$$

$$= 8.4\ g$$

The compressive strength perpendicular to the grain of the redwood supporting the circular plate is 1,260 psi at 40 percent strain (Section 2.6.7.4.1). The maximum compressive stress in the redwood under the circular plate due to a normal transportation acceleration of 7.5 g is 740 psi. The maximum g-load that the redwood material can support without exceeding its compressive stress is calculated as:

$$a = (1260/740)(7.5\ g)$$

$$= 12.8\ g$$

Thus, the NAC-STC impact limiter attachments provide significant resistance to any unspecified separation force on the impact limiter.

Figure 2.6.7.4.1-1 NAC-STC with Redwood Impact Limiters

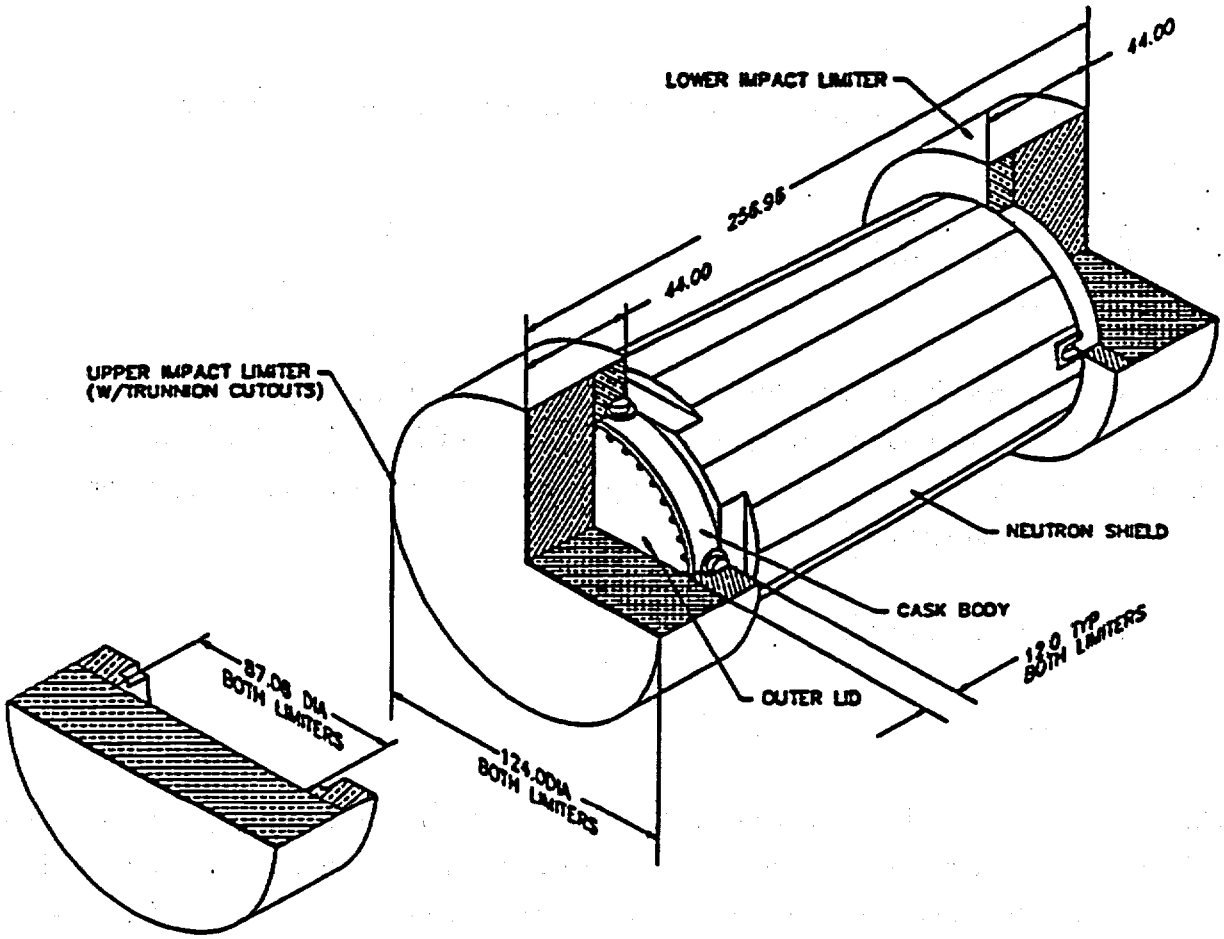

Figure 2.6.7.4.1-2 Cross Section of Redwood Impact Limiter

FIGURE WITHHELD AS SENSITIVE UNCLASSIFIED INFORMATION

Figure 2.6.7.4.1-3 Crush Stress-Strain Curves for Redwood (Crush Strength Parallel to Grain)

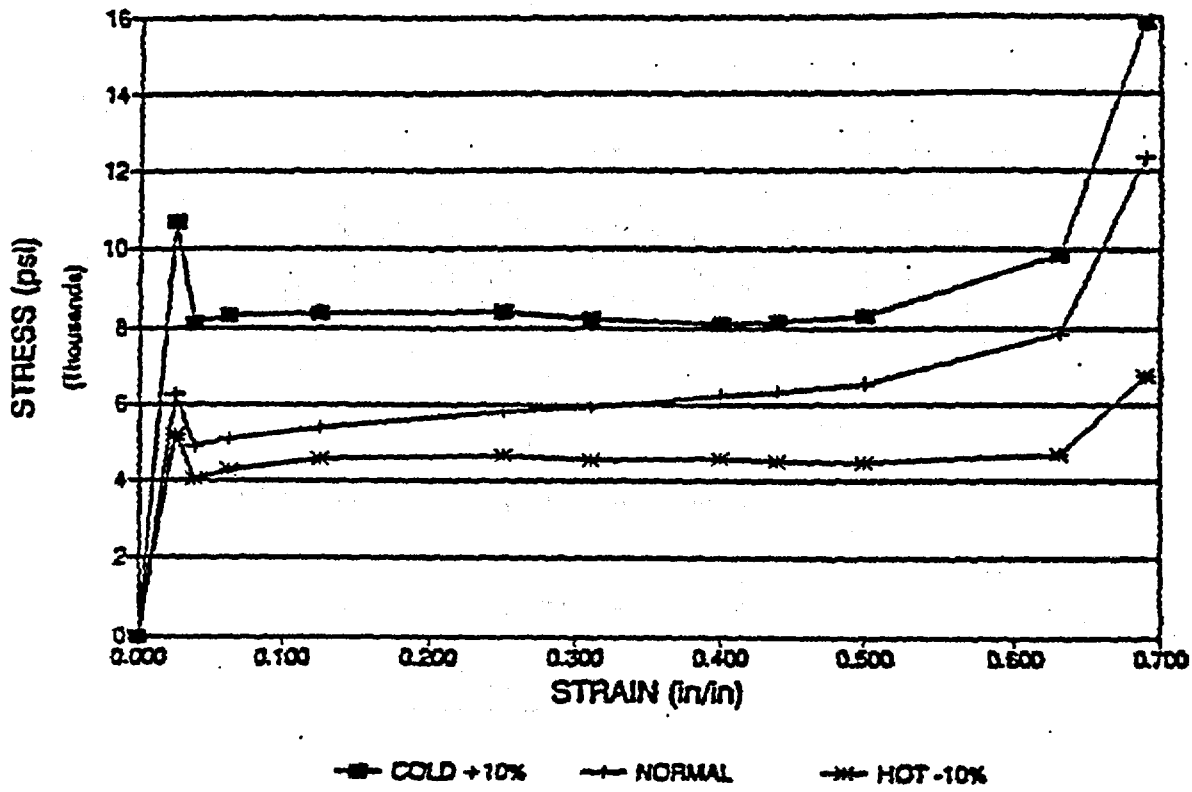

Figure 2.6.7.4.1-4 Crush Stress-Strain Curves for Redwood (Crush Strength Perpendicular to Grain)

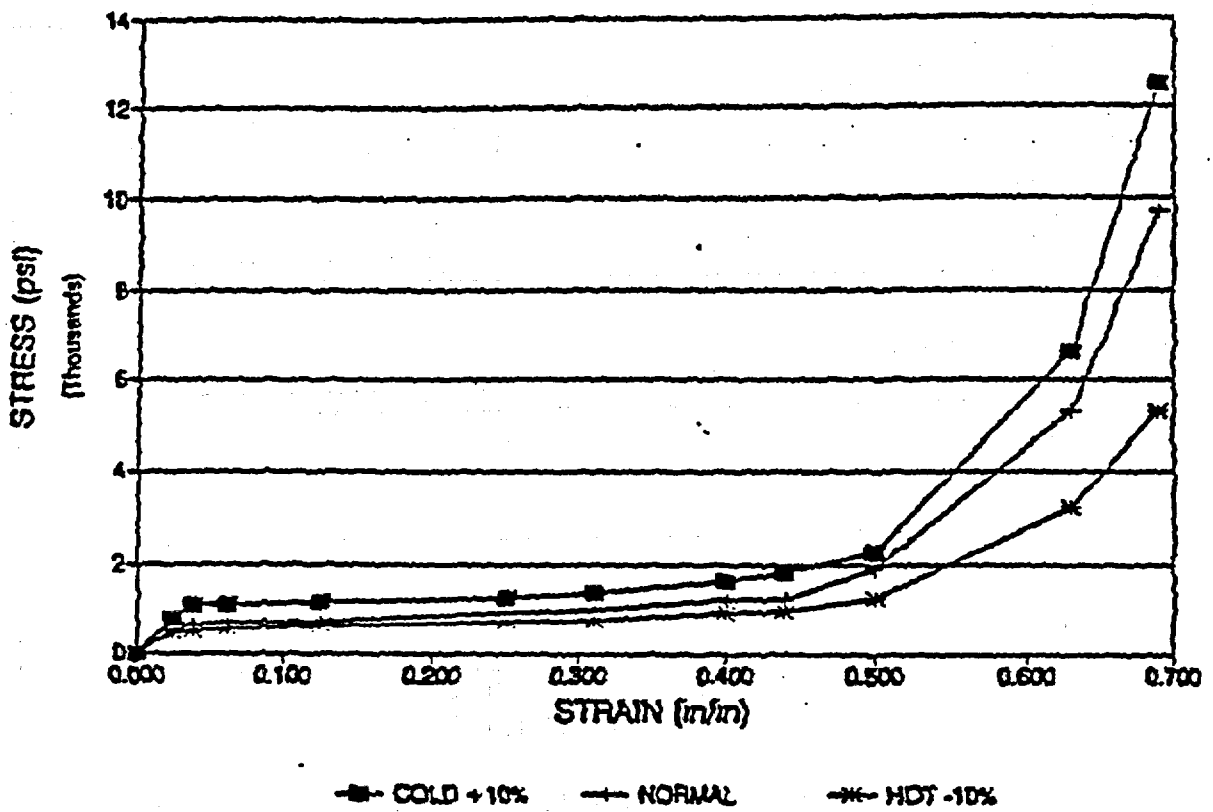

Figure 2.6.7.4.1-5 Crush Stress-Strain Curves for Balsa Wood (Crush Strength Parallel to Grain)

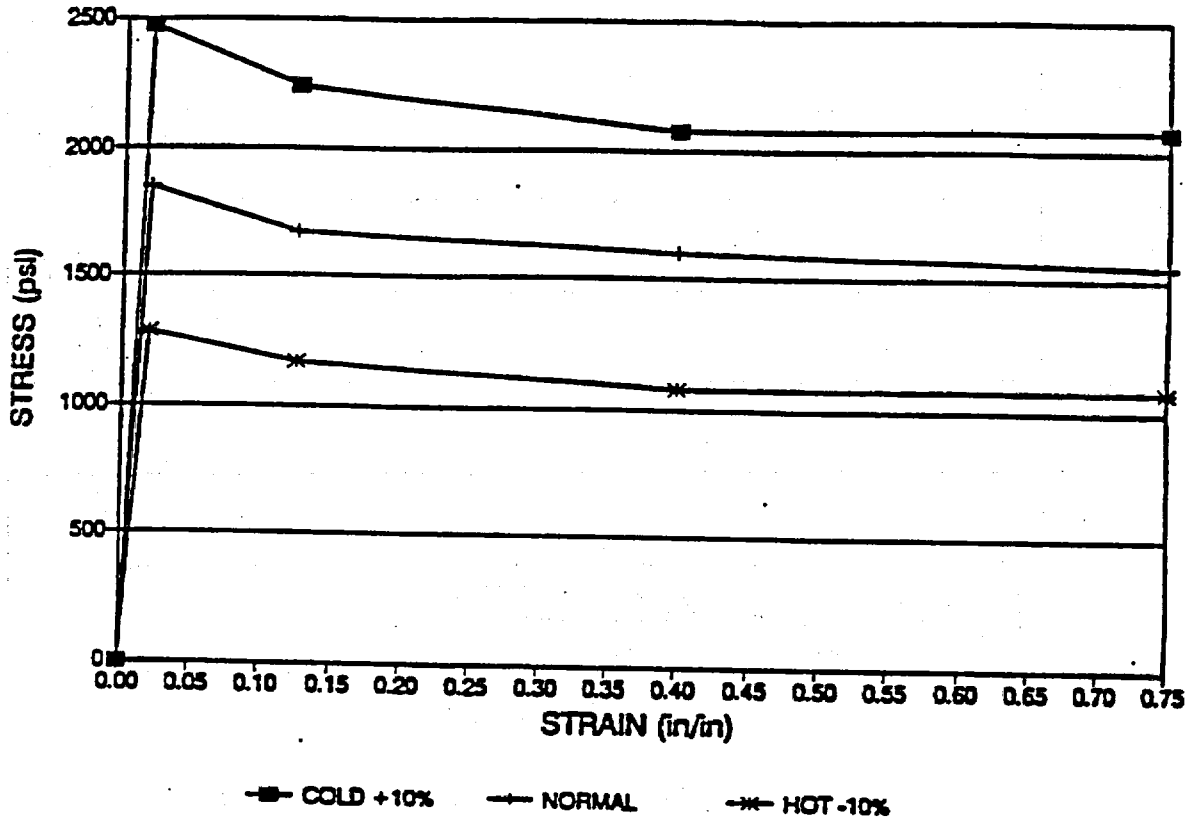

Figure 2.6.7.4.1-6 Variation of Crush Strength of Redwood and Balsa Wood with Impact Angle at 40 Percent Strain

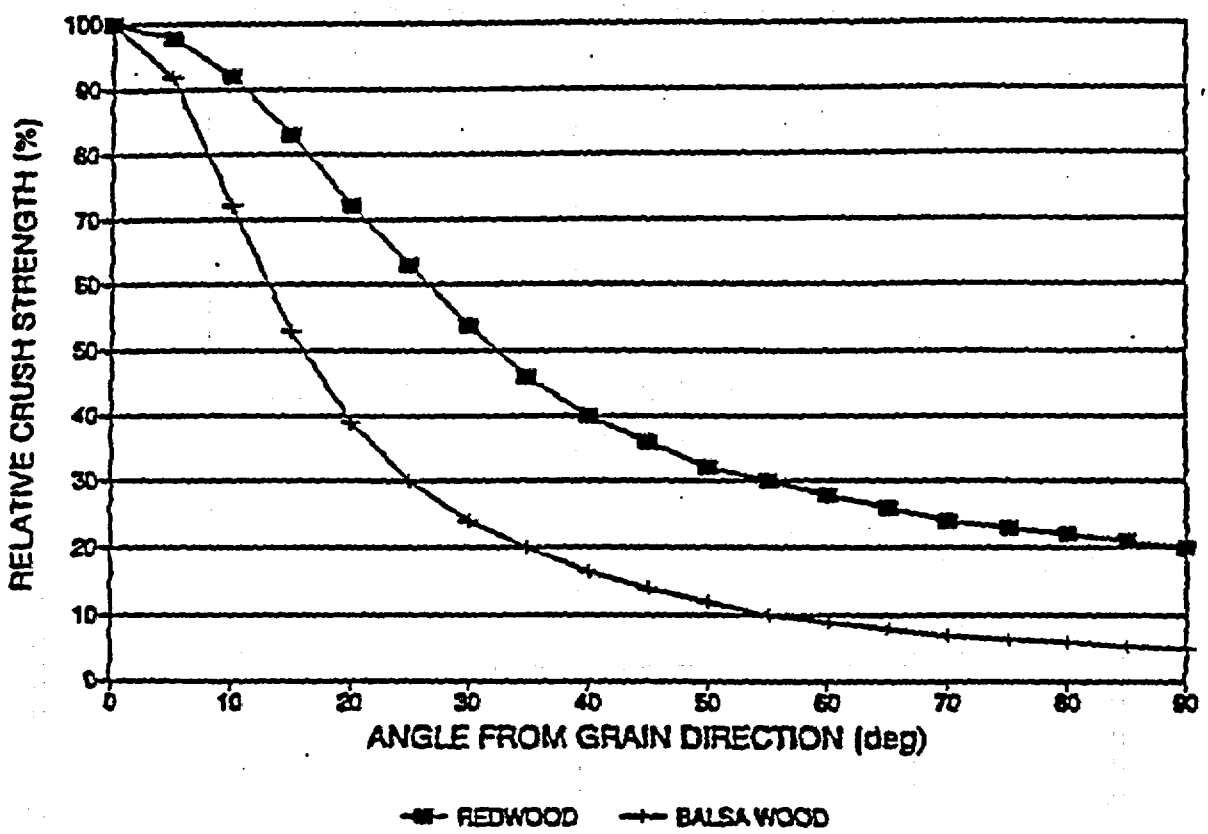

Figure 2.6.7.4.1-7 Redwood Impact Limiter Attachment Geometry

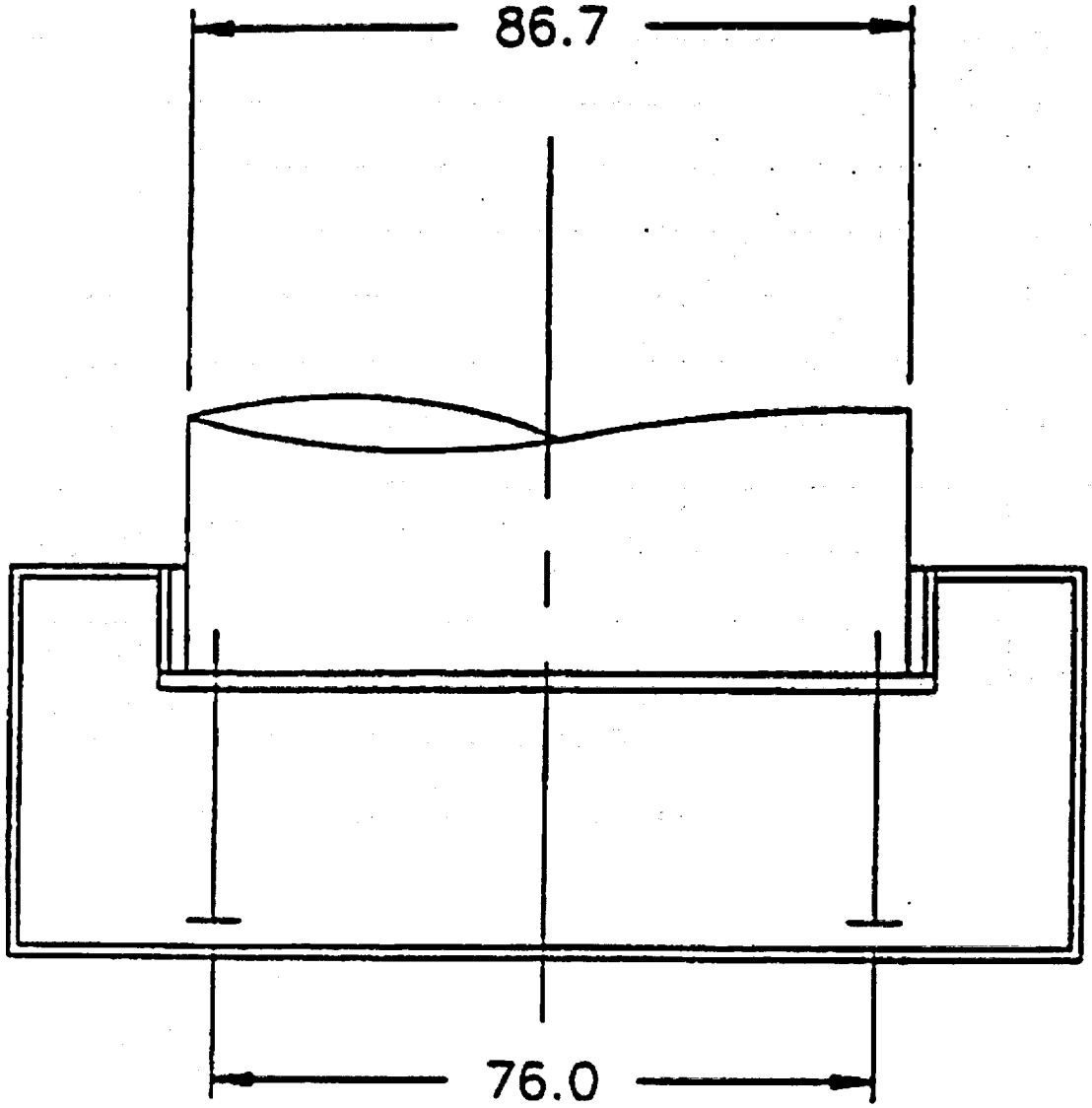

Figure 2.6.7.4.1-8 Anchorage Detail of the Retaining Rod at the End of the Impact Limiter

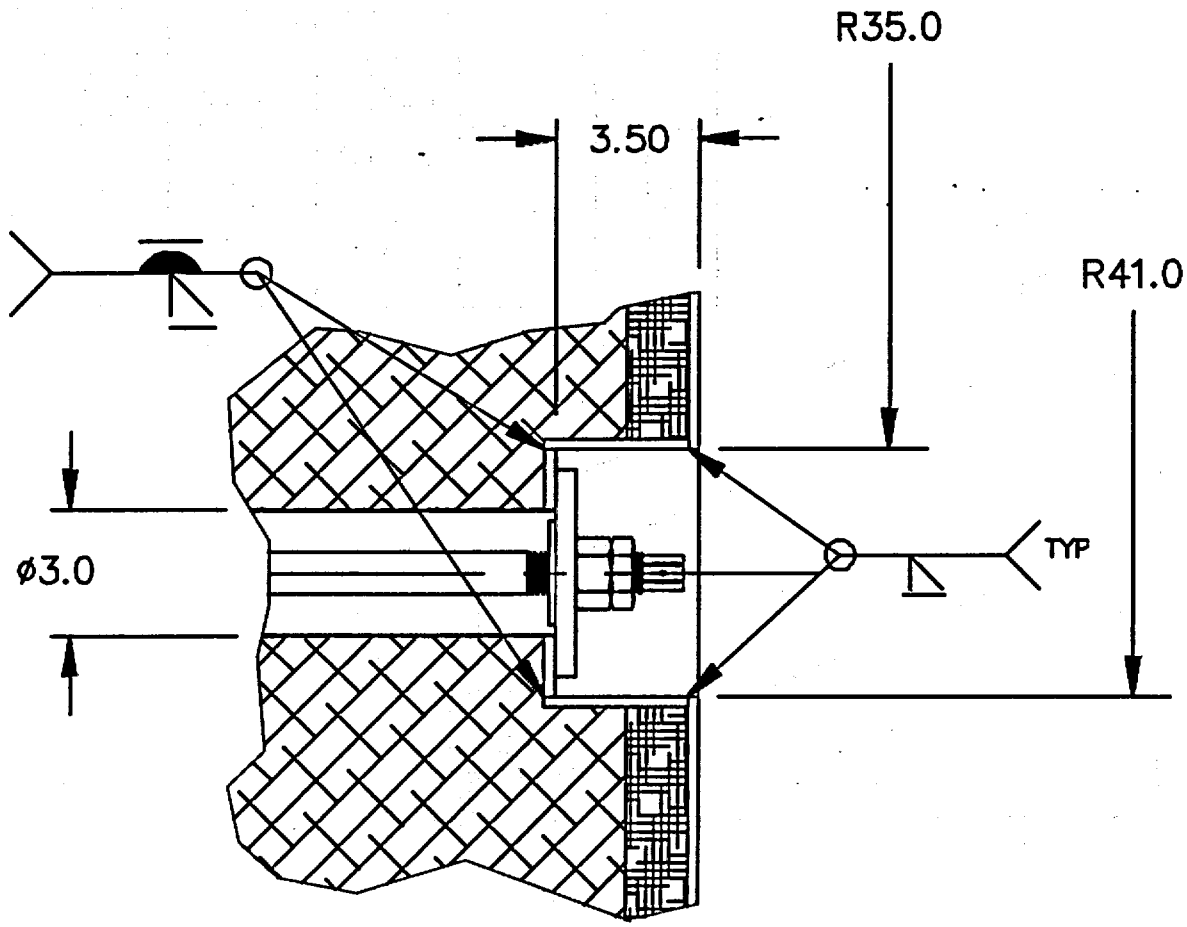

Figure 2.6.7.4.1-9 RBCUBED Output Summary - Center of Gravity Over Top Corner

POSITION	CRUSH DEPTH (IN)	CRUSH FORCE F1 (LB)	PACKAGE VELOCITY (IN/SEC)	APPROXIMATE SEPARATION MOMENT (IN-LB)
①	2	2.92×10^{2}	528	7.88×10^{2}
②	4	3.59×10^{5}	527	3.59×10^{5}
③	6	9.51×10^{5}	521	(-7.61×10^{5})
④	8	1.56×10^{6}	511	(-4.06×10^{6})

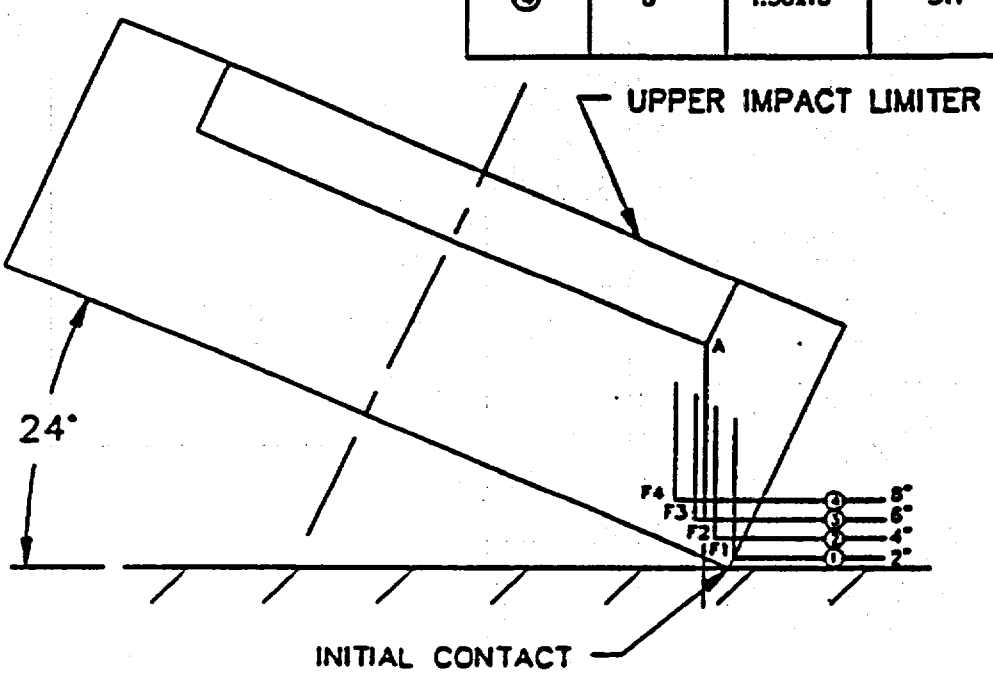

Figure 2.6.7.4.1-10 Free Body Diagram - Upper Impact Limiter - Center of Gravity Over Corner

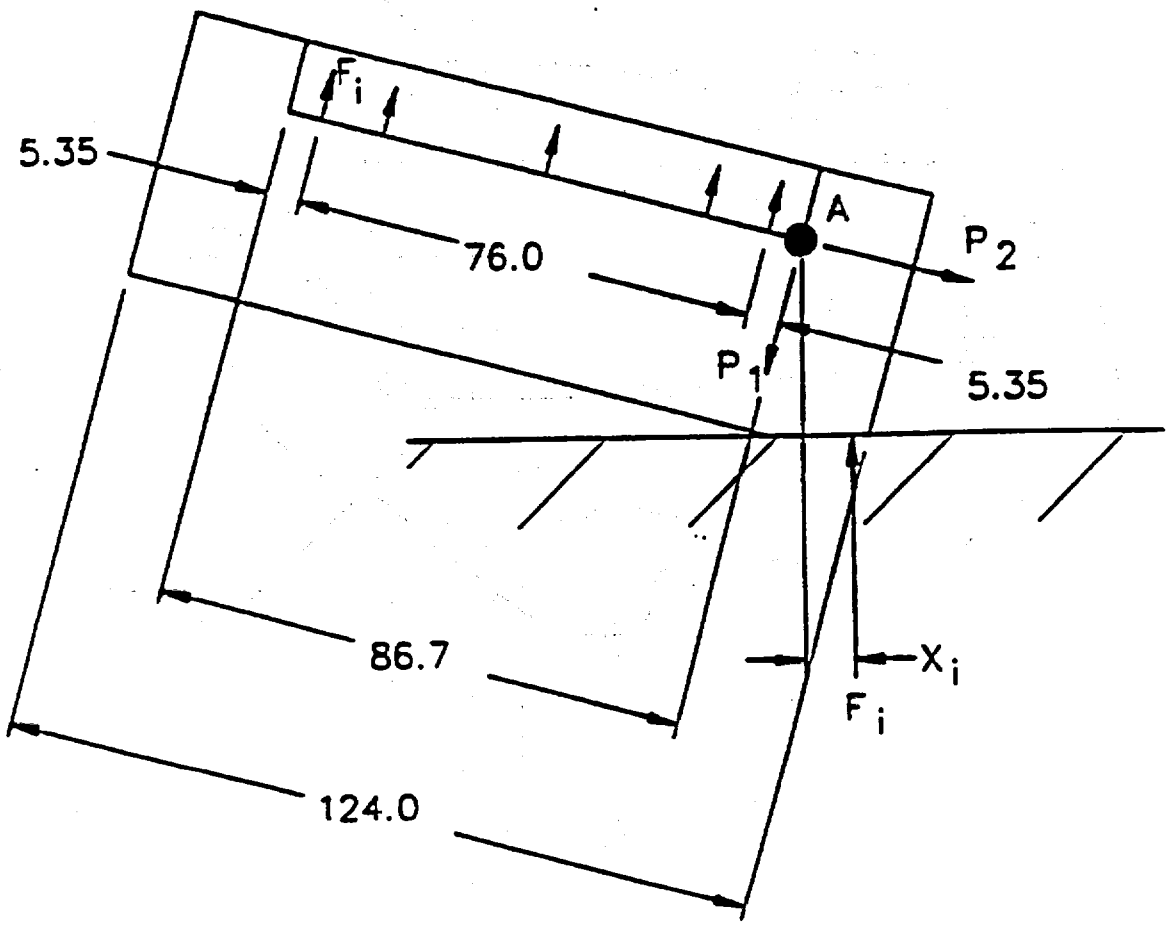

Figure 2.6.7.4.1-11 Free Body Diagram - Upper Impact Limiter - Cask Wedging Forces

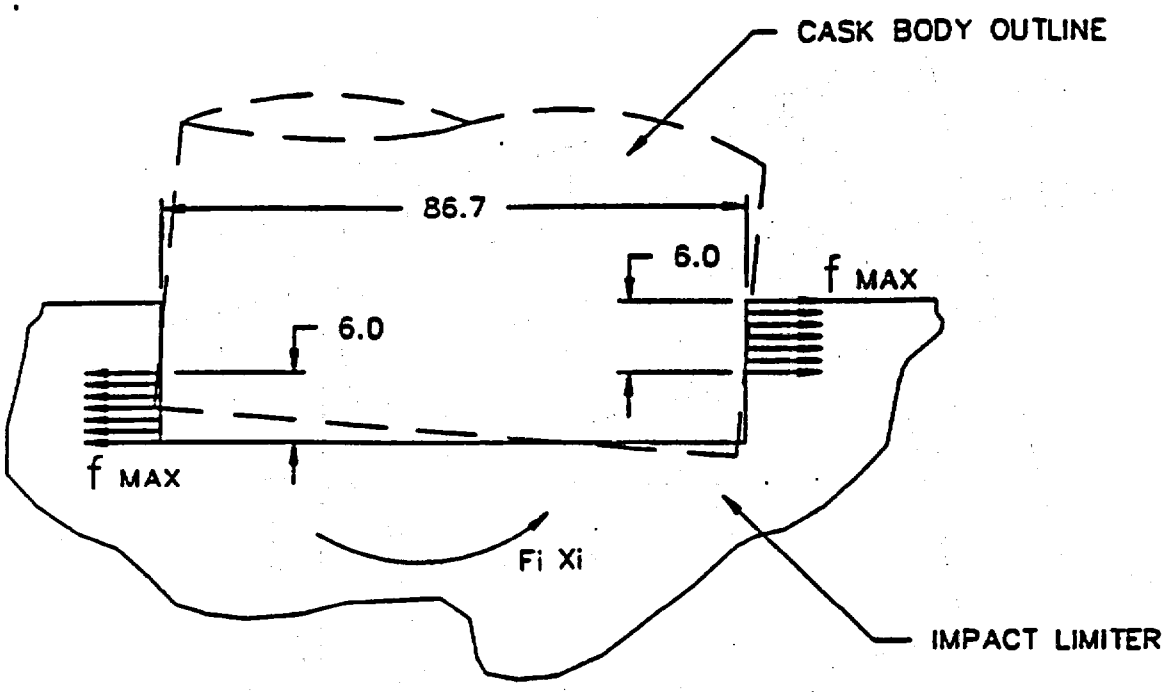

Table 2.6.7.4.1-1 Summary of Results - Impact Limiter Analysis for 1-Foot Free Drop

Analysis Description	Displacement (in)	Force (lb)	Equivalent* G-Load Factor
End Impact			
Lower Impact Limiter (Max. Crush Strength)	1.62	4.91×10^6	19.6
Lower Impact Limiter (Min. Crush Strength)	2.10	4.42×10^6	17.7
Upper Impact Limiter (Max. Crush Strength)	1.62	4.91×10^6	19.6
Upper Impact Limiter (Min. Crush Strength)	2.10	4.42×10^6	17.7
Corner Impact			
Lower Impact Limiter (Max. Crush Strength)	7.2	1.32×10^6	5.3
Lower Impact Limiter (Min. Crush Strength)	9.6	1.12×10^6	4.5
Upper Impact Limiter (Max. Crush Strength)	7.3	1.31×10^6	5.2
Upper Impact Limiter (Min. Crush Strength)	9.7	1.07×10^6	4.3

Table 2.6.7.4.1-1 Summary of Results - Impact Limiter Analysis for 1-Foot Free Drop (continued)

Analysis Description	Displacement (in)	Force (lb)	Equivalent* G-Load Factor
Side Impact			
Lower Impact Limiter (Max. Crush Strength)	1.1	4.53×10^{6}**	18.1
Lower Impact Limiter (Min. Crush Strength)	1.7	2.78×10^{6}**	11.1
Upper Impact Limiter (Max. Crush Strength)	1.1	4.53×10^{6}**	18.1
Upper Impact Limiter (Min. Crush Strength)	1.7	2.78×10^{6}**	11.1

* Equivalent g-load factor = Force/250,000.

** Total force for both impact limiters.

Table 2.6.7.4.1-2 Summary of Results - Impact Limiter Analysis for 30-Foot Free Drop

Analysis Description	Displacement (in)	Force (lb)	Equivalent* G-Load Factor
End Impact			
Lower Impact Limiter (Max. Crush Strength)	10.4	1.12×10^7	44.6
Lower Impact Limiter (Min. Crush Strength)	16.1	1.07×10^7	42.8
Upper Impact Limiter (Max. Crush Strength)	12.5	1.02×10^7	40.6
Upper Impact Limiter (Min. Crush Strength)	17.7	1.40×10^7	56.1
Corner Impact			
Lower Impact Limiter (Max. Crush Strength)	24.2	9.35×10^6	37.4
Lower Impact Limiter (Min. Crush Strength)	30.0	1.09×10^7	43.6
Upper Impact Limiter (Max. Crush Strength)	26.6	1.10×10^7	44.0
Upper Impact Limiter (Min. Crush Strength)	31.6	1.23×10^7	49.3

Table 2.6.7.4.1-2 Summary of Results - Impact Limiter Analysis for 30-Foot Free Drop (continued)

Analysis Description	Displacement (in)	Force (lb)	Equivalent* G-Load Factor
Side Impact			
Lower Impact Limiter (Max. Crush Strength)	10.3	1.29×10^{7}**	51.7
Lower Impact Limiter (Min. Crush Strength)	15.1	1.28×10^{7}**	51.3
Upper Impact Limiter (Max. Crush Strength)	10.3	1.29×10^{7}**	51.7
Upper Impact Limiter (Min. Crush Strength)	15.1	1.28×10^{7}**	51.3

* Equivalent g-load factor = Force/250,000.

** Total force for both impact limiters.

Table 2.6.7.4.1-3 Summary of Cask Drop Equivalent G-Load Factors

Direction	1-Foot Drop	Equivalent G-Load Factor*		
		30-Foot Drop		
		Total	Axial** Comp.	Lateral** Comp.
Lateral (Side)	18.1	51.7	0.0	51.7
Longitudinal (End)	19.6	56.1	56.1	0.0
Corner (24°)	5.3	49.3	45.0	20.1
Oblique (30°)	-	41.8	36.2	20.9
Oblique (45°)	-	34.5	24.4	24.4
Oblique (60°)	-	33.8	16.9	29.3

* Equivalent g-load factor = Force/250,000.

** Axial Component = total x cosθ
Lateral Component = total x sinθ
where: θ = 24°, 30°, 45° or 60°

Table 2.6.7.4.1-4 Summary of 30-Foot Cask Drop Deceleration G-Loads for the Redwood Impact Limiter Obtained from RBCUBED, Tests, and Design

	30-Foot Drop Decelerations (g)			
Drop Orientation	**RBCUBED**	**Test**	**Quasi-Static Test**	**Design**
End (0°)	56.1	55.6	54.8	56.1
Corner (24°)	44.2	29.2	32.6	55.0
Oblique (30°)	39.4	N/A	N/A	55.0
Oblique (45°)	36.4	N/A	N/A	55.0
Oblique (60°)	37.6	N/A	N/A	55.0
Oblique (75°)	34.0[1]	53.8[2]	N/A	55.0
Side (90°)	54.1	51.3	45.6	55.0

RBCUBED: Impact limiter g-load calculations using RBCUBED program. Values taken from Table 2.6.7.4-3.

Drop Test: Quarter-scale cask model dynamic drop test results. Details provided in Section 2.10.6.5.

Quasi-Static Test: Extrapolated from eighth-scale model impact limiter quasi-static compression tests. Details are provided in Section 2.10.6.4.

Design: Design g-load values used in the cask and fuel basket analyses.

[1] Initial impact.

[2] Secondary impact.

2.6.7.4.2 Balsa Impact Limiters

The balsa impact limiter evaluation presented in this section is for all cask configurations, i.e., NAC-STC directly loaded fuel configuration, the Yankee-MPC and CY-MPC canistered fuel configurations, or the Yankee-MPC and CY-MPC canistered GTCC waste configurations, with a total package weight with impact limiters attached not exceeding 260,000 pounds.

The package geometry is identical for all of the configurations, as is the package center of gravity location. Axial spacers are designed for the cask cavity to locate the canister loaded with fuel or GTCC waste such that the package center of gravity location is identical to that of the directly loaded fuel configuration.

Differences in contents weight and the weights of the associated package configurations have no significant effect on the balsa impact limiter design or performance. Therefore, the balsa impact limiter analysis in this section and the cask drop analyses in Sections 2.6.7 and 2.7.1 are applicable for all contents configurations of the NAC-STC, Yankee-MPC, and CY-MPC.

2.6.7.4.2.1 Assumptions

The following assumptions form the basis for the balsa impact limiter analysis:

1. The cask impacts on an unyielding surface.

2. The balsa impact limiter remains in position on the cask during all impact events. (The qualification of the balsa impact limiter attachment is presented in Section 2.6.7.4.2.7.)

2.6.7.4.2.2 Load Conditions

The balsa impact limiters described and analyzed in the following paragraphs decelerate the cask by applying a force in the direction opposite the motion of the cask. Crushing the balsa wood material, the stainless steel gussets, and stainless steel shells of the balsa impact limiter between the cask and the unyielding surface generates the deceleration force.

The specific loading conditions for the transport lightweight impact limiters are defined by 10 CFR 71.71(c)(7), 10 CFR 71.73(c)(1) and Regulatory Guide 7.8, as follows:

1. A 1-foot drop of the cask impacting at any angle from vertical (flat end) to corner (cask center of gravity is directly above the point of impact).

2. A 1-foot drop of the cask in a horizontal orientation position.

3. A 30-foot drop of the cask in an end, a side and an oblique orientation.

Based on these loading conditions, the NAC-STC balsa impact limiters are primarily designed for the 30-foot cask drops but with consideration of the 1-foot end, side and corner drops. The maximum impact forces and the maximum crush depth for the 1-foot and 30-foot cask drops are obtained from the LS-DYNA analyses of the balsa impact limiters. LS-DYNA is an explicit finite element program for the nonlinear dynamic analysis of three-dimensional structures (Section 2.10.1.3).

2.6.7.4.2.3 Description—Balsa Impact limiters

Figures 2.6.7.4.2-1 and 2.6.7.4.2-2 show the primary dimensions of the balsa impact limiters. Figure 2.6.7.4.2-2 shows the cross-section of a balsa impact limiter. Except for the pockets for the lifting trunnions in the upper limiter, the upper and lower balsa impact limiters are identical.

Each balsa impact limiter includes balsa wood as the energy-absorbing material with the grain direction of the balsa oriented to achieve the desired crush strength. The balsa is enclosed in a stainless steel shell to protect and maintain its position and orientation. Stainless steel gussets are arranged in 15-degree increments to maintain the orientation of the wood during the side drop.

2.6.7.4.2.4 Properties of Balsa Wood

To adequately specify the balsa crush strength, NAC conducted dynamic compression tests of specimens taken from balsa obtained from a commercial supplier. The average density of the balsa wood tested was 8.5 lb/ft^3. To ensure an adequate sampling, more than 3 dozen specimens were tested with varying strain rates. The tests included both parallel-to-the-grain (parallel) and

perpendicular-to-the-grain (perpendicular) directions for hot, cold, and ambient temperature conditions.

For each strain rate and temperature condition, a data set was created that consists of 10 to 15 individual test samples. To reduce this data, individual files of a data set were averaged together. These average curves were then simplified using minimal data points. To produce simplified curves, the peak acceleration was retained and the area under the curve that represents the energy absorption capacity was maintained. Stress-strain curves have been developed for balsa wood in the parallel and perpendicular-to-the-grain directions for both hot (200°F) and cold (-40°F) conditions.

2.6.7.4.2.5 Balsa Impact Limiter Finite Element Model

The balsa impact limiter finite element model was built using the ANSYS pre-processor and LS-DYNA's Finite Element Model Builder. The impact analyses were performed using LS-DYNA. The model is constructed of 8-node brick and 4-node shell elements. Using the symmetry planes that exist for the various drop orientations, the model was simplified so that only a quarter model was necessary for the analyses. The balsa impact limiter model is shown in Figure 2.6.7.4.2-3. Figure 2.6.7.4.2-4 shows the steel shells and gussets that support the balsa wood.

Boundary Conditions and Initial Conditions

LS-DYNA "Surface_to_Surface" contact interfaces are employed between the cask body and the impact limiter shells. The model sits on a rigid plane ("Rigidwall_Geometric_Flat"). Symmetry boundary conditions are imposed on the nodes in the Y-Z and X-Z planes for the end drop and the Y-Z plane for the side drop. For the side and corner drop cases, the nodes in the X-Z plane are constrained to simulate the portion of the limiter not modeled. To simulate a rigid cask body, all nodes of the cask shell elements were constrained. To achieve a total weight of 260,000 pounds, the density of the material representing the cask body was increased. The total weight was verified by checking the total kinetic energy of the quarter model. An initial velocity of 96.3 in./sec and 527.4 in./sec was applied to the entire model to represent the 1-foot and 30-foot drops, respectively.

The drop orientations considered in the evaluation of the balsa impact limiter are shown in Figure 2.6.7.4.2-5. The top and bottom impact limiters are identical except for the trunnion

pocket in the upper impact limiter. Since the trunnion provides additional backed area that may contribute to the total acceleration, the upper impact limiter is used to evaluate the end impact condition. Two side drop orientations are considered. The first is a direct drop on the trunnion. The second side drop is centered on a radial gusset. As shown in Figure 2.6.7.4.2-5, two potential corner drops exist. The drop angles of 15 degrees and 27 degrees are measured by placing the cask's center of gravity directly over both the corner of the cask and the corner of the impact limiter.

To bound the extreme temperature conditions and maximize accelerations and crush, cold (-40°F) and hot (200°F) analyses are performed for accident conditions. However, since the amount of crush is small during the 1-ft drop, cold balsa properties are used to maximize accelerations for normal conditions.

Material Properties

To account for gross deformation and buckling, the Type 304 stainless steel shells and gussets were modeled with an elasto-plastic material. The LS-DYNA material Type 24 was used ("Piecewise_Linear_Plasticity"). The required input data is:

Steel Shell Property	Value
Mass Density, ρ	7.51E-04 lb-sec^2/in^4
Modulus of Elasticity, E	27.9E6 psi
Poisson's Ratio, ν	0.30

The stress-strain curve used for Type 304 stainless steel is:

STRESS (psi)	STRAIN (in/in)
23,809	0.000041
28,033	0.001180
29,500	0.003180
31,970	0.007180
36,900	0.015100
42,300	0.039200
85,080	0.230000

An elastic material model with the following properties was used to represent the cask.

Steel Billet Property	Value
Modulus of Elasticity, E	1.0E7 psi
Poisson's Ratio, ν	0.30

The mass density of the cask was adjusted to ensure that the total kinetic energy is accounted for. Therefore, the mass density varies slightly depending on the drop orientation.

The balsa wood is modeled as a homogeneous isotropic material, LS-DYNA type number 83 ("Fu_Chang_Foam"). The required input data is:

Wood Property	Value
Mass Density, ρ	1.0E-5 lb-sec^2/in^4
Modulus of Elasticity, E (psi)	10,000 psi

The modulus of elasticity is an initial arbitrary value and is related to the internal stability of the element. The actual modulus of elasticity is internally calculated from the first values of the stress-strain curve (instantaneous value). The stress-strain curves used as input into the LS-DYNA model were obtained by dynamic crush testing of the balsa specimens.

2.6.7.4.2.6 Results

To obtain results from LS-DYNA, nodes of interest are used to record output data. The output is in the form of displacement and acceleration time histories. However, the acceleration time histories contain high frequency components that are induced by the model's interior geometry but do not represent a global response to the external impact. Therefore, the time histories have to be filtered to obtain true accelerations corresponding to the global response. For this evaluation, the Butterworth low-pass filter in LS-DYNA's post-processor is used with a filter frequency of 500 Hz. Figures 2.6.7.4.2-6 through 2.6.7.4.2-15 provide the filtered acceleration time-history curves for the normal and accident conditions drop analyses.

Evaluation of the balsa impact limiter for the normal conditions of transport shows that a maximum acceleration of 19.8g occurs during the side drop aligned with the trunnion. Table 2.6.7.4.2-1 summarizes the accelerations for the five normal condition cases considered. In each case, the calculated acceleration is less than the design acceleration of 20g.

For accident conditions, the maximum acceleration of 52.5g also occurs during the cold condition side drop aligned with the trunnion. Table 2.6.7.4.2-2 summarizes the accelerations for the five hot and cold accident cases considered. In each case, the calculated acceleration is less than the design acceleration of 55g for the side and corner drops and 56.1g for the end drop. As Table 2.6.7.4.2-2 shows, the maximum strain of 68% occurs during the hot condition side drop on the trunnion. The high strain below the trunnion is considered a localized phenomenon. Strain outside of the trunnion region is less than 50%. Therefore, lock-up of the balsa wood does not occur.

2.6.7.4.2.7 Balsa Impact Limiter Attachment Analysis

Each balsa impact limiter is approximately 3,000 pounds lighter than the redwood impact limiter (refer to Tables 2.2-1 and 2.2-4). Due to the difference in contour of the outside surface, the balsa wood impact limiter uses shorter retaining rods than those used with the redwood impact limiter. Both designs use 16 stainless steel retaining rods, each 1-inch in diameter, equally spaced on a 76.0-inch diameter bolt circle and share the same interior dimensions and cask interface. The balsa impact limiter retaining rods are fabricated from high strength ASTM SA-193 grade B8S stainless steel, which has yield and ultimate strengths of 50 ksi and 95 ksi, respectively. This material is higher strength and more ductile than the retaining rods used with the redwood impact limiters. The retaining rods for the redwood impact limiters are SA-276, Type 304 stainless steel, having yield and ultimate strengths of 30 ksi and 75 ksi, respectively. Therefore, the redwood impact limiter attachment evaluation presented in Section 2.6.7.4.1.4, bounds the balsa impact limiter attachment design.

Figure 2.6.7.4.2-1 Three-Dimensional View of the Balsa Impact Limiter

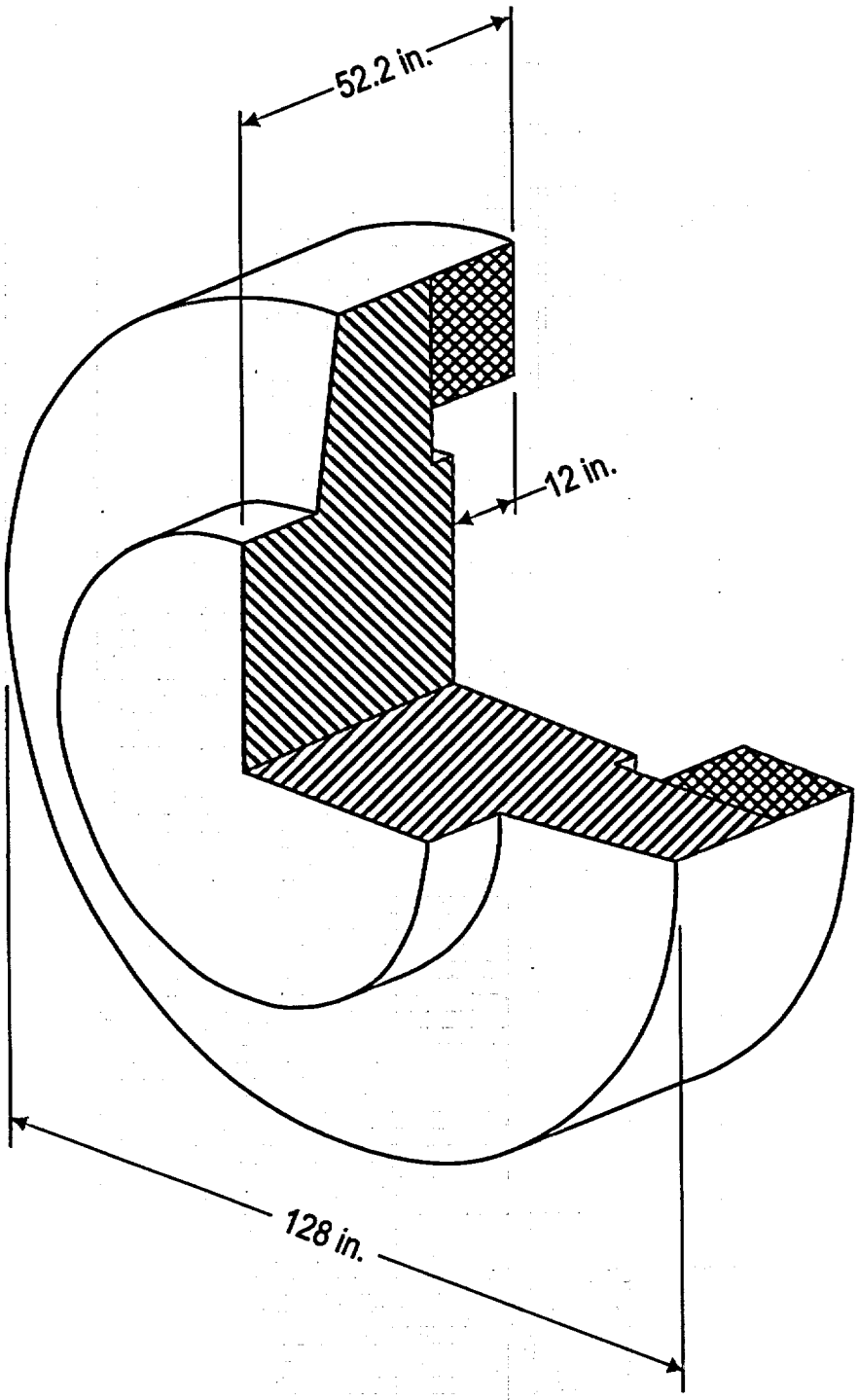

Figure 2.6.7.4.2-2 Cross-Sectional View of the Balsa Impact Limiter

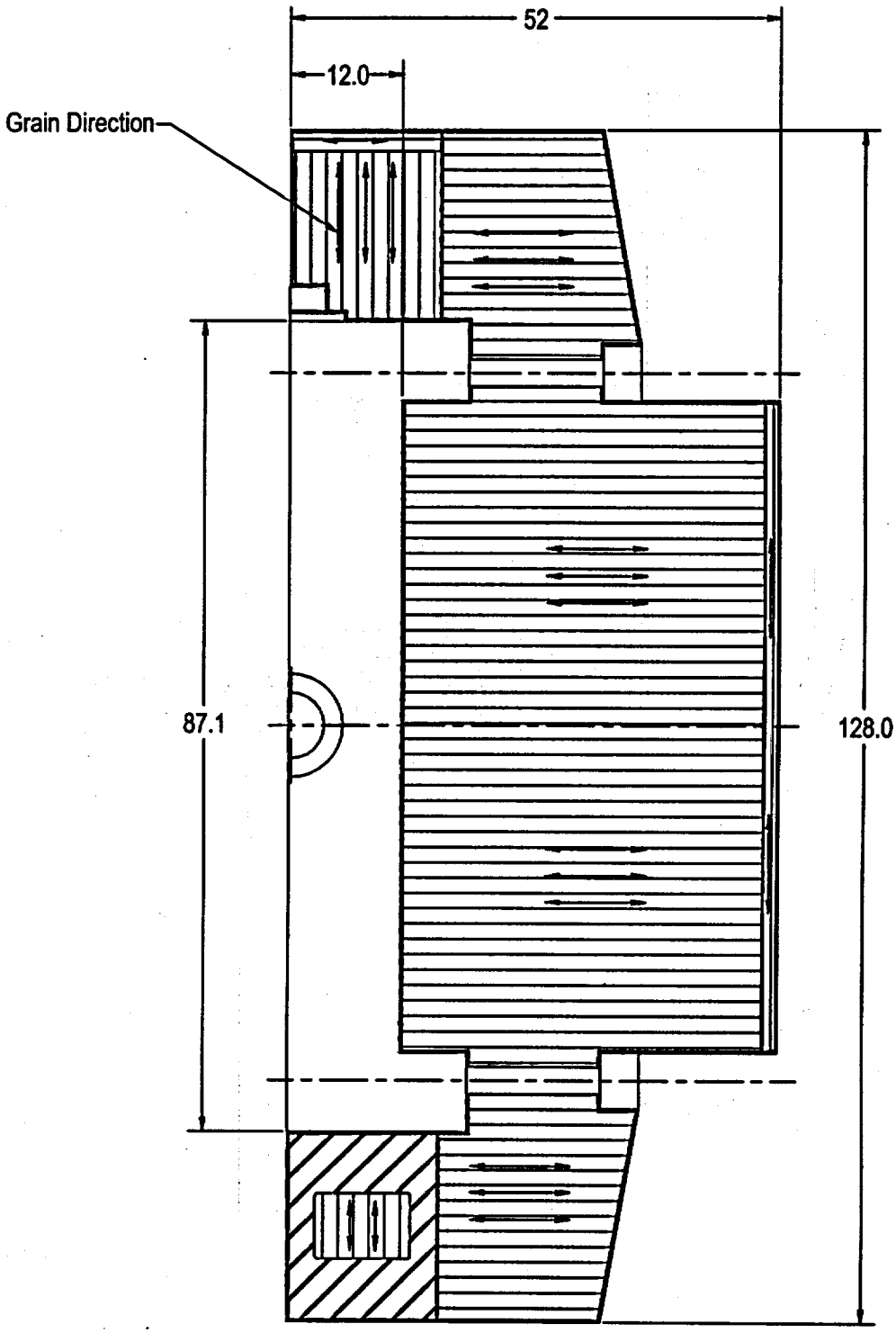

Figure 2.6.7.4.2-3 LS-DYNA Model of the Balsa Impact Limiter

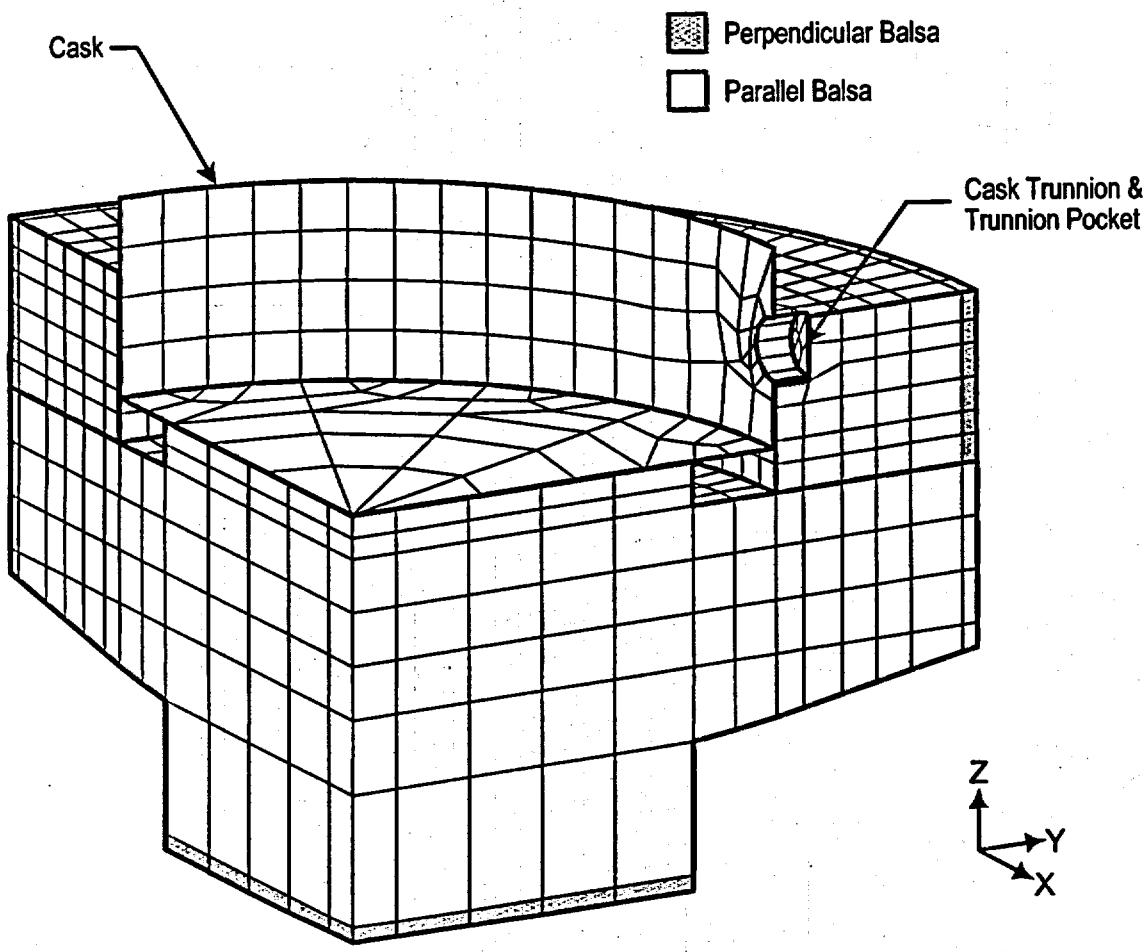

Figure 2.6.7.4.2-4 Detailed View of the LS-DYNA Model for the Balsa Impact Limiter

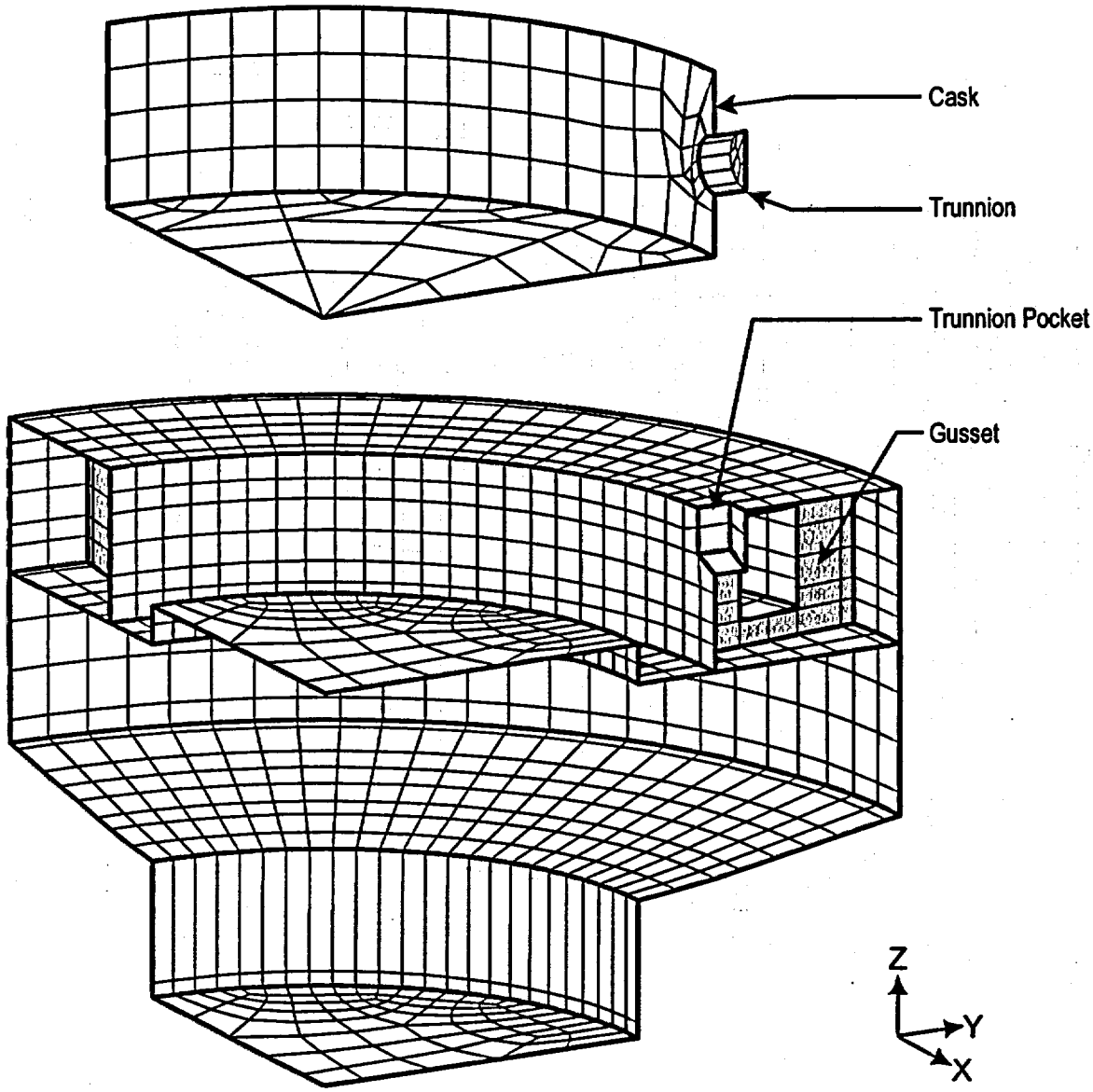

Figure 2.6.7.4.2-5 Balsa Impact Limiter Drop Orientations

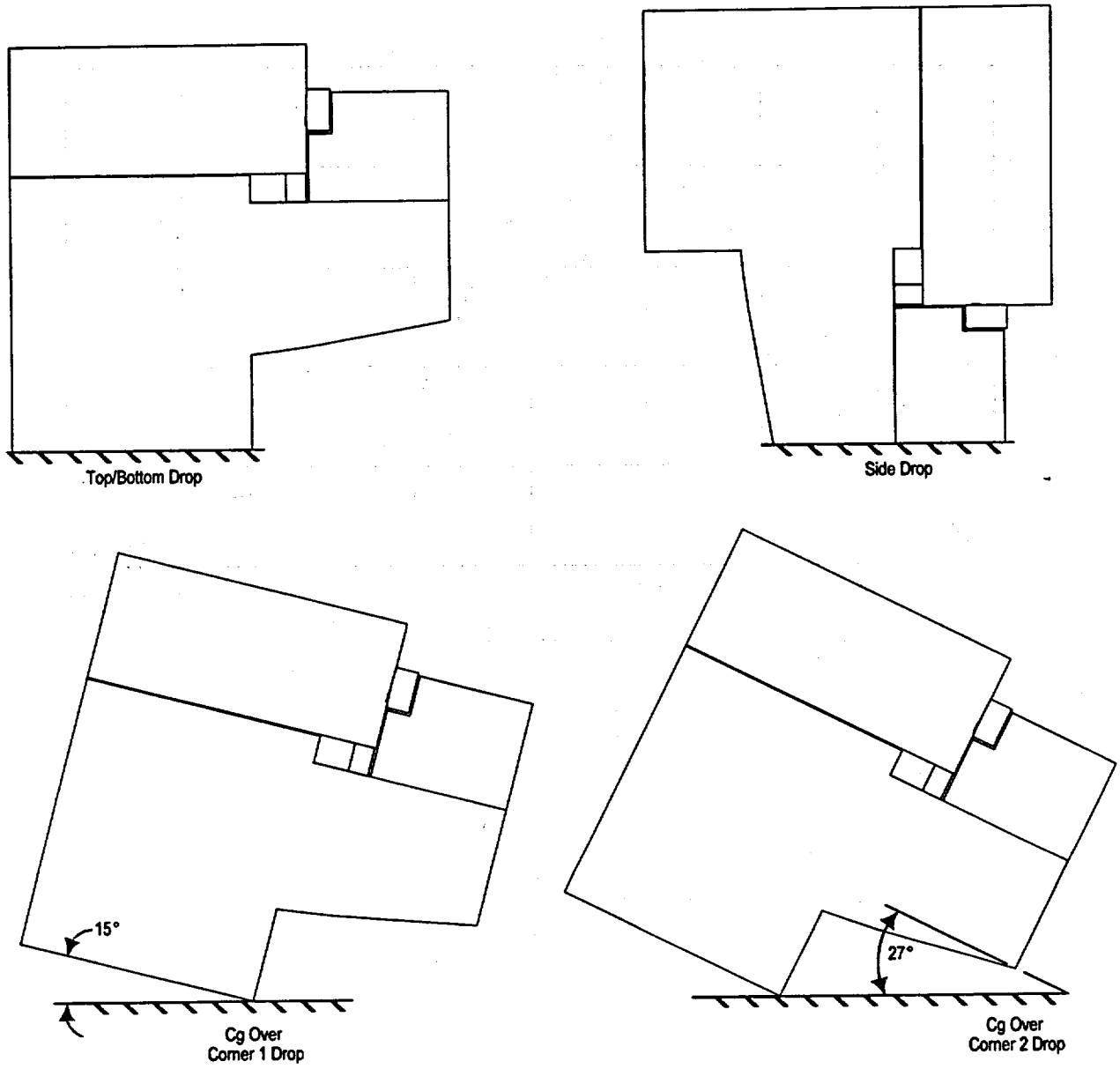

Figure 2.6.7.4.2-6 Acceleration Time-History for 1-ft Side Drop on the Trunnion (Cold Conditions)

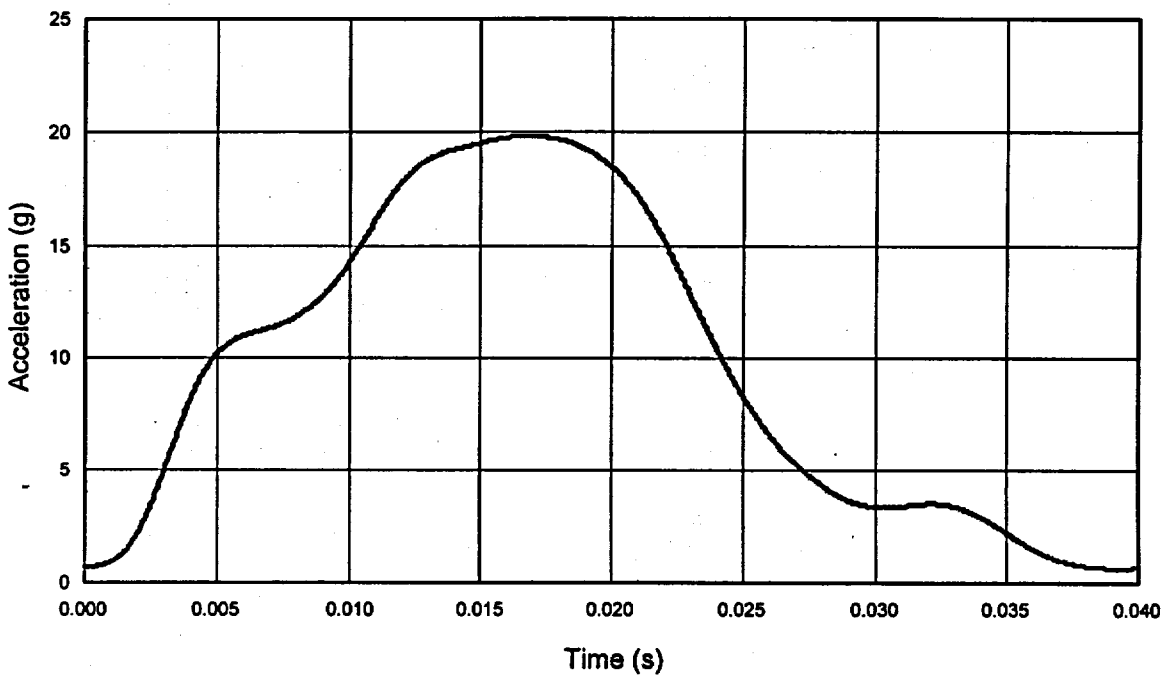

Figure 2.6.7.4.2-7 Acceleration Time-History for 1-ft Side Drop on the Gusset (Cold Conditions)

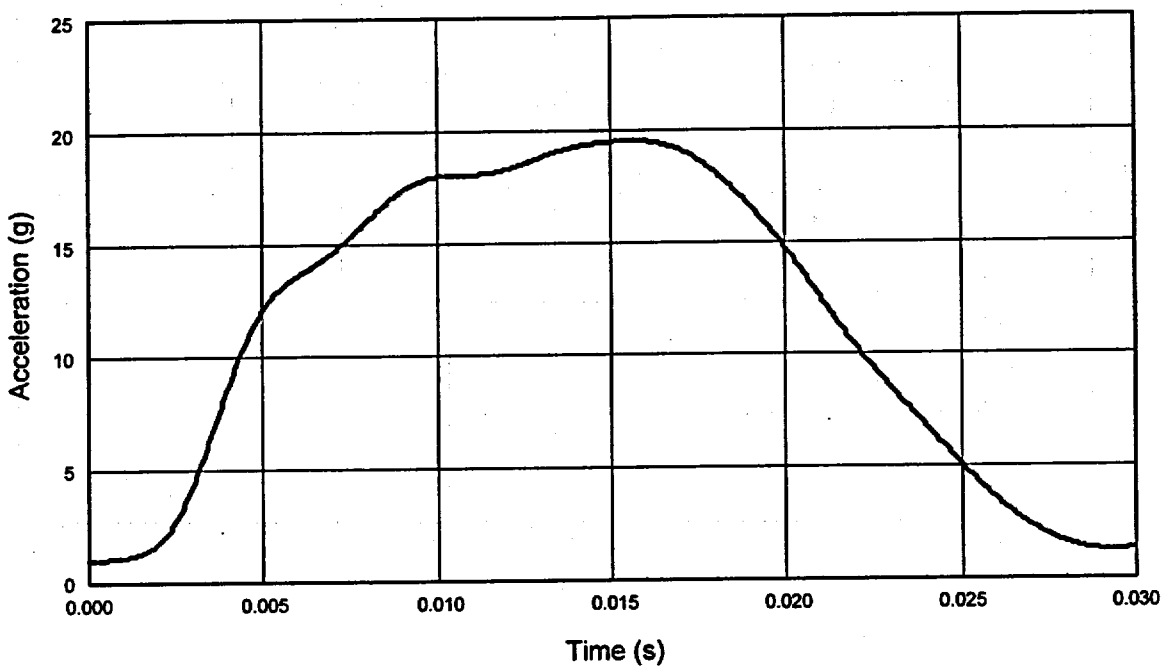

Figure 2.6.7.4.2-8 Acceleration Time-History for 1-ft End Drop (Cold Conditions)

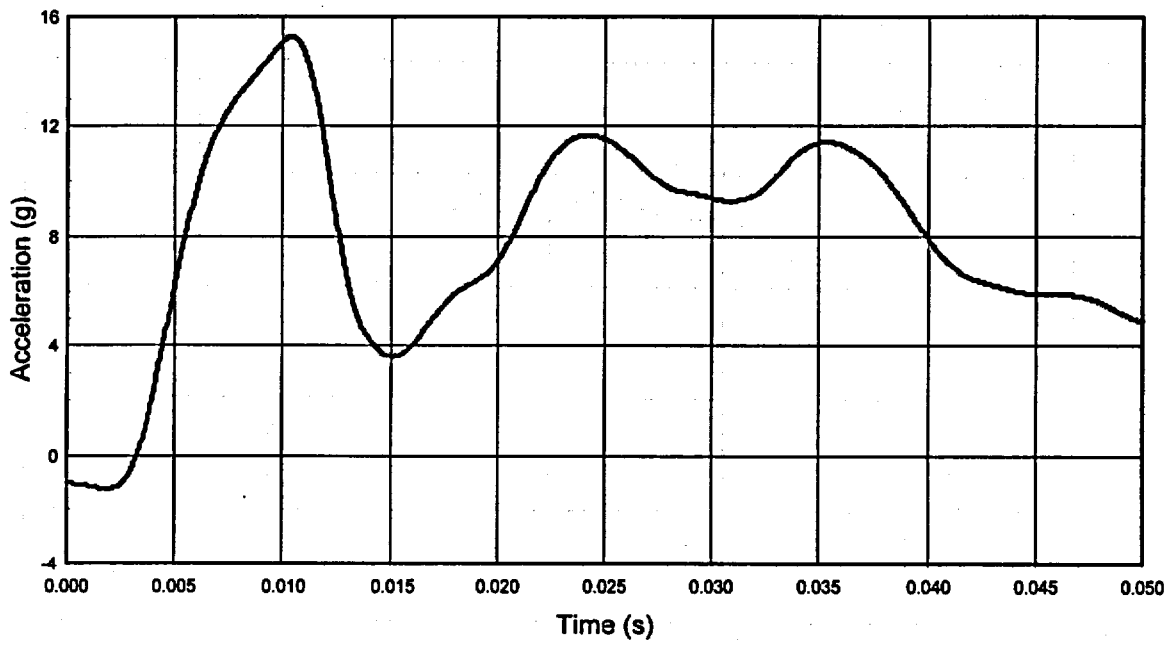

Figure 2.6.7.4.2-9 Acceleration Time-History for 1-ft Drop onto Corner 1 (Cold Conditions)

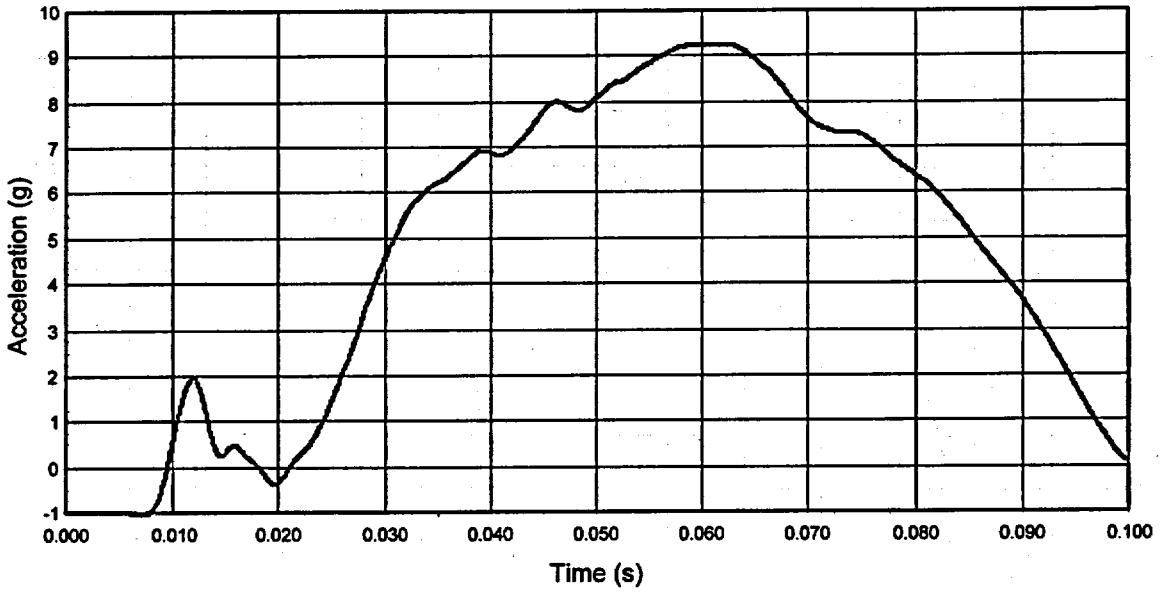

Figure 2.6.7.4.2-10 Acceleration Time-History for 1-ft Drop onto Corner 2 (Cold Conditions)

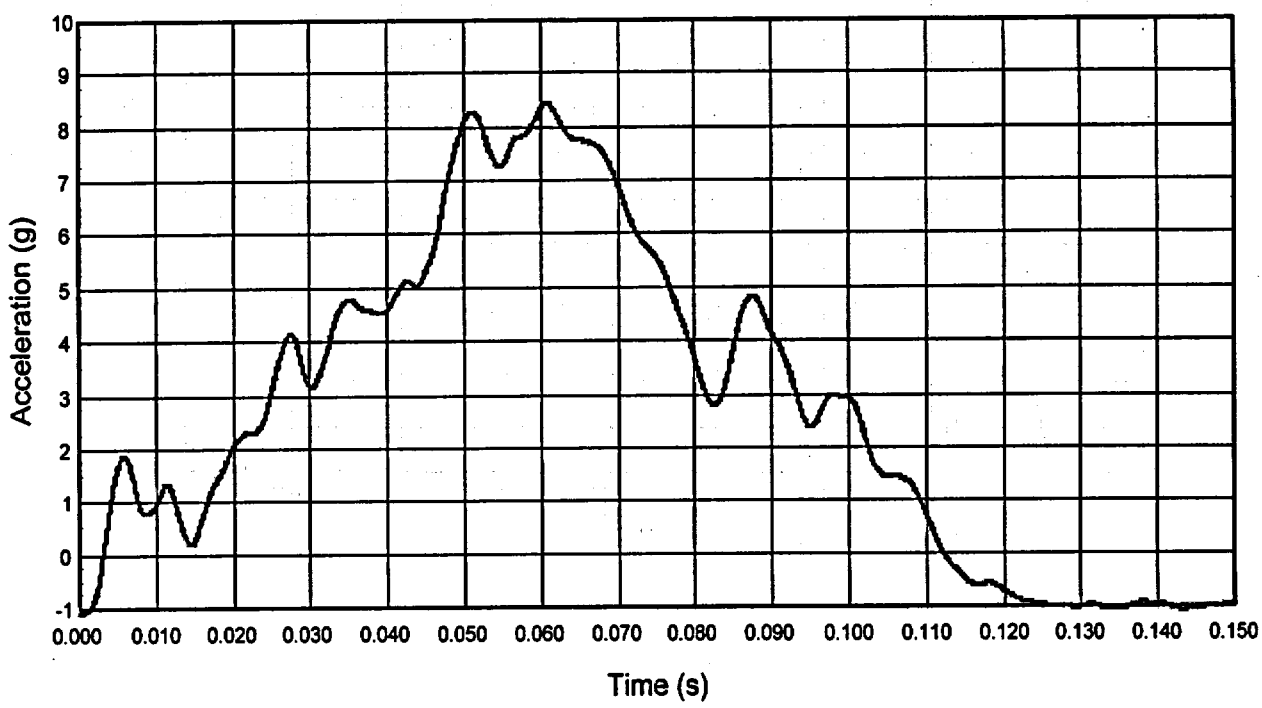

Figure 2.6.7.4.2-11 Acceleration Time-History for 30-ft Side Drop onto Trunnion (Hot and Cold Conditions)

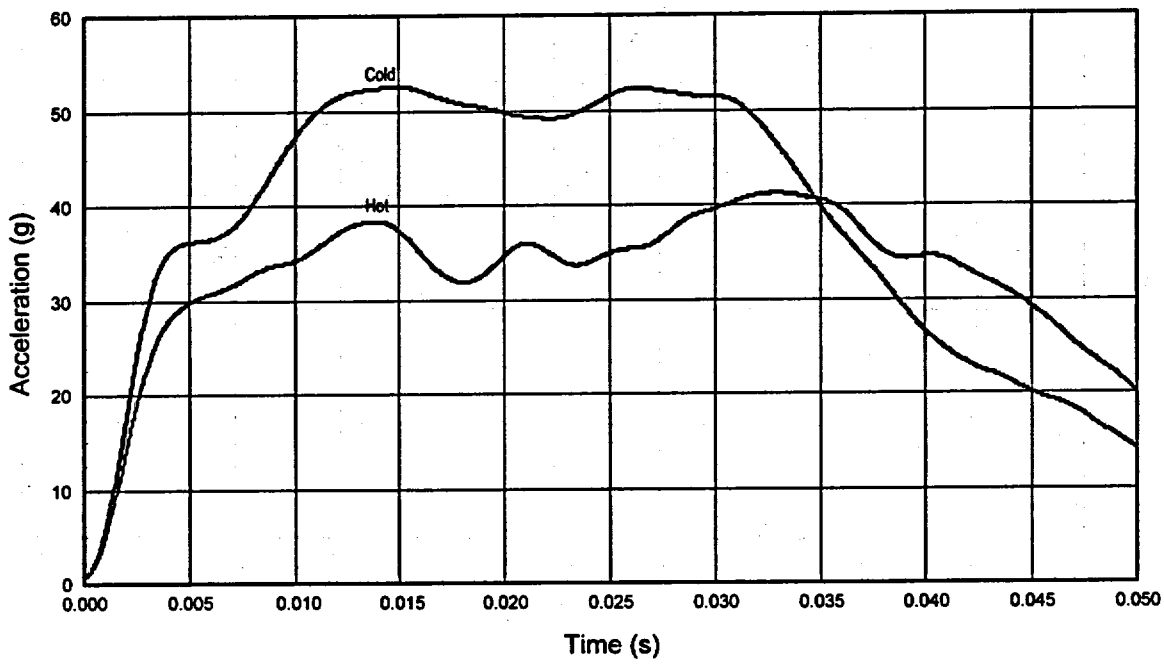

Figure 2.6.7.4.2-12 Acceleration Time-History for 30-ft Side Drop onto Gusset (Hot and Cold Conditions)

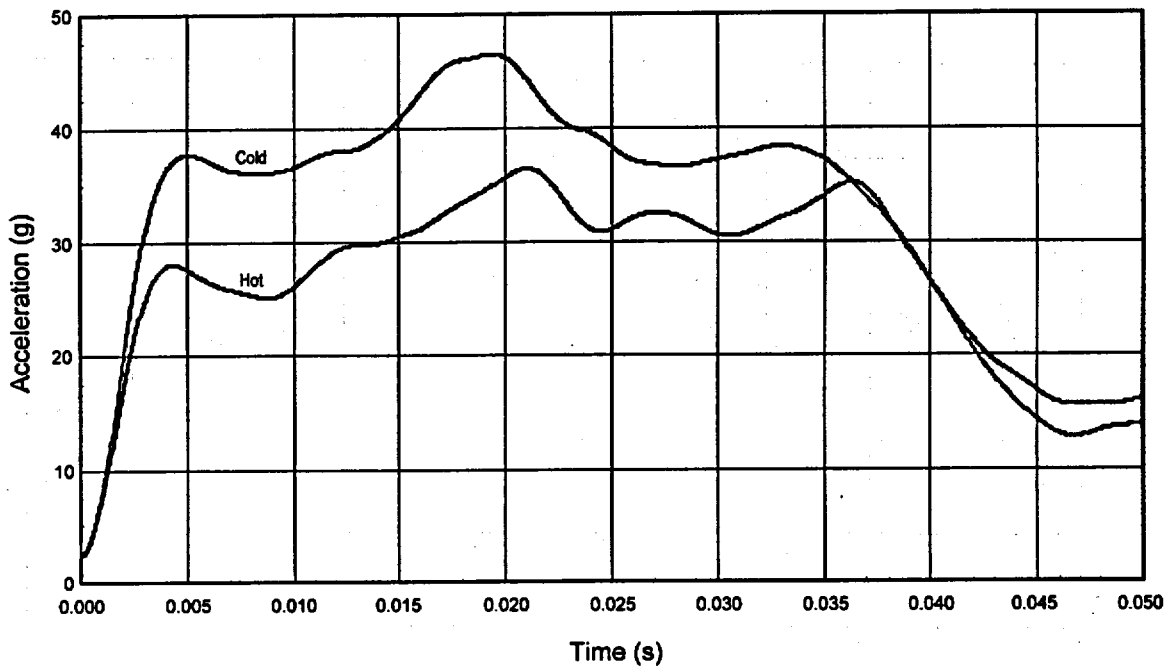

Figure 2.6.7.4.2-13 Acceleration Time-History for 30-ft End Drop (Hot and Cold Conditions)

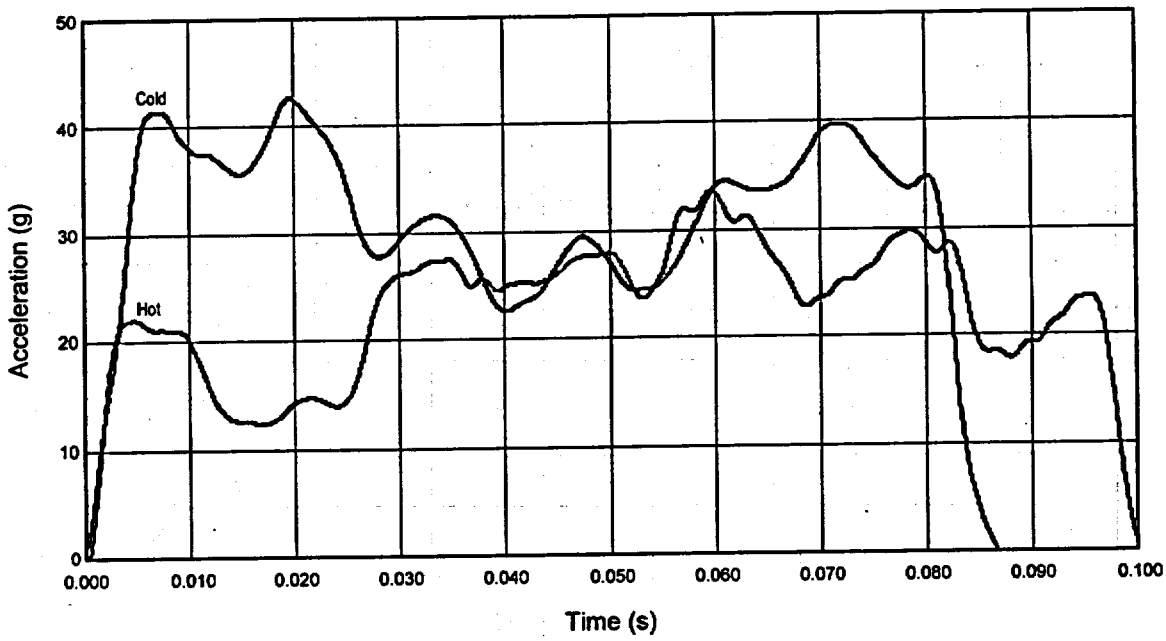

Figure 2.6.7.4.2-14 Acceleration Time-History for 30-ft Drop onto Corner 1 (Hot and Cold Conditions)

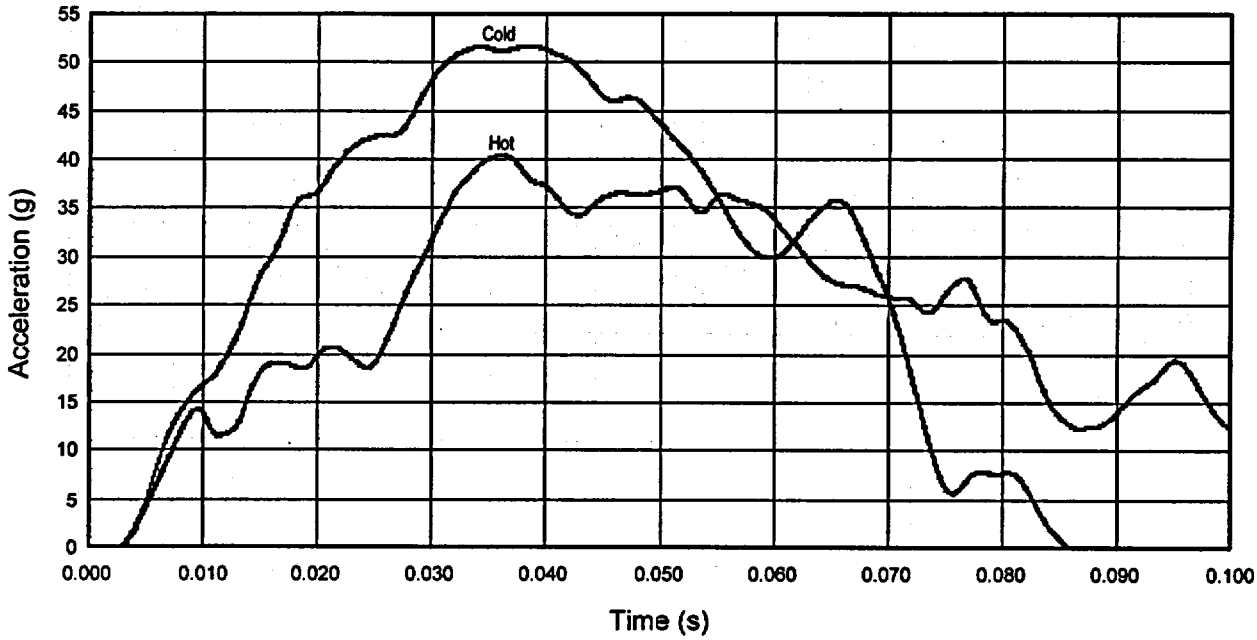

Figure 2.6.7.4.2-15 Acceleration Time-History for 30-ft Drop onto Corner 2 (Hot and Cold Conditions)

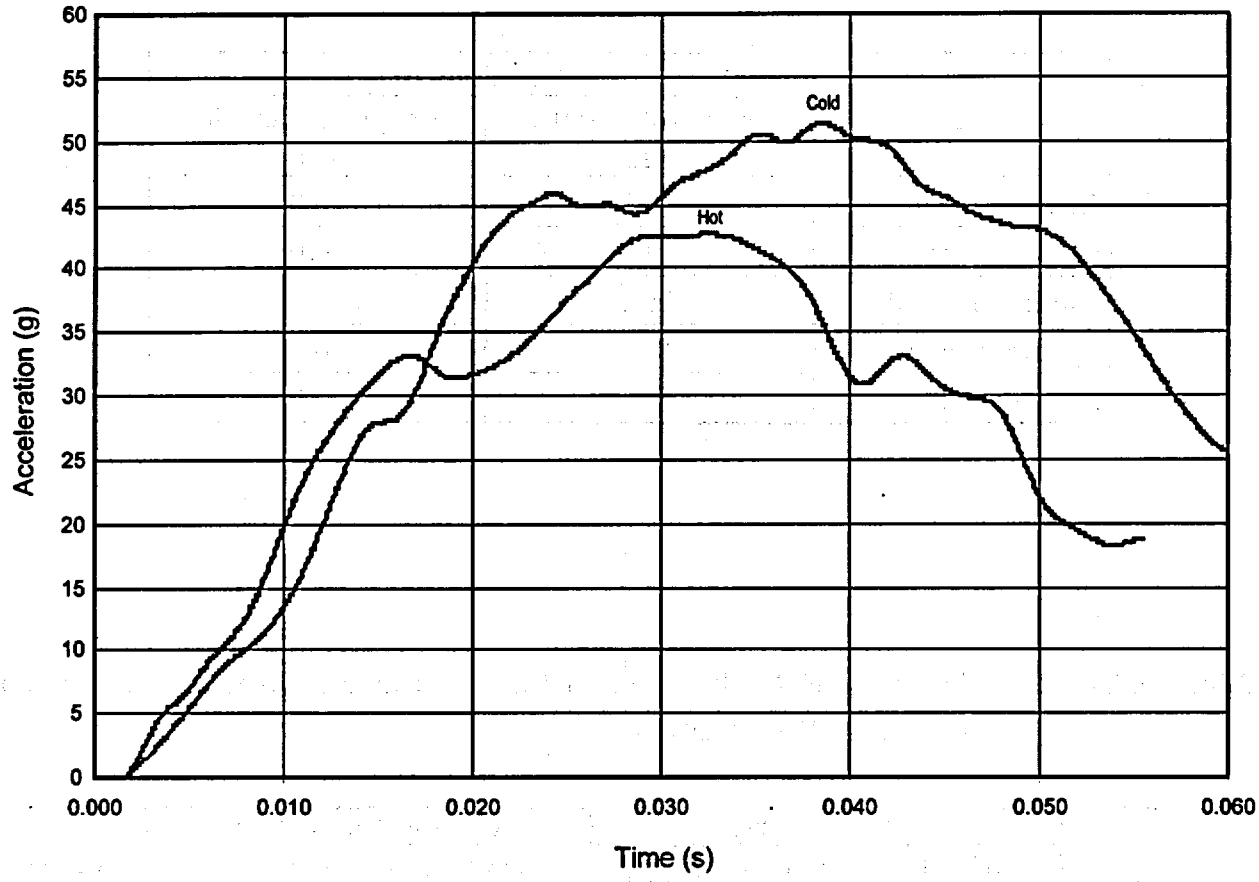

Table 2.6.7.4.2-1 Summary of Results for the Balsa Impact Limiter Normal Conditions of Transport Drop Analysis

Drop Orientation	Cold Condition (-40°F)	
	Normal Acceleration (g)	Design Acceleration (g)
Side on trunnion	19.8	20.0
Side on gusset	19.5	20.0
Top/Bottom End	15.2	20.0
c.g. over Corner 1	9.3	20.0
c.g. over Corner 2	8.4	20.0

Table 2.6.7.4.2-2 Summary of Results for the Balsa Impact Limiter Hypothetical Accident Conditions Drop Analysis

Drop Orientation	Hot Condition (200°F)			Cold Condition (-40°F)			Design Acceleration (g)
	Accident Acceleration (g)	Crush Depth (in.)	Percent Strain	Accident Acceleration (g)	Crush Depth (in.)	Percent Strain	
Side on trunnion	40.6	11.6	68%	52.5	9.1	54%	55.0
Side on gusset	36.4	9.9	48%	46.4	7.8	38%	55.0
Top/Bottom End	33.6	18.6	46%	42.4	11.1	28%	56.1
c.g. over Corner 1	40.5	18.5	45%	51.7	14.4	35%	55.0
c.g. over Corner 2	42.6	15.5	35%	51.4	14.3	32%	55.0