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TN 68 TRANSPORT PACKAGING SAFETY ANALYSIS REPORT

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TN 68 PACKAGING
SAFETY ANALYSIS REPORT

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TN 68 TRANSPORT PACKAGING

CHAPTER 1

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CHAPTER 1

GENERAL INFORMATION

1.1 INTRODUCTION

This Safety Analysis Report (SAR) presents the evaluation of a Type B(U) spent fuel transport packaging developed by Transnuclear, Inc. and designated the TN-68. This SAR describes the design features and presents the safety analyses which demonstrate that the TN-68 complies with applicable requirements of 10 CFR 71[(1)]. The format and content of this SAR follow the guidelines of Regulatory Guide 7.9[(2)].

The TN-68 is a dual purpose cask intended for both storage and transport. A separate SAR has been submitted to address the safety related aspects of storing spent fuel in TN-68 casks in accordance with 10 CFR 72[(3)].

The packaging is intended to be shipped as exclusive use. The Transport Index for nuclear criticality control for the TN-68 cask is determined to be zero (0) in accordance with 10 CFR 71.59. See Chapter 6.

Transnuclear, Inc. has a NRC approved quality assurance program (Docket Number 71-0250) which satisfies the requirements of 10 CFR 71 Subpart H.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The TN-68 packaging will be used to transport 68 intact BWR fuel assemblies with or without channels. Only intact fuel will be transported in the cask. Known or suspected failed fuel assemblies (rods) and fuel with cladding defects greater than pin holes and hairline cracks are not to be transported in the TN-68 packaging. In its transport configuration, the TN-68 packaging consists of the following components:

- A basket assembly which locates and supports the fuel assemblies, transfers heat to the cask body wall, and provided neutron absorption to satisfy nuclear criticality requirements.

- A containment vessel including a closure lid and seals which provides radioactive materials containment and a cavity with an inert gas atmosphere.

- A thick-walled, forged steel cask body for gamma shielding surrounding the containment vessel.

- A radial neutron shield surrounding the gamma shield which provides additional radiation shielding. The neutron shielding is enclosed in an outer steel shell.

- A set of impact limiters consisting of balsa and redwood, encased in carbon steel shells, which are attached to both ends of the containment vessel during the shipment. An aluminum spacer is also present to provide a smooth contact surface between the top impact limiter and the cask lid. The impact limiters are held in place with the use of tie rods and attachment bolts.

- Sets of upper and lower trunnions that provide support, lifting, and rotation capability for the cask.

- During transport, a tarp will be placed around the entire TN-68 transport package (including the impact limiters). To support the tarp, a tubular framing having the same OD as the impact limiters will be placed around the body of the cask between the impact limiters. This covering will protect the TN-68 from debris during transport and will help provide intruder protection.

The overall dimensions of the TN-68 packaging are 269.33 inches long and 144 inches in diameter with the impact limiters installed. The cask body is 197.25 inches long and 84.50 inches in diameter except at the lid which is 79.88 inches in diameter. The cask diameter including the radial neutron shield is 98.0 inches. The cask cavity is 178 inches long and 69.5 inches in diameter. The general arrangement of the TN-68 packaging is depicted in Figure 1-1. Detailed design drawings for the TN-68 packaging are provided in Appendix 1.4. The materials used to fabricate the packaging are shown in the Parts List on Drawing 972-71-3 and the

materials used to fabricate the impact limiters are shown in Parts List on Drawing 972-71-10. Where more than one material has been specified for a component, the most limiting properties are used in the analyses in the subsequent chapters of this SAR.

The maximum gross weight of the loaded package is 130.0 tons including a maximum payload of 47.9 kips. Table 1-1 summarizes the dimensions and weights of the TN-68 packaging. Trunnions attached to the cask body are provided for lifting and handling operations, including rotation of the packaging between the horizontal and vertical orientations. The TN-68 packaging is loaded in the vertical configuration and transported in the horizontal orientation, on a specially designed shipping frame, with the lid end facing the direction of travel.

The maximum normal operating pressure of the TN-68 is 18.5 psig. A cask cavity pressure of 100 psig is conservatively used for the purposes of structural analyses. The spent fuel payload is shipped dry in a helium atmosphere. The heat generated by the spent fuel assemblies is rejected to the surrounding air by convection and radiation. No forced cooling or cooling fins are required.

The following sections provide a physical and functional description of each major component. Detail drawings showing dimensions of significance to the safety analyses, welding and NDE information, and a complete materials list are provided in Appendix 1.4. Reference to these drawings is made in the following physical description sections and in general, throughout this SAR. Fabrication of the TN-68 packaging is performed in accordance with these drawings.

1.2.1.1 Containment Vessel

The containment boundary consists of the inner shell and bottom plate, shell flange, lid outer plate, lid bolts, penetration cover plate and bolts and the inner metallic O-rings of the lid seal and the two lid penetrations (vent and drain). The containment vessel prevents leakage of radioactive material from the cask cavity. It also maintains an inert atmosphere (helium) in the cask cavity. Helium assists in heat removal and provides a non-reactive environment to protect fuel assemblies against fuel cladding degradation which might otherwise lead to gross rupture.

The overall containment vessel length is approximately 189 in. with a wall thickness of 1.5 in. The cylindrical cask cavity has a nominal diameter of 69.5 in. and a length of 178 in. The containment lid is 5 in. thick and is fastened to the body by 48 bolts. Double metallic O-ring seals are provided for the lid closure. To preclude air in-leakage, the cask cavity is pressurized with helium to above the atmospheric pressure.

There are two penetrations through the containment vessel which are in the lid. These penetrations are for draining and venting. Double metallic seals are utilized on these two lid penetrations.

The OP port provides access to the interspace lid seals for testing purposes. The OP transport cover is not part of the containment boundary.

The containment shell, bottom, and lid materials are SA-203, Grade E and SA-350, Grade LF3. The TN-68 containment vessel is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB[4] of the ASME Code to the maximum practical extent. In addition, the design meets the requirements of Subsection WB of the ASME Section III, Division 3[5] and Regulatory Guides 7.6[6] and 7.8[7]. Exceptions to the ASME Code are discussed in Section 2.11 of Chapter 2. The construction of the containment boundary is shown on drawings 972-71-2, 3 and 4 provided in Appendix 1.3. The design of the containment boundary is discussed in Chapter 2 and the fabrication requirements (including examination and testing) of the containment boundary are discussed in Chapter 4.

1.2.1.2 Gamma and Radial Neutron Shielding

A gamma shield is provided around the walls and the bottom of the containment vessel, by an independent shell and bottom plate of carbon steel (Drawings 972-71-2, -3 and –4). The gamma shield completely surrounds the containment vessel inner shell and bottom closure. The 6.0 inch thick gamma shielding cylinder is SA-266, Class 2 and the 8.25 inch thick bottom is SA-266 Class 2 or SA-516, Grade 70.

In order to obtain a close fit between the containment vessel and the gamma shielding for heat transfer, the gamma shielding is heated prior to assembly with the containment shell. As the gamma shielding cools, a gap forms between the containment vessel flange and the gamma shielding. This gap is filled with shims as shown on Drawing 972-71-4. The shims are machined to fill the gap and act as a backing plate for the 0.50 inch weld between the containment flange and the gamma shield shell. The shims are typically less than 0.25 inches and no more than 0.50 inches thick and are made from SA-516, Grade 70 material. The shims are sized so there is no more than 0.03 inch gap between the shims and the flange or the shims and the gamma shield shell.

A 4.50 inch thick gamma shield (SA-105 or SA-516, Grade 70) is also welded to the inside of the containment lid (Drawing 972-71-4).

Neutron shielding is provided by a borated polyester resin compound surrounding the gamma shield. The resin compound is cast into long, slender aluminum containers. The containers are 6063-T5 aluminum. The total thickness of the resin and aluminum is 6.00 inches. The array of resin-filled containers is enclosed within a smooth 0.75 inch thick outer steel shell (SA-516, Grade 70) constructed of two half cylinders. In addition to serving as resin containers, the aluminum provides a conduction path for heat transfer, from the cask body to the outer shell. A pressure relief valve is mounted on top of the resin enclosure (during storage) for venting the overpressure, caused by heating of the resin and the air entrapped after fuel loading.

Noncontainment welds are inspected in accordance with the NDE acceptance criteria of ASME B&PV Code Subsection NF.

The structural analysis of the TN-68 cask body is presented in Chapter 2.

1.2.1.3 Impact Limiters

Front and rear impact limiters, shown on TN Drawings 972-71-1 and -8 through -12, form a part of the TN-68 packaging. The impact limiters are attached to each other using 13 tie rods and to the cask by 8 bolts attaching to brackets welded to the outer shell in eight locations (four bolting locations per impact limiter). The impact limiters consist of balsa wood and redwood blocks, encased in sealed carbon steel shells (A-516, Grade 70) that maintain the wood in a dry atmosphere and provide wood confinement when crushed during a free drop. The impact limiters have internal radial gussets for added strength and confinement.

The impact limiters have an outside diameter of 144 inches, and an inside diameter of 85.55 inches. They extend, axially, 35.25 inches from the ends of the cask, and overlap the sides of the cask by 12.75 inches.

Thirteen 1.5 inch diameter tie-rods are used to hold the impact limiters in place. The tie-rods span the length of the cask and connect to both impact limiters via mounting brackets (See Drawings 972-71-8 through 972-71-11). The impact limiters are also attached to the outer shell of the cask with 1.5 inch diameter bolts. The bolts are attached to brackets (welded to the cask outer shell) and thread into to each impact limiter. There are a total of eight bolt-bracket sets, four per impact limiter.

Each impact limiter is provided with seven fusible plugs that are designed to melt during a fire accident, thereby relieving excessive internal pressure. Each impact limiter has two lifting lugs for handling, and two support angles for holding the impact limiter in a vertical position during storage. The lifting lugs and the support angles are welded to the carbon steel shells.

An aluminum spacer is placed on the cask lid prior to mounting the impact limiters. The purpose of the aluminum spacer is to provide a smooth contact surface for the top impact limiter. The top plate of the spacer has 48 holes to allow clearance for the lid bolt heads. The lip of the spacer is designed to make up the difference between the lid and cask outer diameters so that the top impact limiter cavity mates with a surface of constant diameter (Drawing 972-71-12).

The functional description as well as the performance analysis of the impact limiters are provided in Appendix 2.10.8.

1.2.1.4 Tiedown and Lifting Devices

Threaded holes are provided in the lid for attachment of component lifting devices. These are used as attachment points for sling systems or other lifting tools. These threaded holes are equally spaced 90° apart as shown on Drawing 972-71-4. Prior to transport, any attachments will be removed and access to these threaded holes is prevented by the presence of the top impact limiter.

Four trunnions, which form part of the cask body, are attached for lifting and rotating of the cask. Two of the trunnions are located near the top of the body, and two near the bottom. The upper trunnions are bolted to the gamma shielding and sized for single failure proof lifting. The upper

trunnions are not intended to be removed during transport. The lower trunnions are welded to the gamma shield, and are used for rotating the cask between the vertical and the horizontal positions.

The top trunnions are fabricated and tested in accordance with ANSI N14.6 and are designed for single failure proof lifting.

1.2.1.5 Fuel Basket

The basket structure is designed, fabricated and inspected in accordance with ASME B&PV Code Subsection NG. Exceptions to the code are provided in Section 2.11. The basket structure consists of an assembly of stainless steel cells, joined by a proprietary fusion welding process to 1.75 in. wide stainless steel plates. Above and below the plates are slotted borated aluminum (or boron carbide/aluminum) metal matrix composite plates (neutron poison plates) which form an egg-crate structure. The poison plates provide the necessary criticality control and provide the heat conduction paths from the fuel assemblies to the cask cavity wall. This construction forms a very strong honeycomb-like structure of cell liners, which provide compartments for 68 fuel assemblies. The nominal open dimension of each cell is 6.0 in. x 6.0 in., which provides some clearance around the fuel assemblies. The overall basket length of 164 in. is less than the cask cavity length, and allows for thermal expansion and fuel assembly handling.

A shear key is welded to the inner wall of the containment vessel to prevent the basket from rotating during normal operations. Similarly, a hold down ring is installed above the basket after fuel loading is complete to prevent the basket from moving axially during transport.

1.2.2 Operational Features

There are no complex operational features associated with the TN-68 cask. The TN-68 packaging is designed to be compatible with spent fuel pool loading/unloading methods. The sequential steps to be followed for cask loading, testing, and unloading operations are provided in Chapter 7. These operations are summarized below.

Upon arrival, the empty cask is inspected. Preparation of the packaging for loading/unloading requires that the front (top) and rear (bottom) impact limiters including the tie-rods and attachment bolts are removed from the cask body, first. The cask is then rotated from the horizontal transport orientation to the vertical orientation using a crane and lift beam attached to the front trunnions. The rear trunnions pivot in the shipping frame as the cask is rotated.

The cask is brought into the spent fuel building. Access to the cask cavity and fuel basket is obtained by untorquing and removing the 48 closure lid bolts, and removing the lid using the lifting lugs provided. The cask is then lowered into the cask pit/spent fuel pool. Fuel assemblies are loaded into the 68 basket compartments.

The lid is installed and the cavity is vented and drained. The cask is lifted above the water and some of the lid bolts are installed hand tight. Venting/draining may occur while lifting the cask out of the pool. The cask is moved from the cask pit/spent fuel pool to the decontamination area.

The remaining lid bolts are installed. The cask cavity is then evacuated and dried by means of a vacuum system and then back filled with helium. The lid seals and penetration cover seals are leak tested. The external surface radiation levels are checked to assure that they are within limits.

1.2.3 Contents of Packaging

The contents of the TN-68 packaging are limited to the following.

- Fuel parameters
  - Fuel is limited to 68 unconsolidated intact GE BWR fuel assemblies with zircalloy cladding
  - Fuel may be transported with or without channels. Nominal channel thicknesses up to 0.120 inches thick are acceptable for transport.
  - Permissible fuel assembly types are listed below (fuel designs may be C, D, or S lattice)

GE Type	Designation	# of Fueled Rods	Uranium Content (MTU/assembly)
7x7	2A	49	0.1977
7x7	2, 2B	49	0.1977
7x7	3, 3A, 3B	49	0.1896
8x8	4, 4A, 4B	63	0.1880
8x8	5, 6, 6B, 7, 7B	62	0.1876
8x8	8, 8B	62	0.1885
8x8	8, 8B, 9, 9B, 10	60	0.1824
9x9	11,13	74	0.1757
10x10	12	92	0.1857

  - Provided all the requirements listed in this section are met, the bounding fuel characteristics are:

Characteristic	Parameter
Maximum Initial lattice-average enrichment	3.7%
Minimum Initial bundle average enrichment	3.3%
Maximum assembly average burnup	40,000 MWD/MTU
Minimum cooling time	10 years

- The maximum contents weight shall not exceed 75.6 kips. The total weight of the BWR fuel assemblies shall not exceed 47.9 kips.
- The total decay heat of the cavity contents shall not exceed 21.2 kW.

- Measured external radiation levels shall not exceed the requirements of 10 CFR 71.47. Measured surface contamination levels shall not exceed the requirements of 10 CFR 71.87(i).

1.3 REFERENCES

1. 10 CFR 71, Packaging and Transportation of Radioactive Material.

2. USNRC Regulatory Guide 7.9, "Standard Format and Content of Part71 Applications for Approval of Packaging for Radioactive Material", Rev. 2, May,1986.

3. 10 CFR 72, Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste.

4. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, 1995 including 1996 addenda.

5. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, Division 3, Subsection WB, 1998.

6. USNRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessel", Rev. 1, March 1978.

7. USNRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Cask", Rev. 1, March 1989.

1.4 APPENDIX – TN-68 PACKAGING DRAWINGS

The following Transnuclear drawings are enclosed:

Drawing No	Title
972-71-1	TN-68 Packaging, Transport Configuration
972-71-2	TN-68 Packaging, General Arrangement
972-71-3	TN-68 Packaging, Parts List & Details
972-71-4	TN-68 Packaging, Lid Assembly & Details
972-71-5	TN-68 Packaging, Basket General Arrangement
972-71-6	TN-68 Packaging, Basket Typical Cross Section
972-71-7	TN-68 Packaging, Details
972-71-8	TN-68 Packaging, Cask on Transport Frame
972-71-9	TN-68 Packaging, Transport Impact Limiter Assembly
972-71-10	TN-68 Packaging, Transport Impact Limiter Parts List & Details
972-71-11	TN-68 Packaging, Transport Impact Limiter Details
972-71-12	TN-68 Packaging, Transport Impact Limiter Spacer
972-71-13	TN-68 Packaging, Regulatory Plate

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		Q/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/19/99
Q/A WRS	5/19/99
PS MECH. DES.	5/19/99
PS CHK'D. BY	5/19/99
DWN. BY.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, NY.

TN-68 PACKAGING
TRANSPORT CONFIGURATION

SAR

NONE SCALE	B SIZE	972-71-1 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHKD.	M.D.		Q/A	PROJ.

APPROVALS	DATE
PROJ.	5/19/99
Q/A	5/19/99
MECH. DES.	5/19/99
CHK'D. BY	5/19/99
DWN. BY	18 MAY 98

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
GENERAL ARRANGEMENT

SAR

NONE SCALE	B SIZE	972-71-2 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	N/T	Q/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/14/99
Q/A WKS	5/14/99
MECH. DES. PS	5/14/99
CHK'D. BY PS	5/14/99
DWN. BY. JB	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
GENERAL ARRANGEMENT
PARTS LIST & DETAILS

SAR

NONE SCALE	B SIZE	972-71-3 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	Q/A	PROJ.

APPROVALS	DATE
PROJ.	5/19/99
Q/A	5/19/99
MECH. DES.	5/19/99
CHK'D. BY	5/19/99
DWN. BY	18 MAY 99

TRANSNUCLEAR INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING

LID ASSEMBLY & DETAILS

SAR

NONE SCALE	B SIZE	972-71-4 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.	N/T	Q/A	PROJ.

APPROVALS		DATE
PROJ.	JPh	5/19/99
Q/A	WRS	5/19/99
MECH. DES.	PS	5/19/99
CHK'D. BY	PS	5/19/99
DWN. BY	SAB	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
BASKET
GENERAL ARRANGEMENT

SAR

NONE	B	972-71-5	0
SCALE	SIZE	DWG. NO.	REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.	N/T	Q/A	PROJ.

APPROVALS	DATE
PROJ.	5/19/99
Q/A WRS	5/19/99
MECH. DES. PS	5/19/99
CHK'D. BY PS	5/19/99
DWN. BY	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
BASKET
TYPICAL CROSS SECTION

SAR

NONE	B	972-71-6	0
SCALE	SIZE	DWG. NO.	REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D	M.D.		Q/A	PROJ.
APPROVALS	DATE	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.						
PROJ.		TN-68 PACKAGING DETAILS						
Q/A								
MECH. DES.								
CHK'D. BY								
DWN. BY	18 MAY 99	NONE SCALE	B SIZE	972-71-7 DWG. NO.				0 REV.

SAR

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHKD.	M.D.	O/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/14/99
O/A WK	5/14/99
MECH. DES. PS	5/14/99
CHK'D. BY PS	5/14/99
DWN. BY FD	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
CASK ON TRANSPORT FRAME

SAR

NONE SCALE	B SIZE	972-71-8 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

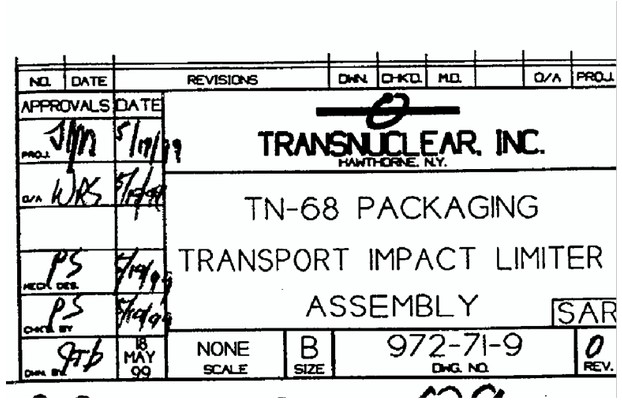


FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHKD.	MD.		Q/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/19/99
Q/A WKS	5/19/99
MECH. DES. PS	5/19/99
CHKD. BY PS	5/19/99
Ajb	18 MAY

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT IMPACT LIMITER
PARTS LIST & DETAILS

SAR

NONE	B	972-71-10	0
	SIZE	DWG. NO.	REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHKD.	M.O.		Q/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/19/99
Q/A WPS	5/19/99
PS MECH. DES.	5/19/99
PS CHKD. BY	5/19/99
DWN. BY 97b	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
TRANSPORT IMPACT LIMITER
DETAILS

SAR

NONE SCALE	B SIZE	972-71-11 DWG. NO.	0 REV.

FIGURE WITHHELD UNDER 10 CFR 2.390

NO.	DATE	REVISIONS	DWN.	CHK'D.	M.D.		Q/A	PROJ.

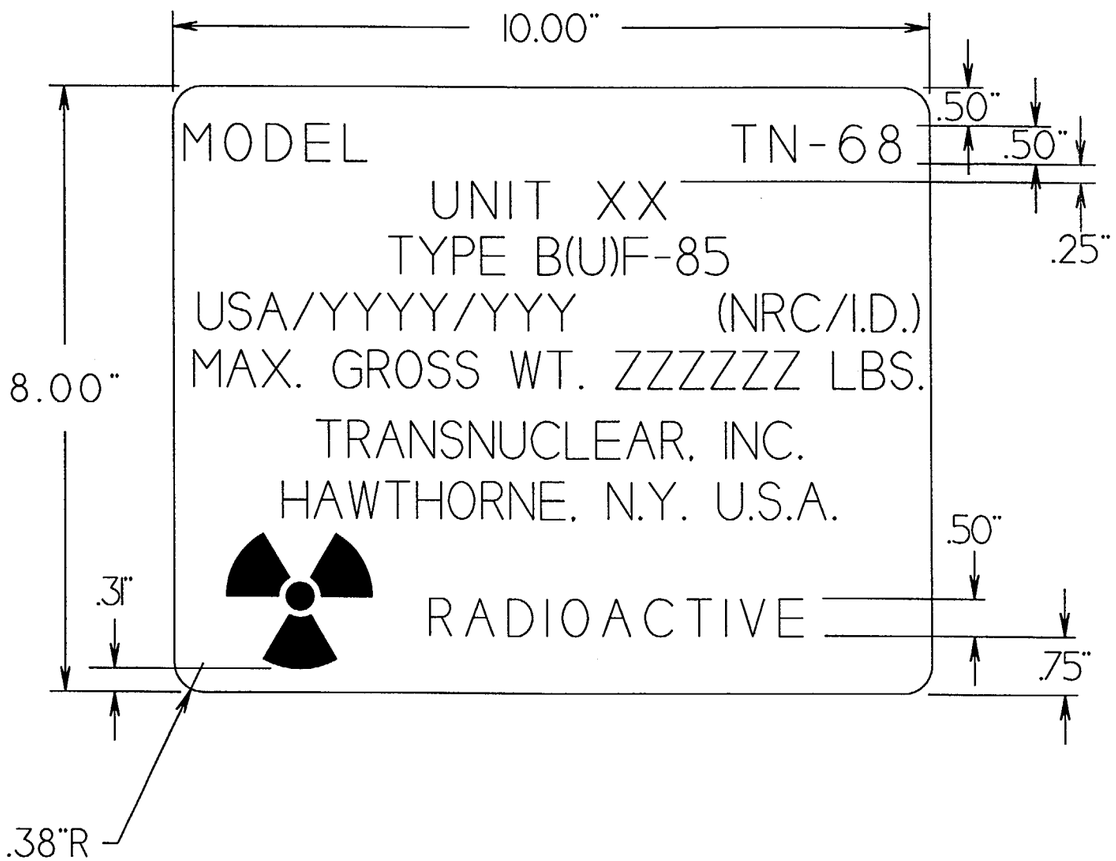
APPROVALS	DATE
PROJ. JJM	5/19/99
Q/A WRS	5/19/99
MECH. DES. PS	5/19/99
CHK'D. BY PS	5/19/99
DWN. BY. JTD	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING
FRONT
TRANSPORT IMPACT LIMITER
SPACER

SAR

NONE	B	972-71-12	0
SCALE	SIZE	DWG. NO.	REV.



NOTES:

1) FOR ATTACHMENT TO CASK SEE DWG. 972-71-8.
2) MATERIAL: SST. .048" THICK.
3) TOLERANCE, UNLESS OTHERWISE SPECIFIED: +/- .12"
4) LETTERS & SYMBOLS TO BE STAMPED OR ENGRAVED THEN PAINTED WITH BLACK PAINT.
5) "XX" SIGNIFIES CASK NUMBER. INSERT APPROPRIATE SEQUENTIAL NUMBER STARTING WITH 01, 02, 03.... ETC.
6) "YYYY/YYY" SIGNIFIES NRC I.D.
7) "ZZZZZZ" SIGNIFIES CASK WEIGHT.

APERTURE CARD
Also Available on Aperture Card

9906210091 -13

NO.	DATE	REVISIONS	DWN.	CHKD.	MD.	N/T	Q/A	PROJ.

APPROVALS	DATE
PROJ. JM	5/19/99
Q/A	5/19/99
N/T	
MECH. DES. PS	5/19/99
CHKD. BY PS	5/19/99
DWN. BY.	18 MAY 99

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-68 PACKAGING

REGULATORY PLATE

SAR

HALF	B	972-71-13	0
SCALE	SIZE	DWG. NO.	REV.

TABLE 1-1

NOMINAL DIMENSIONS AND WEIGHTS OF THE TN-68 PACKAGING

Overall length (with impact limiters, in)	269.33
Overall length (without impact limiters, in)	197.25
Impact Limiter Outside diameter (in)	144
Outside diameter (without impact limiters, in)	98
Cavity diameter (in)	69.5
Cavity length (in)	178
Containment shell thickness (in)	1.5
Containment vessel length (in)	184
Body wall thickness (in)	7.5
Containment Lid thickness (in)	5
Overall Lid thickness (in)	9.5
Bottom thickness (in)	9.75
Resin and aluminum box thickness (in)	6
Outer shell thickness (in)	0.75
Overall basket length (in)	164

Weight of Fuel Assemblies	47.9	kips
Loaded Weight of TN-68 Cask (without impact limiters)	227.4	kips
Weight of Impact Limiters, Aluminum Spacer, and Tie-Rods	32.7	kips
Total Loaded Weight of TN-68 Packaging (w/o shipping frame)	260.1	kips

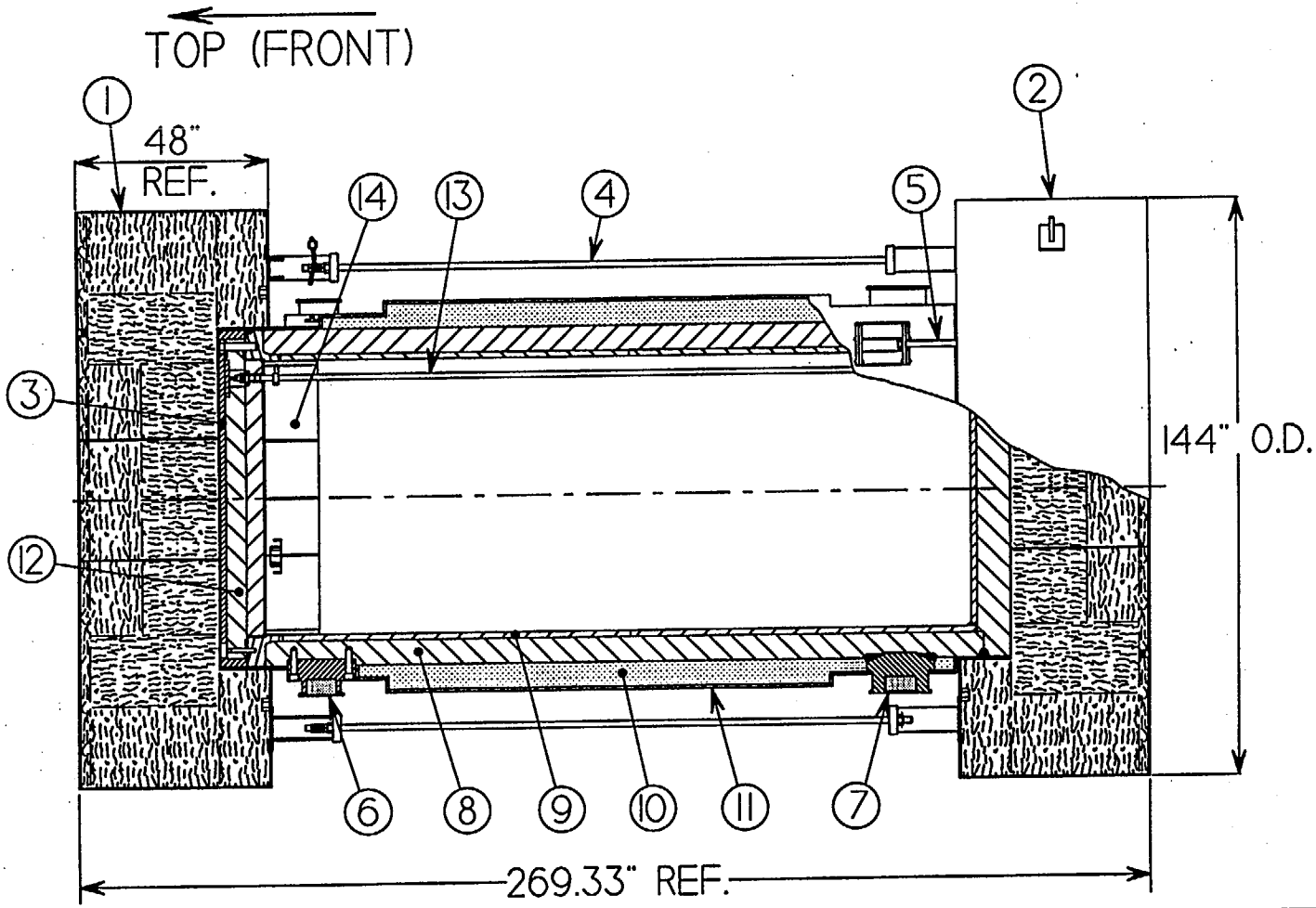


FIGURE 1-1
GENERAL ARRANGEMENT
TN-68 PACKAGING

Notes to Figure 1-1

A. Some details exaggerated for clarity.

B. Components are listed below:

1 Upper (front) impact limiter
2 Lower (rear) impact limiter
3 Aluminum Spacer
4 Impact Limiter Tie Rod
5 Impact Limiter Attachment Bolt & Bracket
6 Upper (bolted) Trunnions
7 Lower Trunnions
8 Cask Body (Gamma Shield Shell & Bottom)
9 Containment Shell (Inner Shell & Bottom)
10 Neutron Shielding
11 External Shell
12 Lid Assembly
13 Drain Tube
14 Basket Hold Down Ring

TN 68 TRANSPORT PACKAGING

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CHAPTER 2

STRUCTURAL EVALUATION

2.1 STRUCTURAL DESIGN

This chapter, including its appendices, presents the structural evaluation of the TN-68 packaging. This evaluation consists of numerical analyses and impact limiter testing which demonstrate that the TN-68 packaging satisfies applicable requirements for a Type B(U) packaging.

2.1.1 Discussion

The structural integrity of the packaging under normal conditions of transport and hypothetical accident conditions specified in 10CFR71[1] is shown to meet the design criteria described in Section 2.1.2. The TN-68 transport package consists of three major structural components: the cask body, the fuel basket, and the impact limiters (front and rear). These components are described in Chapter 1 and are shown on drawings provided in Appendix 1.3.

The cask body is described in Section 1.2. Drawing 972-71-1 shows the overall transport configuration of the TN-68 packaging. Drawings 972-71-2 and 972-71-3 show the general arrangement of the TN-68 packaging. Drawing 972-71-4 presents the lid assembly. Drawings 972-71-5 and 972-71-6 show the basket structure. Drawings 972-71-7 provides additional details of the TN-68 packaging. Drawing 972-71-8 shows the TN-68 Packaging on the transport frame and drawings 972-71-9 through 972-71-11 provide details of the impact limiter design. The impact limiter spacer is shown on drawing 972-71-12. The regulatory plate is provided on drawing 972-71-13.

The containment shell with the welded flange, the inner bottom closure, and the lid materials are made of SA-203, Grade E and SA-350 Grade LF3. The gamma shielding cylinder is SA-266, Grade 2, the lid shield plate is SA-105 or SA-516 Grade 70 and the bottom shield is SA-266 Grade 2 or SA-516 Gr. 70.

In order to obtain a close fit between the containment vessel and the gamma shielding, for better heat transfer, the gamma shielding is heated prior to assembling it with the inner shell. As the gamma shielding cools, a gap forms between the containment vessel flange and the gamma shielding. This gap is filled with shims as shown on Drawing 972-71-4. The shims are machined to fill the gap and act as a backing plate for the 0.50 inch weld, between the containment flange and the gamma shielding shell. The shims are typically less than 0.25 inches wide, no more than 0.50 inches thick, and are made from SA-516, Gr. 70 material. The shims are sized so that there is no more than 0.03 inch gap between the shims and the flange, or the shims and the gamma shield shell.

The two lower trunnions are cylindrical, SA-105 forgings that are welded to the gamma shielding of the cask body. The two upper trunnions are SA-182 Gr. F6NM forgings, and are designed to lift the loaded TN-68 cask vertically. The upper trunnions are bolted to the cask

body with a flange connection, using 12-1 ½" diameter bolts made of SA-320-L43. The lower trunnions provide the capability to rotate the cask on the shipping frame and also act as a tiedown device in the transport configuration. The upper trunnions are designed to meet the requirements of ANSI N14.6[2]. The trunnions are shown in Drawing 972-71-3.

The outer shell around the neutron shield consists of a cylindrical shell section, with closure plates at each end of the shield. The closure plates are welded to the outer surface of the gamma shielding, of the cask body. The outer shell provides an enclosure for the resin-filled aluminum containers, and maintains the resin in the proper location with respect to the active length of the fuel assemblies in the cask cavity. The outer shell has no structural function. The shell is made of painted carbon steel.

The basket is a welded assembly of stainless steel fuel compartment boxes, and designed to accommodate 68 fuel assemblies. The sections of the stainless steel boxes are attached to the 304 SST plates, sandwiched between the box sections, by fusion welds. The fusion welds are spaced intermittently along the box sections. Neutron poison plates, composed of a boron-aluminum alloy (or a boron carbide aluminum metal matrix composite), are sandwiched between the sections of the stainless steel walls of the adjacent box and the adjacent stainless steel plates. The 304 SST members are the primary structural components. The neutron poison plates provide criticality control, and a heat conduction path from the fuel assemblies to the cask cavity wall. The bottom row of plates which are 304 SST (no poison) are also sandwiched between the fuel compartment box sections, and provide structural support to the basket. Drawings 972-71-5 and 972-71-6 show details of the basket.

The basket is supported, laterally by 6061-T6 aluminum rails (shown in Drawing 972-71-5). The rails are attached to the periphery of the basket by welded studs.

A key at the perimeter of the basket maintains the radial alignment of the basket with the cask cavity. This key is designed to prevent the basket from rotating in the cask cavity wall, under the normal transport conditions.

The basket hold down ring is set between the top of the basket assembly and the inside surface of the lid assembly. The hold down ring is used to prevent the basket assembly from sliding freely in the axial direction during the normal transport conditions.

The cask body and the fuel basket together with the two impact limiters, form the packaging is designed to meet all of the applicable 10CFR71 requirements for a Type B(U) packaging and a maximum normal operating pressure within the containment vessel of 18.5 psig.

The wall thickness of the cask body (excluding the outer shell and outer shell closure plates) enables the packaging to withstand the hypothetical puncture accident. This is designed to be both strong and ductile. The top and bottom impact limiters absorb the kinetic energy for the 1 ft. normal and 30 ft. hypothetical accident free drops.

Table 2-1 summarizes the specific evaluation methods that are used to demonstrate compliance with the regulations. Numerical analyses have been performed for the normal and accident

conditions, as well as for the lifting and tie-down loads. In general, numerical analyses have been performed for all of the regulatory events. These analyses are summarized in the main body of this section, and described in detail in Appendices 2.10.1 through 2.10.8. Testing of the impact limiters will be conducted to confirm the analytical assumptions. The test results will be included in Appendix 2.10.9.

The detailed structural analyses of the TN-68 packaging are included in the following appendices:

Appendix 2.10.1	Structural Analysis of the Cask Body
Appendix 2.10.2	Lid Bolt Analysis
Appendix 2.10.3	Structural Analysis of the Outer Shell
Appendix 2.10.4	Fracture Toughness Evaluation of the TN-68 Cask
Appendix 2.10.5	Structural Analysis of the TN-68 Basket
Appendix 2.10.6	Dynamic Load Factor for Basket Drop Analysis
Appendix 2.10.7	Structural Evaluation of the Fuel Rod Cladding Under Accident Impact
Appendix 2.10.8	Structural Evaluation of the Impact Limiters
Appendix 2.10.9	Impact Limiter Testing

2.1.2 Design Criteria

The packaging consists of three major components:

- Cask Body
- Fuel Basket
- Impact Limiters

The structural design criteria for these components are described below.

2.1.2.1 Cask Body

2.1.2.1.1 Containment Vessel

The containment vessel consists of the inner shell with a flange out to the seal seating surface, the bottom closure, and the lid. The lid bolts and seals are also part of the containment vessel as are the drain and vent cover plates, bolts and seals. The containment vessel is designed to the maximum practical extent as an ASME Class I component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB[3]. The Subsection NB rules for materials, design, fabrication and examination are applied to all of the above components to the maximum practical extent. In addition, the design meets the requirements of Subsection WB of the ASME Section III, Division 3[4] and Regulatory Guides 7.6[5] and 7.8[6]. Exception to the ASME Code are discussed in Section 2.11 of this Chapter.

The acceptability of the containment vessel under the applied loads, is based on the following criteria:

- Title 10, Chapter 1, Code of Federal Regulations, Part 71.
- Regulatory Guide 7.6 Design Criteria
- ASME Code Design Stress Intensities
- Preclusion of Fatigue Failure
- Preclusion of Brittle Fracture

The stresses due to each load are categorized as to the type of stress induced, e.g. membrane, bending, etc., and the classification of stress, e.g. primary, secondary, etc. Stress limits for containment vessel components, other than bolts, for Normal (Level A) and Hypothetical Accident (Level D) Loading Conditions are given in Table 2-2. The stress limits used for Level D conditions, determined on an elastic basis, are based on the entire structure (containment shell and gamma shielding material) resisting the accident load. Local yielding is permitted at the point of contact where the load is applied.

The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the cask for normal load conditions.

The hypothetical impact accidents are evaluated as short duration, Level D conditions. The stress criteria are taken from Section III, Appendix F of ASME[7] Code. For elastic quasi-static analysis, the primary membrane stress intensity (P_m) is limited to $0.7S_u$, and membrane plus bending stress intensities ($P_m + P_b$) are limited to $1.5P_m$.

The allowable stress limits for the containment bolts are listed in Table 2-3. The allowable stress limits for the lid bolts are listed separately in Tables 2.10.2-3 and 2.10.2-4.

The allowable stress intensity value, S_m, as defined by the Code, is taken at the maximum temperature calculated for each service load condition.

2.1.2.1.2 Non-Containment Structure

Certain components such as the gamma shielding, the neutron shield outer shell and the trunnions are not part of the cask containment vessel but do have structural functions. These components referred to as non-containment structures are required to react to the containment environmental loads, and in some cases share the loads with the containment vessel. The stress limits for the non-containment structures (excluding the basket) are given in Table 2-4. The gamma shield and neutron shield outer shell are designed, fabricated and inspected in accordance with the ASME Code Subsection NF[3], to the maximum practical extent. Other structural and structural attachment welds are examined by the liquid penetrant or the magnetic particle method, in accordance with Section V, Article 6 of the ASME Code[8]. The magnetic particle and liquid penetrant examination acceptance standards are in accordance with Section III, Subsection NF, Paragraphs NF-5340 and NF-5350[3].

Seal welds are examined visually, or by liquid penetrant or magnetic particle methods, in accordance with Section V of the ASME Code[8]. Electrodes, wire, and fluxes used for fabrication, comply with the applicable requirements of the ASME Code, Section II, Part C[9]. The welding procedures, welders and weld operators are qualified in accordance with Section IX of the ASME Code[10].

The radial neutron shield, including the carbon steel enclosure, have not been designed to withstand all of the hypothetical accident loads. The shielding may degrade during the fire or due to the 40 inch drop onto the puncture bar. Therefore a bounding shielding analysis, assuming that the exterior neutron shielding is completely removed, has been performed. This analysis shows that the accident dose rates are not exceeded. These accident analyses are described in Chapter 5.

2.1.2.2 Basket

The basket is designed, fabricated and inspected in accordance with the ASME Code Subsection NG[3], to the maximum practical extent. The following exceptions are taken:

The poison and aluminum plates are not used for structural analysis. Therefore, the materials are not required to be code materials. The quality assurance requirements of NQA-1 is imposed in lieu of NCA-3800. The basket will not be code stamped. Therefore the requirements of NCA are not imposed. Fabrication and inspection surveillance is performed by the owner and design organization in lieu of an authorized nuclear inspector.

The fuel basket rail material is not a Class 1 material. It was selected for its properties. Aluminum has excellent thermal conductivity and a high strength to weight ratio provided that temperatures do not exceed 400°F.

NUREG-3854[11] and NUREG-1617[12] allow materials other than ASME Code materials to be used in the cask fabrication. ASME Code does provide the material properties for the aluminum alloy up to 400°F, and also allows the material to be used for Section III applications (Class 2 or 3) up to 400°F temperature (the maximum rail temperature is less than 310°F). The construction of the aluminum rails will meet the requirements of Section III, Subsection NG[3].

The stress limits for the basket are summarized in Table 2-5. The wall thickness of the basket fuel compartment is established to meet the heat transfer, nuclear criticality, and the structural requirements. The basket structure must provide sufficient rigidity to maintain a subcritical configuration under the applied loads. The 304 stainless steel members in the TN-68 basket are the primary structural components. The neutron poison plates are the primary heat conductors, and they also provide the necessary criticality control.

The basis for the allowable stresses for the 304 stainless steel fuel compartment box and the fusion welds is Section III, Division I, Subsection NG of the ASME Code. The primary membrane stress and primary membrane plus bending stress are limited to S_m (S_m is the code allowable stress intensity) and 1.5 S_m, respectively, at any location in the basket for normal (Design and Level A) load conditions.

The hypothetical impact accidents are evaluated as short duration, Level D conditions. The stress criteria are taken from Section III, Appendix F of the ASME Code[7]. For elastic quasi-static analysis, the primary membrane stress intensity (P_m) is limited to the smaller of $2.4S_m$ or $0.7S_u$, and membrane plus bending stress intensities ($P_m + P_b$) are limited to $1.5P_m$.

The fuel compartment walls under compressive loads are also evaluated against the ASME Code rules for component supports, to ensure that buckling will not occur. The acceptance criteria (allowable buckling loads) are taken from the ASME Code, Section III, Appendix F, paragraph F-1341.4, Plastic Instability Load. The allowable buckling load is equal to 70% of the calculated plastic instability load. The buckling analyses of the aluminum rails are considered separately. See Appendix 2.10.5 for complete details of criteria for these conditions.

The basket hold down ring is set between the top of the basket assembly and inside surface of the lid assembly. The hold down ring is used to prevent the basket assembly from sliding freely in the axial direction during the normal transport conditions. The basket hold down ring is designed, fabricated and inspected in accordance with the ASME Code Subsection NF[3], to the maximum practical extent.

2.1.2.3 Impact Limiters (Front and Rear)

The TN-68 packaging is provided with impact limiters at each end of the cask body. The limiters are identical. The inside diameter of the limiter is determined by the diameter of the cask body. The length and outside diameter of the limiter are sized to limit the cask inertial loads during the 1 foot normal and 30 foot accident drop events so that the containment vessel (and the non-containment structures) meet the design criteria.

The impact limiter carbon steel cylinders, gussets, and end plates, are designed to position and confine the balsa and redwood blocks so that the impact energy is properly absorbed. The carbon steel shell is also designed to support and protect the wood blocks under normal environmental conditions (moisture, pressure, temperature, etc.).

The impact limiter and attachments are designed to withstand the applied loads and to prevent separation of the limiters from the cask during an impact. The design criteria for the impact limiters and attachments are both unique and specific. They are specified in Appendix 2.10.8.

2.1.2.4 Trunnions

The evaluation and design criteria for the lifting/tiedown trunnions are based on the requirements of 10CFR71.45. The details of the evaluation are presented in Section 2.5. Evaluation demonstrates that the front trunnions, used for lifting, have a minimum factor of safety of six against yield or ten against ultimate, whichever is most restrictive. The design and fabrication of the lifting trunnions are in accordance with the requirements of ANSI N14.6.

In the transport configuration (see TN drawing no. 971-71-8), the regulatory tie-down loads [10CFR 71.45(b)(1)] are shared by the rear trunnions and the outer surface of the cask at the front end which contacts the front saddle of the shipping frame. The evaluation provided in

Section 2.5 demonstrates that the tie-down loads do not generate stresses in the trunnion material which exceed the material yield strength.

2.2 WEIGHTS AND CENTER-OF-GRAVITY

The weight of the TN-68 packaging is 130.0 tons. The weights of the major individual subassemblies are listed in Table 2-6. The center of gravity of the cask is located on the axial centerline approximately 97.0 inches from the base of the cask.

Due to fabrication tolerances, the gross weight of the TN-68 package may exceed 130.0 tons. All the stress analyses are performed using a conservatively higher weight of 136 tons.

2.3 MECHANICAL PROPERTIES OF MATERIALS

2.3.1 Cask Material Properties

This section provides the mechanical properties of materials used in the structural evaluation of the TN-68 cask. Table 2-7 lists the materials selected, the applicable components, and the minimum yield, ultimate, and design stress values specified by the ASME Code, Section II, Part D[9]. All values reported in Table 2-7 are for metal temperatures up to 100°F. For higher temperatures, the temperature dependency of the material properties is reported in Table 2-8.

Table 2-9 summarizes the thermal analysis results from Chapter 3. These results support the selection of cask body and basket component design temperatures for structural analysis purposes.

2.3.2 Basket Material Properties

The material properties of the 304 stainless steel plates are taken from the ASME Code, Section II, Part D[9]. The material properties of the aluminum alloy (6061-T6) are also taken from the ASME Code. These properties are listed with specific references in Tables 2-10 and 2-11.

2.3.3 Impact Limiter Material Properties

Mechanical properties of the energy absorbing wood and wood adhesive used in the impact limiters are are both unique and specific. They are specified in Appendix 2.10.8 (Table 2.10.8-1).

2.3.4 Fracture Toughness Requirements

The cask body and closure lid material is a ferritic steel and is therefore subject to fracture toughness requirements in order to assure ductile behavior at the lowest service temperature (LST) of –20°F. The containment boundary materials (including lid bolts) are selected to meet the fracture toughness criteria of ASME Code Section III, Division 3, Subsection WB[4],. Transnuclear has also performed a fracture mechanics evaluation of the TN-68 package gamma shield based on a service temperature of -20°F. Detail of the fracture toughness evaluations of the containment boundary materials, lid bolt material, and gamma shield materials are specified in Appendix 2.10.4.

2.4 GENERAL STANDARDS FOR ALL PACKAGES

The TN-68 is designed to comply with the general standards for all packages specified by 10CFR71.43.

2.4.1 Minimum Package Size

The overall package dimensions of 269.33 inches long and 144 inches in diameter exceed the minimum dimension requirement of 10 cm (4 inches).

2.4.2 Tamper-proof Feature

The only access path into the package is through the closure lid and associated closure bolts. During transport the top (front) impact limiter entirely covers and prevents access to the cask closure lid and the vent and access port penetrations in the lid. A security wire seal is installed in the upper impact limiter attachment tierod prior to each shipment. The presence of this seal demonstrates that unauthorized entry into the package has not occurred.

2.4.3 Positive Closure

Positive fastening of all access openings through the containment vessel is accomplished by bolted closures which preclude unintentional opening. In addition, the presence of the impact limiters and security seals described in Section 2.4.2 provide further protection against unintentional opening.

2.4.4 Chemical and Galvanic Reactions

The materials of the TN-68 cask have been reviewed to determine whether chemical, galvanic or other reactions among the materials, contents and environment might occur during any phase of loading, unloading, handling or transport. This review is summarized below:

The TN-68 cask components are exposed to the following environments:

- During loading and unloading, the casks are submerged in pool water. For BWR plants the pool water is deionized. This affects the interior and exterior surfaces of the cask body, lid and the basket. The casks are only kept in the spent fuel pool for a short period of time, typically about 6 hours to load or unload fuel, 1 - 2 hours to drain, and another 8 - 10 hours to completely dry, evacuate and backfill the cask with helium.

- During handling and transportation, the exterior of the cask is exposed to normal environmental conditions of temperature, rain, snow, etc. All of the exterior surfaces with the exception of stainless steel components are protected from environmental exposure by a polyamide enamel epoxy coating. The paint is touched up periodically if there are any areas which peel or otherwise deteriorate. Therefore, the cask exterior is protected from chemical, galvanic or other reactions during storage.

- During transportation, the interior of the cask is exposed to an inert helium environment. The helium environment does not support the occurrence of chemical or galvanic reactions because both moisture and oxygen must be present for a reaction to occur. The cask is thoroughly dried before transport by a vacuum drying process. It is then sealed and backfilled with helium, thus stopping corrosion. Since the cask is vacuum dried, galvanic corrosion is also precluded since there is no water present at the point of contact between dissimilar metals.

- The radial neutron shielding materials and the aluminum resin boxes are sealed during all normal operations. The amount of oxygen in the sealed region is very small. The resin material is inert after it has cured and does not affect the aluminum boxes or the carbon steel housing.

2.4.4.1 Cask Interior

The TN-68 cask materials are shown in the Parts List on Drawing 972-71-3. The containment vessel is made from SA-203 Grade E and SA-350 LF3. This low-alloy carbon steel is uncoated.

All sealing surfaces are stainless steel clad by weld overlay.

Within the cask cavity, there are basket rails made from 6061-T6 aluminum. The cask basket is assembled from SA-240, Type 304 stainless steel boxes which are joined together by a proprietary fusion welding process and separated by neutron poison and stainless steel plates which form a sandwich panel. The neutron poison is not welded or bolted to the stainless steel, but is held in place by the geometry of the boxes and stainless steel plates.

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, aluminum-based neutron poison and stainless steel within the basket itself, and the interaction of the aluminum basket rails with the carbon steel cask cavity wall and the pool water.

Typical water chemistry in a BWR Spent Fuel pool is as follows:

pH	5.6 - 7.1
Chloride	1 - 10 ppb
Conductivity	0.7 - 1.8 µmho
Silica	2.5 - 2.7 ppm
Pool Temperature	70 - 115°F

Behavior of Aluminum in Deionized Water

Aluminum is used for many applications in spent fuel pools. In order to understand the corrosion resistance of aluminum within the normal operating conditions of spent fuel storage pools, a discussion of each of the types of corrosion is addressed separately. None of these corrosion mechanisms are expected to occur in the short time period that the cask is submerged in the spent fuel pool.

General Corrosion

General corrosion is a uniform attack of the metal over the entire surfaces exposed to the corrosive media. The severity of general corrosion of aluminum depends upon the chemical nature and temperature of the electrolyte and can range from superficial etching and staining to dissolution of the metal. Figure 2-1 shows a potential -pH diagram for aluminum in high purity water at 77°F. The potential for aluminum coupled with stainless steel and the limits of pH for BWR pools are shown in the diagram to be well within the passivation domain. The passivated surface of aluminum (hydrated oxide of aluminum) affords protection against corrosion in the domain shown because the coating is insoluble, non-porous and adherent to the surface of the aluminum. The protective surface formed on the aluminum is known to be stable up to 275°F and in a pH range of 4.5 to 8.5[13].

Galvanic Corrosion

Galvanic corrosion is a type of corrosion which could cause degradation of dissimilar metals exposed to a corrosive environment for a long period of time.

Galvanic corrosion is associated with the current of a galvanic cell consisting of two dissimilar conductors in an electrolyte. The two dissimilar conductors of interest in this discussion are aluminum and stainless steel or aluminum and carbon steel in deionized water. There is little galvanic corrosion in deionized water since the water conductivity is very low. There is also less galvanic current flow between the aluminum-stainless steel couple than the potential difference on stainless steel which is known as polarization. It is because of this polarization characteristic that stainless steel is compatible with aluminum in all but severe marine, or high chloride, environmental conditions[14].

At points of contact between the aluminum basket rails and the carbon steel shell, some galvanic reaction may occur, with the aluminum acting as a sacrificial anode. The carbon steel shell will be protected from corrosion as a result of this reaction. The corrosion of the aluminum rails will not be sufficient to affect their thermal or mechanical performance given the water purity and short immersion time.

Pitting Corrosion

Pitting corrosion is the forming of small sharp cavities in a metal surface. The first step in the development of corrosion pits is a local destruction of the protective oxide film. Pitting will not occur on commercially pure aluminum when the water is kept sufficiently pure, even when the aluminum is in electrical contact with stainless steel. Pitting and other forms of localized corrosion occur under conditions like those that cause stress corrosion, and are subject to an induction time which is similarly affected by temperature and the concentration of oxygen and chlorides. As with stress corrosion, at the low temperatures and low chloride concentrations of a spent fuel pool, the induction time for initiation of localized corrosion will be greater than the time that the cask internal components are exposed to the aqueous environment.

Crevice Corrosion

Crevice corrosion is the corrosion of a metal that is caused by the concentration of dissolved salts, metal ions, oxygen or other gases in crevices or pockets remote from the principal fluid stream, with a resultant build-up of differential galvanic cells that ultimately cause pitting. Crevice corrosion could occur in the basket plates, around the stainless steel welds. However, due to the short time in the spent fuel pool, this type of corrosion is not expected to be significant.

Intergranular Corrosion

Intergranular corrosion is corrosion occurring preferentially at grain boundaries or closely adjacent regions without appreciable attack of the grains or crystals of the metal itself. Intergranular corrosion does not occur with commercially pure aluminum and other common work hardened aluminum alloys.

Stress Corrosion

Stress corrosion is failure of the metal by cracking under the combined action of corrosion and high stresses approaching the yield stress of the metal. During normal operations, the cask is upright and there is negligible load on the basket. The stresses on the basket plates are very small, well below the yield stress of the basket materials.

Behavior of Carbon Steel in Deionized Water

The corrosion rate of iron in aerated soft water with the range $4 \leq pH \leq 10$ is 0.01 inch/year. For 48 hour submersion during fuel loading, the total corrosion would be 5×10^{-5} inch, which is negligible. Hydrogen evolution from iron corrosion does not occur in near neutral water[15]. See Figure 2-2. Low alloy carbon steel is slightly more resistant to corrosion than iron under these conditions.

Behavior of Austenitic Stainless Steel in Deionized Water

The fuel compartments and the structural plates which support the fuel compartments are made from Type 304 stainless steel. In addition, the gasket sealing surfaces are stainless steel clad. Stainless steel does not exhibit general corrosion when immersed in deionized water. Galvanic attack can occur between the aluminum in contact with the stainless steel in the water. However, the attack is mitigated by the passivity of the aluminum and the stainless steel in the short time the pool water is in the cask. Also the low conductivity of the pool water tends to minimize galvanic reactions.

Stress corrosion cracking in the Type 304 stainless steel welds of the basket to the structural stainless steel plates is also not expected to occur, since the baskets are not highly stressed during normal operations. There may be some residual fabrication stresses as a result of welding of the stainless steel boxes and fusion welds between the boxes and stainless steel plates. Of the corrosive agents that could initiate stress corrosion cracking in the 304 stainless steel basket

welds, only the combination of chloride ions with dissolved oxygen occurs in spent fuel pool water. Although stress corrosion cracking can take place at very low chloride concentrations and temperatures such as those in spent fuel pools (less than 10 ppb and 160°F, respectively), the effect of low chloride concentration and low temperature is to greatly increase the induction time, that is, the period during which the corrodent is breaking down the passive oxide film on the stainless steel surface. Below 60°C (140°F), stress corrosion cracking of austenitic stainless steel does not occur at all. At 100 °C (212 °F), chloride concentration on the order of 15% is required to initiate stress corrosion cracking[16]. At 288 °C (550 °F), with tensile stress at 100% of yield in BWR water containing 100 ppm O_2, time to crack is about 40 days in sensitized 304 stainless steel [17]. Thus, the combination of low chlorides, low temperature and short time of exposure to the corrosive environment eliminates the possibility of stress corrosion cracking in the basket welds.

The chloride content of all expendable materials which come in contact with the basket materials are restricted and water used for cleaning the baskets is restricted to 1.0 ppm chloride.

Behavior of Aluminum Based Neutron Poison in Deionized Water

The aluminum component of the borated aluminum is a ductile metal having a high resistance to corrosion. Its corrosion resistance is provided by the buildup of a protective oxide film on the metal surface when exposed to a corrosive environment. As stated above for aluminum, once a stable film develops, the corrosion process is arrested at the surface of the metal. The film remains stable over a pH range of 4.5 to 8.5.

Tests were performed by Eagle Picher[18] which concluded that borated aluminum exhibits a strong corrosion resistance at room temperature in deionized water. Satisfactory long-term usage in these environments is expected. At high temperature, the borated aluminum still exhibits high corrosion resistance in the pure water environment.

From tests on pure aluminum, it was found that borated aluminum was more resistant to uniform corrosion attack than pure aluminum.

The alternate neutron poison material is a boron carbide / aluminum composite. The billet is produced by blending of aluminum and boron carbide powders, cold isostatic compacting, and vacuum sintering. The plates are formed from the billet by rolling or extrusion. The result is a matrix of full-density aluminum with a fine dispersion of boron carbide particles throughout. The corrosion behavior is similar to that of the base aluminum alloy.

There are no chemical, galvanic or other reactions that could reduce the areal density of boron in the TN-68's neutron poison plates with either of the poison plate materials.

2.4.4.2 Cask Exterior

The exterior of the cask is carbon steel. The exterior of the cask, with the exception of the trunnion bearing surfaces is painted using an epoxy, acrylic urethane, or equivalent enamel

coating with the appropriate primer. The paint should be compatible with the pool water and easy to decontaminate.

The paint is visually inspected prior to installation of the cask in the spent fuel pool and periodically during storage. Touch up painting is performed if the paint deteriorates.

2.4.4.3 Lubricants and Cleaning Agents

The following lubricants and cleaning agents may be used on the TN-68 cask:

- Neolube or equivalent is used to coat the threads and bolt shoulders of the closure bolts. Never-seez or equivalent is also used to coat the contact areas of the top and bottom trunnions during transport and lifting operations to prevent impregnation of contamination.

The lubricant should be selected for compatibility with the spent fuel pool water and the cask materials, and for its ability to maintain lubricity under long term storage conditions.

- During fabrication, expendable materials are restricted to limit exposure to water leachable chlorides, halogenated compounds and sulfur and its compounds. As the cask is lowered into the spent fuel pool, the cask is sprayed with demineralized water to provide a film of clean water on the cask surfaces. The time in the pool is minimized in order to minimize cask contamination levels.

The cask body is cleaned in accordance with approved procedures to remove cleaning residues prior to shipment to the Power Station. The basket is also cleaned prior to installation in the cask. The cleaning agents and lubricants have no significant affect on the cask materials and their safety related functions.

2.4.4.4 Hydrogen Generation

During the initial passivation state, small amounts of hydrogen gas may be generated in the TN-68 cask. The passivation stage may occur prior to submersion of the cask into the spent fuel pool. Any amounts of hydrogen generated in the cask will be insignificant and will not result in a flammable gas mixture within the cask.

The small amount of hydrogen which may be generated during cask operations does not result in a safety hazard. In order for concentrations of hydrogen in the cask to reach levels that could ignite or explode, most of the cask would have to be filled with water for the hydrogen generation to occur, and the lid would have to be in place with both the vent and drain ports closed. This does not occur during TN-68 loading or unloading operations.

After loading fuel into the TN-68, the lid, with the vent port quick-disconnect coupling removed, is placed on the cask and the cask is raised to the pool surface. At this time the cask is completely filled with water. Any hydrogen generated inside the cask will be released at the vent port. Once the process of pumping out the water is begun, it is carried through to completion without interruption, a process which takes 1 to 2 hours. The vent port remains open

during this process, allowing air into the vent. The rate of hydrogen generation is too low and the time period too short to generate an ignitable or explosive mixture. After a short period of passivating the surfaces of the aluminum and aluminum-based neutron poison, there is no source for further generating H_2 gas.

An estimate of the maximum hydrogen concentration can be made, ignoring the effects of radiolysis, recombination, and solution of hydrogen in water. Testing was conducted by Transnuclear[19] to determine the rate of hydrogen generation for aluminum metal matrix composite in intermittent contact with 304 stainless steel and for aluminum 6061 in intermittent contact with SA203 low alloy steel. The samples represent the basket rails paired with the cask cavity wall, and the neutron poison plates paired with the basket compartment tubes. The test specimens were submerged in deionized water for 12 hours at 70 °F to represent the period of initial submersion and fuel loading, followed by 12 hours at 150 °F to represent the period after the fuel is loaded, until the water is drained. The hydrogen generated during each period was removed from the water and the test vessel and measured.
The test results were:

	12 hour @ 70 °F		12 hour @ 150 °F	
	$cm^2hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$	$cm^2hr^{-1}dm^{-2}$	$ft^3hr^{-1}ft^{-2}$
aluminum MMC/SS304	0.517	1.696E-4	0.489	1.604E-4
low alloy steel/ Al plate	0.476	1.562E-4	0.644	2.113E-4

The total surface area of the aluminum/steel interface at the basket perimeter is 186.3 ft^2 and the total area of neutron absorber/compartment wall interface is 1976.4 ft^2. These surface areas, combined with the data at 150 °F above result in a hydrogen generation rate of

$$[(2.1\text{x}10^{-4}\ ft^3/ft^2hr)(186.3\ ft^2)]+[(1.6\text{x}10^{-4}\ ft^3/ft^2hr)(1976.4\ ft^2)] = 0.355\ ft^3/hr$$

in the TN-68. The total free volume in the cask, with fuel in place, and without water, is 211.6 ft^3. The following assumptions are made to arrive at a conservative estimate of hydrogen concentration:

- The hydrogen generation rate is constant, that is, no credit is taken for the fact that less surface area is submerged as draining proceeds
- The draining rate is constant
- All generated hydrogen is released instantly to the plenum between the water and the lid, that is, no dissolved hydrogen is pumped out with the water, and no released hydrogen escapes through the open vent port.

Under these assumptions, the hydrogen concentration in the space between the water and the lid is constant during draining, and is a function of the total drain time only. For a typical drain time of 2 hours, the hydrogen concentration is 0.335 ft^3 H_2/hr (2 hr)/211.6 ft^3 = 0.3 %. For a drain time of 18 hours, much longer than expected, the concentration would be 3.0%, still well below the lower flammable limit of 4%.

Unlike welded canisters, the TN-68 cask has a bolted closure. There is no source of ignition to result in an explosion or fire.

2.4.4.5 Effect of Galvanic Reactions on the Performance of the Cask

There are no significant reactions that could reduce the overall integrity of the cask or its contents during storage. The cask and fuel cladding thermal properties are provided in Chapter 3. The emissivity of the fuel compartment is 0.3, which is typical for non-polished stainless steel surfaces. If the stainless steel is oxidized, this value would increase, improving heat transfer. The fuel rod emissivity value used is 0.8, which is a typical value for oxidized Zircaloy. Therefore, the passivation reactions would not reduce the thermal properties of the component cask materials or the fuel cladding.

There are no reactions that would cause binding of the mechanical surfaces or the fuel to basket compartment boxes due to galvanic or chemical reactions.

There is no significant degradation of any safety components caused directly by the effects of the reactions or by the effects of the reactions combined with the effects of long term exposure of the materials to neutron or gamma radiation, high temperatures, or other possible conditions.

2.5 LIFTING AND TIE-DOWN STANDARDS

2.5.1 Lifting Devices

10CFR 71-45(a) requires that a minimum factor of safety of three against yield is required for all lifting attachments which are structural parts of the package. In addition, the package must be designed such that failure of any lifting device under excessive load would not impair the ability of the package to meet the requirements of 10CFR71. Section 2.5.1.1 provides the analysis of the trunnions which are the only components used to lift the cask. Appendix 2.10.1.8 provides an analysis of the global stresses in the cask wall due to the effect of a 6G lifting load on the trunnions. The global stress intensities from the ANSYS run at the stress reporting locations of the containment vessel and gamma shield are presented in Tables 2.10.1-47 and 48. The local stress intensities in the cask wall due to the 6G lifting load are calculated in Appendix 2.10.1.10 and are presented in Tables 2.10.1-57 and 58. The maximum combined stress intensity is 20.95 ksi (1,243 + 19,705) and occurs at location 36. This stress is less than the yield stress of the gamma shield material (31.45 ksi, SA-266 Class 2 at 250°F). Therefore the requirements of 10CFR 71-45(a) are met. The stress analyses of the front (top) trunnion and trunnion flange bolts are provided in the following sections.

2.5.1.1 Trunnion Analysis

This section provides the structural analysis of the TN-68 cask trunnions. The front (top) and rear (bottom) trunnion geometry is shown in Figure 2-3. The front trunnions are SA-182 Grade F6NM alloy forgings and are attached to the cask body with bolted flange connections. The rear trunnions are SA-105 carbon steel forgings, and are welded to the cask body. A flat surface is machined on the cask body outer surface at each trunnion location for this purpose.

The two front trunnions are used for lifting the cask and are designed to the requirements of ANSI N14.6[(2)]. They can support a loading equal to 6 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also lift 10 times the weight of the cask without exceeding the ultimate tensile strength of the material. A dynamic load factor of 1.15 is used in evaluating the trunnion stresses.

The rear trunnions are used to rotate the cask from a horizontal orientation to the vertical orientation. The rear trunnions also serve as the packaging tie-down devices which are designed to withstand 2/5/10 G tie-down loads (see Section 2.5.2 for detail description).

Figure 2-3 shows the basic dimensions of the front and rear trunnions. A cask weight of 240,000 lbs. is used in this calculation. Table 2-12 shows the cross sectional area and moment of inertia at shoulder cross section A-A of the front trunnions. The loads applied to this section (for 6 W and 10 W loading) to evaluate the yield and ultimate limits are also listed.

Table 2-13 presents a summary of the stresses at the same location to compare against the trunnion yield and ultimate strengths. Also listed at the bottom of the table are the allowable

stresses (yield and ultimate strengths). All of the calculated stresses in the trunnions are acceptable. Therefore the requirements of 10CFR 71-45(a) are met.

The trunnions are designed such that the minimum margin of safety (shear stress) occurs at the trunnions' shoulders. Hence an "excessive load" would damage the trunnion, but the cask would not lose its structural integrity satisfying the requirement of 10CFR71.45(a).

2.5.1.2 Front (Top) Trunnion Bolt Stresses

The front trunnion flange is attached to the gamma shield vessel by twelve 1.5-8UN-2A bolts of SA-320 Gr. L43 material. The bolted flange is tightly fitted into the recess in the cask body. This recess provides a bearing area between the outside perimeter of the trunnion flange and the cask body. The radial clearance between the bolt shank and trunnion flange bolt holes is large enough so that shear loads are carried by the trunnion flange-to-cask body recess interface and not the bolts. The bolts develop only the tensile load due to trunnion moment.

The bending moment at the flange interface due to 10G is equal to 1,380,000 x 7.51 = 10,363,800 in-lbs. From Reference 20, Case 3, (for bolt patterns symmetrical about the vertical axis and flange rotating about the bottom bolt) the maximum bolt force due to bending moment M is:

$$F_{max} = (4/(3RN))M$$

where

R = Bolt circle radius = 6.875 in.
N = No. of bolts = 12

$$F_{max} = 4(10{,}363{,}800)/(3 \times 6.875 \times 12) = 167{,}496 \text{ lbs.}$$

The bolt stress area = 1.492 in^2

Max. tensile stress = 167,496/1.492 = 112.3 ksi

Bolt allowable tensile stress = S_u (at 300°F) = 125 ksi

For yield load (6G), the maximum tensile stress = (6/10)(112,263) = 67.4 ksi

The bolt allowable yield stress = S_y (at 300°F) = 95.7 ksi

Therefore the bolt stresses are acceptable for both 10G (ultimate) and 6G (yield) trunnion loads.

2.5.2 Tie-Down Devices

The rear trunnions also serve as the packaging tie-down devices which are designed to withstand 2/5/10 G tie-down loads.

The trunnions are analyzed assuming that the longitudinal load (10g) is taken by the two rear trunnions. The vertical load (2G) is taken 50 percent by the trunnions and 50 percent by the front support. The 5G lateral load is taken 50 percent by one trunnion and 50 percent by the front saddle support.

The maximum load seen by a trunnion is a 0.5G vertical load, a 5G longitudinal load and a 2.5G lateral load. The vertical and longitudinal loads are combined to form a resultant G load of 5.03G .

The dimensions and geometry terms required for the analysis are shown on Figure 2-3. A package weight of 271,950 lbs. is used in this calculation. Table 2-14 shows the cross sectional area and moment of inertia at shoulder cross section A-A and B-B of the rear trunnions. In addition the loads applied to this section (2/5/10g) to evaluate the yield limits are also listed.

Table 2-15 presents a summary of the stresses at the same location to compare against the trunnion yield strengths. Also listed on the table are the allowable stresses (yield strengths). All of the calculated stresses in the trunnions are acceptable.

The trunnions are designed such that the minimum margin of safety (shear stress) occurs at the trunnions' shoulders. Therefore, the trunnion shoulder would fail before the trunnion welds. Hence an "excessive load" would damage the trunnion, but the cask would not lose its structural integrity satisfying the requirement of 10CFR71.45(b)(3).

Appendix 2.10.1.7 provides an analysis of the global stresses in the cask wall due to the effect of a 2/5/10G tie-down load on the trunnions. The global stress intensities from the ANSYS run at the stress reporting locations of the containment vessel and gamma shield are presented in Tables 2.10.1-45 and 46. The local stress intensities in the cask wall due to the 2/5/10G tie-down load are calculated in Appendix 2.10.1.10 and are presented in Tables 2.10.1-55 and 56. The resulting local stresses in the cask wall are conservatively added to global stresses intensities and are presented in Tables 2-103 and 104 of this Chapter. The maximum stress intensity is 30.8 ksi and occurs at location 28. This stress intensity is less than the yield stress of the gamma shield material (31.45 ksi, SA-266 Class 2 at 250°F).

2.6 NORMAL CONDITIONS OF TRANSPORT

Overview

This section describes the response of the TN-68 package to the loading conditions specified by 10CFR71.71. The design criteria established for the TN-68 for the normal conditions of transport are described in Section 2.1.2. These criteria are selected to ensure that the package performance standards specified by 10CFR71.43 and 71.51 are satisfied. Under Normal Conditions of Transport there will be no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging. Under Hypothetical Accident conditions, the cask is protected so that there is no escape of radioactive material exceeding a total amount A_2 in one week, and no external dose rate exceeding one rem per hour at one meter from the external surface of the package.

Detailed structural analyses of various TN-68 package components subjected to individual loads are provided in the Appendices to this chapter. The limiting results from these analyses are used in this section to quantify package performance in response to the normal condition of transport load combinations, specified in 10CFR71.71 and Regulatory Guide 7.8. Table 2-16 provides an overview of the performance evaluations reported in each load combination subsection. Each subsection provides the limiting structural analysis result for the affected cask component(s) in comparison to the established design criteria. This comparison permits the minimum margin of safety for a given component subjected to a given loading condition to be readily identified. In all cases, the acceptability of the TN-68 packaging design with respect to established criteria, and consequently with respect to 10CFR71 performance standards is demonstrated.

The structural analysis of the cask body is presented in Appendix 2.10.1 and covers a wide range of individual loading conditions. The stress results from the various individual loads must be combined in order to represent the stress condition in the cask body under the specified condition evaluated in this section. An explanation of the reporting format used for the results, and the stress combination technique used in applying the results from Appendix 2.10.1 is provided here.

Reporting Method for Cask Body Stresses

Appendix 2.10.1 provides the detailed description of the structural analyses of the TN-68 cask body. That appendix describes the detailed ANSYS[21] model used to analyze various applied loads. Table 2-17 identifies the individual loads (IL) analyzed which are applicable to normal conditions of transport. Some of these individual loads are axisymmetric (e.g. pressure) and others are asymmetric (e.g. gravity).

Figures 2-4 and 2-5 show the selected locations on the cask body numbered 1 through 39 where stress results for these analyses are reported. Detailed stresses are available at as many locations as there are nodes in the finite element model. However, for practical considerations, the reporting of stress results is limited to those locations shown on Figures 2-4 and 2-5. These locations were selected to be representative of the stress distribution in the cask body with

special attention given to areas subject to high stresses. The maximum stress may occur at a different location for each individual load.

The stress results for the individual load case (tables reported in Appendix 2.10.1) are for one individual load only. Two or more individual load cases must be combined to determine the total stresses at the standard stress reporting locations for the various load combinations. This is accomplished using the ANSYS post-processor.

Several other items should be noted. In the TN-68, thermal stresses occur due to the effects of differential thermal expansion between the gamma shield and the inner vessel. These thermal stresses are conservatively treated as primary stresses, and the combined stresses due to primary loads (like pressure) and differential expansion (such as heating from 70°F to hot thermal conditions) are evaluated as primary stresses.

For the axisymmetric cases, the stress is constant around the circumference of the cask at each stress reporting location. The stresses, where there are significant differences in stress magnitudes on the different orientations of the cask (usually contact side and side away from contact for a horizontal cask), are reported in separate tables (e.g. stress at 90° away from contact side in Table 2-47 and stress at contact side in Table 2-49 for the 1 foot side drop).

In cases where the cask is supported on the trunnions, the stresses under transverse loads (such as gravity) are nearly equal in magnitude at the top and bottom. Therefore only the tensile results for the bottom side are listed.

Finally, for those load combinations that include trunnion reactions, the local stresses at the trunnion locations found by the Bijlaard[22] method are superimposed on the ANSYS combined stresses. These local stresses really occur on the sides of the cask, and not the top and bottom where the ANSYS results are reported. However, their absolute values are still added to the ANSYS stress intensities (membrane to membrane, and membrane plus bending to membrane plus bending, respectively) for conservatism.

Table 2-18 provides a matrix of the individual loads, and the various combinations, to determine the cask body stresses for the specified normal conditions of transport. The thermal stresses due to the hot and cold conditions are actually secondary stresses that could be evaluated using higher allowable stresses than for the primary stresses. They are added to the primary stresses, for conservatism, and the combined stresses are evaluated using the primary allowable stresses. An X in Table 2-18 indicates that the stress results for the individual load case are used in the load combinations.

For the increased external pressure load combination, it is assumed that the TN-68 cask cavity is at 0 psia. Since the specified load combination condition is 20 psia, the net differential pressure acting on the cask body is 20 psi. However, for conservatism, a 25 psi external pressure is used for load combinations.

2.6.1 Heat

Chapter Three describes the thermal analyses of the TN-68 package, subjected to high temperature environmental conditions. The analyses results are used to support various aspects of the structural evaluations as described in the following subsections.

2.6.1.1 Maximum Temperatures

Allowable stresses for the packaging components are a function of the component temperatures, which are based on actual maximum calculated temperatures or conservatively selected higher temperatures. Chapter 3 summarizes the significant temperatures calculated for the TN-68 subjected to high temperature environmental conditions. These temperatures are used in establishing the allowable values for every normal and hypothetical accident (except the thermal accident, which has higher temperatures) load combination, evaluated in this Safety Analysis Report.

Table 2-9 summarizes the thermal analysis results from Chapter 3. The table also lists the selection of cask and basket component design temperatures for structural analysis purposes.

2.6.1.2 Maximum Internal Pressure

The thermal analysis, presented in Chapter 3, also provides the average cavity gas temperature under high temperature environmental conditions. This value is used in Chapter 4 to determine the Maximum Normal Operating Pressure (MNOP). For purposes of the structural analysis of containment, a value of 100 psig (much higher than the Chapter 4 value) is conservatively assumed for cask body stress calculation. This pressure loading is analyzed using the ANSYS model of the cask body as described in Appendix 2.10.1, and the results are reported in Tables 2.10.1-5 and 6 of that Appendix. This load case and corresponding results are designated as individual load IL-3. IL-3 is used to support evaluations of various load combinations as listed in Table 2-18.

2.6.1.3 Thermal Stresses (Hot)

The thermal analysis of the TN-68 is performed as described in Chapter 3. The temperature distribution from that analysis is used to perform an ANSYS structural analysis of the cask body thermal stresses, with stress results reported at the standard locations shown on Figures 2-10 and 11. The stress results for this load case are reported on Tables 2.10.1-13 and 14 of Appendix 2.10.1. This load case is designated as IL-7 and is used to support various load combinations.

2.6.1.4 Hot Environment Load Combinations

Cask body stresses for the high temperature environment for normal condition of transport, are obtained by a combination of individual loads as summarized in Table 2-18. For this condition, it is assumed that the cask is in its normal transport configuration, mounted horizontally on the transport cradle, and supported by the front saddle and two rear trunnions. Pre-load effects on

the lid bolts, fabrication stress, 100 psi internal pressure, thermal stresses calculated in load case IL-7, and the local stresses at the trunnions due to their reactions to the dead weight loading, are also included. The maximum nodal stress intensity at each of the standard reporting locations for this load combination are listed in Table 2-19 and 2-20.

2.6.2 Cold Environment

2.6.2.1 Cold Environment Load Combinations at –40°F Ambient Temperature

The Regulatory Guide 7.8[6] cold environment load combination results in all cask components in thermal equilibrium at -40°F. Containment vessel thermal stresses do occur in this case due to the differential thermal expansion between the steels. The thermal stresses are determined in load case IL-9 with results tabulated in Tables 2.10.1-17 and 18. The cask cavity pressure at the cold environment condition is conservatively assumed to be 0 psia. This results in a net external pressure loading of 14.7 psi (25 psi is conservatively used). The stresses due to 25 psi external pressure are determined in load case IL-4 with results in Tables 2.10.1-7 and 8. Again, lid bolt preload, fabrication stress, gravity and trunnion local loads are included. The maximum nodal stress intensity at each of the standard reporting locations for this load combination are listed in Table 2-21 and 2-22.

2.6.2.2 Thermal Stresses for Cold Environment at –20°F Ambient Temperature

The Regulatory Guide 7.8[6] requires that the stresses due to the normal and hypothetical accident load conditions to be combined with the thermal stresses for cold environment conditions at -20°F ambient temperature. A uniform temperature of –20°F is input to the structure model to calculate the cask body stresses due to differential thermal expansion between the two shell of the cask. The thermal stresses are determined in load case IL-8 with results tabulated in Tables 2.10.1-15 and 16.

2.6.3 Increased External Pressure

Cask body stresses for the increased external pressure, 20 psia, normal condition of transport are obtained by a combination of individual loads as summarized in Table 2-18. The conservatively assumed minimum cask cavity pressure of 0 psia results in a net external pressure loading of 20 psi (25 psi is conservatively used). For this condition, the cask is assumed to be in the horizontal orientation, supported on the transport cradle by front saddle and two rear trunnions. Lid bolt pre-load, fabrication stress, gravity and the local trunnion effects are included. In addition, the thermal stresses for the -20°F minimum temperature are also included in the combination. The maximum nodal stress intensity at each of the standard reporting locations for this load combination are listed in Table 2-23 and 2-24.

2.6.4 Reduced External Pressure

Cask body stresses for the 3.5 psia ambient normal condition of transport are obtained by a combination of individual loads as summarized in Table 2-18. The conservatively assumed MNOP of 30 psig results in a net internal pressure loading of (30 + 14.7 –3.5) 41.2 psi (cask

stresses are conservatively calculated based on 100 psi pressure). For this condition, the cask is in the horizontal orientation supported on the transport cradle by front saddle and two rear trunnions. Lid bolt pre-load, fabrication stress, gravity, and the local trunnion effects are included. The thermal stresses for the hot thermal condition are included in the load combination. The maximum nodal stress intensity at each of the standard reporting locations for this load combination are listed in Table 2-25 and 2-26.

2.6.5 Transport Shock Loading

Transport By Truck

The transport truck shock loadings used to evaluate the TN-68 transport cask are based on truck bed accelerations in ANSI N14.23[23] which are :

Vertical	3.5G
Longitudinal	2.3G
Lateral	1.6G

The resultant transverse load is $(3.5^2 + 1.6^2)^{1/2} = 3.85$ G

The stresses due to the transport truck shock individual load case are presented in Tables 2.10.1-19 and 20. Tables 2-27 and 28 list the combined stresses under hot thermal conditions where the load combination is performed for the maximum temperature thermal stresses. Lid bolt pre-load, fabrication stress, internal pressure, and the local trunnion effects are included.

In addition, Tables 2-29 and 30 list the combined stresses under –20°F thermal conditions where the load combination is performed for the –20°F thermal stresses. Lid bolt pre-load, fabrication stress, external pressure, and the local trunnion effects are included.

Transport By Rail

The transport rail shock loadings used to evaluate the TN-68 transport cask are based on NUREG 766510[24] which specifies a maximum inertia loading of 4.7G in each of the three x-y-z coordinate directions:

Vertical	4.7G
Longitudinal	4.7G
Lateral	4.7G

The resultant transverse load is $(4.7^2 + 4.7^2)^{1/2} = 6.65$ G

The stresses due to the transport rail shock individual load case are presented in Tables 2.10.1-61 and 62. Tables 2-31 and 32 list the combined stresses under hot thermal conditions where the load combination is performed for the maximum temperature thermal stresses. Lid bolt pre-load, fabrication stress, internal pressure, and the local trunnion effects are included.

In addition, Tables 2-33 and 34 list the combined stresses under –20°F thermal conditions where the load combination is performed for the –20°F thermal stresses. Lid bolt pre-load, fabrication stress, external pressure, and the local trunnion effects are included.

2.6.6 Transport Vibration Loading

Transport By Truck

The input loading conditions used to evaluate the TN-68 cask for transport truck vibration are also obtained from truck bed accelerations in ANSI N14.23[23]. The peak inertia values used are:

Vertical	0.60G
Longitudinal	0.30G
Lateral	0.30G

The resultant transverse load is $(0.6^2 + 0.3^2)^{1/2} = 0.67$ G

The stresses due to the transport truck vibration individual load case are presented in Tables 2.10.1-43 and 44. Tables 2-35 and 36 list the combined stresses under hot thermal conditions where the load combination is performed for the maximum temperature thermal stresses. Lid bolt pre-load, fabrication stress, internal pressure, and the local trunnion effects are included.

In addition, Tables 2-37 and 38 list the combined stresses under –20°F thermal conditions where the load combination is performed for the –20°F thermal stresses. Lid bolt pre-load, fabrication stress, external pressure, and the local trunnion effects are included.

Transport By Rail

The input loading conditions used to evaluate the TN-68 cask for transport rail vibration are obtained from NUREG 766510[24]. The peak inertia values used are:

Vertical	0.37G
Longitudinal	0.19G
Lateral	0.19G

These values are less than the truck vibration loadings, therefore, the stresses obtained from the truck vibration analysis are used to perform both truck and rail car transport vibration load combinations.

2.6.7 Water Spray

All exterior surfaces of the TN-68 cask body are metal and therefore not subject to soaking or structural degradation from water absorption. The water spray condition is therefore of no consequence to the TN-68.

2.6.8 Free Drop

Two drop orientations are considered credible for the one-foot free drop normal condition of transport (see Section 2.10.8.7 of Appendix 2.10.8 for detail descriptions). The structural response of the TN-68 cask body is evaluated for a one-foot end drop of the package on the bottom end, one foot end drop of the package on the lid end, and a one-foot side drop. The assessment of cask body stresses follows the same logic as that established in the previous sections. For the three drop cases, the evaluations are performed for both the high temperature environment and at the -20°F minimum transport temperature.

The load combinations performed to evaluate these drop events are indicated in Table 2-18. In all cases, bolt pre-load effects and fabrication stress are included. For the hot environment condition, thermal stress load, 100 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Tables 2-39 and 2-40 list the combined stress intensities for the bottom end drop under hot environment conditions. Tables 2-41 and 2-42 list the combined stress for the bottom end drop under cold environment conditions.

Tables 2-43 and 2-44 list the combined stress intensities for the lid end drop under hot environment conditions. Tables 2-45 and2-46 list the combined stress for the lid end drop under cold environment conditions.

Tables 2-47 through 2-50 list the combined stress intensities for the side drop under hot environment conditions. Tables 2-51 through 2-54 list the combined stress for the side drop under cold environment conditions.

2.6.9 Corner Drop

This test does not apply to the TN-68 Package since the package weight is in excess of 100 kg (220 lbs.).

2.6.10 Compression

This test does not apply to the TN-68 Package since the package weight is in excess of 5,000 kg (11,000 lbs.).

2.6.11 Penetration

Due to lack of sensitive external protuberances, the one meter (40 in.) drop of a 13 pound steel cylinder of 1-1/4 inch diameter, with a hemispherical head, is of negligible consequence to the TN-68 Package.

2.6.12 Lid Bolt Analysis

The lid bolts are analyzed for both normal and accident condition loadings in Appendix 2.10.2. The analysis is based on NUREG/CR-6007[25]. The bolts are analyzed for the following normal and accident loading conditions: operating pre-load, gasket seating load, internal pressure, temperature changes, impact loads, and puncture loads.

The bolt preload is calculated to withstand the worst case load combination and to maintain a clamping (compressive) force on the closure joint, both under normal and accident conditions. Based upon the load combination results (see Appendix 2.10.2, Section 2.10.2.3), it is shown that a positive (compressive) load is maintained on the clamped joint for all load combinations. Therefore, in both normal and accident load cases, the maximum non-prying tensile force of 135,200 lbs from preload + temperature load is used for bolt stress calculations.

A summary of the calculated stresses is listed in the Appendix 2.10.2, Section 2.10.2.5. The calculations result in a maximum average tensile stress of 56.0 ksi, which is below the allowable tensile stress of 92.4 ksi. The average shear stress in the bolts is due to torsion during pre-loading. This stress is 12.0 ksi, which is well below the allowable shear stress of 55.4 ksi. The maximum combined stress intensity due to tension plus shear plus bending is 83.6 ksi which is also less than the allowable maximum stress intensity of 124.7 ksi.

The bolt fatigue analysis is also presented in Appendix 2.10.2. This analysis shows that the bolts should be replaced after approximately 150 shipments. This is primarily due to the pre-load stresses.

2.6.13 Fatigue Analysis of the Containment Boundary

The purpose of the fatigue analysis is to show that the containment vessel stresses are within acceptable limits under normal transport conditions. This is done by determining the fatigue damage factor for each normal transport event at locations on the containment vessel with the highest stresses. The cumulative fatigue damage or usage factor for all of the events is conservatively determined by adding the fatigue usage factors for the individual events, assuming these maximum stress intensities occur at the same location.

The fatigue analysis is based on the procedure described in Regulatory Guide 7.6 and ASME Code Section III[7]. When determining the stress cycles, consideration is given to the superposition of individual loads which can occur together and produce a total stress intensity range greater than the stress intensity range of individual loads. Also, the maximum stress intensities for all individual loads are conservatively combined simultaneously. The following sequence of events was assumed for the fatigue evaluation. The fatigue evaluation is based on 450 shipments.

1. Lifting
2. Test pressure
3. Road shock/vibration

4. Pressure and temperature fluctuations
5. 1 foot normal condition drop

Lifting

The stresses due to the 6 G lifting load are listed in Appendix 2.10.1, Tables 2-10.1-47, 48, 57, and 58. The maximum stress intensity at the containment vessel is 20,517 psi (812 + 19705, including local stresses) occurs at location 15. The cask lifting is assumed to occur twice per round trip, so the total number of cycles of lifting is 900.

Test Pressure

The proof test is 1.25 × (maximum design pressure) = 125 psi, and will only be performed once. The test pressure loads are calculated using the pressure loads computed in Appendix 2.10.1, Table 2.10.1-6. Table 2.10.1-6 lists the stresses based on 100 psi internal pressure, and the maximum stress occurs in the containment vessel is 2330 psi occurs at location 22. Therefore, the maximum stress due to 125 psi test pressure is 2330 × 1.25 = 2,913 psi.

Shock

Since the TN-68 Cask may be shipped either by truck or by rail car, the shock loading for both cases will be considered.

Truck Shock

Truck shock input was obtained form ANSI N14.23[23]. This standard specifies shock loads that correspond to normal transport over rough roads or minor accidents such as backing into a loading dock. Since the TN-68 cask will be transported on interstate highways or major good roads, the shock loads will not be applied continuously to the normal transport mode for the package. The fatigue calculation assumes an average trip of 600 miles in 12 hours.

Assume the driver stops and leaves the interstate every 4 hours and assume that one shock could be experienced during each of these stops. The return trip package behavior is assumed to be the same as the "loaded" trip even though the cargo is no longer present. Therefore shock loading occurs 3 (shocks per trip) × 2 (round trip) × 450 shipments = 2,700 cycles.

The stresses due to the truck shock load are listed in Appendix 2.10.1, Tables 2-10.1-19 and 20. The maximum stress intensity at the containment vessel is 1,946 psi occurs at location 17.

Rail Car Shock

Again, assume 450 round trip shipments, averaging 600 miles each way. Assume that there are roughly 9 shock cycles per 100 miles of rail car transport. Therefore the total number of cycles is 600 (miles) × 2 (round trip) × 450 (shipments) × 0.09 (Shocks per mile) = 48,600 cycles.

The stress intensities due to the rail shock load are listed in Appendix 2.10.1, Tables 2-10.1-61 and 62. The maximum stress intensity at the containment vessel is 3,408 psi occurs at location 17.

Vibration

Since vibration accelerations are higher on a truck than on a rail car, the truck vibration loads are considered bounding. The stresses due to the rail shock load are listed in Appendix 2.10.1, Tables 2-10.1-43 and 44. The maximum stress intensity at the containment vessel is 332 psi occurs at location 17. This stress is negligible for the containment boundary structure.

Pressure and Temperature Fluctuations

There are four environmental conditions identified for normal transportation. These are hot environment, cold environment, reduced external pressure, and increase external pressure. The Containment Vessel stresses in response to these environmental load combinations were reported in Tables 2-19 to 2-26. The highest total stress intensity from these four cases was calculated to occur during the hot environment condition (19,023 psi, Table 2-19, location 16).

The pressure fluctuation is assumed to occur once per round trip, since there is no cargo, and therefore no pressurization, during the return trip. So the total number of cycles of pressure fluctuation is 450.

1 Foot Normal Condition Drop

The stress intensities due to the 1 foot end drop on bottom are listed in Appendix 2.10.1, Tables 2-10.1-9 and 10. The maximum stress intensity at the containment vessel is 312 psi (1G) occurs at location 5. Therefore, for a 15 G normal condition end drop, the maximum stress intensity is $312 \times 15 = 4{,}680$ psi.

The stress intensities due to the 1 foot end drop on lid end are listed in Appendix 2.10.1, Tables 2-10.1-11 and 12. The maximum stress intensity at the containment vessel is 441 psi (1G) occurs at location 22. Therefore, for 15 G normal condition end drop, the maximum stress intensity is $441 \times 15 = 6{,}615$ psi.

The stress intensities due to the 1 foot side drop are listed in Appendix 2.10.1, Tables 2-10.1-23 to 26. The maximum stress intensity at the containment vessel is 351 psi (1G) occurs at location 19. Therefore, for 35 G normal condition end drop, the maximum stress intensity is $351 \times 35 = 12{,}285$ psi.

For fatigue evaluation conservatively assumes that the cask is dropped once per shipment, resulting in 450 normal condition drops and using the maximum side stress intensity of 12,285 psi for damage factor calculation.

Damage Factor Calculation

The following table is a summary calculation sheet for the fatigue evaluation. Although the maximum stress intensities for the different loading conditions do not occur at the same location, it is conservatively assumed that they do for the purpose of the fatigue evaluation. The value of the alternating stress, S_a, is determined as follows:

If one cycle goes from 0 to S.I:

$S_a = S.I. \times K_F \times K_E / 2$

If one cycle goes from –S.I. to S.I:

$S_a = S.I. \times K_F \times K_E$

Where:

K_F = fatigue strength reduction factor, 4

K_E = correction factor for modulus of elasticity, $30 \times 10^6 / 27.8 \times 10^6 = 1.08$

The fatigue curve shown in Table I-9.1 of ASME Section III Appendices is used for this evaluation.

Summary of Fatigue Evaluation

Event	Stress Intensity (psi.)	$S.I. \times K_F \times K_E$ (psi.)	S_a (psi.)	Cycles		Damage Factor n / N
				n	N	
Lifting	20,517	88,633	44,316	900	7,000	0.129
Test Pressure	2,913	12,582	6,291	1	∞	0.00
Truck Shock	1,946	8,407	8,407	2,700	∞	0.00
Rail Car Shock	3,408	14,723	14,723	48,600	4×10^5	0.12
Pressure and Temperature	19,023	82,179	82,179	450	1,400	0.32
1 Foot Normal Condition Drop	12,285	53,071	26,536	450	4×10^4	0.011
Σ						0.58

The above table shows that the total damage factor is less than one. Therefore the fatigue effects on the TN-68 containment vessel are acceptable.

A separate fatigue analysis of the lid bolts is presented in Section 2.10.2.

2.6.14 Structural Evaluation of the Basket Under Normal Condition Loads

The loading conditions considered in the evaluation of the fuel basket consist of inertial loads resulting from normal inertial loading (1foot drop), accident inertial loading (30 foot drop) and thermal loads. The inertial loads of significance for the basket analysis are those transverse to the cask and basket structural longitudinal axes, so that the loading from the fuel assemblies is applied normal to the basket plates and transferred to the cask wall by the basket.

To determine the structural adequacy of the basket plate in the TN-68 BWR fuel assembly basket under a normal condition free drop, the basket is evaluated for 15 G end drop and 35G side drop. The G loads and drop orientations used for structural analysis of the basket are described in Appendix 2.10.8. The stress analysis of the basket due to inertial loading analysis is described in detail in Appendix 2.10.5. The results of the analyses are summarized in Table 2-55. Based on the results of these analyses, the basket, rails, and hold down ring are structurally adequate for loads up to 40G. This G load is higher than the calculated G load of 15G from 1 foot end drop and 35G from 1 foot side drop.

The basket is structurally adequate and it will properly support and position the fuel assemblies under normal loading conditions.

2.6.15 Summary of Normal Condition Cask Body Structural Analysis

The following table lists the highest stress intensities in the containment vessel and gamma shield and also identifies the load combination tables and locations where these maximum stresses occur. Also listed in the tables are the stress limits for the service condition based on the Section 2.1.2 structural design criteria.

Comparison of the Maximum Stress Intensities with the Allowables
(Cask Body)

Component		Maximum Nodal Stress Intensity (ksi)	Stress Resultant Table	Stress Category (ksi)	Allowable Stress Intensity (ksi)
Inner Containment	Shell	30.1	2-31 Location 7	$P_m = 22.12$	23.3*
				$P_m + P_b = 30.1$	34.95**
	Flange	18.4	2-52 Location 19	$P_m + P_b$	23.3*
	Lid	13.4	2-50 Location 21	$P_m + P_b$	23.3*
Gamma Shield	Cylinder	28.0	2-32 Location 28	$P_m = 12.67$ $P_m + P_b = 28.0$	21.3* 31.95**
	Bottom	11.9	2-50 Location 25	$P_m + P_b$	21.3*
	Welds	10.9	2-48 Location 38	$P_m + P_b$	21.3*

* P_m allowable
** $P_m + P_b$ allowable

From the analysis results presented in the above table, it can be shown that the normal loads will not result in any structural damage to the cask and that the containment function of the basket and fuel assembly will be maintained.

2.7 HYPOTHETICAL ACCIDENT CONDITIONS

Overview

This section describes the response of the TN-68 package to the accident loading conditions specified by 10CFR71.73. The design criteria established for the TN-68 Packaging for the hypothetical accident conditions are described in Section 2.1.2. These criteria are selected to ensure that the packaging performance standards specified by 10CFR71.51 are satisfied.

The presentation of the hypothetical accident condition analyses and results is accomplished in the same manner as that used for the normal condition of transport. The detailed analyses of the various packaging components under different loading conditions are presented in the Appendices to this Chapter. The limiting results for the specified hypothetical accident loading conditions are taken from the Appendices and summarized here along with a comparison made to the established design criteria. In all cases, the acceptability of the TN-68 packaging design with respect to hypothetical accident loads is demonstrated.

Table 2-56 provides an overview of the performance evaluations presented in this section. The stress results for the cask body are obtained by combining or superimposing the stresses from appropriate individual load cases reported in Appendix 2.10.1, to represent the stress condition under the specified hypothetical accident condition. This combination method is essentially the same as that presented in Section 2.6. Stress analysis results for the lid bolts are taken directly from Appendix 2.10.2. The impact limiter attachment evaluations are described in Appendix 2.10.8.

Reporting Method for Cask body Stresses

The structural analysis of the cask body was performed using an ANSYS finite element model. Stress results are reported at selected representative locations as described in Section 2.6. Because of the asymmetric characteristic of most of the hypothetical accident loads, stress results are generally reported on two different sides of the cask body.

Appendix 2.10.1 provides the detailed description of the structural analyses of the TN-68 cask body. That Appendix describes the detailed ANSYS model, used to analyze the cask under various applied loads. Table 2-57 identifies the individual loads (IL) analyzed using the ANSYS model, which are applicable to the hypothetical accident conditions. Some of these individual loads are axisymmetric (e.g. pressure) and others are asymmetric (e.g. side impact). None of the load cases in this section involve loadings applied locally at the trunnions. Figures 2-4 and 5 show the selected locations on the cask body where stress results for these analyses are reported. Detailed stresses are actually available at as many locations as there are nodes in the finite element model. However, for practical considerations, the reporting of stress results is limited to those locations shown on Figures 2-4 and 2-5. These locations were selected to be representative of the stress distribution in the cask body, with special attention given to areas subject to high stresses. The maximum stress may occur at a different location for each individual load.

The stress results for the individual load case (tables reported in Appendix 2.10.1) are for one individual load only. Two or more individual load cases must be combined to determine the total stresses at the standard stress reporting locations for the various load combinations. This is accomplished using the ANSYS post-processor.

Several other items should be noted. In the TN-68, thermal stresses occur due to the effects of differential thermal expansion between the gamma shield and the inner vessel. These thermal stresses are conservatively treated as primary stresses, and the combined stresses due to primary loads (like pressure) and differential expansion (such as heating from 70°F to hot thermal conditions) are evaluated as primary stresses.

For the axisymmetric cases, the stress is constant around the circumference of the cask at each stress reporting location. The stresses, where there are significant differences in stress magnitudes on the extreme opposite sides of the cask (usually top and bottom for a horizontal cask), are reported in separate tables (e.g. contact side in Table 2-67 for the 30 foot side drop and 90° away from contact in Table 2-69).

Table 2-58 provides a matrix of the individual loads and how they are combined to determine the cask body stresses for the hypothetical accident conditions. The thermal stresses due to the hot and cold conditions are actually secondary stresses that could be evaluated using higher allowables than for primary stresses. They are conservatively added to the primary stresses, and the combined stresses are evaluated using the primary stress allowables. An x in Table 2-58 indicates that the stress results for the individual load case are used for load combinations.

2.7.1 30 Foot Free Drop

The response of the TN-68 Packaging is evaluated for a free drop from a height of 30 feet onto an unyielding surface at various orientations. The inertial loading applied to the TN-68 components is determined in the dynamic analysis presented in Appendix 2.10.8. The 30 foot drop is measured from the impact surface to the bottom of the impact limiter; the C.G. of the cask is much higher than 30 feet.

The stresses in the cask body are reported for the following drop orientations:

- End drop onto bottom end
- End drop onto lid end
- Side drop
- C. G. over corner drop on bottom end
- C. G. over corner drop on lid end
- 15° slap down impact on lid end.

2.7.1.1 End Drop

The dynamic impact analysis of the TN-68 Packaging shows that the maximum expected inertia loading from the 30-foot end drop is 66 g's. Because of the symmetry of the cask and impact limiters, these values are applicable for both the bottom end drop and lid end drop.

The structural analysis of the cask body for these loading conditions were conservatively performed using an inertial loading of 80 g. The load combinations performed to evaluate these drop events are indicated in Table 2-58. In all cases, bolt pre-load effects and fabrication stresses are included. For the hot environment condition, thermal stress, 100 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Tables 2-59 and 2-60 list the combined stress intensities for the bottom end drop under hot environment conditions. Tables 2-61 and 2-62 list the combined stress for the bottom end drop under -20°F cold environment conditions.

Tables 2-63 and 2-64 list the combined stress intensities for the lid end drop under hot environment conditions. Tables 2-65 and 2-66 list the combined stresses for the lid end drop under -20°F cold environment conditions.

2.7.1.2 Side Drop

The dynamic analysis of the 30-foot side drop provided a maximum expected inertial loading of 53 g (Appendix 2.10.8). The structural analysis of the cask body for this loading condition was conservatively performed using an inertial loading of 80 g. The load combinations performed to evaluate these drop events are indicated in Table 2-58. In all cases, bolt pre-load effects and fabrication stress are included. For the hot environment condition, thermal stress, 100 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Tables 2-67 and 2-68 list the combined stress intensities for the side drop (contact side) under hot environment conditions. Tables 2-69 and 2-70 also list the combined stress intensities for the side drop (90° away from contact) under hot environment conditions.

Tables 2-71 and 2-72 list the combined stress intensities for the side drop (contact side) under -20°F cold environment conditions. Tables 2-73 and 2-74 also list the combined stress intensities for the side drop (90° away from contact) under -20°F cold environment conditions.

2.7.1.3 C.G. Over Corner Drop

The response of the TN-68 Package to the 30-foot corner drops were analyzed for impact on the bottom end and lid end. The analyses were performed using the ANSYS model as described in Appendix 2.10.1. The C.G. over corner drop occurs at a drop angle of approximately 60°. That is, the longitudinal axis of the containment vessel is at an angle of 60° from the impact surface. The dynamic analysis (Appendix 2.10.8) of the 60° drop orientation calculated maximum inertia

loadings of 33g (axial) along the cask longitudinal axis and 17g transverse to the longitudinal axis. The ANSYS analysis of the C.G. over corner drop was conservatively performed using a high axial inertia loading of 69g and high transverse inertia loading of 40g.

The load combinations performed to evaluate these two drop events are indicated in Table 2-58. In all cases, bolt pre-load effects and fabrication stresses are included. For the hot environment condition, thermal stress, 100 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, 25 psi external pressure, and impact load cases are combined.

Tables 2-75 and 2-76 list the combined stress intensities for the C.G. over corner bottom end drop (contact side) under hot environment conditions. Tables 2-77 and 2-78 also list the combined stress intensities for the C.G. over corner bottom end drop (90° away from contact) under hot environment conditions.

Tables 2-79 and 2-80 list the combined stress intensities for the C.G. over corner bottom end drop (contact side) under -20°F cold environment conditions. Tables 2-81 and 2-82 also list the combined stress intensities for the C.G. over corner bottom end drop (90° away from contact) under -20°F cold environment conditions.

Tables 2-83 and 2-84 list the combined stress intensities for the C.G. over corner lid end drop (contact side) under hot environment conditions. Tables 2-85 and 2-86 also list the combined stress intensities for the C.G. over corner lid end drop (90° away from contact) under hot environment conditions.

Tables 2-87 and 2-88 list the combined stress intensities for the C.G. over corner lid end drop (contact side) under -20°F cold environment conditions. Tables 2-89 and 2-90 also list the combined stress intensities for the C.G. over corner lid end drop (90° away from contact) under -20°F cold environment conditions.

2.7.1.4 15° Slap Down Impact at Lid End

The 15° slap down impact at lid end (second impact) has a maximum combined transverse inertia load of 72.2g ($G_{normal} = 25.4$, $G_{rotational} = 46.8$) at the lid end. The simultaneous inertia load at the opposite end is 19g and the axial load is 0.045G. The stress analysis was performed using the ANSYS model as described in Appendix 2.10.1. The maximum normal and rotational accelerations are conservatively increased to 42.22G and 77.78G, respectively for the ANSYS analysis.

The load combinations performed to evaluate this drop event are indicated in Table 2-58. In all cases, bolt pre-load effects and fabrication stresses are included. For the hot environment condition, thermal stress, 100 psi internal pressure, and impact load cases are combined. For the cold environment evaluation, -20°F thermal stress, the 25 psi external pressure, and impact load cases are combined.

Tables 2-91 and 2-92 list the combined stress intensities for the 15° slap down impact (contact side) under hot environment conditions. Tables 2-93 and 2-94 also list the combined stress intensities for the 15° slap down impact (90° away from contact) under hot environment conditions.

Tables 2-95 and 2-96 list the combined stress intensities for the 15° slap down impact (contact side) under -20°F cold environment conditions. Tables 2-97 and 2-98 also list the combined stress intensities for the 15° slap down impact (90° away from contact) under -20°F cold environment conditions.

2.7.1.5 Lid Bolts

The lid bolts are analyzed for normal and accident condition loadings in Appendix 2.10.2. The analysis is based on NUREG/CR-6007[25]. The bolts are analyzed for the following normal and accident conditions: operating pre-load, gasket seating load, internal pressure, temperature changes, impact loads, and puncture loads.

The bolt preload is calculated to withstand the worst case load combination and to maintain a clamping (compressive) force on the closure joint, both under normal and accident conditions. Based upon the load combination results (see Appendix 2.10.2, Section 2.10.2.3), it is shown that a positive (compressive) load is maintained on the clamped joint for all load combinations. Therefore, in both normal and accident load cases, the maximum non-prying tensile force of 135,200 lbs from preload + temperature load is used for bolt stress calculations.

A summary of the calculated stresses is listed in the Appendix 2.10.2, Section 2.10.2.5. The calculations result in a maximum average tensile stress of 56 ksi, which is below the allowable tensile stress of 115.5 ksi. The average shear stress in the bolts is due to torsion during pre-loading. This stress is 12.0 ksi, which is well below the allowable shear stress of 69.3 ksi.

2.7.1.6 Impact Limiter Attachments

The impact limiters must remain attached to the cask body before, during, and after each hypothetical accident drop condition. The impact limiter attachments are designed in such a way that during the accident drop condition, if one of the four attachment bolts and one of the 13 tierods fail, the impact limiter is still going to be secured by the remaining attachment bolts/tierods and will not affect the integrity of the packaging.

The limiting loading condition for the impact limiter attachments is the secondary impact (slap-down) associated with the 15° slap down 30-foot drop. This loading condition applies the greatest overturning moment on to the impact limiter and cask body interface. Although this loading condition is not limiting with respect to any other cask components, an evaluation of the attachments is performed to demonstrate that the affected impact limiter remains in place to insulate the cask during the subsequent hypothetical thermal accident.

The analysis and results, summarized here, are provided in detail in Section 2.10.8.6 of Appendix 2.10.8.

The analysis concludes that the impact limiter attachment design is sufficiently strong to ensure that the impact limiters remain attached to the cask body during and following all hypothetical accident conditions.

2.7.2 Puncture

The impact limiters will protect the ends of the cask body from a 40-inch drop, onto a 6-inch diameter bar. The most severe damage to the body resulting from the puncture drop will occur on the side walls of the gamma shield cylindrical shell, between the impact limiters. This portion of the package is not the containment vessel, so that a release of the contents cannot occur.

An evaluation of the puncture drop event includes the local effects on the containment vessel at the impact point as well as the overall inertia loading on the packaging components.

For this load condition it is assumed that the containment vessel surface impacts the puncture bar directly. The puncture bar as specified in 10CFR71, is a solid, vertical, cylindrical, mild steel bar 6 inches in diameter.

The impact force exerted by the bar on the containment vessel surface is calculated assuming the bar behaves as an elastic, perfectly plastic material with yield strength of 50 ksi which is a typical yield strength of mild steel.

Puncture Analysis

Method 1:

The maximum force, F_p, acting on the cask body due to impact on the puncture bar is:

$$F_p = \sigma_y A_b$$

Where σ_y is the yield strength of the bar, 50 ksi, and A_b is cross sectional area of the 6 inch diameter bar, 28.27 in.^{2}

Therefore,

$$F_p = 1.415\times10^6 \text{ lb.}$$

The thickness of the cask body is 7.50" which provides the following shear area.

$$A = \pi(6)(7.5) = 141 \text{ in.}^2$$

The resulting maximum shear stress is the following:

$$\tau = F_p/A = 1.415\times10^6/141 = 10{,}009 \text{ psi.}$$

The allowable shear stress for the gamma shield (ASME SA-266 Class 2) is 0.42 S_u = 0.42 × (70,000) = 29,400 psi, which is well above the maximum shear stress.

This maximum impact force also produces a cask deceleration and induces a bending moment at the midsection of the cask. If the cask is considered a beam uniformly loaded (downward) by its inertial load and supported by the puncture bar at the center, the deceleration, g, caused by the puncture drop is then the following:

$$g = \frac{F_p}{W_{package}} = \frac{1.415\times10^6}{271{,}950} = 5.20$$

Here, $W_{package}$ is the weight of the TN-68 transport package.

If the cask body is considered to be uniformly loaded and supported as described above, then the maximum moment, M, in the cask shell is:

$$M = \frac{F_p L}{8} = \frac{(1.415\times10^6)(197.25)}{8} = 3.489\times10^7 \text{ in. lb.}$$

Conservatively neglecting the outer shell and neutron shield, the moment of inertia of the cask shell is:

$$I = \pi R^3 t = \pi(77^3)(7.5) = 1.076\times10^7 \text{ in.}^4$$

The shell bending stress is then:

$$\sigma_b = \frac{Mr_0}{I} = \frac{(3.489\times10^7)(42.25)}{1.076\times10^7} = 137 \text{ psi.}$$

Since the stress is nearly constant through the wall thickness, it should be treated as a membrane stress, P_m. The allowable stress for this accident condition is $0.7S_u$ or 49,000 psi, which is well above σ_b.

The deceleration of 5.20 gs is small compared to the g-loads that will occur during the 30 foot free drop. Therefore, the global stresses that result from the inertial forces will be neglected during the load combination analysis. The bending stress of 137 psi at the center of the cask is also negligible compared to stresses due to other loads considered.

Method 2:

An additional cask wall puncture analysis was performed using the equations presented in NUREG/CR-4554[26]. The analysis in this reference provides a conservative relationship

between the energy for puncture, the puncture rod diameter, and cask wall thickness required to prevent puncture. The following equation is a reproduction of reference 26, equation 5.

$$T_d = 1.61 \exp[-0.681 + 0.685 \ln(Y) + \ln(d)]$$

Where T_d is the cask wall thickness required to prevent puncture, d is the puncture rod diameter, and Y is the non-dimensional energy absorbed by the puncture event. From reference 4,

$$Y = \frac{E_i}{S_u d^3}$$

Here, E_i is the actual energy absorbed by the puncture event, and S_u is the ultimate strength of the cask wall material. S_u for both cask wall materials is 70,000 psi. and E_i is taken to be the potential energy of the TN-68 package, 40 inches above the puncture rod. Therefore, E_i = 271,950×40 = 1.088×10^7 lb. in., So,

$$Y = \frac{1.088\times10^7}{70{,}000(6^3)} = 0.719, \text{ and}$$

$$T_d = 1.62 \exp[-0.681 + 0.685 \ln(0.719) + \ln(6)] = 3.90 \text{ inches.}$$

Since the cask wall is 7.50 inches thick (> 3.90 inches), the cask wall will not fail due to the puncture event.

2.7.3 Thermal

2.7.3.1 Summary of Pressures and Temperatures

The analysis of the thermal accident is presented in Chapter Three. The maximum internal pressure during the thermal accident is calculated in Section 4.3. The calculated pressure is 4.2 atm, or 47.0 psig. The structural analysis is, however, performed conservatively, assuming 100 psi internal pressure for the pressure stress calculations.

An ANSYS transient thermal analysis of the cask for the 30 minute thermal accident is reported in Chapter 3. The initial condition is steady state, at an ambient temperature of 100°F and maximum decay heat. The initial steady state condition is followed by a 0.5 hour severe thermal transient which is then followed by a cool-down period. The temperatures from the thermal analysis are reported in Chapter 3.

The temperature through the cross section of the cask, at the time of the maximum thermal gradient, is used for input to the cask model for thermal stress analysis.

2.7.3.2 Thermal Stresses due to Fire accident

Stress analyses of the cask body due to the differential thermal expansion under the above temperature distributions are performed as individual load case IL-16. The stress component results of these analyses using the same ANSYS structural model are presented in Table 2.10.1-39 and 2.10.1-40 in Appendix 2.10.1. These results are tabulated for the same standard locations shown in Figures 2-4 and 5.

2.7.3.3 Combined Stresses

The stress components from the thermal stress cases are combined with those due to the lid bolt pre-load, the internal pressure and fabrication stress, using the same procedure described above for the 30 foot drop events. Tables 2-99 and 2-100 present the combined stress intensities at the standard locations.

2.7.4 Water Immersion

2.7.4.1 Immersion - Fissile Material (Water Head of 3 feet, 1.3 psi External Pressure)

The criticality evaluation presented in Chapter 6.0 considers the effect of water in-leakage. Thus, the requirements of 10CFR71.73(c)(5) are met. The cask body stresses for this immersion condition (1.3 psi external pressure) is enveloped by the immersion condition for all packages (water pressure of 290 psi) described in Section 2.7.4.3 below.

2.7.4.2 Immersion - All Packages (Water Head of 50 feet, 21.7 psi External Pressure)

The immersion loading condition results in an external pressure applied to the cask body corresponding to a 50 foot head of water. Assuming a 0 psia cask cavity pressure, this results in a maximum external pressure loading of 36.4 psi (21.7 + 14.7). The cask body stresses for this immersion condition (36.4 psi external pressure) is enveloped by the immersion condition for all packages (water pressure of 290 psi) described in Section 2.7.4.3 below.

2.7.4.3 Immersion - All Packages (Water Pressure of 290 psi)

10CFR 71.61 requires that the package be subjected to an external water pressure of a 290 psi for a period of not less than one hour without collapse, buckling, or inleakage of water. The containment vessel stresses under this loading condition are obtained by a combination of lid bolt pre-load individual load case, fabrication stress and 25 psi external pressure load case with a load factor of 11.6 applied to obtain stresses corresponding to the 290 psi external loading. Tables 2-101 and 2-102 provide the maximum stress intensities for this loading condition and shows that calculated values are well below specified allowables for P_m and $P_m + P_b$.

The containment boundary consists of the inner shell (both cylinder and bottom) and closure flange out to the seating surface and lid assembly outer plate. The inner shell and inner bottom plate of the containment vessel is completely enclosed by the gamma shield, therefore, they will never be exposed to an external pressure due to immersion. However, for conservatism, additional analysis is performed to evaluate the containment vessel stresses when the 290 psi

external pressure is directly applied to the outer surface of the containment vessel. This analysis is performed by using the same finite element model used for calculating the cask body stresses for the normal and accident load conditions (Appendix 2.10.1) except that the elements of the gamma shield shell and bottom shield plate are removed. Elastic – plastic analysis is performed for this load case. The material properties of the SA-203 Gr. E are taken from the ASME Code, Section II, Part D. A stress strain relationship is used to simulate the correct nonlinear material behavior. The following elastic and plastic material properties are used in the analysis:

Mechanical properties of SA-203 Gr. E (300°F)

$$E = 26.7 \times 10^6 \text{ psi}$$
$$S_y = 35.4 \times 10^6 \text{ psi}$$
$$S_u = 70.0 \times 10^6 \text{ psi}$$

Strain (in./in.)	Stress (psi)
0.00126	33,600
0.00326	35,400
0.045	42,000
0.11	53,200
0.21	70,000

The 290 psi external pressure load was applied in a number of sub-steps and a converged solution was obtained at each sub-step. The last sub-step with a converged solution gave stresses, strains and displacements for 290 psi pressure load.

The maximum membrane stress intensities are 0.1 ksi (lid), 38.5 ksi (inner shell), and 20.7 ksi (bottom inner plate). These stresses are below the allowable stress of 49.0 ksi (0.7 S_u, Appendix F, F-1341.2a).

The maximum membrane plus bending stress intensities are 8.9 ksi (lid), 41.4 ksi (inner shell), and 61.9 ksi (bottom inner plate). These stresses are below the allowable stress of 63.0 ksi (0.9 S_u, Appendix F, F-1341.2b).

Based on the results, the stresses in the inner cylinder shell and inner bottom plate are all within the ASME Code allowables. The stresses in the lid and flange are low and still within elastic range (less than the yield stress) and the effect of the external pressure on lid bolts stresses is also minimal.

Additional analysis is also performed to evaluate the inner cylindrical shell stability when subject to the 290 psi external pressure. Code Case N-284[27] is used for calculating the buckling stress due to this load case. Based on the criteria presented in the Code Case N-284, the 1.5" thick inner cylindrical shell can withstand up to 670 psi without exceed the allowable buckling stress.

The following table summarizes the code case N-284 buckling stress calculations.

Summary of Code Case N-284 Buckling Stress Calculations

Code Case N-284 Reference Paragraphs	Stress Calculations
Compression Stress Based on 670 psi External Pressure	16.6 ksi
Factor of Safety (Para. 1400)	1.34
	22.24 ksi
Capacity Reduction Factor (Para. 1500)	0.8
Elastic Amplified Stress	27.8 ksi
Plastic Reduction Factor (Para. 1600)	1
Plastic Amplified Stress	27.8 ksi
Theoretical Buckling Stress (Para. 1712)	44.9 ksi
Analysis Result	27.8 ksi < 44.9 ksi

It is concluded that the containment vessel is adequate for 290 psi external pressure due to immersion. The buckling pressure of the containment vessel is much higher than 290 psi external pressure and thus there is no potential of buckling of the containment vessel structure.

Therefore, the TN-68 cask satisfies all of the immersion requirements for a package that is used for shipment of radioactive materials.

2.7.5 Structural Evaluation of the Basket Under Accident Loads

To determine the structural adequacy of the basket plate in the TN-68 BWR fuel assembly basket under accident condition free drops, the basket is conservatively evaluated for an 80 G end drop and an 80 G side drop. The G loads and drop orientations used for structural analysis of the basket are described in Appendix 2.10.8. The stress analysis and buckling analysis of the basket due to inertial loading analysis is described in detail in Appendix 2.10.5. The results of the stress analyses are summarized in the following tables.

Stress Summary of Accident Condition Basket Structural Stress Analysis

Loading	Stress Category	Max. Stress (ksi) (1G)	Allowable Stress (ksi)	Max. Allowable G load	Max. Calculated G Load Including Dynamic Load Factor	Reference Section/Table
304 Stainless Steel Plate						
End Drop	P_m	0.1	42.0	420	80	Sect. 2.10.5.3.3
Side drop	P_m	0.33	42.0	127	80	Table 2.10.5-1 (0° drop)
	$P_m + P_b$	0.59	63.0	107	80	Table 2.10.5-1 (0° drop)
Stainless Steel Fusion weld						
End Drop	τ	0.02	21.0	1050	80	Sect. 2.10.5.3.3
Side Drop	τ	0.07	22.44	321	80	Table 2.10.5-1 (45° drop)
6061-T6 Aluminum Rail						
End Drop	P_m	0.02	15.12	756	80	Sect. 2.10.5.3.3
Side Drop	P_m	0.10	15.12	151	80	Table 2.10.5-2 (Location 1)
	$P_m + P_b$	0.15	22.40	149	80	Table 2.10.5-2 (Location 1)
304 Stainless Steel Basket Hold Down Ring						
End Drop	P_m	0.08	42.0	525	80	Sect. 2.10.5.3.3

Plastic Instability Load and Allowable Buckling Load

Drop Orientation (Degree)	Plastic Instability Load (G)		Allowable Buckling Load (0.7 × G)	
	400°F	500°F	400°F	500°F
0	174	162	122	113
10	160	151	112	106
20	154	146	108	102
30	152	145	106	101
45	164	155	115	109

Based on the results of these analyses, the basket, rails, and hold down ring are structurally adequate up to 101G (limited by 30^0 buckling), this G load is higher than the calculated G load of 80G from 30 foot end drop and 30 foot side drop.

The basket is structurally adequate and it will properly support and position the fuel assemblies under accident loading conditions.

2.7.6 Summary of Accident Condition Cask Body Structural Analysis

The following table lists the highest stress intensities in the containment vessel and gamma shield and also identifies the load combination tables and locations where these maximum occur. Also listed in the tables are the stress limits for the service condition based on the Section 2.1.2 structural design criteria.

Comparison of the Maximum Stress Intensities with the Allowables
(Cask Body)

Component		Maximum Nodal Stress Intensity (ksi)	Stress Resultant Table	Stress Category	Allowable Stress Intensity (ksi)
Inner Containment	Shell	37.5	2-91 Location 1	$P_m + P_b$	49.0*
	Flange	47.2	2-90 Location 19	$P_m + P_b$	49.0*
	Lid	53.6	2-88 Location 22	$P_m = 30.0$ (ksi)	49.0*
				$P_m + P_b = 53.6$ (ksi)	73.5**
Gamma Shield	Cylinder	22.0	2-68 Location 32	$P_m + P_b$	49.0*
	Bottom	47.1	2-80 Location 24	$P_m + P_b$	49.0*
	Welds	42.8	2-66 Location 39	$P_m + P_b$	49.0*

* P_m allowable
** $P_m + P_b$ allowable

From the analysis results presented in the above table, it can be shown that the accident loads will not result in any structural damage to the cask and that the containment function of the basket and fuel assembly will be maintained.

As described above, the integrity of the TN-68 Packaging is not compromised by the accident test sequence set forth in 10 CFR71.73, since it meets the design criteria of Regulatory Guide 7.6 for the Load Combinations identified in Regulatory Guide 7.8.

2.8 SPECIAL FORM/FUEL RODS

2.8.1 Special Form

This section does not apply to the TN-68 Packaging.

2.8.2 Fuel Rods

As discussed in Chapter 4, containment of the radioactive material is provided by the cask containment boundary. Analyses of the cask boundary for all normal conditions of transport and hypothetical conditions defined by the Part 71 Regulations demonstrate that the cask remains leak tight.

In addition, Appendix 2.10.7 of the SAR assesses the response of a typical BWR fuel assembly during 30 foot hypothetical end drop and 30 foot hypothetical side drop. Results from these analyses indicate that the lowest buckling load for GE fuel assemblies is about 95G which is well above 80G end drop and the maximum stress due to the side drop load is much less than the yield stress of the irradiated zicaloy tube. Therefore, the integrity of the fuel rods will not be breached during the normal and hypothetical accident loads.

2.9 REFERENCES

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26. NUREG/CR-4554, "SCANS A Microcomputer Based Analysis System for shipping Cask Design review", April, 1989.

27. ASME Section III, Code Case No. N-284, "Metal Containment Shell Buckling Design Methods", August, 1980.

2.10 APPENDICES

The detailed structural analyses of the TN-68 packaging are included in the following appendices:

Appendix 2.10.1	Structural Analysis of the Cask Body
Appendix 2.10.2	Lid Bolt Analysis
Appendix 2.10.3	Structural Analysis of the Outer Shell
Appendix 2.10.4	Fracture Toughness Evaluation of the TN-68 Cask
Appendix 2.10.5	Structural Analysis of the TN-68 Basket
Appendix 2.10.6	Dynamic Load Factor for Basket Drop Analysis
Appendix 2.10.7	Structural Evaluation of the Fuel Rod Cladding Under Accident Impact
Appendix 2.10.8	Structural Evaluation of the Impact Limiters
Appendix 2.10.9	Impact Limiter Testing

2.11 ASME Code Exceptions

The cask containment boundary is designed, fabricated and inspected in accordance with the ASME Code Subsections NB/WB to the maximum practical extent. The basket is designed, fabricated and inspected in accordance with ASME Code Subsection NG to the maximum practical extent. The gamma shielding, which is primarily for shielding, but also provides structural support to the containment boundary during accident events, was designed in accordance with Subsection NF of the code. Inspections of the gamma shielding are performed in accordance with ASME code Subsection NF as detailed in the SAR. Other cask components, such as the protective cover, outer shell and neutron shielding are not governed by the ASME Code.

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
TN-68 Cask	NB-1100/ Subsection NCA NB-2000 or WB-1100/ WB-2000	Stamping and preparation of reports by the Certificate Holder, Surveillances, Use of ASME Certificate Holders	The TN-68 cask is not N/TP stamped, nor is there a code design specification or stress report generated. A design criteria document is generated in accordance with TN's QA Program and the design and analysis is performed under TN's QA Program and presented in the SAR. The cask may also be fabricated by other than N-stamp holders and materials may be supplied by other than ASME Certificate holders. Surveillances are performed by TN and utility personnel rather than by an Authorized Nuclear Inspector (ANI)
TN-68 Cask	NCA-3800	QA Requirements	The quality assurance requirements of NQA-1 or 10 CFR 71 are imposed in lieu of NCA-3800 requirements.
Containment Vessel	NB-6200/WB-6200	Hydrostatic Testing	The containment vessel is hydrostatically tested in accordance with the requirements of the ASME B&PV Code, Section III, Articles NB-6200/WB-6200 with the exception that the containment vessel is installed in the gamma shield shell during testing. The containment vessel is supported by the gamma shield during all design and accident events.

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Weld of bottom inner plate to the containment shell	NB-5231/WB-5231	Full penetration corner welded joints require the fusion zone and the parent metal beneath the attachment surface to be UT after welding.	The required UT inspection will be performed on a best efforts basis. The joint will be examined by RT and either PT or MT methods in accordance with ASME Subsection NB/WB requirements. The joint may be welded after the containment shell is shrink fitted into the gamma shield shell. The geometry of the joint does not allow for UT inspection.
Containment Shell Rolling Qualification	NB-4213/WB-4213	The rolling process used to form the inner vessel should be qualified to determine that the required impact properties of NB-2300/WB-4213 are met after straining by taking test specimens from three different heats.	If the plates are made from less than three heats, each heat will be tested to verify the impact properties.
Containment Vessel	NB-7000	Vessels are required to have overpressure protection	No overpressure protection is provided. Function of containment vessel is to contain radioactive contents under normal and accident conditions of transport. Confinement vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Containment Vessel	NB-8000/WA-8000	Requirements for nameplates, stamping and reports per NCA-8000	TN-68 cask is to be marked and identified in accordance with 10 CFR71 requirements. Code stamping is not required. QA data package to be in accordance with Transnuclear approved QA program.
Containment Vessel	NB-1131/WB-1132	The design specification shall define the boundary of a component to which other component is attached.	A code design specification was not prepared for the TN-68 cask. A TN design criteria was prepared in accordance with TN's QA program.
Basket poison and aluminum plates	NG-2000	Use of ASME Materials	The poison material and the aluminum plates are not used for structural analysis, but to provide criticality control and heat transfer. They are not code materials.
Basket Rails	NG-2000	Use of ASME Materials	The fuel basket rail material is not a Class 1 material. It was selected for its properties. Aluminum has excellent thermal conductivity and a high strength to weight ratio. NUREG-3854 and 1617 allow materials other than ASME Code materials to be used in the cask and basket fabrication. ASME Code does provide the material properties for the aluminum alloy up to 400°F and also allows the material to be used for Section III applications (Class 2 and 3). The construction of the aluminum rails will meet the requirements of Section III, Subsection NG.

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Table 2-1
Evaluation Method Employed to Demonstrate Compliance With Specific Regulatory Requirements

10CFR71		Numerical Analysis	Material** Test	Model Tests
Normal Condition	Heat	X		
	Cold	X		
	Reduced External Pressure	X		
	Increased External Pressure	X		
	Shock and Vibration	X		
	One Foot Free drop	X		
Accident Condition	30 foot Free Drop-Cask and Basket	X	X	
	30 foot Free Drop- Impact Limiters	X	X	X
	Puncture	X		
	Thermal Event	X		
	Water Immersion	X		
others	Lifting	X		
	Tie-Down	X		

** Material tests include crush and shear tests of the wood, and charpy and tensile tests of the containment materials.

Table 2-2
Containment Vessel Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions[1]	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m \text{ or } P_l) + P_b$	$1.5\ S_m$
Shear Stress	$0.6\ S_m$
Bearing Stress	S_y
$(P_m \text{ or } P_l) + P_b + Q$	$3\ S_m$
$(P_m \text{ or } P_l) + P_b + Q + F$	S_a
Hypothetical Accident (Level D)[2]	
P_m	$0.7\ S_u$
P_l	$1.5 \times P_m$
$(P_m \text{ or } P_l) + P_b$	$1.5 \times P_m$
Shear Stress	$0.42\ S_u$

NOTES:

1. Classifications and Stress Intensity Limits are as defined in ASME B&PV Code, Section III, Subsection NB.

2. Stress intensity limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-3
Containment Bolt Stress Limits [1][5]

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions [2]	
Average Tensile Stress	$2\ S_m$
Maximum Combined Stress	$3\ S_m$
Bearing Stress	S_y
Hypothetical Accident (Level D)[3]	
Average Tensile Stress	Smaller of S_y or $0.7\ S_u$
Average Shear Stress	Smaller of $0.4\ S_u$ or $0.6\ S_y$
Maximum Combined Stress	S_u
Combined Shear & Tension	$R_t^2 + R_s^2 < 1$[4]

NOTES:

1. The stress analysis of the lid bolt is performed in accordance with NUREG/CR-6007[25] described in Appendix 2.10.2. The stress limits for the lid bolt are listed separately in Tables 2.10.2-3 and 4.

2. Classification and stress limits are as defined in ASME B&PV Code, Section III, Subsection NB.

3. Stress limits are in accordance with ASME B&PV Code, Section III, Appendix F.

4. R_t : Ratio of average tensile stress to allowable average tensile stress
   R_s : Ratio of average shear stress to allowable average shear stress

5. All stresses include the effect of tensile and torsional loads due to bolt preloading.

Table 2-4
Non Containment Structure Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions [1]	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m + P_l) + P_b$	$1.5\ S_m$
$(P_m + P_l) + P_b + Q$	$3\ S_m$
Shear Stress	$0.60\ S_m$
Bearing Stress	S_y
Hypothetical Accident (Level D) [2]	
P_m	$0.7\ S_u$
P_l	$1.5 \times P_m$
$(P_m + P_l) + P_b$	$1.5 \times P_m$
Shear Stress	$0.42\ S_u$

NOTES:

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NF.

2. Stress intensity limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-5
Basket Stress Limits

CLASSIFICATION	STRESS INTENSITY LIMIT
Normal (Level A) Conditions [1]	
P_m	S_m
P_l	$1.5\ S_m$
$(P_m + P_l) + P_b$	$1.5\ S_m$
$(P_m + P_l) + P_b + Q$	$3\ S_m$
$(P_m + P_l) + P_b + Q + F$	S_a
Shear Stress	$0.6\ S_m$
Hypothetical Accident (Level D) [2]	
P_m	Smaller of $2.4\ S_m$ or $0.7\ S_u$
P_l	$1.5 \times P_m$
$(P_m + P_l) + P_b$	$1.5 \times P_m$
Shear Stress	Smaller of $0.42\ S_u$ or $2(0.6S_m)$

NOTES:

1. Classifications and stress intensity limits are as defined in ASME B&PV Code, Section III, Subsection NG.

2. Limits are in accordance with ASME B&PV Code, Section III, Appendix F.

Table 2-6
Cask Weight and Center Gravity

COMPONENT	NOMINAL WEIGHT (lbs. x 1000)
Body	94.4
Bottom	15.6
Lid and Lid Bolts	12.3
Neutron Shield Aluminum Boxes	2.5
Resin	13.9
Outer Shell	11.2
Trunnions - Upper - Lower	0.8 0.9
Basket and Rails	25.9
Shield Ring	0.5
Basket Hold Down Ring	1.4
Fuel Assemblies	47.9
Overpressure Tank, Drain Tube	0.1
Cask Weight w/o Impact Limiters and Attachments	**227.4**
Impact Limiters (2)	30.6
Spacer (1)	1.1
Tie Rods (13)	1.0
Total Package Weight	**260.1**

* Center of Gravity of the package is approximately 97 inches and is measured along the axial centerline from the rear (bottom) of the cask.

Summary of weights used for Analysis:

1. Front (Top) Trunnion Lifting (w/o impact limiters) 240,000 lbs.
2. Rear (Bottom) Trunnion Tie-Down Analysis 271,950 lbs.
3. Cask Body Analysis 271,950 lbs.

Table 2-7

Mechanical Properties of Body Materials (Note 1)

Material Specification (Nominal Composition)	Application	Minimum Yield Strength S_y, psi	Minimum Ultimate Strength S_u, psi	Design Stress Value,Psi (Note 2)	Data Source (Note 3)
ASME SA-350, Grade LF3 (3 ½ Ni)	Flange Containment Lid	37,500	70,000	S_m=23,300	Table 2A
ASME SA-203, Grade E (3-1/2 Ni)	Containment Lid Containment Shell	40,000	70,000	S_m=23,300	Table 2A
ASME SA-266, Class 2 (C-Si)	Gamma Shielding	35,000	70,000	S_m= 23,300	Table 2A
ASME SA-516, Gr. 70 (C-Mn-Si)	Outer Shell Lid Shield Plate, Protective Cover	38,000	70,000	S_m= 23,300	Table 2A
ASME SA-105, (C-Si)	Lower Trunnion	36,000	70,000	S_m= 23,300	Table 1A
ASME SA-182 Gr. F6 NM (13 Cr – 4 Ni)	Upper Trunnion	90,000	115,000	S_m= 38,300	Table 2A
ASME SA-540 Gr. B24 Cl. 1 (2Ni-3/4 Cr-1/3 Mo)	Lid Bolts	150,000	165,000	S_m= 50,000	Table 4
ASME SA-320, Grade L43 (1 ¾ Ni-3/4 Cr - ¼ Mo)	Upper Trunnion Bolts	105,000	125,000	S_m= 35,000	Table 4

Table 2-7 (continued)
Mechanical Properties of Body Materials (Note 1)

NOTES:

1. Mechanical properties listed are for metal temperatures up to 100°F to provide a baseline comparison of all structural materials.
   Temperature dependent properties required for structural analysis are provided in Table 2-8.
2. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
   S refers to the ASME allowable stress for Class 2 or Class 3 components,

   S_m refers to the ASME design stress intensity for Class 1 components, and S_y

   refers to minimum yield strength.
3. Data is taken from tables in ASME Section II, Part D, 1995 including 1996 Addenda, unless otherwise noted.

Table 2-8

Temperature Dependent Body Material Properties (Sheet 1 of 4)

Coefficients Of Thermal Expansion (Note 1)

Material/Temp., °F	100	150	200	250	300	350	400	450	500	550	600
SA350,SA320, SA540, SA203 (Note 2)	6.27	6.41	6.54	6.65	6.78	6.88	6.98	7.07	7.16	7.24	7.32
SA105,SA266 and SA516 (Note 2)	5.73	5.91	6.09	6.27	6.43	6.59	6.74	6.89	7.06	7.18	7.28
SA182 Gr F6NM (Note 2)	5.37	5.45	5.52	5.59	5.65	5.70	5.75	5.80	5.85	5.90	5.95

NOTES:

1. Values listed are the mean coefficients of thermal expansion x 10^{-6} (in./in.°F) from 70°F to the indicated temperature.
2. Source of data is ASME Section II, Part D, 1995 including 1996 Addenda, Table TE-1.

Table 2-8
Temperature Dependent Body Material Properties (Sheet 2 of 4)
Modulus Of Elasticity, E (Note 1)

MATERIAL/ TEMPERATURE °F	70	200	300	400	500	600
SA-203, SA-320, SA-540 and SA-350 (Note 2)	27.8	27.1	26.7	26.1	25.7	25.2
SA-105, SA-266 And SA-516 (Note 2)	29.5	28.8	28.3	27.7	27.3	26.7
SA-182 Gr F6 NM (Note 2)	29.2	28.5	27.9	27.3	26.7	26.1

NOTES:

1. Values listed are the modulus of elasticity x 10^6 psi for the indicated temperature.

2. Source of data is ASME SECTION II, Part D, 1995 including 1996 addenda, Table TM-1.

Table 2-8

Temperature Dependent Body Material Properties (Sheet 3 of 4)

MATERIAL	STRESS PARAMETER (NOTE 1)	100°F	200°F	300°F	400°F	500°F	600°F	DATA SOURCE (NOTE 2)
SA-350, Gr. LF3	S_m	23.3	22.8	22.2	21.5	20.2	Note 4)	Table 2A
	S_y	37.5	34.2	33.2	32.2	30.3	-	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	-	Table U(E) (Note 5)
SA-203, Grade E	S_m	23.3	23.3	23.3	22.9	21.6	(Note 4)	Table 2A
	S_y	40.0	36.5	35.4	34.3	32.4	-	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	-	Table U (E)
SA-266 Class 2	S_m	23.3	21.9	21.3	20.6	19.4	17.8	Table 2A
	S_y	35.0	31.9	31.0	30.0	28.3	25.9	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-516 Grade 70	S_m	23.3	23.1	22.5	21.7	20.5	18.7	Table 2A
	S_y	38.0	34.6	33.7	32.6	30.7	28.1	Table 4-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-105	S_m	23.3	21.9	21.3	20.6	19.4	17.8	Table 2A
	S_y	36.0	32.8	31.9	30.8	29.1	26.6	Table Y-1
	S_u	70.0	70.0	70.0	70.0	70.0	70.0	Table U
SA-182 Gr. F6 NM	S_m	38.3	38.3	38.3	37.9	36.6	35.0	Table 2A
	S_y	90.0	86.5	84.6	82.8	80.8	78.5	Table Y-1
	S_u	115.0	115.0	115.0	113.6	109.7	105.1	Table U
SA-540 Gr. B24, CL.1 (Bolt)(Note3)	S_m	50.0	47.8	46.2	44.8	43.4	41.4	Table 4
	S_y	150.0	143.4	138.6	134.4	130.2	124.2	Table Y-1
	S_u	165.0	165.0	165.0	165.0	165.0	165.0	Table U (E)
SA-320, Gr. L43 (Bolt)(Note3)	S_m	35.0	33.0	31.9	30.6	29.5	28.1	Table 4
	S_y	105.0	99.0	95.7	91.8	88.5	84.3	Table Y-1
	S_u	125.0	125.0	125.0	125.0	125.0	125.0	Table U (E)

Table 2-8

Temperature Dependent Body Material Properties (Sheet 4 of 4)

NOTES FOR SHEET 3 OF 4:

1. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
   S refers to the ASME allowable stress for Class 2 or Class 3 components, or Section VIII, Division 1
   S_m refers to the ASME design stress intensity for Class 1 components, and
   S_y refers to minimum yield strength.
2. Data is taken from ASME Section II, Part D, 1995 including 1996 addenda.
3. For bolting materials, $S_y \geq 3\ S_m$.
4. Properties are not available at 600F in ASME Section II, Part D.
5. Table U (E) has listed estimated ultimate strength at temperatures 200F to 600F.

Table 2-9
Reference Temperatures For
Stress Analysis Acceptance Criteria*

Component	Max. Calculated Temperature, °F	Selected Design** Temperature, °F
Outer Shell	204	250
Gamma Shield	260	300
Inner Shell	262	300
Basket Rail	319	350
Basket	469	400 and 500
Lid Bolts	234	300
Front Trunnion	240	250
Front Trunnion Bolts	240	250
Rear Trunnion	245	250

* For normal loading conditions
** Temperatures specified are used to determine allowable stresses. They are not a maximum use temperature for the material.

Table 2-10
Mechanical Properties of Basket Materials (Note 1)

Material Specification (Nominal Composition)	Minimum Yield Strength S_y, psi	Minimum Ultimate Strength S_u, psi	Design Stress Value, psi (Note 2)	Data Source (Note 3)
ASME SA-240, Type 304 (Basket Plates)	30,000	75,000	$S_m = 20{,}000$	Table 2A
ASME SB 221, 6061-T6 Aluminum (Aluminum Rails)	35,000	38,000	$S = 9{,}500$	Table 1B

NOTES

1. Mechanical properties listed are for metal temperatures up to 100°F to provide a baseline comparison of all structural materials.

   Temperature dependent properties required for structural analysis are provided in Table 2-11

2. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.

   S refers to the ASME allowable stress for Class 2 or Class 3 components, S_m refers to the ASME design stress intensity for Class 1 components, and S_y refers to minimum yield strength.

3. Data is taken from tables in ASME Section II, Part D,1995 including 1996 addenda unless otherwise noted.

Table 2-11
Temperature Dependent Basket Material Properties (Sheet 1 of 3)
Coefficients of Thermal Expansion (Note 1)

	TEMPERATURE, °F										
MATERIAL	100	150	200	250	300	350	400	450	500	550	600
SA 240, TYPE 304	8.55	8.67	8.79	8.90	9.00	9.10	9.19	9.28	9.37	9.45	9.53
SB-221, 6061-T6 ALUMINUM	12.60	12.76	12.91	13.07	13.22	13.37	13.52	---	---	---	---

1. Values listed are the mean coefficients of thermal expansion x 10^{-6} (in./in.°F from 70°F to the indicated temperature).
2. Source of data is ASME Section II, Part D, 1995 including 1996 addenda.

Table 2-11
Temperature Dependent Basket Material Properties (Sheet 2 of 3)
Moduli of Elasticity, E (Note 1)

	TEMPERATURE, ^{o}F					
MATERIAL	70	200	300	400	500	600
SA-240, TYPE 304 STAINLESS STEEL	28.3	27.6	27.0	26.5	25.8	25.3
SB-221, 6061-T6 ALUMINUM	10.0	9.6	9.2	8.7	8.1	

NOTES:

1. Values listed are the moduli of elasticity x 10^6 psi for the indicated temperature.

2. Source of data is ASME Section II, Part D, 1995 including 1996 addenda.

Table 2-11
Temperature Dependent Basket Material Properties (Sheet 3 of 3)
Design Stress Parameters

		TEMPERATURE,°F						
MATERIAL	STRESS PARAMETER (KSI) (NOTE 1)	100	200	300	350	400	500	DATA SOURCE
ASME SA-240 Type 304	S_y	30.0	25.0	22.5	21.6	20.7	19.4	Table Y-1 (NOTE 2)
	S_u	75.0	71.0	66.0	65.2	64.4	63.5	Table U
	S_m	20.0	20.0	20.0	19.4	18.7	17.5	TABLE 2A
ASME SB-221 Alloy 6061-T6 (Aluminum)	S_y	35.0	33.7	27.4	20.0	13.3		TABLE Y-1
	S_u	38.0	35.5	28.7	22.4	16.0		NOTE 3
	S	9.5	9.5	7.9	6.3			TABLE 1B

NOTES:

1. Values listed are the stress parameters which form the basis for structural analysis acceptance criteria.
2. S_m refers to the ASME design stress intensity for Class 1 components, and
   S_y refers to minimum yield strength.
   S_u refers to minimum ultimate strength.
3. S_u is available in ASME Section II, Part D only at room temperature. For elevated temperatures, S_u was obtained by ratioing S_u data in Aluminum Association "Aluminum Standards and Data" 1990.

Table 2-12
Front (Top) Trunnion Section Properties And Loads

Item	Section A-A
Cross Section Area, In^2	29.3
Area Moment Of Inertia, In^4	279.83
Yield Condition* Shear Force, Lbs	828,000
Yield Condition* Bending Moment, In- Lbs	1,705,680
Ultimate Condition ** Shear Force, Lbs.	1,380,000
Ultimate Condition ** Bending Moment, In-Lbs	2,842,800

* Trunnion Loads to Support (6 * 1.15) times Cask Weight (240,000 lbs)
** Trunnion Loads to Support (10 * 1.15) times Cask Weight (240,000 lbs)

Table 2-13
Front (Top) Trunnion Stresses When Loaded
By 6 And 10 Times Cask Weight

Stress	Yield Limit (Ksi)
	SECTION A-A
Shear Stress	28.3
Bending Stress	29.8
Stress Intensity	63.9
Allowable Stress, S_y	85.55 (SA-182 Gr. F6NM at 250°F)
	Ultimate Limit (ksi)
Shear Stress	47.1
Bending Stress	49.6
Stress Intensity	106.5
Allowable Stress, S_u	115.0 (SA-182 Gr. F6NM at 250°F)

NOTE:
1. Sections A-A is shown on Figure 2-3.

Table 2-14
Rear (Bottom) Trunnion Section Properties and Loads

Item	Section A-A	Section B-B
Cross Section Area, In^2	106.8	191.3
Area Moment of Inertia, In^4	1708.6	4442.3

Load per trunnion:

Lateral Load = 2.5 × weight of package (271,950) = 679,875 lbs

Longitudinal and vertical loads are combined to form a resultant load : 5.03 × weight of package (271,950) = 1,367,909 lbs

Table 2-15

Rear (Bottom) Trunnion Stresses Due to 2/5/10 G Tie-Down Loads

Stress	Yield Limit (ksi)
	Section A-A Yield Stress = 32.35 ksi (SA-105 at 250°F)
Shear Stress	12.81
Bending Stress	10.48
Tensile Stress	6.37
Stress Intensity	30.67
	Section B-B Yield Stress = 31.45 ksi (SA-266 Class 2 at 250°F)
Shear Stress	7.15
Bending Stress	20.23
Tensile Stress	3.55
Stress Intensity	27.75

NOTE:

1. Sections A-A is shown on Figure 2-3.

Table 2-16
TN-68 Performance Evaluation Overview
(Normal Conditions of Transport)

Loading Condition	SAR Section	Scope of Evaluation
Heat 71.71(c)(1)	2.6.1.1	Maximum component temperatures for material allowables
	2.6.1.2	Cask cavity maximum pressure, 100 psi
	2.6.1.3	Cask body thermal gradients
	2.6.1.4	Cask body stresses due to hot environment load combinations
Cold 71.71(c)(2)	2.6.2	Cask body stresses due to cold environment load combinations
Increase External Pressure 71.71(c)(4)	2.6.3	Cask body stresses due to 25 psi external pressure load combinations
Reduced External pressure 71.71(c)(3)	2.6.4	Cask body stresses due to 100 psi internal pressure load combinations
Shock Loads 71.71(c)(5)	2.6.5	Cask body stresses due to truck shock loads
		Cask body stresses due to rail shock loads
Vibration Loads 71.71(c)(5)	2.6.7	Cask body stresses due to truck vibration loads
		Cask body stresses due to rail vibration loads
Water Spray 71.71(c)(6)	2.6.8	Negligible for TN-68 cask
Free Drop 71.71(c)(7)	2.6.9	Cask body stresses due to 1 foot bottom end drop
		Cask body stresses due to 1 foot lid end drop
		Cask body stresses due to 1 foot side drop
Corner Drop 71.71(c)(8)	2.6.10	Not applicable
Compression 71.71(c)(9)	2.6.11	Not applicable
Penetration 71.71(c)(10)	2.6.12	Not applicable
Lid Bolt Analysis	2.6.13	Bolt stresses due to preload, pressure loads, temperature, impact and puncture loads
Fatigue Analysis of Containment Vessel	2.6.14	Fatigue evaluation of containment vessel due to lifting, pressure, temperature, shock/vibration, and 1 foot drop loads
Basket Evaluation	2.6.15	Structural analysis of the basket due to 1 foot end drop and 1 foot side drop loads
Summary of Normal Condition Structural Analysis	2.6.16	Lists the highest stress intensities in the containment vessel and gamma shield and compares results with the allowables

Table 2-17
Individual Load Runs for Normal Condition of Transport

Run No.	Individual Load Type	Load Used in Run	Factor Used for Normal Conditions Load Combinations
IL-1	Bolt preload and lid seating pressure	-	1.0
IL-2	Fabrication Stresses	-	1.0
IL-3	Internal pressure	100 psig	1.0
IL-4	External pressure	25 psig	1.0
IL-5	End drop on bottom	1G	15.0
IL-6	End drop on lid	1G	15.0
IL-7	Thermal stresses at hot environment	-	1.0
IL-8	Thermal stresses at –20° F cold environment	-	1.0
IL-9	Thermal stresses at –40° F cold environment	-	1.0
IL-10	Horizontal cask, truck shock	3.5G- vertical 2.3G-long. 1.6G-lateral	3.85- vertical 2.3 long.
IL-11	Horizontal cask , 1g down	1G	1.0
IL-12	Side drop	1G	35.0
IL-18	Horizontal cask, truck vibration	0.6G- vertical 0.3G-long. 0.3G-lateral	0.67 vertical 0.3 long.
IL-19	Horizontal cask, tie-down	2G- vertical 10G-long. 5G-lateral	5.39 vertical 10 long.
IL-27	Horizontal cask, Rail car shock	4.7G – all directions	6.47 vertical 4.7 long.

Table 2 -18

Summary of Load Combinations for Normal Condition of Transport

Load Combination	Applicable Individual Loads												
	IL-1 Bolt Pre-load	IL-2 Fab. Stress	IL-3 Int. P	IL-4 Ext p	IL-5 Bot. drop	IL-6 Lid drop	IL-7 Ther mal hot	IL-8 Ther mal -20	IL-9 Ther mal -40	IL-10 Truck Shock	IL-11 Grav -ity 1g	IL-12 Side drop	Stress Result Tables 2-
Hot Environment (100° F amb.)	x	x	x				x				x		19, 20
Cold Environment (-40° F amb.)	x	x		x					x		x		21, 22
Increased External Pressure	x	x		x				x			x		23, 24
Min. External Pressure	x	x	x				x				x		25, 26
Truck Shock	x	x	x				x			x			27, 28
	x	x		x				x		x			29, 30
1 Ft End Drop,Bottom	x	x	x		x		x						39, 40
	x	x		x	x			x					41, 42
1 Ft End Drop,Lid	x	x	x			x	x						43, 44
	x	x		x		x		x					45, 46
1 Ft Side Drop	x	x	x				x					x	47, 48 49, 50
	x	x		x				x				x	51, 52 53, 54

Table 2 –18 (continued)
Summary of Load Combinations for Normal Condition of Transport

Load Combination	Applicable Individual Loads (see Table 2-17)								
	IL-1	IL-2	IL-3	IL-4	IL-7	IL-8	IL-18	IL-27	Stress Result Table 2-
	Bolt Pre-load	Fabrication Stress	Int. Pres	Ext. Pres	Thermal hot	Thermal -20	Truck Vibration	Rail Car Shock	
Truck Vibration	x	x	x		x		x		35, 36
	x	x		x		x	x		37, 38
Rail Car Shock	x	x	x		x			x	31, 32
	x	x		x		x		x	33, 34

Table 2-19
Hot Environment (100° F amb.) Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 1g Down)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6154
	2	2150
	3	6070
	4	2182
	5	7697
	6	7108
Inner Shell	7	17338*
	8	16886*
	9	17161
	10	16789
	11	17333
	12	17068
	13	17751
	14	17191
	15	17044
	16	19023
	17	10562
	18	9504

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 7: 16634 + 704 = 17338 psi.
at Location 8: 16182 + 704 = 16886 psi.

Table 2-20
Hot Environment (100° F amb.) Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 1g Down)

Location		Nodal Stress Intensity
Flange	19	11240
	20	3217
Lid	21	4307
	22	4708
Outer Bottom Plate	23	2698
	24	3894
	25	9326
	26	2796
Outer Shell	27	4886*
	28	10254*
	29	5020
	30	9277
	31	3845
	32	8851
	33	4944
	34	9350
	35	1765
	36	7939
Weld	37	2214
	38	8662
	39	3378

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 27: 4182 + 704 = 4886 psi.
at Location 28: 9498 + 756 = 10254 psi.

Table 2-21
Cold Environment (-40° F amb.) Load Combination
(Preload + Fabrication + External Pressure + -40°F + 1g Down)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1538
	2	2501
	3	1528
	4	2463
	5	2824
	6	1824
Inner Shell	7	13835*
	8	14090*
	9	13144
	10	13129
	11	13203
	12	13195
	13	13159
	14	13138
	15	14893
	16	11839
	17	4902
	18	7636

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 7: 13131 + 704 = 13835 psi.
at Location 8: 13386 + 704 = 14090 psi.

Table 2-22
Cold Environment (-40° F amb.) Load Combination
(Preload + Fabrication + External Pressure + -40°F + 1g Down)

Location		Nodal Stress Intensity
Flange	19	14389
	20	7051
Lid	21	1584
	22	983
Outer Bottom Plate	23	181
	24	783
	25	5136
	26	317
Outer Shell	27	4383*
	28	3883*
	29	3489
	30	3064
	31	3466
	32	2977
	33	3504
	34	3005
	35	3770
	36	2543
Weld	37	283
	38	1729
	39	1620

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 27: 3679 + 704 = 4383 psi.
at Location 28: 3127 + 756 = 3883 psi.

Table 2-23

Increased External Pressure Load Combination
(Preload + Fabrication + External Pressure + -20°F + 1g Down)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1794
	2	2239
	3	1785
	4	2205
	5	2733
	6	1851
Inner Shell	7	13807*
	8	14060*
	9	13115
	10	13100
	11	13173
	12	13166
	13	13130
	14	13111
	15	14910
	16	12145
	17	5115
	18	7537

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 7: 13103 + 704 = 13807 psi.
at Location 8: 13356 + 704 = 14060 psi.

Table 2-24
Increased External Pressure Load Combination
(Preload + Fabrication + External Pressure + -20°F + 1g Down)

Location		Nodal Stress Intensity
Flange	19	14113
	20	6919
Lid	21	1373
	22	883
Outer Bottom Plate	23	240
	24	759
	25	4444
	26	317
Outer Shell	27	4391*
	28	3877*
	29	3575
	30	3059
	31	3553
	32	2972
	33	3590
	34	2996
	35	3658
	36	2549
Weld	37	262
	38	1779
	39	1293

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 27: 3687 + 704 = 4391 psi.
at Location 28: 3121 + 756 = 3877 psi.

Table 2-25
Minimum External Pressure Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 1g Down)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6154
	2	2150
	3	6070
	4	2182
	5	7697
	6	7108
Inner Shell	7	17338*
	8	16886*
	9	17161
	10	16789
	11	17333
	12	17068
	13	17751
	14	17191
	15	17044
	16	19023
	17	10562
	18	9504

*Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 7: 16634 + 704 = 17338 psi.
at Location 8: 16182 + 704 = 16886 psi.

Table 2-26
Minimum External Pressure Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 1g Down)

Location		Nodal Stress Intensity
Flange	19	11240
	20	3217
Lid	21	4307
	22	4708
Outer Bottom Plate	23	2698
	24	3894
	25	9326
	26	2796
Outer Shell	27	4886*
	28	10254*
	29	5020
	30	9277
	31	3845
	32	8851
	33	4944
	34	9350
	35	1765
	36	7939
Weld	37	2214
	38	8662
	39	3378

Includes Local Stresses From Trunnion Due to 1g Down Load
at Location 27: 4182 + 704 = 4886 psi.
at Location 28: 9498 + 756 = 10254 psi.

Table 2-27
Transport Truck Shock in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Truck Shock)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6099
	2	2187
	3	5942
	4	2149
	5	7547
	6	6838
Inner Shell	7	22697*
	8	22214*
	9	17095
	10	16687
	11	17294
	12	16968
	13	17607
	14	17014
	15	17561
	16	19658
	17	10959
	18	10480

*Includes Local Stresses From Trunnion Due to Truck Shock Load
At Location 7: 16312 + 6385 = 22697 psi
At Location 8: 15829 + 6385 = 22214 psi

Table 2-28

Transport Truck Shock in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Truck Shock)

Location		Nodal Stress Intensity
Flange	19	12178
	20	3876
Lid	21	5044
	22	6059
Outer Bottom Plate	23	2447
	24	3752
	25	8587
	26	2793
Outer Shell	27	10680*
	28	17528*
	29	4759
	30	9504
	31	3483
	32	9117
	33	4759
	34	9592
	35	1329
	36	7337
Weld	37	2355
	38	9479
	39	3700

*Includes Local Stresses From Trunnion Due to Truck Shock Load
at Location 27: 4295 + 6385 = 10680
at Location 28: 9539 + 7989 = 17528

Table 2-29
Transport Truck Shock in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Truck Shock)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1739
	2	2504
	3	1656
	4	2331
	5	2606
	6	2019
Inner Shell	7	19347*
	8	19630*
	9	13421
	10	13369
	11	13590
	12	13560
	13	13331
	14	13336
	15	15748
	16	12780
	17	5512
	18	7801

*Includes Local Stresses From Trunnion Due to Truck Shock Load
at Location 7: 12962 + 6385 = 19347
at Location 8: 13245 + 6385 = 19630

Table 2-30
Transport Truck Shock in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Truck Shock)

Location		Nodal Stress Intensity
Flange	19	15121
	20	7741
Lid	21	676
	22	524
Outer Bottom Plate	23	715
	24	1127
	25	5184
	26	453
Outer Shell	27	8183*
	28	11824*
	29	3720
	30	2933
	31	3602
	32	2963
	33	3705
	34	2928
	35	2814
	36	1971
Weld	37	342
	38	1657
	39	1992

*Includes Local Stresses From Trunnion Due to Truck Shock Load
at Location 27: 3911 + 6385 = 8183
at Location 28: 3835 + 7989 = 11824

Table 2-31

Transport Rail Car Shock in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Rail Car Shock)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6040
	2	2224
	3	5811
	4	2116
	5	7397
	6	6562
Inner Shell	7	30080*
	8	29565*
	9	17030
	10	16587
	11	17257
	12	16871
	13	17466
	14	16841
	15	18073
	16	20285
	17	11348
	18	11441

*Includes Local Stresses From Trunnion Due to Rail Car Shock Load

Linaerized stresses:

Location 7: $P_m = 15733 + 6382 = 22115$, $P_m + P_b = 15991 + 14089 = 30080$

Location 8: $P_m = 15733 + 6382 = 22115$, $P_m + P_b = 15476 + 14089 = 29565$

Table 2-32

Transport Rail Car Shock in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Rail Car Shock)

Location		Nodal Stress Intensity
Flange	19	13094
	20	4586
Lid	21	5813
	22	7466
Outer Bottom Plate	23	2185
	24	3593
	25	7802
	26	2786
Outer Shell	27	18487*
	28	28029*
	29	4488
	30	9728
	31	3115
	32	9377
	33	4568
	34	9829
	35	1468
	36	6749
Weld	37	2499
	38	10298
	39	4087

*Includes Local Stresses From Trunnion Due to Rail Car Shock Load

Linaerized stresses:

Location 27: $P_m = 6290 + 6382 = 12672$, $P_m + P_b = 4398 + 14089 = 18487$

Location 28: $P_m = 6290 + 6382 = 12672$, $P_m + P_b = 9568 + 18461 = 28029$

Table 2-33
Transport Rail Car Shock in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Rail Car Shock)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1680
	2	2763
	3	1525
	4	2456
	5	2481
	6	2201
Inner Shell	7	26918*
	8	27235*
	9	13735
	10	13647
	11	14010
	12	13959
	13	13537
	14	13565
	15	16583
	16	13408
	17	6761
	18	8063

*Includes Local Stresses From Trunnion Due to Rail Car Shock Load
at Location 7: 12829 + 14089 = 26918
at Location 8: 13146 + 14089 = 27235

Table 2-34

Transport Rail Car Shock in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Rail Car Shock)

Location		Nodal Stress Intensity
Flange	19	16092
	20	8549
Lid	21	195
	22	1924
Outer Bottom Plate	23	1196
	24	1508
	25	5969
	26	597
Outer Shell	27	18271*
	28	23025*
	29	3865
	30	3133
	31	3650
	32	3224
	33	3818
	34	3166
	35	3202
	36	1498
Weld	37	439
	38	2634
	39	2988

*Includes Local Stresses From Trunnion Due to Rail Car Shock Load
at Location 27: 4182 + 14089 = 18271
at Location 28: 4564 + 18461 = 23025

Table 2-35
Transport Truck Vibration in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Truck Vibration)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6138
	2	2151
	3	6066
	4	2189
	5	7705
	6	7098
Inner Shell	7	17735*
	8	17280*
	9	17167
	10	16802
	11	17339
	12	17081
	13	17770
	14	17213
	15	16997
	16	18966
	17	10511
	18	9397

*Includes Local Stresses From Trunnion Due to Truck Vibration Load
at Location 7: 16649 + 1086 = 17735
at Location 8: 16194 + 1086 = 17280

Table 2-36
Transport Truck Vibration in Hot Environment Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Truck Vibration)

Location		Nodal Stress Intensity
Flange	19	11006
	20	3138
Lid	21	4408
	22	4874
Outer Bottom Plate	23	2663
	24	3834
	25	9176
	26	2781
Outer Shell	27	5223*
	28	10821*
	29	4991
	30	9255
	31	3835
	32	8821
	33	4924
	34	9323
	35	1799
	36	7994
Weld	37	2218
	38	8616
	39	3495

*Includes Local Stresses From Trunnion Due to Truck Vibration Load
at Location 27: 4137 + 1086 = 5223
at Location 28: 9438 + 1383 = 10821

Table 2-37
Transport Truck Vibration in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Truck Vibration)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1778
	2	2204
	3	1781
	4	2189
	5	2746
	6	1903
Inner Shell	7	14229*
	8	14493*
	9	13131
	10	13117
	11	13168
	12	13163
	13	13139
	14	13119
	15	14856
	16	12088
	17	5064
	18	7516

*Includes Local Stresses From Trunnion Due to Truck Vibration Load
at Location 7: 13143 + 1086 = 14229
at Location 8: 13407 + 1086 = 14493

Table 2-38
Transport Truck Vibration in Cold Environment Load Combination
(Preload + Fabrication + External Pressure + -20°F + Truck Vibration)

Location		Nodal Stress Intensity
Flange	19	13867
	20	6799
Lid	21	1265
	22	702
Outer Bottom Plate	23	245
	24	796
	25	4594
	26	343
Outer Shell	27	4730*
	28	4522*
	29	3571
	30	3027
	31	3548
	32	2958
	33	3577
	34	2981
	35	3700
	36	2606
Weld	37	295
	38	1882
	39	1408

*Includes Local Stresses From Trunnion Due to Truck Shock Load
at Location 27: 3644 + 1086 = 4730
at Location 28: 3139 + 1383 = 4522

Table 2-39
1 Foot Bottom End Drop, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Bottom End Drop)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	4034
	2	1843
	3	4204
	4	1740
	5	10392
	6	5643
Inner Shell	7	16441
	8	16031
	9	17255
	10	16902
	11	17392
	12	17148
	13	17846
	14	17299
	15	16856
	16	18777
	17	10497
	18	9194

Table 2-40
1 Foot Bottom End Drop, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Bottom End Drop)

Location		Nodal Stress Intensity
Flange	19	11830
	20	2933
Lid	21	2945
	22	2487
Outer Bottom Plate	23	1988
	24	675
	25	3506
	26	3934
Outer Shell	27	6184
	28	10009
	29	5992
	30	9160
	31	4715
	32	8770
	33	5505
	34	9273
	35	2221
	36	8236
Weld	37	3841
	38	8250
	39	3066

Table 2-41
1 Foot Bottom End Drop, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Bottom End Drop)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	384
	2	2503
	3	207
	4	2748
	5	2768
	6	2706
Inner Shell	7	11822
	8	11823
	9	11985
	10	11970
	11	12209
	12	12209
	13	12480
	14	12451
	15	14118
	16	11899
	17	5050
	18	7132

Table 2-42
1 Foot Bottom End Drop, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Bottom End Drop)

Location		Nodal Stress Intensity
Flange	19	14690
	20	6634
Lid	21	2746
	22	3077
Outer Bottom Plate	23	4890
	24	5288
	25	11173
	26	2921
Outer Shell	27	5693
	28	4579
	29	4459
	30	4138
	31	4295
	32	3827
	33	4006
	34	3580
	35	4416
	36	2897
Weld	37	2214
	38	2180
	39	1538

Table 2-43
1 Foot Lid End Drop, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Lid End Drop)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	5600
	2	2104
	3	5625
	4	2105
	5	7895
	6	6721
Inner Shell	7	16658
	8	16220
	9	17226
	10	16871
	11	17387
	12	17143
	13	17847
	14	17304
	15	16709
	16	18580
	17	10598
	18	9151

Table 2-44
1 Foot Lid End Drop, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Lid End Drop)

Location		Nodal Stress Intensity
Flange	19	14558
	20	2666
Lid	21	599
	22	1926
Outer Bottom Plate	23	1461
	24	2457
	25	7348
	26	2523
Outer Shell	27	4700
	28	9581
	29	5508
	30	9196
	31	4662
	32	8768
	33	5941
	34	9263
	35	3394
	36	8461
Weld	37	2582
	38	8156
	39	6435

Table 2-45
1 Foot Lid End Drop, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Lid End Drop)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1253
	2	2188
	3	1354
	4	2288
	5	1547
	6	2025
Inner Shell	7	12627
	8	12863
	9	12454
	10	12445
	11	12202
	12	12202
	13	11983
	14	11943
	15	13037
	16	11702
	17	5151
	18	6373

Table 2-46
1 Foot Lid End Drop, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Lid End Drop)

Location		Nodal Stress Intensity
Flange	19	17460
	20	6602
Lid	21	6248
	22	7474
Outer Bottom Plate	23	1442
	24	2177
	25	6448
	26	1065
Outer Shell	27	4205
	28	3468
	29	3974
	30	3557
	31	4243
	32	3775
	33	4443
	34	4036
	35	5655
	36	3623
Weld	37	924
	38	2348
	39	7203

Table 2-47
1 Foot Side Drop, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Side Drop 90°)
(Stress At 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	8950
	2	4939
	3	8870
	4	4909
	5	10050
	6	8834
Inner Shell	7	16676
	8	16382
	9	15534
	10	16039
	11	14839
	12	15796
	13	16311
	14	16575
	15	17234
	16	19460
	17	13625
	18	11190

Table 2-48

1 Foot Side Drop, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Side Drop 90°)
(Stress At 90° Away From Contact Side)

Location		Nodal Stress Intensity
Flange	19	16232
	20	10209
Lid	21	8853
	22	8080
Outer Bottom Plate	23	5510
	24	3461
	25	8227
	26	1837
Outer Shell	27	9140
	28	10510
	29	7944
	30	9374
	31	5958
	32	6915
	33	7478
	34	8579
	35	8146
	36	9129
Weld	37	7148
	38	10937
	39	2793

Table 2-49
1 Foot Side Drop, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Side Drop 180°)
(Stress at Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	8041
	2	4352
	3	10038
	4	6406
	5	13233
	6	14624
Inner Shell	7	16588
	8	15518
	9	16877
	10	15728
	11	17773
	12	16407
	13	17529
	14	16211
	15	18142
	16	19485
	17	15679
	18	14985

Table 2-50
1 Foot Side Drop, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + Side Drop 180°)
(Stress at Contact Side)

Location		Nodal Stress Intensity
Flange	19	11787
	20	9746
Lid	21	13369
	22	7248
Outer Bottom Plate	23	5327
	24	3119
	25	11863
	26	5800
Outer Shell	27	3334
	28	10102
	29	3146
	30	12626
	31	2277
	32	12796
	33	2336
	34	12761
	35	2544
	36	10011
Weld	37	5011
	38	3020
	39	3171

Table 2-51
1 Foot Side Drop, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Side Drop 90°)
(Stress At 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	4591
	2	2126
	3	4587
	4	2316
	5	6939
	6	5436
Inner Shell	7	13917
	8	14248
	9	11618
	10	12050
	11	10457
	12	11160
	13	11987
	14	12362
	15	16466
	16	13087
	17	10277
	18	11647

Table 2-52
1 Foot Side Drop, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Side Drop 90°)
(Stress At 90° Away From Contact Side)

Location		Nodal Stress Intensity
Flange	19	18354
	20	12355
Lid	21	5456
	22	8028
Outer Bottom Plate	23	2614
	24	3781
	25	7233
	26	1867
Outer Shell	27	8896
	28	5659
	29	6755
	30	5173
	31	5624
	32	2831
	33	6192
	34	4361
	35	9120
	36	5559
Weld	37	7193
	38	7548
	39	2045

Table 2-53
1 Foot Side Drop, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Side Drop 180°)
(Stress at Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	3681
	2	66
	3	5753
	4	2057
	5	10273
	6	8420
Inner Shell	7	13577
	8	14635
	9	15906
	10	15594
	11	17625
	12	17158
	13	15458
	14	15136
	15	14799
	16	12608
	17	10231
	18	11037

Table 2-54
1 Foot Side Drop, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + Side Drop 180°)
(Stress at Contact Side)

Location		Nodal Stress Intensity
Flange	19	11627
	20	11179
Lid	21	7786
	22	10123
Outer Bottom Plate	23	2563
	24	5599
	25	5113
	26	8369
Outer Shell	27	2842
	28	4331
	29	4488
	30	6030
	31	4426
	32	6749
	33	4188
	34	6099
	35	4821
	36	6531
Weld	37	6167
	38	7047
	39	1939

Table 2-55
Stress Summary of Normal Condition Basket Structural Analysis

Loading	Stress Category	Max. Stress (ksi) (1G)	Allowable Stress (ksi)	Max. Allowable G load	Max. Calculated G Load Including DLF*	Reference Section/Table
304 Stainless Steel Plate						
End Drop	P_m	0.1	15.75	158	15	Sect. 2.10.5.3.3
Side drop	P_m	0.33	15.75	48	35	Table 2.10.5-1 (0° drop)
	$P_m + P_b$	0.59	23.63	40	35	Table 2.10-1 (0° drop)
Stainless Steel Fusion weld						
End Drop	τ	0.02	3.15	158	15	Sect. 2.10.5.3.3
Side Drop	τ	0.07	3.37	48	35	Sect. 2.10.5.3.2
6061-T6 Aluminum Rail						
End Drop	P_m	0.02	6.30	315	15	Sect. 2.10.5.3.3
Side Drop	P_m	0.10	6.30	63	35	Table 2.10.5-2 (Location 1)
	$P_m + P_b$	0.15	9.45	63	35	Table 2.10.5-2 (Location 1)
304 Stainless Steel Basket Hold Down Ring						
End Drop	P_m	0.08	15.75	197	15	Sect. 2.10.5.3.3

* DLF = Dynamic Load Factor

Table 2-56
TN-68 Performance Evaluation Overview
(Accident Conditions of Transport)

Loading Conditions	SAR Section	Scope of Evaluation
30 foot Free Drop 71.73-(c)(1)	2.7.1.1	Cask body stresses due to bottom end drop
		Cask body stresses due to lid end drop
	2.7.1.2	Cask body stresses due to side drop
	2.7.1.3	Cask body stresses due to CG over corner drop
	2.7.1.4	Cask body stresses due to 15° slap down impact at lid end
	2.7.1.5	Lid bolt analysis
	2.7.1.6	Impact limiter attachment analysis
Puncture 71.73-(c)(2)	2.7.2	Cask body evaluation for 40 inch drop onto the puncture bar
Thermal 71.73-(c)(3)	2.7.3.1	Maximum component pressures and temperatures
	2.7.3.2	Cask body thermal stresses due to fire accident
	2.7.3.3	Maximum combined stresses
Immersion 71.73-(c)(5) 71.73-(c)(6) 71.61	2.7.4.1	Cask body stresses due to 3 foot water head (1.3 psi)
	2.7.4.2	Cask body stresses due to 50 foot water head (21.7 psi)
	2.7.4.3	Cask body stresses due to 656 foot water head (290 psi) Containment vessel stresses due to 290 psi external pressure (pressure directly applies to the containment vessel) Buckling analysis of the containment vessel due to 290 psi external pressure
Basket Evaluation	2.7.5	Structural analysis of the basket due to 30 foot end drop and 30 foot side drop loads
Summary of Accident Condition Structural Analysis	2.7.6	Lists the highest stress intensities in the containment vessel and gamma shield and compare with the allowables

Table 2-57

Summary - Individual Load Runs for Accident Condition of Transport

Run No.	Individual Load Type	Load used in run	Factor used for accident condition load combinations
IL-1	Bolt preload and lid seating pressure	-	1.0
IL-2	Fabrication Stresses (0.015" shrink-fit)	-	1.0
IL-3	Internal pressure	100 psig	1.0
IL-4	External pressure	25 psig (290 psig for Immersion)	1.0
IL-5	30-foot end drop on bottom	1G	80.0
IL-6	30-foot end drop on lid	1G	80.0
IL-7	Thermal stresses at hot environment	-	1.0
IL-8	Thermal stresses at –20° F cold environment	-	1.0
IL-12	30-foot side drop	1G	80.0
IL-13	30-foot C.G.- over -corner drop on bottom	1G	80.0
IL-14	30-foot C.G.- over -corner drop on lid	1G	80.0
IL-15	30-foot, slap down drop impact on lid	$G_{normal} = 42.22$ $G_{rotational} = 77.78$	1.0
IL-16	Accident Fire	Fire Accident temperatures	1.0

Table 2-58

Summary of Load Combinations for Accident Condition of Transport

Load Combi--nation	Applicable Individual Load													Stress Result Table 2-
	IL-1	IL-2	IL-3	IL-4	IL-5	IL-6	IL-7	IL-8	IL-12	IL-13	IL-14	IL-15	IL-16	
	Bolt Pre-load	Fab. Stress	Int. Pres	Ext. Pres	Bot. drop	Lid drop	Ther mal hot	Ther mal -20	Side drop	Cor drop bot	Cor drop lid	Slap down lid	Fire	
30 Ft. End Drop on Bottom End	x	x	x		x		x							59, 60
	x	x		x	x			x						61, 62
30 Ft. End Drop on Lid End	x	x	x			x	x							63, 64
	x	x		x		x		x						65, 66
30 Ft. Side Drop	x	x	x				x		x					67, 68 69, 70
	x	x		x				x	x					71, 72 73, 74
30 Ft. CG Over Corner Drop on Bottom End	x	x	x				x			x				75, 76 77, 78
	x	x		x				x		x				79, 80 81, 82
30 Ft. CG Over Corner Drop on Lid End	x	x	x				x				x			83, 84 85, 86
	x	x		x				x			x			87, 88 89, 90
30 Ft. 15° Slap Down Impact on Lid End	x	x	x				x					x		91, 92 93, 94
	x	x		x				x				x		95, 96 97, 98
Fire Accident	x	x	x										x	99, 100
Immersion (290 psi)	x	x		x										101, 102

Table 2-59
30 ft End Drop on Bottom, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft End Drop on Bottom)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	5405
	2	536
	3	4627
	4	940
	5	30644
	6	5017
Inner Shell	7	15253
	8	15017
	9	17570
	10	17229
	11	17579
	12	17335
	13	18029
	14	17490
	15	16749
	16	18577
	17	10851
	18	9298

Table 2-60

30 ft End Drop on Bottom, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft End Drop on Bottom)

Location		Nodal Stress Intensity (psi)
Flange	19	16596
	20	2813
Lid	21	3138
	22	7161
Outer Bottom Plate	23	22282
	24	20358
	25	26641
	26	13641
Outer Shell	27	15246
	28	12880
	29	10181
	30	8974
	31	8255
	32	8819
	33	7912
	34	9298
	35	4443
	36	8697
Weld	37	12276
	38	7516
	39	11656

Table 2-61
30 ft End Drop on Bottom, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft End Drop on Bottom)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	9765
	2	4077
	3	8912
	4	5303
	5	23021
	6	10298
Inner Shell	7	10634
	8	10428
	9	12174
	10	11887
	11	12012
	12	11705
	13	11989
	14	11704
	15	11695
	16	11700
	17	5404
	18	5717

Table 2-62

30 ft End Drop on Bottom, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft End Drop on Bottom)

Location		Nodal Stress Intensity (psi)
Flange	19	19513
	20	6844
Lid	21	8799
	22	12709
Outer Bottom Plate	23	25184
	24	24976
	25	40128
	26	14161
Outer Shell	27	14760
	28	11366
	29	8650
	30	8903
	31	7835
	32	7354
	33	6414
	34	6018
	35	6714
	36	4292
Weld	37	10711
	38	3031
	39	12573

Table 2-63
30 ft End Drop on Lid, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft End Drop on Lid)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	3272
	2	1927
	3	3649
	4	1702
	5	13107
	6	4885
Inner Shell	7	16413
	8	16025
	9	17416
	10	17064
	11	17552
	12	17308
	13	18033
	14	17518
	15	15964
	16	17524
	17	16092
	18	9067

Table 2-64
30 ft End Drop on Lid, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft End Drop on Lid)

Location		Nodal Stress Intensity (psi)
Flange	19	31310
	20	3367
Lid	21	21819
	22	30611
Outer Bottom Plate	23	3890
	24	3771
	25	3952
	26	4322
Outer Shell	27	7317
	28	10347
	29	7597
	30	9166
	31	7973
	32	8808
	33	10238
	34	9248
	35	11047
	36	10701
Weld	37	5360
	38	8125
	39	41948

Table 2-65
30 ft End Drop on Lid, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft End Drop on Lid)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	1125
	2	2397
	3	825
	4	2850
	5	5484
	6	3911
Inner Shell	7	11794
	8	11436
	9	12020
	10	11722
	11	11985
	12	11678
	13	11993
	14	11732
	15	9727
	16	10646
	17	10893
	18	2798

Table 2-66
30 ft End Drop on Lid, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft End Drop on Lid)

Location		Nodal Stress Intensity (psi)
Flange	19	34300
	20	7556
Lid	21	27482
	22	36159
Outer Bottom Plate	23	6792
	24	8388
	25	14844
	26	4265
Outer Shell	27	6827
	28	5438
	29	6064
	30	5806
	31	7553
	32	7077
	33	8741
	34	8450
	35	13328
	36	8645
Weld	37	3778
	38	4746
	39	42840

Table 2-67
30 ft Side Drop, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Side Drop 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	10484
	2	7185
	3	15117
	4	11817
	5	20300
	6	24241
Inner Shell	7	16425
	8	14557
	9	18316
	10	17868
	11	22585
	12	21503
	13	17533
	14	17556
	15	19763
	16	20337
	17	22446
	18	22462

Table 2-68
30 ft Side Drop, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Side Drop 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	21513
	20	19036
Lid	21	25065
	22	16947
Outer Bottom Plate	23	8824
	24	7367
	25	16917
	26	15924
Outer Shell	27	4240
	28	16127
	29	3478
	30	19601
	31	7893
	32	21996
	33	5316
	34	20372
	35	4207
	36	17908
Weld	37	12365
	38	9575
	39	3635

Table 2-69
30 ft Side Drop, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Side Drop 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	12561
	2	8531
	3	12448
	4	8394
	5	13735
	6	11778
Inner Shell	7	18512
	8	18111
	9	14461
	10	15885
	11	11629
	12	14125
	13	15758
	14	16816
	15	23520
	16	22240
	17	22119
	18	20081

Table 2-70
30 ft Side Drop, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Side Drop 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	29373
	20	22247
Lid	21	14996
	22	17046
Outer Bottom Plate	23	9134
	24	6043
	25	9781
	26	2745
Outer Shell	27	18750
	28	13366
	29	13438
	30	10462
	31	8638
	32	4607
	33	11845
	34	8535
	35	18058
	36	12277
Weld	37	16313
	38	18692
	39	3226

Table 2-71
30 ft Side Drop, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Side Drop 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	6124
	2	2897
	3	10831
	4	7468
	5	19914
	6	18036
Inner Shell	7	14081
	8	16159
	9	19538
	10	18833
	11	23458
	12	22390
	13	18482
	14	17779
	15	14956
	16	13871
	17	16999
	18	16193

Table 2-72
30 ft Side Drop, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Side Drop 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	19363
	20	19170
Lid	21	19490
	22	22098
Outer Bottom Plate	23	6060
	24	11881
	25	10219
	26	18863
Outer Shell	27	2119
	28	10359
	29	6615
	30	11974
	31	10042
	32	15950
	33	8692
	34	13200
	35	6023
	36	14547
Weld	37	13732
	38	17081
	39	3891

Table 2-73
30 ft Side Drop, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Side Drop 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	8202
	2	4849
	3	8166
	4	5288
	5	14021
	6	11237
Inner Shell	7	18377
	8	18225
	9	11615
	10	12316
	11	7105
	12	8703
	13	13102
	14	13635
	15	23064
	16	19752
	17	22056
	18	20752

Table 2-74

Stress intensities – 30 ft Side Drop, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Side Drop 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	30718
	20	23608
Lid	21	12490
	22	17863
Outer Bottom Plate	23	6239
	24	7687
	25	11752
	26	4047
Outer Shell	27	18613
	28	11633
	29	12548
	30	10017
	31	8323
	32	4268
	33	10785
	34	7842
	35	18673
	36	11737
Weld	37	16384
	38	17218
	39	4043

Table 2-75

30 ft Corner Drop on Bottom, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Bottom 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	28075
	2	28366
	3	12124
	4	14152
	5	24333
	6	10099
Inner Shell	7	15376
	8	14536
	9	16671
	10	15576
	11	17871
	12	16364
	13	17966
	14	16415
	15	15474
	16	17146
	17	9872
	18	6847

Table 2-76
30 ft Corner Drop on Bottom, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Bottom 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	16761
	20	2473
Lid	21	7204
	22	5375
Outer Bottom Plate	23	26435
	24	42542
	25	28034
	26	9984
Outer Shell	27	11833
	28	10799
	29	8050
	30	12713
	31	3051
	32	13113
	33	3944
	34	13387
	35	3828
	36	11539
Weld	37	17914
	38	11250
	39	6465

Table 2-77

30 ft Corner Drop on Bottom, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Bottom 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	7169
	2	11028
	3	3824
	4	5987
	5	26957
	6	8762
Inner Shell	7	17187
	8	16593
	9	16277
	10	16703
	11	14682
	12	15794
	13	16187
	14	16647
	15	15738
	16	18600
	17	12702
	18	10258

Table 2-78

30 ft Corner Drop on Bottom, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Bottom 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	25147
	20	14595
Lid	21	4162
	22	7306
Outer Bottom Plate	23	17310
	24	25302
	25	16502
	26	12866
Outer Shell	27	16463
	28	13040
	29	12247
	30	8878
	31	9984
	32	6755
	33	10384
	34	8009
	35	9264
	36	9716
Weld	37	13568
	38	19114
	39	8513

Table 2-79

30 ft Corner Drop on Bottom, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Bottom 180°)
(Stress at Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	28088
	2	27157
	3	10409
	4	9789
	5	16710
	6	8757
Inner Shell	7	10757
	8	9947
	9	11276
	10	10753
	11	14399
	12	13873
	13	13735
	14	13296
	15	11849
	16	10268
	17	4674
	18	3038

Table 2-80

30 ft Corner Drop on Bottom, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Bottom 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	19674
	20	5040
Lid	21	12831
	22	10300
Outer Bottom Plate	23	26585
	24	47092
	25	41790
	26	12814
Outer Shell	27	11337
	28	4361
	29	6516
	30	6142
	31	3788
	32	6960
	33	4005
	34	6726
	35	5716
	36	6145
Weld	37	16648
	38	6199
	39	7118

Table 2-81

30 ft Corner Drop on Bottom, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Bottom 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	7540
	2	11035
	3	5383
	4	5331
	5	19364
	6	10581
Inner Shell	7	12141
	8	11673
	9	10763
	10	11283
	11	9115
	12	10164
	13	10086
	14	10850
	15	12982
	16	11635
	17	8795
	18	9823

Table 2-82
30 ft Corner Drop on Bottom, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Bottom 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	27852
	20	16155
Lid	21	9627
	22	12415
Outer Bottom Plate	23	20103
	24	29913
	25	29878
	26	14258
Outer Shell	27	16056
	28	10825
	29	10899
	30	9647
	31	9566
	32	6604
	33	9020
	34	6515
	35	10739
	36	8395
Weld	37	11821
	38	17282
	39	9252

Table 2-83
30 ft Corner Drop on Lid, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Lid 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	29050
	2	28293
	3	11774
	4	11528
	5	13700
	6	11900
Inner Shell	7	16187
	8	14952
	9	17507
	10	16087
	11	18126
	12	16580
	13	17480
	14	16216
	15	18472
	16	19197
	17	20972
	18	20921

Table 2-84
30 ft Corner Drop on Lid, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Lid 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	32107
	20	16125
Lid	21	22364
	22	48142
Outer Bottom Plate	23	22912
	24	22096
	25	22275
	26	7509
Outer Shell	27	7038
	28	12692
	29	4312
	30	13278
	31	2398
	32	13279
	33	6003
	34	13100
	35	12570
	36	11489
Weld	37	3743
	38	10563
	39	31338

Table 2-85
30 ft Corner Drop on Lid, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Lid 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	8148
	2	11820
	3	5922
	4	4525
	5	13894
	6	5881
Inner Shell	7	16180
	8	16255
	9	15387
	10	16135
	11	14619
	12	15762
	13	17318
	14	17479
	15	17882
	16	20107
	17	17875
	18	12629

Table 2-86

30 ft Corner Drop on Lid, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Corner Drop on Lid 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	44091
	20	12870
Lid	21	21406
	22	39573
Outer Bottom Plate	23	7843
	24	6432
	25	6059
	26	4659
Outer Shell	27	12104
	28	10881
	29	10416
	30	8493
	31	9833
	32	6609
	33	11959
	34	3239
	35	14656
	36	12168
Weld	37	9457
	38	12088
	39	30405

Table 2-87

30 ft Corner Drop on Lid, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Lid 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	29037
	2	28306
	3	11760
	4	11543
	5	6833
	6	5696
Inner Shell	7	11569
	8	11614
	9	13759
	10	13276
	11	14102
	12	13559
	13	10935
	14	10430
	15	12236
	16	12319
	17	15525
	18	14652

Table 2-88

30 ft Corner Drop on Lid, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Lid 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	35244
	20	20115
Lid	21	22873
	22	53586*
Outer Bottom Plate	23	23924
	24	22187
	25	8709
	26	9194
Outer Shell	27	6551
	28	5944
	29	4365
	30	6683
	31	3714
	32	7126
	33	4574
	34	6442
	35	14854
	36	6145
Weld	37	5537
	38	18231
	39	32236

Linearized Stress * P_m = 30,020 psi, $P_m + P_b$ = 52,540 psi.

Table 2-89

30 ft Corner Drop on Lid, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Lid 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	8150
	2	11818
	3	4968
	4	5415
	5	7952
	6	6335
Inner Shell	7	11736
	8	11853
	9	9917
	10	10745
	11	9049
	12	10130
	13	11141
	14	11666
	15	13026
	16	13012
	17	13234
	18	9723

Table 2-90
30 ft Corner Drop on Lid, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Corner Drop on Lid 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	47171
	20	16746
Lid	21	16626
	22	44767
Outer Bottom Plate	23	10001
	24	10257
	25	15224
	26	4232
Outer Shell	27	11779
	28	7986
	29	9107
	30	7043
	31	9414
	32	6271
	33	10559
	34	8584
	35	16385
	36	10306
Weld	37	8993
	38	7713
	39	31162

Table 2-91

30 ft, 15° Slap Down, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Slap Down 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	37511
	2	36374
	3	14644
	4	13798
	5	14310
	6	15345
Inner Shell	7	16700
	8	15276
	9	17703
	10	16282
	11	18207
	12	17243
	13	16732
	14	14951
	15	20350
	16	21007
	17	24768
	18	24825

Table 2-92
30 ft, 15° Slap Down, 180°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Slap Down 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	26002
	20	23061
Lid	21	32680
	22	24882
Outer Bottom Plate	23	30355
	24	28617
	25	32057
	26	6447
Outer Shell	27	4790
	28	11971
	29	2049
	30	13579
	31	3385
	32	15244
	33	3167
	34	15868
	35	6872
	36	17400
Weld	37	6609
	38	14351
	39	4114

Table 2-93
30 ft, 15° Slap Down, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Slap Down 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	11024
	2	15522
	3	8858
	4	5600
	5	1089
	6	8031
Inner Shell	7	17158
	8	16985
	9	15637
	10	16256
	11	13740
	12	15214
	13	14937
	14	15850
	15	18673
	16	19824
	17	15614
	18	12701

Table 2-94
30 ft, 15° Slap Down, 90°, Hot Environment, Load Combination
(Preload + Fabrication + Internal Pressure + 100°F + 30ft Slap Down 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	17548
	20	8714
Lid	21	18479
	22	25383
Outer Bottom Plate	23	10188
	24	8476
	25	9924
	26	3199
Outer Shell	27	12203
	28	11179
	29	9159
	30	10020
	31	6954
	32	6396
	33	8588
	34	7506
	35	10942
	36	8995
Weld	37	11025
	38	7767
	39	3290

Table 2-95
30 ft, 15°, Slap Down, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Slap Down 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	37498
	2	36387
	3	14629
	4	13813
	5	10253
	6	9141
Inner Shell	7	13087
	8	14031
	9	16652
	10	16210
	11	18700
	12	18129
	13	15399
	14	14989
	15	14820
	16	14129
	17	19321
	18	18628

Table 2-96
30 ft, 15°, Slap Down, 180°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Slap Down 180°)
(Stress At Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	23544
	20	23362
Lid	21	27096
	22	29885
Outer Bottom Plate	23	30216
	24	28698
	25	18326
	26	9435
Outer Shell	27	4299
	28	6192
	29	4184
	30	6248
	31	5534
	32	9198
	33	5314
	34	8873
	35	7708
	36	14046
Weld	37	8649
	38	21903
	39	3891

Table 2-97

30 ft, 15°, Slap Down, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Slap Down 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	10381
	2	15521
	3	6060
	4	5597
	5	8621
	6	5888
Inner Shell	7	15302
	8	15476
	9	12235
	10	12803
	11	9305
	12	10346
	13	10534
	14	11147
	15	18099
	16	14507
	17	14146
	18	13729

Table 2-98
30 ft, 15°, Slap Down, 90°, Cold Environment, Load Combination
(Preload + Fabrication + External Pressure + -20°F + 30ft Slap Down 90°)
(Stress at 90° Away From Contact Side)

Location		Nodal Stress Intensity (psi)
Flange	19	19597
	20	11618
Lid	21	17202
	22	26051
Outer Bottom Plate	23	10199
	24	8445
	25	9163
	26	1412
Outer Shell	27	12009
	28	7922
	29	8155
	30	6455
	31	6551
	32	2952
	33	7205
	34	4584
	35	11920
	36	5059
Weld	37	11023
	38	3918
	39	4327

Table 2-99
Fire Accident, Load Combination
(Preload + Fabrication + Internal Pressure + Fire Accident)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	5781
	2	1688
	3	5567
	4	1841
	5	6881
	6	6966
Inner Shell	7	15591
	8	14945
	9	16736
	10	16370
	11	16768
	12	16509
	13	17386
	14	16834
	15	14570
	16	14794
	17	10232
	18	5916

Table 2-100
Fire Accident, Load Combination
(Preload + Fabrication + Internal Pressure + Fire Accident)

Location		Nodal Stress Intensity (psi)
Flange	19	6068
	20	11133
Lid	21	4810
	22	889
Outer Bottom Plate	23	6284
	24	3306
	25	8057
	26	4545
Outer Shell	27	7482
	28	14445
	29	6214
	30	4296
	31	5550
	32	3277
	33	6528
	34	3999
	35	6223
	36	11881
Weld	37	3562
	38	31455
	39	5956

Table 2-101
Immersion (290 External Pressure), Load Combination
(Preload + Fabrication + 290 psig. external pressure)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	2301
	2	510
	3	2534
	4	743
	5	3149
	6	3053
Inner Shell	7	14628
	8	14290
	9	14597
	10	14293
	11	14561
	12	14254
	13	14555
	14	14259
	15	15141
	16	14618
	17	7586
	18	7914

Table 2-102
Immersion (290 External Pressure), Load Combination
(Preload + Fabrication + 290 psig. external pressure)

Location		Nodal Stress Intensity (psi)
Flange	19	15235
	20	7676
Lid	21	4025
	22	6445
Outer Bottom Plate	23	2913
	24	4117
	25	7691
	26	2136
Outer Shell	27	3254
	28	2991
	29	2565
	30	2352
	31	2662
	32	2346
	33	2650
	34	2359
	35	3060
	36	2051
Weld	37	2535
	38	1421
	39	2346

Table 2-103
Tie-Down Load, Cask Held at Rear Trunnions and Front Saddle
(5.39G Transverse, 10G Longitudinal Loading)

Location		Nodal Stress Intensity (psi)
Inner Bottom Plate	1	900
	2	576
	3	578
	4	232
	5	378
	6	1955
Inner Shell	7	24268*
	8	24563*
	9	1232
	10	1181
	11	1269
	12	1343
	13	961
	14	1077
	15	2021
	16	1648
	17	3165
	18	1907

*Includes Local Stresses From Trunnion Due to Tie-Down Load
at Location 7: 829 + 23439 = 24268
at Location 8: 1124 + 23439 = 24563

Table 2-104
Tie-Down Load, Cask Held at Rear Trunnions and Front Saddle
(5.39G Transverse, 10G Longitudinal Loading)

Location		Nodal Stress Intensity
Flange	19	1311
	20	1332
Lid	21	3243
	22	5770
Outer Bottom Plate	23	1497
	24	1493
	25	3753
	26	666
Outer Shell	27	24151*
	28	30793*
	29	1494
	30	1190
	31	1294
	32	1646
	33	986
	34	1333
	35	2340
	36	1517
Weld	37	663
	38	3972
	39	5562

*Includes Local Stresses From Trunnion Due to Tie-Down Load
at Location 27: 712 + 23439 = 24151
at Location 28: 2889 + 27904 = 30793

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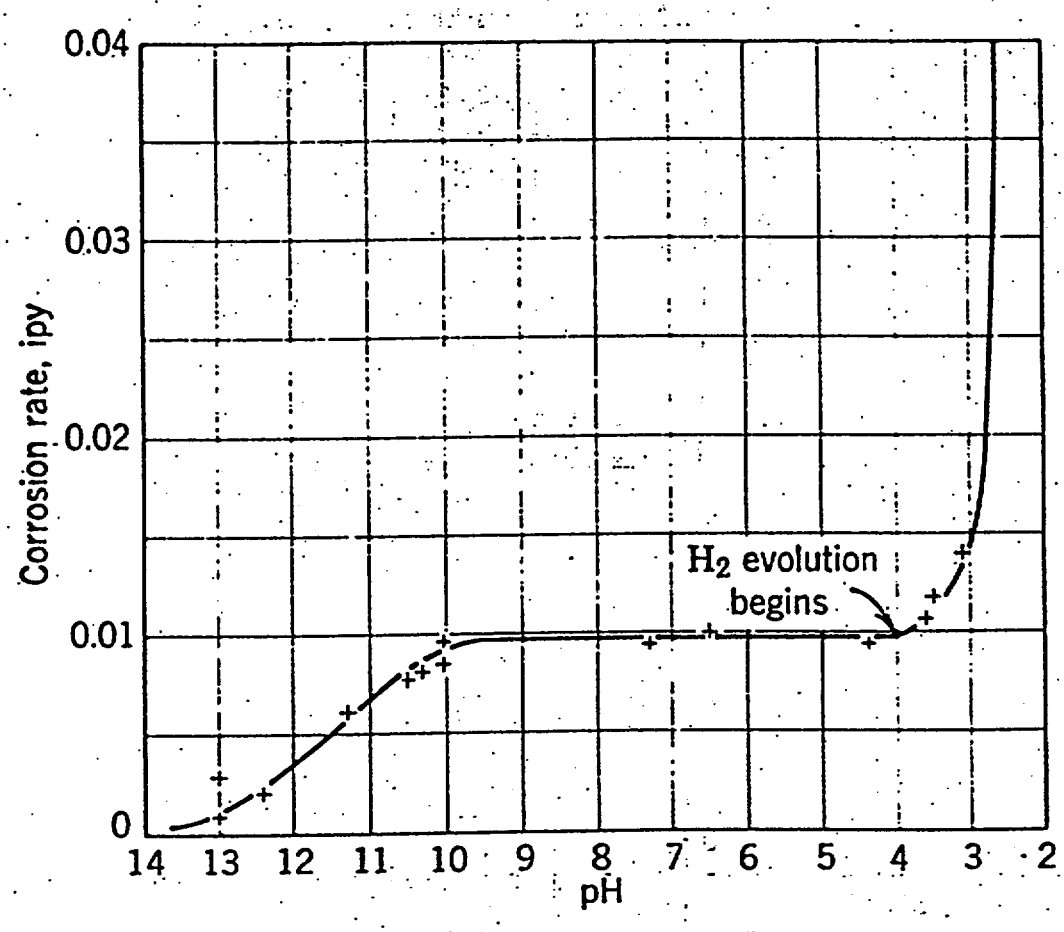
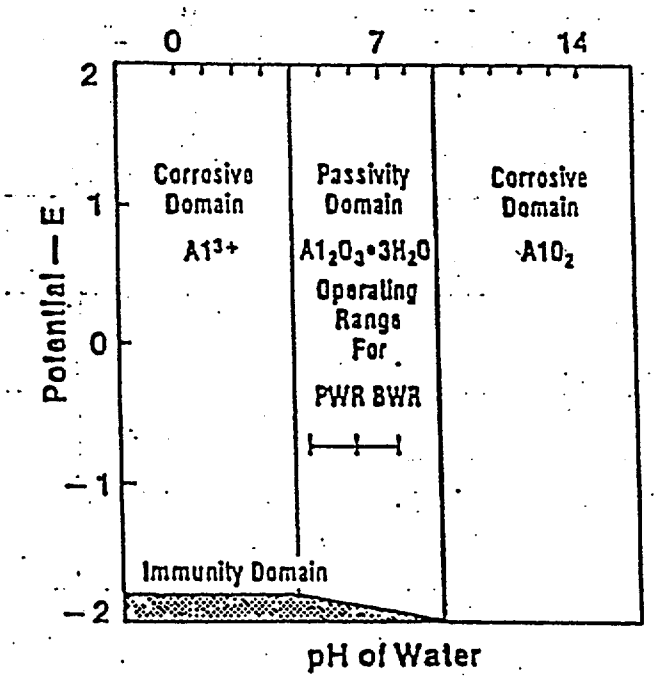


FIGURE 2-1
EFFECT OF pH ON CORROSION OF IRON
IN AERATED SOFT WATER
ROOM TEMPERATURE

At 25°C (77°F):



At 60°C (140°F):

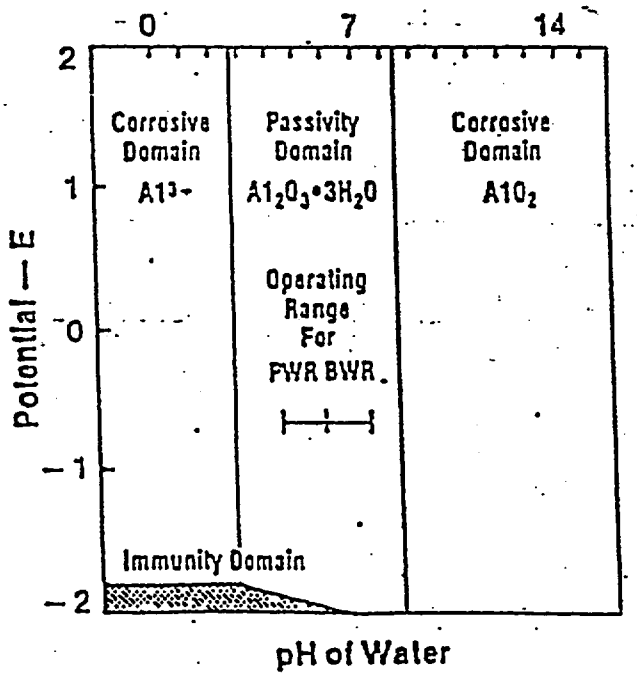


FIGURE 2-2
POTENTIAL VERSUS pH DIAGRAM
FOR ALUMINUM-WATER SYSTEM

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2-3
TRUNNION GEOMETRY

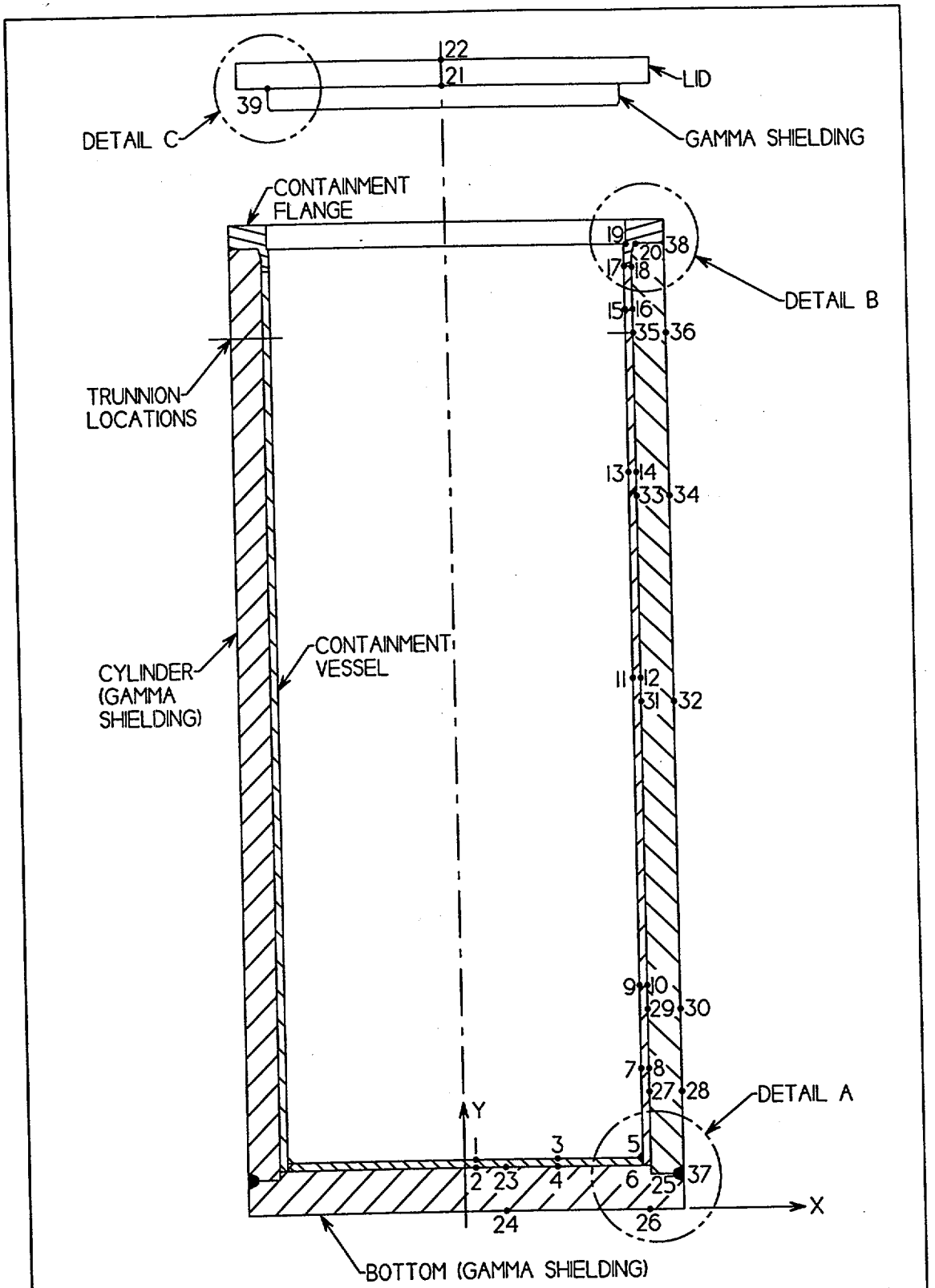


FIGURE 2-4
STANDARD REPORTING LOCATIONS FOR CASK BODY

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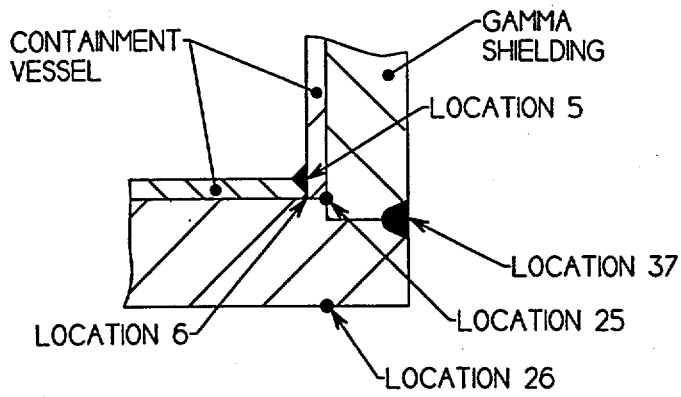
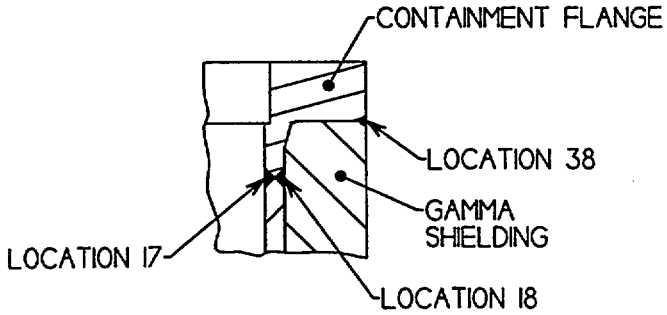
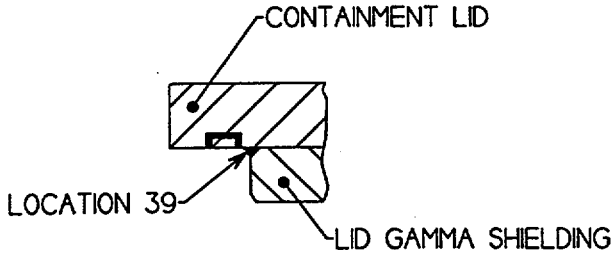


DETAIL A



DETAIL B



DETAIL C

FIGURE 2-5
WELD STRESS LOCATIONS

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