Serial No. 16-055
Docket No. 72-16

Attachment 4

TN-32 Final Safety Analysis Report (FSAR), Revision 2

Attachment 4 provides the TN-32 FSAR, Revision 2. The TN-32 FSAR, Revision 2 was provided to the NRC in AREVA-TN letter, E-19479 on April 19, 2002.

North Anna Power Station ISFSI

Virginia Electric and Power Company

TRANSNUCLEAR

April 19, 2002 E-19479

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington, D.C. 20555-0001

Subject: TN-32 FSAR update per 10CFR72.248
Docket 72-1021

Dear Ms. Ross-Lee:

As required by 10 CFR 72.248, Transnuclear hereby submits the following pages for revision 2 of the TN-32 FSAR:

Drawing 1049-70-2, rev 8
Drawing 1049-70-3, rev 6
Drawing 1049-70-4, rev 3
Drawing 1049-70-8, rev 1
Page 7.1-5 / 7.1-6

Transnuclear has made no changes under the provisions of 10 CFR 72.48 that were not previously submitted to the Commission.

FSAR rev 1 changes associated with Certificate of Compliance 1021 amendment 1 were previously submitted May 22, 2000 under cover E-18172 with June 7, 2000 errata.

I certify that this information accurately represents changes made since that previous submittal.

Sincerely,

Ian Hunter

Ian Hunter
Vice President of Engineering

cc: 1066, 1084, and 1087 Files
Mary Jane Ross-Lee, NRC
Keith Waldrop, Duke Energy
Eric Meils, WEPCO

FOUR SKYLINE DRIVE, HAWTHORNE, NEW YORK 10532
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TN-32 DRY STORAGE CASK FINAL SAFETY ANALYSIS REPORT
RECORD OF REVIEW, REV 2

Thermal Analyst		All revisions
Structural Analyst	4/19/02	All revisions
Nuclear Analyst	4/19/02	All revisions
Project Engineer	4.19.02	All revisions
Chief Engineer	4/19/02	All revisions

Revisions:

Drawing 1049-70-2
Drawing 1049-70-3
Drawing 1049-70-4
Drawing 1049-70-8
Page 7.1-5

TN-32 FINAL SAFETY ANALYSIS REPORT

Transnuclear, Inc.
4 Skyline Drive
Hawthorne, NY 10532

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CHAPTER 1

GENERAL DESCRIPTION

This Safety Analysis Report addresses the safety related aspects of storing spent fuel in the TN-32 dry storage cask. The format follows the guidance provided in NRC Regulatory Guide 3.61(1). (Throughout this report, superscripted numbers in parentheses refer to reference numbers for the Section.) The report is intended for review by the NRC under 10CFR72(2).

The TN-32 dry storage cask provides confinement, shielding, criticality control and passive heat removal independent of any other facility structures or components. The cask also maintains structural integrity of the fuel during storage. It can be used either singly or as the basic storage module in an ISFSI.

This Safety Analysis Report analyzes the safety related aspects of one cask and also the interactions among casks at an ISFSI.

It is intended that a Certificate of Compliance under the requirements of 10CFR72 Subpart L be issued such that the casks can be used for the storage of spent fuel in an independent spent fuel storage installation (ISFSI) at power reactor sites under the conditions of a general license in accordance with 10CFR72 Subpart K.

1.1 Introduction

The TN-32 cask accommodates 32 intact PWR fuel assemblies with or without burnable poison rod assemblies (BPRAs) or thimble plug assemblies (TPAs) and consists of the following components:

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

- A confinement vessel including a closure lid which provides radioactive material confinement and a cavity with an inert gas atmosphere.

- Gamma Shielding surrounding the confinement vessel.

- Radial neutron shielding surrounding the gamma shield, enclosed in an outer steel shell, which provides additional radiation shielding.

- A protective cover which provides weather protection for the closure lid and seal components, the top neutron shield and the overpressure system.

- An overpressure monitoring system which is used to monitor the pressure in the interspace between the inner (confinement boundary) and outer seals on the lid, vent and drain port cover. The overpressure monitoring system consists of a tank filled with helium at a pressure greater than that of the cask cavity and pressure transducers or switches to monitor the pressure of the overpressure system. In the event of a confinement seal leak, helium would leak into the cask cavity, rather than allowing leakage of radioactive gases from the cask cavity. If the overpressure system pressure falls below a set pressure, an alarm will indicate that a cask seal may be leaking.

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

Due to the various designs of nuclear power plants, there are three versions of the TN-32 cask. The standard TN-32 cask has non-single failure proof trunnions and a standard lid. This is the original cask design that was approved by the NRC as a Topical Report in 1996 for reference in site specific applications. TN and its customers have successfully manufactured and placed into service 8 casks under site specific licenses.

An alternative configuration, designated the TN-32A has a shorter lid assembly and longer cavity. The inner shield plate on the lid is reduced from 6 inches to 4.88 inches thickness. To compensate for the reduced lid thickness, the bottom and top plates on the top neutron shield are made correspondingly thicker, so that the top of the cask has the same total shielding as the standard TN-32 design. In all other respects, the cask, lid and basket are the same as in the standard TN-32 configuration. The reduced lid thickness of the TN-32A results in a nominal cold cavity length of 164.37 inches. This additional cavity length allows accommodation of the additional length of the hardware for a Westinghouse Upper Head Injection (UHI) reactor. For this reactor design, the hardware includes an "Upper Head Injection Cup" which increases the overall length of the fuel and hardware to 162.95 inches (cold, unirradiated). Therefore there is an additional 1.4 inches for irradiation and thermal growth.

A second alternative configuration, designated the TN-32B, is identical to the standard TN-32 except that the top lifting trunnions are designed as single failure proof. In all other respects, the cask, lid and basket are the same as in the standard TN-32 configuration.

The type of fuel to be stored in the TN-32 cask (including the standard TN-32, TN-32A and TN-32B configurations) is Light Water Reactor (LWR) fuel of the Pressurized Water Reactor (PWR)

type. A PWR fuel assembly typically consists of zircaloy fuel rods containing uranium dioxide (UO_2) fuel pellets. The fuel rods are assembled into a square array, spaced and supported laterally by grid structures with top and bottom fittings for vertical support and handling. The maximum allowable initial enrichment is 4.05% U-235 and the maximum allowable burnup is 45,000 MWD/MTU. The cask is designed for a maximum heat load of 32.7 kW or 1.02 kW/assembly (includes decay heat from spent fuel and BPRA or TPA). The fuel must be cooled at least 7 years prior to storage. Known or suspected failed fuel assemblies (rods) with cladding defects greater than pin holes or hairline cracks are not to be stored in the TN-32 cask. The fuel which may be stored within the TN-32 cask is presented in Table 2.1-1 and Table 2.1-3.

Along with the spent fuel assemblies, Burnable Poison Rod Assemblies (BPRAs) and Thimble Plug Assemblies (TPAs) may be stored within the TN-32. These assemblies fit into the square array of the fuel assembly. The BPRA's which may be stored in the TN-32 casks are shown in Figure 2.1-4. The TPA's which may be stored in the TN-32 casks are shown in Figure 2.1-5. The acceptance criteria depends on the cooling time since storage and the cumulative exposure. These parameters are used to determine the source term for shielding and thermal analyses presented in later chapters.

The casks are intended for storage on a reinforced concrete pad at a nuclear power plant.

1.2 General Description of the TN-32

1.2.1 Cask Characteristics

Each storage cask consists of a fuel basket, a cask body (shell, bottom and lid), a protective cover, an over pressure system, four trunnions, penetrations with bolted and sealed covers for leak detection and venting, and closure bolts.

A set of reference drawings is presented in Section 1.5. The casks are self-supporting cylindrical vessels. Dimensions and the estimated weight of the cask are shown in Table 1.2-1 for each configuration. The materials used to fabricate the cask are shown in the Parts List on Drawing 1049-70-2. 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 confinement vessel for the TN-32 cask consists of: an inner shell which is a welded, carbon steel cylinder with an integrally-welded, carbon steel bottom closure (Item 1); a welded flange forging (Item 3); a flanged and bolted carbon steel lid (outer plate) with bolts and inner metallic seal (Item 2); and vent and drain covers with bolts and inner metallic seals (Items 4 and 5). The confinement boundary components are shown in Figure 1.2-1. The overall confinement vessel length is 175.25 in. with a wall thickness of 1.5 in. The cylindrical cask cavity has a diameter of 68.75 in. and a length of 163.25 in for the standard TN-32 and TN-32B, while the TN-32A configuration has a cavity length of 164.38 in due to the shorter lid. (All dimensions are nominal).

There are two penetrations through the confinement vessel, both in the lid: one is for draining and the other is for venting. A double-seal mechanical closure is provided for each penetration. The confinement lid is 4.50 in. thick and is fastened to the body by 48 bolts. Double metallic o-ring seals with interspace leakage monitoring are provided for the lid closure. To preclude air in-leakage, the cask cavity is pressurized above atmospheric pressure with helium.

The interspace between the metallic seals is connected to an overpressure tank and a pressure monitoring system. The overpressure tank and the interspace is pressurized with helium to a higher level than the cavity so that any seal leakage would be into rather than out of the cavity. A decrease in the pressure of the overpressure system would be signaled by a pressure transducer/switch wired to a monitoring/alarm panel.

For additional protection a torispherical weather cover with a Viton o-ring is provided above the lid.

A gamma shield is provided around the walls and bottom of the confinement vessel by an independent shell and bottom plate

of carbon steel which is welded to the closure flange. The gamma shield completely encloses the confinement vessel inner shell and bottom closure. Gamma shielding is also welded to the inside of the confinement lid.

Neutron shielding is provided by a borated polyester resin compound surrounding the body. The resin compound is cast into long, slender aluminum containers. The array of resin-filled containers is enclosed within a smooth outer steel shell 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 the top of the resin enclosure for venting pressure due to heating of the resin and entrapped air after fuel loading.

A 4-inch thick disc of polypropylene encased in a 0.25-inch steel shell is attached to the cask lid to provide neutron shielding during storage.

The basket structure consists of an assembly of stainless steel cells joined by a proprietary fusion welding process and separated by aluminum and poison plates which form a sandwich panel. The panel consists of a 0.50-inch thick aluminum plate and a 0.040-inch thick poison plate. The aluminum provides the heat conduction paths from the fuel assemblies to the cask cavity wall. The poison material provides the necessary criticality control. This method of construction forms a very strong honeycomb-like structure of cell liners which provide compartments for 32 fuel assemblies. The open dimension of each cell is 8.70 in. x 8.70 in. which provides a minimum of 1/8 in. clearance around the fuel assemblies. The overall basket length (160 in.) is less than the cask cavity length to allow for thermal expansion and fuel assembly handling.

The cask cavity surfaces have a sprayed metallic coating of aluminum for corrosion protection. The external surfaces of the cask are metal sprayed or painted or both for ease of decontamination and corrosion protection.

A stainless steel overlay is applied to the o-ring seating surfaces on the body for corrosion protection.

Four trunnions are attached to the cask body for lifting and rotation of the cask. Two of the trunnions are located near the top of the body and two near the bottom. The lower trunnions may be used for rotating the unloaded cask between vertical and horizontal positions.

Threaded holes are provided in the lid for attachment of component lifting devices. These are used for attachment points for sling systems or other lifting tools.

Impact limiters are not used during storage.

During dry storage of the spent fuel, no active systems are required for the removal and dissipation of the decay heat from the fuel. The TN-32 cask is designed to transfer the decay heat from the fuel to the basket, from the basket to the cask body and ultimately to the surrounding air by radiation and natural convection. The cask is capable of removing 32.7 kW of decay heat without external fins, thus providing a smooth outer surface for ease of decontamination.

Each cask is labeled with a durable nameplate welded to the outer shell in a visible location. The nameplate includes a unique identification number, the designer and fabricator name, the year built and the empty and loaded weight.

Each standard TN-32 cask is identified by a Mark Number, TN-32-XX, where XX is a sequential number corresponding to a specific cask. The TN-32A casks are identified by a Mark Number TN-32A-XX and the TN-32B casks are identified by a Mark Number TN-32B-XX. Each cask is also marked with the empty weight.

1.2.2 Operational Features

1.2.2.1 General Features

The TN-32 cask is designed to safely store 32 intact design basis PWR fuel assemblies and associated BPRA's and TPA's. Each fuel assembly is assumed to have a maximum initial enrichment not to exceed 4.05% w/o U-235. Further assumptions limit the fuel to a maximum of 45,000 MWD/MTU burnup, a minimum decay time of 7 years after reactor discharge and a maximum decay heat load of 1.02 kw per assembly for a total of 32.7 kW for a TN-32 cask. Fuel assemblies may or may not include burnable poison rod assemblies or thimble plugs.

The heat rejection capability of the TN-32 cask maintains the maximum fuel rod clad temperature below the 322 °C limit (calculated in Section 3.5.1 in accordance with Ref. 4) based on normal operating conditions with a 32.7 kW decay heat load, 100°F ambient air, and solar insolation. The fuel assemblies are stored in an inert helium gas atmosphere.

The shielding features of the TN-32 cask are designed to maintain the average combined gamma and neutron dose rate at accessible surfaces to less than 310 mrem/hr under normal operating conditions.

The criticality control features of the TN-32 cask are designed to maintain the neutron multiplication factor k-effective (including uncertainties and calculational bias) at less than 0.95 minus under all conditions.

A dry run will be performed prior to loading of the first cask by each utility to demonstrate the adequacy of training and operational procedures. This dry run will be used to demonstrate that the loading and unloading processes are sound and the operations personnel are adequately trained. The loading and unloading operations which have an impact on safety will be verified and recorded. These operations include loading and identifying each fuel assembly, ensuring that the fuel assembly meets the fuel acceptance criteria, torquing of the lid and cover bolts, drying, leak testing, backfilling and pressurizing the cask and pressure monitoring system, gas sampling and flooding the cask.

1.2.2.2 Sequence of Operations

A typical sequence of operations to be performed in loading fuel into the TN-32 storage cask is presented in Chapter 8.

These operations are summarized below.

The cask is designed to be loaded in the spent fuel pool or cask pit. Upon arrival, the empty cask is inspected, and the protective cover, overpressure tank, top neutron shield and lid are removed. The cask is then lowered into the cask pit/spent fuel pool. Fuel assemblies may be placed in each of the 32 basket compartments.

The lid is installed and the cavity is vented and drained. While performing initial radiological surveys, 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 or may be postponed until after lid bolt torquing has been completed. 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 top neutron shield is installed on the lid. The external surface radiation levels are checked to assure that they are within acceptable limits.

The overpressure system is installed and the overpressure system and seal interspace is pressurized with helium. The protective cover may be installed either in the decontamination area or at the ISFSI.

The cask is transferred to the ISFSI by a transport vehicle. The cask is set in its storage position, and connected to the site storage cask monitoring system. A functional check of the monitoring system is performed.

To unload the cask, these steps are performed in reverse. The cask is brought back to the reactor building. The protective cover, pressure monitoring system, overpressure tank and top neutron shield are removed. Prior to opening the cask, the cavity gas is sampled through the vent and drain port. The cavity is depressurized and the cask is lowered into the spent fuel pool. The cask is slowly filled with pool water through the vent or drain port. The cask is vented during this process. The water/steam mixture from the vent line may contain some radioactive gas. Protective measures, as necessary, shall be imposed in accordance with ALARA such as routing the gas through the plant gaseous radwaste system. The exit pressure and temperature are monitored during this operation. When the cask is full of water, the lid is removed and the fuel is accessible for unloading.

1.2.2.3 Identification of Subjects for Safety and Reliability Analysis

1.2.2.3.1 Criticality Prevention

Criticality is controlled by utilizing neutron absorption materials in the pool water and basket assembly. These features are only necessary during the loading and unloading operations that occur in the cask loading pool (underwater). During storage, with the cavity dry and sealed from the environment, criticality control measures within the installation are not necessary because no water can enter the cask during storage.

1.2.2.3.2 Chemical Safety

There are no chemical safety hazards associated with operations of the TN-32 dry storage cask.

1.2.2.3.3 Operation Shutdown Modes

The TN-32 dry storage cask is a totally passive system so that consideration of operation shutdown modes is unnecessary.

1.2.2.3.4 Instrumentation

The only instrumentation pertinent to storage are the pressure transducers/switches which monitor the cask seals for leakage. The transducers/switches monitor the pressure in an interspace between the inner and outer seals to provide an indication of seal failure before any release is possible.

An initial functional check of the transducers/switches is performed at the manufacturer's plant and another function check of the switches is performed in preparation for storage. Two identical transducers/switches are used to assure a functional system through redundancy.

1.2.2.3.5 Maintenance Techniques

Because of their passive nature, the storage casks will require little, if any, maintenance over their lifetime. Typical maintenance tasks would involve occasional replacement and recalibration of monitoring instrumentation, repressurizing the overpressure system and repainting of some casks with corrosion-inhibiting coatings. No special maintenance techniques are necessary.

1.2.3 Cask Contents

The TN-32 cask is designed to store up to 32 intact PWR fuel assemblies with or without BPRA's or TPA's. A description of the fuel assemblies is provided in Section 2.1. The maximum allowable initial enrichment of the fuel to be stored is 4.05% U-235 and the maximum burnup is 45,000 MWD/MTU. The fuel must be cooled at least 7 years prior to storage. The cask is designed for a maximum heat load of 32.7 kW or 1.02 kW per assembly. Westinghouse 14 x 14, 15 x 15 or 17 x 17 and B&W Mark BW 17x17 fuel assemblies may be stored in the TN-32 cask provided that

they meet the burnup, enrichment and cooling times required. The BPRA's and TPA's which may be stored in the TN-32 are shown in Figures 2.1-4 and 2.1-5 respectively. A description of the fuel assemblies is provided in Section 2.1.

The quantity and type of radionuclides in the spent fuel assemblies are described and tabulated in Chapter 5. Chapter 6 covers the criticality safety of the TN-32 cask and its contents, listing material densities, moderator ratios, and geometric configurations.

1.3 Identification of Agents and Contractors

Transnuclear, Inc., (TN), provides the design, analysis, licensing support and quality assurance for the TN-32 cask. Fabrication of the cask is done by one or more qualified fabricators under TN's quality assurance program. Personnel are trained and qualified in accordance with industry standards such as SNT-TC-1A for non-destructive testing and the ASME code, Section IX for welding. TN's quality assurance program is described in Chapter 13. This program is written to satisfy the requirements of 10 CFR 72, Subpart G and covers control of design, procurement, fabrication, inspection, testing, operations and corrective action. The TN QA program satisfies the 18 criteria of 10 CFR Part 72, Subpart G, Quality Assurance. Cask operations, site construction and decommissioning activities are performed by the utility under their QA program. Experienced TN operations personnel provide training to utility personnel prior to first use of the cask and prepare generic operating procedures.

The construction of the ISFSI (other than the casks) is performed by others under the direction of the general licensee. Cask operations and maintenance are performed or directed by the general licensee. Decommissioning activities will be performed by the general licensee in accordance with site procedures.

Managerial and administrative controls which are used to ensure safe operation of the casks are provided by the host utility.

Modifications to the TN-32 cask design, when required, may not be performed without concurrence of Transnuclear. The host utility may make changes to the cask as specified in 10 CFR 72.48, as described in the Safety Analysis Report or changes in the procedures described in the Safety Analysis Report or conduct tests or experiments not described in the Safety Analysis Report, without prior NRC approval. If the proposed change, test or experiment involves a change in the license conditions incorporated in the license, an unreviewed safety question, a significant increase in occupational exposure or a significant unreviewed environmental impact, it may not be performed without prior NRC approval.

Transnuclear, Inc. provides specialized services for the nuclear fuel cycle that support transportation, storage and handling of spent nuclear fuel, radioactive waste and other radioactive materials. Transnuclear, Inc. was incorporated in the State of New York in 1965.

Transnuclear, Inc. has been involved in the design, analysis, fabrication, testing, certification and operation of packagings for spent fuel, radioactive waste, and other radioactive materials for over three decades. Transnuclear, Inc.

developed the TN-24 cask which has been licensed for storage in the United States. Transnuclear, Inc. also developed the TN-40 dry storage cask for use at Northern States Power Prairie Island Nuclear Plant. Transnuclear, Inc. has also obtained previous approval of the TN-32 as a Topical Report which can be used for reference in a site specific application.

Transnuclear, Inc. also maintains an NRC Quality Assurance Program Approval for Radioactive Material Transportation Packages.

1.4 Generic Cask Arrays

The installation for storing spent fuel may be designed to include one or more TN-32 casks. The casks will be stored on a concrete slab in a free standing, vertical orientation. Typically, two or three concrete pads are utilized at an ISFSI with each pad containing a 2 by xx array of casks. One possible configuration for a dry storage installation is shown in Figure 1.4-1. Nominal sixteen foot center-to-center spacing is assumed between casks for the thermal analysis.

1.5 Supplemental Data

The following Transnuclear Drawings are enclosed:

1. TN-32 Dry Storage Cask, General Arrangement, Drawing No. 1049-70-1.

2. TN-32 Dry Storage Cask, General Arrangement Cross Section & Details, Drawing No. 1049-70-2.

3. TN-32 Dry Storage Cask, Lid Assembly & Details, Drawing No. 1049-70-3.

4. TN-32 Dry Storage Cask, Protective Cover, Drawing No. 1049-70-4.

5. TN-32 Dry Storage Cask, Basket, General Arrangement, Drawing No. 1049-70-5.

6. TN-32 Dry Storage Cask, Basket, Typical Cross Section, Drawing No. 1049-70-6.

7. TN-32 Dry Storage Cask, Pressure Monitoring System, Drawing No. 1049-70-7.

8. TN-32 Dry Storage Cask, Top Neutron Shield, Drawing No.1049-70-8.

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE	
T.J.N. PROJ.	9 DEC. 93	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
L.C. Q/A	9 DEC. 93	TN-32 DRY STORAGE CASK GENERAL ARRANGEMENT
P.S. ENGR.	9 DEC. 93	SAR
T.J.N. CERT. BY	9 DEC. 93	
J.T.G. DWN. BY	9 DEC. 93	NONE SCALE · B SIZE · 1049-70-1 DWG. NO. · 5 REV.

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
T.J.N. PROJ.	9 DEC. 93	TN-32 DRY STORAGE CASK GENERAL ARRANGEMENT CROSS SECTION & DETAILS SAR
L.C. Q/A	9 DEC. 93	
P.S. MECH. DES.	9 DEC. 93	
T.J.N. CHK'D. BY	9 DEC. 93	
J.T.G. DWN. BY	8 DEC. 93	SCALE: NONE; SIZE: B; DWG. NO.: 1049-70-2; REV.: 8

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.			
PROJ. T.J.N.	9 DEC. 93	TN-32 DRY STORAGE CASK			
Q/A L.C.	9 DEC. 93				
MECH. DES. P.S.	9 DEC. 93	LID ASSEMBLY & DETAILS			
CHK'D. BY T.J.N.	9 DEC. 93	SAR			
DWN. BY. J.T.G.	8 DEC. 93	SCALE NONE	SIZE B	DWG. NO. 1049-70-3	REV. 6

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE	
PROJ. T.J.N.	9 DEC. 93	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
Q/A L.C.	9 DEC. 93	TN-32 DRY STORAGE CASK
		PROTECTIVE COVER
MECH. DES. P.S.	9 DEC. 93	SAR
CHK'D. BY T.J.N.	9 DEC. 93	
DWN. BY. J.T.G.	8 DEC. 93	SCALE: NONE — SIZE: B — DWG. NO.: 1049-70-4 — REV.: 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE
T.J.N. PROJ.	9 DEC. 93
L.C. Q/A	9 DEC. 93
P.S. TECH. DIR.	9 DEC. 93
T.J.N. CHK'D. BY	9 DEC. 93
J.T.O. DWN. BY.	8 DEC. 93

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-32 DRY STORAGE CASK BASKET
GENERAL ARRANGEMENT

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	1049-70-5	5

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	DATE
T.J.N. PROJ.	9 DEC. 93
L.C. Q/A	9 DEC. 93
P.S. MECH. DES.	9 DEC. 93
T.J.N. CHK'D. BY	9 DEC. 93
J.T.G. DWN. BY.	9 DEC. 93

TRANSNUCLEAR, INC.
HAWTHORNE, N.Y.

TN-32 DRY STORAGE CASK BASKET
TYPICAL CROSS SECTION

SAR

SCALE	SIZE	DWG. NO.	REV.
NONE	B	1049-70-6	7

Security-Related Information Figure Withheld Under 10 CFR 2.390.

APPROVALS	TRANSNUCLEAR INC.	
T.J.N.	TN-32 DRY STORAGE CASK	
R.F.	PRESSURE MONITORING SYSTEM	
P.S.		
T.J.N.		
J.T.G.	NONE (SCALE) / B (SIZE) / 1049-70-7 (DWG. NO.)	1 (REV.)

1 — SEE DCN 1049-133

Security-Related Information Figure
Withheld Under 10 CFR 2.390.

NO.	DATE	REVISIONS	DWN.	CHK'D	H.D.		O/A	PROJ.
1	4/1/99	SEE DCN 1049-187	R/A	JS	JC			

APPROVALS	DATE	
T.J.N. PROJ.	05 NOV. 98	TRANSNUCLEAR, INC. HAWTHORNE, N.Y.
R.F. O/A	05 NOV. 98	TN-32 DRY STORAGE CASK
		TOP NEUTRON SHIELD
P.S. MECH. DES.	05 NOV. 98	
T.J.N. CHK'D. BY	05 NOV. 98	SAR
J.T.G. DWN. BY.	05 NOV. 98	NONE (SCALE) — B (SIZE) — 1049-70-8 (DWG. NO.) — 1 (REV.)

Supplemental drawing prepared to support 10CFR72.48 evaluations performed by WEPCO & VEPCO

Security-Related Information Figure Withheld Under 10 CFR 2.390.

	TRANSNUCLEAR INC.
	TN-32 DRY STORAGE CASK PRESSURE MONITORING SYSTEM
SCALE: NONE	SIZE: B
DWG. NO.: 1049-70-27	REV.: 0

1.6 References

1. US Nuclear Regulatory Commission, Regulatory Guide 3.61, Standard Format and Content for a Topical Safety Analysis Report for a Spent Fuel Dry Storage Cask, February, 1989.

2. 10CFR72, Rules and Regulations, Title 10, Chapter 1, Code of Federal Regulations - Energy, U.S. Nuclear Regulatory Commission, Washington, D.C., "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste".

3. 10CFR71, Rules and Regulations, Title 10, Chapter 1, Code of Federal Regulations, Energy, U.S. Nuclear Regulatory Commission, Washington, D.C., "Packaging and Transportation of Radioactive Material."

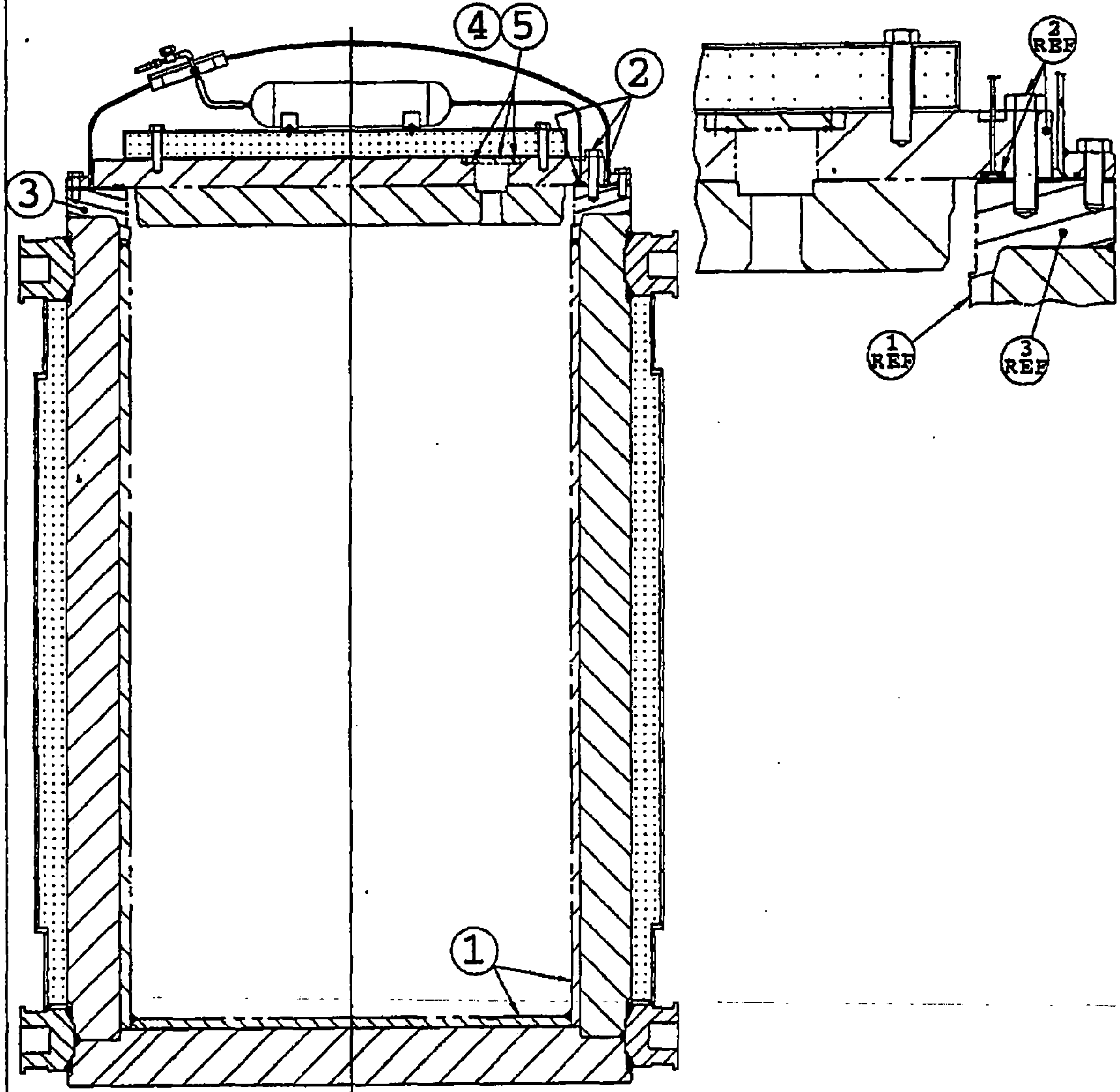
4. Levy, et.al., "Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircaloy - Clad Fuel Rods in Inert Gas," Pacific Northwest Laboratory, PNL-6189.

TABLE 1.2-1

DIMENSIONS AND WEIGHT OF THE TN-32 CASK

Overall length (with protective cover, in)	202.25
Outside diameter (in)	97.75
Cavity diameter (in)	68.75
Cavity length (in)	
TN-32 Standard and TN-32B	163.25
TN-32A	164.38
Body wall thickness (in)	9.50
Lid thickness (in)	10.50
Bottom thickness (in)	10.25
Resin compound thickness (in)	4.50
Outer shell thickness (in)	0.50
Cask weight:	
Loaded on storage pad (tons)	
TN-32	115.5
TN-32A	115.6
TN-32B	115.6
Loaded on pool crane hook without water (tons)	
TN-32	114.1
TN-32A	113.5
TN-32B	114.2
Loaded on pool crane hook with water (tons)	
TN-32	120.2
TN-32A	119.6
TN-32B	120.3

NOTES: 1. FIGURE NOT TO SCALE. FEATURES EXAGGERATED FOR CLARITY.
2. PHANTOM LINE (---------) INDICATES CONFINEMENT BOUNDARY.
3. CONFINEMENT BOUNDARY COMPONENTS ARE LISTED BELOW.



LEGEND

1. INNER SHELL
2. LID ASSEMBLY OUTER PLATE, CLOSURE BOLTS & INNER METALLIC SEALS
3. WELDED FLANGE FORGING
4. VENT PORT COVER PL., BOLTS & INNER SEALS
5. DRAIN PORT COVER PL., BOLTS & INNER SEALS

FIGURE 1.2-1
TN-32 CONFINEMENT BOUNDARY COMPONENTS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 1.4-1
TYPICAL ISFSI VERTICAL STORAGE

CHAPTER 2

PRINCIPAL DESIGN CRITERIA

This chapter provides the principal design criteria for the TN-32 casks. Section 2.1 presents a general description of the spent fuel to be stored. Section 2.2 provides the design criteria for environmental conditions and natural phenomena. This section presents the analysis which shows that the casks will not tip over or slide significant distances under the design basis seismic, tornado, wind and missile loadings, or extreme floods. This section also contains an assessment of the local damage due to the design basis environmental conditions and natural phenomena and the general loadings and design parameters used for analysis in subsequent chapters. Section 2.3 provides a description of the systems which have been designated as important to safety. Section 2.4 provides a general discussion regarding decommissioning considerations. This is further elaborated on in Chapter 14. Section 2.5 summarizes the cask design criteria.

2.1 Spent Fuel To Be Stored

The TN-32 cask is designed to store 32 PWR Westinghouse 14x14 (standard or OFA), 15x15 or 17x17(standard or OFA) and B&W Mark BW 17x17 spent fuel assemblies with or without burnable poison rod assemblies or thimble plug inserts. The physical characteristics of these PWR fuel assemblies are given in Table 2.1-1. The fuel to be stored in the TN-32 is limited to fuel with a maximum initial enrichment of 4.05% U235, maximum burnup of 45,000 MWD/MTU and minimum 7 years cooling time. Table 2.1-3 provides the minimum cooling time required for various combinations of minimum initial enrichment and maximum burnup.

Scoping calculations were performed to determine the fuel assembly type which was most limiting for each of the analyses including shielding, criticality, heat load and confinement. These evaluations are performed in Chapters 5,6,4 and 7 respectively. The fuel assemblies considered are listed in Table 2.1-1. The confinement analyses are based on 15 x 15 fuel assemblies since they contain more free gas than the 14 x 14 and 17 x 17 assemblies. The thermal and shielding analyses are presented for the Westinghouse 17 x 17 standard fuel assembly which is most limiting. For the criticality analysis, all fuel assembly types are analyzed. The Westinghouse 17 x 17 standard fuel assembly is determined to be most reactive, and is evaluated for configurations which bound all normal, off-normal and accident conditions.

The thermal and radiological characteristics for the PWR spent

fuel were generated using the SAS2H/ORIGEN-S computer code[1]. These characteristics for the Westinghouse 17x17 assembly are shown in Table 2.1-2. For the thermal and radiological characteristics, the 17x17 assembly with an initial minimum enrichment of 3.5 w/o U-235 was assumed combined with a burnup of 45,000 MWd/MTU and a seven year cooling time.

Fuel with various combinations of burnup, specific power, enrichment and cooling time can be stored in the TN-32 cask as long as values for decay heat and gamma and neutron sources, including spectra, fall within the design limits specified in Table 2.1-2. For combinations of maximum burnup and minimum enrichment, the minimum cooling time of fuel acceptable for storage in the TN-32 cask is presented in Table 2.1-3. The evaluation performed to determine these cooling times is presented in Chapter 5. Figures 2.1-1, 2.1-2 and 2.1-3 show the total thermal, gamma and neutron sources for the W 17x17 standard fuel assembly, respectively, as a function of cooling time.

Table 2.1-4 presents the thermal and radiological source term for the burnable poison rod assemblies (BPRA's) and the thimble plug assemblies (TPA`s). These values are consistent with the cumulative exposures and cooling times shown in Figures 2.1-4 and 2.1-5. The gamma spectrum for the burnable poison rod assemblies and thimble plug assemblies is presented in chapter 5. Generally any fuel assembly type, with or without associated hardware can be loaded in any of the TN-32 configurations. The one exception is BPRA's used in Upper Head Injection reactors. These BPRA's are longer than the standard BPRA designs, since they have an Upper Head Injection Cup above the Hold-Down Assembly. This type of BPRA is shown in Figure 2.1-6.

Specific gamma and neutron source spectra and fission product gas inventory are given in Chapter 5.

The standard W 14x14 assembly without BPRA'S or TPA'S is used for stability calculations (wind, tornado, missiles, flood and seismic) due to the lighter weight of the contents and the slightly higher center of gravity.

The fuel is stored in the TN-32 in an inert environment since the cavity is vacuum dried and filled with helium after loading.

Fuel assemblies shall be intact. Partial fuel assemblies, that is, fuel assemblies from which fuel pins are missing shall not be loaded unless missing full pins are replaced. Fuel assemblies known or suspected to have cladding defects greater than hairline cracks or pin holes are not permitted in the TN-32 cask.

Although analyses in this Safety Analysis Report are

performed only for the design basis fuel, any other intact PWR fuel which falls within the geometric, thermal and nuclear limits established for the design basis fuel could be stored in the TN-32 cask.

2.2 Design Criteria for Environmental Conditions and Natural Phenomena

The storage cask design ensures that fuel criticality is prevented, cask integrity is maintained, and fuel is not damaged so as to preclude its ultimate removal from the cask. The conditions under which these objectives are met are described below.

The casks are self-contained, independent, passive systems, which do not rely on any other systems or components for their operation. The criteria used in the design of the casks ensure that their exposure to credible site hazards do not impair their safety functions.

The design criteria satisfy the requirements of 10 CFR Part 72[2]. They include the effects of normal operation, natural phenomena and postulated man-made accidents. The criteria are defined in terms of loading conditions imposed on the storage cask. The loading conditions are evaluated to determine the type and magnitude of loads induced on the storage cask. The combinations of these loads are then established based on the number of conditions that can be superimposed. The load combinations are then classified as Service Conditions consistent with Section III of the ASME Boiler and Pressure Vessel Code[3]. The stresses resulting from the application of these loads are then evaluated based on the rules for a Class 1 nuclear component in Subsection NB of the Code.

2.2.1 Tornado and Wind Loadings

The TN-32 storage cask is designed to resist tornado loadings resulting from those in the most tornado prone regions of the United States as defined in NRC Regulatory Guide 1.76[4]. An analysis of impact on the cask by tornado missiles in accordance with NUREG-0800,[5] Section 3.5.1.4, is presented in this Safety Analysis Report. Non-tornado wind loading is not significant in comparison to that due to tornadoes; therefore, the wind loading is conservatively taken to be the same as the tornado wind loading.

2.2.1.1 Applicable Design Parameters

The design basis tornado wind velocity and external pressure drop based on NRC Regulatory Guide 1.76 are 360 mph and 3 psi respectively. The external pressure drop of 3 psi associated with passing of the tornado is small and, when combined with the other internal pressure loads is far exceeded by the design

internal pressure (100 psi) for the cask.

2.2.1.2 Determination of Forces on Structures

The 360 mph tornado wind loading is converted to a dynamic pressure (psf) acting on the cask by multiplying the square of the wind velocity (in mph) by a coefficient (0.002558 at ambient sea level condition) dependent on the air density, based on data presented in a paper by T.W. Singell.[6]. The result is a pressure of 332 psf. The net force acting on the cask is obtained by multiplying this pressure by the product of the area of the cask projected onto a plane normal to the direction of wind times a drag coefficient. A drag coefficient of 1 is used based on the geometric proportions of the cask (i.e. length to diameter ratio of approximately 2) and the conservative assumption that the cask surface is rough. Smooth surfaces would result in less drag forces on the cask.

This results in a distributed load, w lb/in, acting on the cask in a vertical orientation over the length of 201.88 in. as shown in Figure. 2.2-1a. The load is calculated as follows:

$$w = \frac{332}{144} \text{ x outer shell diameter}$$

$$w = \frac{332}{144} \times 97.75 = 225.4 lb/inch$$

An additional type of load on the structure is that created by the impact of tornado missiles on the cask. These impacts are analyzed for 3 types of missiles:

- Missile A: high energy deformable type missile (1800 kg or 4,000 lbs. automobile) impacting the cask horizontally at normal incidence at 35% of the design basis tornado horizontal wind speed.

- Missile B: rigid missile (125 kg. or 276 lb.8" diameter armor piercing artillery shell) impacting the cask:

  a) horizontally at normal incidence at 35% of the design basis tornado horizontal wind speed.

b) vertically at normal incidence at 70% of the horizontal component (i.e. 24.5% of the design basis tornado horizontal wind speed).

- Missile C: small rigid steel sphere 1" in diameter impinging upon the barrier openings in the most damaging directions at 35% of the design basis tornado horizontal wind speed.

2.2.1.2.1 Stability of the Cask in the Vertical Position Under Wind Loading

Cask stability evaluations are performed using a conservatively low cask weight of 218,000 lbs. This is lower than the weight of the cask filled with the 14 x 14 assemblies which have the lowest weight.

The cask rests in an upright position on a concrete pad. To determine an appropriate coefficient of friction between steel and concrete, the following references are cited:

Coefficient of Static Friction	References
Metal on stone: 0.30 - 0.70	Beer and Johnston, Vector Mechanics for Engineers: Static and Dynamic[22]
Metal on Concrete: 0.30 - 0.40	Walmer, M.E., Manual of Structural Design and Engineering Solutions[23]
Concrete-to-Steel: 0.40	PCI Design Handbook, 2^{nd} Edition[24]

The coefficient of static friction is used to calculate the maximum amount of frictional force available to prevent sliding. Once sliding begins, there is lower frictional force available, and the coefficient of kinetic friction should be used. According to the textbook[22], Vector Mechanics for Engineers: Static and Dynamic by F.P. Beer and E.R. Johnston, the coefficient of kinetic friction is approximately 25% smaller than the coefficient of static friction.

In the concrete construction specifications by specify a broom finish for the top surface of the concrete pad, this will result in a more coarse texture than a smooth, troweled finish. It is therefore concluded that a coefficient of static friction value of 0.35 is appropriate for the determination of the factor

of safety against cask sliding. Based on the above, kinetic coefficients of friction between the steel cask and the concrete pad are conservatively taken as 0.2625.

Cask Sliding

The wind loading on the cask body is,

$$q = 0.002558\ V^2 = 0.002558\ (360)^2 = 331.6\ lb/ft^2$$

The projected area A is approximated for a 97.75 inch diameter x 201.88 inch high cylinder,

$$A = (201.88 \times 97.75)/144 = 137.04\ ft^2$$

Therefore, the total wind force is,

$$F_{wind} = 331.6 \times 137.04 = 45{,}442\ lbs.$$

The friction force under the cask is,

$$F_{friction} = W_{cask} \times \mu = 218{,}000 \times 0.35 = 76{,}300\ lbs.$$

A conservatively low weight of 218,000 lbs. is used for the stability analysis.

$F_{friction}/F_{wind} = 76{,}300/45{,}442 = 1.68$, the factor of safety is larger than 1.1 as recommended by ANSI/ANS-57.9[19], Section 6.17.4.1.

Since $F_{friction} > (1.1)F_{wind}$, the wind load will not be able to slide the cask on the concrete pad.

Cask Tipping

The cask has an outer diameter of 87.75 inches at its base (Exclude resin and outer shell). The ability of wind at a constant velocity of 360 mph to tip the cask is calculated by equating the tipping moment due to wind force and the restoring moment due to cask weight.

The tipping moment due to the 360 mph wind about the bottom edge of the cask is:

$M_{tipping} = F_{wind} \times B = 45{,}442 \times 92.3 = 4.19 \times 10^6$ in-lb.

Where:

F_{wind} = 45,442 lbs, Total wind force
B = 92.3", C.G. of the Cask

The restoring moment due to the cask weight is:

$M_{restoring} = W_{cask} \times r = 218{,}000 \times 43.875 = 9.56 \times 10^6$ in-lb.

Where:

W_{cask} = 218,000 lbs, Weight of Cask
r = 43.875", Radius of the Cask

$M_{restoring} / M_{tipping} = 9.56 \times 10^6 / 4.19 \times 10^6 = 2.28$, the factor of safety is larger than 1.1 as recommended by ANSI/ANS-57.9[19], Section 6.17.4.1.

Since $M_{restoring} > (1.1) M_{tipping}$, the wind load will not be able to tip the cask. Therefore, the design basis tornado wind velocity of 360 mph will neither slide nor tip the cask.

2.2.1.2.2 Stability of the Cask in the Vertical Position Under Missile Impact

The cask stability is evaluated for three types of tornado missile impacts of 126 mph velocity. The missile impacts typically occur on the standing cask at normal incidence as shown in Figure 2.2-2. Missiles A(4,000 lb. automobile) is assumed to crush while Missile B (276 lb. 8 inch diameter armor piercing artillery shell) and Missile C (1 inch diameter steel sphere) are assumed to partially penetrate the cask wall.

The cask will tend to slide if a missile strikes it below the C.G. (unless it is blocked in position) or tilt if the missile strikes it above the CG. Conservation of momentum is assumed for both sliding and tipping with a coefficient of restitution of zero. The energy transferred to the cask is dissipated by friction in the sliding case or transformed into potential energy as the cask CG lifts in the tipping case.

When a missile strikes the side of the cask at an elevation near the C.G., the translational velocity of cask after impact, is given by:

$$V = \frac{mv_o}{M+m}$$

Where:

V	= cask translational velocity after impact, (in/sec)
v_0	= missile initial velocity, 126 x 17.6 (in/sec)
m	= mass of Missile, lbf/386.4
M	= cask mass, 218,000/386.4 (lb-sec^2/in)

When the appropriate substitutions are performed for Missile impact, the cask velocity after impact in the sliding case, V, is summarized as follows:

Missile		Mass (lbs.)	Missile Initial Velocity v_0 (mph)	Cask Translational Velocity After Impact V (mph)
A	Automobile	4,000	126	2.270
B	8" Diameter Armor Piercing Artillery Shell	276	126	0.159
C	1" Diameter Steel Sphere	0.152	126	0

Missile A, therefore, has the greatest effect on the stability of the cask. It has the largest mass and produces the highest cask velocity of 2.270 mph or 40.0 in/sec after impact.

Cask Sliding

The cask may tend to slide if the missile A strikes it below the CG. Assuming no rotation and ignoring friction, the cask velocity could reach 2.270 mph or 40.0 in/sec after the impact. Therefore, the final kinetic energy of cask after an impact is:

$$KE = 1/2(W_{cask} \times V^2)/g = 1/2\ (218{,}000 \times 40.0^2)/386.4$$
$$= 4.51 \times 10^5 \text{ in-lb.}$$

This cask kinetic energy after impact is absorbed by friction, as the cask slides on the concrete pad. A dynamic coefficient of friction of 0.2625 is used for this analysis. Thus, the friction work is equated to the kinetic energy for computing the sliding distance.

$$F_{friction} = \mu\ W_{cask} = 0.2625 \times 218{,}000 = 0.572 \times 10^5 \text{ lbs.}$$

Where:

$F_{friction}$ = friction force

μ = dynamic coefficient of friction, 0.2625

Friction Work = $F_{friction}$ x sliding distance

Therefore, Sliding Distance,

$$L = KE/\ F_{friction} = 4.51 \times 10^5/0.572 \times 10^5 = 7.88 \text{ in.}$$

The cask may tend to slide 7.88 inches if the missile A strikes it below the C.G. of the cask.

Cask Tipping

If missile A strikes the cask above the C.G. and the entire momentum of missile A is applied to the cask to result in cask tipping:

Impulse Momentum of missile is (Ref. 20):

$$\text{Impulse Momentum} = (W_{missile}/g) \times (v_o)$$
$$= (4000/386.4) \times (126 \times 5280 \times 12/3600)$$
$$= 2.296 \times 10^4 \text{ lb.-sec}$$

If the entire impulse is conservatively applied near the top and the cask pivots about the bottom corner (no sliding),

Cask angular momentum after impact = Impulse Momentum of missile

The rotational kinetic energy about corner P is (see Figure 2.2-2):

$$KE_{rotation} = 0.5\ (I_{cask\ about\ A} \times \omega^2)$$

$$I_{cask\ about\ P} = I_{C.G.} + (W_{cask}/g)(x)^2$$

$$I_{C.G.} = (W_{cask}/g)(r^2 + A^2/3)/4$$
$$= (218{,}000/386.4)(43.875^2 + (184.0)^2/3)/4$$
$$= 1.86 \times 10^6 \text{ lb-in-sec}^2$$

Therefore,

$$I_{cask\ about\ P} = 1.86 \times 10^6 + (218{,}000/386.4)(102.2)^2$$
$$= 7.75 \times 10^6 \text{ lb-in-sec}^2$$

And, $(I_{cask\ about\ P})(\omega)$ = Impulse x Height

$$= 2.296 \times 10^4 \times 201.88$$
$$= 4.64 \times 10^6 \text{ in-lb.-sec}$$

$$\omega = 4.64 \times 10^6 / I_{cask\ about\ P}$$
$$= 4.64 \times 10^6/7.75 \times 10^6$$
$$= .599 \text{ sec}^{-1}$$

The rotational kinetic energy of cask is,

$$KE_{rotation} = 1/2(I_{cask\ about\ P} \times \omega^2)$$
$$= 1/2(7.75 \times 10^6 \times 0.599^2)$$
$$= 1.390 \times 10^6 \text{ in-lb.}$$

The cask tilts through a small angle before it stops. When the cask tips or pivots about point P after impact, the kinetic energy is transformed into potential energy as the cask C.G. rises (Figure 2.2-2):

$E_{tipping}$ = Increase in Potential Energy = Kinetic Energy = 1.390×10^6 in-lb.

$$E_{tipping} = W_{cask} \times (x) \ (\sin\alpha - \sin\theta)$$

Therefore, $\alpha = \sin^{-1}[\{E_{tipping} / (W_{cask} \times x)\} + \sin\theta]$

$$\theta = \sin^{-1}(B/x) = \sin^{-1}(92.3/102.2) = 64.6°$$

$$\alpha = \sin^{-1}[\{1.390 \times 10^6 / (218{,}000 \times 102.2)\} + \sin 64.6°] = 74.89°$$

So the cask tilts an angle equal to $(\alpha - \theta) = 74.9° - 64.6° = 10.3°$

The cask is still stable since it will keep righting itself until the C.G. lifts over the corner i.e., α reaches 90°.

$$\alpha = 90°$$
$$\alpha - \theta = 90° - 64.6° = 25.4°$$

Therefore, the cask will not tipover due to missile A striking above the center of gravity of cask.

The impact forces applied to the cask as it is struck by the missiles are determined as follows:

- Missile A - (automobile) is assumed to crush 3 feet under a constant force during the impact. The loss of kinetic energy is assumed to be dissipated by crushing of the missile. The frontal area of the automobile is assumed to be 20 sq. ft.

$F_a \times 3\ ft. = 0.5[mv_0^2 - (M + m)V^2]$

$P_a = F_a / 20\ ft^2$

where:

V	= cask translational velocity after impact, 2.27 x 17.6 (in/sec)
v_0	= missile initial velocity, 126 x 17.6 (in/sec)
m	= mass of Missile, 4,000/386.4 ($lb\text{-}sec^2/in$)
M	= cask mass, 218,000/386.4 ($lb\text{-}sec^2/in$)
F_a	= Impact force on cask by Missile A
P_a	= Impact pressure on cask by Missile A

The impact force, F_a, is determined to be 694,324 lb, and the crush pressure on the frontal area of the automobile, p_a, is 241 psi.

- Missile B - (rigid missile) does not deform under impact.

  The loss in kinetic energy is assumed to be dissipated as the missile partially penetrates the cask wall. The penetration force is assumed to be equal to the yield strength of the cask body material multiplied by the frontal area of the 8 in. diameter missile.

$$F_b = S_y\left(\frac{\pi}{4}\right)(8)^2$$

The impact force, F_b, is determined to be 1.603×10^6 lbs. assuming a cask body yield stress, S_y, of 31,900 psi. This force is higher than that developed by Missile A, but the impact time duration is much smaller so that a smaller impulse is applied to the cask producing less cask movement than Missile A. Missile C (1 in. diameter sphere) impact has no effect on cask stability.

The above forces, F_a and F_b, are used in the stress analysis of the cask body.

2.2.1.3 Tornado Missiles

The TN-32 cask has been evaluated for potential damage due to the three tornado missiles identified in 2.2.1.2. The effect of the missiles on the cask is described below. Missile A does

not result in damage to the cask body. However there could be localized damage to the neutron shielding, the protective cover or the over pressure monitoring system. Missiles B and C may partially penetrate the cask wall if the energy is not first dissipated by the outer shell and neutron shielding. It can also dent the protective cover. The overpressure system which has not been designed to withstand accident loads could be rendered inoperable.

2.2.1.3.1 Missile A

Missile A (automobile) deforms and is crushed during the impact. The local pressure on the cask structure is less than 1% of the body yield strength. Therefore, no local penetration occurs. The shear stress in the cask wall is conservatively calculated below. Certain assumptions have been made in order to perform this analysis as stated below. The impact force is concentrated on a small curved section of the cask wall having dimensions w x L. Smaller areas will result in larger forces per unit area. Two edges are tending to shear (above and below the curved section). Actually the sides would also need to shear, resulting in a larger total shear area. Only 3 foot sections are shearing this result in a smaller shear area. Then

Shear Area = 2 x 36 x the thickness of the gamma shielding

= 2 x 36 x 8.0 = 576 in^2

The shear stress, τ = Force/area = 694,324/576 = 1,205 psi, which is well below accident allowable shear stress of 0.42 x S_u = 0.42 x 70.000 = 29,400 psi.

2.2.1.3.2 Missile B

Missile B (rigid) partially penetrates the cask wall. The loss in kinetic energy is dissipated as strain energy in the cask wall. The force developed as the 8 in. diameter missile penetrates the cask body is:

$$F_b = S_y\left(\frac{\pi}{4}\right)(8)^2 = 1.603 \times 10^6 \text{ lbs.}$$

From conservation of energy:

$$F_b x = \frac{1}{2} m_b v_o^2$$

or for constant puncture force:

$$x = \frac{m_b v_o^2}{2 F_b}$$

Where

x = the penetration distance, (in.)

v_o = missile initial velocity, 126 x 17.6 (in/sec)

m_b = mass of Missile, 276/386.4 (lb-sec²/in)

The penetration distance is found to be 1.09 in. The penetration distance is much less than the thickness of the gamma shield shell (8 in.).

As an order of magnitude check, the minimum thickness of a steel plate capable of being perforated by the postulated DBT missile as recommended by NUREG-1536[25]" Standard Review Plan for Dry Cask Storage System" and NUREG-0800[5] is provided by Ballistic Research Laboratory formula described in Reference 22:

$$T = (0.5 \times m_b \times v_o^2)^{2/3}/(672 \times d_m)$$

Where

T = Perforation Thickness (in.)

v_o = missile initial velocity, 184.8 (ft/sec)

m_b = mass of missile, 276/32.2 (lb-sec²/ft)

d_m = missile diameter, 8 in.

Substituting the values given above,

T = 0.54 in.

The 8 inch thick gamma shield exceeds the minimum required perforation thickness of 0.54 inch by a wide margin.

When the impact angle is not 90 degrees, the missile will rotate during impact (conservatively neglected), limiting the energy available for penetration since part of the energy will be transformed into rotary kinetic energy. When hitting the weather protective cover, Missile B deforms the dished head before penetration begins (see Figure 2.2-2c). This will decrease the penetration distance from the above values.

In the worst case (cask vertical with Missile B impacting

vertically at 24.5% of tornado wind), the following results are obtained for impact in the center of the protective cover:

- 94% of the kinetic energy is absorbed by the weather protective cover deformation (see Fig. 2.2-2c)

- 6% of the energy is absorbed in denting the protective cover.

- Depth of indentation into the protective cover: 0.034 in.

The protective cover absorbs all the impact energy, leaving the lid intact. The overpressure monitoring system could be damaged due to a tornado missile.

2.2.1.3.3 Missile C (steel sphere 1" diameter)

The impact of the steel sphere can result in a local dent by penetrating into the cask surface at the yield strength, S_y, for a penetration depth, d. The contact area on the cask surface is:

$$A = \pi(2Rd - d^2)$$

Where:

R is the radius of the sphere
d is the penetration depth

The kinetic energy of the steel sphere is dissipated by displacing the cask surface material:

$$KE = \frac{1}{2} m_c v_o^2 = S_y \int_0^d (\pi)(2Rd-d^2)\,dd$$

Where m_c = sphere mass

$$KE = 0.5(4/3)(\pi)(0.5)^3(0.28)(1/32.2)(126 \times 5280/3600)^2 = 933 \text{ in-lbs}$$

$$S_y \int_0^d (\pi)(2Rd-d^2)\,dd = S_y(\pi)(Rd^2 - d^3/3) = KE = 933 \text{ in-lbs}$$

Hence:

d = 0.14 in.

The area, A, is therefore 0.38 sq. inches. A maximum impact force of 12,122 lb. (A x S_y) will be developed. Therefore only local denting of the cask will result.

If the impact point is at the center of the protective cover (dished head), the deformation will be largely elastic with no possibility of penetrating the cover.

2.2.1.3.4 Ability of Structures to Perform Despite Failure of Structures not Designed for Tornado Loads

The TN-32 cask itself can withstand the tornado loading. It is also evaluated for burial in Chapter 11. Generally, the casks will be stored outside on a flat concrete slab. Therefore, there will be no structures that could collapse above the storage cask. If such structures were present at an ISFSI, further analysis would be required.

2.2.2 Water Level (Flood) Design

The cask has been evaluated for a water level of 57 ft and a water drag force of 57,160 lbs. due to floods, hurricanes, tsunami and seiches. It is demonstrated that the cask is acceptable for these conditions. If a specific site has conditions exceeding these values, further analysis is required.

2.2.2.1 Flood Elevations

It is anticipated that the storage casks will be located on flood-dry sites. However, the storage cask is designed for an external pressure of 25 psi which would be equivalent to a static head of water of approximately 57 ft. This is greater than would be anticipated due to floods, tsunami and seiches regardless of the site.

2.2.2.2 Phenomena Considered in Design Load Calculations

The casks are designed to withstand loads from forces developed by the probable maximum flood including hydrostatic effects and dynamic phenomena such as momentum and drag.

2.2.2.3 Flood Force Application

Using a friction coefficient of 0.35, a drag force greater than 57,160 lb. is required to move the cask when the cask is in an upright position (after taking into account the bouyant force on the cask). The drag force is calculated as follows:

The approximate volume of the cask $= \pi\ (97.75)^2(201.88)/4$
$= 1.515 \times 10^6\ in^3$.

Water density $= 0.0361\ lbs/in^3$

The buoyant force is therefore, $F_b = 1.515 \times 10^6$ (0.0361)
$= 54,692$ lbs.

The weight of the cask in water = 218,000 - 54,692 = 163,308 lbs.

Using a friction coefficient of 0.35, a drag force greater than $0.35 \times 163,308 \approx 57,160$ lbs is required to move the cask when the cask is in the upright position.

This force is equivalent to a stream of water flowing past the cask at 25 ft/sec.

The water velocity was calculated using the following formula (Reference 18, Pg. 4-27) :

$$F = C_D A \rho \frac{V^2}{2g}$$

where F = Drag force, 57,160 lbs.

C_D = Drag coefficient ≈ 0.7

A = Projected area, 137.04 ft^2

ρ = 62.4 lb/ft^3

V = water velocity, ft/sec

g = 32.2 ft/sec^2

Therefore

$$V = \sqrt{\frac{2Fg}{C_D A \rho}}$$

$V \approx 25$ ft/sec

For a lower friction coefficient, the drag force is less and the water velocity to move the cask is less.

2.2.2.4 Flood Protection

The storage cask is designed for an internal pressure of 100 psi. The normal cavity operating pressure is 35 psi. It is demonstrated in Chapter 7 that the leakage rate past the seals will not result in dose levels exceeding regulatory requirements. The seals also prevent water in-leakage.

The interspace between the containment seals and the containment vessel cavity are pressurized to approximately 6 atm and 2 atm, respectively, to preclude any possibility of water in-leakage.

2.2.3 Seismic Design

Seismic design criteria are dependent on the specific site location. These criteria are established based on the general requirements stated in 10CFR Part 72.102. The design earthquake for use in the design of the casks must be equivalent to the safe shutdown earthquake (SSE) for a collocated nuclear power plant, the site of which has been evaluated under the criteria of 10CFR100, Appendix A[8].

2.2.3.1 Input Criteria

The TN-32 cask is a very stiff structure. For the purpose of calculating seismic load, the cask is treated as a rigid body attached to the ground and equivalent static analysis methods are used to calculate loads and overturning moments. This assumption is valid as long as the cask does not slide due to the seismic loads.

The fundamental natural frequency of vibration for the cask is determined as shown below (Formulas for Stress and Strain[21], 4th Edition, Page 369, Case #3):

$$f = 3.89/\ (WL^3/8EI)^{1/2}$$

Where:

- W = Weight of Cask (218,000 lbs)
- L = Height of Cask = 184 in.
- E = Modulus of Elasticity = 28.3×10^6 psi
- $I = (\pi/64)(D_o^4 - D_i^4) = (\pi/64)(87.75^4 - 68.75^4) = 1.8 \times 10^6 \text{ in}^4$

Substituting the values given above,

$$f = 66 \text{ Hz}$$

The vertical structural frequency of cask will be still higher since the cask has higher axial stiffness than the lateral stiffness. Thus the cask standing vertically on its pad has dominant lateral and vertical frequencies higher than 33 Hz (corresponding to the maximum ground acceleration, reference to NUREG 1.60[26]). Therefore, the cask can be treated as a rigid body and the maximum seismic load on the cask is the peak ground acceleration times the mass of the cask. The cask is, therefore, evaluated using an equivalent static seismic loading method, and there is no need to specify a design response spectrum or its associated time history. The factor of 1.5 (reference to NUREG 0800[5], Para. 3.7.2) to account for multimode behavior need not be included in the seismic accelerations for this analysis, as the potential for sliding/uplift is due to rigid body motion, and no frequency content effects are associated with this action.

2.2.3.2 Seismic-System Analysis

Cask Sliding

If the cask is to slide due to seismic loading, the horizontal component of the seismic load must overcome the friction force between the cask base and concrete pad. The friction force is equal to the normal force due to gravity acting at the cask/ground interface multiplied by the coefficient of friction.

The vertical seismic force is applied upward so as to decrease the normal force and hence the sliding resistance force. The equivalent static horizontal acceleration load required to initiate sliding is calculated as follows:

$$g_h \times W = \mu W (1 - 2/3 \cdot g_h)$$

where:

g_h = Fraction of horizontal acceleration value necessary to initiate sliding

W = Weight of cask on pad

μ = Coefficient of friction

For a coefficient of friction of 0.35, the equivalent static horizontal load required to initiate sliding is 0.284g.

Using a safety factor of 1.1 as recommended by ANSI/ANS-57.9, Section 6.17.4.1, the cask will not slide for a horizontal g loading of 0.284/1.1 = 0.26g. The maximum vertical g loading is 2/3 (0.26) or 0.17g.

The two horizontal components of seismic load are combined as indicated in Section 3.7.2 of NUREG-0800. At 45° to either horizontal component, the response due to a N-S earthquake is sin45° x N-S response and likewise for an E-W earthquake is sin45° x E-W response. If both components are equal, the combined response is:

$$(\sin^2 45° + \sin^2 45°)^{1/2} \times \text{response} = \text{response in either axis.}$$

Therefore, we only need to consider a single horizontal axis for the maximum seismic response.

Cask Tipping

The cask will not tipover due to a seismic event if the stabilizing moment due to cask weight is higher than the seismic tipping moment. The vertical acceleration is assumed to be 2/3 the horizontal acceleration in accordance with NUREG-0800. For a circular cask, the horizontal g value necessary to tip the cask is calculated below:

$$M_{tip} = g_h\ W\ L_v + (2/3)\ g_h\ W\ L_r$$

Where:

M_{tip} = Moment necessary to tip the cask, in-lbs
g_h = Acceleration value necessary to tip the cask
W = Weight of cask on pad
L_v = Vertical distance to C.G. = 92.3 in.
L_r = Radial distance to C.G. = 43.875 in.

$$M_{stab} = W\ L_r$$

Where:

M_{stab} = Stabilizing moment of the cask, in-lbs.
W = Weight of cask on pad
L_r = Radial distance to C.G = 43.875 in

Therefore, the g value necessary to tip the cask is found by equating M_{tip} to M_{stab}:

$$g_h\ W\ L_v + (2/3)\ g_h\ W\ L_r = W\ L_r$$

$$g_h = 43.875/(92.3 + 0.66 \times 43.875) = 0.36$$

Using a safety factor of 1.1 as recommended by ANSI/ANS-57.9, Section 6.17.4.1, the cask will not tipover for a horizontal g loading of 0.36/1.1 = 0.33g. The maximum vertical g loading is 2/3 (0.33) or 0.22g.

Conclusion

As demonstrated by the above calculations, an applied horizontal acceleration of 0.26g (and vertical acceleration of 0.17g) or less will neither slide nor tip the cask. The load distribution is shown in Figure 2.2-1b.

For evaluation of the stresses of the cask body, a 1g lateral and 2g down were used for seismic loads on the cask. These loads are applied while the cask is standing in a vertical position on the concrete pad and bound the specified seismic load limits.

2.2.4 Snow and Ice Loadings

The temperature of the protective cover attached to the top of the cask above the lid will generally stay above freezing due to the heat load of the contents. However, if the heat load is neglected under certain conditions could fall below 32°F and a layer of snow or ice might build up. A 50 psf (0.35 psi) snow or ice load corresponds to approximately 6 ft of snow or 1 ft of ice. However, this load is insignificant on the TN-32 since the cover is a 0.38 in. thick torispherical steel head which can withstand an external pressure over 20 psi. Therefore, the cover will maintain its intended protective function under snow or ice loading conditions.

2.2.5 Combined Load Criteria

2.2.5.1 Introduction

Sections 2.2.1 through 2.2.4, describe the most severe natural phenomena considered in the design of the TN-32. it has been shown that the cask is stable When subjected to natural phenomena. It will not tip over under any condition or slide on its pad more than 10 inches. In addition, the forces and pressures applied to the cask due to these phenomena have been determined.

It should be noted that all of the above phenomena are upper bound, low probability events. In most cases, however, there is a more regular and frequent similar phenomena of lower magnitude. For instance, some small wind load occurs often, but a tornado is unlikely. The forces and pressures determined for the severe phenomena can therefore be used as upper bound values for all of the similar events.

These bounding forces and pressures, with a single exception, can occur at any time and their effects are combined with those due to normal operation. The sole exception is the loading(s) due to the tornado missiles as described in Section 2.2.1.3. The missile case is evaluated in combination with others as a low probability event which is postulated only because the consequences of cask penetration might result in severe impact on the immediate environs.

2.2.5.2 TN-32 Cask Loadings

A brief explanation follows of the cask loads due to events that will occur or can be expected to occur in the course of normal operation. The cask loads due to the severe natural phenomena and accidents are compared with those for similar but less severe normal events. Then loads equal to or higher than the upper bound values selected for design and analysis of the TN-32, defined as Service Loads, are described. Finally, the Service Loads are separated into two levels and superposition of simultaneous loadings (combined loads) is discussed.

2.2.5.2.1 Normal Operation

During normal storage on the ISFSI pad, the cask is subjected to loading due to its own dead weight and that of its contents (fuel and basket), assembly stresses due to the bolt preload required to seat the double metallic seals and react to the internal pressure, and internal pressure due to initial

pressurization and any postulated fuel clad failure resulting in fission gas release.

Additional normal loads include wind loading which produces a distributed lateral load on one side of the cask and can also result in slight external pressure drop on other portions of the cask.

Lifting loads are applied to the cask through the trunnions and the cask dead weight is reacted through the trunnions during lifting operations.

If it becomes necessary to unload a recently loaded hot cask, cold water would be pumped into the cask to reduce the temperature before returning the cask to the pool. If proper controls are not maintained, an internal pressure corresponding to saturated steam pressure at the cavity wall temperature could occur which would be higher than the normal internal pressure.

Finally, an increased external pressure is applied to all surfaces of the cask during fuel loading when the cask is at the bottom of the spent fuel pool. Snow and ice loads apply local external pressure loading to the top of the cask. The cask will, of course, be subjected to the full range of thermal conditions produced by ambient variations (including insolation) and decay heat.

Fabrication stresses, due to the shrink fit or welding are not combined with the design stresses in accordance with ASME Section III.

2.2.5.2.2 Loadings Due to Severe Natural Phenomena and Accidents

The cask is subjected to dead weight loading and assembly stresses due to bolt preload and seal compression under all conditions. Other loads act on the cask during various conditions. The tornado wind loading described in Section 2.2.1 could produce higher lateral loading than any normal wind loading or flood water drag force. The external pressure drop due to the tornado wind is also more severe than due to any normal condition. Tornado missile impact described in Section 2.2.1.3 could apply a high local loading to the cask unlike any normal condition.

External pressure loading of the cask could occur due to flooding (see Section 2.2.2), or nearby explosion. The full range of thermal conditions due to ambient variations, decay heat and minor fires in the vicinity of the cask apply.

2.2.5.2.3 Thermal Conditions

The TN-32 component temperatures and thermal gradients are affected by the following thermal conditions:

- Fuel loading
- Decay heat
- Insolation
- Beginning of life unloading
- Ambient variations
- Lightning
- Minor fire

The thermal conditions which are of concern structurally are the temperature distributions in the cask and the differential thermal expansions of interfacing cask components.

2.2.5.2.4 Fuel Loading

The cask is loaded in a spent fuel pool under water. The cask is cooled by pool water; therefore, the thermal gradients established during fuel loading will be negligible.

2.2.5.2.5 Decay Heat/Solar Load

After the cask is loaded and removed from the pool, the body temperature will gradually reach steady state conditions. Since the mass of the cask is large, the time to reach equilibrium will be approximately 1 to 2 days. The temperature gradients in the cask body have an insignificant effect on the structural integrity of the body.

Several thermal analysis calculations were made for different ambient and decay heat load conditions. The methods used to obtain these results are discussed in Ch. 4. The cask temperature distribution for the normal storage condition (See Chapter 4) was used for the structural analysis.

2.2.5.2.6 Beginning of Storage Unloading

This condition would occur if it were necessary to place the cask back in the pool at the beginning of storage after it had been loaded and reached thermal equilibrium. Prior to unloading fuel, the cask and fuel would be cooled by circulating water

through the cask. Therefore, cool water would contact the hotter cask inside surfaces. The thermal gradients in the cask body due to this condition are small and would have an insignificant effect on the cask body. The fuel cladding stresses during beginning of life unloading is evaluated in Section 3.5.

2.2.5.2.7 Ambient Variations

Because the cask thermal inertia is large, the cask temperature response to changes in atmospheric conditions will be relatively slow. Ambient temperature variations due to changes in atmospheric conditions i.e., sun, ice, snow, rain and wind will not affect the performance of the cask. The cyclical variation of insolation during a day will also create insignificant thermal gradients.

The thermal effects due to ambient variations and conditions are discussed in further detail in Ch. 4.

2.2.5.2.8 Lightning

Lightning will not cause a significant thermal effect. If struck by lightning on the lid, the electrical charge will be conducted by paths provided by the lid bolts to the body.

The lid metallic O-ring seals can withstand temperatures of up to 536°F without loss of sealing capability. It is not anticipated that lightning could result in the seals reaching temperatures above these values because they are protected by the heavy wall flange.

The viton O-ring of the protective cover could be effected by a direct lighting strike on the cask. However, the viton seal does not serve a function important to safety, but is used only as a weather seal.

2.2.5.2.9 Fire

The only source of fuel which could cause a fire in the vicinity of the cask is the fuel tank of the tow vehicle which transports the cask to the storage pad. An evaluation was made to determine the thermal response of the cask assuming this minor fire is an engulfing fire. The details of this analysis are given in Ch. 4. It is concluded that the cask will maintain its confinement integrity during and after this bounding hypothetical fire accident.

2.2.5.3 Bounding Loads for Design and Service Conditions

2.2.5.3.1 Dead (Weight) Loads

The only dead loads (hereafter referred to as weight loads) on the cask are the cask weight including the contents. The calculated weights of the individual components of the cask and the total weights are given in Table 3.2-1. The weight of the cask assembly is reacted as a contact force between cask and storage pad except when the cask is supported (lifted) by the pair of trunnions at the top of the cask during handling prior to fuel loading.

2.2.5.3.2 Lifting Loads

The cask is provided with two trunnions at the top spaced 180 degrees apart for lifting. The two trunnions at the bottom of the cask are for rotation of the cask.

Upper Trunnions for TN-32 and TN-32A Casks

The upper trunnions are considered to be lifting devices and are evaluated for lifting for g levels equivalent to 3 times and 5 times the upper bound weight of the cask. These values are based on ANSI N14.6 [10], which requires that single failure proof lifting devices be capable of lifting 3 times and 5 times the cask weight without exceeding the yield and ultimate strengths of the material, respectively. The trunnion loads for the ANSI N14.6 analysis are shown in Figure 2.2-3 and listed in Table 2.2-2. The local region of the cask body is conservatively evaluated for a vertical load of 3 g (i.e., 3 times the weight of the cask) which is reacted at the trunnions involved in the handling operation.

Upper Trunnions for TN-32B Casks

The upper trunnions are considered to be single failure proof lifting devices and are evaluated for lifting for g levels equivalent to 6 times and 10 times the upper bound weight of the cask. These values are based on ANSI N14.6 [10], which requires that lifting devices be capable of lifting 6 times and 10 times the cask weight without exceeding the yield and ultimate strengths of the material, respectively. The trunnion loads for the ANSI N14.6 analysis are shown in Figure 2.2-3 and listed in Table 2.2-2. To account for an additional dynamic load factor of 10%, the weight of the cask used for these analyses is a conservatively assumed maximum loaded weight of 267,300 lbs.

The local region of the cask body is conservatively evaluated for a vertical load of 6 g (i.e., 6 times the weight of

the cask) which is reacted at the trunnions involved in the handling operation. The factor of 6 provides ample allowance for sudden load application during lifting.

Lower Trunnions for TN-32, TN-32A, and TN-32B Casks

The two lower trunnions are cylindrical SA-105 forgings that are welded to the cask body gamma shielding. The lower trunnions provide capability to rotate the cask prior to loading of spent fuel and are evaluated for lifting for g levels equivalent to 3 times and 5 times the upper bound weight of the cask. The geometries of lower trunnions are identical for all TN-32, TN-32A, and TN-32B casks.

2.2.5.3.3 Internal Pressure

The pressure inside the cavity of the storage cask results from several sources. Initially, the cavity is pressurized with helium such that the cavity pressure is about 2.2 atm. The purpose of pressurizing the cavity above atmospheric pressure is to prevent in-leakage of air. The initial pressure is determined on the basis that a 1 atm pressure must exist in the cavity on the coldest day at the end of life. Pressure variations due to daily and seasonal changes in ambient temperature conditions will be small due to the large thermal capacity of the cask.

Postulated fuel clad failure results in the release of fission gas which increases cavity pressure. Fission gas release under normal storage conditions is evaluated in Section 7.2. The evaluation gives an increase in cavity pressure of 3.0 psi. Another condition when internal pressure could increase is the cool down prior to unloading. Unloading could occur at any time while the cask is inservice, but it is worst at the beginning of the storage period. The cask cavity wall temperature at the beginning of life is 314°F (bottom plate). Before unloading fuel, water would be pumped into the cavity to reduce the temperature. When the water contacts the cavity surface, steam will be produced and the resulting pressure inside the cavity could reach the saturated steam pressure of 82.5 psia (5.61 atm) corresponding to the cavity wall temperature of 314°F.

Table 2.2-1 presents a summary of internal pressures for the conditions identified. A pressure of 100 psig was chosen as the design internal pressure, since this value exceeds that of all conditions producing an internal pressure.

2.2.5.3.4 External Pressure

There are several conditions which can result in external pressure on the cask. The external pressure due to flood level is assumed to be equal to or less than 25 psi which is equivalent to a 56 ft. head of water as discussed in Section 2.2.2. This is the limiting condition for external pressure. The various external pressures are summarized in Table 2.2-1.

2.2.5.3.5 Cask Body Loads

Global distributed loads may be applied to the cask by wind (tornado is upper bound case), flood water and seismic excitation. These loads are explained in detail and calculated in Sections 2.2.1 through 2.2.3. Table 2.2-3 lists the numerical values of these forces as calculated in the various sections. Note that bounding loads equal to the weight of the cask (1g load) in each direction (lateral and vertical) applied as inertial loads for stress analysis purposes envelope all of these distributed loads with a large margin. The local loads due to the tornado missile impact loading are unique. The calculated values from Section 2.2.1 are directly used in the cask analysis since there are no other cases to bound.

2.2.5.4 Design Loads

The various cask loading conditions are listed in Table 2.2-4. These loading conditions include those described in 10CFR Part 72[2], which are categorized as normal, man-made and natural phenomena. The applied loads acting on the different cask components due to these loading conditions have been determined and are discussed in the preceding sections and are listed in Tables 2.2-1 through 2.2-3. This section describes the bases which are used to combine the loads for each cask component. The specific stress criteria against which each load combination will be compared are described in Section 3.4.

The bounding pressures and loads described above are used in the load combinations. Certain combinations therefore are conservative evaluations of several events (e.g. one load combination conservatively represents stresses due to tornado wind, hurricane wind, normal wind, flood water, etc.). Several

loads are always present and are included in all evaluations. These are the assembly stresses due to bolt preload and metallic seal compression. Lifting loads are always reacted by the cask weight (supported on trunnions - not the storage pad). Lifting loads are not combined with those due to extreme natural phenomena since cask operations would be halted during a flood, hurricane, etc. Dead weight loads are reacted at the bottom of the cask by the storage pad for all cases except the lifting cases.

2.2.5.4.1 Cask Body

The loading conditions for the cask body including the confinement vessel are categorized based on the rules of the ASME Boiler and Pressure Vessel Code Section III, Subsection NB, for a Class 1 nuclear component. The ASME code categorizes component loadings into five service loading conditions. They include Design Conditions (same as the Primary Service) and Levels A, B, C and D Service Loadings. The code also provides different stress limits for each of these service loadings.

For each of these service loading conditions there are several applied loads which are acting on the cask. The Design Loads are listed in Table 2.2-5. They include internal and external pressure; lid bolt preload including the effect of the gasket reactions; distributed loads due to weight, wind, and handling, and attachment loads applied by the trunnion to the cask body.

The inertia g loads are quasistatically applied loads which are multiples of the weight of the cask and/or contents. The magnitude of the Design Loads envelop the maximum Level A Service Loads. Thermal effects are excluded, except for their influence on the preload of the lid bolts (if any) because the ASME Code does not consider these as Design (i.e. primary) Loads.

The Level A Service loads are listed in Table 2.2-6 and are basically the same as the Design Loadings except that the thermal effects on the containment vessel are included. The thermal effects consist of secondary (thermal) stresses caused by differential thermal expansion due to temperature differences caused by decay heat, solar insolation, ambient temperature variations and ambient conditions, e.g. ice, snow, wind, sun.

There are no Level B or C Service Loading Conditions. All loads are categorized as Level A (which meet design allowables) or Level D, loads.

The loads due to Level D Service Loading Conditions, which are extremely unlikely conditions, are listed in Table 2.2-7.

Loading combinations for Normal Conditions (Design Conditions and Levels A) are given in Table 2.2-8. Loading combinations for Accident Condition (Level D) Loadings which are evaluated are given in Table 2.2-9. The loads are listed across the top of the table and the Load Combinations are designated in the first column of the table. There are seven normal (Design and Level A) load combinations listed, and six accident condition (Level D) combinations. The loads which are acting simultaneously for each of these combinations are denoted by an "X" under the load column heading. For example, for Normal Condition Load Combination N1, internal pressure due to cavity pressurization, fission gas release, distributed weight, heat due to maximum normal temperatures and lid bolt preload are acting simultaneously.

2.2.5.4.2 Basket

Cask body internal and external pressures have no effect on the basket. External loads applied to the TN-32 cask do not result in basket loads unless the cask actually moves. Therefore, tornado wind and flood water produce no basket loads. Seismic loading, however, is an inertial loading since the cask and ISFSI pad experience both horizontal and vertical accelerations during an earthquake as discussed in Section 2.2.3. The seismic acceleration loading (much less than 1g acceleration) does combine with dead weight loading since these two effects occur simultaneously.

Temperature effects due to snow, minor fire and even day/night cycles that can cause thermal transients on the outside of the cask body will not cause similar transients in the basket. The high heat capacity of the body slows the temperature response and effectively eliminates transients at the wall of the cask cavity. The steady state temperature and temperature differences throughout the basket are, however, affected by decay heat, solar insolation and ambient temperature variations.

The basket is important for control of criticality of the fuel assemblies stored in the cask. The bounding lateral and vertical inertial loadings on the basket are equal to 1g (in each direction) have been shown to envelope the basket loadings. For the basket evaluation, an even more conservative 3g loading in the vertical direction is analyzed.

The stresses in the 304 stainless steel portions of the basket due to the primary loading, 1g in any lateral direction combined with 3g vertical (including dead weight), are determined by conservatively neglecting the tensile and bending strength of the aluminum thermal conductor plates between fuel compartment boxes. However, the through thickness strength of the aluminum plates which separate the boxes is considered. Thus the aluminum

is conservatively neglected in the primary load analysis where it can react some of the load. These primary stresses in the steel are evaluated at the maximum metal temperature occurring under extreme ambient conditions.

The secondary (thermal) stresses in the stainless steel are calculated assuming elastic behavior of the steel but considering the actual strength of the aluminum. The local bearing stresses in the aluminum plates adjacent to the plugs are significantly higher than the yield value when calculated elastically. The aluminum would therefore yield and creep resulting in lower thermal stresses in the stainless steel. The primary steel stresses calculated ignoring the aluminum (when it actually can react some of the load) are superimposed on the secondary stresses calculated assuming the full strength of the aluminum is available to induce thermal stresses in the stainless steel. Therefore the primary plus secondary stresses determined for the 304 stainless steel fuel compartment boxes and their attachments in the basket are conservative. The basket design criteria described in Section 3.4 is based on Section III of the ASME Code for stress limits and buckling. The basket evaluation is also summarized in that section.

2.2.5.4.3 Upper Trunnions

The upper trunnions are considered to be lifting devices and are evaluated to the ANSI N14.6 requirements for lifting operations. During lifting, the trunnions are evaluated for vertical lifting reactions applied at the centers of the lifting shoulders required to support three times (six times for single failure proof trunnions, TN-32B Cask) or five times (ten times for single failure proof trunnions, TN-32B Cask)the maximum weight of a fully loaded cask. When the load is equal to three times (six times for single failure proof trunnions) the weight, the maximum tensile stresses shall not exceed the minimum yield strength of the trunnion material. For the load equal to five times (ten times for single failure proof trunnions) the weight, the maximum tensile stresses shall not exceed the minimum ultimate tensile strength of the trunnion material.

In addition to the trunnions themselves, the welds that attach the trunnions to the cask body gamma shielding and the local region of the gamma shielding are analyzed under the same 3W (3 times weight of cask) (6W for single failure proof trunnion) and 5W (10W for single failure proof trunnion) reactions. The stresses in the welds and shielding shall not exceed the minimum yield strength of these components under the 3W (6W for single failure proof trunnion) loading nor the minimum ultimate strength under the 5W (10W for single failure proof trunnion) loading.

The loads acting on the trunnions are given in Table 2.2-2. The structural analysis of the trunnions is presented in Section 3.4.3.1.

2.2.5.4.4 Outer Shell

The outer shell is evaluated for the combined effects of inertia g loads due to lifting and internal pressure.

Outgassing from the resin between the cask body and outer shell may cause a slight pressure on the inside of the outer shell. A pressure relief valve is provided in the outer shell to assure any pressure buildup is small. The outer shell is completely supported by the resin when subjected to an external pressure. An internal pressure of 3 psi will occur due to the reduced external pressure during a tornado. However, since the cask body is designed for an external pressure of 25 psi, an internal pressure of 25 psi is conservatively used to evaluate the outer shell.

The structural analysis of the outer shell is presented in Appendix 3A.4. A summary of results and comparison with design criteria are given in Section 3.4.4.

The combined stress due to the inertia g loads and pressure is less than the minimum yield strength of the outer shell material.

2.3 Safety Protection Systems

2.3.1 General

The TN-32 dry storage cask is designed to provide storage of spent fuel for at least 40 years. The cask materials are selected such that degradation would not be expected during the storage period. The cask cavity pressure is always above ambient during the storage period as a precaution against the in-leakage of air which might be harmful to the fuel. Since the confinement vessel consists of a steel cylinder with an integrally-welded bottom closure, the cavity gas can escape only through the lid closure system. In order to ensure cask leak tightness, two systems are employed. A double barrier system for all potential lid leakage paths consisting of covers with multiple seals is utilized. Additionally, pressurization of monitored seal interspaces provides a continuous positive inward and outward pressure gradient which guards against a release of the cavity gas to the environment and the admission of air to the cavity.

The components of the cask are classified as "Important to Safety" and "Not Important to Safety." A tabulation of the components and their classification is shown in Table 2.3-1. The classification of structures, components, and systems which are part of the ISFSI, but not part of the cask, is included in the Safety Analysis Report submitted by the applicant for a license under 10CFR72.

The following items are considered not important to safety:

- Drain tube with all associated hardware including drain tube clamp, drain tube adapter, attachment screws, and o-ring seals. The drain tube is for operational convenience only and does not perform any safety function. The drain tube can be removed and replaced with a lance that can perform the same function.

- Quick disconnect couplings and associated o-ring seals. The couplings are for operational purposes only. These couplings do not form part of the confinement boundary.

- Pressure Monitoring equipment including pressure switches or transducers and electrical cables. If the monitoring system were not to function, no safety function of the cask would be impaired. There would be no leakage in or out of the cask. The overpressure system and monitoring instrumentation is designated as not important to safety since the failure of the system will not result in a release of radioactive material. The monitoring system has not been designed to prevent failure during accident loadings. If an accident were to occur,

- measures would be taken to replace or repair the system soon after the accident. Leakage of the overpressure system is treated as an off-normal event and addressed in Section 11.1.2. The overpressure system is leak tested at the manufacturer's facility and again after installation to ensure that the total leak rate limits imposed on the cask are not exceeded. The monitoring system is designed so that its failure can readily be identified. The switches are set to alarm if power is lost or if the switch is no longer functioning. Two separate switches are provided for redundancy.

- The top neutron shield and its attachments. The top neutron shield is used for supplemental shielding, but the accident condition dose limits are met assuming the top neutron shield is gone.

- A suitable primer and white topcoat paint for exterior of cask. This coating is used to prevent the cask from rusting. As part of the surveillance activities, the paint coverage is surveyed periodically. The paint is also inspected prior to shipment at the Fabricator to ensure proper thickness, color and adhesion.

2.3.2 Protection By Multiple Confinement Barriers and Systems

2.3.2.1 Confinement Barriers and Systems

A combined cover-seal pressure monitoring system (Figure 2.3-1) always meets or exceeds the requirement of a double barrier closure which guarantees tight, permanent confinement. There are two lid penetrations, one for draining and one for venting and pressurization. When the cask is placed in storage, a pressure greater than that of the cavity is set up in the gaps (interspaces) between the double metallic seals of the lid and the lid penetrations. A decrease in the pressure of the monitoring system would be signaled by a pressure transducer/switch wired to a monitoring/alarm panel (Figure 2.3-1).

Connections to the overpressure tank are welded fittings. A quick connect coupling with a diaphragm valve is used to fill the tank.

The metallic face seals of the lid and lid penetrations possess long-term stability and have high corrosion resistance over the entire storage period. These high performance seals are comprised of two metal linings formed around a helically-wound spring. The sealing principle is based on plastically deforming the seal's outer lining. Permanent contact of the lining against

the sealing surface is ensured by the outward force exerted by the helically-wound spring.

The metallic seals consist of an inner spring, a lining, and a jacket. The spring is Nimonic 90 or an equivalent material. The lining and jacket are stainless steel or nickel alloy and aluminum respectively.

The review of corrosion and galvanic reactions in Section 3.4.1 demonstrates the corrosion resistance of aluminum and stainless 304. The exposure to the borated pool environment is short term. The long term environment of the seals is helium, except for the outside of the outer seal. That is exposed to the air under the protective cover, but it is not exposed to rain or snow. If crevice corrosion at the outer seal were to cause a leak, it would be detected by the overpressure monitoring system.

The maximum seal temperature is 256 °F (Chapter 4). The neutron flux is 2.37×10^5 n/cm^{2}s (Chapter 14) equivalent to less than 1.5×10^{14} n/cm^2 after 20 years. The temperature and neutron fluence are low enough that for these materials, the environment is no more challenging than a non-radiation, ambient air environment.

Cefilac has conducted twice yearly leak testing of Helicoflex seals that were installed in 1973. The test fixture has been indoors, and has never been disassembled. The spring, lining, and jacket on the test seals are music wire, soft steel, and aluminum, respectively. The seal dimensions are 13 mm minor diameter x 3620 mm major diameter and 9.6 mm x 1935 mm. From 1973 to 1984, the seals were cycled 700 times between 20 and 150°C. From 1984 to present, the seals have been maintained at 20 °C. The leak rates have remained below 10^{-7} Pa m^3/m s for the entire test duration. Plots showing test data are attached as Figures 2.3-2 through 2.3-4.

Additionally, all metallic seal seating areas are stainless steel overlay for improved surface control. The overlay technique has been used for Transnuclear's transport casks and storage casks including the TN-24, TN-40 and TN-32 designs.

For protection against the environment, a torispherical protective cover equipped with an elastomer seal is provided above the lid. The lid and cover seals described above are contained in grooves. A high level of sealing over the storage period is assured by utilizing seals in a deformation-controlled design. The deformation of the seals is constant since bolt loads assure that the mating surfaces remain in contact. The seal deformation is set by its original diameter and the depth of the groove.

Metal gasket face seal fittings, diaphragm valves and metallic seals are all capable of limiting leak rates to less than 1×10^{-7} atm-cc/sec of helium.

The initial operating pressure of the monitoring system's overpressure tank is set at 5.5 atm minimum. Over the storage period, the pressure is postulated to decrease as a result of leakage from the system and as a result of temperature reduction of the gas in the system. Since the level of permeation through the confinement vessel is negligible and leakage past the higher pressure of the monitoring system is physically impossible, a decrease in cavity pressure during the storage period occurs only as a result of a reduction in the cavity gas temperature with time. As long as the cavity pressure is greater than ambient pressure and the pressure in the monitoring system is greater than that of the cavity, no in-leakage of air nor out-leakage of cavity gas is possible.

The calculations provided in Chapter 7 define the monitoring system leakage test rate which ensures that no cavity gas can be released to the environment nor air admitted to the casks for the 20 year storage period. All seals are considered collectively in the analysis as the monitoring system pressure boundary. This analysis is performed in accordance with ANSI N14.5[11].

As shown in Chapter 7, the monitoring system pressure is always greater than the cask cavity or atmospheric pressure. Thus, no leakage can occur from the cask cavity during the storage period. The pressure monitoring system alarm will be set to 3.2 atm +/- 5%. This is less than the minimum expected monitoring system pressure and greater than the maximum cavity pressure.

2.3.2.2 Cask Cooling

To establish the heat removal capability of the TN-32 cask, several thermal design criteria are established for the normal conditions. These are:

- Confinement of radioactive material and gases is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the leak tight confinement function during normal and accident conditions. A maximum temperature limit of 536°F (280°C) is set for the seals (double metallic O-rings) in the confinement vessel closure lid and vent and drain covers.

- Maintaining fuel cladding integrity during storage is

another major design consideration. To minimize creep deformation that can occur over the storage duration, the maximum initial storage fuel cladding temperature is determined as a function of the initial fuel age using the guidelines provided by the Commercial Spent Fuel Management Program (CSFM)[13]. These temperature limits are reported in Section 3.5.

- To maintain the stability of the neutron shield resin during normal storage conditions, a maximum temperature limit of 300°F (149°C) is set for the neutron shield.

- Maximum temperatures of the confinement structural components must not adversely affect the confinement function.

The thermal evaluations for normal conditions and hypothetical accident conditions are presented in Chapter 4.0.

2.3.3 Protection by Equipment and Instrumentation Selection

2.3.3.1 Equipment

Design criteria for the casks are described in Section 2.2 and summarized in Table 2.5-1.

2.3.3.2 Instrumentation

Due to the totally passive and inherently safe nature of the storage, safety-related instrumentation is not necessary. Instrumentation to monitor cask pressure is furnished. Appropriate capabilities to check and recalibrate these monitors are also provided. The pressure monitoring system is further described in Section 2.3.2.1.

2.3.4 Nuclear Criticality Safety

2.3.4.1 Control Methods for Prevention of Criticality

The design criterion for criticality is that the effective neutron multiplication factor, k_{eff}, including statistical uncertainties and bias, shall be less than 0.95 for all postulated arrangements of fuel within the cask. The fuel assemblies are assumed to stay within their basket compartment.

The control methods used to prevent criticality are:

(1) Incorporation of neutron absorbing material (boron) in the basket material.

(2) Loading of the irradiated fuel assemblies in the fuel pool water containing at least 2300 ppm boron.

(3) Prevention of fresh water entering the loaded cask.

The basket has been designed to assure an ample margin of safety against criticality under the conditions of fresh fuel in a cask flooded with borated water. The methods of criticality control are in keeping with the requirements of 10CFR72.124.

Criticality analysis is performed using the KENO-V.a Monte Carlo code[1] along with data prepared using the NITAWL code[1] and the SCALE 27-group cross section library. These codes and cross-section library are part of the SCALE system prepared by Oak Ridge National Laboratory for the U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research[1]. They are widely used for criticality analysis of shipping casks, fuel storage pools and storage casks. Benchmark problems are run to verify the codes, methodology and cross section library. Examples of computer input used for criticality evaluation are included in Section 6.6.

In the criticality calculation, the fuel assemblies, basket, and cask geometries are modeled explicitly. Within each assembly, each fuel pin and each guide tube is represented.

Reactivity analyses were performed for Westinghouse 14 x 14 standard, 14 x 14 OFA, 15x15, 17x17 standard, and 17x17 OFA and the B&W Mark BW 17x17 assemblies at 4.05% enrichment, with and without burnable poison rod assemblies (BPRA). Thimble plugs were not analyzed since they displace less borated water than the BPRA assemblies.

The analyses assume fresh fuel composition with 2300 ppm borated water in the cavity, and the cask surrounded by a fresh water reflector.

The results of the analyses (assuming accidental loading of one fuel assembly with an initial enrichment of 5 wt% U-235) with 2300 ppm borated water show the standard 17x17 with BPRA to be most reactive with a $k_{eff}=0.9315\pm0.0009$. Including the bias determined from benchmark calculations and 2 sigma yields $k_{eff}=0.9333$. The criticality analyses are described in Section 6.0.

2.3.4.2 Error Contingency Criteria

Provision for error contingency is built into the criterion used in Section 2.3.4.1 above. The criterion, used in conjunction with the KENO-V.a and NITAWL codes, is common practice for licensing submittals. Because conservative assumptions are made in modeling, it is not necessary to introduce additional contingency for error.

2.3.4.3 Verification Analysis-Benchmarking

Critical benchmarking experiments are taken from NUREG/CR-6361 and described in Section 6.5. An upper subcritical limit (USL) is determined using method 1, " confidence band with administrative margin" to be 0.9341 including modeling bias.

2.3.5 Radiological Protection

Provisions for radiological protection by confinement barriers and systems are described in Section 2.3.2.1.

2.3.5.1 Access Control

The storage casks will be located in a restricted area on a site to which access is controlled. In keeping with the terminology of 10CFR72, the terms restricted and unrestricted area refer only to areas within the controlled area. The controlled area and the site are taken to be the same. The term restricted area is defined in 10CFR20.3[17]. The specific procedures for controlling access to the site and to the restricted area within the site are to be addressed by the license applicant's Safety Analysis Report. The cask will not require the continuous presence of operators or maintenance personnel.

2.3.5.2 Shielding

Shielding has the objective of assuring that radiation dose rates at key locations are at acceptable levels for those locations. Three locations are of particular interest:

(1) Immediate Vicinity of the Cask
(2) Restricted Area Boundary
(3) Controlled Area (Site) Boundary

Dose rates in the immediate vicinity of the cask are important in consideration of occupational exposure. The design criterion for shielding is 310 mrem/hr maximum at the accessible cask surfaces during storage. Because of the passive nature of

storage with this cask, occupational tasks related to the cask are infrequent and short. Personnel exposures due to operational and maintenance activities are discussed in Section 10.3.

Dose rates at the restricted area boundary should be such that people outside the restricted area need not have their radiation exposures monitored. Dose rates at the site boundary should be in accordance with applicable regulatory guides. The estimated occupational doses for personnel comply with the requirements of 10CFR20.1301.

2.3.5.3 Radiological Alarm System

There are no credible events which could result in releases of radioactive products or unacceptable increases in direct radiation. In addition, the releases postulated as the result of the hypothetical accidents described in Chapter 11 are of a very small magnitude. Therefore, radiological alarm systems are not necessary. However, as described in Section 2.3.3.1, nonsafety-grade pressure monitors are provided. Procedures to be followed when these alarms are activated will be specified in the ISFSI operating procedures.

2.3.6 Fire and Explosion Protection

There are no combustible or explosive materials associated with the TN-32 dry storage cask. In general, no such materials would be stored within an ISFSI controlled area. The quantity of fuel carried in a tow vehicle will be limited to 200 gallons, so that only a fire of short duration would be possible. An evaluation of the cask engulfed in a fuel fire is discussed in Section 11.2.5. Due to the large thermal mass of the casks, any minor fires in the vicinity of the ISFSI would raise the cask temperature by only a few degrees and will not affect cask integrity.

As indicated in Section 11.2.4, overpressures of a few psi can be conservatively postulated to occur at the ISFSI as a result of accidents involving explosive materials which are stored or transported near the site. This impact is less than that postulated to result from the tornado wind loading and missile impact analysis, as described in Section 2.2.1, and is well within the design basis of the cask.

2.4 Decommissioning Considerations

The dry cask design concept to be utilized at the ISFSI features inherent ease and simplicity of decommissioning. At the end of its service lifetime, cask decommissioning could be accomplished by one of several options described below.

The casks, including the spent fuel stored inside, could be shipped to a suitable fuel repository for permanent storage. Depending on licensing requirements existing at the time of shipment off site, placement of the entire cask inside a supplemental shipping container or overpack would be considered.

The spent fuel could be removed from the ISFSI cask and shipped in a licensed shipping container to a suitable fuel repository. If desirable, cask decontamination could be accomplished through the use of conventional high pressure water sprays to further reduce contamination on the cask interior. The sources of contamination on the interior of the cask would be crud from the outside of the fuel pins and the crud left by the spent fuel pool water. The expected low levels of contamination from these sources could be easily removed with a high pressure water spray. After decontamination, the ISFSI cask could either be cut-up for scrap or partially scrapped and any remaining contaminated portions shipped as low level radioactive waste to a disposal facility.

For surface decontamination of the ISFSI cask, chemical etching using hydrochloric acid or nitric acid can be applied to remove the contaminated surface of the cask. Alternatively, electropolishing can also be used to achieve the same result.

Cask activation analyses have been performed to quantify specific activity levels of cask materials after years of storage. The following assumptions were made:

- The cask contains 32 design basis PWR assemblies.
- The neutron flux is assumed constant for 20 years.

The cask activation analyses are presented in Chapter 14. The results of these calculations show that the TN-32 will be far below the specific activity limits for both long and short lived nuclides for Class A waste. Consequently, it is expected that after application of the surface decontamination process as described above, the radiation level due to activation products will be negligible and the cask could be disposed of as Class A waste. A detailed evaluation will be performed at the time of decommissioning to determine the appropriate method of disposal.

Due to the leak tight design of the storage casks, no

residual contamination is expected to be left behind on the concrete base pad. The base pad, fence, and peripheral utility structures will require no decontamination or special handling after the last cask is removed.

If the spent fuel pool is to remain functional until the ISFSI is decommissioned, it will allow the pool to be utilized to transfer fuel from the storage casks to licensed shipping containers for shipment off site if this decommissioning option is chosen.

Due to the design of the storage casks and exterior decontamination prior to storage, no residual contamination will be left behind on the concrete base pad.

The volume of waste material produced incidental to ISFSI decommissioning will be limited to that necessary to accomplish surface decontamination of the casks once the spent fuel elements are removed.

The costs of decommissioning the ISFSI are expected to represent a small and negligible fraction of the cost of the decommissioning a Nuclear Generating Plant.

2.5 Summary of Cask Design Criteria

The principal design criteria for the TN-32 cask are presented in Table 2.5-1. The TN-32 dry storage cask is designed to store 32 intact PWR spent fuel assemblies with or without burnable poison rod assemblies or thimble plugs with a maximum assembly average burnup of 45,000 MWD/MTU, maximum initial enrichment of 4.05% and a minimum cooling time of 7 years.

The maximum total heat generation rate of the stored fuel (including BPRA'S and TPA's) is limited to 32.7 kW in order to keep the maximum fuel cladding temperature below the limit necessary to ensure cladding integrity for 40 years storage[12]. The fuel cladding integrity is assured by the limited fuel cladding temperature and maintenance of a nonoxidizing environment in the cask[17].

The confinement vessel (body and lid) is designed and fabricated to the maximum practicable extent as a Class I component in accordance with the rules of the ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, Articles NB-3200. Deviations to the code are listed in Chapter 7. The cask design, fabrication and testing are covered by a Quality Assurance Program which conforms to the criteria in Subpart G of 10CFR72.

The cask is designed to maintain a subcritical configuration during loading, handling, storage and accident conditions. Poison materials in the fuel basket are employed to maintain k_{eff} $\leq$ 0.95 including statistical uncertainties. The TN-32 cask is designed to withstand the effects of severe environmental conditions and natural phenomena such as earthquakes, tornadoes, lightning, hurricanes and floods. Chapter 11 describes the cask behavior under these environmental conditions.

2.6 References

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TABLE 2.1-1

FUEL ASSEMBLY PARAMETERS

Parameter	W14x14	W14x14 OFA	W15x15	W17x17	B&W 17x17 Mark BW	W17x17 OFA
Number of Rods	179	179	204	264	264	264
Cross Section (in.)	7.761x7.761	7.761x7.761	8.426x8.426	8.426x8.426	8.425x8.425	8.426x8.426
Length (in.)	161.3	161.3	160	160	160	160
Fuel Rod Pitch (in.)	0.556	0.556	0.563	0.496	0.496	0.496
Fuel Rod O.D. (in.)	0.422	0.400	0.422	0.374	0.374	0.360 in.
Clad Material	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy	Zircaloy
Clad Thickness (in.)	0.0243	0.0243	0.0243	0.0225	0.0240	0.0225
Pellet O.D. (in.)	0.3659	0.3444	0.366	0.322	0.3195	0.309
U^{235} Enrichment (%wt)	4.05	4.05	4.05	4.05	4.05	4.05
Theoretical Density (%)	95.0	95.0	95.0	95.0	96.0	95.0
Active Fuel Length (in.)	144	144	144	144	144	144
U Content, nominal (kg)	410	360	459	461	456	423
U Content, maximum (kg)[1]	414.4	361.1	467.1	467.1	463.2	428.2
Assembly Weight (lbs)	1300	1150	1439	1467	1470	1380
Assembly Weight including heaviest BPRA (lbs)	1345	1195	1525	1533	1533[(2)]	1446

Notes:

1. Calculated from criticality analysis presented in Chapter 6
2. Mark BW fuel with a B&W 24 finger BPRA weighs more than 1533 lb. Any combination of fuel and hardware which weighs more than 1533 lb is not acceptable for storage in the TN-32.

TABLE 2.1-2

THERMAL, GAMMA AND NEUTRON SOURCES FOR

THE DESIGN BASIS 17 x 17 WESTINGHOUSE FUEL ASSEMBLY

U^{235} Enrichment (%wt)	3.5 (minimum)
Burnup (MWD/MTU)	45,000
Specific Power (MW/assembly)	20
Cooling Time (year)	7 (minimum)
Decay Heat (kw/assembly)	0.986
Gamma Source (photons/sec/assembly)	5.080E15
Neutron Source (neutrons/sec/assembly)	3.278E8

TABLE 2.1-3

COOLING TIME AS A FUNCTION
OF MAXIMUM BURNUP AND MINIMUM INITIAL ENRICHMENT

Initial Enrichment (% wt)	Burnup (GWd/MTU)																
	15	20	30	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1.2	7	7															
1.3	7	7															
1.4	7	7															
1.5	7	7	7	**8**	8	8	**8**	9									
1.6	7	7	7	7	8	8	8	9	9	9	9						
1.7	7	7	7	7	**8**	8	8	**8**	9	**9**	9	10					
1.8	7	7	7	7	7	8	8	8	9	9	9	**10**					
1.9	7	7	7	7	7	7	8	8	**8**	9	9	9	10	10			
2.0	7	7	7	**7**	7	7	**8**	8	8	8	**9**	9	**9**	10	**10**		
2.1	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10		
2.2	7	7	7	7	7	7	7	7	8	**8**	8	**9**	9	**9**	10	10	
2.3	7	7	7	7	7	7	**7**	7	**8**	8	8	9	9	9	**10**	10	
2.4	7	7	7	7	7	7	7	7	8	8	8	**8**	9	9	9	10	10
2.5	7	7	7	7	7	7	7	7	7	**8**	8	8	8	**9**	9	9	**10**
2.6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	10
2.7	7	7	7	7	7	7	7	7	7	7	8	**8**	8	8	9	**9**	9
2.8	7	7	7	7	7	7	7	7	7	7	8	8	8	**8**	9	9	9
2.9	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9
3.0	7	7	7	7	7	7	7	7	7	7	7	**7**	8	8	**8**	9	**9**
3.1	7	7	7	7	7	7	7	7	7	7	7	7	8	**8**	8	9	9
3.2	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8
3.3	7	7	7	7	7	7	7	7	7	7	7	7	**7**	7	8	**8**	8
3.4	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8
3.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	**7**
3.6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.9	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
4.05	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

■ - not evaluated

* Cooling times entered in bold are cases actually run. Other values interpolated.

TABLE 2.1-4

THERMAL AND GAMMA SOURCES FOR

BURNABLE POSION ROD ASSEMBLIES AND THIMBLE PLUG ASSEMBLIES

<u>BURNABLE POISON ROD ASSEMBLY</u>

Cumulative Exposure (MWD/MTU)	See Figure 2.1-4
Cooling Time (days)	See Figure 2.1-4
Decay Heat (kw/assembly)	0.036
Gamma Source (photons/sec/assembly)	2.302E14

<u>THIMBLE PLUG ASSEMBLY</u>

Cumulative Exposure (MWD/MTU)	See Figure 2.1-5
Cooling Time (days)	See Figure 2.1-5
Decay Heat (kw/assembly)	0.00189
Gamma Source (photons/sec/assembly)	3.922E12

TABLE 2.2-1

SUMMARY OF INTERNAL AND EXTERNAL PRESSURES
ACTING ON TN-32 CASK

Individual Loading Conditions	Maximum Pressure, psig
Internal Pressure:	
(a) Initial cavity pressurization at backfill	17.6 (2.2 atm abs)
(b) With 10% fuel failure	25.1
(c) In a minor fire (assuming 100% fuel failure)	58.4
(d) Beginning of life unloading	90
(e) Tornado	3*
(f) Selected bounding pressure	100
External Pressure:	
(a) Flood	25
(b) Snow and ice loading	0.35
(c) Selected bounding pressure	25

*This is due to a reduced external pressure.

TABLE 2.2-2

SUMMARY OF LIFTING LOADS USED IN TRUNNION
ANSI N14.6 ANALYSIS OF TN-32 CASK

Loading Condition		Load at Cask CG (Vertical)	Load at Each Trunnion
TN-32 and TN-32A Casks[1]	Yield Evaluation	729,000 lbs	364,500 lbs
	Ultimate Evaluation	1,215,000 lbs	607,500 lbs
TN-32B cask[2]	Yield Evaluation	1,603,800 lbs	801,900 lbs
	Ultimate Evaluation	2,673,000 lbs	1,336,500 lbs

NOTES:

1. Based on a cask weight of 243,000 lbs (Calculated cask weights are 230,990 lbs and 231,220 lbs)
2. Based on a conservative cask weight of 243,000 lbs and a 10% dynamic load factor (Calculated cask weight is 231,160 lbs)

TABLE 2.2-3

SUMMARY OF LOADS ACTING ON TN-32 CASK DUE
TO ENVIRONMENTAL AND NATURAL PHENOMENA

Distributed Loads

Lateral Loading:

(a) Wind (external force on cask body)	45,500 lb.
(b) Seismic (inertial force throughout system) 0.26W =	56,680 lb.[2]
Selected Bounding Load W x 1G =	218,000 lb.[2]

Vertical Loading[1]:

(a) Seismic (inertial force throughout system) 0.17W =	37,060 lb.[2]
Selected Bounding Load W x 1G =	218,000 lb.[2]

Local Loads

Tornado Missile Loading (external force on local area of body):

(a) Lateral Load	1.603×10^6 lb.
(b) Vertical Load	$<1.603 \times 10^6$ lb.

NOTE:

1. Does not include dead weight or lifting loads
2. A conservatively low weight is used for stability analysis. The actual weight of the cask is used for stress analysis.

TABLE 2.2-4

TN-32 CASK LOADING CONDITIONS

Normal

Assembly Loads (bolt preload and seal compression)
Pressure (internal and external)
Weight
Lifting Loads
Handling
Wind
Thermal variations (e.g. insolation, decay heat, rain, snow, ice, ambient)

Man-Made

Fuel cladding failure
Minor Fire
Explosion

Natural Phenomena

Earthquakes
Tornados
Hurricane
Flood
Tsunami
Seiches
Lightning

TABLE 2.2-5

TN-32 CASK DESIGN LOADS
(Normal Conditions)

Applied Load	Loading Condition
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask Body Contents
	Snow
	Ice
	Wind (Tornado)
	Lifting
Attachment Loads	Lifting
Bolt Loads	Preload for 100 psi and metallic seal compression

(1) Cask designed for 100 psi internal pressure which envelopes all internal pressure effects.

(2) For normal conditions, the fission gas release should be less than 10%. However, for analysis purposes, 100% release is assumed.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects.

TABLE 2.2-6

LEVEL A SERVICE LOADS
(Normal Conditions)

Applied Load	Loading Condition
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask Body Contents
	Snow
	Ice
	Wind (Tornado)
	Lifting
Attachment Loads	Lifting
Bolt Loads	Preload for 100 psi and metallic seal compression
Thermal Effects	Decay Heat
	Solar Insolation
	Cold Rain on Hot Cask

(1) Cask designed for 100 psi internal pressure which envelopes all internal pressure effects.

(2) For normal conditions, the fission gas release should be less than 10%. However, for analysis purposes, 100% release is assumed.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects.

TABLE 2.2-7

LEVEL D SERVICE LOADS

Load	Cause
Internal Pressure	(1) and (2)
External Pressure	(3)
Distributed Loads	Weight Cask body Contents
	Tornado Wind
	Flood Water
	Seismic
Local Loads	Tornado Wind Driven Missiles
Bolt Loads	Preload for 100 psi and metallic seal compression
50G Bottom Impact	18" and 60" Vertical Drop (Handling Accident)
50G Side Impact	Tipover

(1) Cask design for 100 psi internal pressure which envelopes all internal pressure effects.

(2) The fission gas release should be less than 10%. However, for analysis purposes, 100% release is assumed.

(3) Cask designed for 25 psi external pressure which envelopes all external pressure effects including flood water level, cask burial and explosion. Explosions close to the cask are unexpected. Explosions at a significant distance from the cask would have a negligible effect.

TABLE 2.2-8
NORMAL CONDITION LOAD COMBINATIONS

INDIVIDUAL LOAD / COMBINED LOAD	BOLT PRELOAD	1G DOWN	INTERNAL PRESSURE 100 PSI	EXTERNAL PRESSURE 25 PSI	THERMAL	3G or 6G ON TRUNNION	TRUNNION LOCAL STRESS 3G or 6G
N1	X	X	X		X		
N2	X		X		X	X(1)	X(1)
N3	X	X		X			
N4	X	X		X	X		
N5	X			X	X	X(1)	X(1)
N6	X		X		X	X(2)	X(2)
N7	X			X	X	X(2)	X(2)

Notes:
1. Load combination based on 3G lifting weight (TN-32 & TN-32A Casks)

2. Load combination based on 6G lifting weight (TN-32B Cask)

TABLE 2.2-9

ACCIDENT CONDITION LOAD COMBINATIONS

INDIVIDUAL LOAD / COMBINED LOAD	BOLT PRELOAD	INTERNAL PRESSURE 100 PSI	EXTERNAL PRESSURE 25 PSI	18" BOTTOM END DROP 50G	TIP OVER SIDE DROP 50G	SEISMIC, TORNADO, OR FLOOD 1G-LATERAL + 2G-DOWN
A1	X	X		X		
A2	X		X	X		
A3	X	X			X	
A4	X		X		X	
A5	X	X				X
A6	X		X			X

TABLE 2.3-1

CLASSIFICATION OF COMPONENTS

IMPORTANT TO SAFETY	**NOT IMPORTANT TO SAFETY**

Containment Vessel
    Cask Body Shell
    Cask Body Bottom
    Lid
    Lid Bolts
    Lid Gaskets
Lid Vent and Drain Covers, Bolts, Gaskets
Basket Assembly
Trunnions
Radial Neutron Shield
Protective Cover
	Overpressure System
	Drain Tube
	Hansen Couplings
	Paint
	Top Neutron Shield
	Protective Cover Seal

TABLE 2.5-1

DESIGN CRITERIA FOR TN-32 CASKS

Maximum gross weight on crane (with lift beams, without water)	120 tons
Maximum cask height with lid removed	179.5 in.
Minimum design life	40 years
Maximum k_{eff}, including bias and uncertainties	<0.95 Normal <0.95 Accident
Payload Capacity, Fuel assemblies	32 intact W PWR 14x14, 14x14 O.F.A. 15x15, 17x17,17x17 O.F.A. or B&W 17x17 Mark BW with or without BPRA's or TPA's 1533 lb maximum
Spent Fuel Characteristics	
a) Initial Enrichment	4.05%
b) Burnup (max)	45,000 MWD/MTU
c) Cooling time (min)	7 years
d) Decay Heat	32.7 kw (total including BPRA'S or TPA'S)
Max Clad Temperature	328°C
Cask Cavity Atmosphere	Helium gas
Maximum Internal Pressure	100 psig
Ambient Temperature	-30 to 115°F
Daily Averaged Ambient Temperature Over 24 hr. period (min-max)	-20 to 100°F
Maximum Solar Heat Load	2950 BTU/ft^2 (Flat Surfaces) 1474 BTU/ft^2 (Curved Surfaces)
Tornado Wind	290 mph rotational 70 mph translational
Tornado Missiles	1800 kg auto 125 kg 8 in. armor piercing shell 1 in. solid steel sphere
Cask Drop	18" Drop and 5' Drop
Cask Tip	Tip onto ISFSI pad
Seismic Design Earthquake	0.26 g horizontal 0.17 g vertical
Snow and Ice	50 psf load

FIGURE 2.1-1

Decay Heat
Westinghouse 17x17 Standard Fuel Assembly
3.5 wt% U-235 Minimum Initial Enrichment
45,000 MWD/MTU

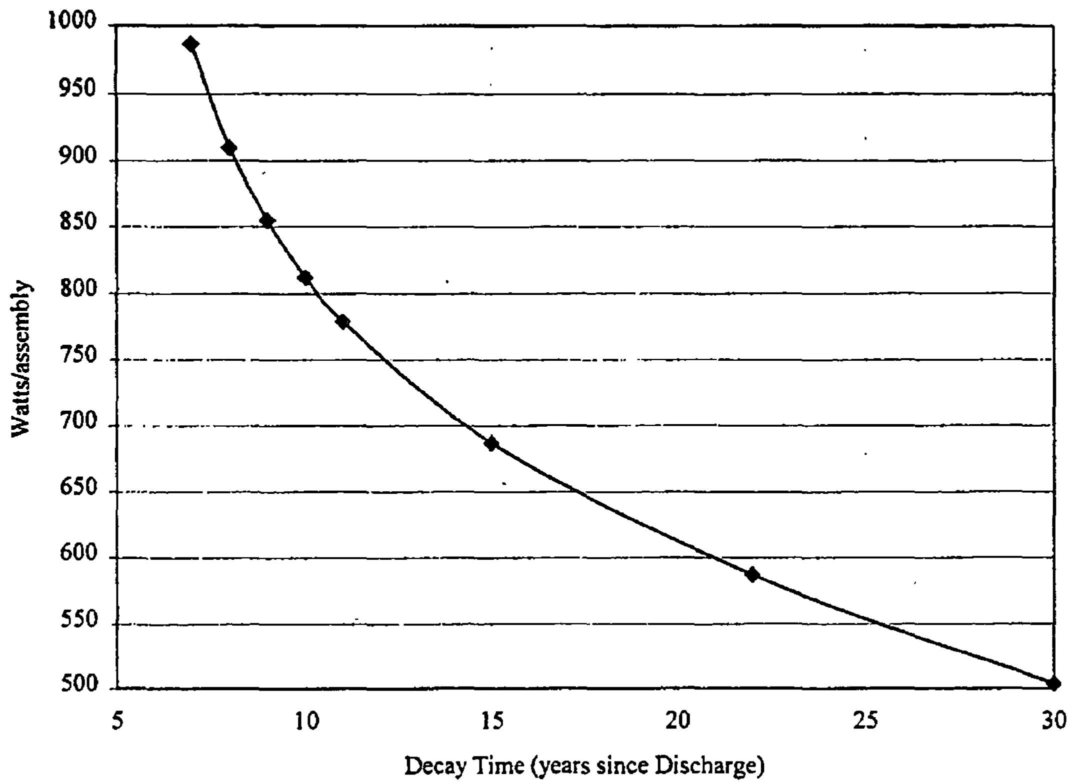


FIGURE 2.1-2

Gamma Source
Westinghouse 17x17 Standard Fuel Assembly
3.5 wt% U-235 Minimum Initial Enrichment
45,000 MWD/MTU

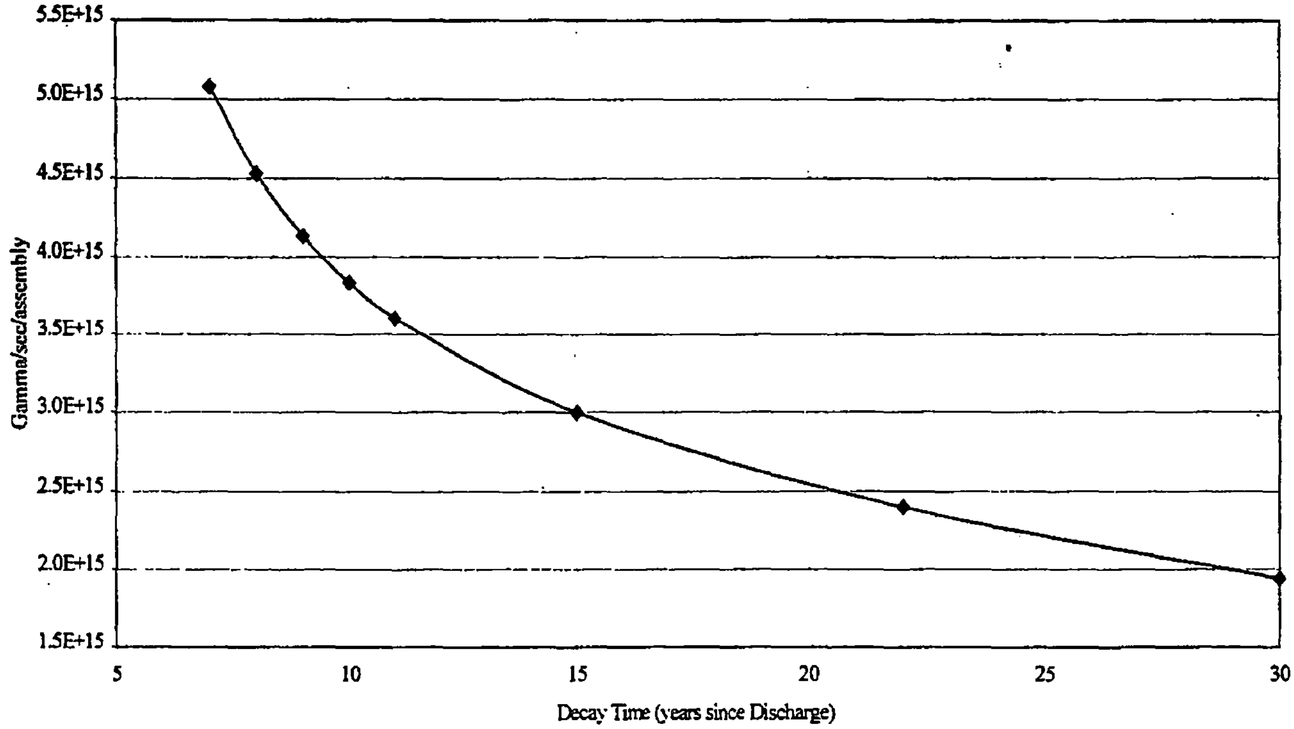


FIGURE 2.1-3

Neutron Source
Westinghouse 17x17 Standard Fuel Assembly
3.5 wt% U-235 Minimum Initial Enrichment
45,000 MWD/MTU

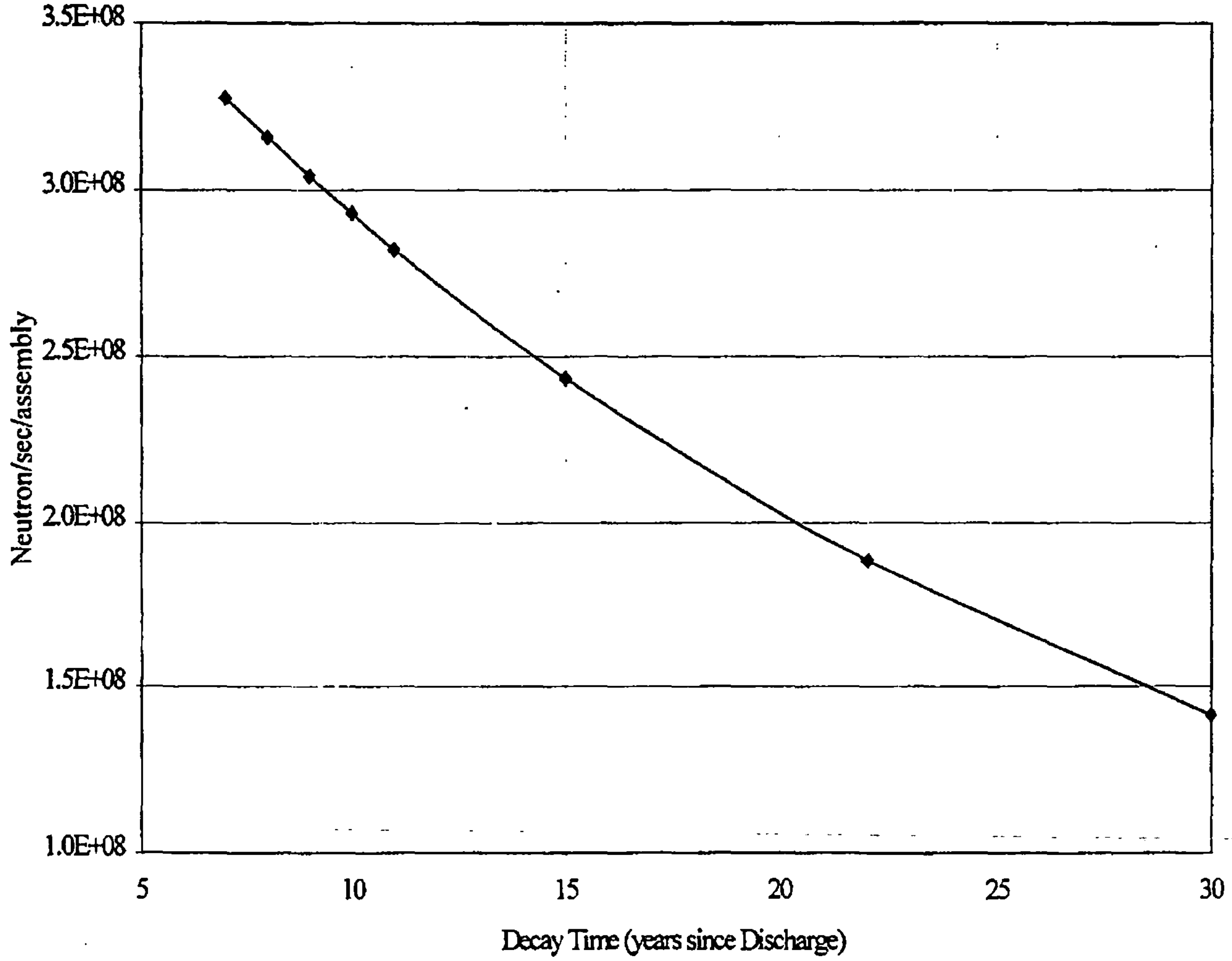


FIGURE 2.1-4
BPRAs PERMISSIBLE FOR STORAGE IN THE TN-32 CASK

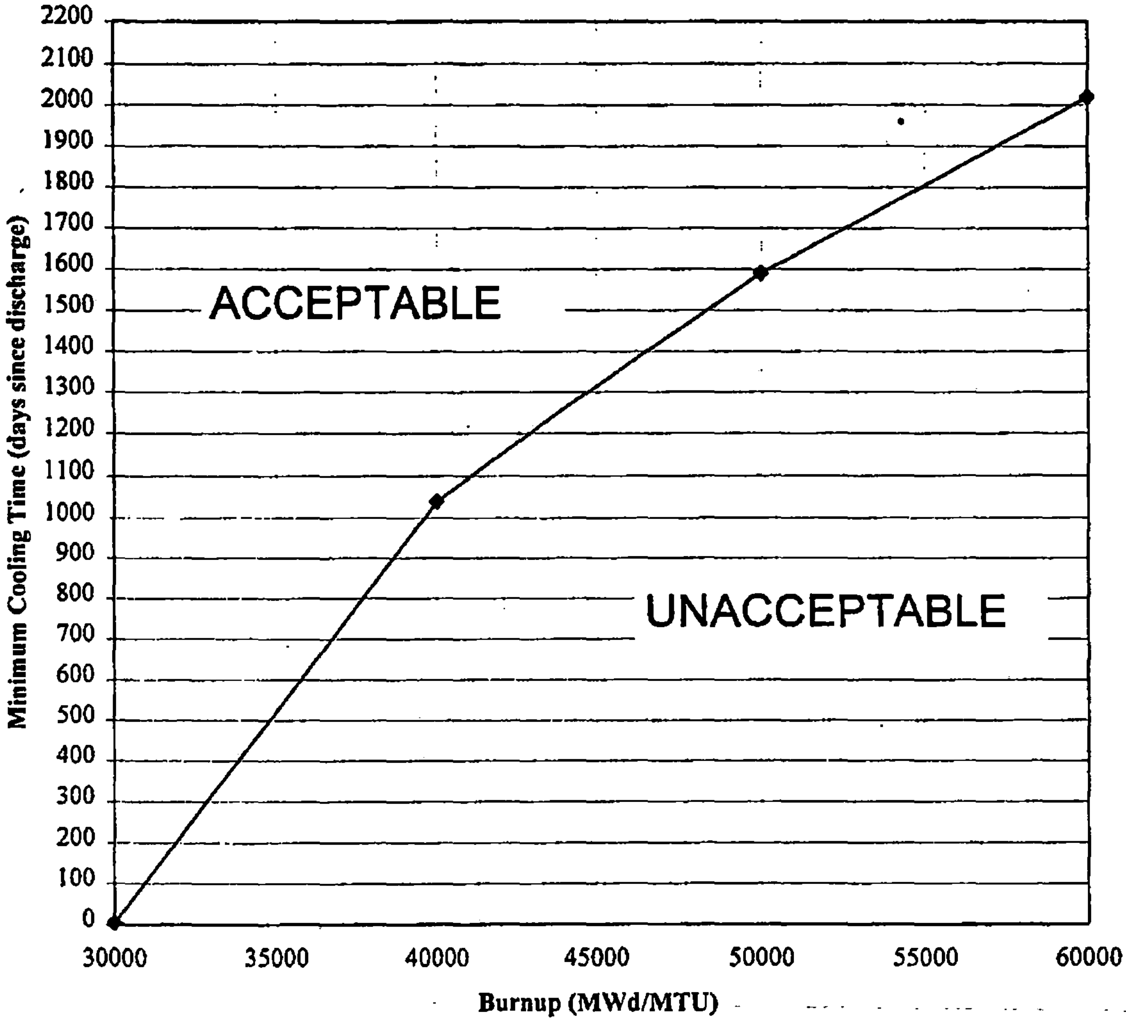


FIGURE 2.1-5
TPAs PERMISSIBLE FOR STORAGE IN THE TN-32 CASK

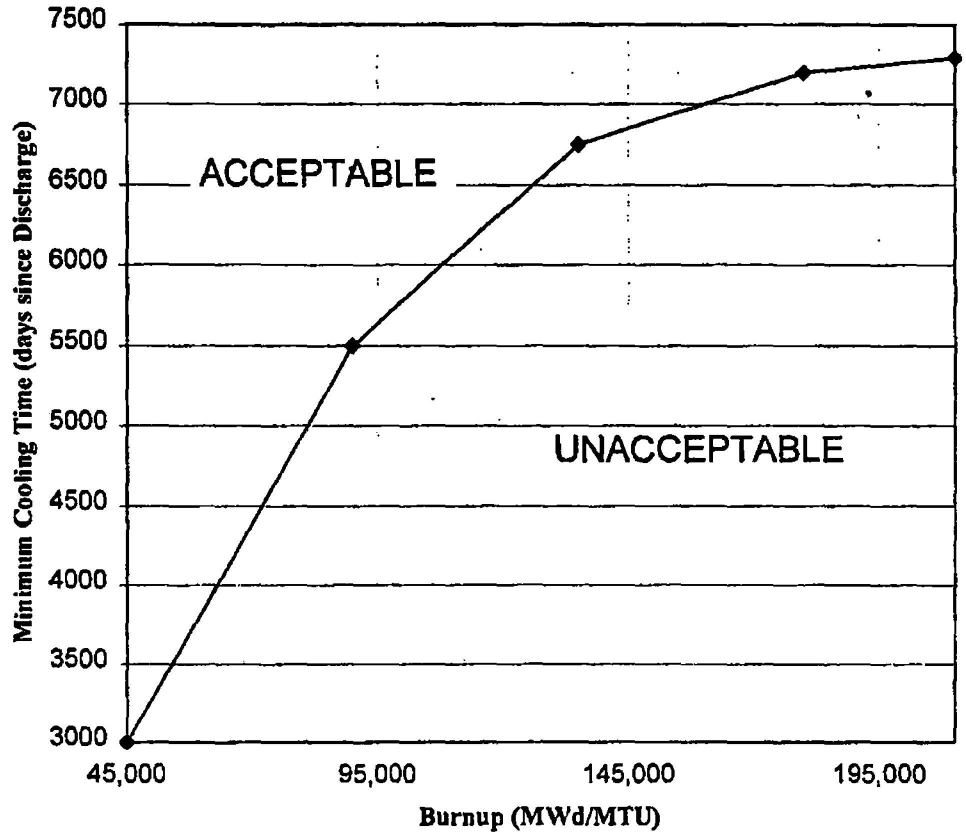
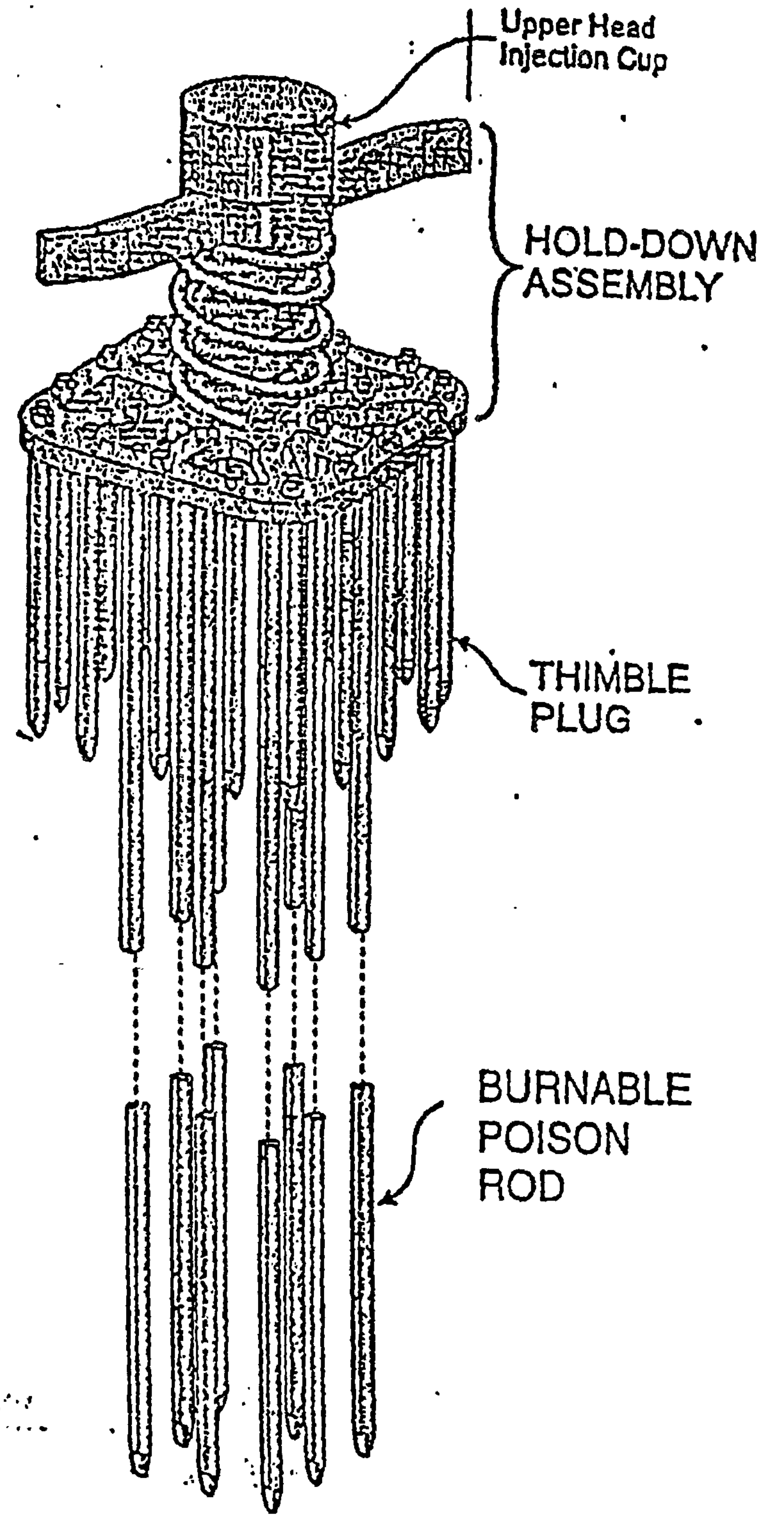


FIGURE 2.1-6
Burnable Poison Rod Assembly, Upper Head Injection Reactor



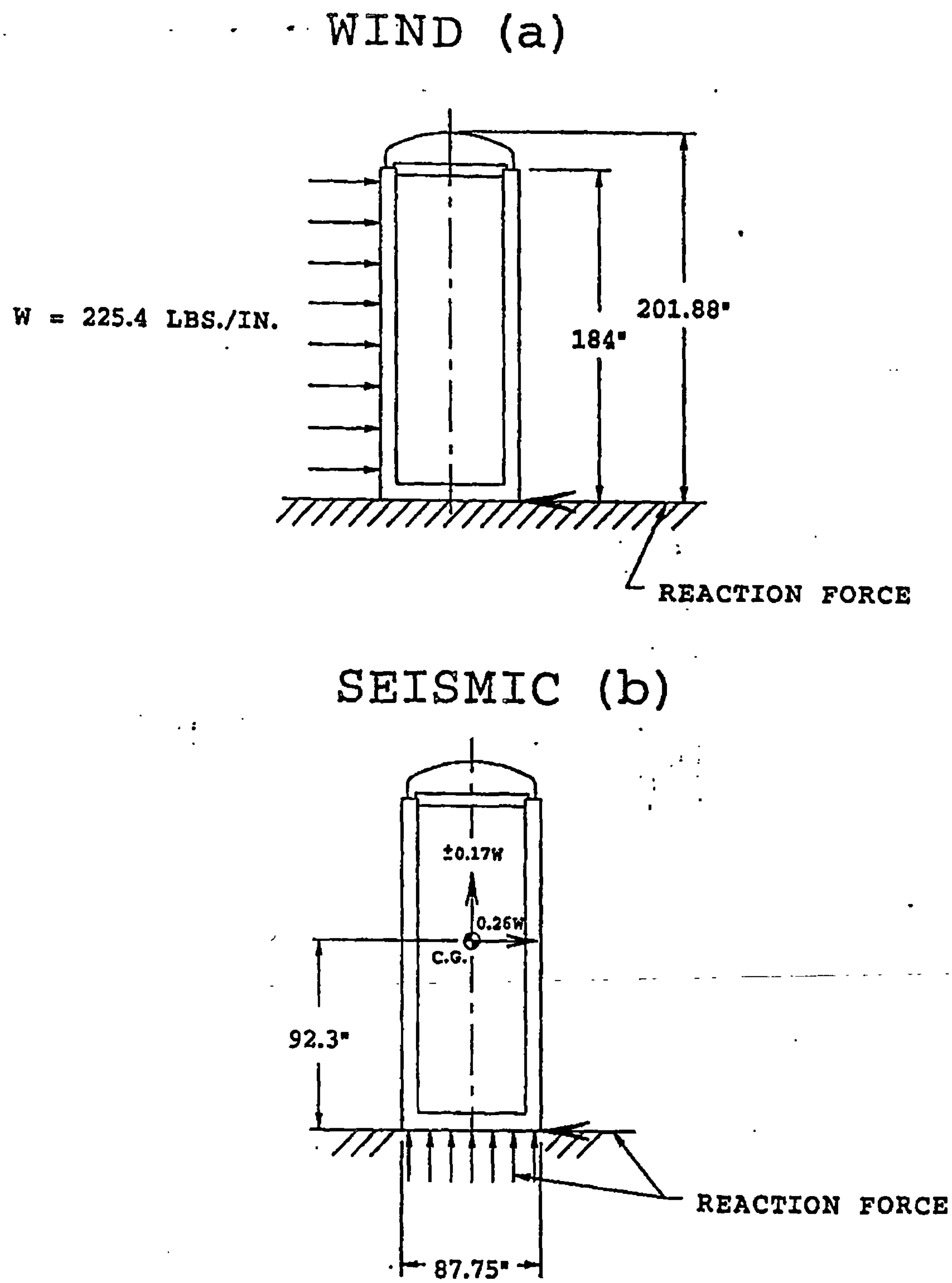


FIGURE 2.2-1
EARTHQUAKE AND WATER LOADS

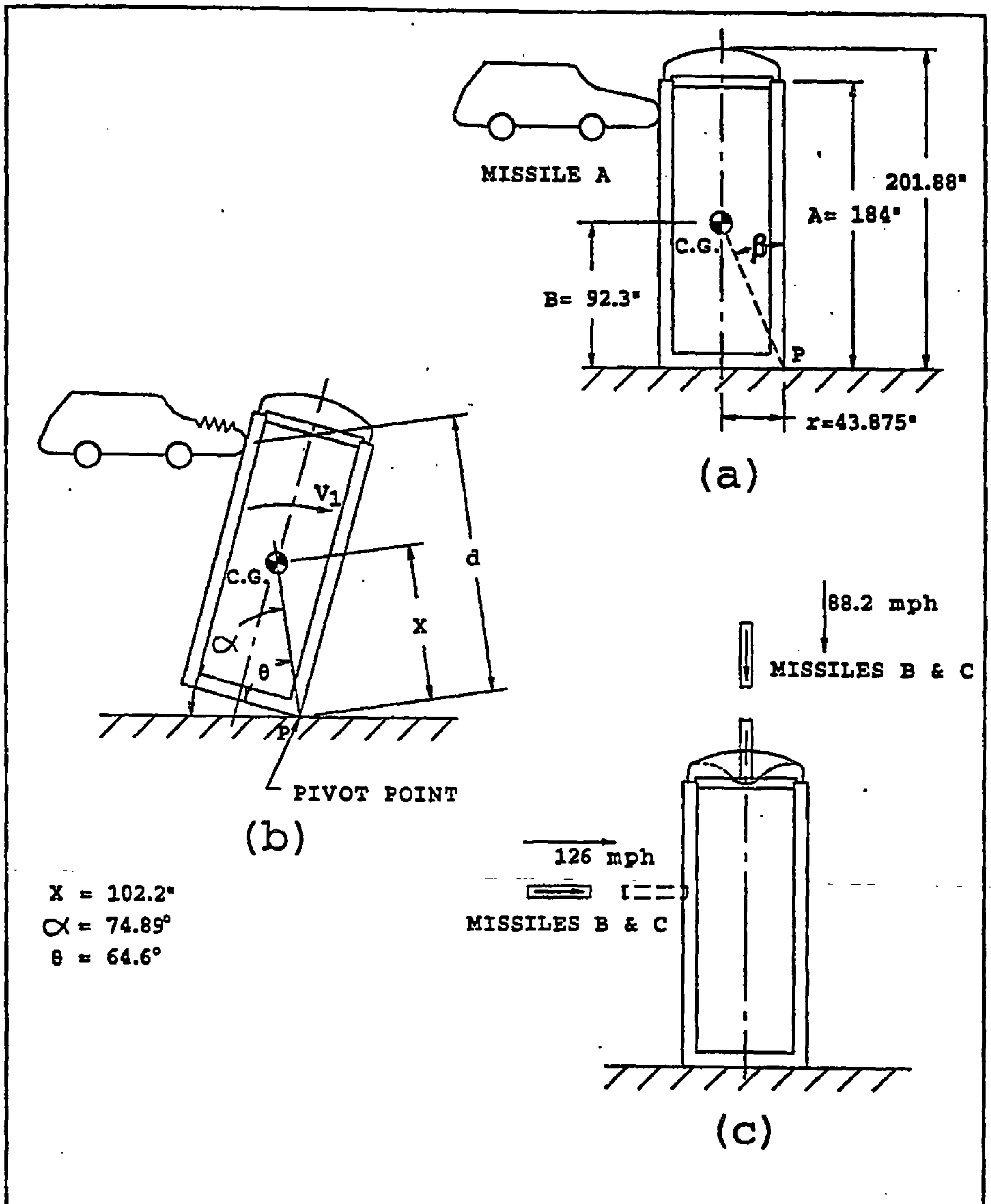


FIGURE 2.2-2
TORNADO MISSILE IMPACT LOADS

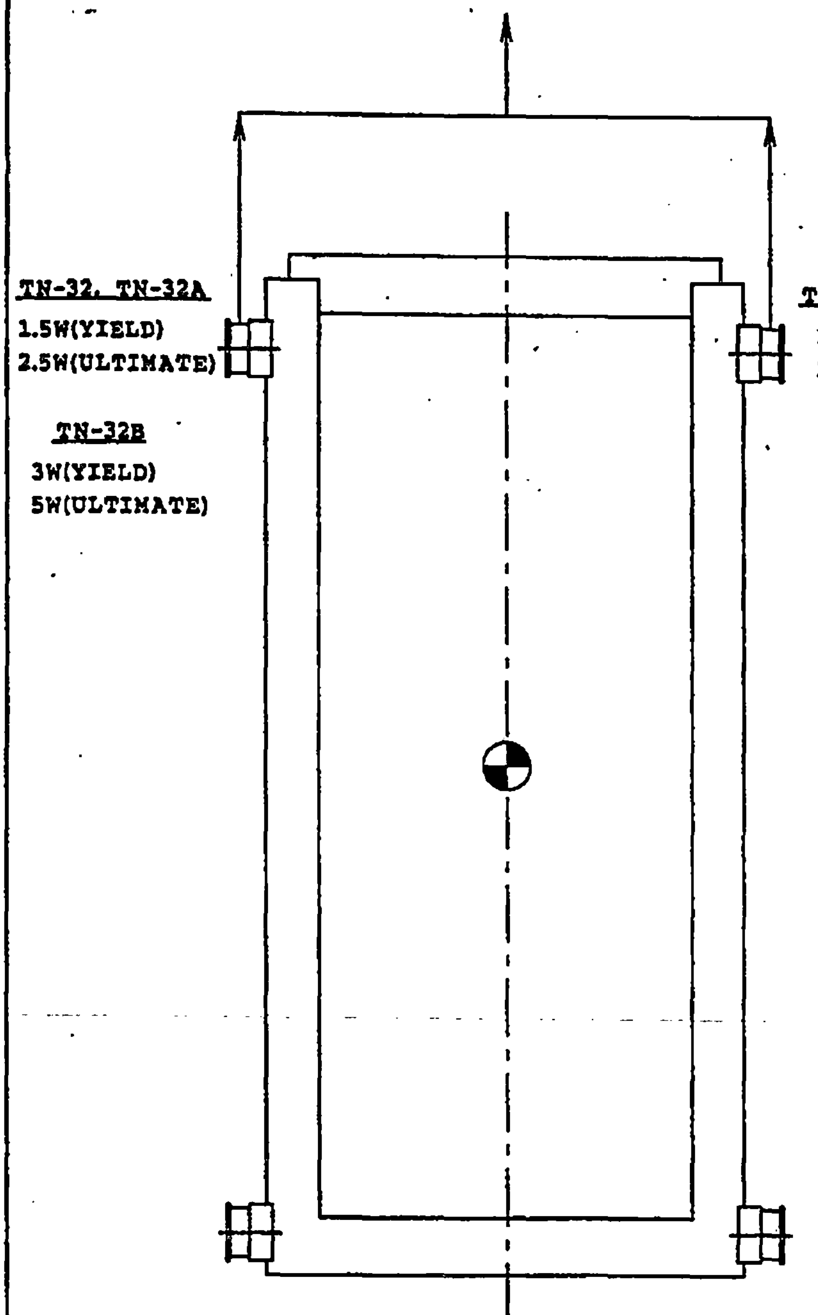


FIGURE 2.2-3
LIFTING LOADS

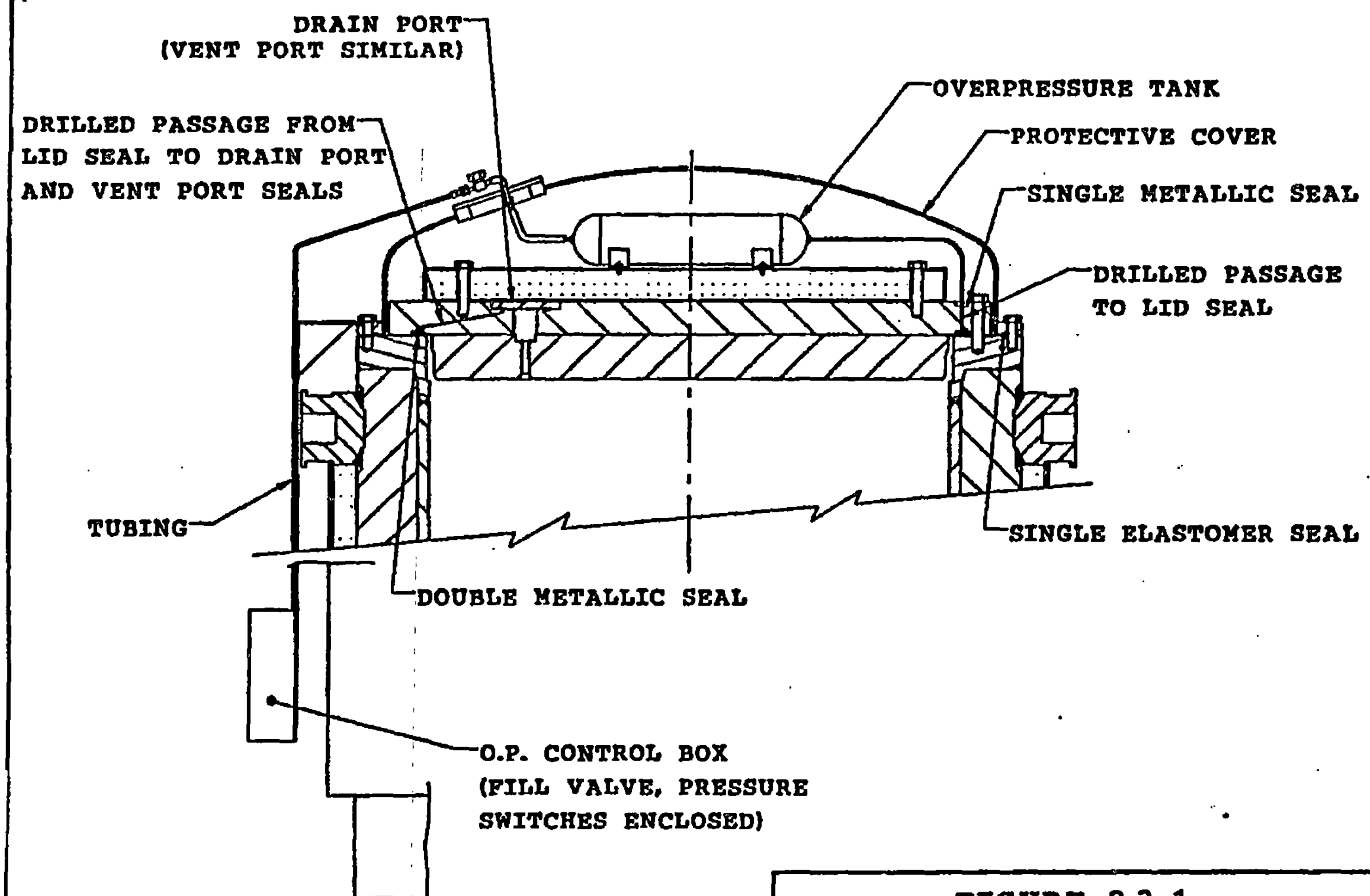


FIGURE 2.3-1

TN-32 CASK SEAL
PRESSURE MONITORING SYSTEM

REV. 0 1/00

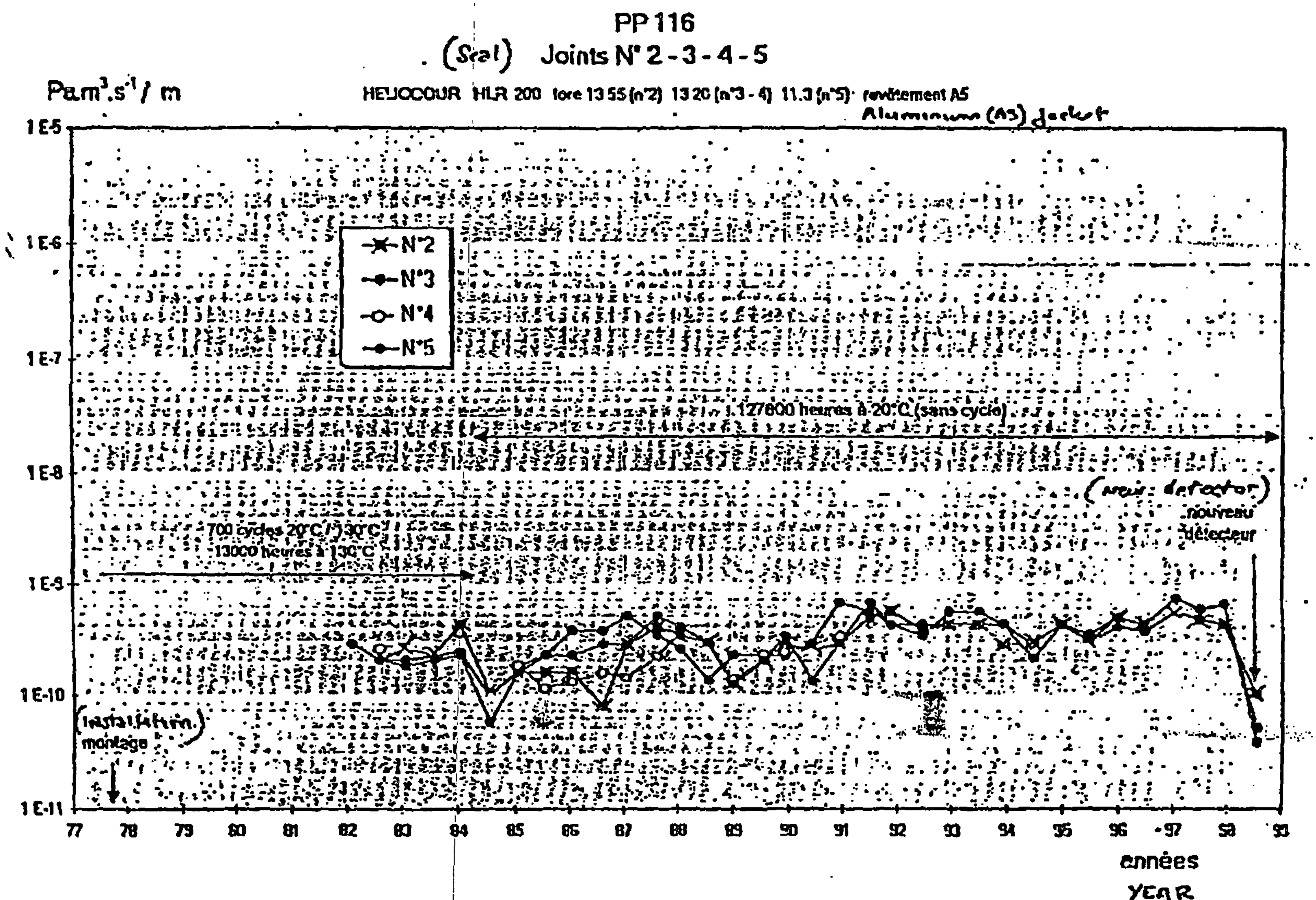


FIGURE 2.3-2
Long Term Leak Test Results on Metallic Seals

REV. 0 1/00

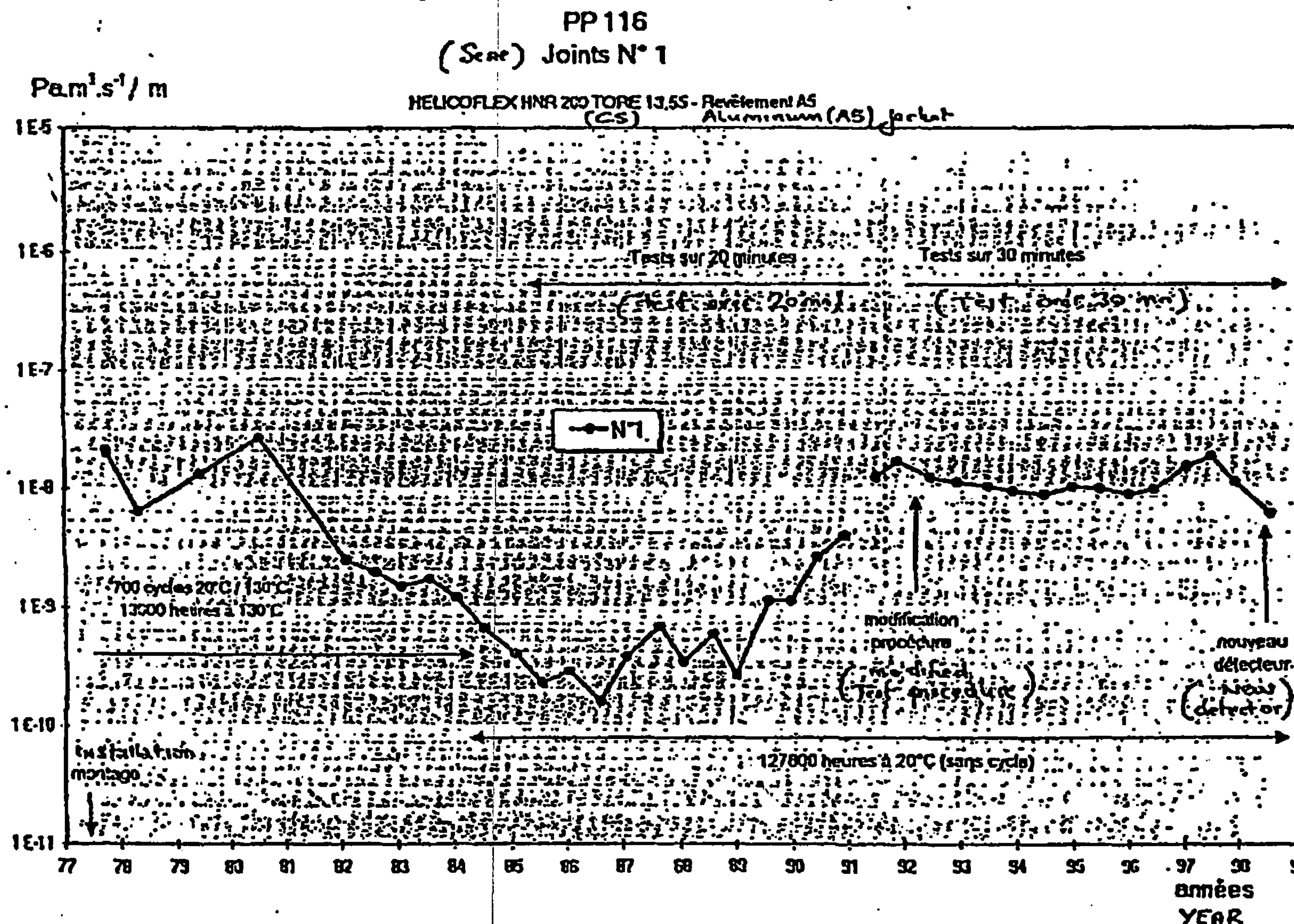


Figure 2.3-3
Long Term Leak Test Results on Metallic Seals

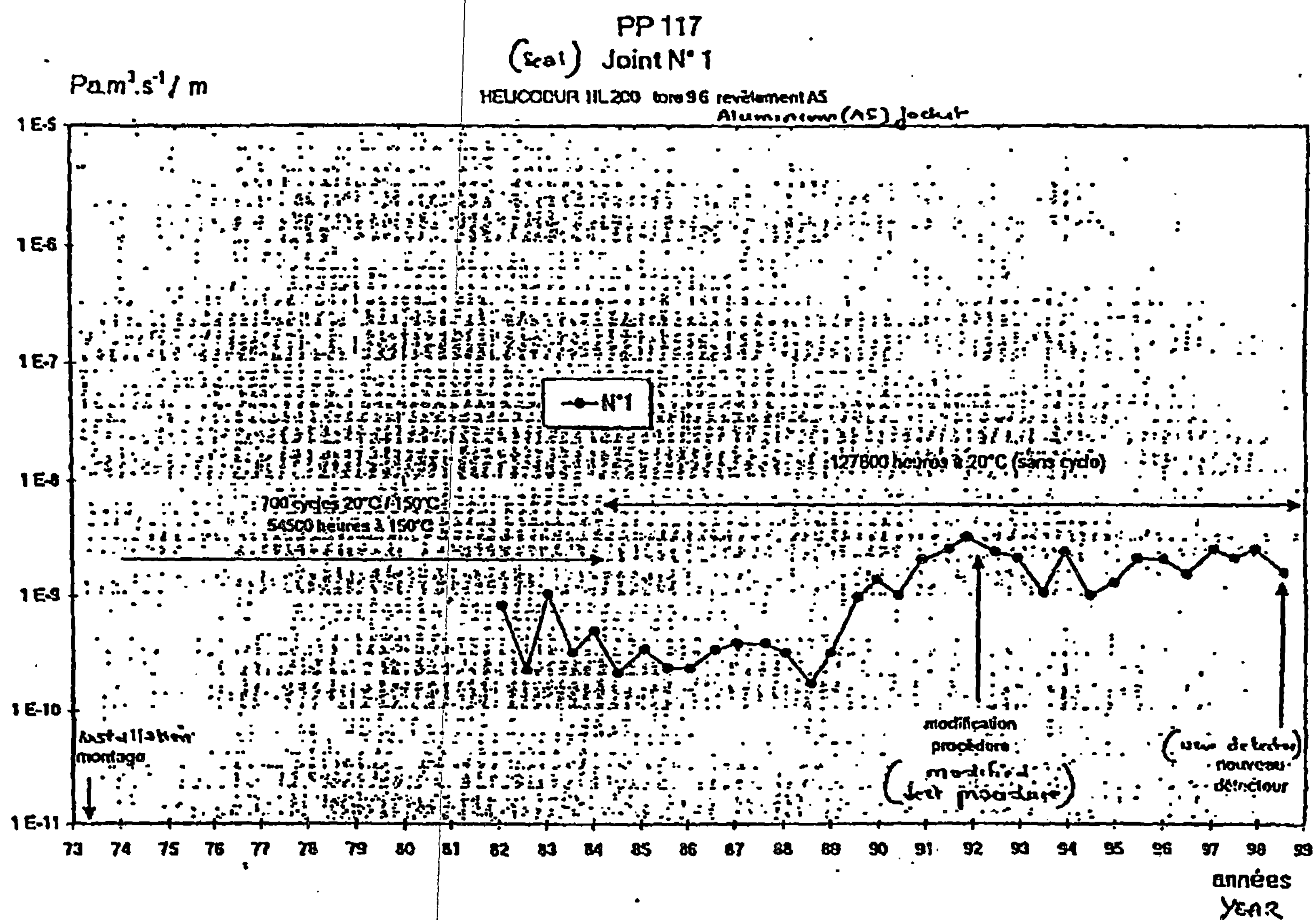


Figure 2.3-4
Long Term Leak Test Results on Metallic Seals

CHAPTER 3

STRUCTURAL EVALUATION

3.1 Structural Design

3.1.1 Discussion

This section summarizes the structural analysis of the TN-32 storage cask. For purposes of structural analysis, the cask has been divided into four components: the cask body (consisting of Confinement vessel and gamma shielding), the basket, the trunnions and the neutron shield outer shell. The following information is provided: a brief description of the components, the design bases and criteria, the method of analysis, a summary of stresses for the highest stressed locations, and a comparison with the allowable stress criteria.

The cask body is described in detail in Section 1.2. Drawings 1049-70-1, 1049-70-2 and 1049-70-3 show the cask body. The confinement shell, bottom and lid materials are SA-203, Grade D and SA-350 Grade LF3. The gamma shield cylinder is SA-266, Grade 2, the top shield plate is SA-105 or SA-516, Gr. 70 and the bottom shield plate is SA-266 Grade 2 or SA-516-70.

In order to obtain a close fit between the confinement vessel and the gamma shielding for heat transfer, the gamma shielding is heated prior to assembly with the confinement shell. As the gamma shielding cools, a gap forms between the confinement vessel flange and the gamma shielding. This gap is filled with shims as shown on Drawing 1049-70-3. The shims are machined to fill the gap and act as a backing plate for the 0.50 inch weld between the Confinement 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, Gr. 70, SA-414, or SA-620. 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.

The TN-32 confinement vessel is designed, fabricated, examined and tested in accordance with the requirements of Subsection NB of the ASME Code[1] to the maximum practical extent. The confinement boundary, which consists of the inner shell and bottom plate, shell flange, lid outer plate, lid bolts, vent and drain cover plates and bolts, is of particular interest. The Confinement boundary welds are full penetration welds examined volumetrically by radiograph. These welds are also liquid penetrant or magnetic particle examined. The acceptance standards are in accordance with Article NB-5000.

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[1]. Acceptance standards are in accordance with Section III,

Subsection NF, Paragraphs NF-5340 and NF-5350[1]. Seal welds are examined visually or by liquid penetrant or magnetic particle methods in accordance with Section V of the ASME Code[1]. Stainless steel overlay welds are examined by the liquid penetrant method in accordance with Section V of the ASME Code. Electrodes, wire, and fluxes used for fabrication comply with the applicable requirements of the ASME Code, Section II, Part C[1]. The welding procedures, welders and weld operators are qualified in accordance with Section IX of the ASME Code[1].

The basket structure consists of an assembly of square 304 stainless steel fuel compartment boxes or cells attached together using cylindrical plugs welded to the walls of adjacent boxes. Trapped between the adjacent boxes are a layer of 6061-T6/T651 aluminum and a layer of borated aluminum. The stainless steel boxes and plugs effectively clamp and pin the aluminum thermal conductor plates and borated aluminum poison plates in place. The plugs are assembled through clearance holes in the aluminum and borated aluminum plates and are only welded to the stainless steel boxes. Drawings 1049-70-5 and 1049-70-6 show details of the basket.

The basket is supported laterally by 6061-T6 aluminum rails (shown in Drawing 972-70-2) which are either bolted directly to the cask wall (Item 26 rails) or bolted to bosses which are welded to the confinement shell using full penetration welds (Item 30 rails).

The trunnions are cylindrical SA-105 forgings that are welded to the cask body gamma shielding using full circumferential welds. The two upper trunnions are designed to lift the loaded TN-32 cask vertically. The lower trunnions provide capability to rotate the cask prior to loading of spent fuel. The upper trunnions are designed to meet the requirements of ANSI N14.6.[2] The upper trunnions for the TN-32 and TN-32A casks are evaluated for lifting 3 times the weight of the loaded cask before reaching the yield strength of materials and 5 times the weight of the cask before reaching the ultimate strength of the materials. The upper trunnions for the TN-32B cask are designed to be single failure proof and are evaluated for lifting 6 times the weight of the loaded cask before reaching the yield strength of the materials and 10 times the weight of the loaded cask before reaching the ultimate strength (including 10% of dynamic load factor). The trunnions are shown in Drawing 1049-70-2.

The outer shell of the neutron shield consists of a cylindrical shell section with closure plates at each end. The closure plates are welded to the outer surface of the cask body gamma shielding. 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 other structural function. The shell is metal-sprayed, and/or painted

carbon steel.

The top neutron shield consists of a disk of commercial grade polypropylene surrounded by a steel enclosure. The top neutron shield is attached to and rests on the cask lid. It is protected from the environment by the protective cover.

3.1.2 Design Criteria

This section describes the TN-32 analyses performed under the various loading conditions identified in Section 2.2. These loadings include all of the normal events that are expected to occur regularly. In addition, they include severe natural phenomena and man induced low probability events postulated because of their potential impact on the immediate environs. The loadings from the hypothetical tipover accident that are shown not to occur are also analyzed in this chapter.

Section 2.2.5 lists all of the TN-32 loadings in Table 2.2-4. These loads are described in detail in Section 2.2.5.2. The loads selected for analysis of the cask are discussed in Section 2.2.5.3. Numerical values of these loads are listed in Tables 2.2-2 and 2.2-3.

The TN-32 components have been evaluated under these loads through numerical analysis. Finite element models of the cask body and basket have been developed, and detailed computer analyses have been performed using the ANSYS computer program.[3] Other components such as the lid bolts and trunnions have been analyzed using conventional textbook methods. Table 3.1-1 lists the specific individual load cases analyzed for each major TN-32 component. The sections where these analyses are described and the tables listing the stress results, where applicable, are also indicated.

3.1.2.1 Confinement Boundary

The confinement boundary consists of the inner shell (both cylinder and bottom) and closure flange out to the seal seating surface and the lid assembly outer plate. The lid bolts and seals are also part of the confinement boundary. The Confinement boundary is designed to the maximum practical extent as an ASME Class I component in accordance with the rules of the ASME Code, Section III, Subsection NB. The Subsection NB rules for materials, design, fabrication and examination are applied to all of the above components to the maximum practical extent. Exceptions to the ASME code are discussed in Chapter 7.

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 confinement vessel components, other than bolts, for Normal (Design and Level A) and Hypothetical Accident (Level D) Loading Conditions are given in Table 3.1-2. The stress limits

used for Level D conditions, determined on an elastic basis, are based on the entire structure (confinement shell and gamma shielding material) resisting the accident loads. Local yielding is permitted at the point of contact where the load is applied. If elastic stress limits cannot be met, the plastic system analysis approach and acceptance criteria of Appendix F of Section III may be used. The limits for the confinement bolts are listed in Table 3.1-3.

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

3.1.2.2 Non- Confinement Structure

Certain components such as the gamma shielding, the neutron shield outer shell and the trunnions are not part of the cask confinement boundary but do have structural functions. These components, referred to as non-confinement structures, do not have confinement functions but are required to react to the confinement or environmental loads and in some cases share loadings with the confinement structure. The stress limits for the remaining non-confinement structures are given in Table 3.1-4. These limits are somewhat less restrictive than those specified in Table 3.1-2 for the confinement vessel.

3.1.2.3 Basket

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

The poison plates are not used for structural analysis. Therefore, the materials are not required to be code materials. The quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are 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 aluminum plate and rail materials are not Class 1 materials. They were selected for their properties. Aluminum has excellent thermal conductivity and a high strength to weight ratio.

The aluminum plate strength is not used for structural analyses under normal operating loads and 50g accident end drop load. The aluminum plate strength is only assumed to be effective for the short duration dynamic loading from tipover accident and for secondary thermal stress calculations.

NUREG-3854 Fabrication Criteria for Shipping Containers and 1617 Standard Review Plan for Transportation Package for Spent

Nuclear Fuel 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. Properties above 400°F are taken from the Aluminum Association Handbook and are described in details in SAR Appendix 3C.3-3.

The allowable stresses used for the aluminum basket plate and rail are based on S, the allowable stress for a Class 2 or 3 component. This is conservative, since the analyses of the basket and rail are performed in accordance with the rules of Subsection NB. Subsection NB allowables are based on S_m, which is 1/3 the ultimate strength, while S is 1/4 the ultimate strength. Thus there is additional margin built into the analysis of the basket and rail over and above the margin required by the ASME Code for Class 1 materials.

The stress limits for the basket are summarized in Table 3.1-5. The basket structural design criteria for a hypothetical impact accident are developed in Appendix 3B (elastic analysis) and Appendix 3C (elastic and plastic analysis). They are summarized here.

The basket fuel compartment wall thickness is established to meet heat transfer, nuclear criticality, and structural requirements. The basket structure must provide sufficient rigidity to maintain a subcritical configuration under the applied loads. The primary stress analysis of the basket for Normal (Design and Level A) Service Conditions does not take credit for the aluminum conductor plates except for through thickness compression. The aluminum is, however, considered when determining secondary stresses in the stainless steel.

The basis for the 304 stainless steel fuel compartment box stress allowables is Section III 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 combinations. The range of primary plus secondary stress is limited to 3 S_m for Level A combinations. This allows some local yielding of the basket structure. However, the thermal stresses are self-relieving and the deformation is insignificant. In addition, the thermal stress will decrease with time as the decay heat load decreases. The average primary shear stress across a section is limited to 0.6 S_m.

The sustained Level D Service Conditions are actually elevated to Level A Conditions and evaluated against Design Limits since the bounding loads are greater than any Level D loads.

The hypothetical drop and tipping impact accidents are considered separately. See Appendices 3B and 3C for complete details of the criteria for these conditions.

details of the criteria for these conditions.

The hypothetical impact accidents are evaluated as short duration Level D conditions. For elastic analyses, the primary membrane stress is limited to the smaller of 2.4 S_m or 0.7S_u and the membrane plus bending stress limited to the smaller of 3.6 S_m or S_u. The average primary shear stress across a section is limited to 0.42 S_u (S_u is the minimum ultimate strength). For plastic analysis, the primary membrane stress is limited to the 0.7S_u and the membrane plus bending stress limited to the smaller of 0.9S_u. The average primary shear stress across a section is limited to 0.42 S_u.

Individual fuel compartment wall panels, when subjected to compressive loadings, are also evaluated against ASME Code rules for component supports and B96.1[4] to ensure that buckling will not occur. The interaction between compression and bending was evaluated using the equations of paragraph NF-3322. These equations reduce to that below for members subjected to both axial compression and bending:

$$\frac{\textit{Applied Compressive Load}}{\textit{Allowable Compressive Load}} + \frac{\textit{Applied Bending Moment}}{\textit{Allowable Bending Moment}} \leq 1.0$$

See Appendix 3B for the development of the stability and interaction criteria.

3.1.2.4 Trunnions

The design criteria for the trunnions are both unique and specific. They are specified in Section 2.2.5.4.3.

3.2 Weights and Centers of Gravity

The maximum total weight of the TN-32 cask and contents is 115.6 tons. The weights of the major individual subassemblies and center of gravity of the cask are listed in Table 3.2-1.

In most of the structural analyses, a conservatively high weight is used. However, in certain cases, such as the analysis of the stability of the cask, a conservatively low weight and high center of gravity are used.

3.3 Mechanical Properties of Materials

3.3.1 Cask Material Properties

This section provides the mechanical properties of materials used in the structural evaluation of the TN-32 storage cask. Table 3.3-1 lists the materials selected, the applicable components, and the minimum yield, ultimate, and design stress values specified by the ASME Code. All values reported in Table 3.3-1 are for metal temperatures up to 100°F. For higher temperatures, the temperature dependency of the material properties is reported in Table 3.3-2.

Table 3.3-3 is provided to summarize thermal analysis results from Chapter 4 which support the selection of cask body component design temperatures for structural analysis purposes. The temperatures specified in Table 3.3-3 are used to determine the allowable stresses. They are not a maximum use temperature for the material.

3.3.2 Basket Material Properties

The material properties of the 304 stainless steel plates are taken from the ASME Code[1]. The material properties of the aluminum alloy (6061-T6) are also taken from the ASME code except at elevated temperatures. The elevated temperature properties not available in the ASME code are obtained from the Aluminum Association [5]. These properties are listed with specific references in Tables 3.3-4 and 3.3-5. The full strength of the aluminum was considered when performing dynamic impact analyses. For long term sustained loading (under normal operation condition), the aluminum strength is generally neglected under primary loading where it can share the load with the stainless steel.

3.3.3 Material Properties Summary

Table 3.3-6 provides a table which susmmarized the components of the TN-32 cask, their primary function, and an overview of the general conditions (stresses, temperatures, pressures, coatings, etc., during storage. This table is intended to summarized the information provided elsewhere in the SAR.

3.3.4 Materials Durability

Materials must maintain the ability to perform their safety-related functions over at least the cask's 20 year lifetime under the cask's thermal, radiological, corrosion, and stress environment.

Metallic components:

Gamma radiation has no significant effect on metals. The effect of fast neutron irradiation of metals is a function of the integrated fast neutron flux, which is on the order of 10^{14} n/cm^2 inside the TN-32 after 20 years. Studies on fast neutron damage in aluminum, stainless steel, and low alloy steels rarely evaluate damage below 10^{17} n/cm^2 because it is not significant. Extrapolation of the data available down to the 10^{14} range confirms that there will be virtually no neutron damage to any of the TN-32 metallic components.

The effect of the TN-32 temperature environment on the required structural properties is evaluated in the SAR. There is no long term degradation of metals in the TN-32 temperature environment. The effect of creep at temperature is the basis for establishing the seal temperature limits. Additional information on the seals, including construction, corrosion evaluation and long term test data, is provided in Sections 2.3.2.1 and 7.1.3.

The cask exterior carbon steel components is protected from corrosion by the paint (epoxy, acrylic urethane or equivalent). The interior is protected by the aluminum thermal spray and by the helium environment inside the cask. The aluminum and stainless steel components are not subject to significant corrosion as discussed in Section 3.4-1.

Non-metallic components:

The radial neutron shield resin is a proprietary reinforced polymer. Appendix 9A provides information on the composition and the radiation and temperature resistance of the resin. Polyester is inert with respect to water, and the fire retardant mineral fill makes it self-extinguishing. Furthermore, the resin is contained in aluminum tubes inside a steel shell, so that the material is retained in place, and isolated from both water and from sources of ignition.

Elastomer o-rings or gaskets in the weather cover, quick disconnects, drain tube, and pressure relief valve are Not safety related; note that the quick disconnects are not part of the containment boundary.

Stem tips on overpressure system valves are Kel-F or similar material, and are not safety related; at the valve locations, the radiation level and temperatures are low.

The top neutron shield (polypropylene) is not safety related.

Paint is subject to routine maintenance and touch-up. Radiation levels and temperature on the cask exterior are not high enough to damage the paint. This is confirmed by dry cask experience.

The top neutron shield (polypropylene) is not safety related. Polypropylene is slow burning to non burning according to Table 24, Section 1 of the <u>Handbook of Plastics and Elastomers</u>[23]. Polypropylene is inert with respect to water. Furthermore, the weather protective cover isolates the top neutron shield material from sources of ignition and from water.

3.4 General Standards for Casks

3.4.1 Chemical and Galvanic Reactions

The materials of the TN-32 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 storage. This review is summarized below:

The TN-32 cask components are exposed to the following environments:

- During loading and unloading, the casks are submerged in borated water (boric acid solution). This affects the interior and exterior surfaces of the cask body, lid and the basket. The protective cover, the top neutron shield, and the overpressure system are not submerged in the spent fuel pool. 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 storage, 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 an epoxy, acrylic urethane, or equivalent enamel 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 storage, 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 storage by a vacuum drying process. It is then sealed and backfilled with helium, thus preventing 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.

3.4.1.1 Cask Interior

The TN-32 cask materials are identified in the drawings provided in Chapter 1.

The confinement vessel is made from SA-203 Grade D and SA-350 LF3. The interior surfaces of the confinement vessel are grit blasted and then metal-sprayed with aluminum of 99.0% purity.

The aluminum metal-spray coating is subject to the following service environments:

- After fabrication closed and shipped under air.
- At fuel loading, borated spent fuel pool water for a short duration.
- Vacuum-dried and helium backfilled for storage lifetime of 20 years or more.
- At fuel removal, it may again be exposed to borated spent fuel pool water for a short duration.

The coating is not subject to abrasion except for the one-time insertion of the basket.

An aluminum metal spray coating will maintain its integrity for 20 to 40 years under rural atmosphere exposure[15], which is a far more severe combination of exposure and time than that experienced by the TN32's internal metal spray coating.

The only alteration that the coating will experience is minor corrosion during the exposure to borated pool water. At a corrosion rate of $0.5.9 \times 10^{-5}$ inch/year[18], the loss of aluminum during the 48 hour period would be 3×10^{-7} inch, which is much less than the 0.004 inch minimum coating thickness. Corrosion of metal-sprayed aluminum also has the positive effect of sealing up the pores in the coating with insoluble and well-adhered corrosion products[17].

Typical composition of flame sprayed aluminum as deposited includes 5 to 10% Al_2O_3 measured metallographically. The balance is the same as the feed wire composition[14]. Other thermal spray methods such as arc spray result in less oxide. During initial exposure to pure water, aluminum metal spray over steel will sometimes stain brown due to the aluminum acting cathodically to the steel, probably due to the very thin aluminum oxide layer surrounding each "splat" of aluminum (aluminum oxide is less anodic than aluminum metal). After a short time, the aluminum acts normally as a sacrificial anode to protect the steel, and the staining ceases. The stains are insoluble aluminum oxides colored by iron, and they do not affect the life expectancy of the coating[17]. In the case of the TN-32, this cathodic action might occur prior to immersion in the spent fuel pool due to exposure to normal atmospheric conditions. However, even if

there is some cathodic action during initial immersion, it will be very short lived, and will not affect the function of the coating.

Grit blasting material used to prepare the steel surface for metal spray is either aluminum oxide or steel grit. The grit used is clean, dry, free of oil, feldspar and other contaminants. The metal spraying procedure was developed following the Guidelines of ANSI/AWS C2.18[15]. The final coating thickness typically is in the range of 0.004 inch to 0.015 inch. Thickness of the coating is inspected. Coating adhesion is periodically checked during fabrication.

The metallic spray coating is deposited as aluminum with an aluminum oxide coating. It is similar in composition to 1100 series aluminum and the borated aluminum in the baskets. The aluminum spray coating, 1100 series aluminum, borated aluminum and 6061-T6 aluminum develop a passive oxide coating and the corrosion rate decreases substantially after the oxide coating develops. Hydrogen is generated during the initial passivation. However, passivation begins in air, and only minimal amounts of hydrogen will be generated after the cask is submerged in the spent fuel pool.

All sealing surfaces are stainless steel clad by weld overlay. The metallic seals have a stainless steel liner and an aluminum jacket.

Within the cask cavity, there are 12 basket rails made from 6061 T6 aluminum. The rails are shown on TN drawing 1049-70-2, provided in Chapter 1. These rails are not coated, and have a total surface area of about 53,000 in^2.

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 aluminum and poison plates which form a sandwich panel. The aluminum plates are 0.5 inches thick 6061 T6 aluminum, with a total surface area of about 196,000 in^2. The aluminum plates are held in place by the stainless steel plugs which are welded to the stainless steel baskets. The aluminum is not welded or bolted to the stainless steel.

The poison plates are borated aluminum, with a total surface area of approximately 196,000 in^2. The borated aluminum plates are also held in place by the stainless steel plugs that are welded to the stainless steel baskets. The borated aluminum is not welded or bolted to the stainless steel.

Potential sources of chemical or galvanic reactions are the interaction between the aluminum, borated aluminum and stainless steel within the basket itself, and the interaction of the aluminum spray on the cask cavity wall and the borated water. Aluminum and stainless steel are both used extensively in the

spent fuel pool.

Behavior of Aluminum in Borated 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 is 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 3.4-5 shows a potential-pH diagram for aluminum in high purity water at 77 °F and 140 °F. The potential for aluminum coupled with stainless steel and the limits of pH for PWR pools are shown in the diagram to be well within the passivation domain at both temperatures. 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].

The water aluminum reactions are self-limiting because the surface of the aluminum becomes passive by the formation of a protective and impervious coating making further reaction impossible until the coating is removed by mechanical or chemical means.

The ability of aluminum to resist corrosion from boron ions is evident from the wide usage of aluminum in the handling of borax and in the manufacture of boric acid. Aluminum storage racks with Boral plates (aluminum 1100 exterior layer)in contact with 800 ppm borated water showed only small amounts of pitting after 17 years in the pool at the Yankee Rowe Power Plant. These racks maintained their structural integrity.

During immersion in the spent fuel pool, the TN-32 basket temperatures are close to the water temperature, which is typically near 80 °F, and the pH range is typically 4.0 to 6.5. Based on the above discussion, general corrosion is not expected on the aluminum or aluminum spray after the protective coating has been formed.

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 borated water. There is little galvanic corrosion in borated 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[19].

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 Austenitic Stainless Steel in Borated 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 borated 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.

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[20]. At 288 °C (550 °F), with tensile stress at

100% of yield in PWR water containing 100 ppm O_2, time to crack is about 40 days in sensitized 304 stainless steel[21]. 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.

Behavior of Borated Aluminum in Borated Water

To investigate the use of borated aluminum in the spent fuel pool, tests were performed by Eagle Picher to evaluate its dimensional stability, corrosion resistance and neutron capture ability. These studies showed that the borated aluminum performed well in a spent fuel pool environment.

The 1100 series aluminum component 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 water or moisture 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 which concluded that borated aluminum exhibits a strong corrosion resistance at room temperature in either reactor grade deionized water or in 2000 ppm borated water. The behavior is only slightly different than 1100 series aluminum, hence, satisfactory long-term usage in these environments is expected. Neutron irradiation up to 10^{17} n/cm^2 level did not cause any measurable dimensional changes or any other damage to the material.

At high temperature, the borated aluminum still exhibits high corrosion resistance in the pure water environment. However, at temperatures of 80° C, in 2000 ppm borated water, local pitting corrosion has been observed. At 100° C and room temperature, the pitting attack was less than at 80° C. In all cases, passivation occurs limiting the pit depth.

From tests on pure aluminum, it was found that borated aluminum was more resistant to uniform corrosion attack than pure aluminum. Local pitting corrosion, can occur over time, causing localized damage to the borated aluminum.

There are no chemical, galvanic or other reactions that could reduce the areal density of boron in the TN-32's neutron poison plates.

3.4.1.2 Cask Exterior

The exterior of the cask is carbon steel. The grades and types of carbon steel are presented in the drawings in Chapter 1. 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 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.

3.4.1.3 Lubricants and Cleaning Agents

The following lubricants and cleaning agents may be used on the TN-32 cask:

- Neolube or equivalent is used to coat the threads and bolt shoulders of the closure bolts. It is also used to coat the contact areas of the top and bottom trunnions during transport and lifting operations to aid rotation of adjacent metal surfaces and to prevent impregnation of contamination.

- During fabrication, the cask and basket are cleaned in accordance with approved procedures that limit the chloride and fluoride content, conductivity, and pH of water used for cleaning.

The cleaning agents and lubricants have no significant affect on the cask materials and their safety related functions.

3.4.1.4 Hydrogen Generation

During the initial passivation stage, small amounts of hydrogen gas may be generated in the TN-32 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 are insignificant and do not result in a flammable gas mixture within the cask.

The small amount of hydrogen which is 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-32 loading or unloading operations.

After loading fuel into the TN-32, 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, solution of hydrogen in water, and passivation. Experiments[18] have measured hydrogen generation from aluminum 1100 in acidic borated water (3000 ppm B, pH 4.5) at 150 °F a rate of 1.9×10^{-6} std ft^3/ft^2hr. The surface area of the aluminum and borated aluminum basket plates and aluminum rails is 3710 ft^2. The surface area of the aluminum metal spray is 296 ft^2. For the purpose of evaluating the hydrogen generation rate, the surface area of the aluminum metal spray is increased by a factor of 50 to account for the higher rate of hydrogen generation from the galvanic coupling of carbon steel and porous aluminum[22]. In two hours, the amount of hydrogen generated would be 0.073 std ft^3, assuming that all the aluminum surfaces are immersed. This is equal to 0.04% of the total free volume in the cask, well below the ignitable limit of 4%.

Unlike welded canisters, the TN-32 cask has a bolted closure. There is no source of ignition to result in an exposion or fire during either loading or unloading.

3.4.1.5 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 4. 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.

3.4.2 Positive Closure

Positive fastening of all access openings through the confinement boundary is accomplished by bolted closures which preclude unintentional opening. All of the openings in the TN-32 cask are through the lid of the cask. A protective cover is installed around the lid during storage. Security seals are installed in two of the protective cover bolts to ensure that no unauthorized entry into the cask has been attempted.

3.4.3 Lifting Devices

Section 3.4.3.1 provides the analysis of the trunnions, which are the only components which are used to lift the cask. Section 3.4.3.2 provides an analysis of the local stresses in the cask wall due to the effect of a 3G (TN-32 and TN-32A) and 6G (TN-32B) lifting loads on the trunnions. The resulting local stresses in the cask wall are conservatively added to the stresses resulting from other load conditions.

3.4.3.1 Trunnion Analysis

The cask is provided with two trunnions at the top spaced 180 degrees apart for lifting. The two trunnions at the bottom of the cask are for rotation of the cask. They are attached to the cask body with penetration welds. A flat surface is machined on the cask body outer surface at each trunnion location for this purpose. This section provides the structural analysis of the TN-32 storage cask trunnions.

Upper Trunnions for TN-32 and TN-32A casks

The two top 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 3 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also lift 5 times the weight of the cask without exceeding the ultimate tensile strength of the material.

Figure 3.4-1A shows the basic dimensions of the top trunnions for TN-32 and TN-32A casks. The cask total weight used in this calculation is W = 243,000 pounds. Table 3.4-1A shows the cross sectional areas and moments of inertia at cross sections A-A, B-B and C-C of the trunnions. In addition the loads applied to these sections (for 3 W and 5 W loading) to evaluate the yield and ultimate limits are listed.

Table 3.4-2A presents a summary of the stresses at the same locations to compare against the yield and ultimate trunnion 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.

Upper Trunnions for TN-32B Cask

The upper trunnions are considered to be single failure proof lifting devices. 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.

Figure 3.4-1B shows the basic dimensions of the TN-32B top trunnions. The cask total weight used in this calculation is W = 267,300 pounds (includes a 10% dynamic load factor). Table 3.4-1B shows the cross sectional areas and moments of inertia at cross sections A-A, B-B and C-C of the trunnions. In addition the loads applied to these sections (for 6W and 10W loading) to evaluate the yield and ultimate limits are listed.

Lower Trunnions for TN-32, TN-32A, and TN-32B casks

The lower trunnions are used to rotate the unloaded cask (without fuel assemblies) from a horizontal orientation to the vertical orientation. The lower trunnions are not used to lift a loaded cask. The geometries of the lower trunnions for TN-32, TN-32A, and TN-32B are identical to the upper trunnions of the TN-32 and TN-32A cask. They can support a loading equal to 3 times the weight of the cask without generating stresses in excess of the minimum yield strength of the material. They can also support 5 times the weight of the cask without exceeding the ultimate tensile strength of the material. Figure 3.4-1C shows the basic dimensions of the lower trunnions for TN-32, TN-32A and TN-32B casks.

3.4.3.2 Local Stresses in Cask Body

This section discusses the analysis performed to calculate the local stresses in the cask body outer gamma shielding at the trunnion locations due to the loadings applied through the trunnions. These local effects are not included in the ANSYS stress result tables reported in Section 3.4.4. The local stresses are superimposed on the ANSYS stress results for the cases where the inertial lifting loads are reacted at the trunnions. The local stresses are calculated in accordance with the methodology of WRC Bulletin 107[6] which is based on the Bijlaard analysis for local stresses in cylindrical shells due to external loadings.

The Bijlaard analysis was performed to support various structural evaluation cases. A summary of the trunnion loads is provided in Table 3.4-3A for analyzed the upper trunnions of the TN-32 and TN-32A casks. Table 3.4-3B summary the trunnion loads for analyzed the upper trunnions of the TN-32B cask.

The local stresses induced in the cask body by the trunnions are calculated using Bijlaard's method. The neutron shield and

thin outer shell are not considered to strengthen either the trunnions or the gamma shielding cylinder. The trunnion is approximated by an equivalent attachment so that the curves of Reference 6 can be used to obtain the necessary coefficients.

These resulting coefficients are inserted into blanks in the column entitled "Read Curves For." in a standard computation form, a sample of which is shown on Table 3.4-4. The stresses are calculated by performing the indicated multiplication in the column entitled "Compute Absolute Values of Stress and Enter Result." The resulting stress is inserted into the stress table at the eight stress locations, i.e., AU, AL, BU, BL, etc. Note that the sign convention for this table is defined on the figure for the load directions as shown. The membrane plus bending stresses are calculated by completing Table 3.4-4.

The cylindrical body is assumed to be a hollow cylinder of infinite length. This is conservative since end restraints reduce the local cylinder bending effects.

The only required input data for this analysis, are the dimensions of the trunnion and the cylinder. These are obtained from Section 1.5 drawings. The dimensions and Bijlaard parameters are listed as follows:

LIST OF BIJLAARD PARAMETERS

Parameter	Parameter Description	TN-32 & TN-32A Top Trunnion Parameter Value	TN-32B Top Trunnion Parameter Value
R_M	Mean Radius	39.465 in.	39.509 in.
T	Effected Wall Thickness of Shell	7.18 in.	7.269 in.
$\gamma = R_M/T$	Shell Parameter	5.497	5.44
r_o	Outer Radius, Attachment	5.0 in.	6.0 in.
$\beta = 0.875\ r_o/R_M$	Attachment Parameter	0.11	0.13

Based on the calculation, the maximum stress intensities are:

SI = 6,624 psi (TN-32 and TN-32A top trunnions)
SI = 16,047 psi (TN-32B top trunnions)

These stress intensities are well below the yield stress of the gamma shield. The stress intensities due to the local trunnion loading are combined with the finite element results at the top trunnion attachment locations and presented in Section 3A.2.

3.4.4 Heat

3.4.4.1 Summary of Pressures and Temperatures

Stress allowables for the cask components are a function of component temperature. The temperatures used to perform the structural analysis are based on actual maximum calculated temperatures or conservatively selected higher temperatures. Chapter Four summarizes significant temperatures calculated for the TN-32 cask. The design temperatures used for stress analysis acceptance criteria for the cask are provided in Table 3.3-3. These temperatures are used to establish the allowables for every normal and accident load combination evaluated in this Safety Analysis Report.

The maximum calculated internal cask pressure is 22.1 psig under normal conditions and 58.4 psig under accident conditions, as calculated in Section 7.2.2 and 7.3.2. The structural analysis of the cask is conservatively performed using 100 psi as internal presure.

3.4.4.2 Differential Thermal Expansion

A thermal evaluation of the cask was performed in Chapter 4 to determine the maximum temperature of the cask components under normal conditions. The analysis considers maximum decay heat and maximum solar heat loading. Analysis of the stresses which resulted from heating the cask from an ambient temperature (70° F) to the steady state maximum temperature is presented in Appendix 3A for the cask and Appendix 3B for the basket. The results of these calculations are presented in Tables 3A.2.3-9 and 3A.2.3-10 for the cask and 3B.3-4 for the basket.

The basket plates are free to expand in the axial direction, since sufficient clearance is provided between the lid and the top of the basket. The clearance between the basket rails and basket plates is also sized to provide sufficient clearance for thermal expansion.

3.4.4.3 Stress Calculations

The stress calculations performed on the cask and basket are presented in Appendices 3A, 3B and 3C. Finite element models of the cask body and basket have been developed, and detailed computer analyses have been performed using the ANSYS computer program[3]. Other components such as the lid bolts and trunnions have been analyzed using conventional textbook methods. Table 3.1-1 lists the specific individual load cases analyzed for each major cask component. The SAR sections where these analyses are described and the tables listing the stress results, where applicable, are also indicated.

Section 2.2 categorizes the loads for the cask body as indicated in Tables 2.2-8 and 2.2-9 into Normal (Level A) and Hypothetical Accident (Level D) Service Loadings and lists the load combinations to be evaluated. Each combination is a set of loads that is assumed to occur simultaneously.

The cask body key dimensions are shown in Figure 3.4-2 (Identical to Figure 3A.1-1). The Standard Reporting Locations for the cask body stresses are shown in Figure 3.4-3 (Identical to Figure 3A.2-12). The stress reporting locations for the basket are shown in Figures 3B.3-2, 3B.3-3 and 3B.3-4.

The cask body shells are assembled to provide the best possible contact at the interface of the inner and gamma shield shells. The gamma shield shells are shrunk fit onto the inner shells. The outside diameter of the inner shell and the inside diameter of the outer shell are measured prior to the shrink fit. The nominal interference between the inner and outer shell is 0.015 inches. This results in a calculated fabrication hoop stress of -10,588 psi in the inner shell and 2182 psi at the gamma shield cylinder. The theoretical buckling stress is 51,144 psi. Therefore, this stress will not result in buckling of the inner shell. The buckling stress calculations are very conservative. Actually, the buckling capacity of preshrunk inner cylinder is much higher than a simple cylinder subjected to external pressure. A thin wall cylinder usually buckles according to a rather define pattern, depending on its relative dimensions and conditions of restraint at its ends or periphery. The most common form assumed is the two lobe buckling which gives the lowest buckling pressure. In this mode, the ideal circular section is deflected into an oval or elliptical section. However, in a preshrunk internal cylinder, the outer cylinder resists the formation of the lobes (the change of the circular section to oval section) and this restraint prevents the buckling of the inner shell.

In accordance with the ASME Boiler and Pressure Vessel Code, the fabrication stresses are not combined with the design and service level stresses. However, the fabrication stresses are included in the fracture toughness evaluations of the confinement boundary and gamma shield as described in Appendix 3E.

3.4.4.3.1 Confinement Vessel

Table 3.4-5 lists the highest confinement shell, flange, and lid stress intensities for each service condition and identifies the load combination and location where those maxima occur. Also listed in the table are the stress limits for that service condition based on the Section 3.1.2 structural design criteria.

The lowest margin to allowable for the normal condition cases is 1.92. The lowest margin to allowable for the accident conditions is 0.41. Therefore, the stresses in the confinement vessel are acceptable.

3.4.4.3.2 Gamma Shielding

The load combinations for the gamma shielding and weld locations indicated in Figure 3.4-3 have also been performed and are presented in Appendix 3A. Table 3.4-6 lists the highest cylinder, bottom and weld stress intensities for each service condition and identifies the load combination and location where those maxima occur.

The lowest margin to allowable for the normal conditions is 1.93, and the lowest margin to allowable for the accident conditions is 0.31. Therefore the stresses in the gamma shielding are acceptable.

3.4.4.3.3 Lid Bolts

The stress intensities in the lid bolts as calculated in Appendix 3A.3 are summarized in Table 3.4-7. These values are well below the allowables.

3.4.4.3.4 Basket

Table 3.4-8 summarizes the stresses in the basket. The values listed are for the 304 stainless steel boxes and plug welds. The aluminum conductor plates and borated aluminum poison plates are assumed to have no load carrying capability, except through thickness compression between boxes, to react long duration primary loads.

The aluminum conductor plates are assumed to have strength to apply differential expansion induced (thermal) secondary stresses to the stainless steel plates and plug welds.

Table 3.4-8 summarizes the maximum stresses in the basket based on 50G elastic analysis as analyzed in Appendix 3B. The analysis presented in Appendix 3B indicates that even in this extreme unlikely hypothetical accident, there is sufficient margin to ensure that the basket performs its function.

The NRC staff requested additional analysis be performed:

- Peak amplitude of 55 G (lateral inertial loading)
- Pulse shape of an isosceles triangle
- Pulse duration of 6 millisecs.

The Dynamic Load Factor (DLF) of 1.6 was uniformly applied to the analysis. This resulted in an applied acceleration of 88G.

For completeness, Transnuclear, Inc. performed a dynamic tipover analysis of the TN-32 cask. Results of this analysis, reported in Appendix 3D, showed that a maximum G load of 74 should be used for basket structure analysis. Therefore, using 88G for structure analysis of the basket is conservative. The stresses resulting from an 88G plastic analysis are summarized in Tables 3C.2-6, 3C.2-7 and 3C.2-8.

3.4.4.3.5 Outer Shell

The neutron shield outer shell stresses are summarized in Table 3.4-9. The shell stresses are highest when the cask is vertical and subjected to 25 psi internal pressure and 3G inertia load. Stresses in the shell will be much lower during normal storage of the TN-32 cask on the ISFSI pad. The shell is not analyzed under tornado missile loading, but it would undoubtedly be damaged by either Missile A or Missile B, as defined in Section 2.2.1. Radiological effects have been shown to be acceptable, as shown in Chapter 10.

3.4.4.4 Comparison with Allowable Stresses

The stresses for each of the major components of the cask are compared to their allowables in Tables 3.4-5 through 3.4-9.

3.4.5 Cold

The cask has been designed for operation at a daily average ambient temperatures as low as -20°F. The confinement seals are all metallic o-rings which are not affected by this temperature. The shielding materials are all solids, so there is no concern over freezing.

The Confinement vessel is made from materials selected for their low temperature fracture toughness properties. The actual materials used for each Confinement vessel will be tested to ensure that the maximum Nil Ductility Transition Temperature does not exceed -80°F. Fracture toughness evaluations of the TN-32 confinement boundary and gamma shield are presented in Appendix 3E.

The pressure switch used for the overpressure system, which is not a safety related component, is selected to operate at temperatures of -20°F and above.

An evaluation has also been performed to evaluate thermal Stresses due to Cold Rain on a Hot Cask. The analysis is provided below.

The cold rain is assumed at 32° F. The maximum cask temperature in unprotected flange-lid region is 263° F (see Chapter 4, Table 4.1-1). It is conservatively assumed that the outer flange surface is at 32° F while the inner surface is at 263° F. Thermal stress calculation are based on a temperature differential of 263-32 = 231° F. The maximum flange thermal stress of 3,699 psi is calculated for 100° F temperature differential in Appendix3A, Table 3A.2.3-10. Therefore,

Maximum thermal stresses for cold rain on hot cask = (231/100) 3,699 = 8,545 psi.

This stress is well below the flange material (SA 350, Grade LF3) allowable (S_m = 22,200 psi at 300° F - see Table 3.3-2).

3.4.6 Fire Accident

A thermal stress analysis of the fire accident is conducted using ANSYS in Section 4.5. The nodal temperatures obtained from the thermal analysis are input to the ANSYS structural finite element model for thermal stress analysis. The stress analysis indicates a maximum membrane stress intensity of 32.0 ksi and maximum membrane plus bending stress intensity of 49.2 ksi. These stresses are well below the Level D secondary allowable stress of 70.0 ksi (S_u). The lid and lid bolts reach about 438°F (See Table 4.1-1). Since the lid and lid bolts have the same thermal expansion coefficients, no bolt preload will be lost and a positive (compressive) load will be maintained during the fire accident conditions.

The maximum temperature in seal region is 380°F (See Table 4.1-1) which is much lower than the maximum allowable operating temperature of 536°F for the metallic seal.

From the analyses shown above, it can be seen that the fire accident will not result in any structure damage of the cask. The confinement function of the cask will be maintained.

3.5 Fuel Rods

The handling of spent fuel within the Nuclear Generating Plant will be conducted in accordance with existing fuel handling procedures. Fuel with gross cladding defects will not be considered for storage at the ISFSI.

3.5.1 Fuel Rod Temperature Limits

The design criteria for the TN-32 dry storage cask requires that the maximum fuel cladding temperature of the hottest fuel rod in the cask shall not exceed the temperature limit calculated according to PNL-6189[7]. This temperature limit has been calculated as a function of fuel age to account for the effect of fuel age on creep deformation and fuel cladding rupture. As the age of fuel increases, its cooling rate rapidly decreases. If the initial fuel temperature is too high at loading, significant creep deformation can occur as a result of the decreasing cooling rates with fuel age. The Commercial Spent Fuel Management Program (CSFM) used the TN-24P packaging as one of its models for developing generic fuel cladding temperature limit curves for 40 year dry storage. The CSFM generic curves are used to establish the fuel cladding temperature limit for 10-year cooled fuel.

From Reference 7, the midwall hoop stress is given by the equation,

$$S_{mhoop}, T_2 = (PD_{mid}/2t)(a)(T_2/T_1)$$

where

S_{mhoop}, T_2 = the midwall hoop=stress (psi) at temperature of interest T_2 (°K)

P = the internal pressure (psi) at the hot-volume average temperature, T_1 (°K)

D_{mid} = the midwall diameter (in.) after accounting for Cladding corrosion

t = the cladding thickness (in.) after accounting for cladding corrosion

a = 0.95 for PWR fuel assemblies

Using fuel data provided in Reference 8, a Westinghouse 15x15 assembly with a burnup of 45,000 MWD/MTU has a lead fuel rod pressure of 1073 psia at 100°C. The corresponding pressure for a 17x17 assembly is 1053 psia. The pressure for a Westinghouse 14x14 fuel assembly with a burnup of 50,000 MWD/MTU is 591 psia at 21°C.

Cladding corrosion is estimated to reduce the outside diameter by 0.004 inch. Nominal diameters and cladding thickness are listed in Table 2.1-1.

Substituting values and simplifying,

S_{mhoop}, T_2 = 17.0T_2 psi/K for the 14x14 assembly

S_{mhoop}, T_2 = 16.0T_2 psi/K for the 14x14OFA assembly

S_{mhoop}, T_2 = 24.2T_2 psi/K for the 15x15 assembly

S_{mhoop}, T_2 = 22.9T_2 psi/K for the 17x17 assembly, and

S_{mhoop}, T_2 = 24.0T_2 psi/K for the 17x17OFA assembly.

The 15x15 is the limiting case. For conservatism, a bounding case for the 15x15 fuel assembly is taken from Reference 7. This bounding case shows an internal gas pressure of 2416 psia at a hot volume temperature of 387°C for a W 15x15 rod with 45,000 MWD/MTU burnup, 1365 psia @ 100°C. Therefore, (S_{mhoop}, T_2 = 30.8T_2 psi/K = 0.213 MPa/K) is used to determine the fuel rod temperature limits. The temperature limits are determined graphically by plotting the midwall hoop-stress equation on the CSFM generic limit curves of Reference 7. The acceptable temperature limits obtained are 333°C (631°F) and 328°C(622°F) for 7 year and 10 year cooled fuel, respectively.

In the fuel rod analysis above, the Westinghouse 15x15 fuel bounds the Westinghouse standard 17x17 fuel. It likewise bounds the Mark BW fuel, which is compared to the Westinghouse 17x17 standard fuel as follows.

The cladding OD is the same for both fuels (0.374 inch), but the cladding thickness is greater on the Mark BW fuel (0.0240 inch compared to 0.0225 for the Westinghouse fuel). The end of life pressure in the Mark BW fuel will be lower than that in the Westinghouse 17x17 fuel for the following reasons:

(a) Westinghouse 17x17 fuel is prepressurized up to 500 psi. Mark BW fuel prepressurization is less than 500 psi.
(b) The UO_2 mass in Westinghouse standard 17x17 fuel is 0.364 lb/ft, and in Mark BW fuel, 0.360 lb/ft. Therefore, for a given mass-specific burnup, the Mark BW fuel will have slightly fewer fission products than the Westinghouse 17x17.
(c) The Mark BW fuel pellet density is 96%, compared to 95% for the Westinghouse fuel. Therefore, there will be slightly less fission gas release in the Mark BW fuel.

3.5.2 Thermal Stress of Fuel Cladding due to Unloading Operations

To evaluate the effects of the thermal loads on the fuel cladding during unloading operations, the following assumptions are made:

- A conservatively high maximum fuel rod temperature of 575°F (actual calculated temperature is 565°F) and low quench water temperature of 50°F are used.
- Each fuel rod is assumed simply supported at both ends.
- The outer surface temperatures of the fuel rod are conservatively assumed to be as shown in Fig. 3.5-2. 50°F, 212°F, and 575°F temperatures occur at three equal heights.

Analysis

Steady state thermal and stress analyses were performed using the ANSYS[3] computer program. The finite element model is shown in Figure 3.5-1. ANSYS finite elements Plane 55 and Plane 42 (Axisymmetric) were used.

The model was based on W 15 x 15 tube, which has the maximum fuel rod outer diameter of 0.422 inches and a maximum clad thickness of 0.0243 in. to bound all Westinghouse type fuel rods specified in Chapter 2. A tube length of two inches was selected for the finite element model so that it is a long cylinder (minimum length = $3.0/\lambda$ = 0.22 inches) and the maximum stresses are not affected by the boundary conditions. The maximum thickness of the cylinder was so selected as to result in higher ΔT and higher thermal stresses.

Material Properties

The following material properties were used for the analyses:

Material Properties of Zircaloy (irradiated)

Temp °F	Conductivity[9] Btu/hr-in-°F	α[10] in/in/°F	E[11] (psi)	S_y[11] (ksi)
200	.574	3.73×10^{-6}	12.8×10^{6}	
248	.579	3.73×10^{-6}	12.7×10^{6}	94.9
284	.583	3.73×10^{-6}	12.5×10^{6}	93.9
334	.588	3.73×10^{-6}	12.3×10^{6}	92.4
415	.593	3.73×10^{-6}	12.0×10^{6}	90.1
615	.614	3.73×10^{-6}	11.1×10^{6}	84.4

Thermal Analysis

The steady state thermal analysis was conducted using the surface nodal temperatures as shown on Figure 3.5-2. The inside surface nodal temperatures are all assumed to be 575°F. The outside surface nodal temperatures conservatively represent the quench water temperature. The temperature distribution resulting from this analysis is shown on Figure 3.5-3.

Thermal Stress Analysis and Results

A thermal stress analysis was conducted using the same model and nodal temperatures obtained from the thermal analysis. The resulting nodal stress intensity distribution is shown on Figure 3.5-4. The maximum nodal stress intensity in the fuel cladding is 17.2 ksi. This stress is much less than the yield strength of zircaloy of 85.5 ksi at 575°F.

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3.6 References

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20. G. Wranglen, An Introduction to Corrosion and Protection of Metals, Chapman and Hall, 1985, pp. 109-112.

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TABLE 3.1-1

INDIVIDUAL LOAD CASES ANALYZED

COMPONENT/ ANALYSIS	LOADING	TSAR SECTION	INDIVIDUAL STRESS RESULTS TABLES
CASK BODY			
Bolt Preload	Preload	3A.2.3.1	3A.2.3-1 3A.2.3-2
Gravity	1G down	3A.2.3.1	3A.2.3-3 3A.2.3-4
Internal Pressure (1)	100 PSI	3A.2.3.1	3A.2.3-5 3A.2.3-6
External Pressure (1)	25 PSI	3A.2.3.1	3A.2.3-7 3A.2.3-8
Thermal Stress	Short Term Temperatures	3A.2.3.1	3A.2.3-9 3A.2.3-10
Lifting	3G on Trunnion 6G on Trunnion	3A.2.3.1 3.4.3	3A.2.3-11 3A.2.3-12 3.4-3
Seismic Load (1)	2G Down + 1G lateral	3A.2.3.1 2.2.3	3A.2.3-19 3A.2.3-20
Tipover	1G Side Drop	3A.2.3.2	3A.2.3-15 through 3A.2.3-18
LID BOLTS			
Preload	Preload Tension	3A.3.1.1	---
Thermal Effects	Differential Expansion	3A.3.1.2	---
Torquing	Preload Torsion	3A.3.1.3	---
Bending	Bending	3A.3.1.4	---

TABLE 3.1-1
Continued

INDIVIDUAL LOAD CASES ANALYZED

COMPONENT/ANALYSIS	LOADING	TSAR SECTION	INDIVIDUAL STRESS RESULTS TABLES
Bottom End Drop	Impact	3A.3.2.1	---
Tipover	Impact	3A.3.2.2	---
BASKET			
Bounding Side Load (2)	1 G Lateral	3B.3.2	3B.3-1 through 3B.3-3
Bounding Down Load (2)	3 G Down	3B.3.3	---
Thermal Stress	Short-Term Temperatures	3B.3.4	3B.3-4
Hypothetical Accident	End Drop	3B.4.1	---
Hypothetical Accident	Tipover	3B.4.2	3B.4-7 through 3B.4-15
Hypothetical Accident	Tipover Plastic Analysis	3C.2 3C.3	3C.2-6 through 8 Fig.3C.3-5 through 8
TRUNNIONS			
Lifting	3 g and 5 g 6 g and 10 g	3.4.3	3.4-2

NOTES

1. The above pressures and bounding loads conservatively envelope all possible pressure effects as well as tornado wind load, flood water load and seismic load.

2. The bounding loads selected for basket evaluation are extremely conservative. These loads are more severe than any loads that will actually be applied to the basket.

TABLE 3.1-2
CONFINEMENT VESSEL STRESS LIMITS (3)

Classification	Stress Intensity Limit(3)
Normal (Level A) Conditions	
P_m	S_m
P_l	1.5 S_m
(P_m or P_l) + P_b	1.5 S_m
Shear Stress	0.6 S_m
(P_m or P_l) + P_b + Q	3 S_m
(P_m or P_l) + P_b + Q + F	S_a
Hypothetical Accident (Level D)(2)	
P_m	Smaller of 2.4 S_m or 0.7 S_u
P_l	Smaller of 3.6 S_m or S_u
(P_m or P_l) + P_b	Smaller of 3.6 S_m or S_u
Shear Stress	0.42 S_u

NOTES

1. Quantities are as defined in ASME Code, Section III, Subsection NB.
2. Limits are in accordance with ASME Code, Section III, Appendix F.
3. When using materials data from Section II, Part D, Table 1A, S values may be substituted for S_m values in these expressions.

TABLE 3.1-3

CONFINEMENT BOLT STRESS LIMITS (1)

Classification	Stress Intensity Limit
Normal (Level A) Conditions	
P_m (Tensile)	$2S_m$
$P_m + P_b$ (Tensile + Bending)	$3S_m$
Combined	$3S_m$
Shear Stress	$0.4S_y$
$(P_m$ or $P_l) + P_b + Q + F$	S_a
Hypothetical Accident (Level D) (2)	
P_m (Tensile)	Smaller of S_y or $0.7\ S_u$
$P_m + P_b$ (Tensile + Bending)	S_u
Combined	S_u
Shear Stress	Smaller of $0.4\ S_u$ or $0.6\ S_y$
Combined Shear & Tension	$\frac{(ft)^2}{(Ftb)^2} + \frac{(fv)^2}{(Fvb)^2} \leq 1$

NOTES

1. Terms are as defined in ASME Code, Section III, Subsection NB.

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

TABLE 3.1-4

NON CONFINEMENT STRUCTURE STRESS LIMITS (1)

Classification	Stress Intensity Limit (3) (4)
Normal (Level A) Conditions	
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
Hypothetical Accident (Level D) (2)	
P_m	Smaller of 2.4 S_m or 0.7 S_u
P_l	Smaller of 3.6 S_m or S_u
$(P_m + P_l) + P_b$	Smaller of 3.6 S_m or S_u
Shear Stress	0.42 S_u

NOTES

1. Quantities are as defined in ASME Code, Section III, Subsection NB.
2. Limits are in accordance with ASME Code, Section III, Appendix F.
3. These limits may be exceeded for non Confinement structure if the resulting deflection can be accommodated.
4. When using materials data from Section II, Part D, Table 1A, S values may be substituted for S_m values in these expressions.

TABLE 3.1-5

BASKET STRESS LIMITS (1)(2)

Classification	Stress Intensity Limit (3)(4)(5)(6)
Normal (Level A) Conditions	
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	Smaller of 3.6 S_m or S_u
$(P_m + P_l) + P_b$	Smaller of 3.6 S_m or S_u
Shear Stress	0.42 S_u

NOTES

1. Quantities are as defined in ASME Code, Section III, Subsection NB.
2. Limits are in accordance with ASME Code, Section III, Appendix F.
3. Under sustained primary loads the strength of the 6061 T6 basket plates shall not be considered.
4. For short duration impact loading the strength of the 6061 T6 basket plates may be considered. For these conditions (Level D Impact) the value of S may be substituted for S_m.
5. Stability shall also be evaluated under compressive loading. See Sections 3B.4, 3C.2, and 3C.3.
6. When evaluating the results from the nonlinear elastic plastic analysis, the general primary membrane stress intensity, P_m, shall not exceed $0.7S_u$ and the maximum primary stress intensity at any location (P_L or $P_L + P_b$) shall not exceed $0.9S_u$.

Table 3.2-1
Cask Weight and Center of Gravity

Component	Weight (lbs)		
	TN-32 Cask	TN-32A Cask	TN-32B Cask
Body	111,860	111,860	111,860
Bottom	17,540	17,540	17,540
Lid	12,760	11,560	12,760
Aluminum Boxes	1,960	1,960	1,960
Resin	10,230	10,230	10,230
Outer Shell	7,230	7,230	7,230
Top Neutron shield assembly	1,490	2,920	1,490
Top trunnions	290	290	460
Bottom Trunnions	290	290	290
Protective Cover	1,380	1,380	1,380
Basket and Rails	16,900	16,900	16,900
Fuel Assemblies (MAX)	49,060	49,060	49,060
Cask Weight w/o Protective Cover and Top Neutron Shield Assembly	228,120	226,920	228,290
Weight on Storage Pad Center of Gravity*	230,990 (218,730)** 92.09 in. (92.25)**	231,220 (218,960)** 92.2 in. (92.36)**	231,160 (218,900)** 92.09 in. (92.25)**

* Center of Gravity is measured along the axial centerline from the base of the cask.

** Cask loaded with W14 x 14 or W14 x 14 OFA fuel assemblies.

Summary of weights used in Analyses:

1. Stability of Cask: 218,000 lbs.
2. Trunnion and Local Stress Analysis
   TN-32 and TN-32A: 243,000 lbs.
   TN-32B: 243,000 lbs with 10% dynamic load factor
3. Cask Body Analysis: 235,000 lbs.

TABLE 3.3-1

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 1/2 Ni)	Flange Confinement Lid	37,500	70,000	S=17,500 S_m= 23,300	Table A Table 2A
ASME SA-203, Grade D	Confinement Vessel	37,000	65,000	S= 16,200	Table 1A
ASME SA-266 Gr. 2	Gamma Shield Cylinder	36,000	70,000	S= 17,500 S_m=23,300	Table 1A Table 2A
ASME SA-105 (C-Si)	Gamma Shielding Trunnions	36,000	70,000	S= 17,500 S_m=23,300	Table 1A Table 2A
ASME SA-516, Grade 70 (C-Mn-Si)	Weather Cover Outer Shell	38,000	70,000	S= 17,500	Table 1A
ASME SA-320, Grade L43 (1 3/4 Ni-3/4 Cr - 1/4 Mo)	Closure Lid Bolts	105,000	125,000	S_m= 35,000	Table 4

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 3.3-2.

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 are taken from tables in ASME Section II, Part D, 1992 unless otherwise noted.

TABLE 3.3-2
TEMPERATURE DEPENDENT MATERIAL PROPERTIES
SHEET 1 OF 3
COEFFICIENTS OF THERMAL EXPANSION (1)(2)

Material/Temp., °F	100	150	200	250	300	350	400	450	500	550	600
SA350 LF3 SA320 L43 SA203 Gr. D	6.27	6.41	6.54	6.65	6.78	6.88	6.98	7.07	7.16	7.24	7.32
SA105 and SA516 Gr55	5.73	5.91	6.09	6.27	6.43	6.59	6.74	6.89	7.06	7.18	7.28
SA516 Gr 70	5.53	5.71	5.89	6.09	6.26	6.43	6.61	6.77	6.91	7.06	7.17

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, 1992.

TABLE 3.3-2

TEMPERATURE DEPENDENT MATERIAL PROPERTIES
SHEET 2 OF 3
MODULI OF ELASTICITY, E (1)(2)

MATERIAL/ TEMPERATURE °F	70	200	300	400	500	600
SA-203 Gr. D SA-320 L43 SA-350 LF3	27.8	27.1	26.7	26.1	25.7	25.2
SA-105	29.5	28.8	28.3	27.7	27.3	26.7
SA-516 Grade 70	29.3	28.6	28.1	27.5	27.1	26.5

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, 1992.

TABLE 3.3-2
TEMPERATURE DEPENDENT MATERIAL PROPERTIES
SHEET 3 OF 3

MATERIAL	STRESS PARAMETER (NOTE 1)	100°F	200°F	300°F	400°F	500°F	600°F	DATA SOURCE (NOTE 2)
SA-350, GRADE LF3	S S_m	17.5 23.3	17.5 22.8	17.5 22.2	17.5 21.5	17.5 20.2	17.5 ---	Table 1A Table 2A
SA-203, Grade D	S	16.2	16.2	16.2	16.2	16.2		Table 1A
SA-320, Grade L43	S_y	105.0	99.0	95.7	91.8	88.5	84.3	Table Y-1
SA-105	S_m S_y S_u	23.3 36.0 70.0	21.9 32.8 70.0	21.3 31.9 70.0	20.6 30.8 70.0			Table 2A Table Y-1 Table U
SA-516, Grade 70	S_y S	38.0 17.5	34.6 17.5	33.7 17.5	32.6 17.5	30.7 17.5	28.1 17.5	Table Y-1 Table 1A

NOTES

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,
   S_m refers to the ASME design stress intensity for Class 1 components, and
   S_y refers to minimum yield strength.
   S_u refer to minimum tensile strength
2. Data are taken from ASME Section II, Part D, 1992

TABLE 3.3-3

REFERENCE TEMPERATURES FOR
STRESS ANALYSIS ACCEPTANCE CRITERIA**

Component	Max. Calculated Temperature, °F	Selected Design Temperature, °F
Confinement Boundary	314	350
Outer Shell	240	300
Cask Lid	263	300
Lid Bolts	263	300
Trunnions	250	300

** Temperatures specified are used to determine allowable stresses. They are not a maximum use temperature for material.

TABLE 3.3-4

MECHANICAL PROPERTIES OF BASKET MATERIALS (1)(2)

Material Specification (Nominal Composition)	Minimum Yield Strength S_y, psi	Minimum Ultimate Strength S_u, psi	Design Stress Value, psi	Data Source (Note 3)
ASME SA-240, Type 304	30,000	75,000	S_m = 20,000	Table 2A
ASME SB 209, 6061-T6/T651 Aluminum Plate	35,000	42,000	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 material.

   Temperature dependent properties required for structural analysis are provided in Table 3.3-5.

2. Data are taken from tables in ASME Section II, Part D, 1992.

TABLE 3.3-5

TEMPERATURE DEPENDENT 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-209, 6061-T6/T651 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, 1992.

TABLE 3.3-5

TEMPERATURE DEPENDENT MATERIAL PROPERTIES
SHEET 2 OF 3
MODULI OF ELASTICITY, E
(Note 1)

TEMPERATURE, °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-209, 6061-T6/T651 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, 1992.

TABLE 3.3-5

TEMPERATURE DEPENDENT MATERIAL PROPERTIES
SHEET 3 OF 3
DESIGN STRESS PARAMETERS

		TEMPERATURE,° F						
MATERIAL	STRESS PARAMETER (KSI) (NOTE 1)	100	200	300	400	500	600	DATA SOURCE
ASME SA-240 Type 304	S_y	30.0	25.0	22.5	20.7	19.4	18.2	Table Y-1
	S_m	20.0	20.0	20.0	18.7	17.5	16.4	TABLE 2A
ASME SB-209 Alloy 6061-T6/T651 (Aluminum)	S_y	35.0	33.7	27.4	13.3	4.4		NOTE 3
	S_u	42.0	36.7	31.7	17.7	7.0		NOTE 3

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. 87.5% of Reference 5 data as recommended by ASME Subgroup on Non Ferrous Alloys.

TABLE 3.3-6 sheet 1
TN-32 Cask Components and Materials

Primary Function	Component	Drawing	Safety Class.	Codes/Standards
Containment	Lid	1049-70-2 It.2	A	ASME Subsection NB
	Inner Confinement(Shell&Bottom)	1049-70-2 It.3,5	A	ASME Subsection NB
	Flange	1049-70-2 It.31	A	ASME Subsection NB
	Lid Bolt (48)	1049-70-2 It.13	A	ASME Subsection NB
	Lid Seal	1049-70-2 It.15	A	
	Drain Port Cover	1049-70-2 It.21	A	ASME Subsection NB
	Vent Port Cover	1049-70-2 It.22	A	ASME Subsection NB
	Vent & Drain Port Cover Seal	1049-70-2 It.23	A	
	Vent & Drain Port Cover Bolts	1049-70-2 It.24	A	ASME Subsection NB
Criticality Control	Poison Plates	1049-70-2 It.29	A	
	Basket Rail Type 1	1049-70-2 It.30	A	
	Basket Rail Type 2	1049-70-2 It.26	A	
	Fuel Compartment	1049-70-2 It.27	A	ASME Subsection NB
Shielding	Gamma Shield	1049-70-2 It.1	A	ASME Subsection NF
	Shield Plate	1049-70-2 It.7	B	
	Bottom	1049-70-2 It.4	A	ASME Subsection NF
	Radial Neutron Shield	1049-70-2 It. 8	B	
	Outer Shell	1049-70-2 It. 9	B	
	Shim	1049-70-2 It. 33	A	
	Top Neutron Shield	1049-70-2 It. 11/11A	B	
Heat Transfer	Radial Neutron Shield Box	1049-70-2 It. 12	B	
	Aluminum Plate	1049-70-2 It.28	A	
	Basket Rail Type 1	1049-70-2 It.30	A	
	Basket Rail Type 2	1049-70-2 It.26	A	
Structural Integrity	Gamma Shield	1049-70-2 It.1	A	
	Bottom	1049-70-2 It.4	A	ASME Subsection NF
Operations Support	Trunnion	1049-70-2 It. 6	B	ANSI N14.6
	Protective Cover	1049-70-2 It. 10	C	
	Protective Cover Bolt	1049-70-2 It. 14	C	
	~~Protective Cover Seal~~	~~1049-70-2 It.16~~	~~C~~	
	Top Neutron Shield Bolt	1049-70-2 It.19/19A	C	
	Top Trunnion	1049-70-2 It. 32	A	ANSI N14.6
	Pressure Relief Valve		C	
	Quick Disconnect Couplings	1049-70-3	C	
Leakage Monitoring Secondary Seal	Overpressure Port Cover	1049-70-2 It. 17	C	
	Overpressure Port Cover Seal	1049-70-2 It. 18	C	
	Pressure Monitoring System	1049-70-2 It. 20	C	
	Overpressure Port Cover Bolts	1049-70-2 It. 25	C	

TABLE 3.3-6 sheet 2, TN-32 Cask Components and Materials

Primary Function	Component	Material	Strength (70 °F.)(ksi)	Coating
Containment	Lid	SA-350, LF3 or SA-203 Gr. D	70	SST Cladding on Sealing Surfaces; Epoxy Paint* on External Surfaces Aluminum Metal Spray Interior
	Inner Confinement(Shell&Bottom)	SA-203 Gr. D	65	Aluminum Metal Spray Interior
	Flange	SA-350, LF3	70	SST Cladding on Sealing Surfaces; Epoxy Paint* on External Surfaces Aluminum Metal Spray Interior
	Lid Bolt (48)	SA320 L43	125	Nuclear Grade Neolube
	Lid Seal	Double Metallic O-Ring		None
	Drain Port Cover	SA-240, Type 304	75	None
	Vent Port Cover	SA-240, Type 304	75	None
	Vent & Drain Port Cover Seal	Double Metallic O-Ring		None
	Vent & Drain Port Cover Bolts	SA-193 Gr. B7 or B8		Nuclear Grade Neolube
Criticality Control	Poison Plates	Borated Aluminum		None
	Basket Rail Type 1	B221, 6061-T6 Aluminum	38	None
	Basket Rail Type 2	B221, 6061-T6 Aluminum	38	None
	Fuel Compartment	SA-240 Type 304	75	None
Shielding	Gamma Shield	SA-266 Class 2	70	Epoxy Paint* on Exterior
	Shield Plate	SA-105 or SA-516, Gr. 70	70	None
	Bottom	SA-516 Gr. 70 or SA-266 Cl. 2	70	Epoxy Paint* on Exterior
	Radial Neutron Shield	Borated Polyester Resin		None
	Outer Shell	SA-516 Gr. 70	70	Epoxy Paint* on Exterior
	Shim	SA-516 Gr. 70, SA-414, or SA-620	70	None
	Top Neutron Shield	Polypropylene		None
Heat Transfer	Radial Neutron Shield Box	6063-T5 Aluminum		None
	Aluminum Plate	B209,6061-T6/T651 Aluminum	42	
	Basket Rail Type 1	B221, 6061-T6 Aluminum	38	None
	Basket Rail Type 2	B221, 6061-T6 Aluminum	38	None
Structural Integrity	Gamma Shield	SA-266 Class 2	70	Epoxy Paint* on Exterior
	Bottom	SA-516 Gr. 70 or SA-266 Cl. 2	70	Epoxy Paint* on Exterior
Operations Support	Trunnion	SA-105	70	Epoxy Paint* on Exterior
	Protective Cover	SA-516 Gr. 70/SA-105	70	Epoxy Paint* on Exterior
	Protective Cover Bolt	SA-193 Gr. B8		Nuclear Grade Neolube
	Protective Cover Seal	Elastomer		None
	Top Neutron Shield Bolt	SA-193 Gr. B8		None
	Top Trunnion	SA-105	70	Epoxy Paint* on Exterior (exc. Seating surfaces)
	Pressure Relief Valve	SST		None
	Quick Disconnect Couplings	SST		None
Leakage Monitoring	Overpressure Port Cover	SA-240 Type 304	75	None
	O.P. Port Cover Seal	Single Metallic O-ring		None
	Pressure Monitoring System	Carbon Steel/Stainless Steel Metal Diaphragm Valves		Epoxy Paint* on Exterior
Secondary Seal	Overpressure Port Cover Bolt	SA-193 Gr. B7 or B8		Nuclear Grade Neolube

*Paint may be epoxy, acrylic urethane, or equivalent

TABLE 3.3-6 sheet 3
TN-32 Cask Components and Materials

Primary Function	Component	Welding/Weld Filler Metal	Max. Stress (ksi)	
			Normal Cond.	Accident Cond.
Containment	Lid	Per Section III, NB and Section IX	2.5	29.5
	Inner Confinement(Shell&Bottom)	Per Section III, NB and Section IX	8.3	26.7
	Flange	Per Section III, NB and Section IX	3.4	18.4
	Lid Bolt (48)	N/A	67.7	80.2
	Lid Seal	N/A		
	Drain Port Cover	N/A		
	Vent Port Cover	N/A		
	Vent & Drain Port Cover Seal	N/A		
	Vent & Drain Port Cover Bolts	N/A	26	47.4
Criticality Control	Poison Plates	N/A		
	Basket Rail Type 1	N/A		22.8
	Basket Rail Type 2	N/A		25.3
	Fuel Compartment	Per Section III, NG and Section IX	32.5	61.6(26.8 inelastic)
Shielding	Gamma Shield	Per Section IX	10.8	53.5
	Shield Plate	Per Section IX	2.5	27
	Bottom	Per Section IX	1.4	9.7
	Radial Neutron Shield		8.9	27.8
	Outer Shell		11.8	N/A
	Shim			
	Top Neutron Shield			
Heat Transfer	Radial Neutron Shield Box			
	Aluminum Plate			7
	Basket Rail Type 1	N/A		22.8
	Basket Rail Type 2	N/A		25.3
Structural Integrity	Gamma Shield	Per Section IX	10.8	53.5
	Bottom	Per Section IX	1.4	9.7
Operations Support	Trunnion		9.4	
	Protective Cover		28	
	Protective Cover Bolt			
	Protective Cover Seal			
	Top Neutron Shield Bolt		16.8	
	Top Trunnion		5.1	
	Pressure Relief Valve			
	Quick Disconnect Couplings			
Leakage Monitoring	Overpressure Port Cover			
	Overpressure Port Cover Seal			
	Pressure Monitoring System			
Secondary Seal	Overpressure Port Cover Bolts			

TABLE 3.3-6 sheet 4
TN-32 Cask Components and Materials

Primary Function	Component	Temp. (Storage) (°F) Min	Max	0 yr. Storage	20 yr. Storage	Pressure Min(psig)	Max(psig)	Gas(type)
Containment	Lid	-20	263	263	197	0	100	Helium
	Inner Confinement(Shell&Bottom)	-20	314	314	227	0	100	Helium
	Flange	-20	308	308	224	0	100	Helium
	Lid Bolt (48)	-20	256	256	194	0	100	Helium
	Lid Seal	-20	256	256	194	0	100	Helium
	Drain Port Cover	-20	263	263	197	0	100	Helium
	Vent Port Cover	-20	263	263	197	0	100	Helium
	Vent & Drain Port Cover Seal	-20	263	263	197	0	100	Helium
	Vent & Drain Port Cover Bolts	-20	263	263	197	0	100	Helium
Criticality Control	Poison Plates	-20	527	527	346			
	Basket Rail Type 1	-20	339	339	240			
	Basket Rail Type 2	-20	339	339	240			
	Fuel Compartment	-20	527	527	346			
Shielding	Gamma Shield	-20	303	303	221			
	Shield Plate	-20	263	263	197			
	Bottom	-20	255	255	196	3	5	Air
	Radial Neutron Shield	-20	280	280	208			
	Outer Shell	-20	240	240	187	3	5	Air
	Shim	-20	303	303	221			
	Top Neutron Shield	-20	256	256	194			
Heat Transfer	Radial Neutron Shield Box	-20	280	280	208			
	Aluminum Plate	-20	527	527	346			
	Basket Rail Type 1	-20	339	339	240			
	Basket Rail Type 2	-20	339	339	240			
Structural Integrity	Gamma Shield	-20	303	303	221			
	Bottom	-20	255	255	196	3	5	Air
Operations Support	Trunnion	-20	240	240	187	3	5	Air
	Protective Cover	-20	240	240	187	3	5	Air
	Protective Cover Bolt	-20	256	256	194	3	5	Air
	Protective Cover Seal	-20	256	256	194			
	Top Neutron Shield Bolt	-20	256	256	194			
	Top Trunnion	-20	240	240	187	3	5	Air
	Pressure Relief Valve	-20	263	263	197			
	Quick Disconnect Couplings	-20	263	263	197			
Leakage Monitoring	Overpressure Port Cover	-20	263	263	197			
	Overpressure Port Cover Seal	-20	263	263	197			
	Pressure Monitoring System	-20	240	240	187	3	5	Air
Secondary Seal	Overpressure Port Cover Bolts	-20	263	263	197			

Table 3.4-1A
Trunnion Section Properties and Loads (TN-32 & TN-32A)

ITEM	SECTION A-A	SECTION B-B	SECTION C-C
CROSS SECTION AREA, IN^2	58.9	66.0	46.47
AREA MOMENT OF INERTIA, IN^4	460.2	478.3	264.80
YIELD CONDITION* SHEAR FORCE, LBS	364,500	364,500	364,500
YIELD CONDITION* BENDING MOMENT, IN- LBS	2,330,978	958,635	820,125
ULTIMATE CONDITION** SHEAR FORCE, LBS.	607,500	607,500	607,500
ULTIMATE CONDITION** BENDING MOMENT, IN-LBS	3,884,963	1,597,725	1,366,875

* Trunnion Loads to Support 3 times Cask Weight
** Trunnion Loads to Support 5 times Cask Weight

Table 3.4-1B
Trunnion Section Properties and Loads (TN-32B)

ITEM	SECTION A-A	SECTION B-B	SECTION C-C
CROSS SECTION AREA, IN^2	105.2	93.5	79.8
AREA MOMENT OF INERTIA, IN^4	1242.5	987.2	755.6
YIELD CONDITION* SHEAR FORCE, LBS	802,000	802,000	802,000
YIELD CONDITION* BENDING MOMENT, IN- LBS	5,120,000	2,101,000	1,804,000
ULTIMATE CONDITION** SHEAR FORCE, LBS.	1,337,000	1,337,000	1,337,000
ULTIMATE CONDITION** BENDING MOMENT, IN-LBS	8,534,000	3,502,000	3,007,000

* Trunnion Loads to Support 6 times Cask Weight (Including 10% DLF)
** Trunnion Loads to Support 10 times Cask Weight (Including 10% DLF)

TABLE 3.4-2A
TRUNNION STRESSES (TN-32 & TN-32A)

STRESS	YIELD LIMIT (ksi)		
Figure 3.4-1A	SECTION A-A	SECTION B-B	SECTION C-C
SHEAR STRESS	6.2	5.5	7.8
BENDING STRESS	25.3	10.0	13.4
STRESS INTENSITY	28.2	14.9	20.7
ALLOWABLE STRESS	31.9	31.9	31.9
	ULTIMATE LIMIT (ksi)		
SHEAR STRESS	10.3	9.2	13.1
BENDING STRESS	42.2	16.7	22.4
STRESS INTENSITY	47.0	24.9	34.4
ALLOWABLE STRESS	70.0	70.0	70.0

TABLE 3.4-2B
TRUNNION STRESSES (TN-32B)

STRESS	YIELD LIMIT (ksi)		
Figure 3.4-1B	SECTION A-A	SECTION B-B	SECTION C-C
SHEAR STRESS	7.6	8.6	10.1
BENDING STRESS	26.2	12.8	13.4
STRESS INTENSITY	30.3	21.4	24.2
ALLOWABLE STRESS	31.9	31.9	31.9
	ULTIMATE LIMIT (ksi)		
SHEAR STRESS	12.7	14.3	16.7
BENDING STRESS	43.6	21.3	22.4
STRESS INTENSITY	50.5	35.6	40.3
ALLOWABLE STRESS	70.0	70.0	70.0

Table 3.4-3A

Trunnion Loadings Used in Cask Body Evaluation (TN-32 & TN-32A)

Loading Description	Inertial Load	Max. Trunnion Load (Load Shared by 2 Top Trunnions)
Lifting Cask Vertical	3 G	V_L = 364.5 kips. M_L = -2,331 in-kips

Table 3.4-3B

Trunnion Loadings Used in Cask Body Evaluation (TN-32B)

Loading Description	Inertial Load	Max. Trunnion Load (Load Shared by 2 Top Trunnions)
Lifting Cask Vertical	6 G (including 10% DLF)	V_L = 801.9 kips. M_L = -5,120.1 in-kips

Table 3.4-4

Bijlaard Computation Sheet

1 APPLIED LOADS

- RADIAL LOAD P = ______ LB
- CIRC MOMENT M_c = ______ IN-LB
- LONG MOMENT M_L = ______ IN-LB
- TORSION MOMENT M_T = ______ IN-LB
- SHEAR LOAD V_c = ______ LB
- SHEAR LOAD V_L = ______ LB

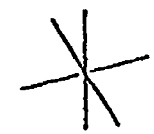
NOTE: ENTER ALL FORCE VALUES IN ACCORDANCE WITH SIGN CONVENTION

2 GEOMETRY

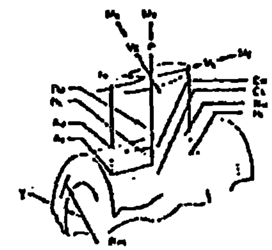
- VESSEL THICKNESS T = ______ IN
- ATTACHMENT RADIUS r_o = ______ IN.
- VESSEL RADIUS R_m = ______ IN

3 GEOMETRIC PARAMETERS

- $\gamma = \frac{R_m}{T}$ = ______
- $\beta = (0.875)\frac{r_o}{R_m}$ = ______



PIPING LOAD COORDINATE SYSTEM



FROM FIG	READ CURVES FOR	COMPUTE ABSOLUTE VALUES OF STRESS AND ENTER RESULT	STRESSES – IF LOAD IS OPPOSITE THAT SHOWN, REVERSE SIGNS SHOWN A_u	A_L	B_u	B_L	C_u	C_L	D_u	D_L
3C AND 4C	$\frac{N_\phi}{P/R_m}$ =	$\left(\frac{N_\phi}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C AND 2C-1	$\frac{M_\phi}{P}$ =	$\left(\frac{M_\phi}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
3A	$\frac{N_\phi}{M_c/R_m^2\beta}$ =	$\left(\frac{N_\phi}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =					−	−	+	+
1A	$\frac{M_\phi}{M_c/R_m\beta}$ =	$\left(\frac{M_\phi}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =					−	+	+	−
3B	$\frac{N_\phi}{M_L/R_m^2\beta}$ =	$\left(\frac{N_\phi}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+				
1B OR 1B-1	$\frac{M_\phi}{M_L/R_m\beta}$ =	$\left(\frac{M_\phi}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−				
ADD ALGEBRAICALLY FOR SUMMATION OF ϕ STRESSES σ_ϕ =										
3C AND 4C	$\frac{N_x}{P/R_m}$ =	$\left(\frac{N_x}{P/R_m}\right)\cdot\frac{P}{R_m T}$ =	+	+	+	+	+	+	+	+
1C-1 AND 2C	$\frac{M_x}{P}$ =	$\left(\frac{M_x}{P}\right)\cdot\frac{6P}{T^2}$ =	+	−	+	−	+	−	+	−
4A	$\frac{N_x}{M_c/R_m^2\beta}$ =	$\left(\frac{N_x}{M_c/R_m^2\beta}\right)\cdot\frac{M_c}{R_m^2\beta T}$ =					−	−	+	+
2A	$\frac{M_x}{M_c/R_m\beta}$ =	$\left(\frac{M_x}{M_c/R_m\beta}\right)\cdot\frac{6M_c}{R_m\beta T^2}$ =					−	+	+	−
4B	$\frac{N_x}{M_L/R_m^2\beta}$ =	$\left(\frac{N_x}{M_L/R_m^2\beta}\right)\cdot\frac{M_L}{R_m^2\beta T}$ =	−	−	+	+				
2B OR 2B-1	$\frac{M_x}{M_L/R_m\beta}$ =	$\left(\frac{M_x}{M_L/R_m\beta}\right)\cdot\frac{6M_L}{R_m\beta T^2}$ =	−	+	+	−				
ADD ALGEBRAICALLY FOR SUMMATION OF x STRESSES σ_x =										
SHEAR STRESS DUE TO TORSION M_T		$\tau_{x\phi} = \tau_{\phi x} = \frac{M_T}{2\pi r_o^2 T}$	+	+	+	+	+	+	+	+
SHEAR STRESS DUE TO LOAD V_c		$\tau_{x\phi} = \frac{V_c}{\pi r_o T}$	+	+	−	−				
SHEAR STRESS DUE TO LOAD V_L		$\tau_{\phi x} = \frac{V_L}{\pi r_o T}$					+	+	−	−
ADD ALGEBRAICALLY FOR SUMMATION OF SHEAR STRESSES τ =										

	LONGITUDINAL σ_x		CIRCUMFERENTIAL σ_ϕ	
PRESSURE STRESS	$\frac{PR-0.4PT}{2ET}$ =	= ______	$\frac{PR+0.6PT}{ET}$ =	= ______
LONGITUDINAL BENDING STRESS		= ______		
TOTAL MEMBRANE STRESS		= ______ < ______		= ______ < ______
TOTAL SURFACE STRESS		= ______ < ______		= ______ < ______

NOZZLE NO. ______

PIPING LOAD CODE ______

ANALYSIS POINT ______

COMPUTATION SHEET FOR LOCAL STRESSES IN CYLINDRICAL SHELLS		
SERVICE:		
ITEM NO		
DATE	BY	SHEET

Table 3.4-5
Comparison of Actual With Allowable Stress Intensity
Confinement Vessel

Service Condition	Component	Stress Category	Stress Resultant Table	Maximum Stress Intensity (PSI)	Allowable Stress Intensity (PSI)	Margin to Allowable
Normal Condition	Shell	P_m			16,200 (S)	
		$P_m + P_b$	3A.2.5-10 Location 8	8,311	24,300 (1.5S)	1.92
	Flange	P_m			17,500 (S)	
		$P_m + P_b$	3A.2.5-3 Location 19	3,442	26,250 (1.5S)	6.63
	Lid*	P_m			16,200 or 17,500 (S)	
		$P_m + P_b$	3A.2.5-3 Location 21	2,470	24,300 or 26,250 (1.5S)	8.84 or 9.63
Accident Condition	Shell	P_m		26,692	38,880 (2.4S)	0.46
		$P_m + P_b$	3A.2.5-23 Location 5	41,283	58,320 (3.6S)	0.41
	Flange	P_m			42,000 (2.4S)	
		$P_m + P_b$	3A.2.5-24 Location 20	18,394	63,000 (3.6S)	2.43
	Lid*	P_m			38,880 or 42,000 (2.4S)	
		$P_m + P_b$	3A.2.5-20 Location 22	29,496	58,320 or 63,000 (3.6S)	0.98 or 1.14

Note: If the primary membrane plus bending stress for a particular component meets the primary membrane stress allowable, only the Normal Condition primary plus bending stress is reported.

For components made from alternate materials, the lowest allowable stress is used. Both allowables are provided for the lid materials.

Table 3.4-6
Comparison of Actual with Allowable Stress Intensity
Gamma Shielding

Service Condition	Component	Stress Category	Stress Resultant Table	Maximum Stress Intensity (PSI)	Allowable Stress Intensity (PSI)	Margin to Allowable
Normal Condition	Cylinder	P_m			21,300 (S_m)	
		$P_m + P_b$	3A.2.5-5 Location 35	10,897	31,950 ($1.5S_m$)	1.93
	Bottom	P_m			21,300 (S_m)	
		$P_m + P_b$	3A.2.5-9 Location 24	1,355	31,950 ($1.5S_m$)	22.58
	Welds	P_m			21,300 (S_m)	
		$P_m + P_b$	3A.2.5-11 Location 39	8,934	31,950 ($1.5S_m$)	2.58
Accident Condition	Cylinder	P_m		30,989	49,000 ($0.7S_u$)	0.58
		$P_m + P_b$	3A.2.5-20 Location 31	53,555	70,000 (S_U)	0.31
	Bottom	P_m			42,000 ($2.4S_m$)	
		$P_m + P_b$	3A.2.5-24 Location 25	9,687	70,000 (S_u)	6.23
	Welds	P_m			49,000 ($0.7S_u$)	
		$P_m + P_b$	3A.2.5-24 Location 38	27,782	70,000 (S_u)	1.52

Note: If the primary membrane plus bending stress for a particular component meets the primary membrane stress allowable, only the Normal Condition primary plus bending stress is reported.

Table 3.4-7
Summary of Maximum Stress Intensity
and Allowable Stress Limits for Lid Bolts

STRESS CATEGORY	SERVICE CONDITION	CALCULATED STRESS (ksi)	ALLOWABLE STRESS (kSI)	Margin to Allowable
Tensile	Level A	39.8	63.8 ($2S_m$)	0.6
	Level D	39.8	79.75 ($0.7\ S_u$)	1.00
Tensile + Bending	Level A	61.2	95.7 ($3S_m$)	0.56
	Level D	61.2	113.93 (S_u)	0.86
Shear	Level A	14.5	38.28 ($0.4S_y$)	1.65
	Level D	25.9	47.85 ($0.42S_u$)	0.85
Combined S.I.	Level A	67.7	95.7 ($3S_m$)	0.41
	Level D	80.2	113.9 (S_u)	0.42

Table 3.4-8
Comparison of Actual with Allowable Stress Intensity in Basket

Service Condition	Component/ Stress Category	Stress Intensity (psi)	Allowable Stress Intensity (psi)	Reference Table #	Margin to Allowable
Normal	**304 SS Fuel Boxes**				
1G Lateral	P_m	394	18,700 (S_m)	3B.3-1 (2D)	46.46
	$P_m + P_b$	12,080	28,050 ($1.5S_m$)	3B.3-1 (1D)	1.32
1G Lateral + Thermal	$P_m + P_b + Q$	32,517	51,690 ($3S_m$)	3B.3-5 (1)	0.59
	Plug Welds				
	P_m (2τ)	547	11,220 ($0.6S_m$)	-	19.51
	$P_m + Q$ (2τ)	34,190	51,690 ($3S_m$)	3B.3-5 (7)	0.51
Accident	**304 SS Fuel Boxes**				
50G Bottom End Drop	P_m	6,650	44,900 ($2.4S_m$)	Section 3B.4.1	5.75
50G Side Drop	P_m	13,140	44,900 ($2.4S_m$)	3B.4-11 (2C)	2.42
	$P_m + P_b$	62,560	64,400	3B.4-10 (1B)	0.03
	Aluminum Plate				
	P_m	3,046	12,400 ($2.4S_m$)	3B.4-14 (1)	3.07
	$P_m + P_b$	7,034	17,700 (S_u)	3B.4-14 (3)	1.52
	Plug Welds				
	τ	21,083	27,000 ($0.42S_u$)		0.28

Note: The calculated and allowable stresses for the plastic analysis of the basket for the hypothetical tipover are presented in Appendix 3C.

Table 3.4-9

Comparison of Maximum Stress Intensity with Allowables in Outer Shell

Load	Maximum Stress Intensity (ksi)	Allowable Stress (kSI)
25 psi internal pressure	7.23	S_y = 33.7
25 psi + 3G down Cask Vertical	11.76	
25 psi + 3G down Cask Horizontal	10.13	

Note: The worst loading orientation is horizontal; therefore stresses will be lower in actual operation since the loaded cask in storage at the ISFSI is vertical.

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3.4-1A
UPPER TRUNNION GEOMETRY
TN-32 & TN-32A CASKS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3.4-1B
UPPER TRUNNION GEOMETRY
TN-32B CASK

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3.4-1C
LOWER TRUNNION GEOMETRY
TN-32, TN-32A & TN-32B CASKS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3.4-2
CASK BODY KEY DIMENSIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3.4-3
STANDARD REPORTING
LOCATIONS FOR CASK BODY

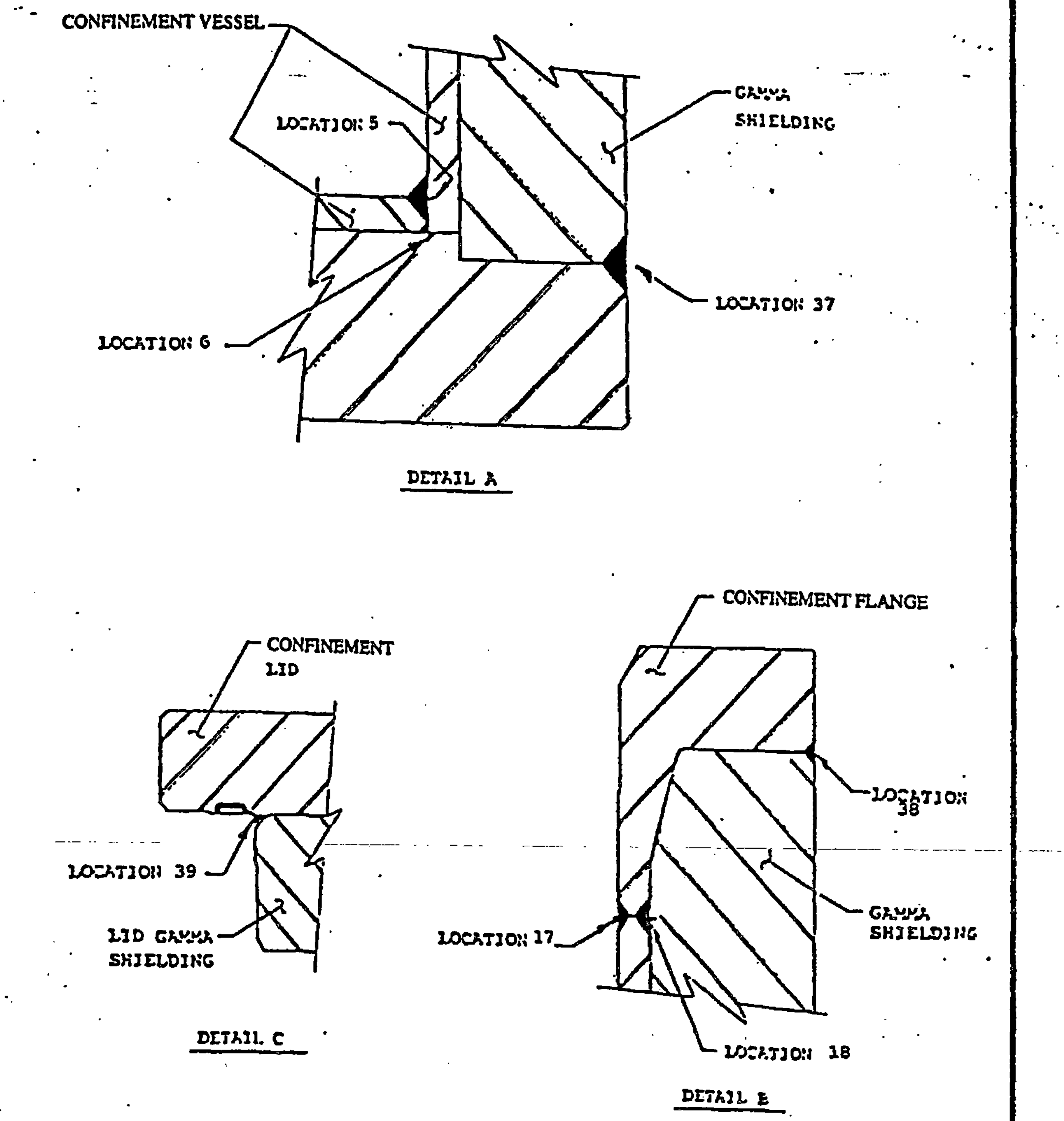
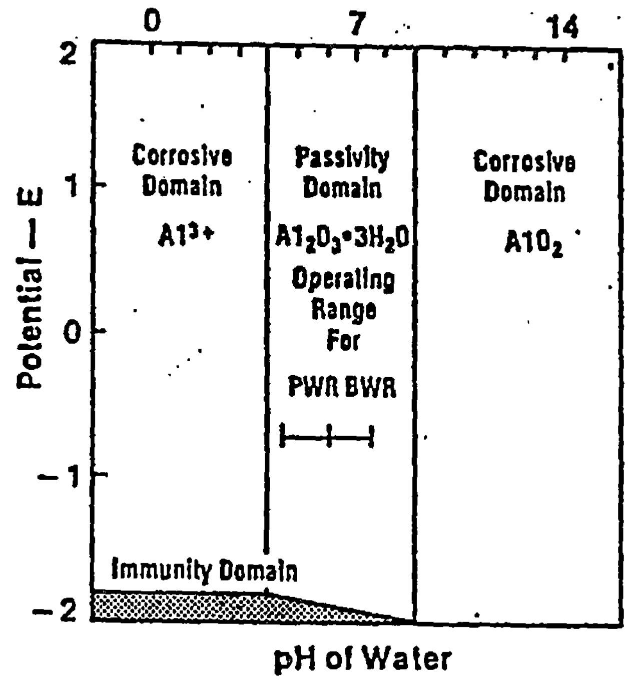


FIGURE 3.4-4
WELD STRESS LOCATIONS

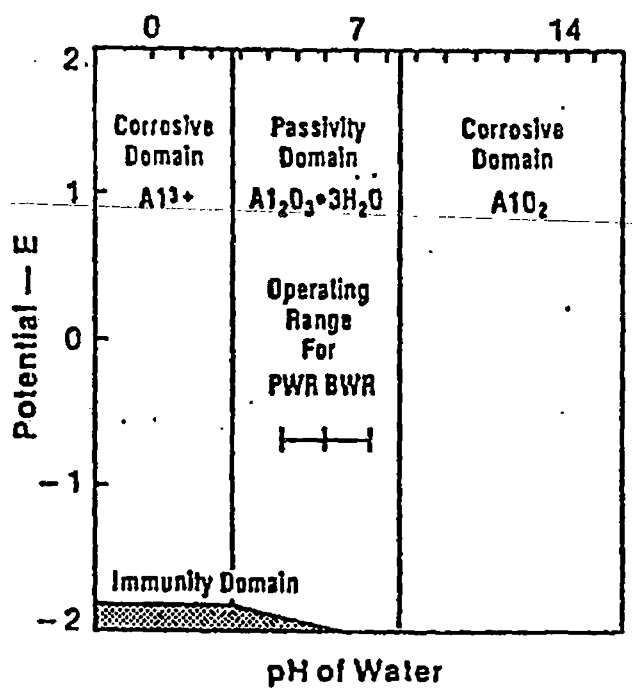
FIGURE 3.4-5

POTENTIAL VERSUS pH DIAGRAM FOR ALUMINUM-WATER SYSTEM

At 25°C (77°F):



At 60°C (140°F):



Source: Reference 13

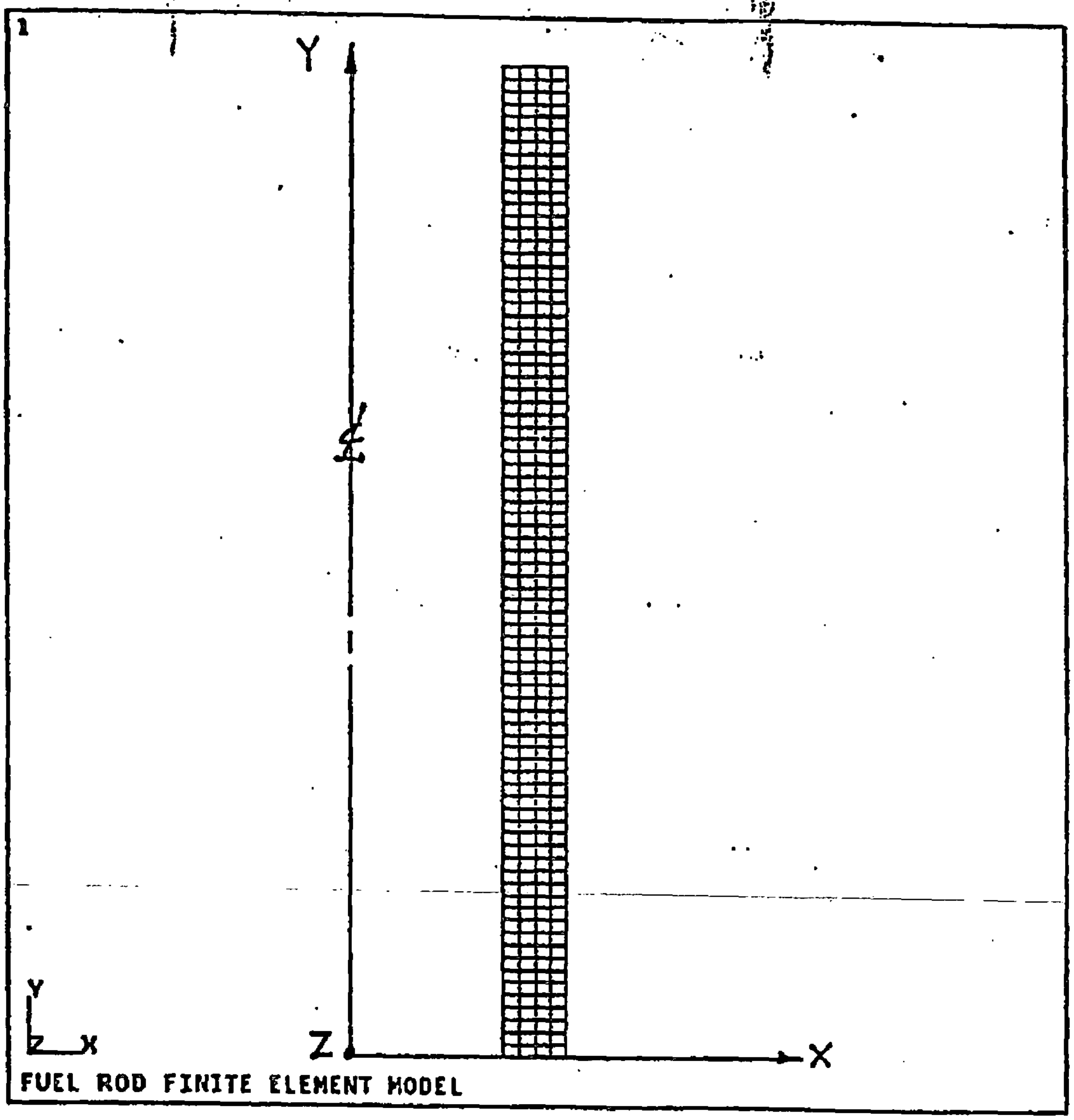


FIGURE 3.5-1
FINITE ELEMENT MODEL

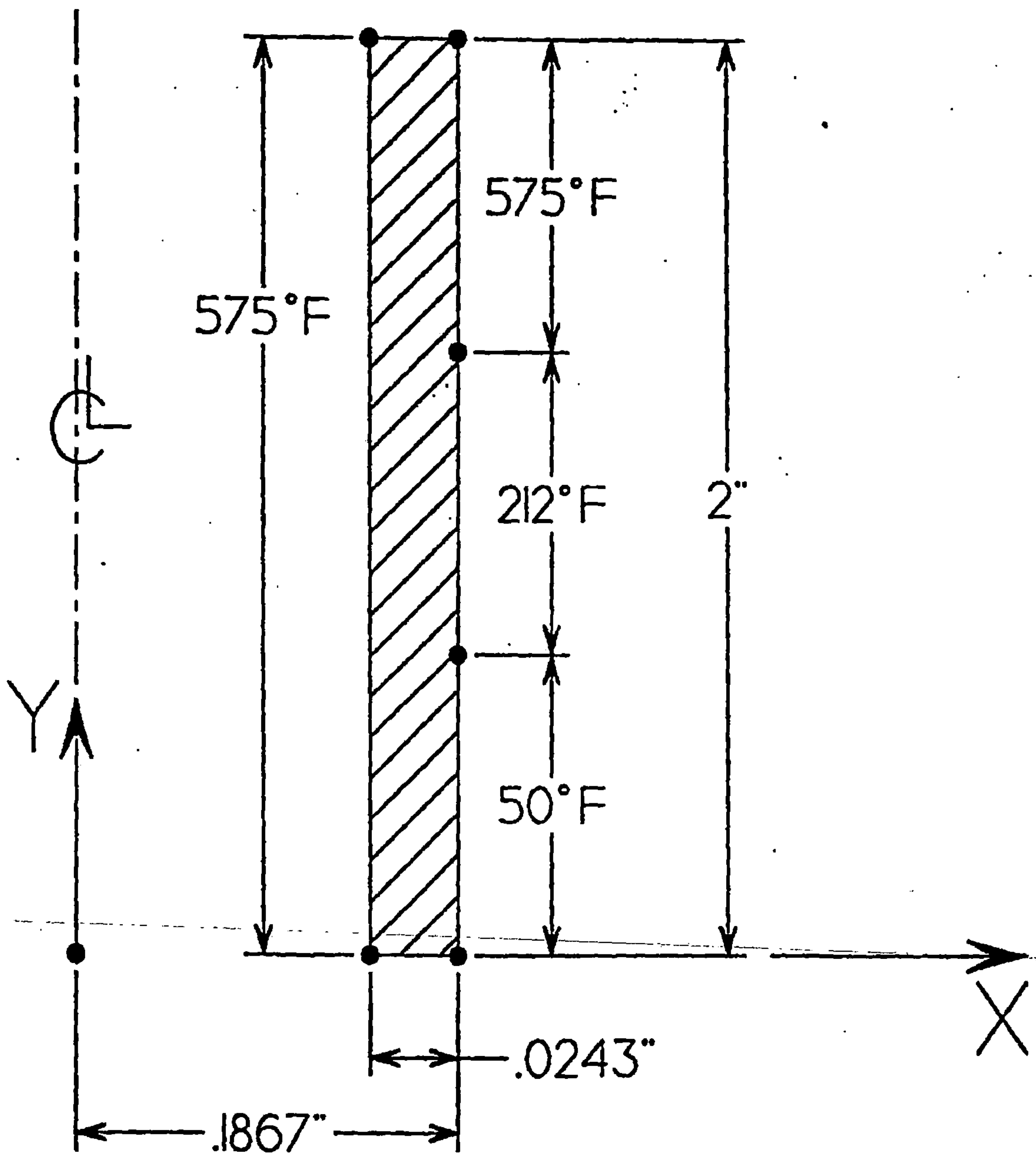


FIGURE 3.5-2
NODAL TEMPERATURE USED
FOR THERMAL ANALYSIS

REV. 0 1/00

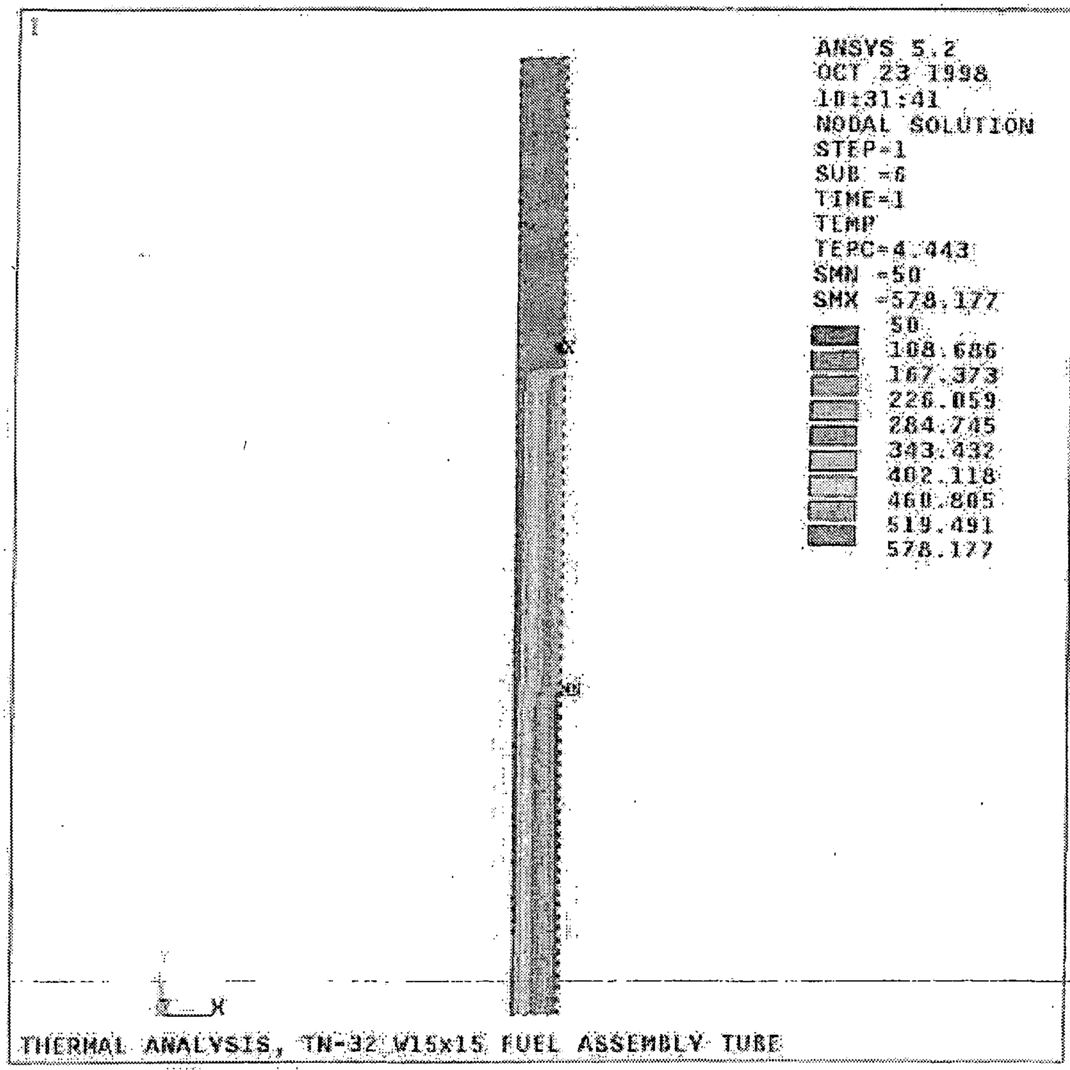


FIGURE 3.5-3
TEMPERATURE DISTRIBUTION
RESULTING FROM THERMAL
ANALYSIS

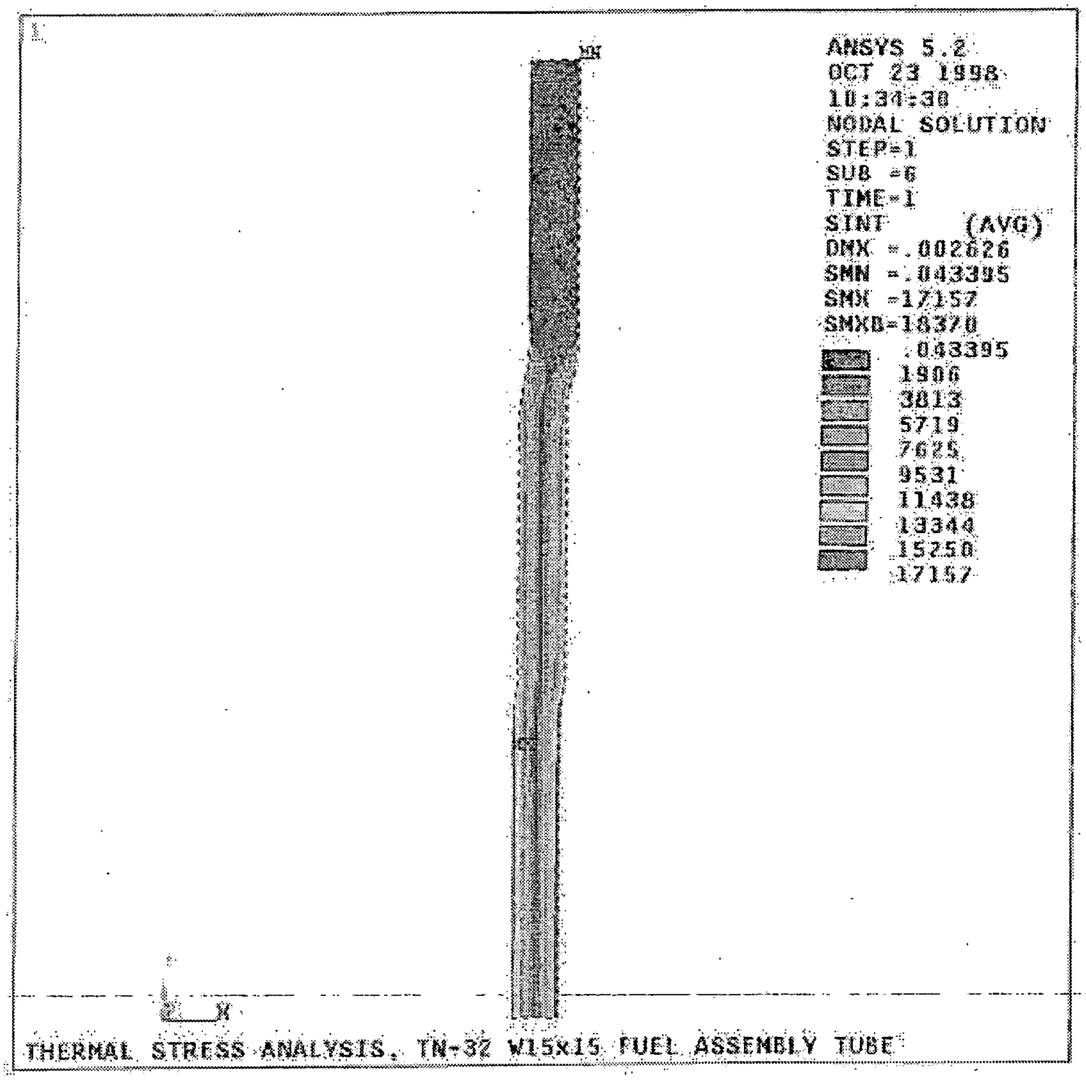


FIGURE 3.5-4
NODAL STRESS INTENSITY

APPENDIX 3A

STRUCTURAL ANALYSIS OF THE TN-32 STORAGE CASK BODY

3A.1 Introduction

This appendix presents the structural analysis of the TN-32 storage cask body which consists of the cask body, the trunnions and the outer shell. Analyses are performed to evaluate the various cask components under the loadings described in Section 2.5.

The detailed calculations for the cask body are presented in Section 3A.2 and the lid bolt analysis is reported in a separate Section 3A.3. The calculations for the outer shell and top neutron shield bolts are reported in Section 3A.4 and 3A.5, respectively. The trunnions are analysed in Chapter 3, Section 3.4.3.

The design criteria used in the analyses of the cask components are in accordance with the ASME Code, Section III, Subsection NB[1]. The material properties used are those obtained from the ASME Code[2]. Key dimensions of the storage cask are shown in Figure 3A.1-1.

3A.2 Cask Body Structural Analysis

3A.2.1 Description

The cask body as shown in Figure 3A.1-1 consists of:

1. A 1 1/2 in. thick inner vessel with a welded flat bottom, a flange at the top, and a lid bolted to the flange by 48, 1 1/2" diameter high strength bolts and sealed with two metallic o-rings. This is the confinement vessel, the primary confinement boundary of the cask.

2. A thick cylindrical vessel with a welded flat bottom surrounding the confinement vessel. This vessel and a steel disk welded to the lid inner surface provide the gamma shielding.

The lid and the flange are carbon steel forgings as are the gamma shielding components. The confinement boundary is designed as a Class 1 component in accordance with the rules of the ASME Code. A static, linear elastic analysis is performed on the cask body so that combinations of loads can be obtained by superposition of individual loads. The stresses and deformations due to the applied loads are generally determined using the ANSYS computer program[3]. A 2D ANSYS Model was specifically developed for this purpose. Exceptions include the analyses of the local effects at the trunnions and of the lid bolts.

3A.2.2 ANSYS Cask Model

A two dimensional ANSYS model is used to evaluate the stresses in the cask body due to the individual load cases. The finite elements used in the model are the axisymmetric shell element, Stif 61, and the axisymmetric harmonic shell element, Stif 25. Both of these elements consider axisymmetric and non-axisymmetric loadings.

The cylindrical confinement shell and bottom are modeled using Stif 61 elements. The remainder of the cask body is modelled with Stif 25 elements except for the lid bolts which are modelled with the two dimensional elastic beam, Stif 3. The finite element model of the cask body is shown in Figure 3A.2-1.

Figure 3A.2-2 shows an enlarged view of the bottom corner with the weld joining the gamma shielding flat bottom to cylinder simulated by coupling nodes 236-107 and 280-108.

The weld connecting the gamma shielding cylinder to the confinement flange is simulated by coupling nodes 63-328 and 64-329 as shown in Figure 3A.2-3. The gamma shielding is heated prior to assembly with the confinement shell and flange for ease of installation. During cool down, a gap may result between the

flange and the gamma shield shell. The gap is filled with shim plates made from SA-516, Grade 70 plate. The plates are fit between the gamma shield shell and the flange behind the weld. These shim plates are not modeled. The weld between the gamma shield and the flange is not affected by the shims. Also shown in this figure are the lid bolts connecting the lid to the confinement flange. The connection is simulated by coupling nodes 505, 506 and 507 of the bolts to the corresponding nodes 81, 74, and 67 of the flange; and nodes 501, 502 and 503 of the bolts to the corresponding nodes 438,439, and 440 of the lid. In this manner the threaded portion of the bolt is fixed to the flange while the bolt head is fixed to the top surface of the lid. In order to prevent the lid from moving into the flange, nodes 79 and 395 are also coupled in the axial or Y direction. The enlarged view in Figure 3A.2-4 shows the coupling of nodes 394-383 and 395-384 which simulates the weld connecting the confinement lid to the gamma shielding disk.

The pairs of nodes listed above, with the exception of nodes 79-395, are coupled in the X, Y and Z directions. The coupling of nodes 79-395 is in the Y direction only and is accomplished using a constraint equation. The reaction at the nodes is monitored during the analysis to insure that tensile forces between the cylinder and the lid are not developed.

Appropriate boundary conditions are applied to prevent rigid body motion and to show that the system of forces applied to the cask in each of the individual load cases is in equilibrium. Generally a node at the center of the vessel bottom is held in all directions and one at the center of the lid is held in the X and Z directions.

3A.2.3 Individual Load Cases

Individual load cases are evaluated to determine the stress contribution due to specific individual loads. Stress results are reported in this Appendix for each individual load. Since the individual load cases are linearly elastic, their results can be ratioed and/or superimposed as required in order to obtain the load combinations characteristic of the particular loading condition.

3A.2.3.1 Normal Conditions

The following individual loads are analyzed using the ANSYS model described in the previous section:

1. Bolt preload and seal seating pressure.
2. Internal Pressure loading.
3. External Pressure loading.
4. 1 g down with cask standing in a vertical position on the concrete storage pad.
5. Lifting (Cask Vertical)

6. Worst normal thermal condition.
7. 1 g lateral and 2 g down bounding loads on the cask standing in a vertical position on the concrete pad.

Loadings for Cases 1 through 6 are axisymmetric. In Case 7 Fourier series representation of the nonaxisymmetric loads are required. Each discrete load acting on the cask body is expanded into a Fourier series and is input into ANSYS as a series of load steps. Each load step contains all the terms from the applied loads having the same mode number. The number of terms in the Fourier series required to adequately represent a load varies with the type of load (concentrated or distributed) and the degree of accuracy required. In this case, the load applied by the internals to the inside wall of the confinement is assumed to be a distributed load varying sinusoidally in the arc 90° to 270° and acting on the total length of the cavity. Figure 3A.2-5 shows that only a few terms of the series are required to get a satisfactory representation of the load.

Since Case 7 is asymmetric, the resulting stresses are also asymmetric. Therefore in order to properly characterize the stress condition in the cask body, results are obtained at the two worst diametrically opposite locations and reported for the location where they are maximum.

The individual loads are described in the following paragraphs:

1. Bolt Preload and Seal Seating Pressure

A lid bolt preload corresponding to 25,000 psi direct stress in the bolt shank is simulated by specifying an initial strain in the elements representing the bolts. A portion of this strain becomes elastic preload strain in the bolts, and a portion becomes strain in the clamped parts. The required ~~initial stain value of 0.00134 in/in (in the bolts)~~ was determined by trial and error.

The selected bolt preload is sufficient to insure a full seating of the metallic seals under a maximum design internal pressure of 100 psig. The metallic seal seating load is 1713 lb./in./seal[4] or 3426 lb./in. for 2 seals. This load is simulated by applying a pressure of 3115 psi on an annular ring on both the confinement lid and flange surfaces as shown in Figure 3A.2-6.

The stresses in the confinement boundary and gamma shield are based on bolt preload corresponding to 25,000 psi direct stress in the shank and are listed in Tables 3A.2.3-1 and 2. It is seen that the stresses are very small. The maximum stress intensity is 831 psi at location 19. In Section 3A.3, the lid bolt was reanalyzed for a bolt preload of 39,810 psi direct tensile stress in the shank. The

effect of the bolt preload change on confinement boundary and gamma shield stress is approximately 500 psi and is, therefore negligible.

2. Internal Pressure Loading

A conservative design pressure of 100 psig is used as the maximum pressure acting in the confinement vessel cavity as shown in Figure 3A.2-7.

3. External Pressure Loading

A pressure of 25 psig is used as the maximum external pressure acting on the outer surface of the cask body as shown in Figure 3A.2-8.

4. 1 g Down

The cask is stored vertically on the concrete storage pad as shown in Figure 3A.2-9, with the following loads acting on it:

a. A distributed vertical down inertia force of 1 g acting at each finite element in the model. For practical purposes, the resultant of all these forces is shown acting at the C.G. of the cask. Note that the resin, the outer shell and the trunnions are not included in the model. They are accounted for by increasing the density of the gamma shielding.

b. Since the internals are not included in the model, their loading effects are simulated by a distributed pressure acting on the inside bottom surface of the cask cavity.

c. All nodes on the outside bottom surface of the cask are fixed in the axial directions.

5. Lifting: 3g and 6g Vertical Up

The cask is oriented vertically in space held by the 2 top trunnions and subjected to a vertical down load of 3g (TN-32 and TN-32A casks) or 6g (TN-32B cask), as shown on Figure 3A.2-10.

<u>3g Vertical Up</u>

The inertia force acting on the cask elements and the pressure from the internals on the confinement bottom inner surface are as described in Case 4 multiplied by a factor of 3. The total cask weight (including internals) is replaced by forces applied to the 2 top trunnions so that the system of forces acting on the cask is again in equilibrium. A

cask weight of 235,000 lb. is used to calculate the global stresses of the cask. For trunnion and trunnion local stress calculations, a conservative cask weight of 243,000 lb. is used.

For calculating the cask body global stresses, the two trunnion forces F_{TR} = 1.5W are replaced by a uniform line force:

$$q_Y = \frac{3\ W}{2\ \pi\ R} = \frac{3 \times 235,000}{2 \times 3.14 \times 43.875} = 2558.7 \text{ lb. / in.}$$

acting in the Y direction on the outer surface of the gamma shielding at the trunnion location. Superimposed on this solution are the local trunnion effects at two locations around the circumference which are determined by using the Bijlaard method.

<u>6g Vertical Up</u>

Same methodology as described above is used for calculating the cask body global stresses due to 6g lifting load.

6. Worst Temperature Distribution in the Cask Body

A thermal analysis of the cask body using a 3D ANSYS thermal model is described in Chapter 4. The thermal model is used to obtain the steady state metal temperatures in the cask body for the normal condition which includes 100° F ambient air temperature, maximum decay heat and maximum solar heat loading. The thermal stress evaluations were conservatively based on an outside gamma shield temperature of 260°F and an inside cavity temperature of 330°F (temperature differential of 70°F). The actual temperature difference is less than 10°F from the thermal analysis presented in Chapter 4. Therefore the thermal stresses calculated here are conservative. It may be pointed out that the cask metal temperature differential (ΔT) for -20° F ambient and 100°F ambient are about the same. Therefore, thermal stresses are reported only for 100°F ambient temperature.

7. 1 g Lateral and 2 g down Bounding Loads - Cask Standing in a Vertical Orientation on the Pad

The sinθ and cosθ terms of the Fourier series are used to represent the 1 g lateral load acting at the CG of each finite element of the model. The load applied by the internals to the inside surface of the confinement is assumed to vary sinusoidally on a 180° arc as shown in Figure 3A.2-5, and the same Fourier representation applies. The 2 g down load is applied simultaneously (as described in 4, above) with the 1 g lateral load. The cask is held at

the bottom and no tilting or sliding is allowed (See Figure 3A.2-11). This load combination is an upper bound loading for tornado wind, flood water, seismic loads, etc. (See Table 2.2-3).

3A.2.3.2 Accident Conditions

This section evaluates the effects of a hypothetical drop or tipover of the cask on the ISFSI storage pad. The following cases are evaluated:

- An 18 inch drop onto a concrete storage pad. This is the maximum height the cask will be lifted during transport to the storage location.

- A tipover of the cask onto a storage pad.

The stability of the TN-32 storage cask in the upright position on the ISFSI concrete storage pad is demonstrated in Section 2.2 of this TSAR. The effects of tornado wind and missiles, flood water and earthquakes are described in Sections 2.2.1, 2.2.2 and 2.2.3, respectively. It is shown in those sections that the cask will not tip over under the bounding natural phenomena specified in this Safety Analysis Report. The cask will not slide on its pad any more than about eight inches under any of these loadings.

The storage pad is the hardest concrete surface outside of the confinement building. The cask is always oriented vertically and is not lifted higher than 18 in. once it leaves the confinement building. Therefore this case is an upper bound drop event since impact onto a softer surface would result in lower cask deceleration and a lower impact force.

The impact analysis is based on the methodology of EPRI NP-4830[5]. This report considers the mass and geometry of the cask but assumes it to be rigid compared to the concrete storage pad. The storage pad properties and the cask geometry are used to determine the pad hardness parameter. The report provides graphs that show the force on the cask as a function of storage pad hardness. Scale model drop testing at Sandia National Laboratories and full scale cask drop testing in England have recently been performed in an attempt to "benchmark" the EPRI methodology. The preliminary results of the tests show excellent correlation with the predicted results.

3A.2.3.2.1 Storage Pad Hardness

The target (or storage pad) hardness parameter, S, for the end drop case is calculated using the following formula. Values of the storage pad parameters are taken from the Virginia Power ISFSI site data. These values are representative of typical storage pad parameters. The resulting g loadings are increased to allow for the effects of variations on these parameters.

$$S_{end} = \frac{2}{W^3} \frac{r A k M_u \sigma_u}{(1 - e^{-\beta r} \cos \beta r)} = 120{,}145 \quad \text{(formula 4, Reference 5)}$$

Where
- r = cask bottom radius = 43.875 in.
- A = bottom area = πr^2 = 6047.6 in.^{2}
- $k = \dfrac{\pi E_s}{1 - \nu_s^2}$ = 134,776 psi/in.
- E_s = Soil modulus = 32,600 psi
- ν_s = Poisson's ratio of soil = 0.49
- M_u = is based on pad thickness of 36 in., #11 rebar @ 12 in. spacing (nominal), S_y rebar of 60,000 psi, 2 in. cover (nominal), σ_u of 6000 psi concrete compressive strength = 3.0378 x 10^6 in.-lb/ft.
- β = 0.0274
- W = 230,000 lbs

If it is assumed that the entire cask side crushes into the pad during the tipover, the storage pad hardness parameter (S) is:

$$\frac{2 A E_s M_u \sigma_u}{W^3 \beta} = 23{,}913 \quad \text{(formula 5, Reference 5)}$$

Where
- A = cask length x 10 in. = 1837.5 in.^{2}
- β = 0.0075
- E_s = Soil modulus = 32,600 psi
- W = 230,000 lbs
- σ_u = concrete compressive strength = 6,000 psi
- M_u = is based on pad thickness of 36 in., #11 rebar @ 12 in. spacing (nominal), S_y rebar of 60,000 psi, 2 in. cover (nominal), σ_u of 6000 psi concrete compressive strength = 3.0378 x 10^6 in.-lb/ft.

3A.2.3.2.2 Decelerations

Figure 22 for a 20 in. drop height from EPRI NP-4830[5] can be conservatively used to determine the cask deceleration after the 18 in. end drop. The upper bound deceleration is 42 g's for a hardness parameter, S, of 120,145. The maximum impact force is then 42 times the weight of the cask.

The end drop analysis for the TN-32 cask is performed assuming a conservatively high value of 50 g's deceleration.

During tipover, the center of gravity (CG) of the cask moves beyond the corner of the cask and then drops as the cask falls. The CG drops 53.05 in. after moving over the corner. The change in potential energy of the cask is then equal to the rotational kinetic energy as it impacts after tipover.

$KE = ½ I\omega^2 = Wh$

Where h = 53.05 in. (d_{cg} - cask o.d./2, Figure 2.2-2)

I = Mass moment of inertia of cask about corner = 8.09×10^6 lb.in.sec2

Then $\omega = (2Wh/I)^{1/2} = 1.729$ rad/sec

which is the rotational velocity of the cask as it strikes the pad.

If the cask is pivoting about the bottom corner, the impact velocity of the top of the cask is equal to the length multiplied by ω:

$V_{impact} = l\omega$
$= 184 \text{ in.} \times 1.729 \text{ rad/sec} = 318.1 \text{ in/sec.}$

If it is conservatively assumed that the entire side of the cask impacts at this velocity, the equivalent drop height (to produce a velocity of 318.1 in/sec) would be:

$$h = \frac{V^2}{2g} = \frac{(318.1)^2}{2 \times 386} = 131 \text{ in.}$$

The impact velocity of the CG is approximately half of the top velocity or 160 in/sec. The drop height to produce this velocity is only 33.2 in. Therefore, the 131 in. height assumed above is very conservative.

Figure 19 of EPRI NP-4830[5] shows that, for a target hardness of 23,913, the upper bound cask deceleration is 27 g for any drop height above 15 in. Therefore the maximum side impact force is equal to 27 times the weight of the cask. The stress analyses described below for the TN-32 cask tipover, with one exception, are therefore conservatively performed for a side impact with deceleration of 50 g's. The exception is the lid bolt analysis where the tipover can cause lid bolt tension whereas the side impact will not cause bolt tension. The conservative assumptions made for the bolt analysis are described in Section 3A.3.

The analysis results for two hypothetical impact accidents are reported in this section. These are the 50 g bottom end drop onto the storage pad and a side drop which envelops the tip over case. As explained in Section 11.2.8, these accidents have a very low probability of occurrence, but in view of their potential impact on the environs, a detailed analysis was performed.

3A.2.3.2.3 Cask Body Analysis

A conservative 50 g bottom drop onto the concrete pad was analyzed. The ANSYS model in Section 3A.2.2 was used to evaluate the stresses in the cask body due to the drop. The 50 g bottom drop individual load case is simply 50 times the 1g vertical load case described previously.

A 50 g side drop was also analyzed. The applied load is asymmetric and a Fourier series representation of the loading is required. Figure 3A.2-14 shows the degree of approximation obtained when the series is truncated after 20 terms and the foot print of the external impact force is a rectangular strip 10 in. wide along the cask length. This approximation was used in this analysis. The side impact analysis results, at the selected locations, are reported in Table 3A.2.3-15 through 3A.2.3-18 for a side load of 1 g. Since a linear analysis was performed, the stresses for the 50 g load case will be 50 times the 1 g load case results.

3A.2.3.3 Summary of Individual Load Cases

Stress results for these individual loads are reported in Tables 3A.2.3-1 through 3A.2.3-20. Figure 3A.2-12 shows the locations on the cask body, where stress results are reported. These locations are divided into two groups, confinement and non-confinement. Stress components and stress intensities at nodal locations on the inner and outer surfaces of each cask body component are reported in these tables.

These results are provided in this report to indicate the relative significance of the individual loads. These point-wise results are combined in Section 3A.2.5 with the results of several hand computations to provide results for the various load combinations which are compared to the design criteria in Chapter 3.

The stress results presented in Tables 3A.2.3-1 through 3A.2.3-20 are based on the TN-32 and TN-32B lid configurations. In these configurations, the lid and lower shield plate thickness is 10.5 inches. For the TN-32A Lid Assembly, the combined lid and lower shield plate thickness is reduced to 9.38 inches as shown on TN drawing 1049-70-3. The confinement lid thickness is 4.5 inches for all three lid designs. It is only the shielding plate thickness that has been reduced in the TN-32A lid system.

Of the individual load cases, only the internal pressure and external pressure loads are affected by the reduction in lid shield thickness. To determine the stresses in the TN-32A lid, the bending stresses reported in Tables 3A.2.3-6 and 3A.2.3-8 are scaled by the square of the lid assembly thickness. The results are reported below:

Condition	Type of Stress	TN-32 & TN-32B Lid Design	TN-32A Lid Design	Net Stress Increase
100 psig Internal Pressure	Bending	1,638 psi (SAR Table 3A.2.3-6)	2,053 psi	415 psi
25 psig External Pressure	Bending	418 psi (SAR Table 3A.2.3-8)	524 psi	106 psi

3A.2.4 Additional Cask Body Analyses

Additional analyses of the cask body were performed using classical methods rather than the ANSYS finite element method. These analyses determine the maximum stresses at local points on the body: (a) due to the trunnion reactions (while lifting the cask) and (b) in the locations where tornado missile impact might occur.

3A.2.4.1 Trunnion Local Stresses

The local stresses in the cask body outer gamma shielding at the trunnion locations due to the loadings applied through the trunnions are described in Section 3.4.3. These local effects are not included in the ANSYS stress result tables reported above

in Section 3A.2.3. The local stresses must be superimposed on the above stress results for the cases where the inertial lifting loads are reacted at the trunnions. The local stresses are calculated in accordance with the methodology of WRC Bulletin 107[6] which is based on the Bijlaard analysis for local stresses in cylindrical shells due to external loadings.

The maximum stress intensity due to a vertical lift is 6,624 psi for TN-32, TN-32A casks and 16,047 psi for TN-32B cask. These local stresses are combined with the finite element results from Section 3A.2.3 at the same locations and compared with allowables in Section 3A.2.5.

3A.2.4.2 Tornado Missile Impact

Local stresses due to tornado missiles are evaluated in Section 2.2.1.3.

3A.2.4.3 Impact on a Trunnion

This section describes the analysis of the storage cask tipping over and impacting against the ISFSI concrete pad with the cask oriented so that an upper trunnion contacts the pad. The analyses of the trunnions and cask body under Normal conditions (when the trunnions are used to lift the cask) are reported in Section 3.4.3. This analysis is a variation of the Hypothetical Tipping Accident analyzed in 3A.2.3.2 to consider the particular case of the cask contacting the pad on a trunnion.

The upper trunnion could strike the pad during tipover, but the consequences would be minimal. The contact area between the cask and pad would initially be equal to the projected end area of the trunnion. The trunnion would punch into the pad for a few inches until the neutron shield and then the forged gamma shield strike the concrete pad. At this point the contact area between the cask and pad would be the full side area of the cask (as analyzed in Section 3A.2.3.2).

Impact on Trunnion - TN-32 and TN-32A Casks

Figure 3A.2-15 shows the upper trunnion geometry for TN-32 and TN-32A casks. The projected trunnion area is $(\pi/4)(10.17^2-4^2)$ or 68.67 in^2. For a 3,000 psi concrete compressive strength, the impact force on the end of the trunnion would be (68.67)(3000) = 206,010 lbs.

The trunnion is welded to the gamma shielding of the cask body using a weld that has at least as large a cross section as the trunnion base area. The compressive stress in the weld due to the trunnion impact force would be $206{,}010/((\pi/4)(10^2-5^2))$ or 3.5 ksi. The minimum wall thickness of the gamma shielding at the flat machined for the trunnions is 7.275 in. Therefore the

shear stress around the plug of gamma shield material behind the 10 inch diameter trunnion is 206,010/(π x 10 x 7.275) or 0.9 ksi.

We can conservatively assume that the entire impact force is reacted in bending by a 10 in. high ring (one trunnion diameter) or gamma shielding as shown in the bottom diagram of Figure 3A.2-16. In this case, w = F/2πR = 206,010/(2π x 39.88) or 822 lb/in. The maximum moment in the ring section is then (3/2)(w R^2) = (3/2)(822) (39.88^2) = (1.96 x 106) in.-lb. The moment of inertia of the 10 in. high ring section based on a minimum thickness of 7.275 in. is I = (1/12)(10)(7.2753) = 320.9 in^4 and the distance from the center to the surface, c, is t/2 = 3.638 in. The bending stress in the ring section is then Mc/I = (1.96 x 10^6)(3.638)/320.9 = 22.2 ksi.

The allowable stress intensities for nonconfinement structure in Table 3.1-4 for Level D loads can be used to evaluate these Hypothetical Accident stresses, in the gamma shielding.

Su for the SA-105 gamma shielding (and welds) at 350°F is 70.0 ksi. The allowable membrane stress, P_m, is 0.7 S_u or 49.0 ksi. The membrane plus bending allowable, $P_m + P_b$, is Su or 70.0 ksi. The allowable shear stress is 0.42 S_u or 29.4 ksi.

The 3.5 ksi compressive stress in the weld is considered to be a membrane stress and this stress level is well below the 49.0 ksi limit. The 0.9 ksi plug shear stress is also well below the 29.4 ksi shear limit. If the 3.5 ksi compressive stress, the 0.9 ksi shear stress and 22.2 ksi bending stress (compression side at trunnion) are all assumed to occur at the same point, the maximum combined stress intensity is 25.8 ksi, which is well below the allowable of 70.0 ksi.

The center of the trunnion is 167 in. above the corner of the cask (the pivot point). The 206,010 lb. impact force would apply a torque or moment about the pivot point of (206,010)(167) or 34.4 x 10^6 in. lb. The moment of inertia of the cask about the corner pivot point is I_p = 8.09 x 10^6 lb. in. sec^2. The rotational deceleration that would occur as the trunnion punches into the concrete can be determined from the relationship Torque = I α or α = Torque/I. The rotational deceleration, α, = 34.4 x 10^6 in.lb/8.09 x 10^6 lb. in. $sec.^2$ or 4.252 radians/sec^2.

The translational deceleration at any distance (d) from the pivot point is equal to (d) x α. The deceleration at the CG where d = 101.93 in. from Figure 2.2-2 is (101.93)(4.252) = 433.4 in./sec^2. This is a deceleration at the CG of 433.4/386 = 1.12g. Therefore, the peak CG deceleration of the cask during initial trunnion impact after tipover is much less than 23 g deceleration conservatively determined in Section 3A.2.3.2 for full side impact. Therefore the stress analysis cases for the cask body

(except for the local gamma shielding stresses due to the trunnion loads) and basket, conservatively determined above assuming 50 g deceleration, bound those for the 1.12g trunnion impact case.

Therefore tipping of the cask onto a trunnion results in acceptable stresses.

Impact on Trunnion - TN-32B cask

Figure 3A.2-15A shows the upper trunnion geometry for the TN-32B cask. The projected trunnion area at contact is $(\pi/4)(12.75^2-5.0^2)$ or 108.04 in^2. For a 3,000 psi concrete compressive strength, the impact force on the end of the trunnion would be (108.04)(3000) = 324,120 lbs.

The trunnion is welded to the gamma shielding of the cask body using a weld that has at least as large a cross section as the trunnion base area. The compressive stress in the weld due to the trunnion impact force would be:

$$\sigma_{comp.} = 324{,}120/[(\pi/4)(12.0^2-5.25^2)] = 3{,}544 \text{ psi} \approx 3.6 \text{ ksi}$$

The minimum wall thickness of the gamma shielding at the flat machined for the trunnions is 7.538 in. Therefore the shear stress around the plug of gamma shield material behind the 12 inch diameter trunnion is:

$$\tau = 324{,}120/(\pi \times 12 \times 7.538) = 1{,}141 \text{ psi} \approx 1.2 \text{ ksi}$$

We can conservatively assume that the entire impact force is reacted in bending by a 12 inch high ring (one trunnion diameter of gamma shielding cylinder) similar to shown in SAR Figure 3A.2-16. In this case,

$$w = F/2\pi R = 324{,}120/(2\pi \times 39.88) = 1293.5 \text{ lb/in.}$$

The maximum moment in the ring section is then:

$$M = (3/2)(w\ R^2) = (3/2)(1293.5)(39.88^2) = (3.09\text{x}10^6) \text{ in-lb}$$

The moment of inertia of the 12 inch high ring section based on a minimum thickness of 7.538 inch is:

$$I = (1/12)(12)(7.538^3) = 428.3 \text{ in}^4$$

and the distance from the center to the surface, c, is t/2 = 3.769 in. The bending stress in the ring section is then:

$$\sigma_b = Mc/I = (3.09\text{x}10^6)(3.769)/428.3 = 27{,}192 \text{ psi} \approx 27.2 \text{ ksi}$$

The allowable stress intensities for the non-confinement structure in SAR Table 3.1-4 for Level D loads can be used to evaluate these Hypothetical Accident stresses.

S_u for the SA-105 gamma shielding (and welds) at 350°F is 70.0 ksi. The allowable membrane stress, P_m, is 0.7 S_u or 49.0 ksi psi. The membrane plus bending allowable, $P_m + P_b$, is S_u or 70.0 ksi. The allowable shear stress is 0.42 S_u or 29.4 ksi.

The 3.6 ksi compressive stress in the weld is considered to be a membrane stress and this stress level is well below the 49.0 ksi limit. The 1.2 ksi plug shear stress is also well below the 29.4 ksi shear limit. If the 3.6 ksi compressive stress, the 1.2 ksi shear stress and 27.2 ksi bending stress (compression side at trunnion) are all assumed to occur at the same point, the maximum combined stress intensity is 30.8 ksi, which is also well below the allowable of 70.0 ksi.

The center of the trunnion is 167 inches above the corner of the cask (the pivot point). The 324,120 lbs impact force would result in a torque or moment about the pivot point of:

$$\text{Torque} = (324{,}120)(167) = 54.1 \times 10^6 \text{ in-lb}$$

The moment of inertia of the cask about the corner pivot point is:

$$I_p = 7.93 \times 10^6 \text{ lb-in-sec}^2$$

The rotational deceleration α that would occur as the trunnion punches into the concrete can be determined from the relationship

$$\text{Torque} = I\,\alpha$$

$$\alpha = 54.1 \times 10^6 \text{ in.lb}/7.93 \times 10^6 \text{ lb-in-sec}^2$$
$$= 6.822 \text{ radians/sec}^2$$

The translational deceleration at any distance (d) from the pivot point is equal to d x α. The deceleration at the top trunnion is:

$$A = (167.0)(6.822) = 1139.3 \text{ in./sec}^2 \text{ or } 1139.3/386 = 2.95g$$

The peak deceleration of the cask during initial trunnion impact after tipover is much less than 50g deceleration determined in SAR Section 3A.2.3.2 for full side impact. Therefore, the stress analysis cases for the cask body and basket determined in Chapter 3 bound those for the 2.95g trunnion impact case. ISFSI concrete storage pads have typical compressive strengths in the range of 3,000 to 6,000 psi. Based on the above evaluation, these concrete compressive strengths would have no significant impact on stresses at the cask and basket.

The tipping of the cask onto a trunnion, therefore, results in acceptable stresses in trunnions, cask body and basket.

3A.2.5 Evaluation (Load Combinations Vs. Allowables)

The TN-32 cask loading conditions are listed in Section 2.2.5, Table 2.2-4. The individual loads acting on the various cask components due to these loading conditions have been applied to the cask and the resulting stresses are reported in Tables 3A.2.3-1 through Table 3A.2.3-20.

The loading conditions listed in Table 2.2-4 are categorized according to the rules of the ASME Code, Section III, Subsection NB for Class 1 nuclear components. These categories include Normal (Design and Level A) and Hypothetical Accident (Level D) loading conditions. See Tables 2.2-5 through 2.2-7 for these categories. Next, the load combinations are determined based on those loads that can occur simultaneously. The individual loads of each combination are indicated in Tables 2.2-8 and 2.2-9.

The stress intensities for the combined load cases are evaluated at the locations indicated in Figure 3A.2-12 and compared to the stress limits associated with each service loading. The normal condition load combinations are summarized in Table 3A.2.5-1. Stresses due to normal condition load combinations are presented in Tables 3A.2.5-2 through 3A.2.5-11. The accident condition load combinations are summarized in Table 3A.2.5-12. Stresses due to accident condition load combinations are presented in Tables 3A.2.5-13 through 3A.2.5-28.

Tables 3A.2.5-1 and 3A.2.5-12 provide matrices of the individual loads and how they are combined to determine the cask body stresses for the specified normal and accident conditions. The thermal stresses 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 primary stress allowables. Finally, for those load combinations that include trunnion reactions, the local stresses at the trunnion locations found by the Bijlaard method are superimposed on the ANSYS combined stresses at the stress reporting locations near the trunnions. Also the membrane and bending stresses are not separated so the combined stress intensity is compared to the lower membrane allowable. In nearly all of the locations selected the stress intensities thus calculated are less than the membrane allowable stress. At the two locations where this simple conservative approach does not show margin, the membrane and bending stresses are separated.

TN-32A Lid Stresses

The Normal Condition combined stresses reported in Tables 3A.2.5-2 to 3A.2.5-11 are reviewed to determine the maximum stress intensity in the TN-32 standard lid design. The maximum stress intensity of 2,470 psi occurs due to Bolt preload + 100 psig internal pressure + 1g down + Thermal (see Table 3A.2.5-3). Therefore, the maximum stress intensity in the Type A lid is (2,470 + 415) 2,885 psi (2.89 ksi).

This value is well below the allowable of 24.30 ksi ($1.5\ S_m = 1.5 \times 16.2$ ksi= 24.30 ksi).

The Accident Condition combined stresses reported in Tables 3A.2.5-13 to 3A.2.5-28 are reviewed to determine the maximum stress intensity in the TN-32 standard lid design. The maximum stress intensity of 29,496 psi occurs due to Bolt preload + 100 psig internal pressure + 50g tip over (see Table 3A.2.5-20). Therefore, the maximum stress intensity in the Type A lid is (29,496 + 415) 29,911 psi (29.9 ksi).

This value is well below the allowable of 58.32 ksi ($3.6\ S_m = 3.6 \times 16.2$ ksi = 58.32 ksi).

Based on the above evaluation, all of the calculated maximum normal and accident condition stresses in TN-32A cask are acceptable.

3A.3 Lid Bolt Analyses

The lid bolt analysis presented below is performed using the weight of the TN-32A lid (including top neutron shield) since it is slightly heavier than the standard TN-32 lid assembly (with tip neutron shield).

3A.3.1 Normal Conditions

3A.3.1.1 Bolt Preload

The lid is secured to the cask body by forty eight 1.5 in. diameter bolts. The selected bolt preload is such that the metallic confinement seals are properly compressed and the lid is seated against the flange with sufficient force to resist the maximum cavity internal pressure and any dead weight loads acting to unseat the lid. The corresponding tensile preload stress in the bolts at temperature is 39,810 psi(corresponding to 980 ft-lb torque with lubrication)which is less than the stress allowable for the bolt material for Normal (Level A) Conditions. The load per bolt is:

$$F_B = A_B \times 39{,}810$$
$$= 1.492 \times 39{,}810 = 59{,}397 \text{ lb./bolt}$$

Since we have 48 bolts, the total seating force of all 48 bolts is 48 F_B = 2,851,056 lb.

The force required to seat the metallic seals, from Reference 4, is a line load of 1399 pounds per inch of seal circumference. The diameter of the outer seal is 72.65 in. and the diameter of the inner seal 71.05 in. The seal seating force is then:

$$F_{seating} = 1399\,\pi(72.65 + 71.05) = 631{,}574 \text{ lb.}$$

The maximum cask cavity internal pressure is the Design Pressure of 100 psi. The force required to react the pressure load (conservatively assuming the pressure is applied over the outer seal diameter) is:

$$F_{Pressure} = 100\left(\frac{\pi}{4}\right)(72.65)^2 = 414{,}535 \text{ lbs.}$$

The TN-32 cask is always oriented vertical during loading, during transfer to the ISFSI and during storage on the pad. Dead weight of the lid and cask contents do not actually load the lid bolts. In fact the lid weight (and external pressure) helps to seat the lid. However, it is conservative to require that the bolt preload maintain lid seating in any cask orientation. The weights of the lid, fuel and basket are:

Lid Assembly Weight	=	14,480 lb.
Fuel Weight	=	49,060 lb.
Basket Weight	=	16,900 lb.
W_{Total}		80,440 lb.

The total of the seal seating force, pressure load and dead weight loads is:

$F_{seating}$	=	631,574
$F_{pressure}$	=	414,535
W_{total}	=	80,440
		1,126,549 lb. < 2,851,056 lb.

Therefore the selected bolt preload stress of 39,810 psi provides ample lid seating force. The average bolt tensile stress required to react the lid loadings under Normal Conditions is the preload stress of 39,810 psi which is well below the limiting value of $2S_m$ (63,800 psi) for the bolt material at 300°F.

3A.3.1.2 Differential Thermal Expansion

The 48 lid bolts preload the outer rim of the closure lid against the cask body flange. The 1.5 in. diameter bolts are installed through 1.56 in. diameter clearance holes in the 4.50 in. thick lid periphery. Preloading of the bolts against the lid is accomplished by tightening the bolts so that the shank portions of the bolts within the clearance holes are stretched elastically. The bolt loads will therefore change from the initial installed values if any thermal expansion differences should occur between the lid (through thickness direction) and the bolts.

The bolt material is SA 320 Grade L43 (1 3/4 Ni 3/4 Cr 1/4 Mo). The lid and body flange are both SA 350 Grade LF3 (3 1/2 Ni). The Section III Code Appendices specify the same coefficient of thermal expansion for these materials. The bolts are in intimate contact with the lid and flange and will therefore operate at the same temperature as these components. Therefore there will be no thermal expansion differences between the lid and bolts, and the assembly preload will be maintained under all temperatures.

3A.3.1.3 Bolt Torsion

The torque required to preload the bolt is:

$T = K\ D_N\ F_B$ (Reference 10)

Where

T = 0.132(1.5)(59,397)=11,760 in-lb = 980 ft-lb
K = Nut Factor = 0.132 for neolube lubricant
A_B = Bolt stress area = 1.492 in.^{2}
D_N = Bolt nominal dia = 1.5 in.
F_B = 39,810 psi preload stress x A_B = 59,397 lb

The residual torque in the bolt is:

T_R = 0.5625T = 0.5625 x 11,760 = 6,615 in.lb.

The shear stress in the bolt due to the residual torque from preload given by Reference 7:

$$\tau_{torsion} = \frac{T_R\ r}{J}$$

where r and J are based on the bolt effective radius for the above stress area.

r = 0.689 in. effective bolt radius

J = torsional moment of inertia of threaded bolt

$$J = \frac{\pi r^4}{2} = 0.354 \text{ inch}^4$$

$\tau_{torsion}$ = 6,615(0.689)/0.354 = 12,875 psi (Torsional Shear)

3A.3.1.4 Bolt Bending

It is assumed that bolt bending does not occur during seating of the lid against the cask body during assembly. The bolts are rotated as they are torqued so any slight relative movement between lid and body flange during preloading will not result in a net offset between the bolt head and tapped flange holes. In addition, since the lid, flange and bolt materials have the same coefficient of thermal expansion and will operate at essentially the same temperature, differential expansion between components will not produce bolt bending.

As internal pressure is applied to the cask cavity, the lid will bulge slightly and its edge will rotate. In addition the body cylinder radius will increase slightly due to the internal pressure resulting in outward radial movement of the tapped bolt holes in the body flange. Since no net membrane stress is developed in the lid, the lid bolt holes (at the mid surface) will remain at the original location. Rotation of the edge of the lid will, however, produce radial movement of the outer surface of the lid at the bolt head location.

The hoop stress in the cask body cylinder is:

$$S_{hoop} = \frac{P\ R_i}{t}$$

Where P = 100 psi Design Pressure
R_i = 34.375 in. inside radius
T = 9.5 in. thickness

$$S_{hoop} = \frac{100 \times 34.375}{9.5} = 361.8 \text{ psi}$$

The radial deflection at the bolt circle is:

$$\delta_{b.c.} = R_{bc} \times \frac{S_{hoop}}{E}$$

R_{bc} = 38.03 in. bolt circle radius

$$\delta_{b.c.} = \frac{38.03 \times 361.8}{28 \times 10^6} = 0.0004914 \text{ inches outward}$$

When pressure is applied to the lid, the edge rotation can be calculated assuming the lid is simply supported. From Reference 8, Table X, Case 1:

$$\theta = \frac{3W\ (m - 1)\ R}{2\ \pi\ E\ m\ t^3}$$

Where θ = edge rotation, radians
W = total applied load
~~M = 1/Poisson's ratio = 3.33~~
R = 36.35 in. outer seal radius
T = 4.5 in. lid thickness

$$\theta = \frac{3 \times 100 \times \pi \times (36.35)^3 \times 2.33}{2\pi \times 28 \times 10^6 \times 3.33 \times (4.5)^3} = 0.001976 \text{ radians}$$

Figure 3A.3-1 shows the net movement of the threaded hole and the Point on the lid under the bolt head.

If it is assumed that the bolt head doesn't slide on the lid surface, the head will be forced from position a to a' as the lid deflects. Point a' under the bolt head moves outward 0.00444 in. while the threaded hole moves only 0.0004914 in. outward. The bolt head will be bent laterally by 0.00444 - 0.0004914 in. or 0.00395 in. from the threaded end.

The bending model of the bolt is shown in Figure 3A.3-2. The moment on the bolt is calculated assuming the bolt is subjected to affect bending with the head and threaded end prevented from rotating. For a cantilevered bolt free to rotate at the head, the bending moment would be reduced by one half. Therefore the assumption of fixed ends is the most conservative and results in the highest stress.

The shear force, P, and bending moment, M, for a beam subjected to offset bending with ends prevented from rotating are:

$$P = \frac{12EI\,\delta}{l^3}$$

$$M = \frac{6EI\,\delta}{l^2}$$

Where

P = lateral load to deflect the bolt distance δ, lb.
δ = lateral displacement
  = 0.00395 in.
E = Young's modulus, 28×10^6 psi @300°F
L = bolt length in bending
  = 4.625 in. (including tapped hole chamfer)
I = $\pi r^4/4$
  = 0.177 in.^{4} (r=0.689 in. based on stress area of 1.492 in.^{2})

Therefore

$$M_B = \frac{6 \times 28 \times 10^6 \times 0.177 \times 0.00395}{4.625^2}$$

$$= 5{,}491 \text{ in - lb.}$$

$$P = \frac{12 \times 28 \times 10^6 \times 0.177 \times 0.00395}{4.625^3}$$

$$= 2{,}375 \text{ lb.}$$

The bending stress in the bolt is

$$\sigma_b = \frac{Mr}{I} = \frac{5{,}491 \times .689}{0.177}$$

$$= 21{,}375 \text{ psi}$$

The shear stress due to the lateral force is

$$\tau_p = P/A = 2,375/1.492 = 1,592 \text{ psi}$$

3A.3.1.5 Combined Stresses

The total shear stress is then equal to the residual torsional shear stress plus that due to force P.

$$\tau_{total} = \tau_{torsion} + \tau_p$$

$$= 12,875 + 1,592$$
$$= 14,467 \text{ psi}$$

The average tensile stress is the bolt preload stress:

$$\sigma_{average} = 39,810 \text{ psi}$$

The maximum tensile stress at two locations in the bolt is the preload stress plus the bending stress.

$$\sigma_{max} = 39,810 + 21,375 = 61,185 \text{ psi}$$

Therefore, the average combined stress intensity is:

$$SI_{average} = (\sigma_{average}{}^2 + 4\ (\tau_{total})^2)^{1/2}$$

$$= (39,810^2 + 4 \times 14,467^2)^{1/2}$$

$$= 49,214 \text{ psi } (49.2 \text{ ksi}) < 2S_m = 63.8 \text{ ksi}$$

The maximum combined stress intensity is:

$$SI_{max.} = (\sigma_{max}{}^2 + 4\ (\tau_{total})^2)^{1/2}$$

$$= (61,185^2 + 4 \times 14,467^2)^{1/2}$$

$$= 67,682 \text{ psi} = 67.7 \text{ ksi} < 3S_m = 95.7 \text{ ksi}$$

For Level A conditions, the average bolt stress is limited to 2 S_m or 2 x 31.9 = 63.8 ksi. The maximum bolt stress is limited to 3 S_m or 95.7 ksi. We are well within these limits as well as the yield strength of the bolt material (also 95.7 ksi).

3A.3.2 Accident Conditions

The lid bolts are analyzed in this section under the loadings selected to bound those for the hypothetical bottom end drop and tipover onto the concrete storage pad.

3A.3.2.1 Bottom End Drop

The bottom end drop from a height of 5 feet onto the concrete storage pad is analyzed in Section 3A.2.3.2. That section indicates that the cask deceleration may reach 42 g. This analysis conservatively examines the effects (if any) of a 50 g quasistatic loading on the lid bolts.

During a bottom end drop, the rim of the lid is forced against the flange of the cask body. The lid is initially seated against the flange by preloading (torquing) the bolts. The bolt preload will not be affected if compressive yielding of the contact bearing area does not occur.

The contact force on the bearing area, conservatively neglecting internal pressure, is the bolt preload force less the seal compression force plus the 50 g inertial force of the lid system. The preload force, from Section 3A.3.1, is 2,851,056 lb. The seal seating force is 631,750 lb. The weight of the lid system (weight of lid plus weight of top neutron shield assembly, 11560 + 2960 = 14,480 lbs, the highest weight among TN-32, TN-32A and TN-32B casks) is 14,480 lb .

Therefore, during a 50 g deceleration in the axial direction the contact force between lid and cask body is:

$$F_{contact} = F_{Bolt\ Preload} - F_{seal\ seating} + 50\ (W_{lid\ system})$$

$$= 2,851,056 - 631,574 + 50(14,480)$$

$$= 2,943,482 \text{ lb}$$

Figure 3A.3-3 illustrates the bearing interface between lid edge and body flange. The bearing area equals the area within the diameter of the lid raised section (74.0 in.) less the outside of the body chamber (70.22 in.) less the area of the seal groove.

$$A_{Bearing} = \frac{\pi}{4}(74^2 - 72.95^2 + 70.75^2 - 70.22^2) = 180\,\text{in}^2$$

The bearing stress during impact is then equal to:

$$S_{bearing} = 2,943,482/180 = 16,353 \text{ psi (16.35 ksi)}$$

This contact stress is well below the 33.2 ksi yield strength of the lid and flange material at 300°F. The bolt preload will not be affected by the bottom drop. Therefore, this hypothetical accident case will not affect the bolt stresses.

3A.3.2.2 Tipover

The tipover onto the concrete storage pad is analyzed in Appendix 3D.2.5. The tipover scenario is summarized in Figure 3A.3-4. The peak deceleration occurs at the top of the cask. The deceleration at this location reaches 67g. The deceleration is much less at the center of gravity and essentially zero at the bottom corner pivot point. The lateral deceleration at the lid end of the body is taken as 67g and that at the pivot point is zero.

There are two dynamic loadings acting on the lid tending to push or throw it off of the cask body (i.e. producing tensile forces in the lid bolts). There is a small axial (parallel to cask longitudinal axis) centrifugal inertia load due to the internals acting on the lid and the lid weight itself while the cask is rotating.

For the evaluation of the lid bolts it is assumed herein that the cask impacts on the corner at the lid end. There is no accident condition postulated that would cause greater load on the lid bolts. The cask orientation for the analysis is shown in Figure 3A.3-5. The axis of the cask is 5° (corresponding to 16 inches pad crush) from horizontal with the lid down. Note that this orientation is well beyond that predicted in the tipover analysis (Appendix 3D, Figure 3D.2-4, maximum displacement is 0.73 inches). The lateral load, G_L, is 67g, the axial load used is 67 x tan 5° or 5.86g.

The loads acting on the cask are shown in Figure 3A.3-5. The loads acting on the lid are shown in Figure 3A.3-6. Also shown is the reaction load at the cask interface and the pivot point, O, for analysis of lid rotation. Figure 3A.3-7 shows the lid bolt loads resisting rotation of the lid about pivot point O The increase in bolt load beyond the preload varies uniformly from pivot point, O, to the bolt farthest from O.

The moment acting on the lid about pivot point, O, due to the inertia load is calculated as follows:

$$M_I = W_I \times 5.86 \times R_T + W_L \times 5.86 \times R_T + W_L \times 67 \times a + P_A \times R_T$$

Where M_I = Total moment about pivot point, in-lb

W_I = Weight of internals

= 16,900 + 49,060 = 65,960 lb

W_L = Weight of lid system (including shield plate and resin disk), 14,480 lb

P_A = Internal pressure load

= 414,535 lb

R_T = Distance from center of lid to pivot point

= 39.75 in.

a = Moment arm of lid inertia load, W_L, in.

= 2.26 in. (very conservative since shield weight effect moves CG toward 0)

Therefore:

$$M_I = (65,960 \times 5.86 \times 39.75) + (14,480 \times 5.86 \times 39.75)$$

$$+ (14,480 \times 67 \times 2.26) + (414,535 \times 39.75)$$

$$= 37.41 \times 10^6 \text{ in-lb.}$$

This moment is resisted by the effect of the preload on the lid bolts. The moment due to preload is calculated as follows:

$$M_p = N \times F_B \times R_T$$

Where

M_p = moment due to bolt preload, in-lb
N = number of bolts, 48
F_B = preload per bolt
= A_B x preload stress
= stress area bolt x preload stress
= 1.492 in.^{2} x 39,810 psi = 59,397 lb
R_T = distance from center of lid to pivot point, 39.75 in.

Therefore:

$$M_p = 48 \times 59,397 \times 39.75$$
$$= 113.3 \times 10^6 \text{ in-lb.} > 37.41 \times 10^6 \text{ in-lb.}$$

Since bolt preload moment ,M_p, is higher than the moment due to inertial load, M_T, there will not be any additional load due to tipover accident.

In the true rotational impact case, the gravitational force to keep the lid on and contents in the cask is greatest as the cask reaches the final tipping angle. In this case, the cask reaches an angle of approximately 1° below horizontal (Figure Figure 3A.3-4). The gravitational forces acting on the lid and contents at this angle (conservatively using 5 degrees), in the direction of the axis of the cask are:

$F_{lid} = W_{lid} (\sin \alpha) = 14,370 (\sin 5^{\circ}) = 1,252$ lb

$F_{content} = W_{content} (\sin \alpha) = 65,960 (\sin 5^{\circ}) = 5,749$ lb

Total gravitational tensile force = 1,252 + 5,749 = 7,001 lb

Since the bolt preload seating force, F_B (2,851,056 lb) is higher than the gravitational tensile force, there will not be any additional tensile load due to tipover accident.

The shear stress due to the 67g side impact is calculated as follows:

$\tau_{impact} = W_L x\ 67/(N \times A_s)$

Where W_L: weight of lid system (14,480 lb)
N: Number of lid bolts (48)
A_s: Bolt shank shear area ($\pi \times D^2/4 = 1.767\ in^2$)

The shear stress is:

$\tau_{impact} = 14,480 \times 67/(48 \times 1.767) = 11,438$ psi

The total shear stress is equal to the residual torsional shear stress plus the shear stress due to internal pressure plus the shear stress due to the 67g side impact:

$\tau_{total} = 12,875 + 1,592 + 11,438$
$= 25,905$ psi (25.91 ksi) $< 0.42S_u = 47.9$ ksi

The average tensile stress is the bolt preload stress.

$\sigma_{average} = 39,810$ psi

The maximum stress at two locations in the bolt is the preload stress plus the bending stress.

$\sigma_{max} = 39,810 + 21,375 = 61,185$ psi

The average combined stress intensity is:

$SI_{average} = (\sigma_{average}^2 + 4 (\tau_{total})^2)^{1/2}$

$= (39,810^2 + 4 \times 25,905^2)^{1/2}$

$= 65,338$ psi (65.34 ksi) $< S_y = 95.7$ ksi

The maximum combined stress intensity is:

$$SI_{max.} = (\sigma_{max}^2 + 4\ (\tau_{total})^2)^{1/2}$$

$$= (61,185^2 + 4 \times 25,905^2)^{1/2}$$

$$= 80,174 \text{ psi } (80.17 \text{ ksi}) < S_u = 113.9 \text{ ksi}$$

In addition to the above calculations, the lid bolts are evaluated based on the interaction formula from Appendix F of the ASME Code[6] for tension and shear :

$$\frac{(f_t)^2}{(F_{tb})^2} + \frac{(f_v)^2}{(F_{vb})^2} \leq 1$$

Where:

f_t and f_v are the applied tensile and shear stresses

F_{tb} = allowable tensile stress, smaller of $(0.7S_u)$ or S_y(TSAR Table 3.1-3) = 0.7 x 113,930 = 79,750 psi

F_{vb} = allowable shear stress, smaller of $(0.42S_u)$ or $0.6S_y$(SAR Table 3.1-3) = 0.42 x 113,930 = 47,850 psi

$$\frac{39,810^2}{79,750^2} + \frac{25,905^2}{47,850^2} = 0.54 < 1.0$$

3A.3.3 Conclusions

Based on the above evaluation, it is concluded that:

1. The maximum normal and accident condition stresses in the lid bolts are acceptable.
2. A positive (compressive) load is maintained on seals during normal and accident condition loads as bolt preload is higher than the applied loads.

3A.4 Outer Shell

This section presents the structural analysis of the outer shell of the TN-32 storage cask. The outer shell consists of a cylindrical shell section and closure plates at each end which connect the cylinder to the cask body. The normal loads acting on the outer shell are due to internal and external pressure and the normal handling operations. Membrane stresses and bending due to the pressure difference and handling loads are determined. These stresses are compared to the allowable stress limits in Section 3.1 to assure that the design criteria are met.

3A.4.1 Description

The outer shell is constructed from low-alloy carbon steel and is welded to the outer surface of the cask body gamma shielding. The cylindrical shell section is 0.50 in. thick and the closure plates are 0.75 in. thick. Pertinent dimensions are shown in Fig. 3A.4-1 and Drawing 1040-70-2.

3A.4.2 Materials Input Data

The outer shell cylindrical section and closure plates are SA 516-GR 70. The material properties are taken from the ASME Code, Section II, Part D. The yield strength of the material is also obtained from the code at a temperature of 300°F.

3A.4.3 Applied Loads

It is assumed that a pressure of 25 psi may be applied to the inside or outside of the outer shell. This bounding assumption envelopes the actual expected pressures described in Section 2.2.5.

The handling loads acting on the outer shell are a result of lifting. The loads applied to the shell as a result of these operations consist of the values given in Section 2.2.5. The weight or inertia g load can include all of the weights of the outer shell, neutron resin shield, and aluminum containers. The most severe Normal Service (Design and Level A) Condition load is assumed 3 g inertia load in the vertical lifting orientation. The shell is also analyzed for 3 g loading when the cask is oriented horizontally to ensure it is not damaged during delivery.

The following cases are evaluated:

- Cask in the Vertical Orientation
  - Stress due to 25 psi pressure
  - Stress due to 3G inertia load (lifting)

- Cask in the Horizontal Orientation
  - Stress due to 25 psi pressure
  - Stress due to 3G inertia load
  -

3A.4.4 Method of Analysis

ANSYS Model

A finite element model was built for the structural analysis of the outer shell and closure plates. The outer shell and closure plates were modeled with ANSYS Plane 42 elements. The element is used as an axisymmetric element. The partial penetration welds are simulated by reducing the thickness at weld locations. The basic geometry of the outer shell and weld sizes used for analysis are shown in Figure 3A.4-1. The finite element model is shown in Figures 3A.4-2, -3, and 4. In finite element model for pressure run, the entire ½ inch cylinder thickness was conservatively reduced to 0.375 inch to simulate the longitudinal partial penetration weld.

A. Cask in the Vertical Orientation

- Stresses due to 25 psi Pressure

An external pressure of 25 psi will not induce any load or stress in the outer shell since it is in contact with and supported by the resin filled aluminum containers.

An internal pressure of 25 psi is used as the maximum pressure acting at the inner surface of the outer shell as shown on Figure 3A.4-5. The maximum stress intensity for this load case is 7,238 psi.

- 3G Down

The weight of the resin (10,230 lbs) and aluminum containers (1,960 lbs) is modeled as an additional pressure on the bottom inner surface as shown on Figure 3A.4-6.

$$P = 3 \times (10{,}230 + 1{,}960)/[\pi\ (48.375^2 - 43.875^2)] = 28.0 \text{ psi}$$

The maximum stress intensity for this load case is 4,517 psi.

B. Cask in the Horizontal Orientation

The stress due to 25 psi internal pressure is same as for the vertical orientation. The stress due to 3G inertia load conservatively assumes that the weight of the outer shell, resin, and aluminum containers is uniformly distributed over the 160 in.

length and at a 45° angle only. Therefore, the equivalent pressure applied to the outer shell is:

Weight of outer shell: 7,230 lbs
Weight of resin: 10,230 lbs
Weight of alum. Containers: 1,960 lbs

$$P_{equipment} = (7230+10230+1960)(3)(360)/(\pi)(96.75)(154.5)(45)$$
$$\approx 10 \text{ psi}$$

It is assumed that this pressure is acting like the internal pressure and applied on the full 360° inner surface of the outer shell. Therefore, the stress due to the this 3G inertia load can be ratioed from the 25 psi internal pressure case and is:

$$\sigma = 7,238\ (10)/25 = 2,895 \text{ psi}$$

C. Maximum Combined Stress Intensities

Based on the above calculations, the stress intensities are summarized in the following table:

Loading	Stress Intensities
25 psi Internal Pressure	7,238 psi
25 psi + 3G Down (Cask in Vertical Orientation)	11,755 psi
25 psi + 3G Down (Cask in Horizontal Orientation)	10,133 psi

3A.4.5 Results

The stresses acting on the outer shell and closure plates are also listed in Table 3A.4-1. They are compared with the allowable values in Table 3.4-9.

3A.5 TOP NEUTRON SHIELD BOLT ANALYSIS

3A.5.1 Discussion

The top neutron shield is bolted to the outside of the TN-32 lid using four 1 ¼ inch diameter, SA-193, Gr. B-8 bolts. The overpressure tank is attached to the upper surface of the neutron shield. The weight of the top neutron shield assembly (neutron shield plus expansion tank) for the TN-32A cask is 2,920 lb. (see Table 3.2-1, the heaviest weight among TN-32, TN-32A and TN-32B casks).

Shielding analyses show that the dose rate at the top of the lid without the neutron shield is below the acceptable accident limit. Therefore, the analysis below is limited to design primary loadings.

Under normal conditions the assembled and loaded (with fuel) TN-32 cask never experiences a net upward acceleration or a side load exceeding the 1.0g bounding load listed in Table 2.2-3. Nevertheless, a 3.0g upward or lateral load (not simultaneous) is assumed to conservatively evaluate these shield attachment bolts.

3A.5.2 Bolt Stress Calculation

Under normal conditions, the only loads on the attachment bolt are the assembly preload and 3g upward or lateral load as described above.

1. Stresses due to assembly preload

   An assembly torque of 90 (+10, -0) ft-lb is used with lubrication:

   $Q = K\ D_b\ F_a$ (Reference 3)

   Where Q = applied torque (in.-lb) for the preload
   K = Nut factor = 0.132 (with lubrication)
   D_b = Nominal bolt dia. = 1.25 in.
   (Stress area = 0.9034 in^2)
   F_a = Tensile force (lb)

   Therefore, the maximum tensile force is:

   $F_a = Q/(K \times D_b) = 100 \times 12/(0.132 \times 1.25) = 7{,}273$ lb

The maximum tensile stress is:

f_t = 7,273/0.9034 = 8,050 psi (8.1 ksi)

The maximum shear stress due to the residual torque is:

f_s = 5.093 × Q/d^3 (d = 1.0725 inches, min. bolt dia.)
= 5.093 (100 × 12)/1.0725^3 = 4,954 psi (5.0 ksi)

2. Maximum tensile or shear stress due to 3g upward or lateral load

$S_t = S_s$ = 2,920 × 3/(4 × 0.9034) = 2,424 psi (2.4 ksi)

Since bolt preload seating force, F_a (7,273 lb) is higher than the 3g tensile force, there will not be any additional tensile load due to 3g upward load. Therefore, the maximum tensile stress is:

σ_{max} = 8,050 psi (8.1 ksi) < $2S_m$ = 15.0 ksi

The total shear stress is equal to the residual torsional shear stress plus 3g lateral shear stress:

τ_{max} = 4,954 psi + 2,424 psi
= 7,378 psi (7.4 ksi) < $0.4S_y$ = 9.0 ksi

and the maximum combined stress intensity is:

$SI_{max} = (f^2_t + 4f^2_s)^{1/2} = (8{,}050^2 + 4 \times 7{,}378^2)^{1/2}$
= 16,810 psi (16.8 ksi) < $3S_m$ = 22.5 ksi

3A.5.3 Results

The calculated bolt stresses are all less than the specified allowable stresses.

3A.6 References

1. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section III, 1992.

2. American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section II, Part D, 1992.

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4. Resilient Metal Seals and Gaskets, Helicoflex Catalog H.001.002, Helicoflex Co., Boonton, N.J., 1983 pp.5-7.

5. Electric Power Research Institute, Report No. NP-4830, The Effects of Target Hardness on the Structural Design of Concrete Storage Pads for Spent-Fuel Casks, October, 1986.

6. WRC Bulletin 107, March 1979 Rev: "Local Stresses in Spherical and Cylindrical Shells Due to External Loadings."

7. Hopper, A.G. and Thompson, G.V. "Stress in Preloaded Bolts," Product Engineering, 1964.

8. Roark, R.J.: "Formulas for Stress & Strain", 4th Edition, McGraw-Hill Book Co.

9. Timoshenko and Woinowsky-Krieger, Theory of Plates and Shells, Second Edition.

10. NUREG/CR-6007, Stress Analysis of Closure Bolts for Shipping Casks, April 1992.

TABLE 3A.2.3-1

BOLT PRELOAD (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-5		-13	13
INNER	2	0		7		7
	3		-3		-6	6
BOTTOM	4	-2		0		2
	5		6		0	7
PLATE	6	-12		-5		12
	7		-15		-6	15
	8	-15		-6		15
	9		-15		-5	15
INNER	10	-15		-4		15
	11		-15		-5	15
SHELL	12	-15		-5		15
	13		-14		-3	14
	14	-16		-4		16
	15		-42		0	42
	16	11		16		16
	17		309		96	309
	18	-334		-97		334

TABLE 3A.2.3-2

BOLT PRELOAD (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-40	-765	-218	202	831
	20	-182	109	2	270	613
LID	21	43	1	43	-4	43
	22	198	4	197	11	195
OUTER BOTTOM PLATE	23	-20	0	-29	0	29
	24	20	2	30	0	28
	25	-1	0	-11	1	11
	26	4	0	14	1	14
OUTER SHELL	27	0	5	-1	0	6
	28	0	2	-1	0	4
	29	0	3	1	0	3
	30	0	4	1	0	4
	31	0	3	1	0	4
	32	0	4	1	0	4
	33	0	9	3	0	9
	34	0	-1	-1	0	2
	35	-5	-112	-21	13	110
	36	-3	114	43	7	118
WELDS	37	1	-5	-2	-1	6
	38	30	65	0	-25	78
	39	-355	44	-97	-31	404

TABLE 3A.2.3-3

ONE(1) G DOWN (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		51		30	67
INNER	2	-29		-7		29
	3		21		17	37
BOTTOM	4	2		6		6
	5		-37		0	36
PLATE	6	59		23		59
	7		-60		-1	60
	8	-59		-1		59
	9		-51		0	51
INNER	10	-51		0		51
	11		-37		-1	37
SHELL	12	-37		-1		37
	13		-23		0	23
	14	-24		0		24
	15		-14		-1	14
	16	-9		1		9
	17		1		1	1
	18	-20		-6		20

TABLE 3A.2.3-4

ONE(1) G DOWN (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	0	-24	-9	2	24
	20	-1	-10	-4	4	12
	21	26	0	27	0	27
LID	22	-60	-1	-61	-3	60
	23	3	-17	3	0	20
OUTER	24	2	-19	2	0	21
BOTTOM	25	5	-17	4	0	21
PLATE	26	1	-18	2	0	20
	27	0	-64	-2	0	64
	28	0	-56	0	0	56
OUTER	29	0	-52	0	0	52
	30	0	-51	0	0	52
	31	0	-38	0	0	38
	32	0	-38	0	0	38
	33	0	-24	0	0	24
SHELL	34	0	-25	0	0	25
	35	0	-23	-4	1	23
	36	0	1	4	1	4
	37	0	-72	-9	1	72
WELDS	38	0	5	0	1	5
	39	28	37	18	24	50

TABLE 3A.2.3-5

INTERNAL PRESSURE - 100 PSI (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-19		-125	106
INNER	2	-151		-45		151
	3		-146		-193	93
BOTTOM	4	-24		23		47
	5		1113		266	1213
PLATE	6	-1284		-436		1284
	7		199		304	404
	8	214		279		279
	9		223		441	541
INNER	10	190		401		401
	11		228		428	528
SHELL	12	185		385		385
	13		225		430	530
	14	188		389		389
	15		191		304	404
	16	222		284		284
	17		-221		182	403
	18	627		407		627

TABLE 3A.2.3-6

INTERNAL PRESSURE - 100 PSI (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-10	687	439	-59	707
	20	3	200	277	-122	333
LID	21	-726	-30	-742	11	712
	22	1642	25	1660	68	1638
OUTER BOTTOM PLATE	23	-799	-91	-809	-49	721
	24	1088	2	1095	-28	1093
	25	-355	-97	-581	23	486
	26	623	-12	851	28	865
OUTER SHELL	27	-78	107	199	23	279
	28	-6	204	189	17	212
	29	-78	104	393	-6	472
	30	1	201	341	-5	341
	31	-78	158	396	0	475
	32	0	152	317	0	316
	33	-78	142	396	2	474
	34	0	166	324	1	324
	35	-80	372	342	-32	457
	36	-3	-55	162	-27	228
WELDS	37	38	-419	-111	-40	464
	38	19	-96	182	-4	278
	39	-683	-1005	-438	-646	1332

TABLE 3A.2.3-7

EXTERNAL PRESSURE - 25 PSI (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI) OUTER SURFACE	MERIDIONAL (PSI) INNER SURFACE	HOOP (PSI) OUTER SURFACE	HOOP (PSI) INNER SURFACE	STRESS INTENSITY (PSI)
	1		52		54	54
INNER	2	-41		-43		43
	3		36		44	44
BOTTOM	4	-25		-33		33
	5		-332		-90	332
PLATE	6	343		101		343
	7		-67		-91	91
	8	-82		-95		95
	9		-73		-126	126
INNER	10	-76		-127		127
	11		-75		-123	123
SHELL	12	-75		-123		123
	13		-74		-122	122
	14	-75		-122		122
	15		-98		-128	128
	16	-52		-115		115
	17		8		-113	121
	18	-156		-162		162

TABLE 3A.2.3-8

EXTERNAL PRESSURE - 25 PSI (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-4	-184	-181	10	181
	20	-16	-80	-144	26	138
LID	21	165	-18	170	-2	187
	22	-445	-32	-449	-19	418
OUTER BOTTOM PLATE	23	195	-2	207	10	210
	24	-316	-28	-328	8	300
	25	64	-1	132	-7	133
	26	-183	-22	-250	-6	229
OUTER SHELL	27	-5	-51	-74	-6	69
	28	-23	-75	-72	-4	53
	29	-5	-50	-124	2	119
	30	-25	-75	-111	1	86
	31	-5	-64	-125	0	120
	32	-25	-62	-105	0	80
	33	-5	-59	-123	0	118
	34	-25	-67	-106	0	81
	35	-6	-142	-147	5	141
	36	-25	12	-81	5	93
WELDS	37	-35	86	5	10	122
	38	-29	17	-106	1	123
	39	164	234	100	159	326

TABLE 3A.2.3-9

THERMAL STRESS (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
INNER BOTTOM PLATE	1		-795		-797	797
	2	-1153		-1151		1153
	3		-785		-792	792
	4	-1164		-1156		1164
	5		245		-387	631
	6	-2193		-1562		2193
INNER SHELL	7		-887		-6689	6689
	8	-5714		-8137		8137
	9		-3544		-2140	3544
	10	-3106		-2009		3106
	11		-3309		-2505	3309
	12	-3337		-2513		3337
	13		-3385		-2370	3385
	14	-3262		-2333		3262
	15		-4306		-103	4306
	16	-2359		481		2840
	17		-7890		-1788	7890
	18	1175		931		1175

TABLE 3A.2.3-10

THERMAL STRESS (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-1478	815	-603	-1452	3699
	20	-2365	-3029	-2020	-1695	3454
LID	21	-1865	-36	-1859	95	1838
	22	148	-3	150	-11	154
OUTER BOTTOM PLATE	23	1074	-3	1069	78	1088
	24	-1124	-22	-1121	53	1107
	25	1068	-10	1070	27	1080
	26	-1115	0	-1115	52	1120
OUTER SHELL	27	-99	399	457	517	1148
	28	2	692	447	1508	3093
	29	-104	-1486	224	-209	1741
	30	7	2420	1221	-167	2436
	31	-103	653	546	6	756
	32	0	453	385	5	453
	33	-104	319	602	39	710
	34	6	760	599	31	756
	35	-646	1815	3339	-171	3997
	36	-787	-2842	1055	-216	3919
WELDS	37	94	-1136	99	-215	1304
	38	902	-3581	1317	-390	4931
	39	9533	708	4826	1392	9253

TABLE 3A.2.3-11

THREE(3) G ON TRUNNION (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
INNER BOTTOM PLATE	1		-138		-206	157
	2	-137		-70		137
	3		-192		-222	174
	4	-83		-53		83
	5		451		18	499
	6	-726		-293		726
INNER SHELL	7		92		-75	167
	8	99		-72		172
	9		117		-6	123
	10	124		-4		128
	11		161		-8	169
	12	162		-8		169
	13		210		8	210
	14	196		4		196
	15		184		-25	209
	16	295		6		295
	17		271		-119	391
	18	220		-135		355

TABLE 3A.2.3-12

THREE(3) G ON TRUNNION (SOLID ELEMENTS)

LOCATION		SX	SY	SZ	SXY	STRESS INTENSITY (PSI)
		STRESS COMPONENTS (PSI)				
FLANGE	19	46	127	-200	66	364
	20	51	151	-178	75	369
LID	21	67	-1	69	0	70
	22	-224	-4	-226	-10	222
OUTER BOTTOM PLATE	23	-598	-45	-625	-35	582
	24	741	9	768	-19	759
	25	-292	-49	-449	13	401
	26	431	-6	588	16	594
OUTER SHELL	27	0	186	-71	18	259
	28	-3	74	-86	14	162
	29	0	126	-7	-2	133
	30	0	176	8	-2	176
	31	0	193	1	0	193
	32	0	193	1	0	193
	33	0	269	15	-2	269
	34	0	202	-6	-2	208
	35	-4	-185	-137	-11	182
	36	-61	244	-13	241	570
WELDS	37	21	-232	-102	-26	259
	38	-39	-179	-276	-11	238
	39	202	244	130	116	236

TABLE 3A.2.3-13

ONE(1) G LATERAL (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI) OUTER SURFACE	MERIDIONAL (PSI) INNER SURFACE	HOOP (PSI) OUTER SURFACE	HOOP (PSI) INNER SURFACE	STRESS INTENSITY (PSI)
	1		27		25	27
INNER	2	4		12		12
	3		40		86	86
BOTTOM	4	39		83		83
	5		-27		146	173
PLATE	6	188		242		242
	7		322		55	323
	8	310		58		310
	9		228		-13	241
INNER	10	237		2		237
	11		107		-20	127
SHELL	12	116		1		116
	13		21		-15	36
	14	27		7		27
	15		-40		-60	60
	16	-16		-35		35
	17		-63		-97	96
	18	3		-60		63

TABLE 3A.2.3-14

ONE(1) G LATERAL (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-22	-34	-114	-6	94
	20	-24	-25	-95	-7	77
LID	21	2	0	0	0	3
	22	3	0	0	0	3
OUTER BOTTOM PLATE	23	-18	-1	-36	-5	36
	24	-95	42	-142	7	184
	25	-72	-1	-75	-5	74
	26	-75	5	-109	2	114
OUTER SHELL	27	2	365	25	2	362
	28	1	333	15	-7	332
	29	1	245	-45	6	290
	30	-1	274	-5	-3	279
	31	0	119	-61	3	180
	32	0	160	18	-3	161
	33	0	44	-66	2	110
	34	0	68	22	-2	68
	35	1	-46	-100	0	101
	36	-1	63	8	0	64
WELDS	37	-14	696	170	-15	711
	38	0	66	-17	6	84
	39	86	86	65	36	72

TABLE 3A.2.3-15

ONE(1) G SIDE DROP - CONTACT SIDE (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-112		96	209
INNER	2	-122		93		215
	3		-167		103	269
BOTTOM	4	-148		113		262
	5		-819		-258	819
PLATE	6	235		96		235
	7		51		125	132
	8	-106		-250		250
	9		-1		190	197
INNER	10	-174		-297		297
	11		-12		231	243
SHELL	12	-197		-311		311
	13		11		191	199
	14	-162		-305		305
	15		134		52	142
	16	64		-259		323
	17		299		107	306
	18	-23		-248		248

TABLE 3A.2.3-16

ONE(1) G SIDE DROP - CONTACT SIDE (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	71	45	21	51	106
	20	59	125	-183	63	346
	21	0	104	-90	-16	197
LID	22	553	39	159	-92	546
	23	-80	0	43	-9	125
OUTER	24	-62	0	52	1	114
BOTTOM	25	-178	0	13	-12	193
PLATE	26	-15	3	82	-3	98
	27	-8	217	617	-11	625
	28	-142	-368	-602	-11	460
OUTER	29	-3	247	897	-1	900
	30	-144	-470	-868	-2	724
	31	-1	257	1061	0	1062
	32	-144	-508	-983	0	840
	33	-2	248	975	1	977
SHELL	34	-144	-478	-920	2	776
	35	-18	163	551	12	570
	36	-146	-287	-640	4	493
	37	-159	153	-142	-11	312
WELDS	38	-128	-232	-677	-49	568
	39	-132	-121	-93	-55	111

TABLE 3A.2.3-17

ONE(1) G SIDE DROP - SIDE OPPOSITE CONTACT (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-106		75	181
INNER	2	-93		82		175
	3		-88		49	137
BOTTOM	4	-76		53		128
	5		-241		-54	241
PLATE	6	109		63		109
	7		1		6	6
	8	-26		-43		43
	9		-36		24	60
INNER	10	-75		-62		75
	11		-54		46	100
SHELL	12	-104		-68		104
	13		-36		24	60
	14	-75		-62		75
	15		33		-48	81
	16	36		-68		103
	17		70		-59	129
	18	36		-83		119

TABLE 3A.2.3-18

ONE(1) G SIDE DROP - SIDE OPPOSITE CONTACT (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	10	9	-90	19	119
	20	9	36	-98	27	151
LID	21	5	-104	85	15	190
	22	-514	-39	-201	94	511
OUTER BOTTOM PLATE	23	-62	0	24	-5	87
	24	-15	1	35	0	50
	25	-82	0	5	-4	87
	26	19	1	26	-4	26
OUTER SHELL	27	0	15	95	-3	95
	28	-1	-76	-76	-5	76
	29	1	25	173	0	173
	30	-2	-151	-169	-3	167
	31	2	28	255	0	253
	32	-1	-204	-228	0	227
	33	1	22	199	1	198
	34	-2	-172	-187	2	186
	35	-4	-18	31	4	50
	36	-3	-35	-64	4	62
WELDS	37	-7	62	23	3	70
	38	-2	-29	-85	-3	83
	39	-33	-57	-19	-7	40

TABLE 3A.2.3-19

SEISMIC LOAD - 2G DOWN + 1G LATERAL (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		129		85	162
INNER	2	-54		-3		54
	3		82		119	151
BOTTOM	4	42		94		94
	5		-101		146	246
PLATE	6	306		288		306
	7		203		53	203
	8	193		56		193
	9		126		-14	140
INNER	10	135		1		135
	11		32		-21	54
SHELL	12	41		0		42
	13		-26		-15	26
	14	-21		6		27
	15		-67		-62	67
	16	-33		-34		34
	17		-60		-95	95
	18	-37		-72		72

TABLE 3A.2.3-20

SEISMIC LOAD - 2G DOWN + 1G LATERAL (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI) SX	SY	SZ	SXY	STRESS INTENSITY (PSI)
FLANGE	19	-22	-82	-131	-2	109
	20	-26	-45	-104	1	78
LID	21	55	0	53	-1	55
	22	-117	-2	-121	-5	119
OUTER BOTTOM PLATE	23	-12	-35	-30	-5	24
	24	-90	4	-137	7	142
	25	-62	-34	-67	-4	33
	26	-73	-30	-105	3	75
OUTER SHELL	27	2	237	21	2	235
	28	1	221	16	-7	220
	29	1	141	-44	6	186
	30	-1	171	-4	-3	175
	31	0	43	-61	3	104
	32	0	84	18	-3	85
	33	0	-3	-65	2	66
	34	0	18	22	-2	23
	35	0	-93	-107	2	108
	36	-1	66	16	2	67
WELDS	37	-14	553	151	-13	567
	38	0	76	-17	7	93
	39	142	161	101	85	171

TABLE 3A.2.5-1
NORMAL CONDITION LOAD COMBINATIONS

INDIVIDUAL LOAD COMBINED LOAD	BOLT PERLOAD	1G DOWN	INTERNAL PRESSURE 100 PSI	EXTERNAL PRESSURE 25 PSI	THERMAL	3G OR 6G ON TRUNNION	TUNNION LOCAL STRESS 3G OR 6G	STRESS TABLE NO.
N1	X	X	X		X			3A.2.5-2 3A.2.5-3
N2	X		X		X	X(1)	X(1)	3A.2.5-4 3A.2.5-5
N3	X	X		X				3A.2.5-6 3A.2.5-7
N4	X	X		X	X			3A.2.5-8 3A.2.5-9
N5	X			X	X	X(1)	X(1)	3A.2.5-10 3A.2.5-11
N6	X		X		X	X(2)	X(2)	3A.2.5-4 3A.2.5-5
N7	X			X	X	X(2)	X(2)	3A.2.5-10 3A.2.5-11

Notes:

1) Load combination based on 3G lifting weight (TN-32 & TN-32A Casks)
2) Load combination based on 6G lifting weight (TN-32B Cask)

TABLE 3A.2.5-2

BOLT PRELOAD+100 PSI INTERNAL PRESSURE+1G DOWN+THERMAL
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-768		-905	789
INNER	2	-1333		-1196		1333
	3		-913		-974	858
BOTTOM	4	-1188		-1127		1188
	5		1328		-121	1449
PLATE	6	-3429		-1980		3429
	7		-764		-6392	6292
	8	-5574		-7865		7865
	9		-3387		-1705	3287
INNER	10	-2982		-1613		2982
	11		-3133		-2082	3033
SHELL	12	-3205		-2133		3205
	13		-3197		-1943	3097
	14	-3114		-1948		3114
	15		-4171		200	4371
	16	-2135		781		2916
	17		-7800		-1509	7700
	18	1448		1236		1448

TABLE 3A.2.5-3

BOLT PRELOAD+100 PSI INTERNAL PRESSURE+1G DOWN+THERMAL
(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-1528	712	-391	-1307	3442
	20	-2545	-2729	-1744	-1543	3091
LID	21	-2522	-66	-2532	102	2470
	22	1928	25	1946	65	1924
OUTER BOTTOM PLATE	23	257	-112	233	30	374
	24	-13	-37	6	24	58
	25	717	-123	482	51	846
	26	-487	-30	-248	81	485
OUTER SHELL	27	-177	448	653	540	1248
	28	-4	842	634	1524	3164
	29	-183	-1431	618	-215	2085
	30	8	2574	1564	-171	2589
	31	-182	776	944	6	1125
	32	0	571	702	5	702
	33	-183	447	1001	40	1186
	34	6	900	923	32	917
	35	-730	2052	3657	-189	4400
	36	-793	-2781	1264	-234	4072
WELDS	37	133	-1633	-24	-255	1837
	38	951	-3608	1498	-418	5144
	39.	8524	-215	4309	738	8862

TABLE 3A.2.5-4

BOLT PRELOAD+100 PSI PRESSURE+THERMAL+3G UP+TRUNNION LOCAL STRESS (SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-957		-1141	992
INNER	2	-1442		-1258		1442
	3		-1126		-1213	1065
BOTTOM	4	-1273		-1186		1273
	5		1816		-103	1964
PLATE	6	-4215		-2296		4215
	7		-612		-6466	6366
	8	-5416		-7937		7937*
	9		-3219		-1710	3119
INNER	10	-2807		-1617		2807
	11		-2934		-2089	2834
SHELL	12	-3006		-2140		3006
	13		-2964		-1934	2864
	14	-2895		-1944		2895
	15		-3973		177	4149
	16	-1831		789		2620
	17		-7531		-1629	7431
	18	1688		1107		1688

* Maximum combined stress intensity due to 6 G up is 8,775 psi

TABLE 3A.2.5-5

BOLT PRELOAD+100 PSI(INT. P)+THERMAL+3G UP+TRUNNION LOCAL STRESS
(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI) SX	SY	SZ	SXY	STRESS INTENSITY (PSI)
FLANGE	19	-1482	863	-582	-1242	3416
	20	-2492	-2567	-1918	-1472	2944
LID	21	-2481	-66	-2489	102	2427
	22	1764	21	1780	58	1761
OUTER BOTTOM PLATE	23	-343	-140	-395	-5	255
	24	725	-9	772	6	781
	25	420	-155	29	64	589
	26	-56	-18	337	97	474
OUTER SHELL	27	-177	698	584	558	1419
	28	-7	973	548	1538	3229
	29	-183	-1253	611	-217	1906
	30	8	2801	1571	-173	2815
	31	-182	1006	945	6	1188
	32	0	802	703	5	802
	33	-183	739	1016	38	1201
	34	7	1127	917	30	1122
	35	-734	1890	3523	-200	10897*
	36	-854	-2538	1247	6	10410
WELDS	37	154	-1793	-116	-282	2027
	38	912	-3791	1222	-430	5052
	39	8698	-8	4421	830	8863

* Maximum combined stress intensity due to 6G up is 20,975 psi

TABLE 3A.2.5-6

BOLT PRELOAD+1G DOWN+25 PSI EXTERNAL PRESSURE
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		98		72	115
INNER	2	-70		-43		70
	3		54		55	71
BOTTOM	4	-25		-27		27
	5		-362		-91	346
PLATE	6	391		119		391
	7		-142		-99	142
	8	-156		-103		156
	9		-140		-131	140
INNER	10	-142		-132		142
	11		-127		-128	128
SHELL	12	-127		-128		128
	13		-111		-125	125
	14	-115		-126		126
	15		-153		-129	153
	16	-49		-98		98
	17		319		-16	335
	18	-511		-265		511

TABLE 3A.2.5-7

BOLT PRELOAD+1G DOWN+25 PSI EXTERNAL PRESSURE
(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-44	-974	-408	214	1024
	20	-199	19	-146	300	638
LID	21	234	-17	239	-6	256
	22	-307	-29	-313	-11	284
OUTER BOTTOM PLATE	23	178	-19	181	10	201
	24	-294	-45	-296	8	251
	25	69	-17	124	-6	142
	26	-178	-40	-234	-5	194
OUTER SHELL	27	-6	-110	-77	-6	105
	28	-24	-129	-73	-4	106
	29	-6	-99	-123	1	117
	30	-25	-122	-110	1	97
	31	-6	-98	-124	0	119
	32	-25	-96	-104	0	79
	33	-6	-74	-120	-1	115
	34	-25	-93	-107	-1	82
	35	-11	-277	-171	19	269
	36	-28	127	-34	13	162
WELDS	37	-34	9	-6	10	47
	38	1	86	-107	-23	199
	39	-163	316	20	152	567

TABLE 3A.2.5-8

BOLT PRELOAD+1G DOWN+25 PSI EXTERNAL PRESSURE+THERMAL
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-697		-725	709
INNER	2	-1223		-1194		1223
	3		-731		-737	721
BOTTOM	4	-1189		-1182		1189
	5		-117		-477	461
PLATE	6	-1802		-1442		1802
	7		-1030		-6788	6788
	8	-5870		-8240		8240
	9		-3683		-2271	3683
INNER	10	-3247		-2141		3247
	11		-3436		-2633	3436
SHELL	12	-3464		-2642		3464
	13		-3496		-2494	3496
	14	-3378		-2459		3378
	15		-4459		-232	4459
	16	-2408		383		2791
	17		-7571		-1804	7571
	18	664		667		667

TABLE 3A.2.5-9

BOLT PRELOAD+1G DOWN+25 PSI EXTERNAL PRESSURE+THERMAL
(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-1522	-159	-1011	-1238	2826
	20	-2563	-3009	-2166	-1395	2825
LID	21	-1630	-53	-1620	89	1587
	22	-159	-33	-163	-22	134
OUTER BOTTOM PLATE	23	1252	-22	1250	89	1286
	24	-1417	-67	-1416	61	1355
	25	1136	-27	1194	21	1222
	26	-1293	-39	-1349	46	1312
OUTER SHELL	27	-105	289	380	512	1097
	28	-22	563	374	1503	3063
	29	-110	-1585	101	-207	1715
	30	-18	2298	1111	-166	2339
	31	-109	554	422	6	663
	32	-25	357	281	5	382
	33	-110	245	482	38	595
	34	-19	667	492	30	689
	35	-657	1537	3168	-152	3835
	36	-815	-2715	1021	-203	3757
WELDS	37	60	-1128	93	-205	1257
	38	903	-3494	1210	-413	4743
	39	9370	1024	4846	1544	8899

TABLE 3A.2.5-10

BOLT PRELOAD+25 PSI(EXT. P)+THERMAL+3G UP+TRUNNION LOCAL STRESS
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-886		-961	913
INNER	2	-1332		-1256		1332
	3		-944		-976	928
BOTTOM	4	-1273		-1241		1273
	5		370		-459	829
PLATE	6	-2588		-1758		2588
	7		-878		-6861	6861
	8	-5712		-8311		8311*
	9		-3515		-2277	3515
INNER	10	-3073		-2144		3073
	11		-3237		-2640	3237
SHELL	12	-3265		-2649		3265
	13		-3263		-2486	3263
	14	-3158		-2455		3158
	15		-4261		-256	4261
	16	-2105		391		2496
	17		-7301		-1924	7301
	18	904		538		904

*Maximum combined stress intensity due to 6G up is 8,591 psi

TABLE 3A.2.5-11

BOLT PRELOAD+25 PSI(EXT. P)+THERMAL+3G UP+TRUNNION LOCAL STRESS (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-1476	-9	-1202	-1173	2768
	20	-2511	-2848	-2339	-1324	2669
	21	-1589	-54	-1578	90	1546
LID	22	-323	-36	-329	-29	296
	23	651	-51	622	54	710
OUTER	24	-679	-39	-651	42	645
BOTTOM	25	839	-59	741	33	901
PLATE	26	-863	-28	-764	62	845
	27	-105	540	311	530	1240
	28	-25	693	288	1517	3118
OUTER	29	-110	-1407	94	-209	1534
	30	-18	2525	1119	-167	2565
	31	-109	785	423	6	894
	32	-25	588	282	5	613
	33	-110	537	497	36	651
SHELL	34	-19	894	487	29	915
	35	-661	1376	3034	-164	10332*
	36	-877	-2472	1004	37	10101
	37	82	-1288	0	-232	1446
WELDS	38	864	-3678	934	-425	4651
	39	9544	1230	4958	1636	8934

*Maximum combined stress intensity due to 6G up is 20,659 psi

TABLE 3A.2.5-12
ACCIDENT CONDITION LOAD COMBINATIONS

INDIVIDUAL LOAD / COMBINED LOAD	BOLT PERLOAD	INTERNAL PRESSURE 100 PSI	EXTERNAL PRESSURE 25 PSI	18" BOTTOM END DROP 50G	TIP OVER SIDE DROP 50G	SEISMIC, TORNADO, OR FLOOD 1G-LATERAL+ 2G-DOWN	STRESS TABLE NO.
A1	X	X		X			3A.2.5-13 3A.2.5-14
A2	X		X	X			3A.2.5-15 3A.2.5-16
A3	X	X			X		3A.2.5-17 3A.2.5-18 3A.2.5-19 3A.2.5-20
A4	X		X		X		3A.2.5-21 3A.2.5-22 3A.2.5-23 3A.2.5-24
A5	X	X				X	3A.2.5-25 3A.2.5-26
A6	X		X			X	3A.2.5-27 3A.2.5-28

TABLE 3A.2.5-13

BOLT PRELOAD + 50G DOWN END DROP + 100 PSI INTERNAL PRESSURE
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI) OUTER SURFACE	MERIDIONAL (PSI) INNER SURFACE	HOOP (PSI) OUTER SURFACE	HOOP (PSI) INNER SURFACE	STRESS INTENSITY (PSI)
	1		2543		1362	3449
INNER	2	-1591		-411		1591
	3		892		638	1798
BOTTOM	4	60		313		313
	5		-711		251	1157
PLATE	6	1663		701		1663
	7		-2812		230	3042
	8	-2729		225		2954
	9		-2343		415	2758
INNER	10	-2374		375		2750
	11		-1652		393	2045
SHELL	12	-1693		351		2044
	13		-962		417	1378
	14	-1011		372		1383
	15		-545		257	802
	16	-196		332		527
	17		146		303	403
	18	-700		20		719

TABLE 3A.2.5-14

BOLT PRELOAD + 50G DOWN END DROP + 100 PSI INTERNAL PRESSURE (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-66	-1297	-212	244	1325
	20	-228	-170	72	355	713
LID	21	658	-38	671	-13	709
	22	-1201	-31	-1217	-47	1188
OUTER BOTTOM PLATE	23	-675	-940	-687	-36	274
	24	1230	-948	1235	-35	2184
	25	-113	-927	-403	47	819
	26	671	-900	967	47	1869
OUTER SHELL	27	-79	-3083	83	15	3166
	28	-9	-2599	201	11	2800
	29	-80	-2488	415	-10	2903
	30	1	-2363	366	-8	2728
	31	-79	-1734	400	0	2134
	32	0	-1739	320	0	2059
	33	-79	-1029	413	-1	1442
	34	1	-1071	320	-1	1391
	35	-90	-903	142	31	1047
	36	-5	132	396	28	406
WELDS	37	39	-4011	-581	-8	4050
	38	40	196	176	0	156
	39	370	911	368	543	1213

TABLE 3A.2.5-15

BOLT PRELOAD + 50G DOWN END DROP + 25 PSI EXTERNAL PRESSURE
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		2614		1542	3420
INNER	2	-1481		-409		1481
	3		1074		875	1880
BOTTOM	4	59		258		258
	5		-2156		-105	2051
PLATE	6	3289		1239		3289
	7		-3078		-165	3078
	8	-3024		-149		3024
	9		-2639		-152	2639
INNER	10	-2640		-152		2640
	11		-1955		-158	1955
SHELL	12	-1952		-157		1952
	13		-1260		-135	1260
	14	-1274		-140		1274
	15		-833		-170	833
	16	-470		-61		470
	17		374		16	374
	18	-1482		-541		1482

TABLE 3A.2.5-16

BOLT PRELOAD + 50G DOWN END DROP + 25 PSI EXTERNAL PRESSURE
(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-56	-2191	-851	313	2225
	20	-243	-437	-357	508	1034
LID	21	1606	-23	1640	-28	1664
	22	-3344	-89	-3383	-136	3300
OUTER BOTTOM PLATE	23	319	-850	329	23	1180
	24	-175	-979	-187	1	804
	25	307	-831	310	16	1141
	26	-135	-910	-134	12	776
OUTER SHELL	27	-7	-3241	-189	-13	3234
	28	-27	-2879	-60	-10	2852
	29	-7	-2642	-103	-2	2636
	30	-24	-2639	-87	-2	2615
	31	-6	-1956	-121	0	1949
	32	-25	-1953	-102	0	1928
	33	-6	-1230	-107	-3	1224
	34	-25	-1304	-110	-2	1279
	35	-16	-1416	-341	68	1407
	36	-27	197	156	59	254
WELDS	37	-33	-3506	-465	42	3473
	38	-8	311	-104	6	415
	39	1180	2151	912	1347	2865

TABLE 3A.2.5-17

BOLT PRELOAD + TIP OVER(50G) + 100 PSI INTERNAL PRESSURE
OPPOSITE CONTACT SIDE(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-5337		3604	8941
INNER	2	-4803		4082		8885
	3		-4552		2244	6796
BOTTOM	4	-3817		2651		6467
	5		-10931		-2425	10831
PLATE	6	4135		2738		4135
	7		233		580	691
	8	-1088		-1876		1876
	9		-1593		1619	3211
INNER	10	-3569		-2687		3569
	11		-2487		2707	5194
SHELL	12	-5017		-2999		5017
	13		-1579		1592	3172
	14	-3578		-2697		3578
	15		1835		-2043	3878
	16	2031		-3030		5061
	17		3652		-2581	6233
	18	2102		-3752		5854

TABLE 3A.2.5-18

BOLT PRELOAD + TIP OVER(50G) + 100 PSI INTERNAL PRESSURE
OPPOSITE CONTACT SIDE(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	466	270	-4411	1120	5903
	20	266	2177	-4715	1550	7757
LID	21	-358	-5174	3657	744	8943
	22	-24175	-1924	-8418	4833	24260
OUTER BOTTOM PLATE	23	-3929	-82	360	-308	4314
	24	354	42	2882	-31	2843
	25	-4431	-98	-336	-186	4349
	26	1582	24	2144	-174	2139
OUTER SHELL	27	-80	855	4929	-145	5031
	28	-68	-3607	-3606	-253	3575
	29	-34	1370	9056	-10	9090
	30	-81	-7334	-8095	-130	8016
	31	5	1538	13114	-2	13109
	32	-72	-10028	-11061	-18	10989
	33	-25	1216	10317	31	10342
	34	-76	-8416	-9003	111	8928
	35	-262	-661	1835	197	2577
	36	-136	-1661	-2929	192	2817
WELDS	37	-327	2700	1049	123	3037
	38	-54	-1403	-3948	-131	3906
	39	-2765	-3904	-1566	-1086	2994

TABLE 3A.2.5-19

BOLT PRELOAD + TIP OVER(50G) + 100 PSI INTERNAL PRESSURE
CONTACT SIDE(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-5637		4674	10311
INNER	2	-6228		4629		10857
	3		-8477		4946	13423
BOTTOM	4	-7448		5693		13142
	5		-39838		-12641	39738
PLATE	6	10473		4350		10473
	7		2730		6538	7002
	8	-5089		-12211		12211
	9		164		9922	10387
INNER	10	-8516		-14459		14459
	11		-395		11968	12433
SHELL	12	-9670		-15175		15175
	13		734		9965	10430
	14	-7957		-14861		14861
	15		6939		2825	7404
	16	3576		-12523		16099
	17		15363		5561	15828
	18	-884		-11980		11980

TABLE 3A.2.5-20

BOLT PRELOAD + TIP OVER(50G) + 100 PSI INTERNAL PRESSURE
CONTACT SIDE(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	3637	1810	1101	2795	5881
	20	2878	6834	-9177	3476	18032
	21	-857	5115	-5460	-761	10671
LID	22	30050	2001	9973	-4561	29496
	23	-4829	-90	1325	-515	6210
OUTER	24	-1986	7	3715	43	5701
BOTTOM	25	-9274	-104	80	-570	9389
PLATE	26	-135	119	4974	-125	5160
	27	-457	10941	31033	-502	31511
	28	-7100	-18191	-29886	-537	22812
OUTER	29	-213	12450	45232	-52	45445
	30	-7194	-23325	-43048	-113	35856
	31	-126	13020	53429	-13	53555
	32	-7189	-25243	-48826	-7	41638
	33	-183	12527	49046	67	49229
SHELL	34	-7191	-23765	-45625	102	38435
	35	-1016	8322	27455	608	28511
	36	-7323	-14279	-31374	166	24055
	37	-7888	7233	-7218	-603	15168
WELDS	38	-6399	-11584	-33019	-2359	27532
	39	-7683	-7277	-5255	-3508	7027

TABLE 3A.2.5-21

BOLT PRELOAD + TIP OVER(50G) + 25 PSI EXTERNAL PRESSURE
OPPOSITE CONTACT SIDE(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-5266		3784	9050
INNER	2	-4693		4084		8777
	3		-4369		2481	6850
BOTTOM	4	-3817		2596		6413
	5		-12376		-2781	12376
PLATE	6	5761		3276		5761
	7		-32		185	217
	8	-1383		-2250		2250
	9		-1889		1052	2941
INNER	10	-3834		-3215		3834
	11		-2790		2156	4946
SHELL	12	-5276		-3507		5276
	13		-1878		1041	2918
	14	-3841		-3209		3841
	15		1548		-2471	4018
	16	1757		-3423		5180
	17		3881		-2869	6749
	18	1320		-4313		5633

TABLE 3A.2.5-22

BOLT PRELOAD + TIP OVER(50G) + 25 PSI EXTERNAL PRESSURE
OPPOSITE CONTACT SIDE(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	475	-623	-5049	1190	6286
	20	251	1910	-5144	1703	8118
LID	21	591	-5159	4626	729	9876
	22	-26318	-1982	-10585	4744	26120
OUTER BOTTOM PLATE	23	-2935	7	1377	-250	4332
	24	-1050	11	1459	5	2510
	25	-4011	-2	376	-216	4399
	26	775	14	1043	-209	1082
OUTER SHELL	27	-7	697	4657	-173	4704
	28	-86	-3887	-3867	-274	3840
	29	39	1215	8539	-3	8500
	30	-107	-7611	-8547	-124	8443
	31	78	1317	12593	-2	12515
	32	-98	-10243	-11483	-18	11385
	33	48	1014	9797	29	9750
	34	-102	-8649	-9433	110	9333
	35	-188	-1174	1352	235	2579
	36	-158	-1596	-3169	224	3044
WELDS	37	-400	3205	1166	173	3621
	38	-102	-1288	-4228	-126	4139
	39	-1956	-2663	-1023	-281	1738

TABLE 3A.2.5-23

BOLT PRELOAD + TIP OVER(50G) + 25 PSI EXTERNAL PRESSURE
CONTACT SIDE(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		-5566		4853	10419
INNER	2	-6118		4631		10749
	3		-8294		5183	13477
BOTTOM	4	-7449		5638		13087
	5		-41283		-12997	41283
PLATE	6	12100		4888		12100
	7		2464		6142	6507
	8	-5384		-12585		12585
	9		-132		9356	9721
INNER	10	-8781		-14986		14986
	11		-698		11417	12115
SHELL	12	-9929		-15683		15683
	13		435		9413	9778
	14	-8220		-15372		15372
	15		6652		2398	7017
	16	3302		-12916		16218
	17		15592		5273	15957
	18	-1666		-12541		12541

TABLE 3A.2.5-24

BOLT PRELOAD + TIP OVER(50G) + 25 PSI EXTERNAL PRESSURE
CONTACT SIDE(SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI) SX	SY	SZ	SXY	STRESS INTENSITY (PSI)
FLANGE	19	3647	917	462	2864	6346
	20	2864	6566	-9606	3628	18394
LID	21	91	5130	-4491	-776	9737
	22	27907	1942	7806	-4650	27580
OUTER BOTTOM PLATE	23	-3835	-1	2342	-456	6230
	24	-3390	-23	2292	80	5684
	25	-8854	-8	792	-600	9687
	26	-941	109	3873	-160	4838
OUTER SHELL	27	-384	10783	30760	-530	31169
	28	-7118	-18470	-30147	-558	23056
	29	-140	12296	44715	-44	44855
	30	-7220	-23602	-43501	-107	36282
	31	-53	12799	52908	-13	52961
	32	-7214	-25457	-49248	-7	42034
	33	-110	12326	48526	65	48637
	34	-7216	-23998	-46055	100	38840
	35	-942	7808	26972	645	27962
	36	-7345	-14214	-31613	198	24274
WELDS	37	-7960	7738	-7102	-554	15737
	38	-6447	-11470	-33299	-2353	27782
	39	-6873	-6036	-4712	-2703	5471

TABLE 3A.2.5-25

BOLT PRELOAD+100 PSI INTERNAL PRESSURE+SEISMIC(TORNADO,FLOOD)
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		105		-53	237
INNER	2	-205		-40		205
	3		-68		-79	65
BOTTOM	4	16		117		117
	5		1019		411	1152
PLATE	6	-989		-153		989
	7		387		351	487
	8	392		328		392
	9		334		422	522
INNER	10	310		397		397
	11		246		402	502
SHELL	12	211		380		380
	13		185		412	512
	14	152		392		392
	15		83		240	340
	16	201		263		263
	17		19		177	277
	18	267		239		267

TABLE 3A.2.5-26

BOLT PRELOAD+100 PSI INTERNAL PRESSURE+SEISMIC(TORNADO,FLOOD)
CONTACT SIDE (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-75	-149	97	140	354
	20	-210	266	180	146	559
LID	21	-673	-31	-692	7	661
	22	1767	27	1781	76	1757
OUTER BOTTOM PLATE	23	-831	-126	-868	-53	746
	24	1018	9	988	-21	1010
	25	-418	-131	-659	20	529
	26	554	-43	760	32	805
OUTER SHELL	27	-76	349	218	25	428
	28	-5	427	203	10	432
	29	-78	248	350	0	428
	30	0	377	338	-8	377
	31	-78	204	337	3	415
	32	0	240	336	-3	336
	33	-78	148	334	3	412
	34	0	183	346	-1	346
	35	-84	170	213	-17	298
	36	-7	124	219	-18	228
WELDS	37	25	129	38	-54	149
	38	48	37	160	-24	142
	39	-849	-808	-436	-594	1188

TABLE 3A.2.5-27

BOLT PRELOAD+25 PSI EXTERNAL PRESSURE+SEISMIC(TORNADO,FLOOD)
(SHELL ELEMENTS)

LOCATION		MERIDIONAL (PSI)		HOOP (PSI)		STRESS INTENSITY (PSI)
		OUTER SURFACE	INNER SURFACE	OUTER SURFACE	INNER SURFACE	
	1		176		126	209
INNER	2	-95		-38		95
	3		115		158	190
BOTTOM	4	15		62		62
	5		-426		55	481
PLATE	6	638		384		638
	7		121		-44	165
	8	96		-46		142
	9		38		-145	182
INNER	10	44		-131		175
	11		-57		-149	149
SHELL	12	-48		-128		128
	13		-113		-140	140
	14	-112		-120		120
	15		-205		-187	204
	16	-73		-130		130
	17		247		-111	358
	18	-515		-322		515

TABLE 3A.2.5-28

BOLT PRELOAD+25 PSI EXTERNAL PRESSURE+SEISMIC(TORNADO,FLOOD)
CONTACT SIDE (SOLID ELEMENTS)

LOCATION		STRESS COMPONENTS (PSI)				STRESS INTENSITY (PSI)
		SX	SY	SZ	SXY	
FLANGE	19	-65	-1042	-541	210	1063
	20	-225	-1	-249	289	638
	21	275	-16	278	-7	294
LID	22	-376	-31	-386	-13	356
	23	163	-37	149	6	200
OUTER	24	-386	-22	-435	16	414
BOTTOM	25	2	-35	54	-11	92
PLATE	26	-252	-52	-341	-3	289
	27	-3	191	-54	-4	245
	28	-22	148	-57	-11	206
OUTER	29	-5	94	-167	8	262
	30	-26	100	-114	-2	215
	31	-5	-18	-185	3	180
	32	-26	26	-86	-3	112
	33	-5	-53	-186	1	181
SHELL	34	-25	-50	-85	-3	60
	35	-10	-343	-270	20	335
	36	-29	189	-20	14	219
	37	-48	634	154	-4	681
WELDS	38	1	152	-120	-18	274
	39	-39	433	107	211	633

Table 3A. 4-1
Stress in outer shell and closure plate

Load	Maximum Stress Intensity (PSI)	Allowable Stress (PSI)
25 psi internal pressure	7,238	S_Y = 33,700
25 psi = 3G down Cask Vertical	11,755	
25 psi = 3G down Cask Horizontal	10,133	

Note: The worst loading orientation is horizontal; therefore stressess will be lower in actual operation since the loaded cask in storage at the ISFSI is vertical.

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Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3A.1-1
CASK BODY KEY DIMENSIONS

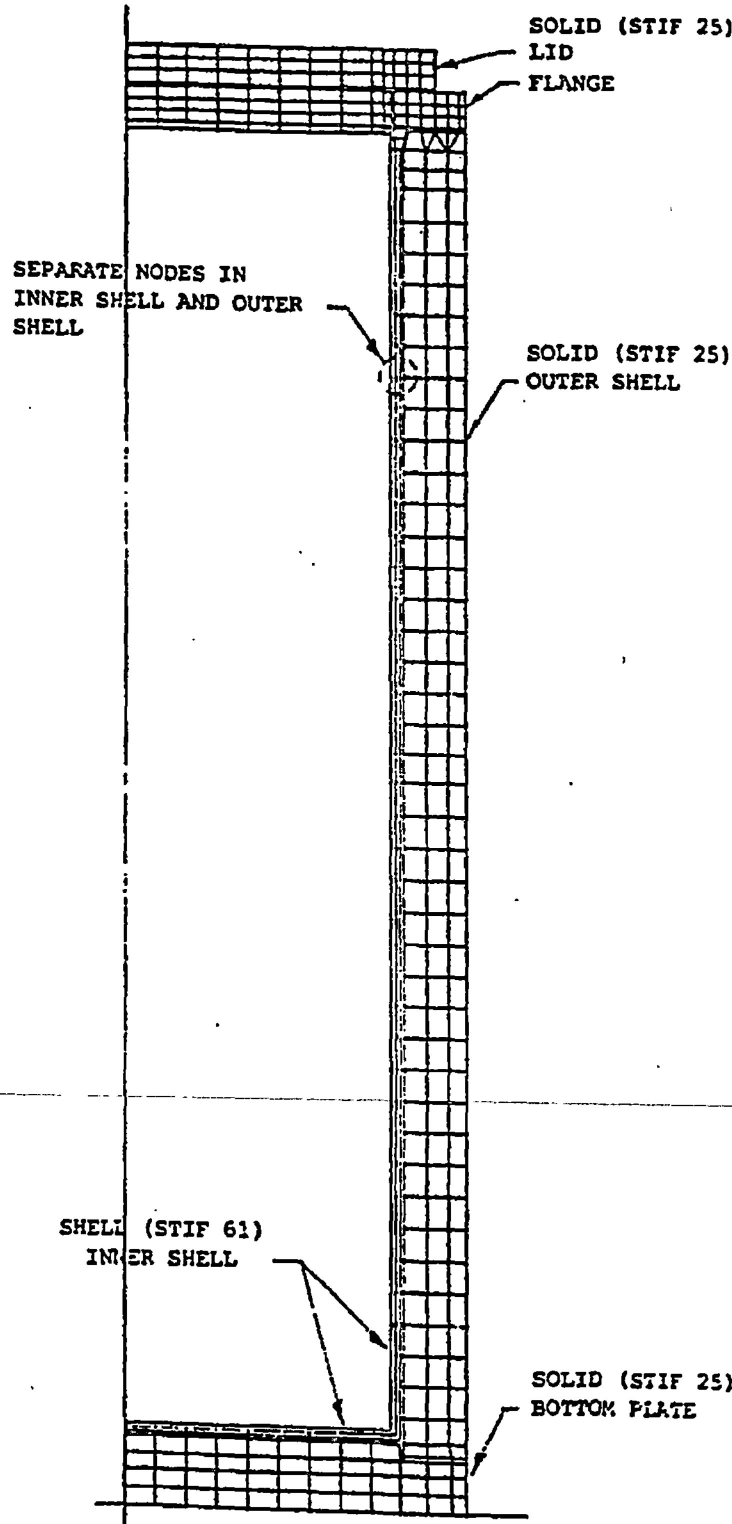
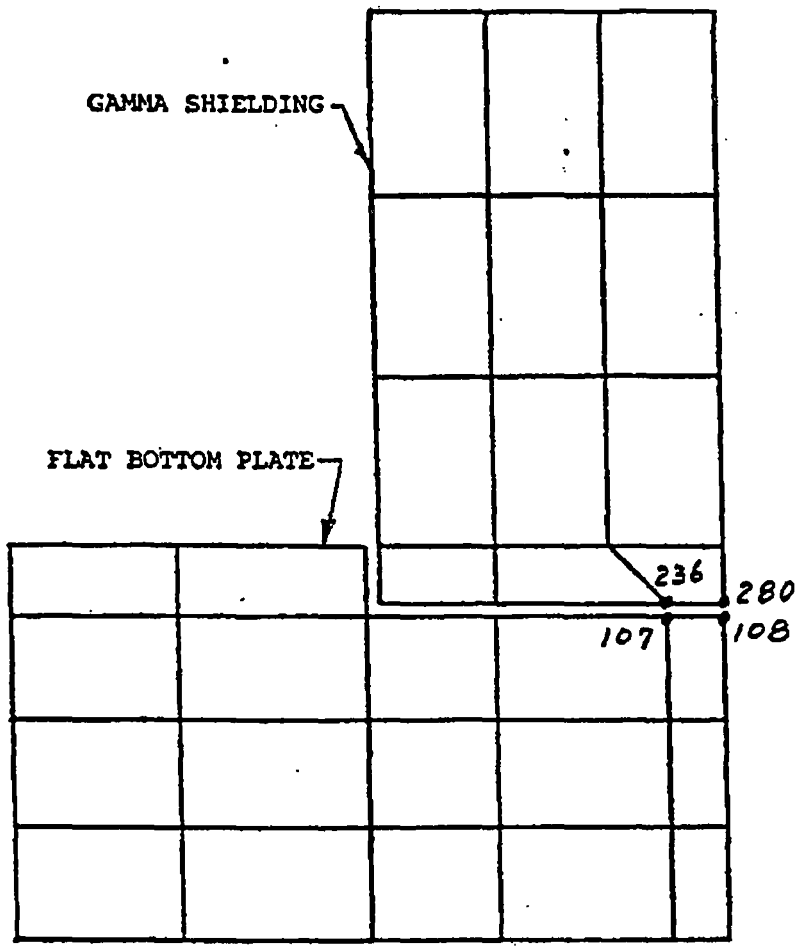


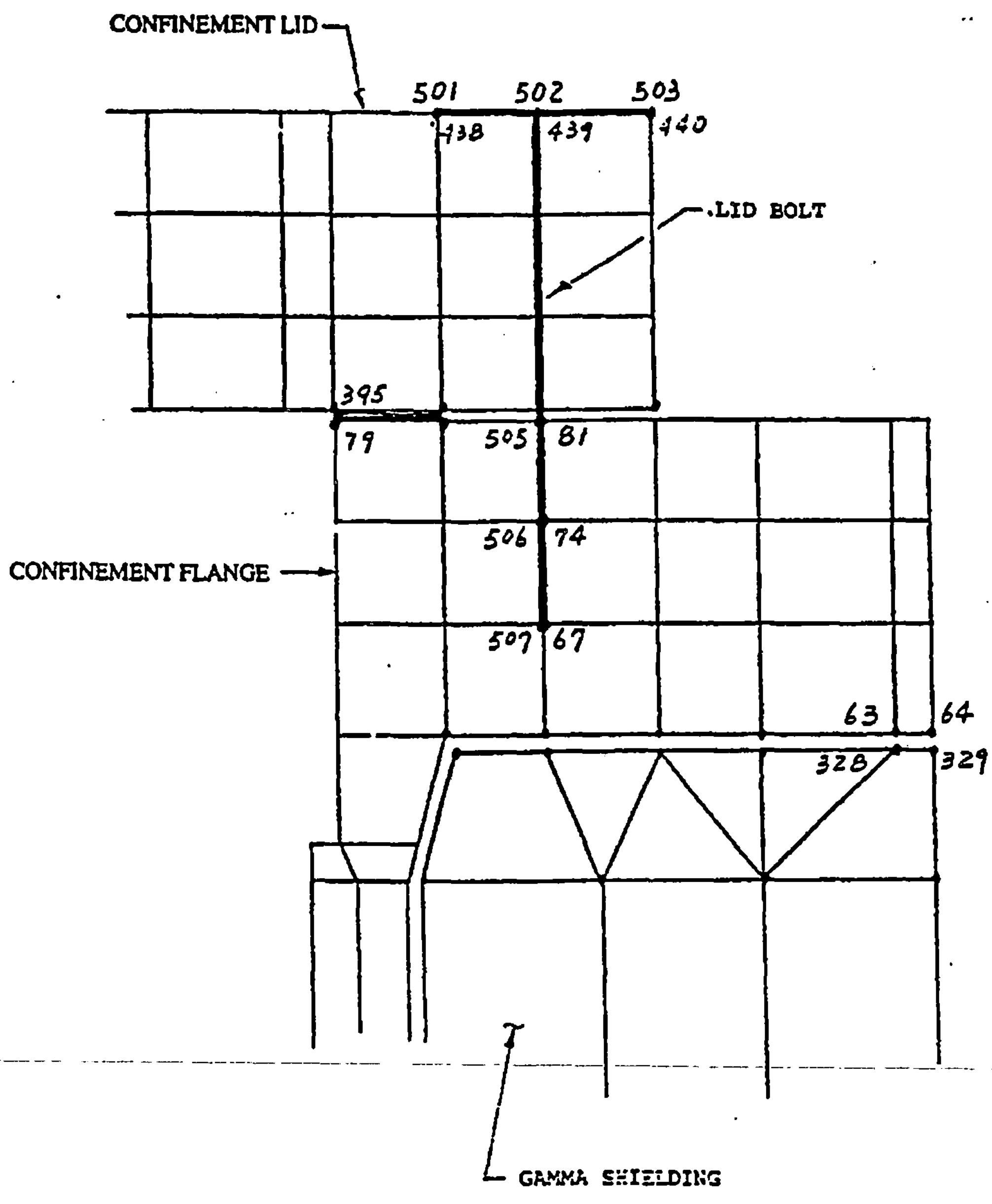
FIGURE 3A.2-1
CASK BODY
ANSYS MODEL



WELD SIMULATION AT JUNCTION OF GAMMA SHIELDING CYLINDRICAL SHELL TO FLAT BOTTOM BY COUPLING NODES 107-236 AND 108-280

FIGURE 3A.2-2
CASK BODY
BOTTOM CORNER

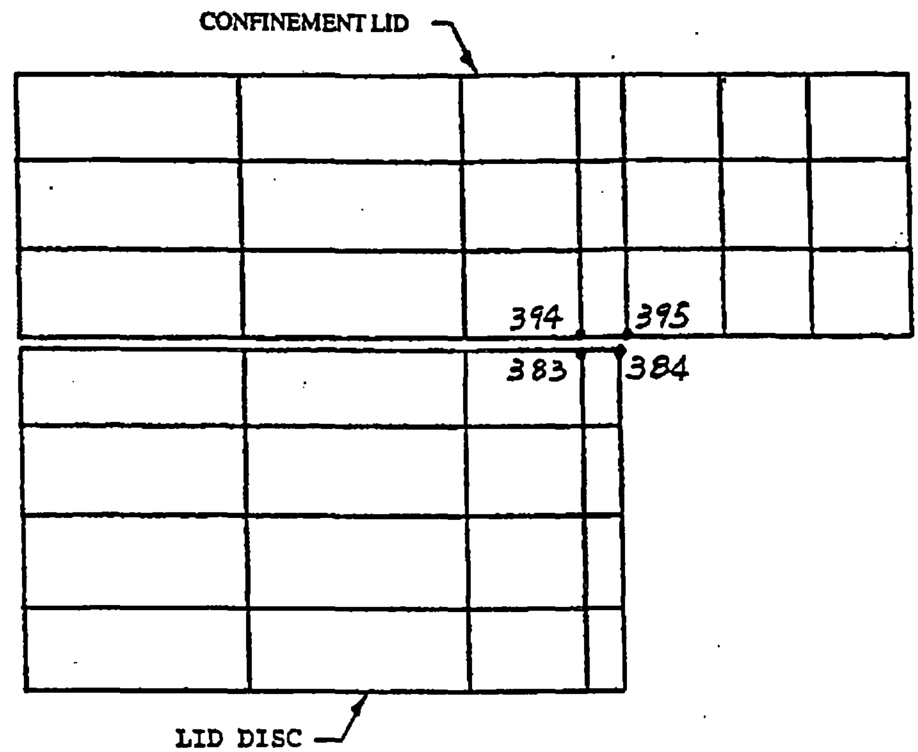
REV. 0 1/00



LID BOLTS CONNECTING PRIMARY LID TO CONFINEMENT FLANGE
AND WELD ATTACHING GAMMA SHIELDING TO FLANGE

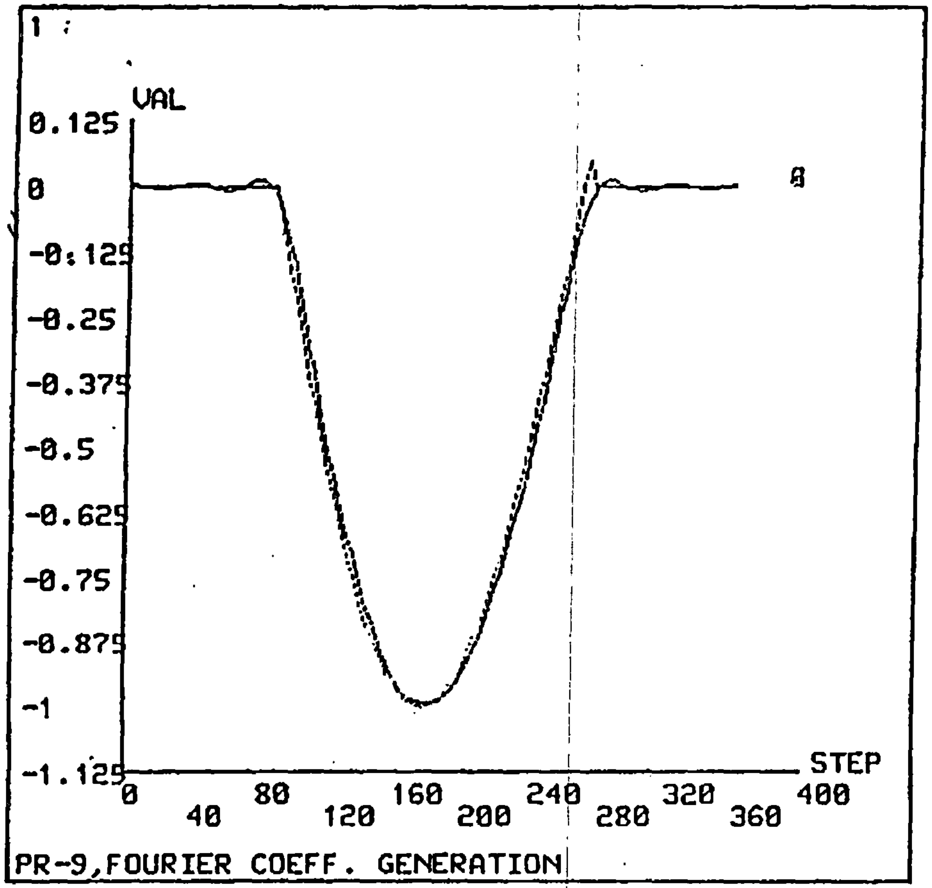
FIGURE 3A.2-3
CASK BODY
TOP CORNER

REV. 0 1/00



SIMULATION OF WELD CONNECTING CONFINEMENT LID TO LID DISC BY COUPLING NODES 383-394 AND 384-395

FIGURE 3A.2-4
CASK LID TO SHIELD PLATE CONNECTION



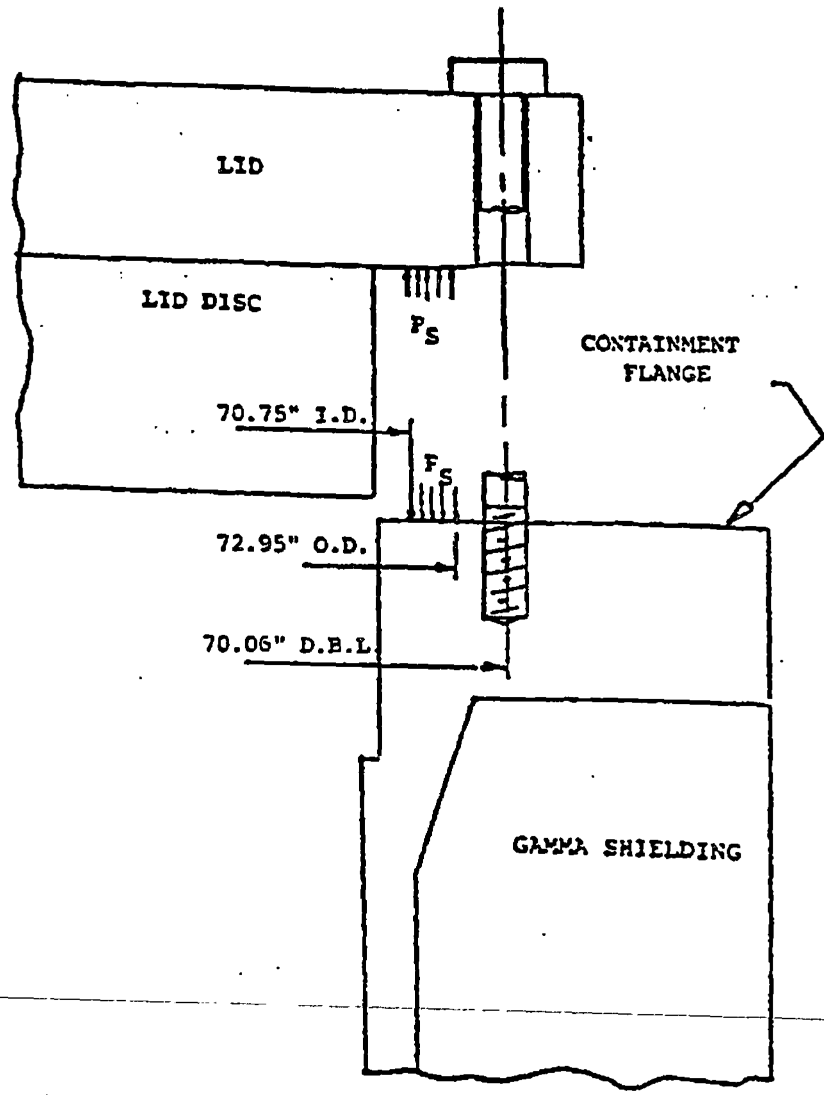
NUMBER OF FOURIER TERMS= 9

***** FOURIER COEFFICIENTS *****

TERM	MODE*ISYM	COEFFICIENT
1	0	-0.31780103E+00
2	1	0.49931477E+00
3	2	-0.21206110E+00
4	3	0.19045333E-13
5	4	0.42528724E-01
6	5	-0.29574938E-13
7	6	-0.18310180E-01
8	7	0.68572428E-13
9	8	0.10237762E-01

FOURIER COEFFICIENTS FOR THE FUNCTION COS | 270°
WITH SERIES TRUNCATED AFTER THE FIRST | 90°
9 TERMS

FIGURE 3A.2-5
FOURIER COEFFICIENTS FOR THE 1g LATERAL



SEAL LOAD $F_S = 2 \times 1713$ #/in. = 3426 #/in. at D_{av} = 71.85"

$$\text{SEAL PRESSURE } P_S = \frac{\pi(71.85)(3426)}{\pi/4\,(72.95^2-70.75^2)} = 3115 \text{ psi}$$

FIGURE 3A.2-6
BOLT PRELOAD AND SEAL REACTION

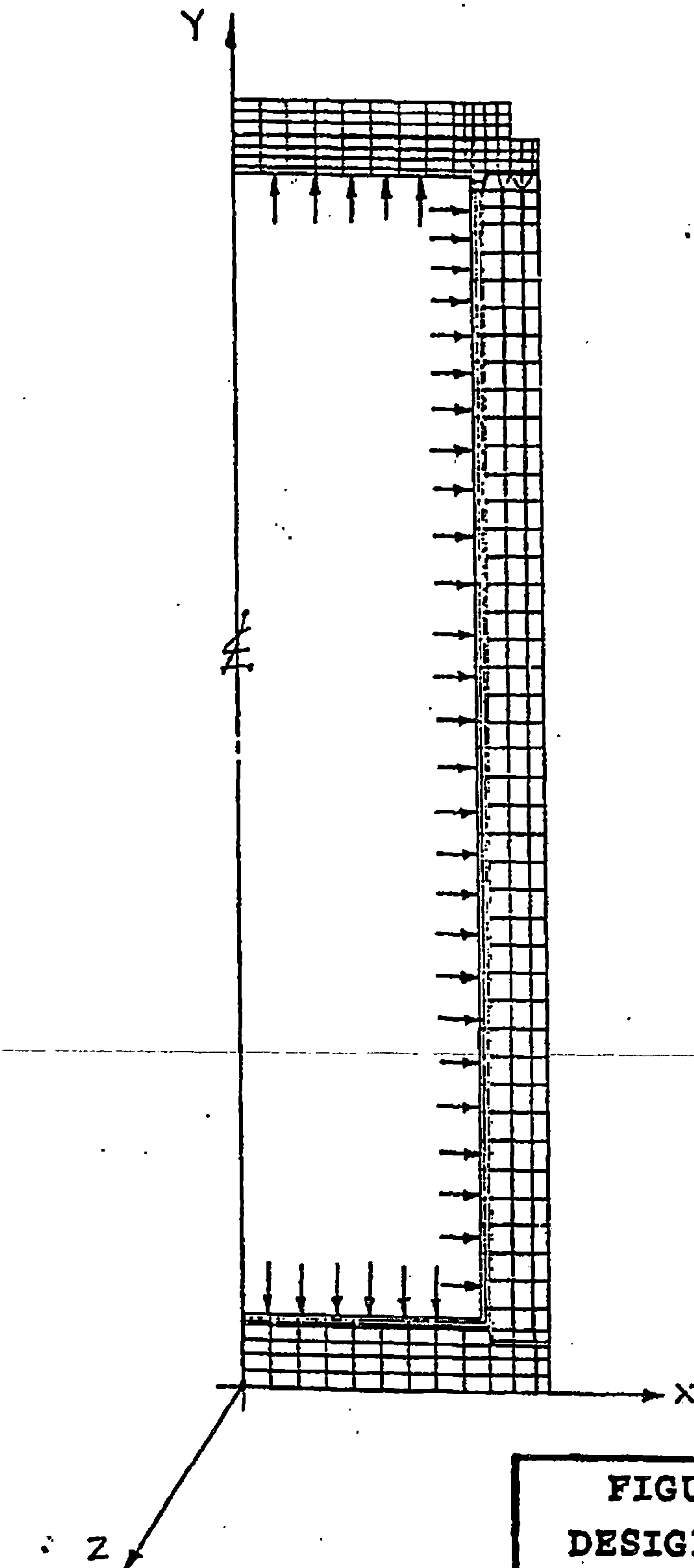


FIGURE 3A.2-7
DESIGN INTERNAL PRESSURE (100 PSIG)

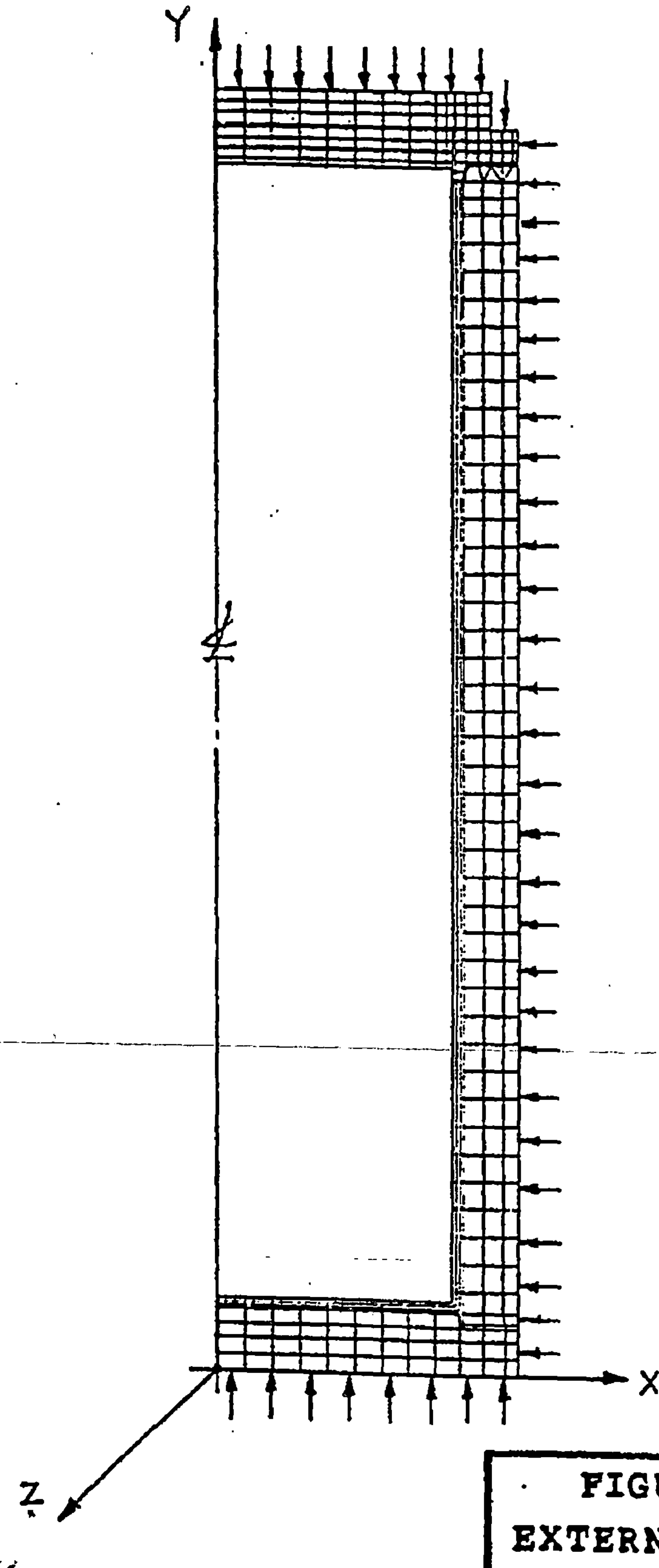


FIGURE 3A.2-8
EXTERNAL PRESSURE LOADING (25 PSIG)

W = TOTAL WEIGHT OF CASK
(BASED ON 235,000 LBS.)
- TOTAL WEIGHT OF INTERNALS
(BASED ON 62500 LBS.)
= 172,500 LBS.

Pi = PRESSURE ON CONTAINMENT BOTTOM INNER SURFACE DUE TO WEIGHT OF INTERNALS

$$= \frac{62500}{\pi(34.375^2)}$$

= 16.84 psi

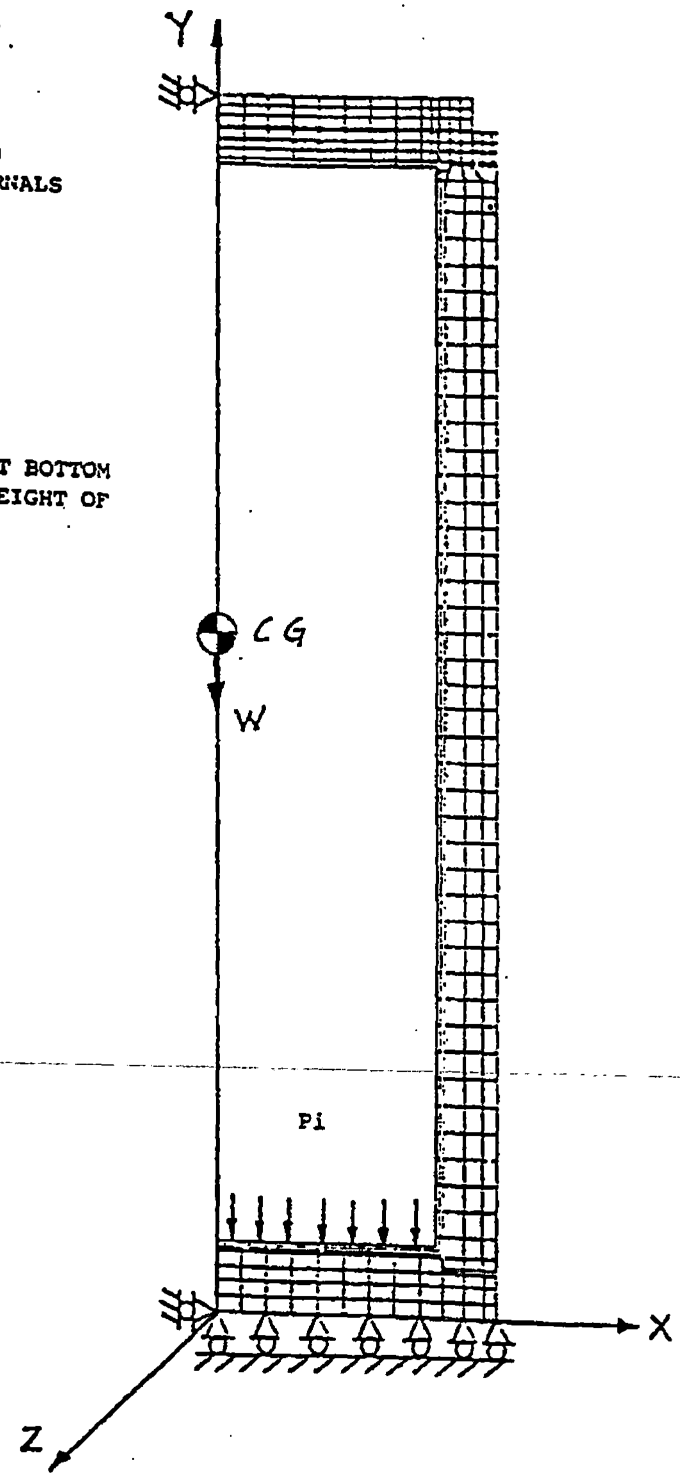
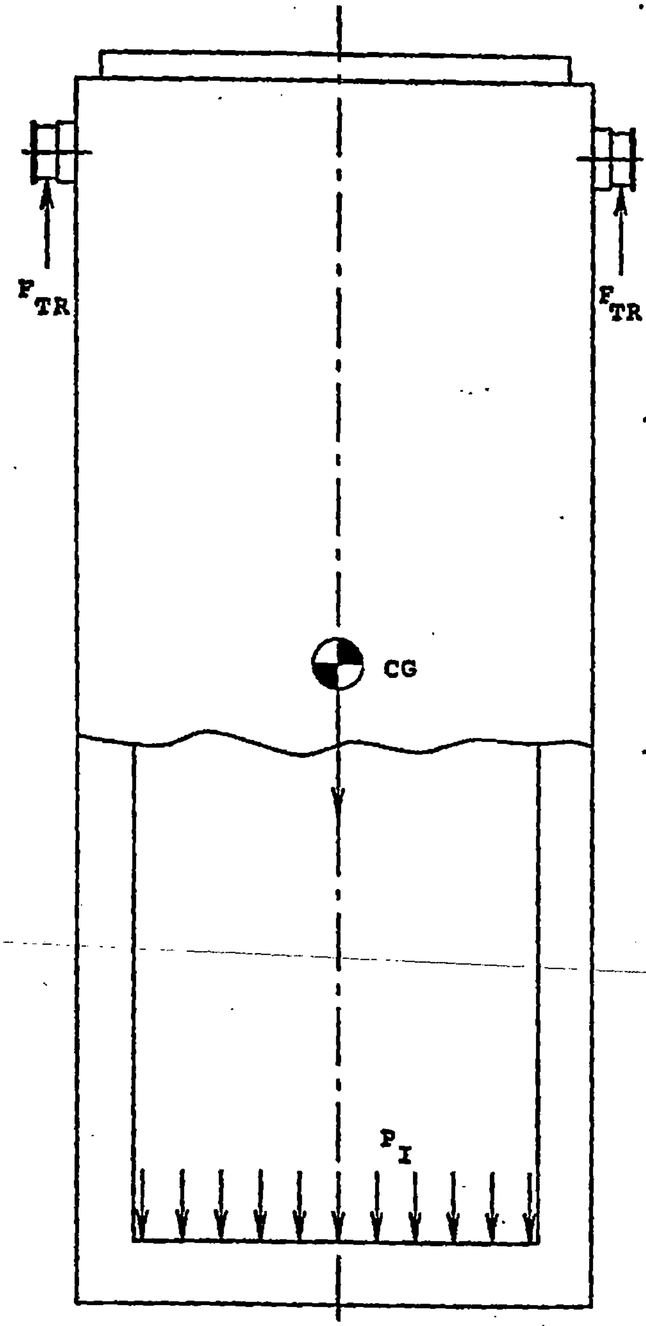


FIGURE 3A.2-9
1g DOWN LOADING



TN-32 & TN-32A CASKS

$$F_{TR} = \frac{3W}{2} = \frac{3 \times 235{,}000^{*}}{2} = 353{,}500 \text{ LBS.}$$

$$P_I = \frac{3 \times 62{,}500}{\pi(34.375)^2} = 50.51 \text{ psi}$$

TN-32B CASK

$$F_{TR} = \frac{6W}{2} = \frac{6 \times 235{,}000^{*}}{2} = 705{,}000 \text{ LBS.}$$

$$P_I = \frac{6 \times 62{,}500}{\pi(34.375)^2} = 101 \text{ psi}$$

* 235,000 LBS WAS USED TO CALCULATE THE GLOBAL STRESSES AT THE CASK

FOR TRUNNION AND TRUNNION LOCAL STRESS ANALYSIS, A CONSERVATIVE WEIGHT OF 243,000 LBS WAS USED.

FIGURE 3A.2-10
LIFTING: 3g & 6g
VERTICAL UP

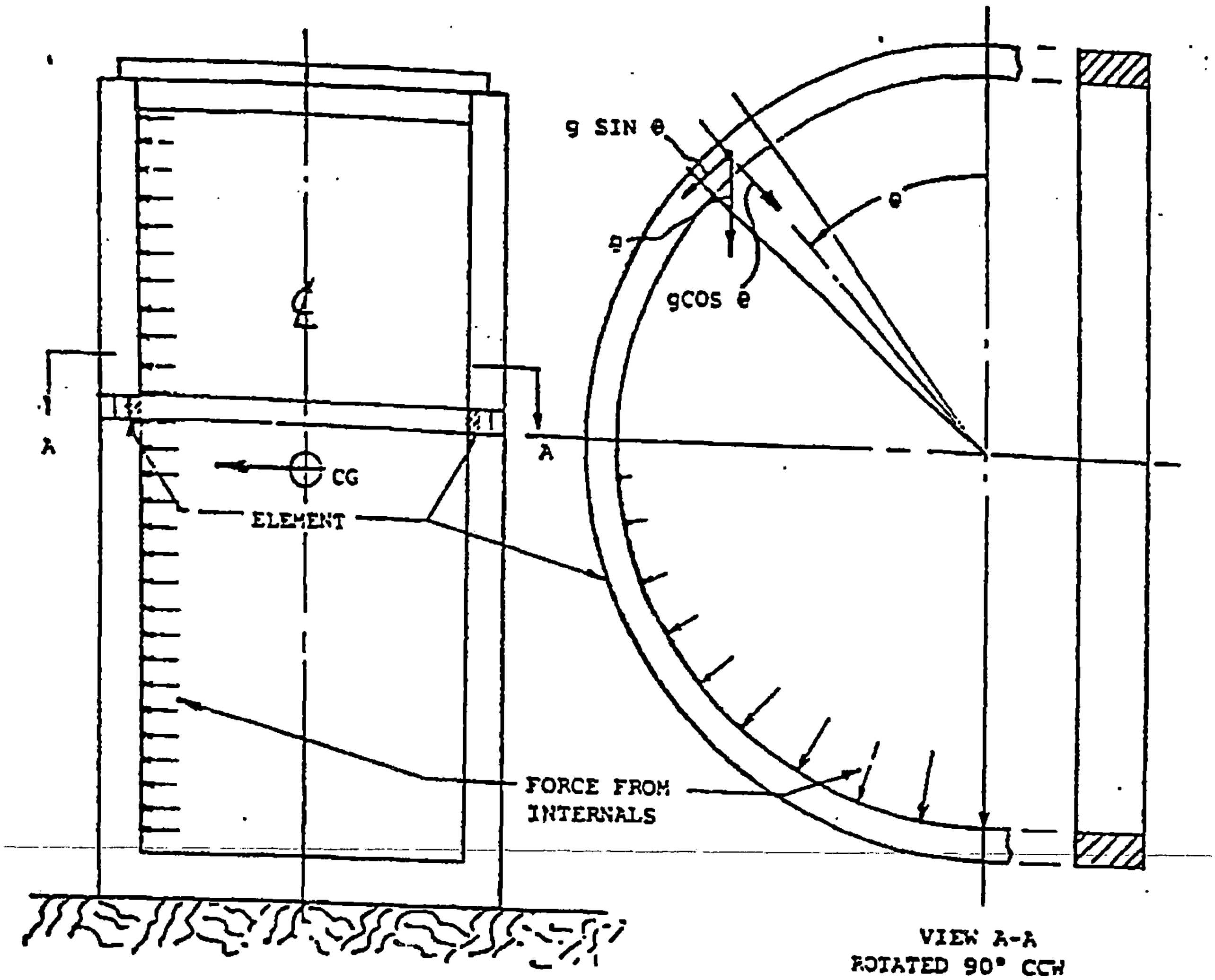


FIGURE 3A.2-11
1g LATERAL

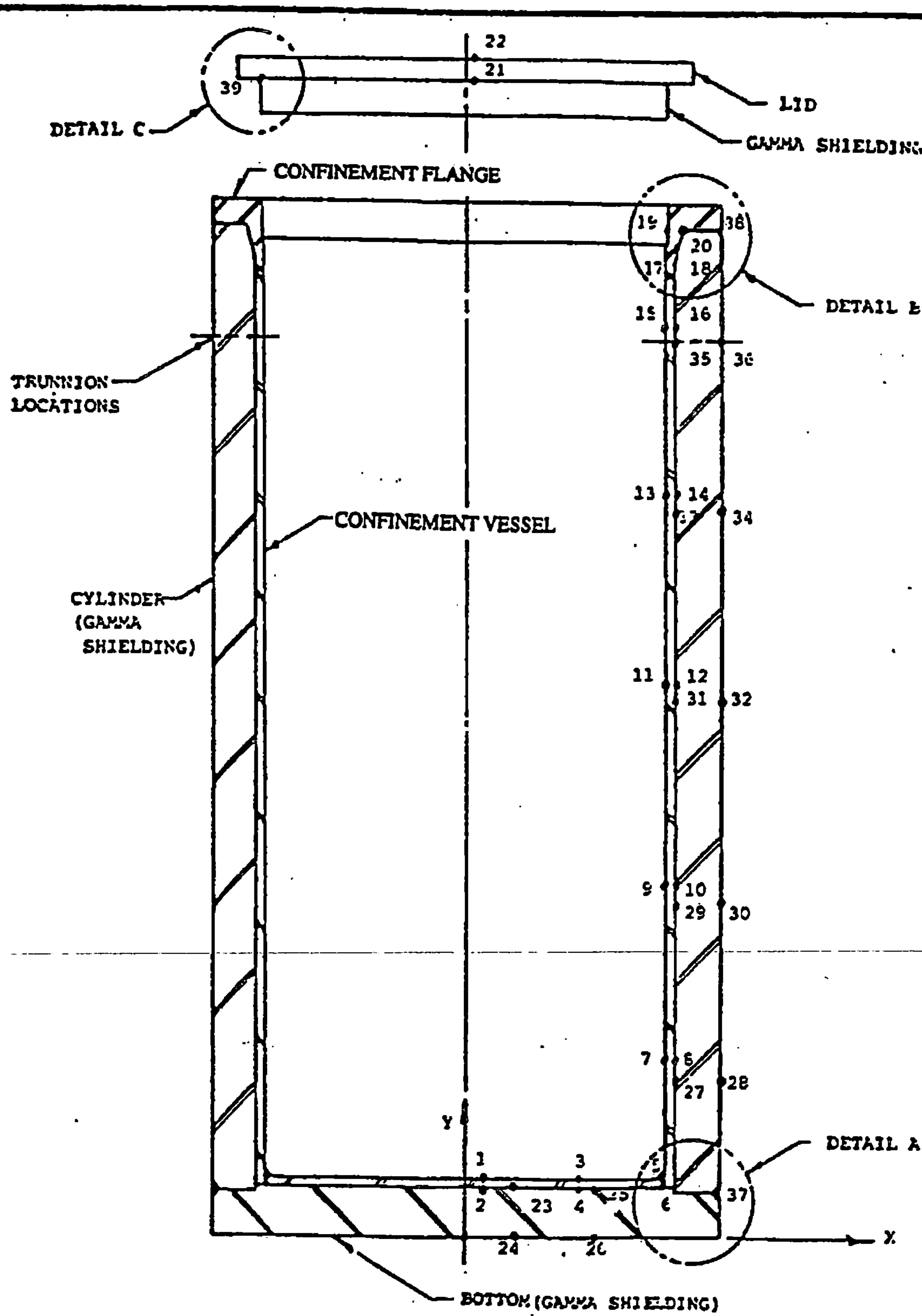


FIGURE 3A.2-12
STANDARD REPORTING LOCATIONS FOR CASK BODY

REV. 0 1/00

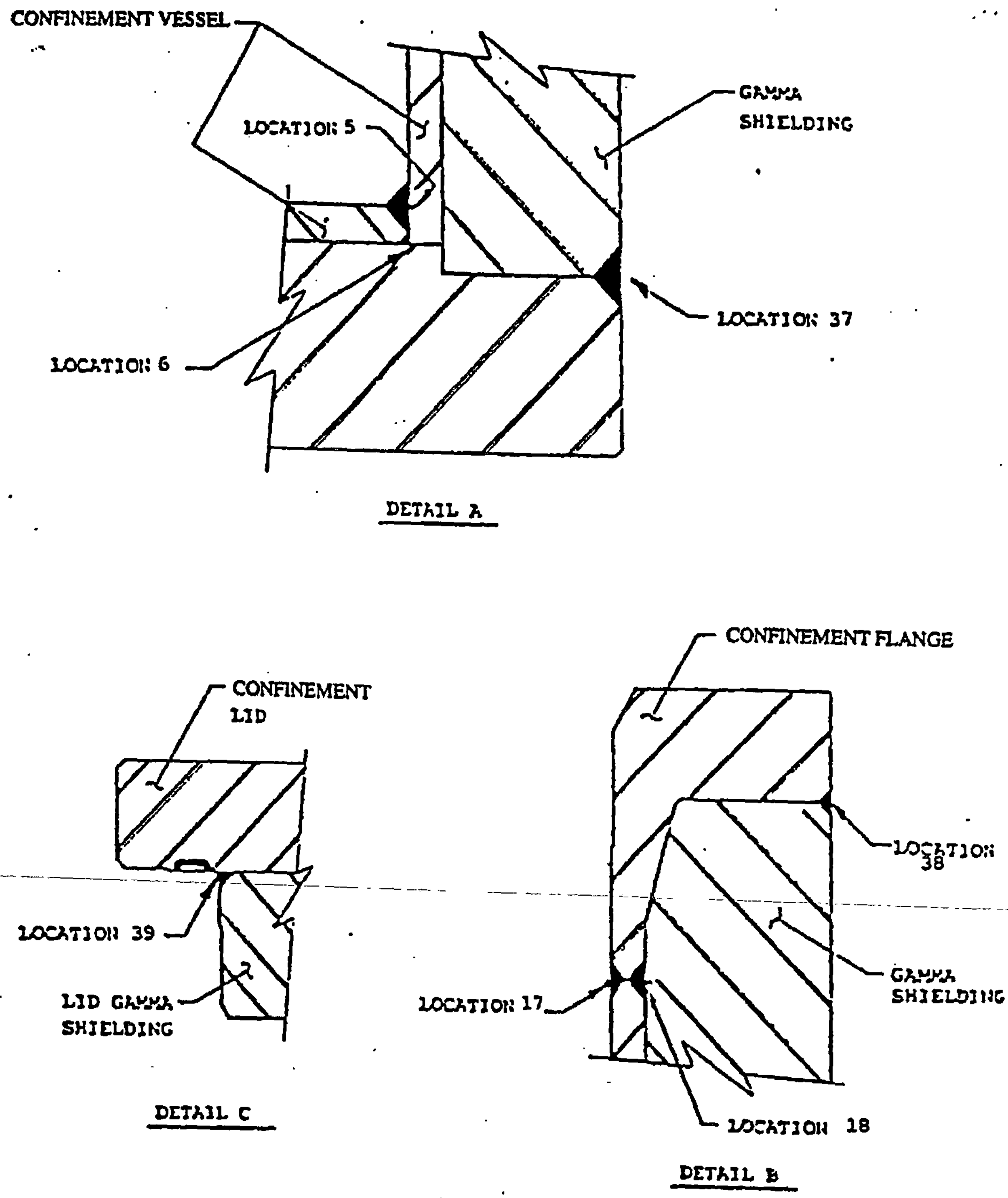
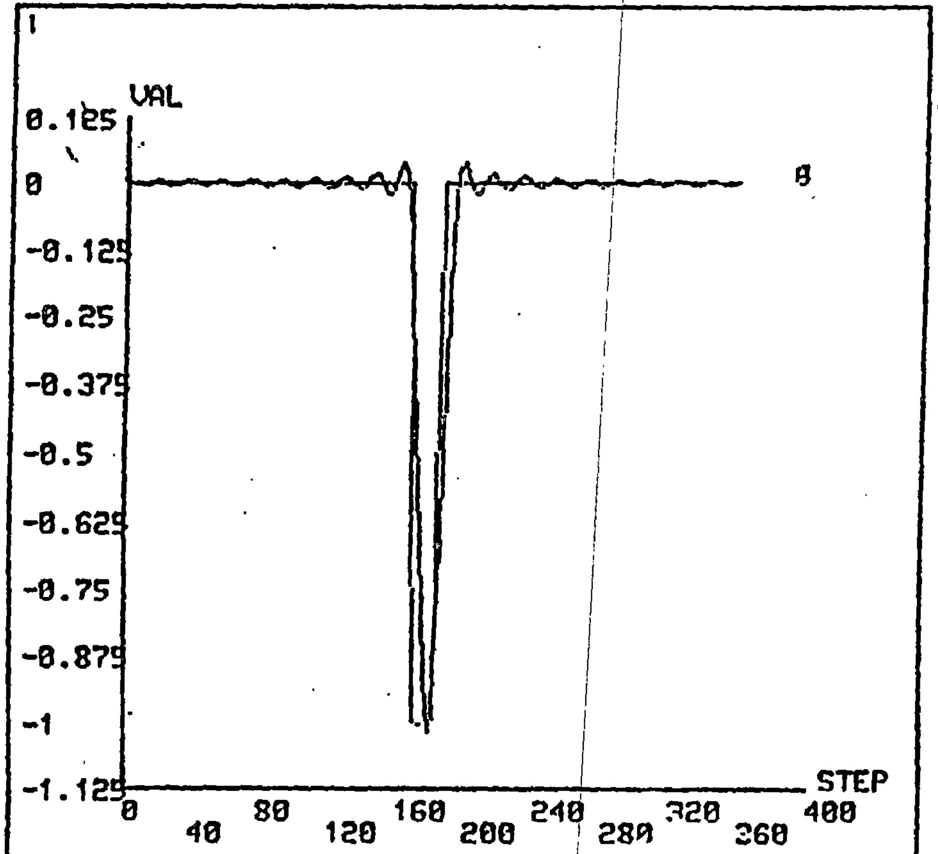


FIGURE 3A.2-13
WELD STRESS LOCATIONS

NUMBER OF FOURIER TERMS= 20

***** FOURIER COEFFICIENTS *****

TERM	MODE*ISYM	COEFFICIENT
1	0	-0.41552524E-01
2	1	0.82764244E-01
3	2	-0.81747981E-01
4	3	0.80074570E-01
5	4	-0.77774082E-01
6	5	0.74887691E-01
7	6	-0.71466769E-01
8	7	0.67571767E-01
9	8	-0.63270895E-01
10	9	0.58638646E-01
11	10	-0.53754182E-01
12	11	0.48699634E-01
13	12	-0.43558350E-01
14	13	0.38413124E-01
15	14	-0.33344468E-01
16	15	0.28428939E-01
17	16	-0.23737581E-01
18	17	0.19334510E-01
19	18	-0.15275668E-01
20	19	0.11607785E-01



FOURIER COEFF. GENERATION FOR COSθ (174<θ>186)

FOURIER COEFFICIENTS FOR THE FUNCTION COS
WITH SERIES TRUNCATED AFTER THE FIRST
20 ITEMS

186°
174°

FIGURE 3A.2-14

FOURIER SERIES APPROXIMATION OF THE FOOTPRINT PRESSURE FOR THE SIDE DROP

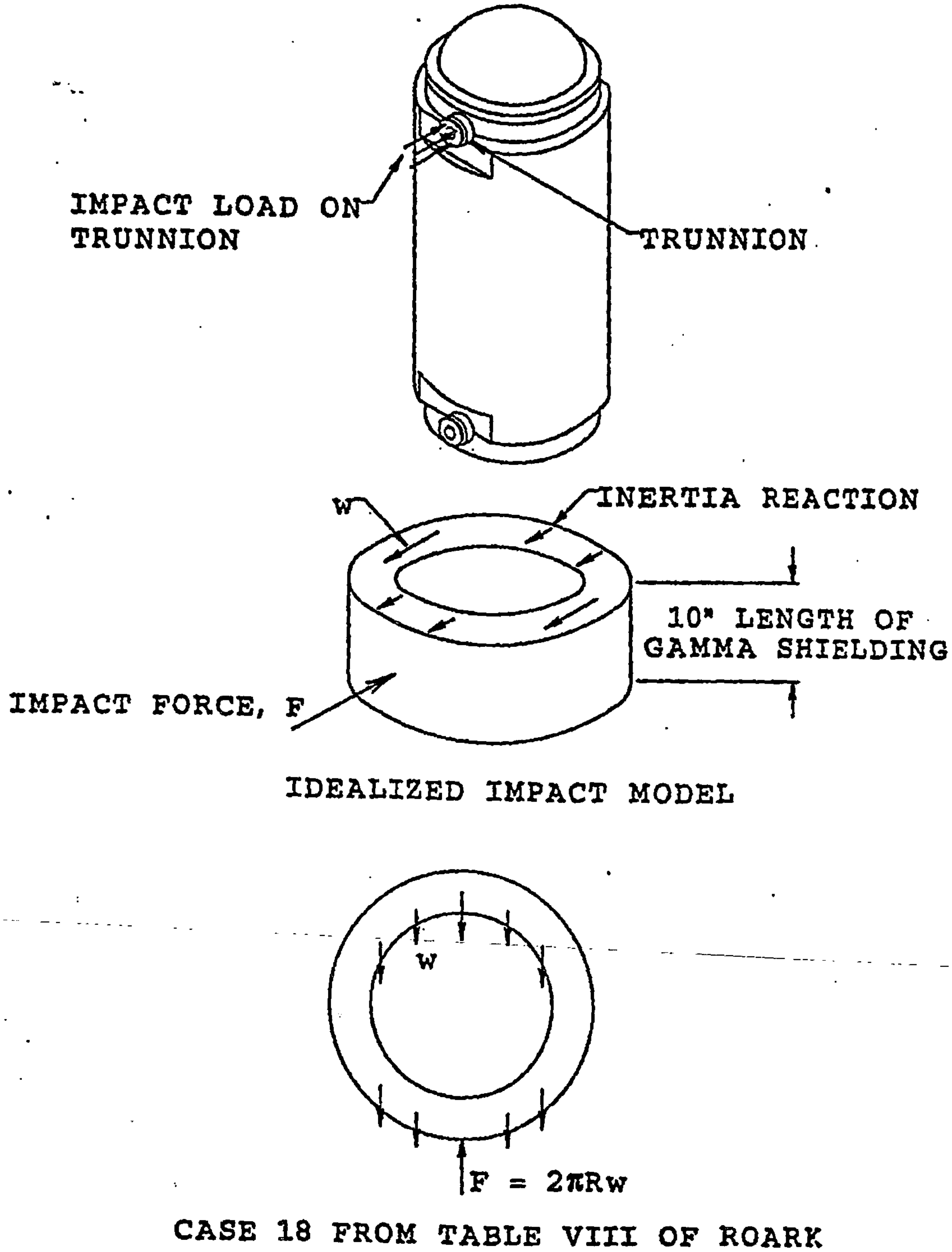
Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3A.2-15A
UPPER TRUNNION GEOMETRY
TN-32 & TN-32A CASKS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3A.2-15B
UPPER TRUNNION GEOMETRY
TN-32B CASK



(REFERENCE 8)

FIGURE 3A.2-16
IDEALIZED IMPACT ON TRUNNION ONTO GAMMA SHIELD CYLINDER

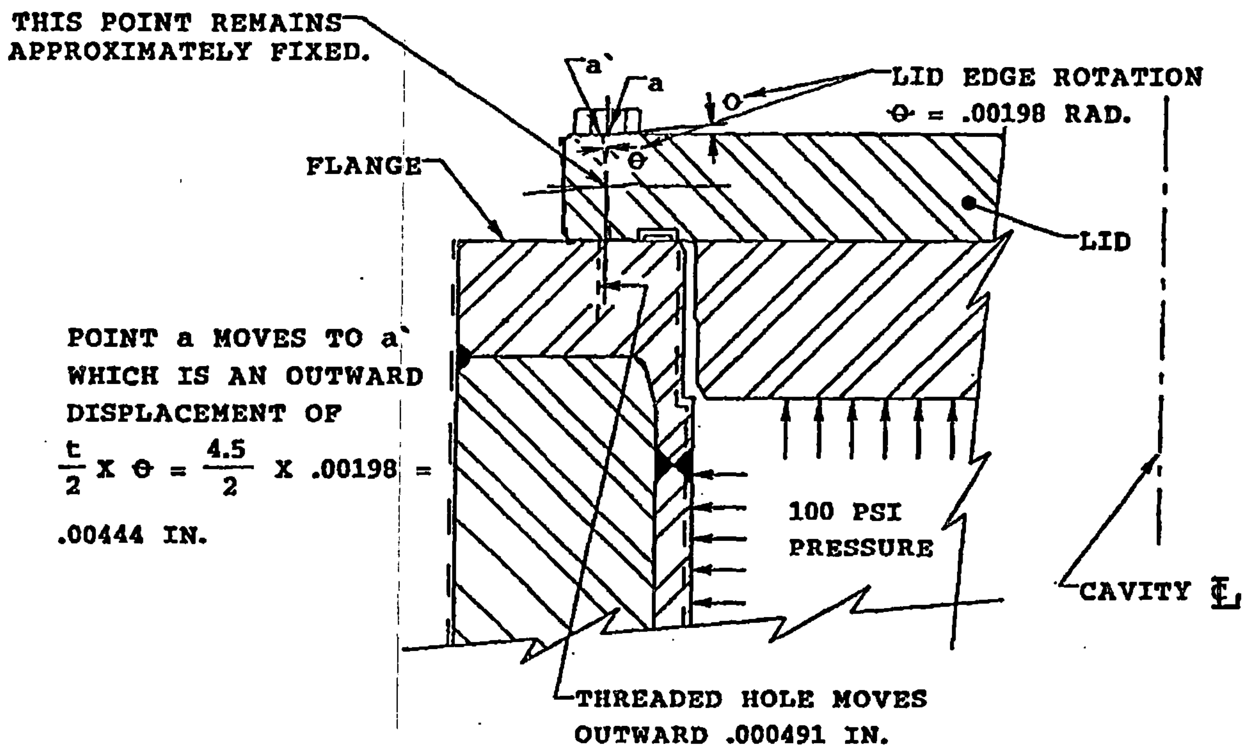


FIGURE 3A.3-1
SUMMARIZING THE BOLT END MOTIONS DUE TO 100 PSIG PRESSURE IN THE CASK CAVITY

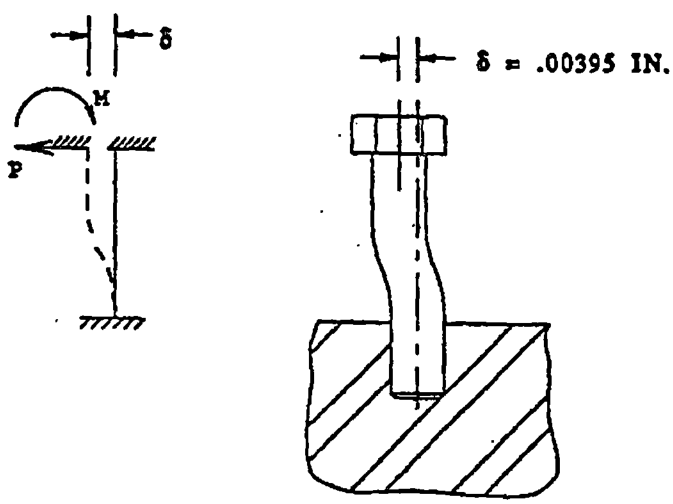


FIGURE 3A.3-2
LID BOLT BENDING DUE TO LID EDGE ROTATION UNDER INTERNAL PRESSURE

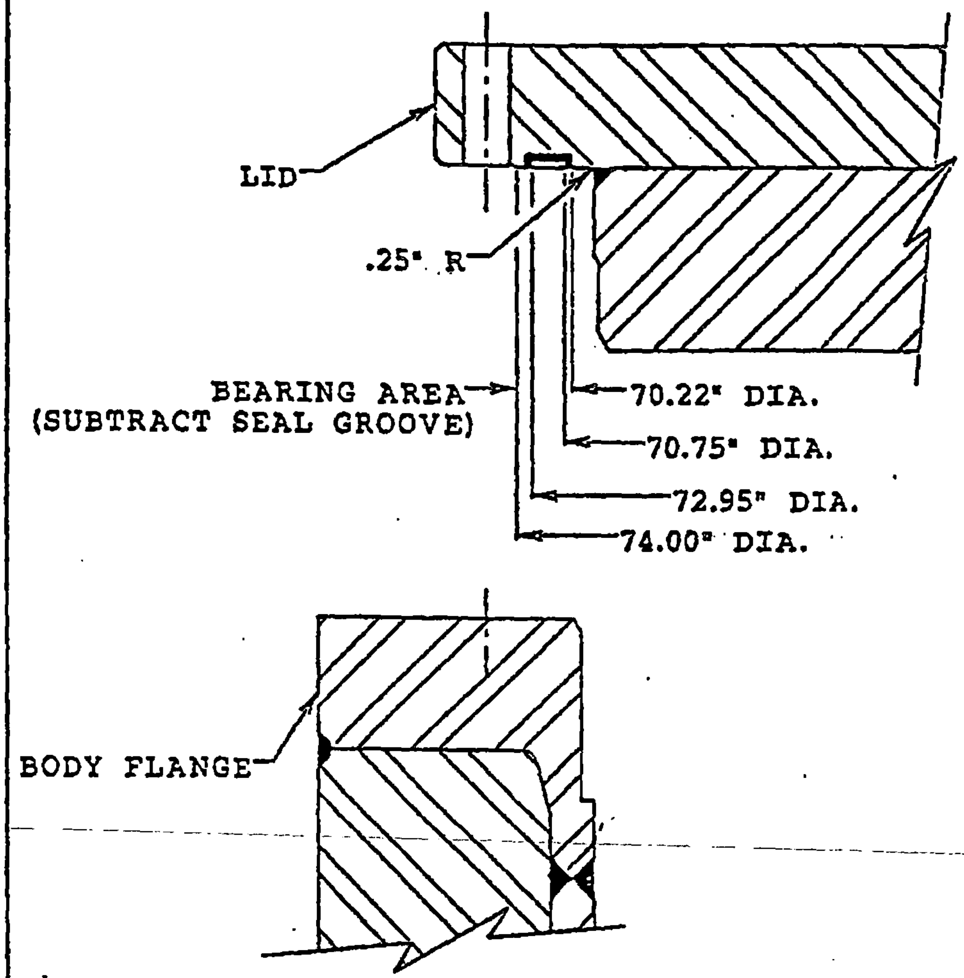
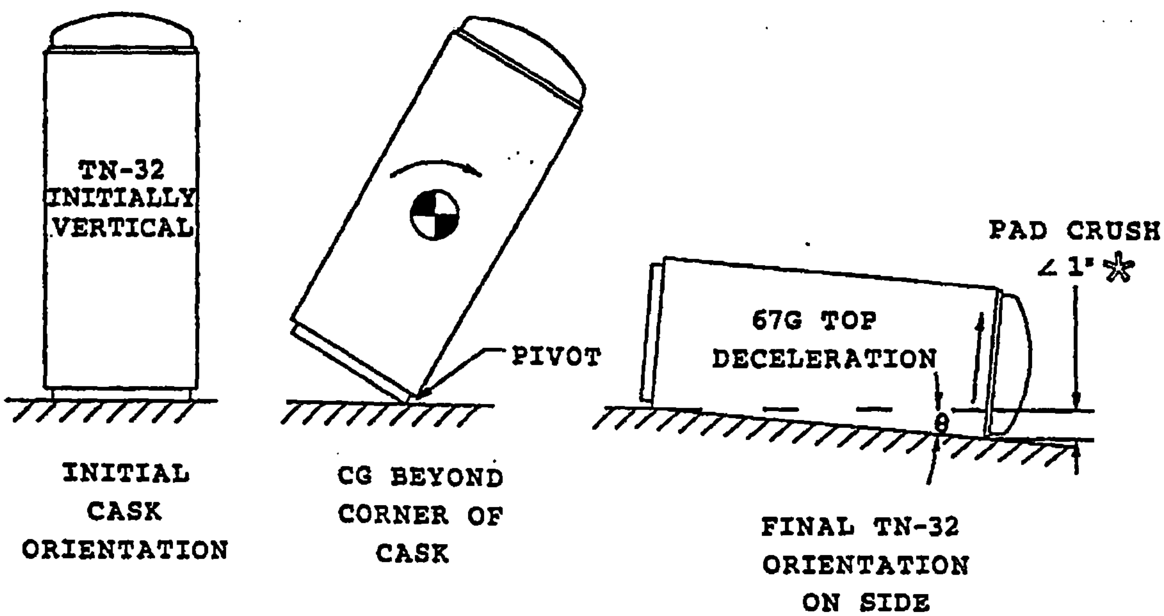


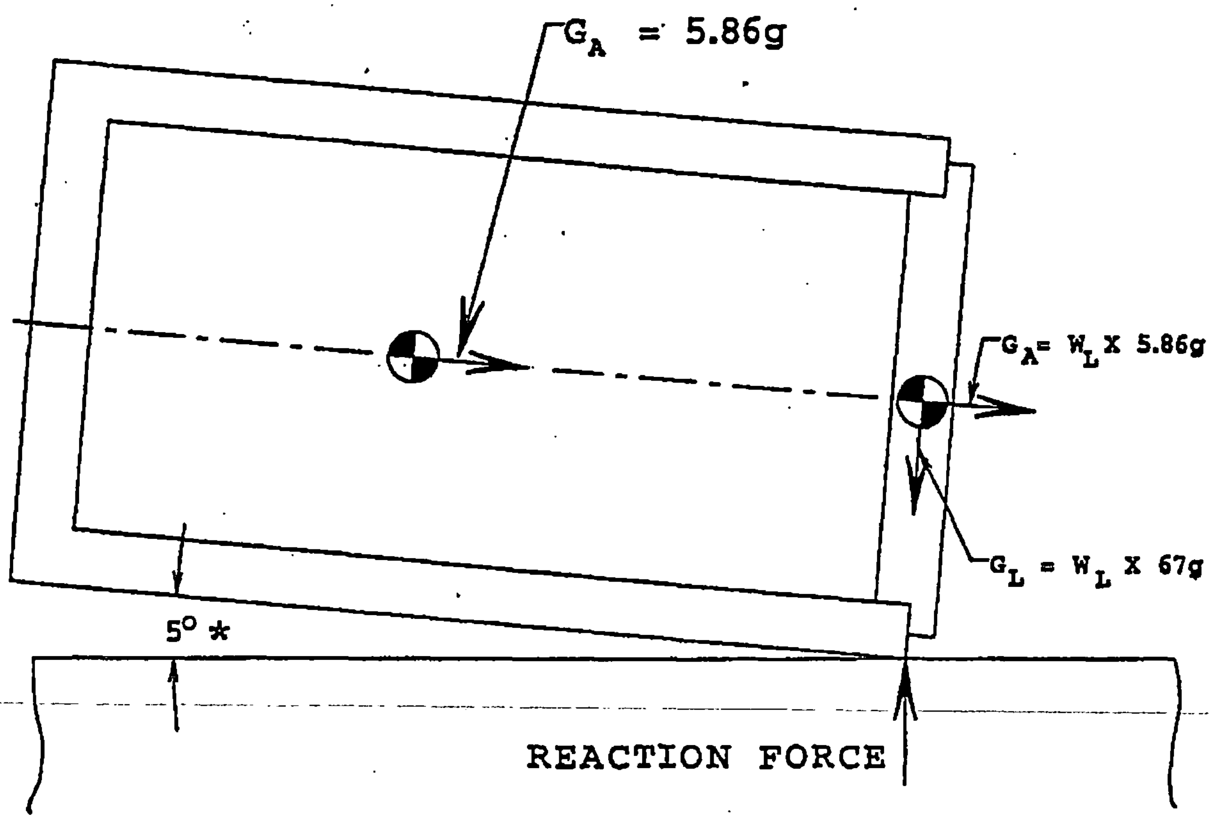
FIGURE 3A.3-3
BEARING AREA BETWEEN
LID AND CASK BODY FLANGE



$$\theta = \sin^{-1}\frac{1"}{184} < 1^{\circ}$$

☆ MAX. DISPLACEMENT FROM TIPOVER ANALYSIS (FIG. 3D.2-4) IS 0.73".

FIGURE 3A.3-4
TIPOVER ONTO CONCRETE STORAGE PAD



* 5° WAS CONSERVATIVELY USED INSTEAD OF CALCULATED 1°

FIGURE 3A.3-5
SYSTEM OF INERTIA LOADS APPLIED ON CASK

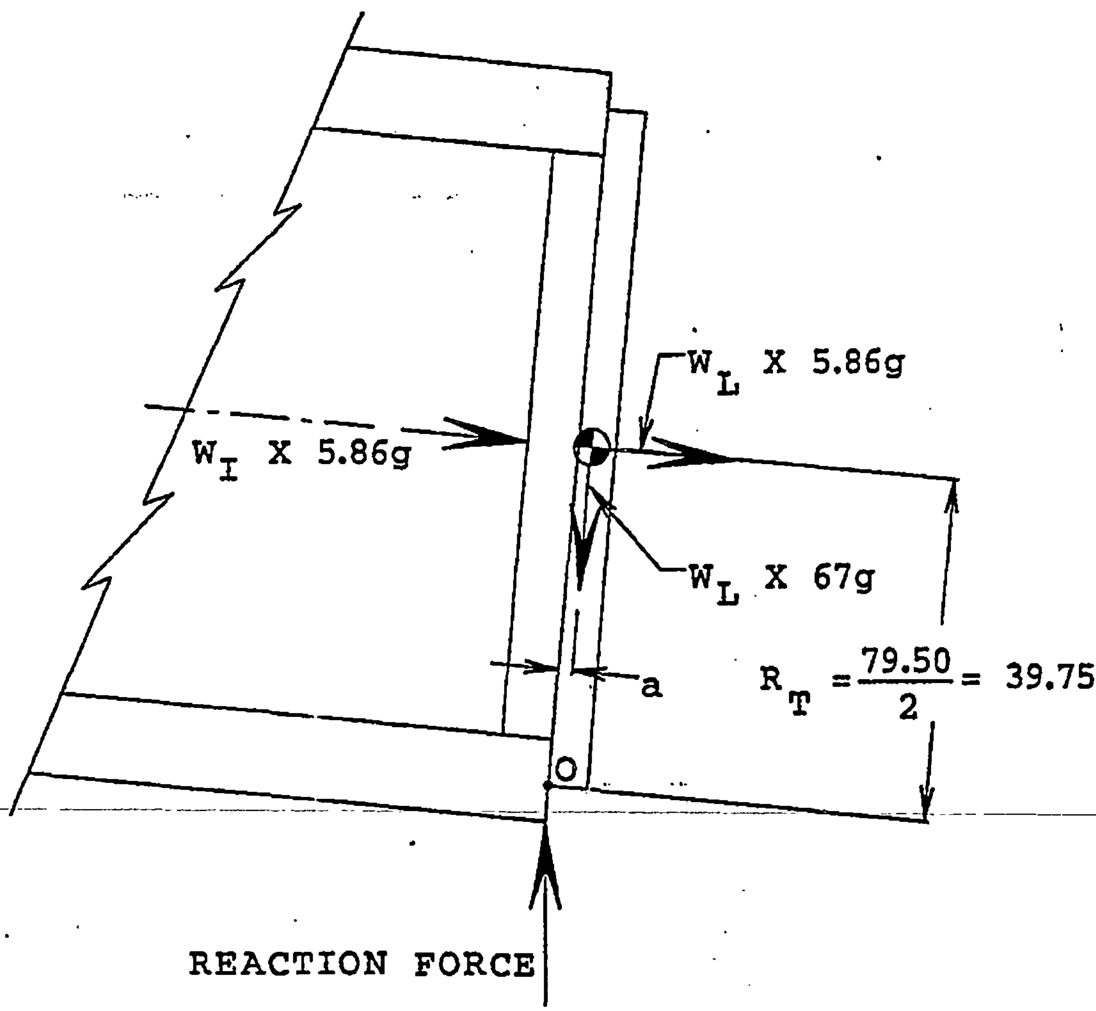


FIGURE 3A.3-6
INERTIA LOADS APPLIED ON LID

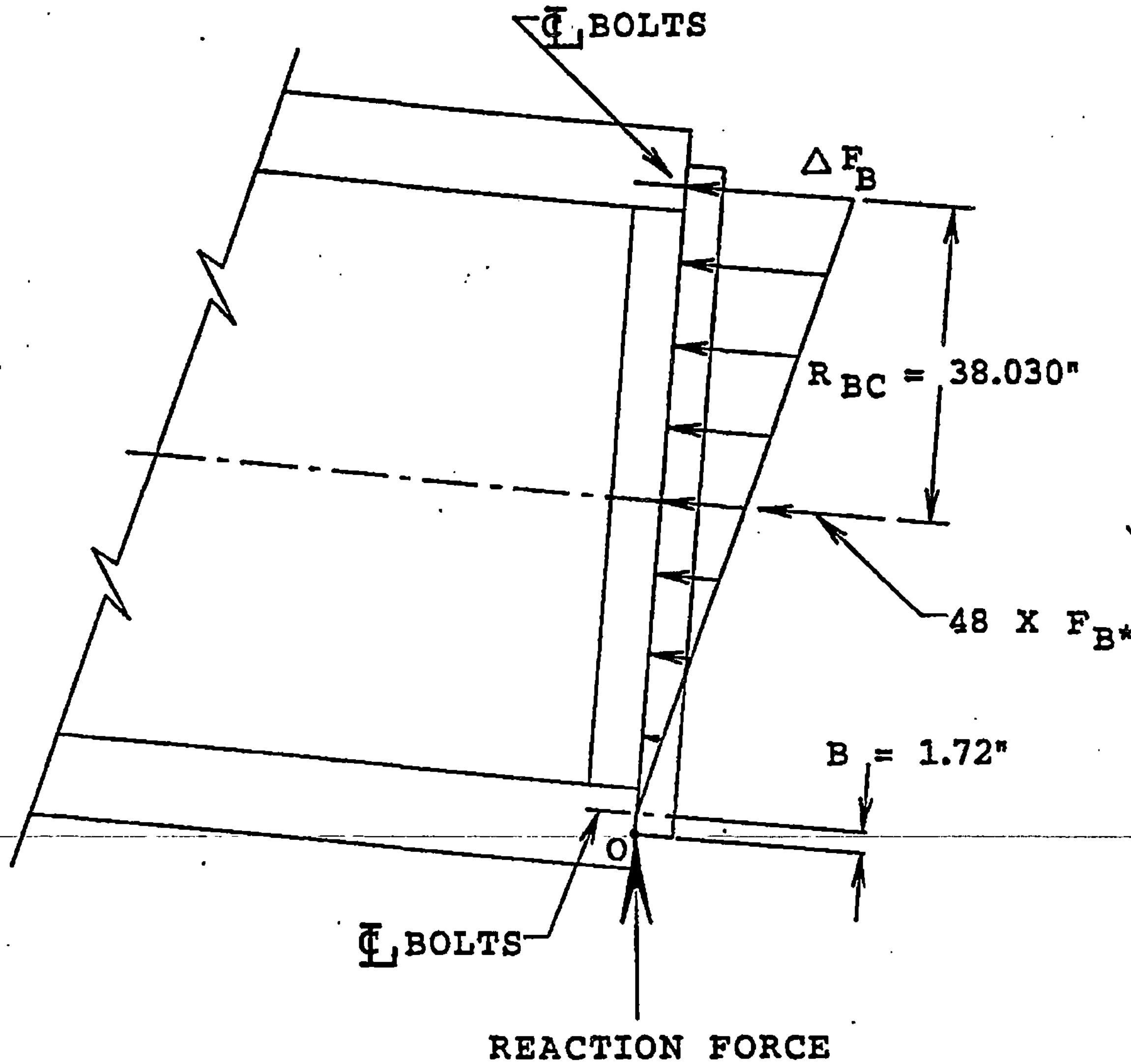


FIGURE 3A.3-7
LID BOLTS REACTING
INERTIA LOADS

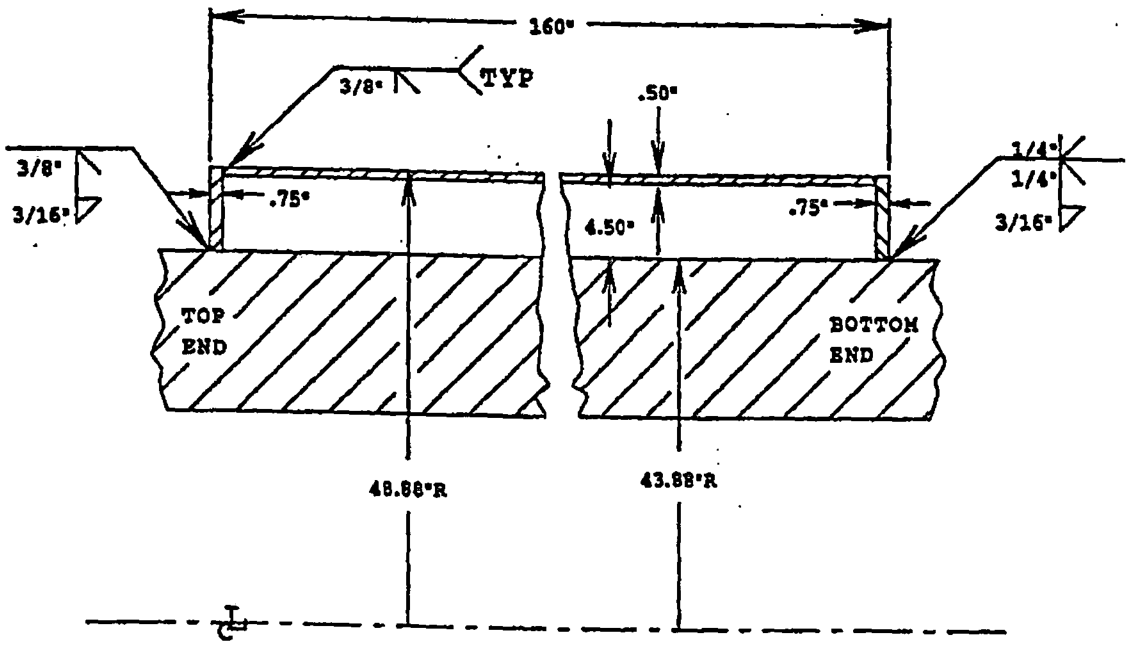


FIGURE 3A.4-1
CASK OUTER SHELL AND
CONNECTION WITH CASK BODY

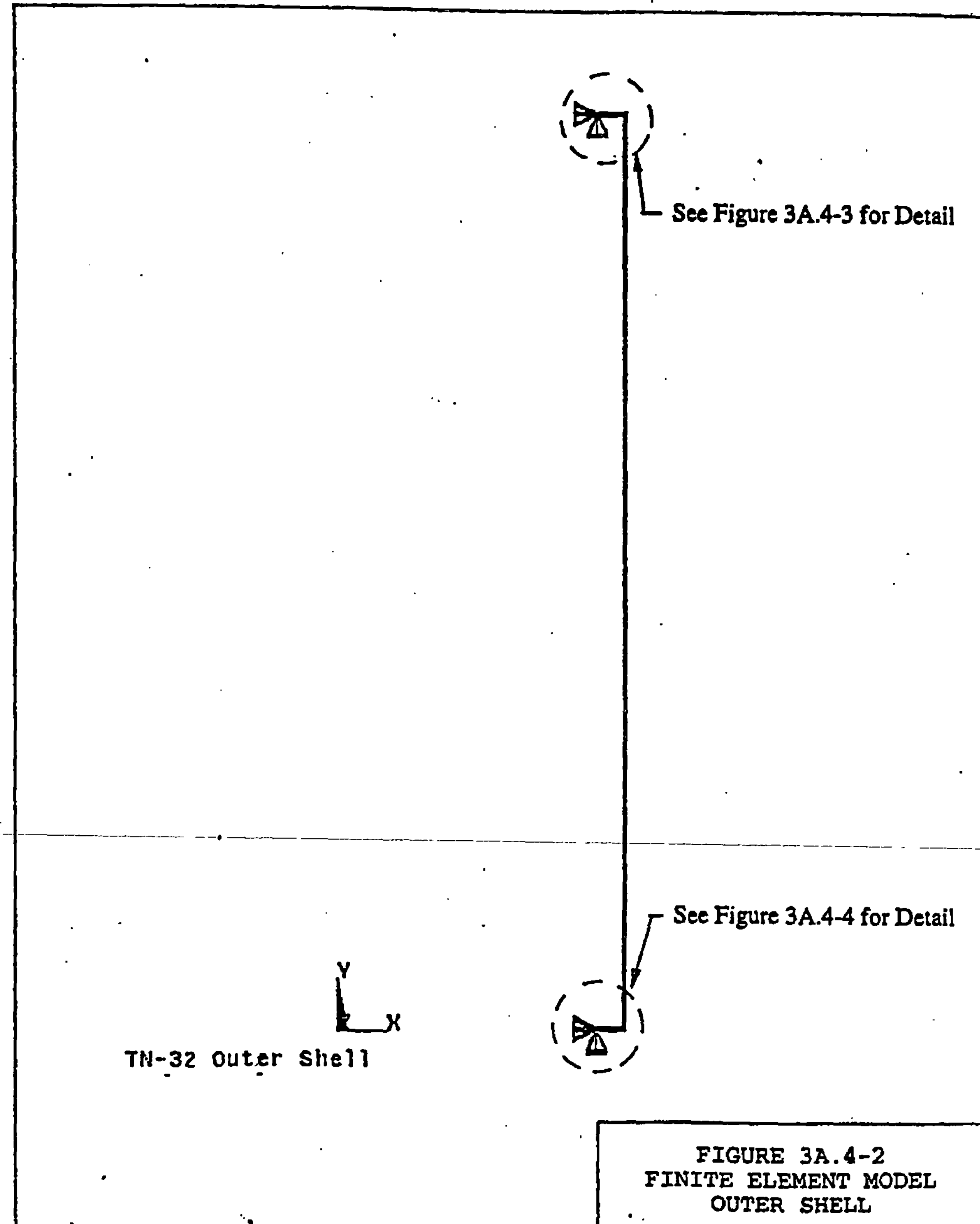


FIGURE 3A.4-2
FINITE ELEMENT MODEL
OUTER SHELL

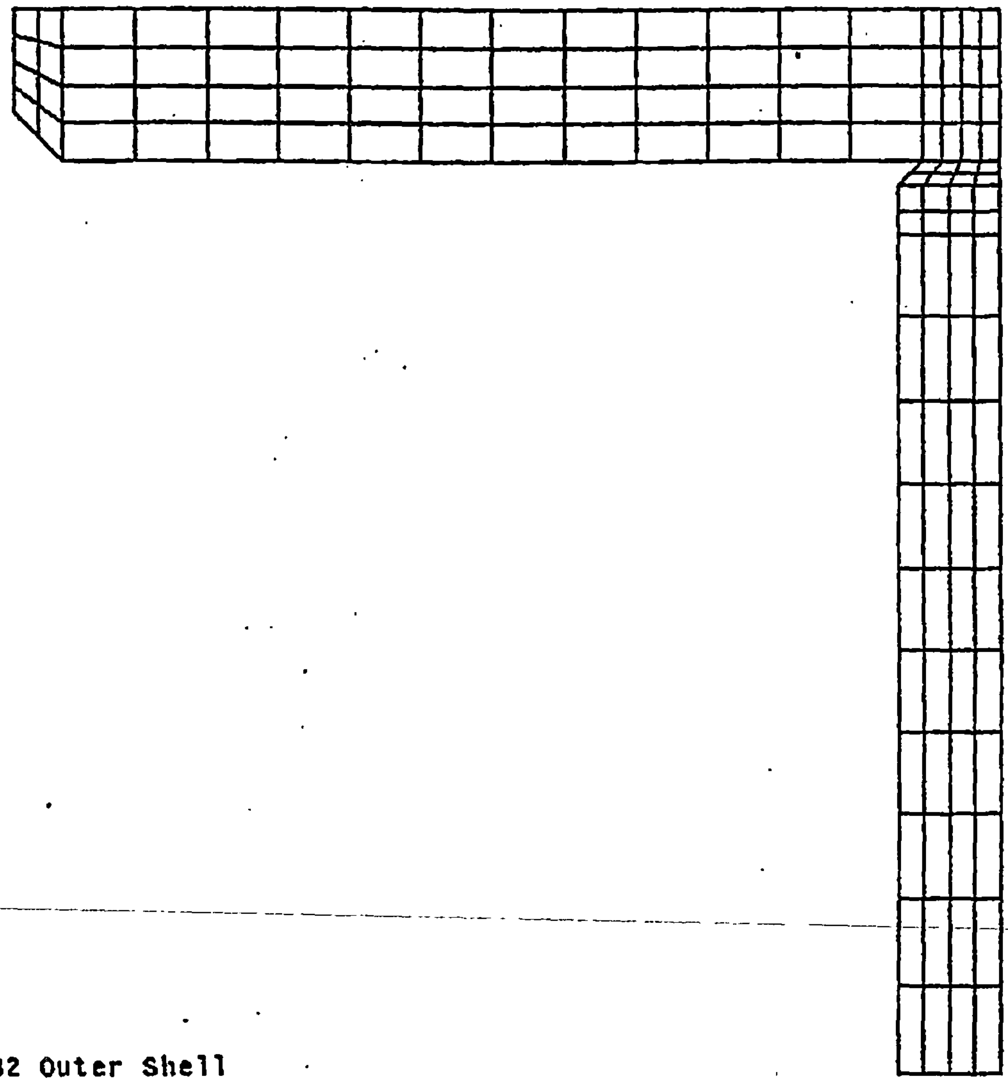


FIGURE 3A.4-3
FINITE ELEMENT MODEL
TOP CORNER

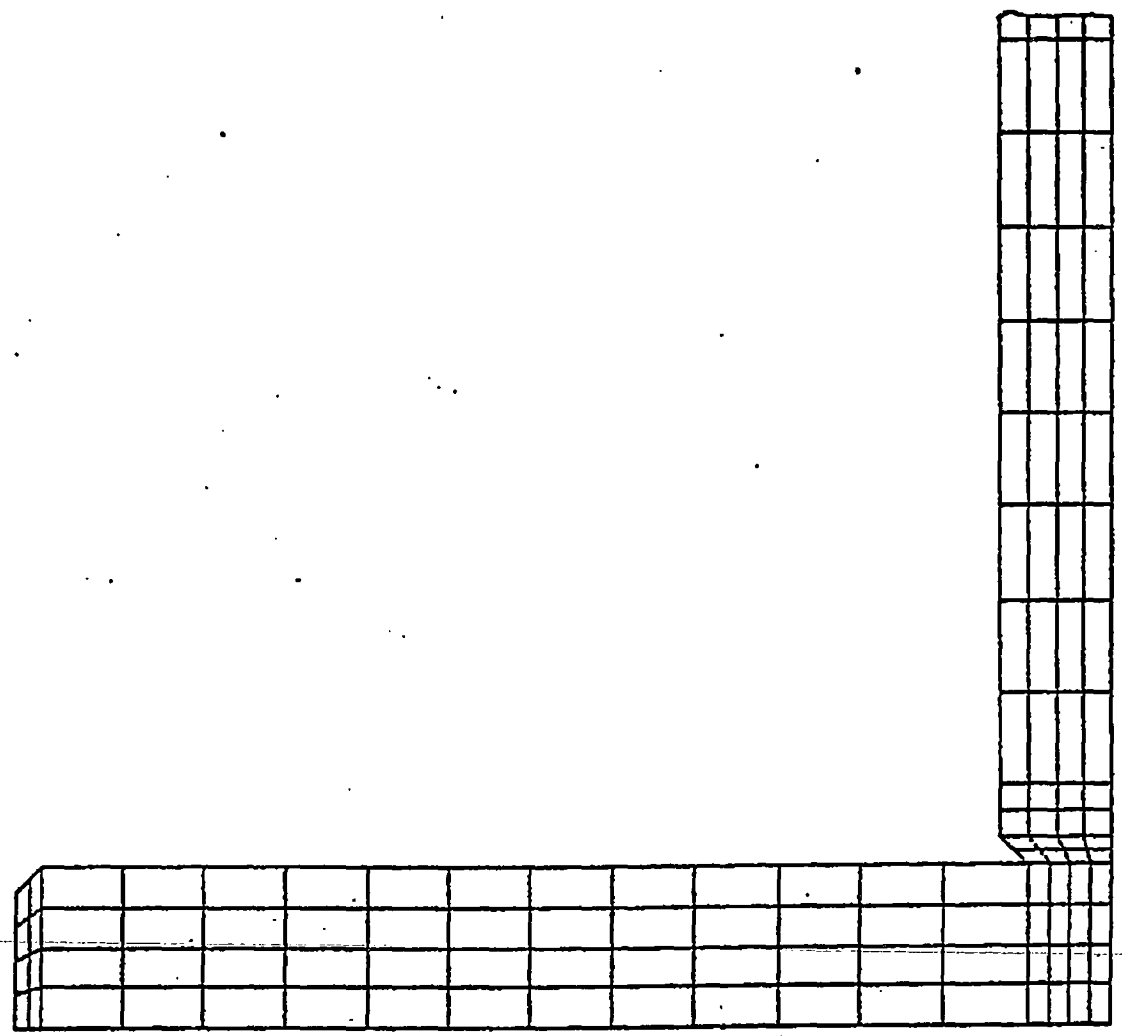
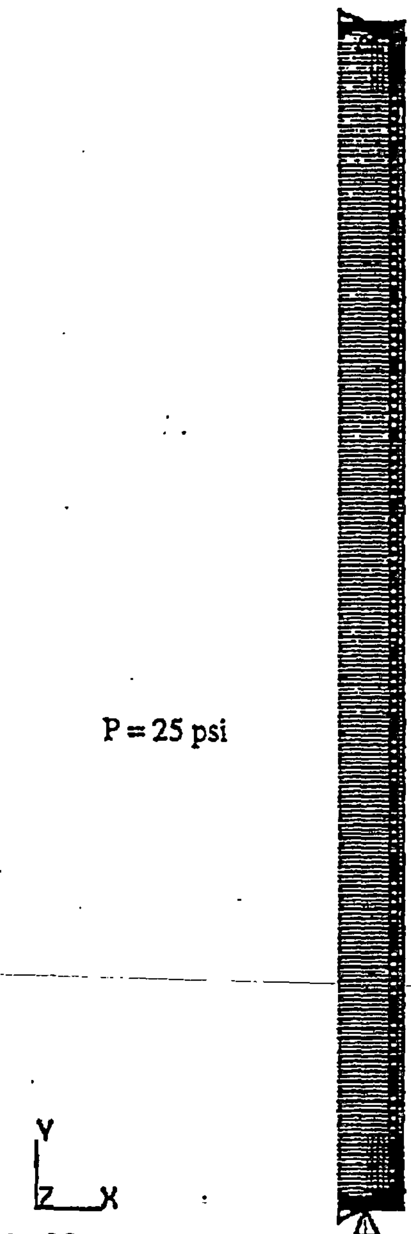


FIGURE 3A.4-4
FINITE ELEMENT MODEL
BOTTOM CORNER



TN-32 Outer Shell, 25 PSI INTERNAL PRESSURE

FIGURE 3A.4-5
INTERNAL PRESSURE
(25 PSIG)

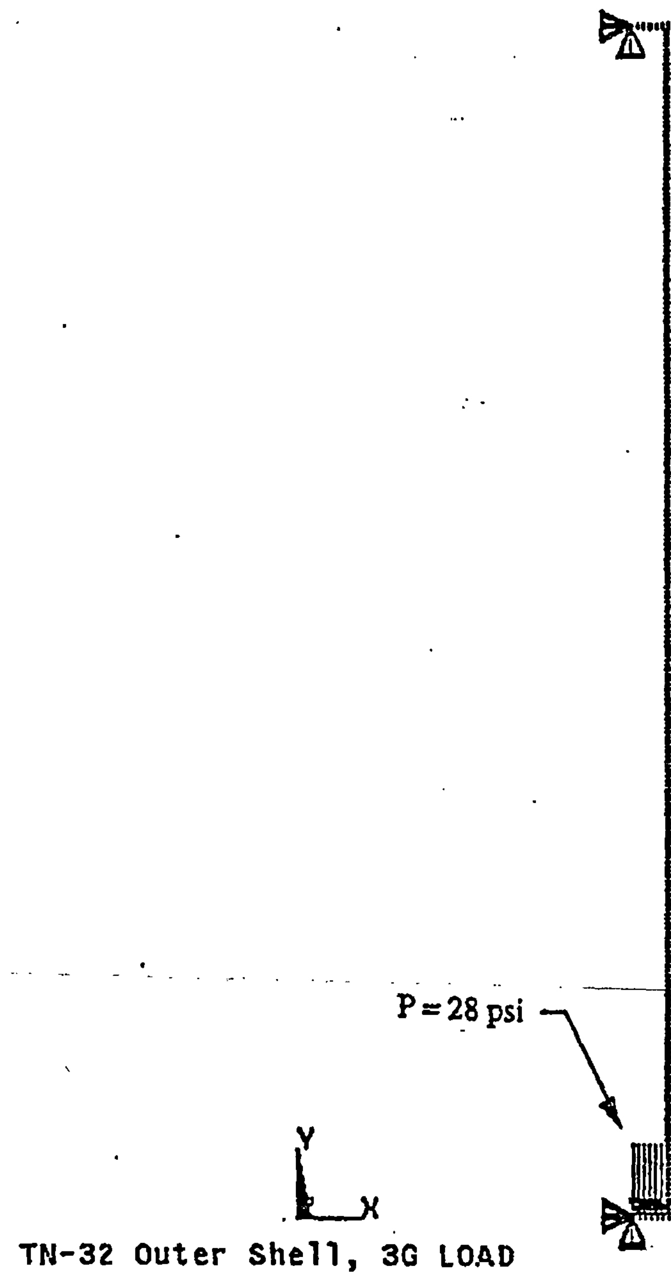


FIGURE 3A.4-6
3 G DOWN

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APPENDIX 3B

STRUCTURAL ANALYSIS OF THE TN-32 BASKET

3B.1 Introduction

This appendix presents the structural analysis of the TN-32 fuel support basket. The basket is a welded assembly of stainless steel boxes. The fuel compartment stainless steel box sections are attached together locally by cylindrical stainless steel plugs (that pass through the aluminum and poison plates) that are fusion welded to both adjacent box sections. The poison and aluminum plates are thus sandwiched between the stainless steel walls of adjacent box sections. The basket contains 32 compartments for proper spacing and support of the fuel assemblies.

G loads used for evaluation of the basket structure were based on the following methodologies:

- G loads calculated using the methodology of EPRI report NP-4830 as described in Section 3A.2.3.2. The maximum calculated G loads are 36 G's for an 18" end drop and 23 G's for a tipover side drop. The basket analysis presented in this appendix is performed using 50 G for both end drop and tipover side drop.
- G loads calculated using dynamic tipover analysis as described in Appendix 3D. Appendix 3C performed Additional basket analyses based on the G loads calculated from this dynamic tipover analysis.

The deformations and stresses induced in the basket structure due to the applied lateral loads are determined using the ANSYS computer program[1]. The most severe loading for which the basket is evaluated is the 50 g lateral inertial loading selected in Section 3A.2.3.2 to conservatively represent a hypothetical tipover accident. A 50 g vertical loading of the basket is also evaluated to represent a hypothetical end drop accident. Also a 3 g loading is applied to the basket in the vertical directions and 1 g loading is applied to the lateral direction as a bounding load to represent Level A (normal) Conditions. In addition, primary plus secondary (thermal) stresses due to differential thermal expansion are evaluated against Level A limits. The inertial loads of the fuel assemblies are applied to the basket structure as distributed loads applied to the plate surfaces. Quasistatic stress analyses are performed with applied loads in equilibrium with the reactions at the periphery of the basket. The calculated

stresses in the basket structure are compared with the stress limits to demonstrate that the established design criteria are met.

3B.1.1 Geometry

The details of the TN-32 basket are shown on TN Drawing Nos. 1049-70-5 and -6. As described above, the basket structure consists of an assembly of stainless steel boxes or cells joined by fusion welded steel plugs and separated by aluminum and poison plates. The stainless, aluminum and poison wall between fuel compartments is effectively a sandwich panel. The panel consists of two 0.105 in. (12 gage) thick 304 stainless plates and one 0.5 in. thick 6061 T6 aluminum plate (except at the center cross panels, which have two 0.5 in. aluminum plates) surrounding the poison plate. The aluminum provides the heat conduction path from the fuel assemblies to the cask cavity wall, and the poison material provides the necessary criticality control.

A representative basket wall panel between fuel compartments is shown in Figure 3B.1-1. The panel plates are fastened together at discrete locations (2 attachments every 8 inches) along their lengths. The adjacent fuel compartment stainless steel walls are fusion welded to cylindrical plugs that pass through holes in the poison and aluminum plates. This method of construction forms a very strong honeycomb-like structure of boxes. The open dimension of each fuel compartment cell or box is 8.7 in. x 8.7 in. which provides a minimum of 1/8 in. clearance around the fuel assemblies. The pitch of the cells is approximately 9.485 in. The overall basket length (160 in.) is less than the cask cavity length to allow for thermal expansion and tolerances.

Several of the aluminum conductor plates are continuous across the diameter of the basket to provide uninterrupted heat conduction paths. Other shorter plates are provided between and perpendicular to these continuous plates. Some of the aluminum plates are as short as one cell dimension in width.

Structural rails oriented parallel to the axis of the cask are attached to the inner cavity wall of the cask body to establish and maintain basket orientation, to prevent twisting of the basket assembly, and to support the edges of those plates adjacent to the rails which would otherwise be free to slide tangentially around the cask cavity wall under lateral inertial loadings.

3B.1.2 Weight

A conservative value of 1,533 lb. is assumed for the weight of each fuel assembly. Under lateral inertial loading each assembly is assumed to be uniformly supported across the width and along the length of the basket wall. The inertia of the

basket structure (weight of the basket x g load) is also included in the analysis.

3B.1.3 Temperature

Thermal analyses are performed to obtain the temperature distributions in the basket for various conditions. These analyses are presented in Chapter 4. Stress analysis of the basket using the thermal results are described in Section 3B.3.4.

3B.2 Basket Finite Element Model Development (For Side Impact Analysis)

The basket model is an extremely large and complex ANSYS model. Because of the number of plates in the basket and the size of the basket certain modeling approximations are necessary. The basket structure construction is repetitive symmetry (2 plug welds every 8 inches along their length). It is practical to model only a single transverse slice (4 inches length) using a three-dimensional finite element model. The elements used in the model to represent the plates are STIF 63 quadrilateral shell elements and the plug welds are modeled by STIF 16 pipe elements. For conservatism, the borated aluminum (poison material) is not assumed to carry the structural load and is not included in the model, but its weight (inertia load) is included in the stress calculation.

Several of the aluminum conduction paths consist of two 0.5" aluminum plates. These two 0.5" plates are replaced with a single plate having equivalent bending and tensile stiffness in the model. The fuel compartment corners and basket periphery are carefully modeled to define each plate connection. Interface elements are provided between the corner nodes of the stainless steel shell elements to simulate the through thickness support provided by the aluminum. The basket has one axis of symmetry; therefore only one half of the slice is modeled. Figures 3B.2-1 and 2 show the typical basket panel ANSYS finite element model simulation. The system model is shown on Figures 3B.2-3 and the computer plot is shown on Figure 3B.2-4.

3B.3 Basket Under Normal Condition Loads

3B.3.1 Description

The aluminum plates in the TN-32 basket are primarily heat conductors. The 304 stainless steel members are the primary structural components.

For long term sustained loading the 6061 aluminum strength is generally neglected (except for through thickness strength) under primary loading where the aluminum can share the load with the 304 stainless steel. This analysis approach produces conservatively high calculated values of primary stresses in the stainless steel components. Since the aluminum strength is already neglected in this approach, creep, relaxation, yielding, etc. in the aluminum cannot increase the stainless steel primary stresses above these bounding results. The actual aluminum strength is considered, however, when determining the secondary (thermal) stresses that it can apply to the 304 stainless steel members. Thus the aluminum strength is neglected when it might reduce the calculated primary stresses in the stainless components but it is considered completely effective when it can induce secondary stresses in the stainless steel.

The primary stress analysis of the basket under the bounding loads for Level A and sustained Level D (not impact accidents) conditions are described below.

3B.3.2 Basket Analysis Under 1 g Side Load

The basket analysis is performed with a 1 G lateral inertial load at the 90° orientation shown in Figure 3B.3-1. The elastic modulus of the aluminum is assumed to be small (10,000 psi) to simulate very weak material. Tables 3B.3-1, 3B.3-2 and 3B.3-3 list the stresses at the corners, central regions and plug regions, respectively. Their corresponding locations are shown on Figures 3B.3-2 through 3B.3-4. These stresses will be evaluated below to verify that the design criteria are met.

3B.3.3 Basket Analysis Under Vertical Load

Under vertical loads, the fuel assemblies and basket are forced against the bottom of the cask. It is important to note that, for any vertical or near vertical loading, the fuel assemblies react directly against the bottom of the cask cavity and not through the basket structure as in lateral loading. The fuel assemblies weigh 49,056 lbs. and the basket weighs 13,374 lbs. Therefore the basket weight is only about 21% of the total cask internals weight (of fuel and basket). Therefore the vertical basket inertial loading is only about 21% of the lateral loading for a given g level.

3 g Vertical Load Without Credit for Aluminum Strength

The analysis of the basket subjected to the 3 g bounding vertical load (bounds all Level A (Normal condition) and Level D sustained loads) for the panels with two aluminum plates is shown in Figure 3B.3-5. A full length of compartment wall (160 in. long) with a span length of 8.7 in. is evaluated for compressive loading. A maximum compressive force of 729 lbs. occurs at the bottom of the wall. Stresses are conservatively calculated by assuming all of the load is taken by the 304 stainless steel. Therefore

$$\sigma = \frac{\text{Total Compressive Load}}{\text{Cross Section Area of 304SS}}$$

$$= \frac{729\ \text{lb}}{1.827\ \text{in.}^2}$$

$$= 399\ \text{(psi)}$$

Based on the above results it is concluded that the stress in the stainless steel panel due to the 3 g vertical load is insignificant and additional analysis is not necessary.

There are cutouts in 4 locations at the bottom of the basket for lifting. In addition there are chamfers at the corners of the basket (in 8 locations) to prevent interference with the inner shell to bottom plate weld. The location of the cutouts and chamfers are shown in Figure 3B.3-7. For these locations, an analysis of the vertical g loadings has been evaluated for each box section. The weight of the load for each box consists of the weight of 8 panels of stainless steel (.105" thick), 4 aluminum panels (0.5" thick) and 2 sheets of borated aluminum (0.075" thick)

$$\sigma = \frac{\text{Total Compressive Load}}{\text{Cross Section Area of 304SS}}$$

$$= \frac{659\ \text{lb} \times 3}{5.39\ \text{in.}^2}$$

$$= 0.4\ \text{ksi}$$

This is much less than the allowable stress.

3B.3.4 Thermal Stress

The thermal analysis of the basket is described in Chapter 4. That analysis is performed to determine the basket temperatures for the condition with maximum solar heating, maximum decay heat from the cask contents, and 100°F ambient air. The temperatures from that thermal analysis are used directly in

the ANSYS structural models to calculate the basket panel stresses due to differential thermal expansion. Stresses occur due to the differences between the coefficients of thermal expansion of the 304 stainless, the aluminum and the poison material.

When a panel consisting of aluminum (and poison) and stainless plates is heated, the aluminum expands more than the stainless steel. For example, if a 6 in. long strip (the plug to plug centerline spacing across the panel) of 304 stainless is heated from 70°F to 400°F, it expands 0.01819 in. A 6 in. strip of aluminum expands 0.02676 in. or 0.00857 in. more than the stainless. A simple hand analysis (assuming tight plugs) would result in an aluminum bearing stress of 74,559 psi, far above the aluminum yield stress of 13,300 psi at 400°F. Therefore local plastic deformation of the aluminum plates in areas adjacent to the plugs will occur (if the plugs are not centered in the holes at assembly) and this effect must be properly considered to accurately determine the 304 stainless steel secondary stress state.

The detailed panel model used for the panel thermal stress analysis is shown in Figure 3B.3-6 (thermal analysis was based on maximum panel temperature of 531°F, the actual temperature at the hottest central part of the panel is 527°F as shown on Figure 4.4-8, therefore, the thermal stresses calculated here are conservative). It is conservatively assumed that the 1.375 in. diameter stainless steel plugs that penetrate the 1.5 in. diameter holes in the aluminum (and poison) plates are not centered. The plugs are assumed to be in contact initially (at 70°) with the opposing sides of the two holes in the aluminum (the sides toward the center of the panel) so that the maximum interference of aluminum and steel will occur when the panel is heated. It should be noted that this is a condition that cannot reverse. If the temperature decreases after initial heatup, the plug to aluminum contact will be lost but tension cannot be developed at the plug to aluminum interface.

The holes in the aluminum and poison plates are modeled (see square holes in Figure 3B.3-6). Also the bearing interfaces between the aluminum plates and plugs are approximately modeled using rigid members connected between the edges of the holes and nodes on the axis of the pipe elements representing the plugs. Plasticity is considered in the local regions (only) of the aluminum plates at the plug/aluminum bearing interfaces. In the local areas of the aluminum the ANSYS STIF 63 elastic shell elements are replaced with STIF 43 plastic shell elements. The 304 stainless steel structural members are still modeled elastically. The stress vs. strain curve used for the aluminum was based on the following table from the Aluminum Association data[2].

STRESS VS. STRAIN CURVE FOR 6061 T6 ALUMINUM

(BASED ON TEMPERATURE of 550°F)	
STRAIN (LB.-IN/IN)	STRESS (PSI)
0.00032	2500
0.00243	3370
0.6	5650

Table 3B.3-4 lists the thermal stresses from this detailed panel analysis. These stresses in the 304 stainless steel structural plates are elastic stresses. The stainless steel is modeled as an elastic material even though local plasticity is considered in the aluminum (which applies differential expansion loading to the stainless steel). These stresses are conservatively combined with the stresses from the 1 g side load by adding stress intensities at the stress reporting locations. The combined primary plus secondary (thermal) stresses are listed in Table 3B.3-5. The stresses are compared with the specified limits below.

3B.3.5 Design Criteria

The primary stress analysis of the basket for Level A (Normal Service) and sustained Level D Service Conditions does not take credit for the aluminum conductor plates except for through thickness compression. The aluminum strength is, however, considered when determining secondary stresses in the stainless steel.

The basis for the 304 stainless steel fuel compartment box section stress allowables is Section III of the ASME Code. The primary membrane stress intensity and primary membrane plus bending stress intensities 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 Level A (Normal Service) load combinations.

The ASME Code provides a basic 3 S_m limit on primary plus secondary stress intensity for Level A conditions. That limit is specified to prevent ratcheting of a structure under cyclic loading and to provide controlled linear strain cycling in the structure so that a valid fatigue analysis can be performed. The Code also provides guidance in the application of plastic analyses which can be performed to demonstrate shakedown (absence of ratcheting) and to determine stresses for fatigue evaluation. Ratcheting and fatigue cannot occur in the basket since thermal

cycling will not occur and interference loading at the plug/aluminum interfaces cannot reverse.

3B.3.6 Evaluation

Tables 3B.3-1, 3B.3-2 and 3B.3-3 list the stress intensities for the 1 G side load in the basket at the corners, central regions and plug regions, respectively. Note that these stresses have been calculated elastically (assuming structurally ineffective aluminum). The highest membrane stress intensity is 394 psi (Table 3B.3-1, 2D). The highest membrane plus bending stress intensity is 12,080 psi (Table 3B.3-1, 1D). These stresses are well below the allowable membrane stress intensity(S_m) of 18,700 psi and the allowable membrane plus bending stress intensity (1.5 S_m) of 28,050 psi based on the temperature of 400°F at these panel locations. The maximum shear stress at the stainless steel plug is 547 psi, this stress is less than the allowable shear stress (0.6 S_m) of 11,220 psi based on a temperature of 400°F at the plug location.

Table 3B.3-4 lists the stress intensities due to differential thermal expansion in the basket panel. These stress intensities are conservatively combined with the stress intensities from the 1 G side load in Table 3B.3-5. The basic primary plus secondary stress limit at any location on the 304 Stainless steel panel is 3 S_m or 51,690 psi at the maximum temperature of 531°F. The maximum primary plus secondary stress intensities of 32,517 psi occurs at stress location 1 of Table 3B.3-5 and is well below the allowable stress. The maximum weld stress intensity is 2 x 17095 = 34190 psi which is also below the limit.

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

1. The maximum stresses in the 304 stainless steel (fuel compartment box) both in the center and corner regions of the basket, are well below the specified allowable stresses under normal service (1 g side load) and sustained Level D service (1 g side load plus thermal stress).

2. The maximum shear stress in the plug welds is low under the 1 g side loading above. The stainless and aluminum plates may push against the plugs due to differential thermal expansion if the plugs are not centered in the holes in the aluminum at assembly. In the worst plug misalignment case, the weld shear stress could reach a maximum of 17,095 psi. The corresponding stress intensity is 2 x σ or 34,190 psi. This stress intensity is below the basic 3 S_m limit of 51,690 psi. This basic limit ensures that thermal ratcheting of a structure does not occur. This primary plus secondary limit could be exceeded in the TN-32 basket since

the stress does not cycle and since the loading cannot reverse.

3. The aluminum plates are generally not considered to have a structural function under Level A conditions. Nevertheless, the primary plus secondary (thermal) stress in the aluminum plates midway between the stainless plugs (stress reporting location 3) is no greater than 2,238 psi. This upper bound stress was calculated assuming the stainless plugs were misaligned in the aluminum holes in the worst possible way. The 2,238 psi stress is also far below the 5,470 psi allowable compressive stress (based on stability or buckling) in the aluminum from Table 3B.4-4. Therefore compressive stress developed in the aluminum cannot cause the plates to buckle.

4. The basket is structurally adequate and it will properly support and position the fuel assemblies.

3B.4 Basket Under Accident Condition Loads

3B.4.1 Basket Analysis Under 50 g Bottom End Drop

Appendix 3A presents the dynamic impact analysis of the TN-32 cask during a hypothetical end drop accident. In that section of the SAR, the cask is conservatively evaluated for a 50 g vertical load. This section evaluates the basket stresses for a 50 g vertical load which is a conservative representation of the end drop. Appendix 3B.3.3 presents the analysis of the basket due to a 3 g vertical load neglecting the strength contribution from the aluminum. It is conservatively assumed that all the load is taken by the 304 stainless steel. Therefore:

σ = Total Compressive Load/Cross Section of 304 SS

on a single wall panel

σ = 50 (Weight of 304SS, Aluminum, Poison)/Area of SS

= 50 x (243 lb)/1.827 in^2

= 6,650 psi

This 6,650 psi compressive stress is acceptable since the Section 3B.4.3 Level D membrane stress intensity limit for 304 stainless is 44,900 psi (2.4 S_m at 400°F, the approximate maximum temperature at the end of the basket).

There are cutouts in 4 locations at the bottom of the basket for lifting. In addition there are chamfers at the corners of the basket (in 8 locations) to prevent interference with the inner shell to bottom plate weld. The location of the cutouts and chamfers are shown in Figure 3B.3-7. For these locations, an analysis of the vertical g loadings has been evaluated for each box section. The weight of the load for each box consists of the weight of 8 panels of stainless steel (.105" thick), 4 aluminum panels (0.5" thick) and 2 sheets of borated aluminum (0.075" thick)

$$\sigma = \frac{\text{Total Compressive Load}}{\text{Cross Section Area of 304SS}}$$

= 659 lb x 50

5.39 in.^{2}

= 6 ksi

This is much less than the allowable stress.

3B.4.2 Basket Analysis Under 50 g Side Impact

This section describes the analysis of the TN-32 basket in the unlikely event of cask tipover on the concrete pad. The analyses performed assume a 50 g lateral inertial loading of the basket as shown to be conservative in Appendix 3A where the cask impact analysis is described. The design criteria established for the TN-32 basket for the hypothetical accident condition are described in Section 3B.4.3. These criteria were selected to ensure that the basket is structurally adequate under these loads. The results from the analyses presented in this section are evaluated against the design criteria in Section 3B.4.3.

The finite element basket models for this accident analysis are described in Section 3B.2. The aluminum plates are assumed to be effective for the short duration dynamic loading from the tipover accident. The 50 g loading selected for the basket analysis is conservatively selected to be higher than the deceleration of the top end of the cask during tipping. Analyses were performed for three different loading orientations relative to the basket plates: 90°, 45°, and 0°. It should be noted that, for the 45° and 0° load orientations, the total inertial force from the half of the basket not modeled is applied to the Y-Z plane (basket centerline) on the left side of the model.

The boundary condition at each point of contact between the basket and cask body cavity depends on the direction of the applied inertial load. As the basket is forced in a particular lateral direction it separates from the cask wall on one side and reacts against the wall on the other side. At the locations where the basket loses contact with the wall, no restraint or support is provided in the model. For vertical inertial loading on a horizontal cask and basket, contact is lost between the basket and cask wall at the top half of the structure. The load distributions and boundary conditions are shown on Figures 3B.4-1 through 3B.4-3. A large deflection analysis of the basket model is performed since the basket structure is redundant and the support is indeterminate without considering deflections. Also the basket panels subjected to both bending and compression require a large deflection analysis to determine the correct panel center moments under combined loading (beam-column effects).

3B.4.3 Design Criteria For Impact Accident

Section 3B.3.5 presents the basket design criteria for Level A (Normal Service) and sustained Level D conditions. This section describes the design criteria for the hypothetical impact accident which is evaluated as a very short duration Level D loading. There are four general types of structural criteria discussed below. These are the stress criteria, the criteria to ensure stability under compressive loading, the criteria to ensure stability under bending and the criteria to prevent failure under combined loading.

3B.4.3.1 Stress Criteria

The stress criteria are taken from Section III, Appendix F of the ASME Code[3] which is applied directly to the 304 stainless steel components. The Appendix F basis is also applied to the 6061 T6 aluminum members, but the material strength is based on the yield strength (at actual temperature) for this impact event rather than the Code Section III Appendix values of allowable stress, S, which are based on creep limits.

The thermal stresses are self-relieving and cannot cause failure of a structure from a one-time occurrence. Therefore, as stated in the Code, they are not combined with the primary stresses due to the inertia loads from the accident. The aluminum conductor plate strength is considered for short duration dynamic events. Since elastic quasistatic analyses are performed, the primary membrane stress is limited to the smaller of 2.4 S_m or 0.7 S_u and the membrane plus bending stress is limited to the smaller of 3.6 S_m or S_u. The average primary shear stress across a section is limited to 0.42 S_u (S_u is the minimum ultimate strength). For the aluminum plates the value of 2/3 S_y is substituted for S_m. Table 3B.4-1 summarizes these stress criteria and Table 3B.4-2 provides numerical values of the limits for 400°F metal temperature. Numerical limits for other temperatures can be readily calculated using the Code Section III Appendices.

3B.4.3.2 Stability Under Applied Compressive Load (Without Bending)

The basic structural element of the basket is considered to be a wall between fuel compartments which consists of one poison plate (neglected structurally when computing P_a) and one 0.5 in. aluminum plate sandwiched between two 0.105 in. stainless plates. The overall dimensions of this wall are 8.7 in. wide x 160 in. long x 0.785 in. thick. For analysis purposes, a unit length of the wall (called a panel) is studied since lateral loading of the basket produces panel planar loads in the 8.7 in. direction and bending about axes running along the 160 in. length of the wall.

The structural elements (panels) are connected together at the fuel compartment corners to form a frame that is supported on

the cask body inner wall and rails (see Figure 3B.4-7). When the basket is loaded as shown in Figure 3B.4-1, the vertical frame members (or panels) are braced laterally at the ends of each panel by the horizontal frame members as indicated in Figure 3B.4-7.

It is assumed that any panel may fail as a column (column buckling), may fail locally or both failures may occur simultaneously. The failure mode with the lower ASME limit will be assumed to govern.

The 8.7 in. long panel is conservatively assumed to have hinged ends since the fuel box corners are not reinforced. It is assumed that the welds tie the stainless fuel box sides and aluminum plates together at the weld lines (down the length of the basket). The overall panel as sketched on the left side of Figure 3B.4-8 is evaluated for column buckling. It is also assumed that the plates might separate (shown on the right side of Figure 3B.4-8) since there is no structure or surface loading holding the plates together. Therefore, the individual plates are evaluated between the plug weld lines assuming they can bulge apart. Detailed calculations and results are presented in Tables 3B.4-3 and 3B.4-4.

From Tables 3B.4-3 and 3B.4-4, the allowable compressive stress at 400°F for the 304 stainless steel plates is 7,670 psi and for the aluminum plates is 5,470 psi. It is not correct to assume that both the stainless steel and aluminum plates will reach these stresses at the same time. If the panel is compressed as shown by an axial load (Figure 3B.4-8), and if sliding between plates does not occur until one material or the other buckles, the strain in all plates is equal. By looking at the elastic strain level in each plate when it reaches its limit:

304 SS $\varepsilon = 7{,}670/(26.5 \times 10^6) = 0.000289$

Aluminum $\varepsilon = \sigma/E = 5{,}470/(8.7 \times 10^6) = 0.000629$

The limiting stainless steel strain of 0.000289 will be reached first since the corresponding strain level is lower than in the aluminum.

These allowable compressive loads or stresses are well below the yield points (see Tables 3B.4-3 and 3B.4-4). Therefore it is assumed that, for each material, as the strain is increased beyond that where the allowable compressive load is developed, the load will remain relatively constant until the other material reaches its limit. Therefore the allowable compressive load on the basket panel is the aluminum allowable plus the steel allowable. Looking at the 400°F situation, the total compressive load limit for a panel that might buckle as a column or could

experience local plate separation is:

$$P_a \text{ panel} = P_a(\text{304 SS}) + P_a(\text{Aluminum}) = 1611 \text{ lb/in.} + 2735 \text{ lb/in.} = 4346 \text{ lb/in.}$$

NOTE: The allowable compressive load for panels with two 0.5 inches aluminum plates is shown on Figure 3B.4-9 and Tables 3B.4-5 and 3B.4-6.

3B.4.3.2A <u>Inelastic Analysis of Basket to Determine Bucking Loads</u>

The cask has been analyzed to show that the cask does not tip over. However in the hypothetical event of cask tipover on the concrete pad, the aluminum plates carry a portion of the short duration dynamic loading from the impact.

The basic structural element of the basket is considered to be a wall between fuel compartments which consists of one poison plate (neglected structurally when computing P_a) and one 0.5 in. aluminum plate sandwiched between two 0.105 in. stainless plates. The overall dimensions of this wall are 8.7 in. wide x 160 in. long and 0.785 in. thick. For analysis purposes, a unit length of the wall (called a panel) is studied.

In order to calculate the buckling load, a two-dimensional inelastic ANSYS finite element model is constructed using a stif 23 plastic beam element to represent the TN-32 basket panel configuration. This two-dimensional beam element is a uniaxial element with tension-compression and bending capabilities. The element has three degrees of freedom at each node: Translations in the Nodal X and Y directions and rotation about the Nodal Z axis.

Large deformation of the beam and inelastic behavior of the material were included in the analysis to properly determine the effect of geometry and material behavior on the buckling calculation.

The load applied to the top of the basket panel is shown in Figure 3B.4-18 and the finite element model is shown in Figure 3B.4-19.

Tables 3B.4-19 and 3B.4-20 summarize the mechanical properties used for the 2-D ANSYS analysis.

The load exerted on the top of the basket panel is simulated by imposing a displacement at Node 14 (Nodes 7, 14 and 21 are coupled in the Y direction, so they will have the same vertical movement). A nonlinear solution was calculated with the deflection forced through seven load steps. The analysis was continued until the buckling load was exceeded.

The ANSYS results include stresses, forces and displacements at all load steps. The results are shown below.

Maximum Vertical Deflection	0.007"
Maximum Lateral Deflection	0.004138"
Maximum Compressive Load before Reaching Buckling Mode	7,974 lbs.

The maximum compressive load before reaching the buckling load is 7,974 lbs. This load is considerably greater than the hand calculated allowable compressive load of 4,346 lbs. (Ref. Tables 3B.4-3 and 4). Therefore, the allowable buckling load (4,346 lbs) is conservative. The compressive stress developed in the 304 stainless steel and aluminum plates cannot cause the panel to buckle.

Under the above compressive load, the maximum lateral deflection occurs at Node 4 and is 0.004138 inches. Therefore, the open dimension of the fuel compartment will be reduced to 8.7-2 (0.004138) = 8.6917 inches. This opening is greater than the size of a fuel assembly (8.426 in. x 8.426 in.) and provides sufficient clearance for fuel removal.

An additional analysis was made by assuming the aluminum panel is the only supporting structure. The results are shown below.

Maximum Vertical Deflection	0.01"
Maximum Lateral Deflection	0.00011"
Maximum Compressive Load before Reaching Buckling Mode	4,999 lbs.

Based on the analysis described above, the aluminum panel can withstand the 50 G load due to the side drop by itself without buckling.

The basket is structurally adequate and will properly support and position the fuel assemblies during and after the side drop.

3B.4.3.3 Stability Under Applied Bending Moment (Without Compression)

When determining the allowable compressive load in a basket wall panel (above), it is conservatively assumed that the panel edges are hinged and that there is no edge restraint to stabilize the panel against buckling. However, the various stainless and aluminum plates forming the panel extend beyond the panel and connect into other panels so that moments can be developed at the panel edges. Thus, the bending moment in a panel may be developed by the lateral (surface) loading in combination with edge reactions or it may be entirely applied through edge reaction(s) from adjacent panels.

Accordingly, evaluation of the bending stability of the multiple plate panels must distinguish between panel bending induced by lateral (surface) loading and that applied through edge reaction(s). The loading arrangement for the first case, (surface loading), is shown in Figure 3B.4-10. The strain developed in the various plates as the panel bends is a linear function of y, the distance from the common neutral axis. It is assumed that the plug welds effectively tie the various plates together into a laminated or composite panel. The steel outer fiber stress is conservatively limited to the yield stress at temperature. When the outer fiber of steel reaches its yield strength, the aluminum stress is well below the yield strength. Figure 3B.4-10 shows the derivation of the section moment, M, required to produce yielding of the steel. Note that the compression side of the panel is subjected to the applied load which prevents the outer stainless plate from buckling away from the panel between welds. This 1,739 in-lb/in bending moment limit, M_a, is used to evaluate only those panels subjected to surface loading as shown in Figure 3B.4-10.

In the other case, panel bending is induced by edge reactions (moments) as shown in Figure 3B.4-11. There is no surface loading on the compression side of the panel. It is, therefore, conservatively assumed that the outer stainless plate might buckle away from the panel as illustrated in Figure 3B.4-11, although the initial curved shape of the panel makes that unlikely. The stainless steel stress is limited to the value determined in Table 3B.4-3 of 7,670 psi which is the Level C allowable compressive stress in the 6 in. long 0.105 in. thick plate between welds. In this case, the allowable bending moment, M_a, is limited as determined in Figure 3B.4-11 to 644 in-lb/in.

NOTE: The allowable bending moments for panels with two 0.5 inches aluminum plates are shown on Figures 3B.4-12 and 3B.4-13.

3B.4.3.4 Combined Loading

The ANSYS Finite Element System Model is used to perform a large deflection analysis. The beam-column effects (where a compressive force applied to a bent member increases the bending moment due to the deflection) have already been considered. Therefore, Tables 3B.4-7 through 3B.4-9 results already include these interactive effects.

The allowable panel compression and bending loadings are determined above. These allowables ensure stability of the panel under compression loads (in the absence of bending) and under a bending moment (in the absence of compression).

The 4,346 lb/in. compressive load limit ensures that, in the absence of bending, the overall panel will not buckle as a column or fail locally due to plate separation and buckling between welds. The 4,346 lb/in. value is the total of 1,611 lb/in. (or 7,670 psi) in both steel plates and 2,735 lb/in. (or 5,470 psi) in both aluminum plates. These values are listed in Tables 3B.4-3 and 3B.4-4.

If a bending moment is applied to the above panel loaded in compression at 4,346 lb/in., the compressive stresses on one side of the neutral axis will decrease and those on the other side of the neutral axis will increase. If there is no surface loading on the side of the panel where the compressive stresses increase, the 0.105 in. stainless plate could separate since the 7,670 psi allowable stress ensuring that it does not buckle as indicated in Figure 3B.4-11 will be exceeded. Therefore, as the moment is applied the compressive force must be decreased. In order to maintain the compressive plate stress at 7,670 psi, the interaction limits are:

$$(1)\quad \frac{\text{Applied Compressive Load}}{\text{Allowable Compressive Load}} + \frac{\text{Applied Bending Moment}}{\text{Allowable Bending Moment}} \leq 1.0$$

$$(1A)\quad \frac{\text{Applied Compressive Load}}{4{,}346\ \text{lb/in}} + \frac{\text{Applied Bending Moment}}{644\ \text{in-lb/in}} \leq 1.0$$

If a bending moment is developed in a panel loaded in compression at 4,346 lb/in by means of surface loading (with appropriate edge reactions), compressive stresses in the plates on the unloaded side of the neutral axis decrease and those on the loaded side of the panel increase. The outer stainless plate on the loaded side of the panel cannot separate and buckle away from the panel toward the load. Since the compressive stress on the stainless plate on the unloaded side of the panel is decreasing, it will not buckle. Therefore, the surface loading prevents buckling of the panel due to plate separation and permits higher stresses to be developed before column buckling can occur.

For conservatism, no credit is taken for the surface loading other than that it will prevent the compressive stainless plate from buckling away from the panel. Therefore the interaction limit for a panel with surface loading is:

$$(2)\quad \frac{\text{Applied Compressive Load}}{\text{Allowable Compressive Load}} + \frac{\text{Applied Bending Moment}}{\text{Allowable Bending Moment}} \leq 1.0$$

Where, with surface load:

$$(2A)\quad \frac{\text{Applied Compressive Load}}{4{,}346 \text{ lb/in}} + \frac{\text{Applied Bending Moment}}{1{,}739 \text{ in-lb/in}} \leq 1.0$$

3B.4.4 Evaluation

Analyses using the basket system model are performed for the three different load orientations relative to the basket plates (90°, 45°, and 0°) as indicated in Figures 3B.4-1 through 3B.4-3. The displacement plots for the entire basket are shown in Figures 3B.4-4 through 3B.4-6.

The panel load results from these three system analyses are presented in Tables 3B.4-7 through 3B.4-9. Their corresponding locations are shown on Figure 3B.4-14. These tables show the highest forces (F) and Moments (M) for each load orientation. These are the panels most likely to buckle when the basket is subjected to lateral inertial loads. The maximum force of 3,240 lb/in. occurs in the 0-degree case. The highest moment of 146 in-lb/in occurs in the 45 degree case. These forces and moments are evaluated using the interaction equation described in the structural design criteria, Section 3B.4.3. The interaction equation for compression and bending is:

$$F/P_a + M/M_a \leq 1.0$$

The allowable compressive force and bending moment, P_a and M_a, are determined as described in Section 3B.4.3. At 400°F, the resulting values of P_a and M_a are 4,346 lb/in. and 1,739 in-lb/in. respectively (or 8,046 lb/in. and 5,051 in-lb/in. for panels with two 0.5 inches aluminum plates). Note that the 1,739 in-lb/in. limit is for a panel with surface loading. For a panel without surface loading, M_a is 644 in-lb/in. See Section 3B.4-3. The buckling interaction total, also listed in Tables 3B.4-7 through 3B.4-9, s a maximum of 0.679 for the panel at location 1 for the 90° load orientation case. The design meets the criteria with margin at a load level of 50 g's. The basket satisfies the criteria at loads up to about 74 g's, much higher than would occur in the TN-32 cask during the tip-over onto a concrete pad (23 g). This buckling analysis is performed conservatively assuming the maximum temperature of all panels is 400°F. The

temperature varies along and across the basket and is only 330°F at the outer basket panels at the top of the cask. The loads in the center of the basket at the mid length position where the temperature can reach 527°F are much less than the loads reported in Table 3B.4-7 through Table 3B.4-9.

Tables 3B.4-10 through 3B.4-12 list the stresses at the corner regions and Tables 3B.4-13 through 3B.4-15 list the stresses at the central regions. Their corresponding locations are shown on Figures 3B.4-14 and 3B.4-15. Based on the results in the stress tables, it is concluded that:

304 S.S. Plate:

The maximum membrane stress intensity at 50 G's is 13,140 psi and occurs at location 2 corner C (Table 3B.4-11) in the 45° load case. This stress is below the allowable stress of 44,900 psi (2.4 S_m) at a temperature of 400°F. The maximum membrane plus bending stress intensity is 62,560 psi and occurs at location 1 corner B (Table 3B.4-10) in the 90° load case. This stress is below the allowable stress of 64,400 psi (S_u) at a temperature of 400°F.

Shear Stress in 1/2 in. Plug Welds:

The maximum shear stress in the plug weld is 21,083 psi at location 3 (Figure 3B.4-14) in the 0° load case. This stress is below the allowable stress of 27,000 psi (0.42 S_u) at a temperature of 400°F.

Aluminum Plate:

The maximum membrane stress intensity due to 50 G's is 3,046 psi and occurs at location 1 (Table 3B.4-14) in the 45° load case. This stress is below the allowable stress of 12,400 psi (0.7 S_u) at a temperature of 400°F.

The maximum membrane plus bending stress intensity is 7,034 psi and occurs at location 3 (Table 3B.4-14) in the 45° load case. This stress is below the allowable stress of 17,700 psi (S_u) at a temperature of 400°F.

The basket plates are therefore structurally satisfactory under these loads.

3B.4.5 Basket Rails Under 50 g Side Impact

The details of the TN-32 aluminum rails are shown on Drawing 1049-70-2. The rails are aluminum alloy 6061-T6 extrusions which are oriented parallel to the cask longitudinal axis and are attached to the inner cavity wall. The rails establish and maintain basket orientation, prevent twisting of the basket assembly, and support the edges of those plates adjacent to the

rails which would otherwise be free to slide tangentially around the cask cavity wall under normal and accident lateral inertial loadings.

Two-dimensional elastic ANSYS finite element models were constructed using stif 3 beam elements to represent the TN-32 basket rail configurations. (Significant dimensions used in creating the models are shown in Figures 3B.4-16 and 3B.4-17). This two-dimensional beam element is a uniaxial element with tension-compression and bending capabilities. The element has three degrees of freedom at each node: Translations in the Nodal X and Y directions and rotation about the Nodal Z axis. This element can properly model both the tensile and flexural stiffness of the aluminum rail.

The lateral inertia loads (50G) on the aluminum rail applied by the fuel assemblies and the weight of the basket plates are represented by distributed loads (P) on the rail contact surfaces as shown on Figures 3B.4-16 and 3B.4-17. These loads are taken from the 50 G side drop analysis. Table 3B.4-16 summarizes the aluminum alloy mechanical properties used for the 2-D ANSYS Analysis.

The maximum membrane and membrane plus bending stresses in the aluminum rails for the 50G side drop load are summarized in Table 3B.4-17. The stress criteria are taken from Section III, Appendix F of the ASME Code and are listed in Table 3B.4-18. The stress results in Table 3B.4-17 are evaluated using these criteria. The maximum membrane stress is 4,533 psi and occurs at Location 2 in the bottom rail. This stress is below the allowable stress of 20,090 psi at a temperature of 300°F. The maximum membrane plus bending stress is 25,187 psi and occurs at Location 1 in the bottom rail. This stress is also below the allowable stress of 28,700 psi.

The allowable compressive stress is 2/3 of the buckling load based on Paragraph F-1334.3 of Appendix F of the ASME Code. The critical buckling load is determined using the Euler equation:

$$P_{cr} = n \pi^2 E I / l^2$$

where

n = the end condition constant
E = modulus of elasticity, $9.2x10^6$ psi
I = moment of inertia, in^4
l = length of the vertical member, inches

The rail vertical members are fixed at both ends. The theoretical value for the end condition constant is 4, but a value of 1 was used for conservatism.

The allowable compressive stresses for the most highly stressed location in the vertical member of each rail are listed below.

LOCATIONS	Critical Load (lbs) P_{cr}	Allowable Compressive Load $P=2/3\ P_{cr}$	Allowable Compressive Stress (psi) $F_a=P/A$	Compress. Stress f_a ANSYS run (Table 3B.4-17)
Bottom Rail l=4.715", t=0.47" (Fig. 3B.4-16, Location 2)	35,534	23,689	50,402	4,533
Side Rail l=7.83", t=0.67" (Fig. 3B.4-17, Location 2)	37,174	24,783	36,989	2,250

As indicated above, the compressive stresses from the accident loads are well below the allowable compressive stresses.

For combined axial compression and bending, equations 20 and 21 of Paragraph NF-3322.1 (e) (1) apply.

$$f_a/F_a + C_{mx}\, f_b \;/\; [1-(f_a\,/F_e)]\; F_b \le 1$$

and

$$f_a\;/(1.4)(0.6)S_y + f_b\;/\;F_b \le 1$$

The allowable stresses for the above equations are determined as follows:

	Allowable Stress	ASME Reference
F_a	P/A (see above table)	F-1334.5(a)
F_b	1.5 S_y = 40,650 psi	F-1334.5(c)
C_{mx}	0.6	NF 3322.1(e)(1)(b)
Note	The allowable stress F_a is multiplied by 1.4 as allowed by Paragraph F-1334	

The value of F_e is calculated by the formula below per Paragraph F-1334.5(b):

$$F_e = \pi^2 E / [1.30 \times (kl/r)^2]$$

where

k is conservatively taken as 1
l is the free length of the member, in.
r is the radius of gyration, in.
E is the modulus of elasticity, 9.2×10^6 psi

This formula gives the following results for F_e:

Location	F_e (psi)
Bottom rail l = 4.715", r = 0.1361" (Fig. 3B.4-16, Location 2)	58,196
Side Rail l = 7.83", r = 0.1936" (Fig. 3B.4-17, Location 2)	42,700

The interaction equations were evaluated for the stresses presented in Table 3B.4-17. The highest stress combination occurs at Location 2 of the side rail resulting in the left hand side of Equation (2) of 0.5 which is less than 1.

Based on the results of this analysis, it was concluded that the stresses in the aluminum rails under the 50G side drop load are acceptable.

3B.5 References

1. ANSYS Engineering Analysis System User's Manual, Volume 1 and Volume 2, Rev. 4.4, 1989.
2. Aluminum Standards and Data, 1990.
3. ASME B&PV Code Section III Division and Appendices (1992).
4. American Institute of Steel Construction, Manual of Steel Construction, 1980.
5. ASME B&PV Code, Subsection NF, 1992.
6. ASME B96.1, Welded Aluminum Alloy Storage Tanks, 1989.

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TABLE 3B.3-1

BASKET PANEL CORNER REGION STRESSES UNDER 1G LATERAL
90° LOAD ORIENTATION

Location Fig 3B.3-2		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		AVERAGE	TOP SURFACE	BOTTOM SURFACE
1	A	244	1384	1817
	B	243	1383	1839
	C	381	10180	10910
	D	383	11350	12080
2	A	203	957	1337
	B	309	2225	2816
	C	178	192	164
	D	394	10290	11050
3	A	221	1417	1836
	B	200	1442	1805
	C	169	1678	1655
	D	167	1651	1554
4	A	174	995	1313
	B	218	2000	2404
	C	209	1883	1897
	D	153	1147	1051
5	A	178	1492	1826
	B	143	1394	1634
	C	141	172	282
	D	158	673	550
6	A	167	1492	1817
	B	131	1589	1821
	C	137	1636	1632
	D	147	1635	1600

TABLE 3B.3-2

BASKET PANEL CENTER REGION STRESSES UNDER 1G LATERAL
90° LOAD ORIENTATION

LOCATION FIG 3B.3-3	MAXIMUM STRESS INTENSITIES (PSI)			
	304 S.S.		ALUMINUM	
	Pm	Pm + Pb	Pm	Pm + Pb
3	75	1052	---	---
4	56	1018	---	---
7	78	1065	---	---
8	62	1025	---	---

TABLE 3B.3-3

BASKET PANEL 304 S.S.STRESSES AT PLUG WELD REGION
90^{0} LOAD ORIENTATION

LOCATION FIG 3B.3-4	MAXIMUM STRESS INTENSITIES (PSI)			
	304 S.S.		ALUMINUM	
	Pm	Pm + Pb	Pm	Pm + Pb
1	159	3215	---	---
2	136	2667	---	---
3	99	1824	---	---
4	189	3817	---	---
5	156	3215	---	---
6	134	2658	---	---
7	98	1819	---	---
8	188	3823	---	---
9	144	2789	---	---
10	153	3031	---	---
11	86	1437	---	---
12	209	4225	---	---
13	133	2783	---	---
14	147	3015	---	---
15	83	1442	---	---
16	206	4376	---	---

TABLE 3B.3-4

BASKET PANEL STRESSES - THERMAL

LOCATION FIG 3B.3-6	MAXIMUM STRESS INTENSITIES (PSI) THERMAL STRESS (SECONDARY STESS) Q				
	304 S.S.		ALUMINUM		SHEAR STRESS AT PLUG WELD
	AVERAGE	TOP OR BOTTOM	AVERAGE	TOP OR BOTTOM	
1	3474	29302			
2	3066	3074			
3			2228	2238	
4			1518	1564	
5	3589	28479			
6	3207	3221			
7					16812

TABLE 3B.3-5

BASKET PANEL STRESSES
THERMAL STRESS + 1G LATERAL

LOCATION FIG 3B.3-6	MAXIMUM STRESS INTENSITIES (PSI) PRIMARY + SECONDARY STRESS (Pm + Pb + Q)				
	304 S.S.		ALUMINUM		SHEAR STRESS AT PLUG WELD
	AVERAGE	TOP OR BOTTOM	AVERAGE	TOP OR BOTTOM	
1	3633	32517			
2	3144	4139			
3			2228	2238	
4			1518	1564	
5	3798	31694			
6	3285	4286			
7					17095

TABLE 3B.4-1

TN-32 BASKET STRUCTURAL DESIGN CRITERIA
FOR LEVEL D IMPACT ACCIDENT CONDITIONS

	PRIMARY STRESS LIMITS FOR ELASTIC ANALYSIS	ASME[3] REFERENCE
MEMBRANE STRESS INTENSITY, P_m	LESSER OF 2.4 S_m, 0.7 S_u (1.6 S_y)[1]	APPENDIX F F 1331.1a
MEMBRANE PLUS BENDING STRESS INTENSITY, $P_m + P_b$	LESSER OF 3.6 S_m, 1.0 S_u (2.4 S_y)[1]	APPENDIX F F 1331.1c
SHEAR STRESS, ô	0.42 S_u	APPENDIX F F 1331.1d

NOTE:

(1) $S_m \sim 2/3\ S_y$ FOR MOST CLASS 1 MATERIALS. THE 6061 ALUMINUM LIMITS FOR A SHORT DURATION IMPACT EVENT ARE BASED ON THIS RELATIONSHIP SINCE 6061 CODE S_m VALUES ARE BASED ON CREEP LIMIT.

(2) SELF RELIEVING (SECONDARY) STRESSES ARE NOT CONSIDERED FOR LEVEL D SERVICE LIMITS (F-1310C).

(3) SINCE COMPRESSIVE STRESSES ARE PRESENT THE STABILITY OF THE COMPONENT IS ALSO CONSIDERED (F-1310D).

TABLE 3B.4-2

TN-32 BASKET STRUCTURAL DESIGN CRITERIA
FOR LEVEL D IMPACT ACCIDENT CONDITIONS

NUMERICAL VALUES OF PRIMARY STRESS INTENSITY LIMITS AT 400°F		
	304 STAINLESS STEEL (PSI)	6061 T6 ALUMINUM (PSI)
MEMBRANE STRESS INTENSITY, P_m	44,900	12,400
MEMBRANE PLUS BENDING STRESS INTENSITY, $P_m + P_b$	64,400	17,700
SHEAR STRESS, δ	27,000	7,400

NOTE: THESE LIMITS ARE FOR METAL TEMPERATURE OF 400°F. THE SAR EVALUATES RESULTS AT SEVERAL TEMPERATURES.

TABLE 3B.4-3

BUCKLING LIMITS - 304 S.S.
PANEL - ONE 0.5" ALUMINUM AND TWO 0.105" S.S.

EVALUATING THE PANEL ASSUMING STABLE CROSS SECTION WITH EACH MEMBER BENDING ABOUT COMMON N.A. (FIG. 3B.4-8.A)	EVALUATING INDIVIDUAL PLATES ASSUMING PLATES SEPARATE BETWEEN WELDS & BEND ABOUT OWN N.A. (FIG. 3B.4-8.B)
$I = 1/12\ W(0.71^3 - 0.5^3) = 0.0194\ in^4$ $A = 2xWx0.105 = 0.21\ in^2/in.$ $r = \sqrt{I/A} = 0.304$ in.	$I = 1/12\ W(0.105)^3 = 0.0000965\ in^4$ $A = 0.105\ in^2/in.$ r = 0.0303 in.
Assuming Hinged Ends l = 8.7 k = 1 kl/r=28.62 K_{bk}=1.5 (Ref. 5, NF-3523b-1) Ref. NF-3322.1-E2.ba) $F_a = 1.5\ S_y\ (0.47 - kl/r/444)$ at T=400°F S_y=20700 psi F_a=12592 psi	Assuming Fixed Ends l = 6 k = 0.5(Ref. 4) kl/r=99 K_{bk}=1.5 $F_a=1.5\ S_y(0.47 - kl/r/444)$ (Ref. 5) at T=400°F S_y=20700 psi F_a=7670 psi
$P_{critical} = F_a \times A$ P_c=12592x0.21 = 2644 lb/in.	$P_c = F_a \times 2A$ P_c = 7670x2x0.105 = 1611 lb/in.
CONCLUSION: THE LOWER VALUE OF F_a (7670 PSI) WILL BE USED TO ESTABLISH THE ALLOWABLE COMPRESSIVE LOAD.	

TABLE 3B.4-4
BUCKLING LIMITS - ALUMINUM
PANEL- ONE 0.5" ALUMINUM AND TWO 0.105" S.S.

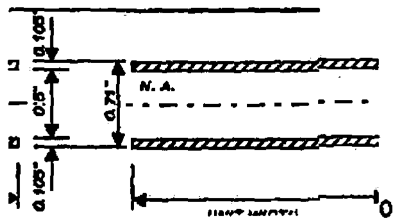
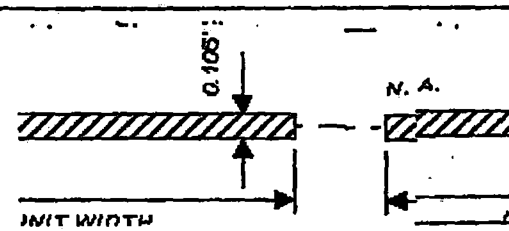
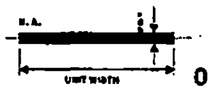
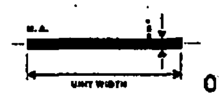
EVALUATING THE PANEL ASSUMING STABLE CROSS SECTION WITH EACH MEMBER BENDING ABOUT COMMON N.A. (FIG. 3B.4-8.A)	EVALUATING INDIVIDUAL PLATES ASSUMING PLATES SEPARATE BETWEEN WELDS & BEND ABOUT OWN N.A. (FIG. 3B.4-8.B)
	
$I = 1/12\ W(0.5^3) = 0.0104\ in^4/in$ $A = 0.5\ in^2/in.$ $r = \sqrt{I/A} = 0.1443$ in.	$I = 1/12\ W(0.5)^3 = 0.0104\ in^4/in.$ $A = 0.5\ in^2/in.$ $r = \sqrt{I/A} = 0.1443$ in.
Assuming Hinged Ends l = 8.7 k = 1 kl/r=60.29 at T=400°F F_c = 7.4-0.032 kl/r (Ref.6 Tab. 10) = 5.47 ksi = 5470 psi	Assuming Fixed Ends l = 6 k = 0.5 kl/r=20.79 at T=400°F F_c=7.4-0.032 kl/r (Ref. 6, Tab. 10) = 6.734 ksi = 6734 psi
$P_{critical} = F_c \times A$ P_c=5470x0.5 = 2735 lb/in.	$P_c = F_c \times A$ P_c = 6734x0.5 = 3367 LB/IN
CONCLUSION: THE LOWER VALUE OF F_c (5470 PSI) WILL BE USED TO ESTABLISH THE ALLOWABLE COMPRESSIVE LOAD. *TOTAL ALLOWABLE COMPRESSIVE LOAD= $P_{SS} + P_{ALU.}$= 1611 + 2735 = 4346 LB./IN.	

TABLE 3B.4-5

BUCKLING LIMITS - 304 S.S.
PANEL - TWO 0.5" ALUMINUM AND TWO 0.105" S.S.

EVALUATING THE PANEL ASSUMING STABLE CROSS SECTION WITH EACH MEMBER BENDING ABOUT COMMON N.A. (FIG. 3B.4-9.A)	EVALUATING INDIVIDUAL PLATES ASSUMING PLATES SEPARATE BETWEEN WELDS & BEND ABOUT OWN N.A. (FIG. 3B.4-9.B)
	
$I = 1/12\ W(1.21^3 - 1^3) = 0.0643\ in^4$ $A = 2xWx0.105 = 0.21\ in^2/in.$ $r = \sqrt{I/A} = 0.553$ in.	$I = 1/12\ W(0.105)^3 = 0.0000965\ in^4$ $A = 0.105\ in^2/in.$ $r = 0.0303$ in.
Assuming Hinged Ends $l = 8.7 \quad k = 1 \quad kl/r = 15.73$ $K_{bk} = 1.5$ $F_a = 1.5\ S_y\ (0.47 - kl/r/444)$ at $T = 400^0F \quad S_y = 20700$ psi $F_a = 13493$ psi	Assuming Fixed Ends $l = 6 \quad k = 0.5 \quad kl/r = 99$ $K_{bk} = 1.5$ $F_a = 1.5S_y(0.47 - kl/r/444)$ at $T = 400^0F \quad S_y = 20700$ psi $F_a = 7670$ psi
$P_{critical} = F_a \times A$ $P_c = 13493x0.21 = 2834$ lb/in.	$P_c = F_a \times 2A$ $P_c = 7670x2x0.105 = 1611$ lb/in.

CONCLUSION: THE LOWER VALUE OF F_a (7670 PSI) WILL BE USED TO ESTABLISH THE ALLOWABLE COMPRESSIVE LOAD.

*TOTAL ALLOWABLE COMPRESSIVE LOAD = $P_{SS} + P_{ALU.} = 1611 + 6435$
= 8046 LB./IN.

TABLE 3B.4-6

BUCKLING LIMITS - ALUMINUM
PANEL - TWO 0.5" ALUMINUM AND TWO 0.105" S.S.

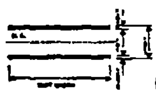
EVALUATING THE PANEL ASSUMING STABLE CROSS SECTION WITH EACH MEMBER BENDING ABOUT COMMON N.A. (FIG. 3B.4-9.A)	EVALUATING INDIVIDUAL PLATES ASSUMING PLATES SEPARATE BETWEEN WELDS & BEND ABOUT OWN N.A. (FIG. 3B.4-9.B)
 0	 0
$I = 1/12\ W(1^3) = 0.0833\ in^4/in$ $A = 1\ in^2/in.$ $r = \sqrt{I/A} = 0.2886$ in.	$I = 1/12\ W(0.5)^3 = 0.0104\ in^4/in.$ $A = 0.5\ in^2/in.$ $r = \sqrt{I/A} = 0.01443$ in.
Assuming Hinged Ends $l = 8.7$ $k = 1$ $kl/r = 30.145$ at $T = 400^{\circ}F$ $F_c = 7.4 - 0.032\ kl/r$ $= 6.435$ ksi $= 6435$ psi	Assuming Fixed Ends $l = 6$ $k = 0.5$ $kl/r = 20.79$ at $T = 400^{\circ}F$ $F_c = 7.4 - 0.032\ kl/r$ $= 6.734$ ksi $= 6734$ psi
$P_{critical} = F_c \times A$ $P_c = 6435 \times 1 = 6435$ lb/in.	$P_c = F_c \times 2A$ $P_c = 6734 \times 2 \times 0.5 = 6734$ lb/in.
CONCLUSION: THE LOWER VALUE OF F_c (6435 PSI) WILL BE USED TO ESTABLISH THE ALLOWABLE COMPRESSIVE LOAD.	

TABLE 3B.4-7

BASKET PANEL LOADS - COMPRESSION AND BENDING UNDER 50G SIDE DROP 90° DROP ORIENTATION

PANEL LOCATION FIGURE 3B.4-14	F_Y #/in.	M_Z in-#/in.	INTERACTION $\frac{F}{P_a} + \frac{M}{M_a}$	MARGIN OF SAFETY
1	2592	≈ 0	0.679	0.473
2	1023	≈ 0	0.235	3.26
5	2377	≈ 0	0.546	0.83
6	2262	*43	0.587	0.704

NOTE:AT 400°, P_a=4346 #/in, M_a=1739 in-#/in WITH SURFACE LOAD
*M_a=644 in-#/in WITHOUT SURFACE LOAD

TABLE 3B.4-8

BASKET PANEL LOADS - COMPRESSION AND BENDING UNDER 50G SIDE DROP 45° DROP ORIENTATION

PANEL LOCATION FIGURE 3B.4-14	F_X #/in.	F_Y #/in.	M_Z in-#/in.	INTERACTION $\frac{F}{P_a} + \frac{M}{M_a}$	MARGIN OF SAFETY
1		2073	113	0.542	0.845
3	1307		146	0.385	1.59
4	1716		129	0.469	1.13
5		1672	88	0.435	1.29
6		1605	72	0.411	1.43
8	1306		66	0.338	1.96
9	1691		116	0.456	1.19
10		1295	72	0.339	1.95
11		1158	144	0.349	1.86

NOTE: AT 400°, P_a=4346 #/in, M_a=1739 in-#/in WITH SURFACE LOAD
*M_a=644 in-#/in WITHOUT SURFACE LOAD

TABLE 3B.4-9

BASKET PANEL LOADS - COMPRESSION AND BENDING UNDER 50G SIDE DROP 0° DROP ORIENTATION

PANEL LOCATION FIGURE 3B.4-14	F_x #/in.	M_z in-#/in.	INTERACTION $\frac{F}{P_a} + \frac{M}{M_a}$	MARGIN OF SAFETY
4	2451	*32	0.614	0.629
8	1887	*9	0.448	1.23
9	2439	≈ 0	0.561	0.783
12	**2637	≈ 0	0.328	2.05
13	**3240	≈ 0	0.403	1.48

NOTE: At 400°, P_a=4346 #/in, M_a=1739 in-#/in WITH SURFACE LOAD
*M_a=644 in-#/in WITHOUT SURFACE LOAD
**P_a=8046 #/in AT THIS PANEL LOCATION

TABLE 3B.4-10

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
90° DROP ORIENTATION

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
1	A	9526	47340	61390
	B	11010	43900	62560
	C	8647	13370	10010
	D	5189	7994	8102
2	A	10940	42990	61550
	B	7196	47260	60840
	C	8257	7977	8541
	D	8443	13010	10170
3	A	8666	48280	61350
	B	7544	44190	57670
	C	5064	49890	56030
	D	5131	50880	57230
4	A	6670	34710	46740
	B	5116	10340	19240
	C	6366	51610	52010
	D	4658	49170	54650

TABLE 3B.4-10

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
90^{0} DROP ORIENTATION
(continued)

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
5	A	4839	31540	7867
	B	3110	7361	10770
	C	9775	8053	12370
	D	10820	10500	11200
6	A	5293	36790	45180
	B	3967	3773	10690
	C	3824	49410	52350
	D	4363	51930	57530

TABLE 3B.4-11

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
45° DROP ORIENTATION

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
1	A	5057	40300	38890
	B	8396	26250	40720
	C	8892	6242	12480
	D	3933	6736	3870
2	A	9328	29400	46690
	B	10800	28400	48810
	C	13140	9696	16860
	D	6528	14960	8550
3	A	2764	39820	42430
	B	3996	28320	35240
	C	3578	40380	44870
	D	9329	29600	42350
4	A	7027	24470	37600
	B	3795	22430	18720
	C	1751	47500	47800
	D	3833	29480	28420

TABLE 3B.4-11

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
45° DROP ORIENTATION
(continued)

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
5	A	7882	24320	39100
	B	4426	11840	8310
	C	12370	9453	15350
	D	11850	8374	23030
8	A	7765	32240	45820
	B	3143	8731	6972
	C	6910	5372	9038
	D	6808	28100	39420

TABLE 3B.4-12

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
0° DROP ORIENTATION

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
2	A	4742	1701	8885
	B	10750	9798	12130
	C	12820	10400	16990
	D	4960	9295	12060
4	A	3587	1482	7407
	B	3239	42120	45870
	C	7886	16030	16340
	D	3699	7477	14130
5	A	8031	37450	51490
	B	6846	10690	8144
	C	10240	9688	10860
	D	7248	10950	24070
6	A	3347	4384	5160
	B	1978	39930	42750
	C	4222	6330	11770
	D	4878	6217	5726

TABLE 3B.4-12

BASKET PANEL CORNER REGION STRESSES UNDER 50G SIDE DROP
0° DROP ORIENTATION
(continued)

LOCATION FIGURE 3B.4-15		STRESS INTENSITIES (PSI)		
		MEMBRANE (Pm)	MEMBRANE + BENDING (Pm + Pb)	
		Average	Top Surface	Bottom Surface
7	A	5225	37280	46240
	B	5393	49670	57790
	C	4094	49450	54860
	D	5345	4955	13990
8	A	9220	46510	61930
	B	5225	8265	7786
	C	7093	10840	8197
	D	9092	44570	60070

TABLE 3B.4-13

BASKET PANEL CENTER REGION STRESSES UNDER 50G SIDE DROP
90° DROP ORIENTATION

LOCATION FIGURE 3B.4-14	MAXIMUM STRESS INTENSITIES (PSI)			
	304 S.S.		ALUMINUM	
	Pm	Pm + Pb	Pm	Pm + Pb
3	2772	7115	295	6626
4	2436	7226	319	6657
7	2834	8022	271	6704
8	1956	5336	268	5213

TABLE 3B.4-14

BASKET PANEL CENTER REGION STRESSES UNDER 50G SIDE DROP
45^0 DROP ORIENTATION

LOCATION FIGURE 3B.4-14	MAXIMUM STRESS INTENSITIES (PSI)			
	304 S.S.		ALUMINUM	
	Pm	Pm + Pb	Pm	Pm + Pb
1	4926	6766	3046	6353
3	5860	9058	2575	7034
4	5853	10660	1548	6041
5	4418	6280	1853	4836
6	5834	9317	1284	5183
7	4715	7830	1832	6311
8	3745	6363	1671	5199
9	4086	5673	2532	5668
10	4149	7031	1413	5085
11	3917	8133	1126	5721

TABLE 3B.4-15

BASKET PANEL CENTER REGION STRESSES UNDER 50G SIDE DROP
0° DROP ORIENTATION

LOCATION FIGURE 3B.4-14	MAXIMUM STRESS INTENSITIES (PSI)			
	304 S.S.		ALUMINUM	
	Pm	Pm + Pb	Pm	Pm + Pb
5	1110	3419	195	4342
6	2188	5865	195	5884
10	2084	5792	192	5386
11	2397	7678	199	6612

TABLE 3B.4-16

MECHANICAL PROPERTIES OF ALUMINUM ALLOY[(1)]
ASTM B221 6061-T6

Minimum Ultimate Strength, S_u	28,700 psi
Minimum Yield Strength, S_y	27,100 psi
Design Stress Value, S_m	9,567 psi [(2)]
Modulus of Elasticity, E	9.2×10^6 psi
Density	0.105 lbs/in^3

NOTES:

1. Mechanical properties listed are for a metal temperature of 300°F.

2. According to the ASME B&PV Code, Section III, Appendix III, the design stress intensity value (S_m) is the smaller of the following:

   a. One-third of the tensile strength at temperature;
   b. Two-thirds of the yield strength at temperature.

TABLE 3B.4-17

SUMMARY OF ALUMINUM RAIL STRESSES

LOCATION		MEMBRANE P_m (psi)	BENDING P_b (psi)	MEMBRANE + BENDING P_m+P_b (psi)
Bottom Rail	1	89	25,187	25,276
(Fig. 3B.4-16)	2	4,533	650	5,183
Side Rail	1	301	22,524	22,825
(Fig. 3B.4-17)	2	2,250	16,350	18,600

TABLE 3B.4-18

ALUMINUM RAIL DESIGN CRITERIA FOR LEVEL D ACCIDENT CONDITIONS

	PRIMARY STRESS LIMITS FOR ELASTIC ANALYSIS	ASME REFERENCE
P_m	20,090	Appendix F F-1331.1a
$P_m + P_b$	28,700	F-1331.1C

TABLE 3B.4-19

Mechanical Properties of SA-240- Type 304 SST (400°F)

$E = 26.5 \times 10^6$ psi
S_y= 20,700 psi
S_u = 64,400 psi

STRAIN (in./in.)	STRESS (psi)
0.000781132	20,700
0.1	31,000
0.2	42,000
0.3	53,000
0.4	64,400

TABLE 3B.4-20

Mechanical Properties of Aluminum 6061-T6 (400°F)

$E = 8.7 \times 10^6$ (psi)
S_y = 13,300 (psi)
S_u = 17,700 (psi)

STRAIN (in./in.)	STRESS (psi)
0.0015287	13,300
0.1	14,500
0.2	15,600
0.28	17,700

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Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.1-1
REPRESENTATIVE BASKET
WALL PANEL

REV. 0 1/00

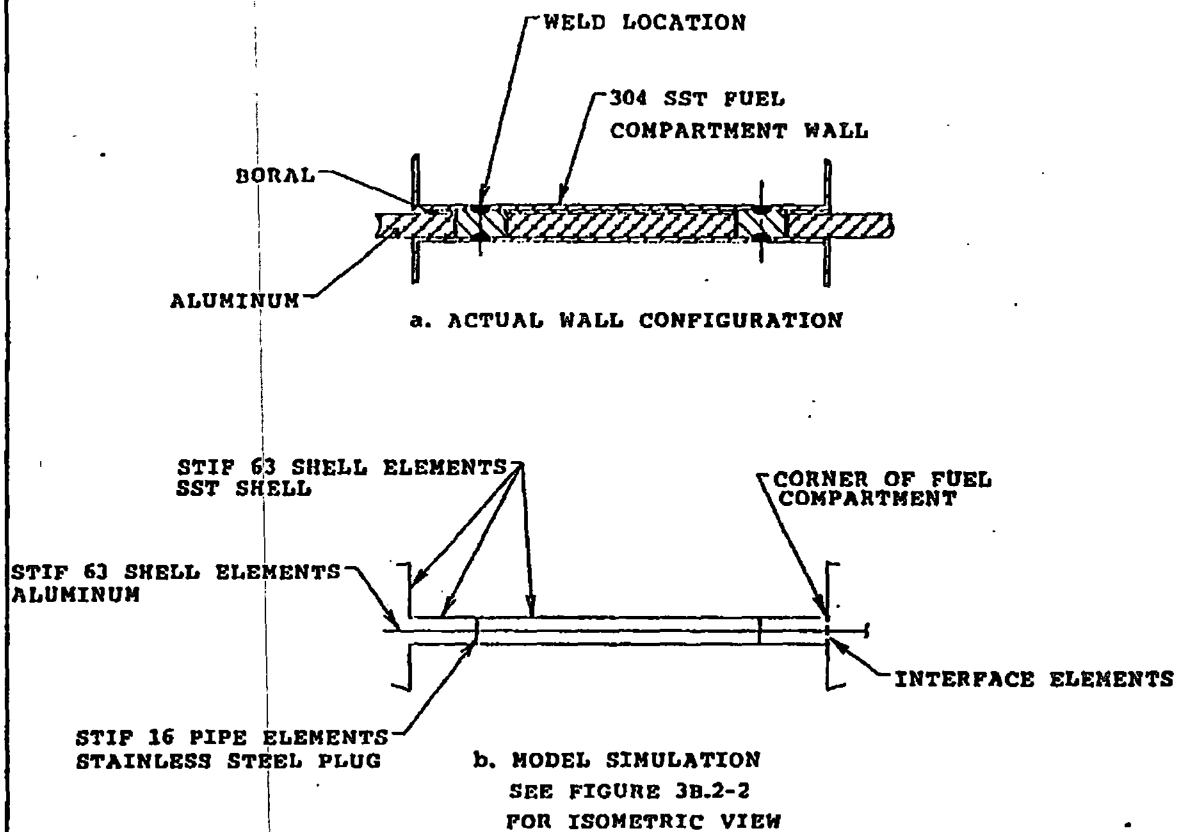
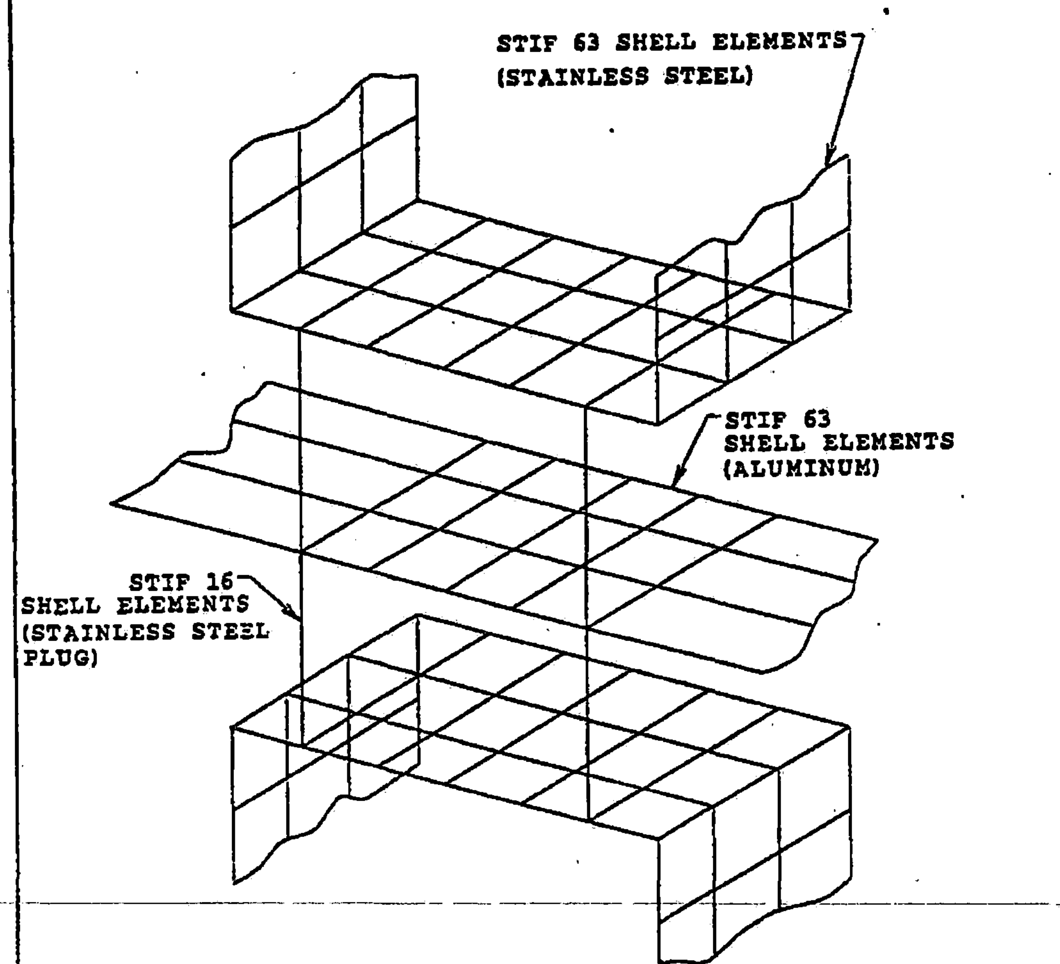


FIGURE 3B.2-1
REPRESENTATIVE BASKET MODEL SIMULATION

REV. 0 1/00



MODEL SIMULATION

FIGURE 3B.2-2
REPRESENTATIVE BASKET
MODEL SIMULATION

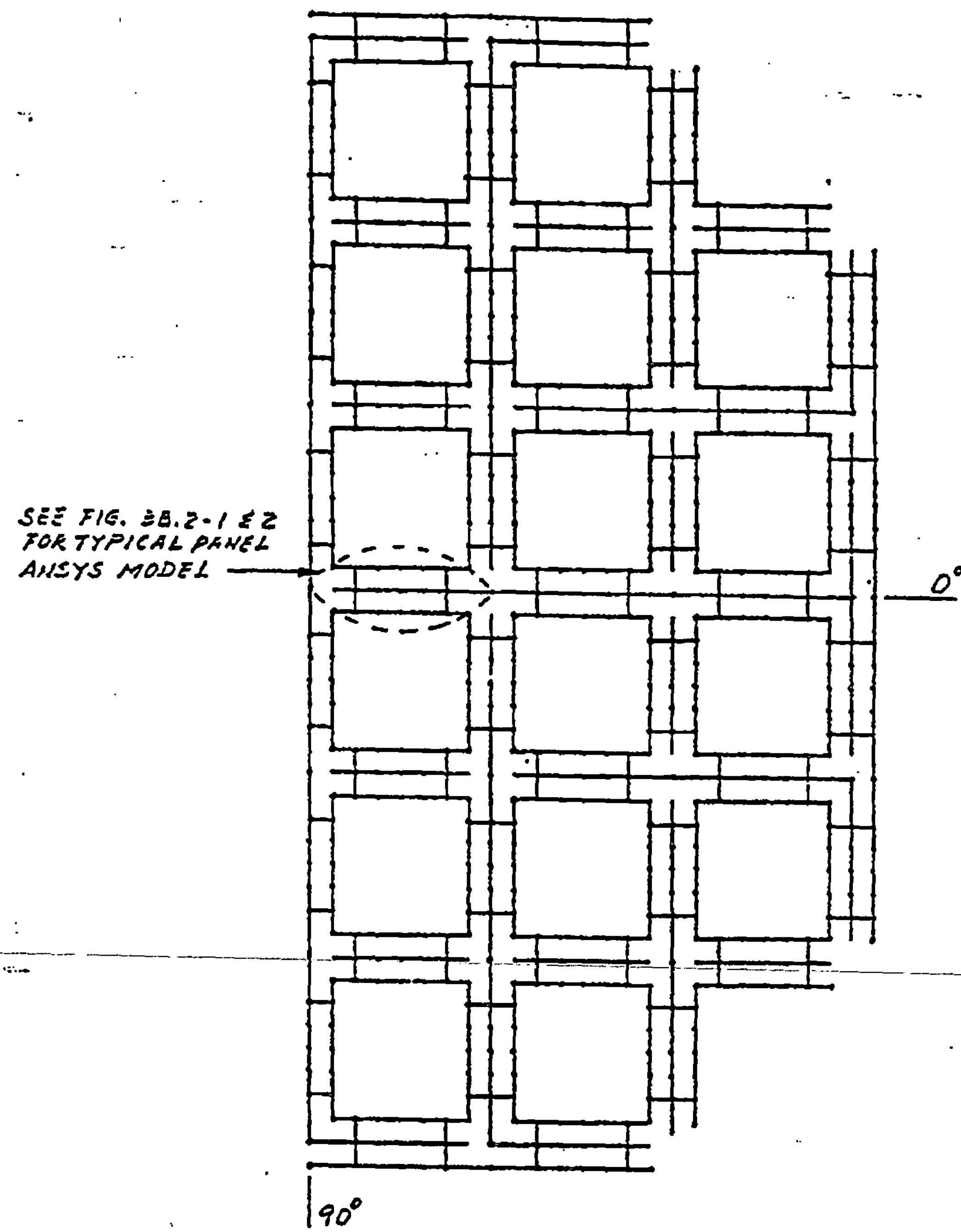


FIGURE 3B.2-3
BASKET ANSYS MODEL

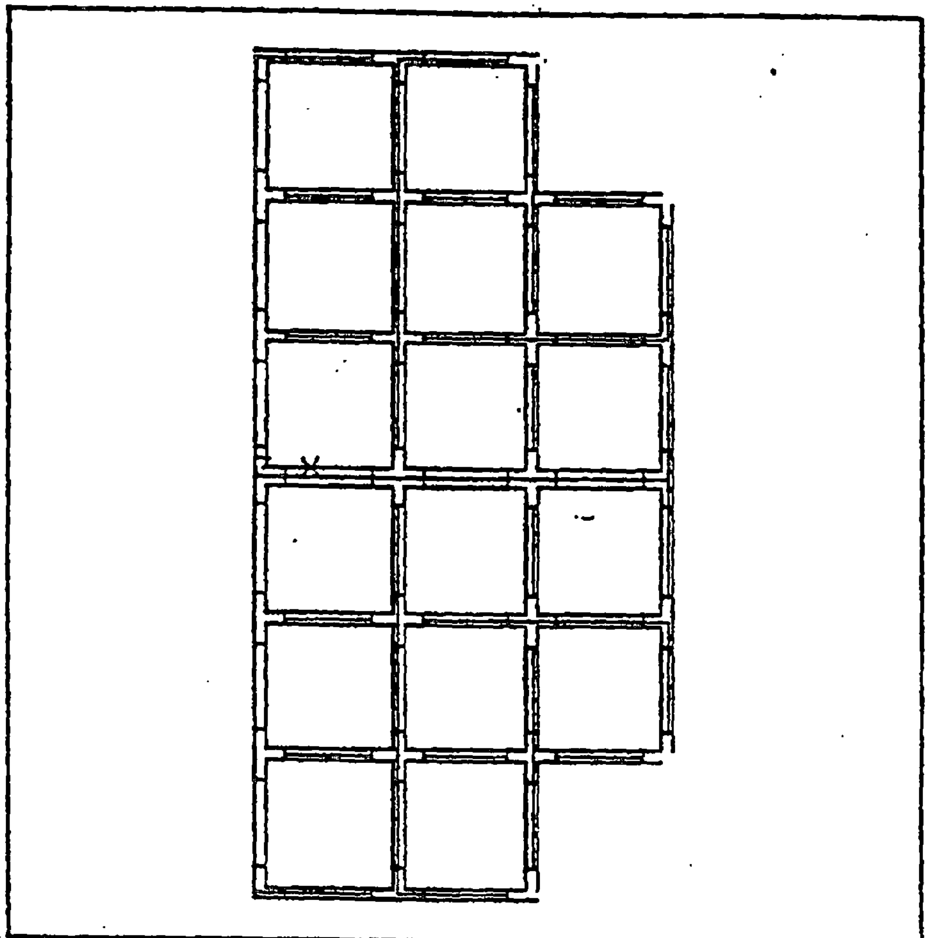


FIGURE 3B.2-4
BASKET SYSTEM MODEL
COMPUTER PLOT

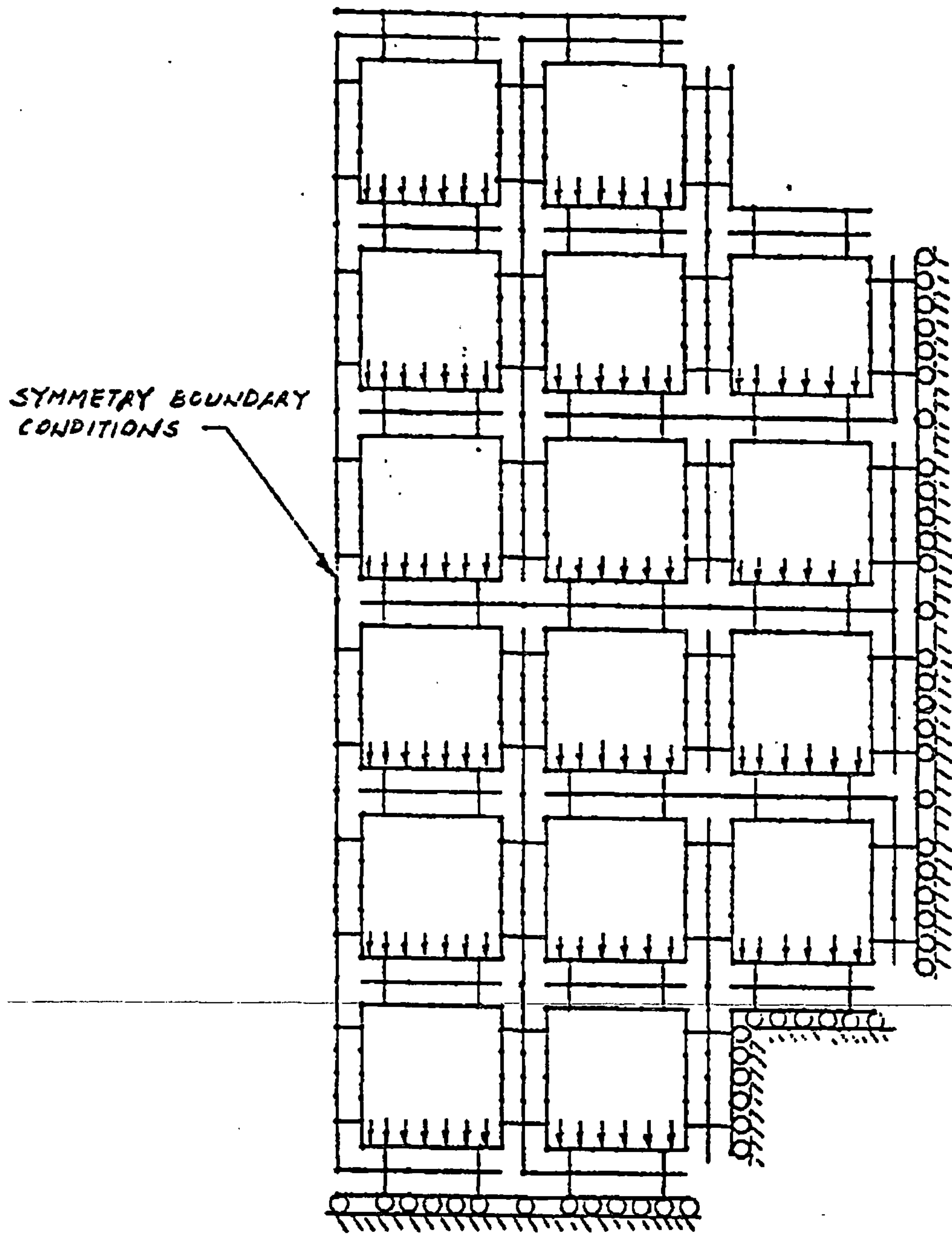


FIGURE 3B.3-1
LOAD DISTIBUTION AND BOUNDARY CONDITIONS-
1G LATERAL (90° ORIENTATION)

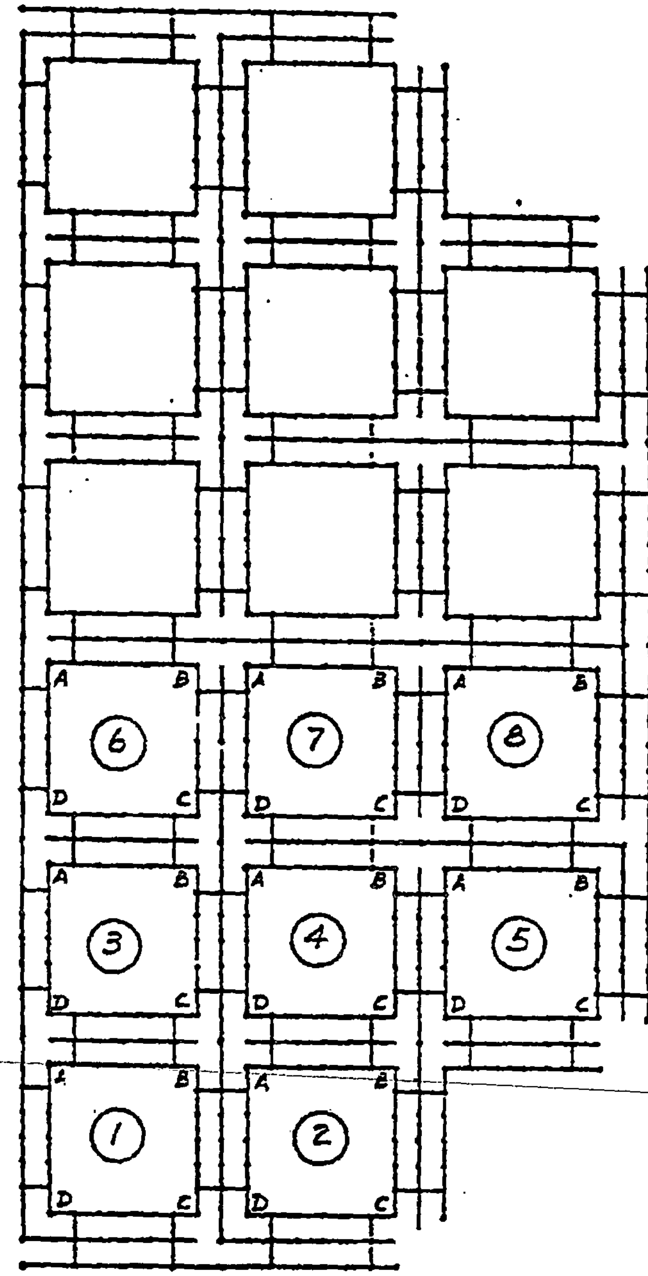


FIGURE 3B.3-2
BASKET PANEL CORNER REGION
STRESS REPORT LOCATIONS

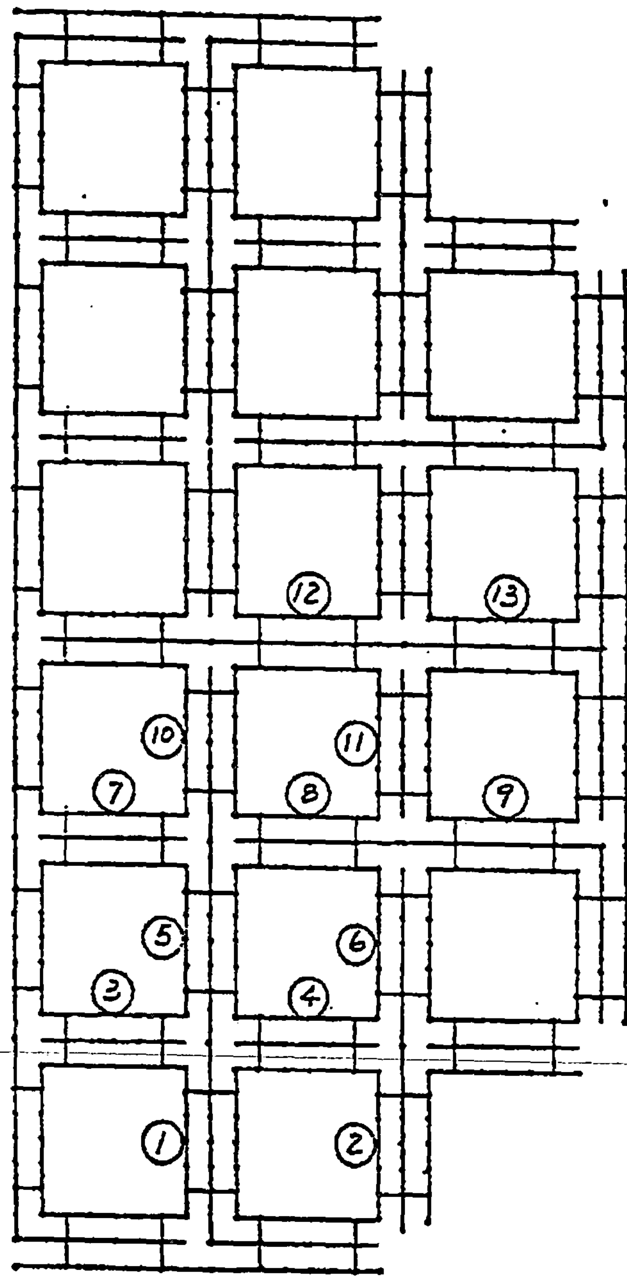


FIGURE 3B.3-3
BASKET PANEL CENTER REGION
STRESS REPORT LOCATIONS

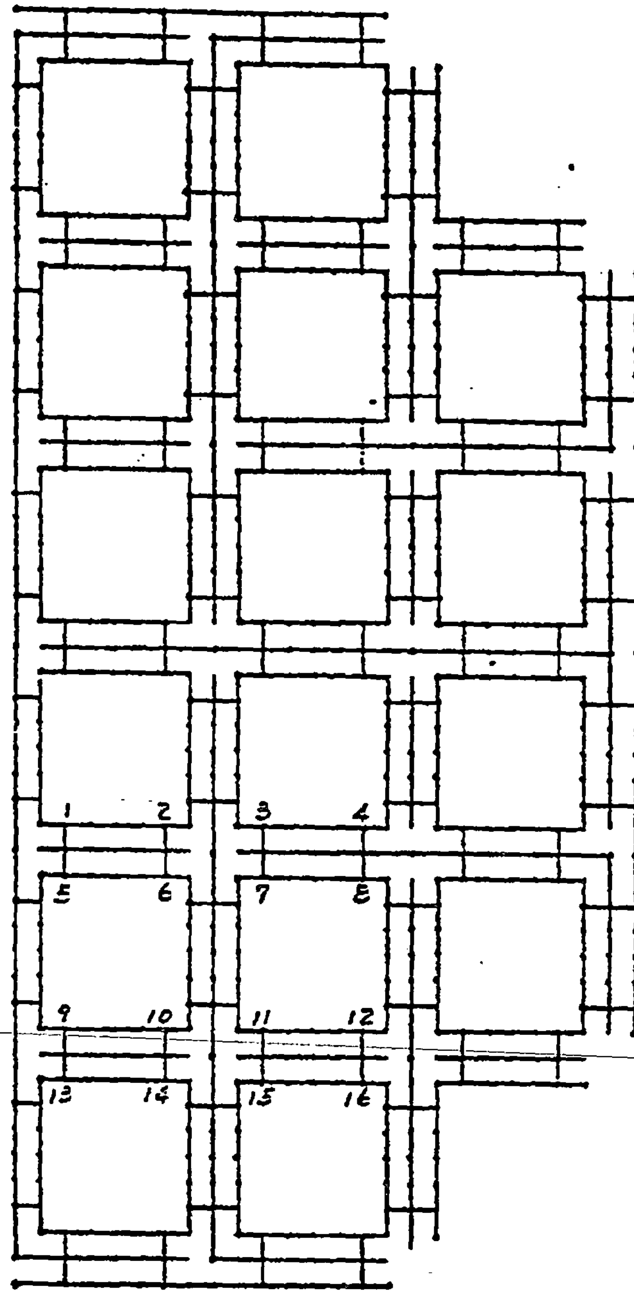
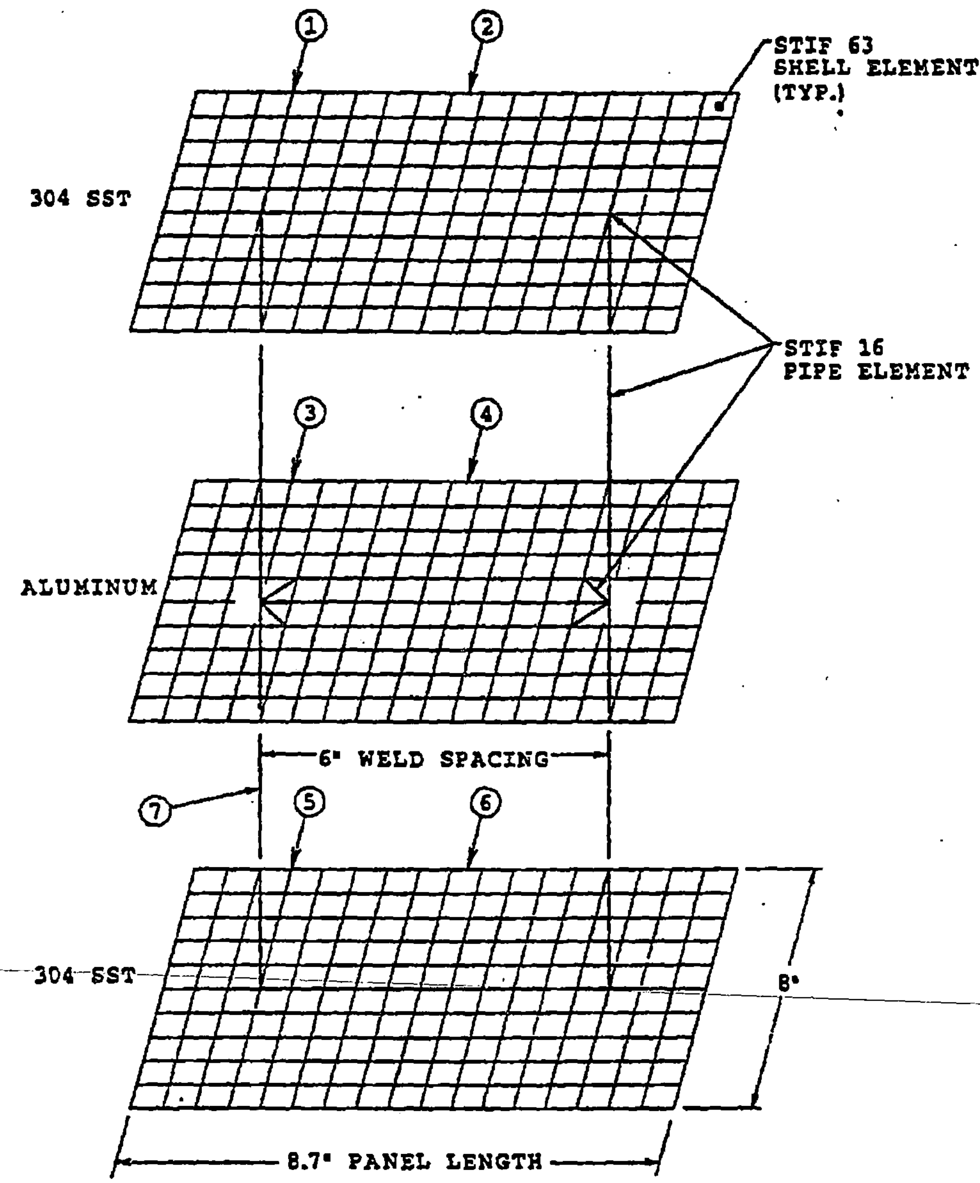


FIGURE 3B.3-4
BASKET PANEL PLUG WELD REGION
STRESS REPORT LOCATIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.3-5
BASKET STRESS DUE TO
3G VERTICAL LOAD

REV. 0 1/00



NOTE: STRESSES REPORTED AT THESE LOCATIONS ARE AN AVERAGE ALONG THE SECTION OF THE PLATE.

FIGURE 3B.3-6
DETAILED PANEL MODEL
THERMAL RUN & STRESS
REPORTING LOCATIONS

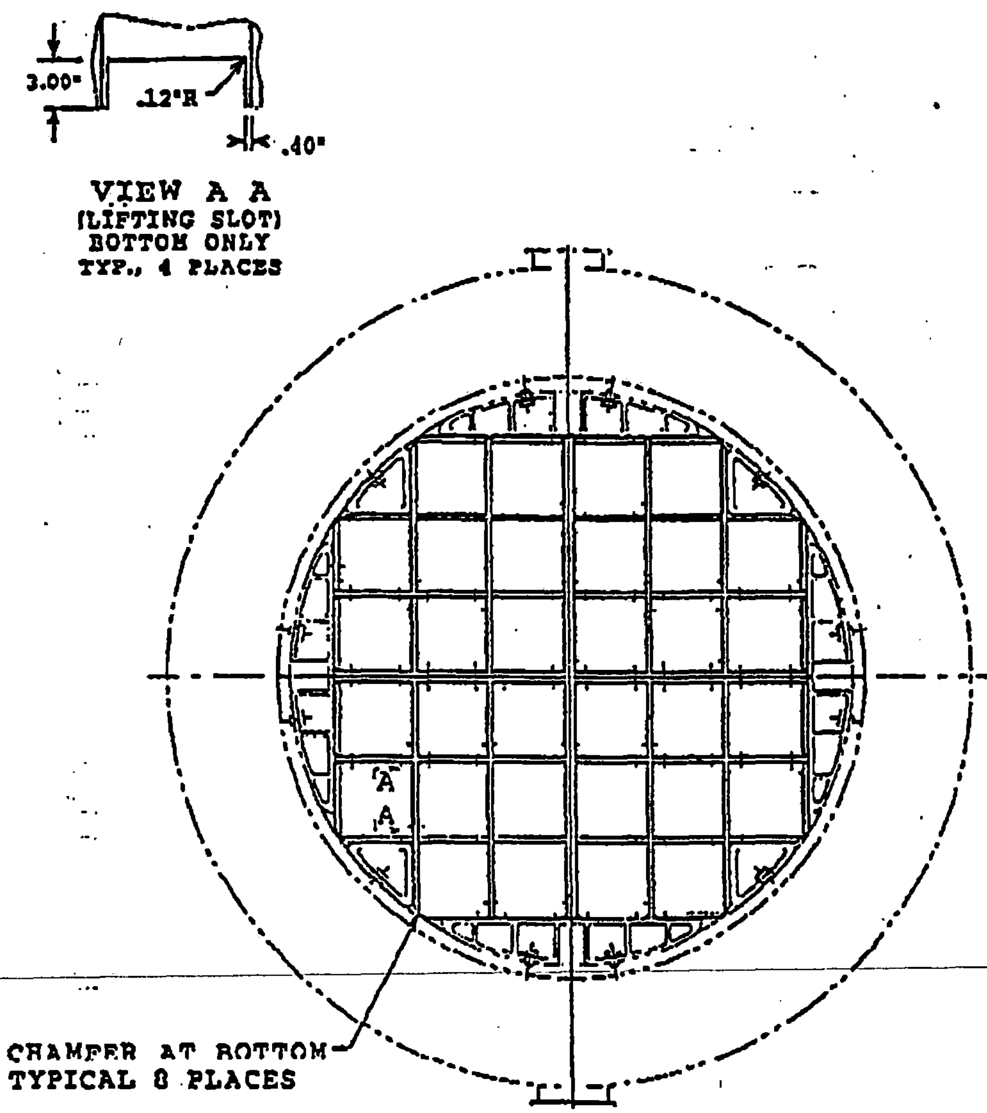


FIGURE 3B.3-7
BASKET LIFTING SLOTS AND CHAMFERS

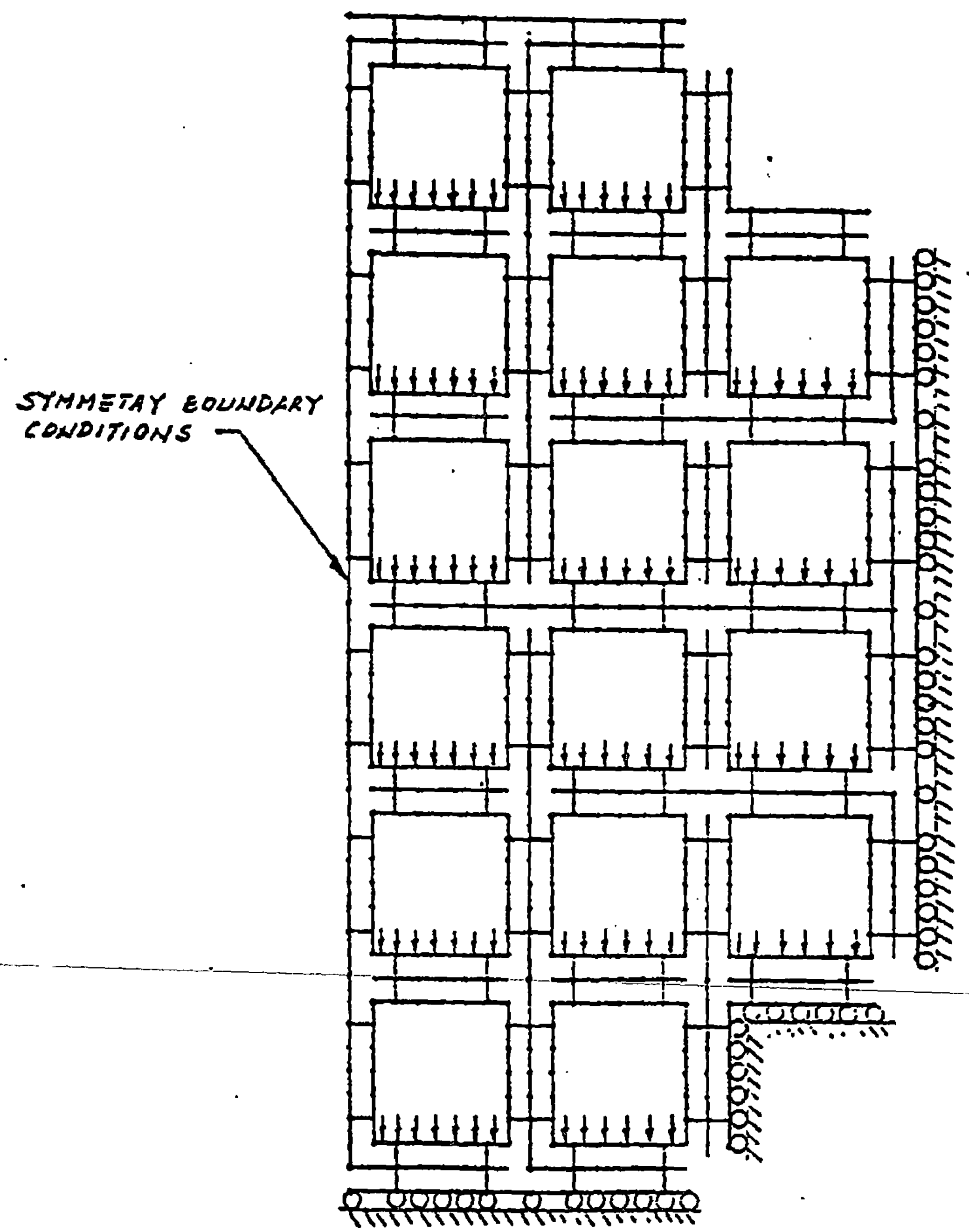


FIGURE 3B.4-1
LOAD DISTRIBUTION AND BOUNDARY CONDITIONS-90° DROP

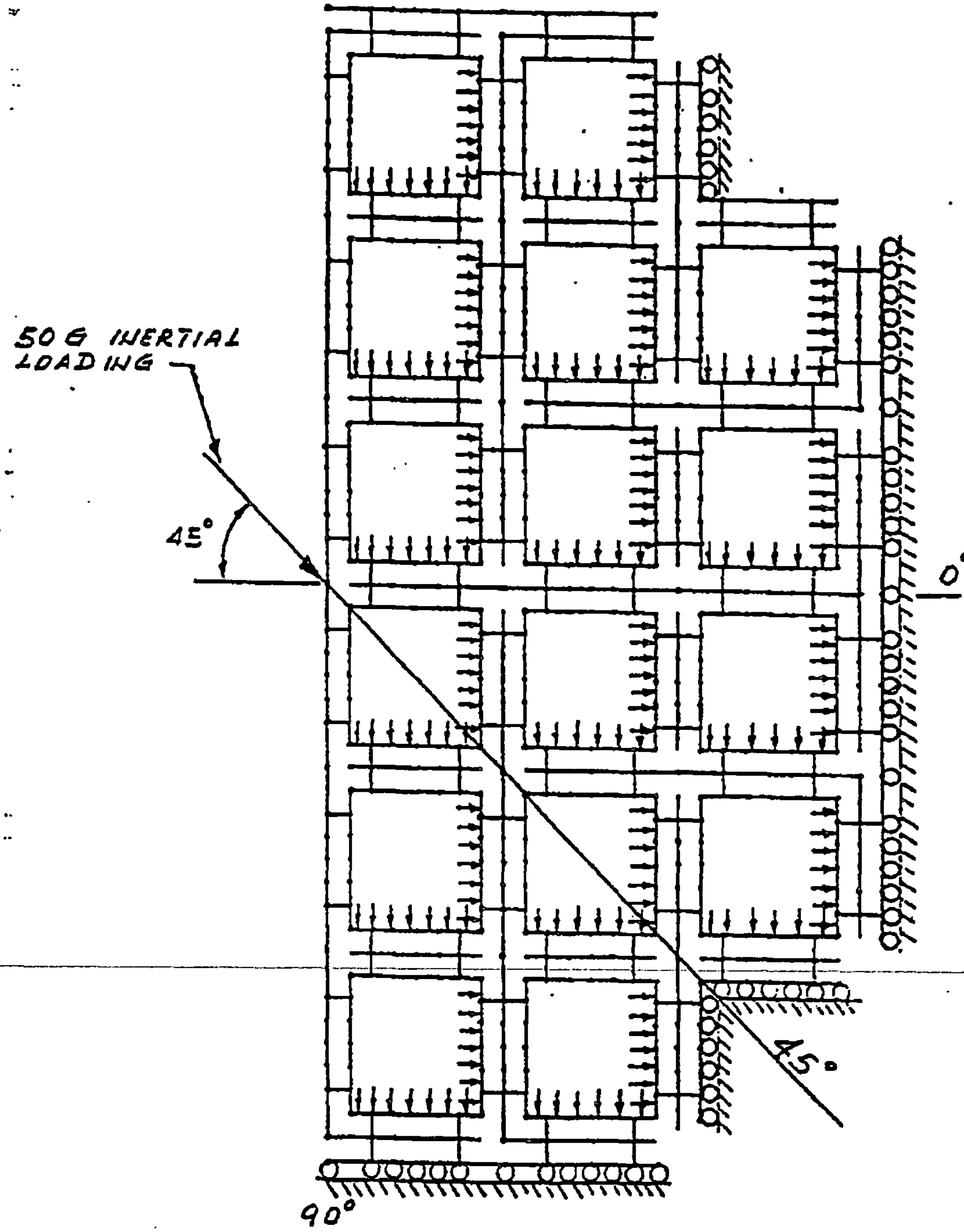


FIGURE 3B.4-2
LOAD DISTRIBUTION AND BOUNDARY
CONDITIONS-45° DROP

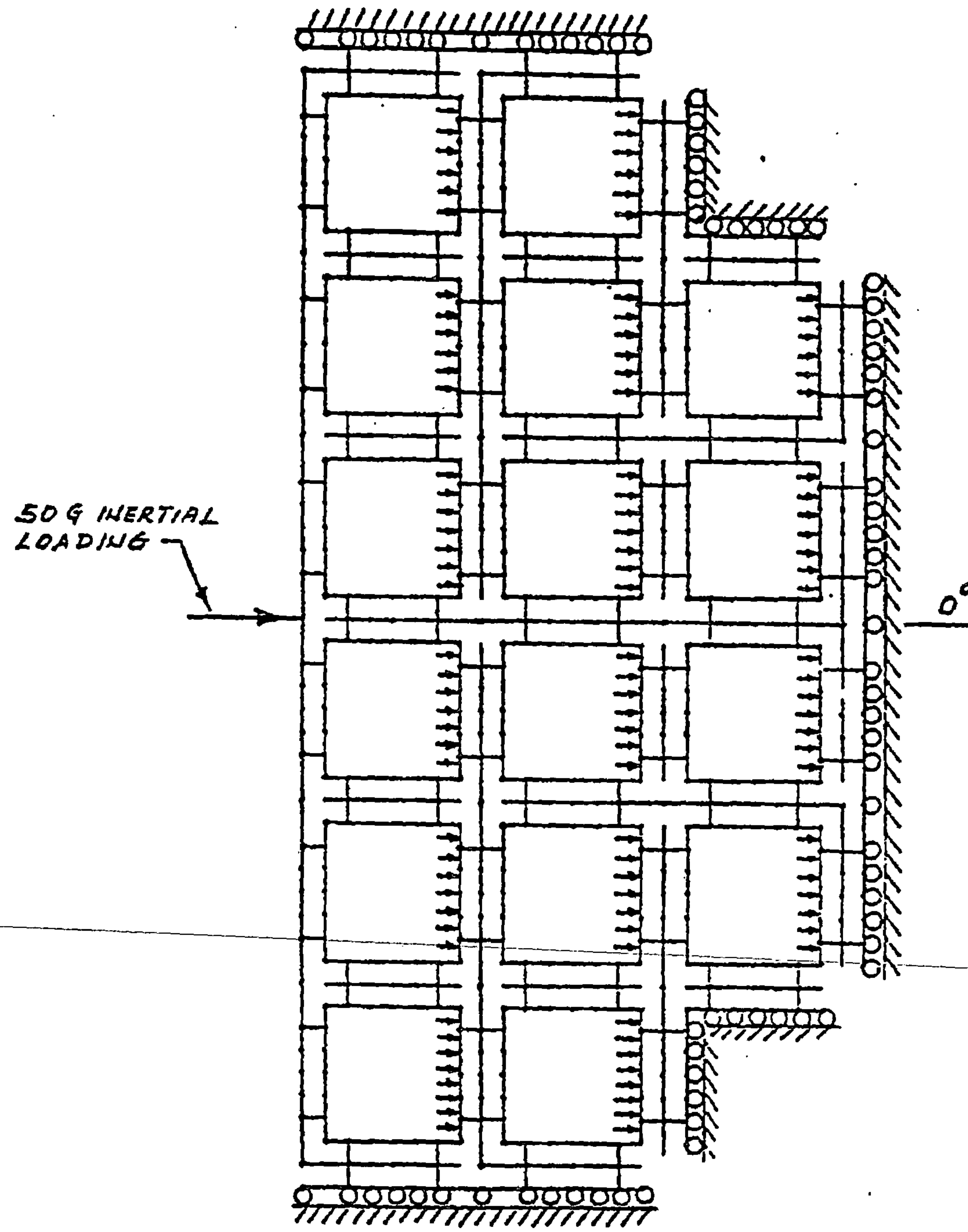


FIGURE 3B.4-3
LOAD DISTRIBUTION AND BOUNDARY CONDITIONS-0° DROP

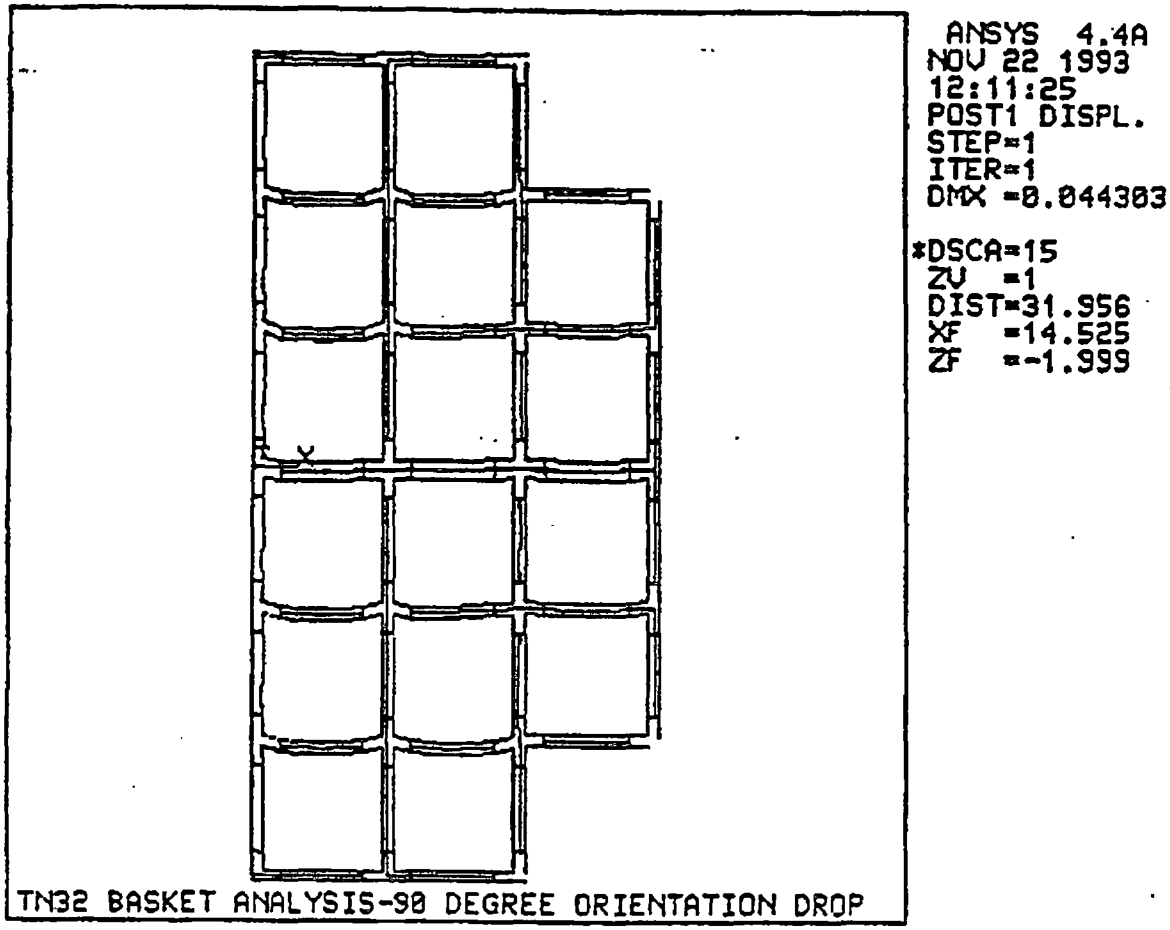


FIGURE 3B.4-4
DISPLACEMENT PLOT
90° DROP

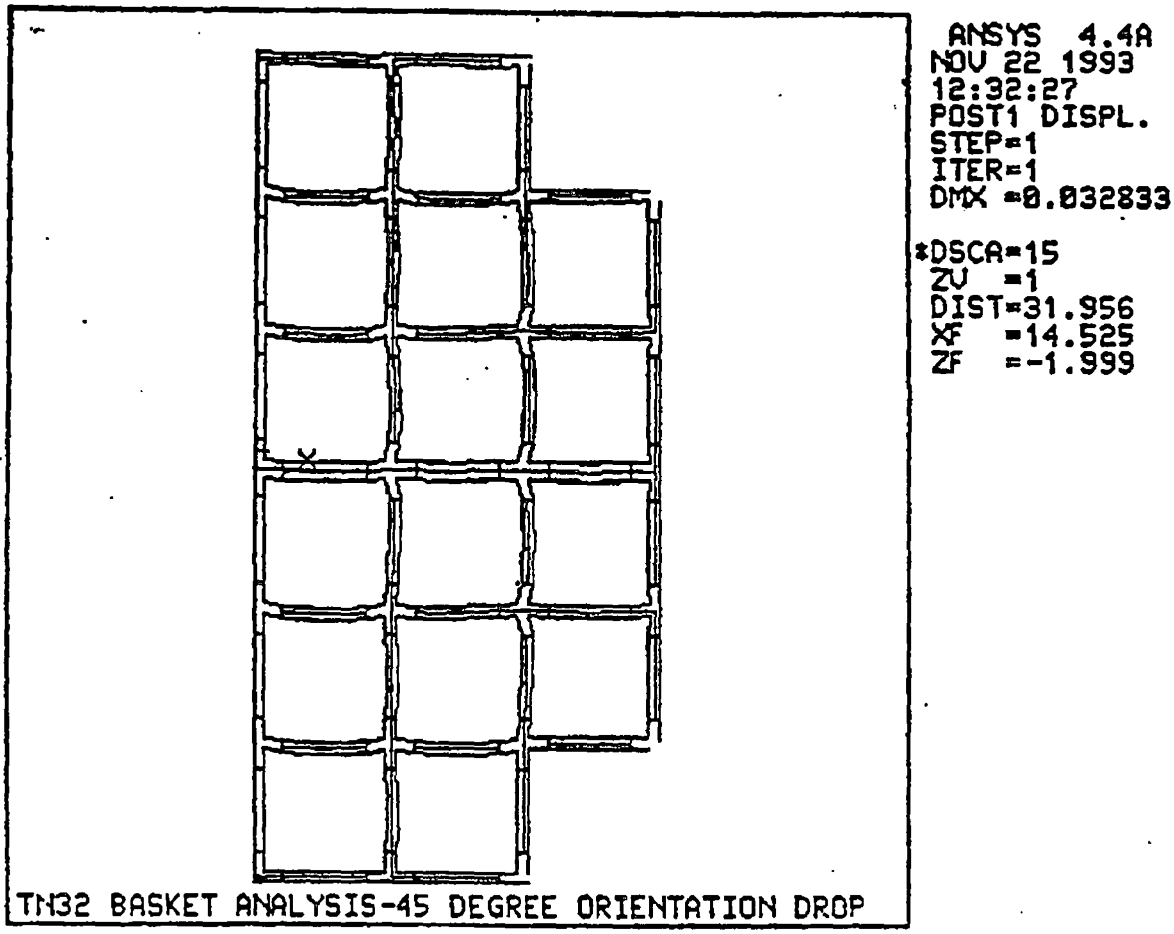


FIGURE 3B.4-5
DISPLACEMENT DROP
45° DROP

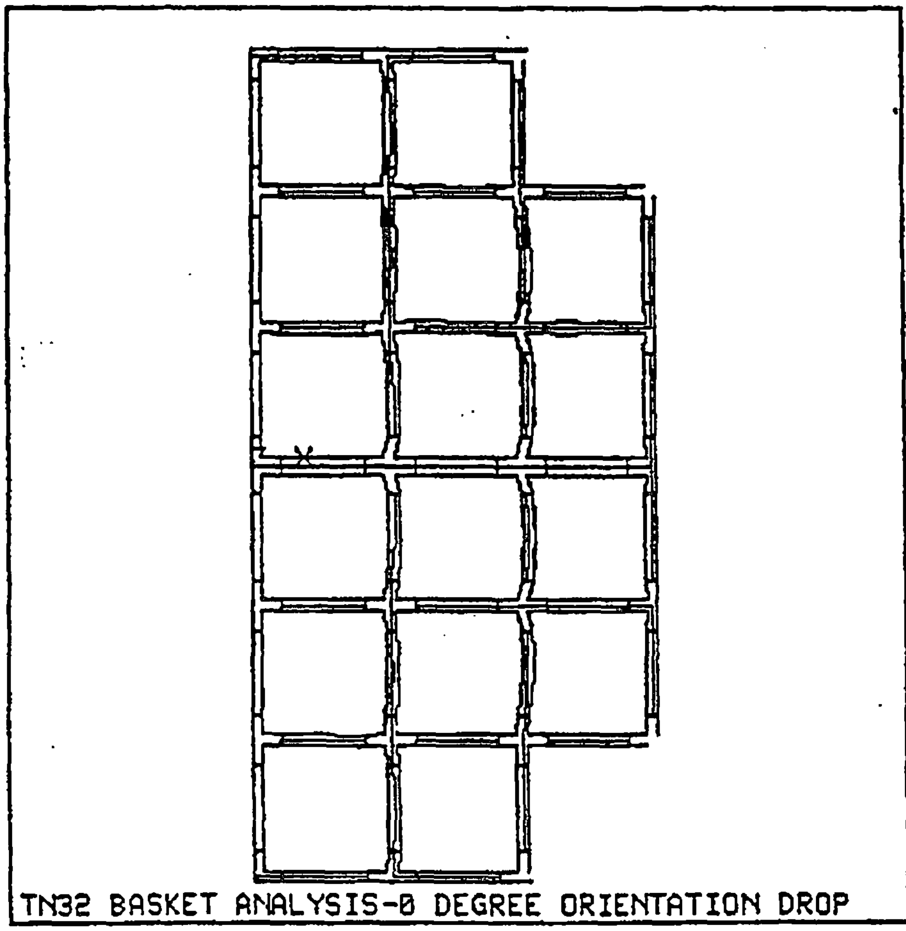


FIGURE 3B.4-6
DISPLACEMENT PLOT
0° DROP

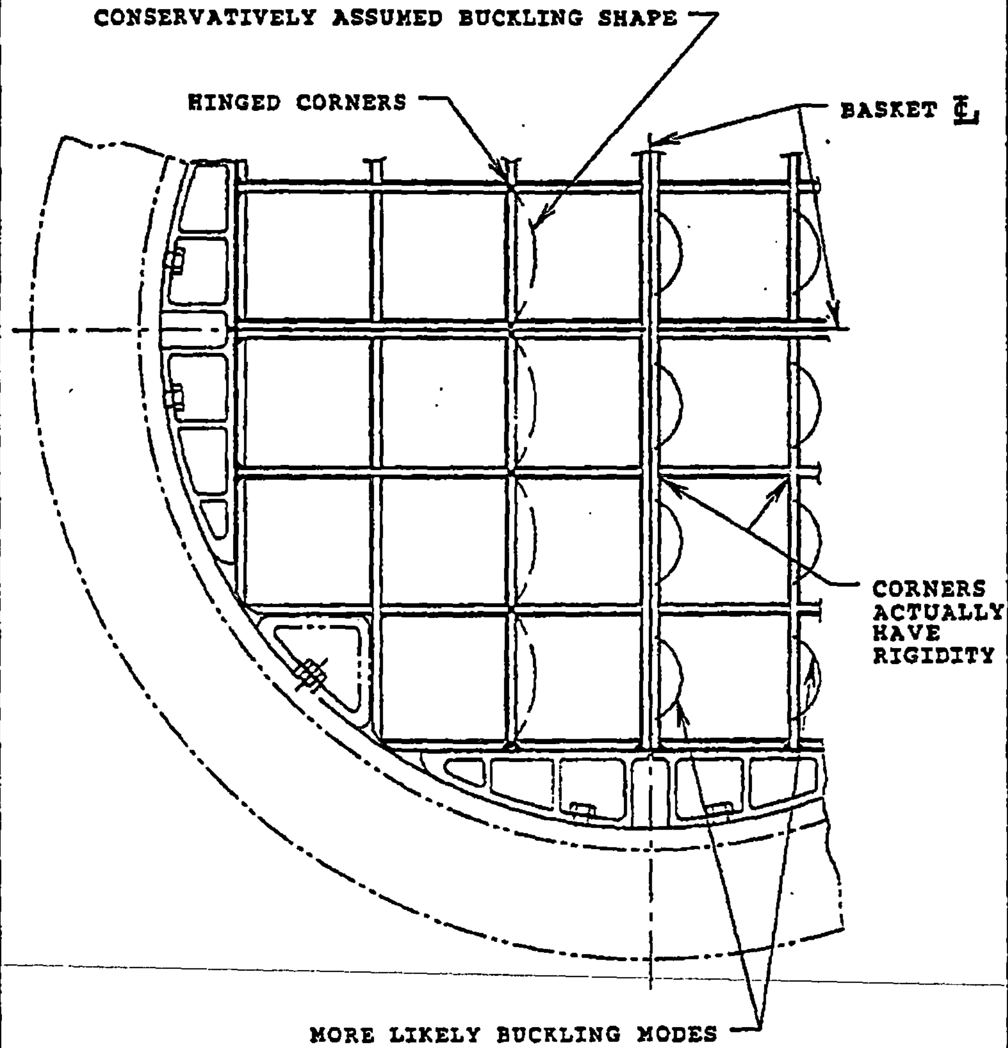


FIGURE 3B.4-7
BASKET BUCKLING MODES

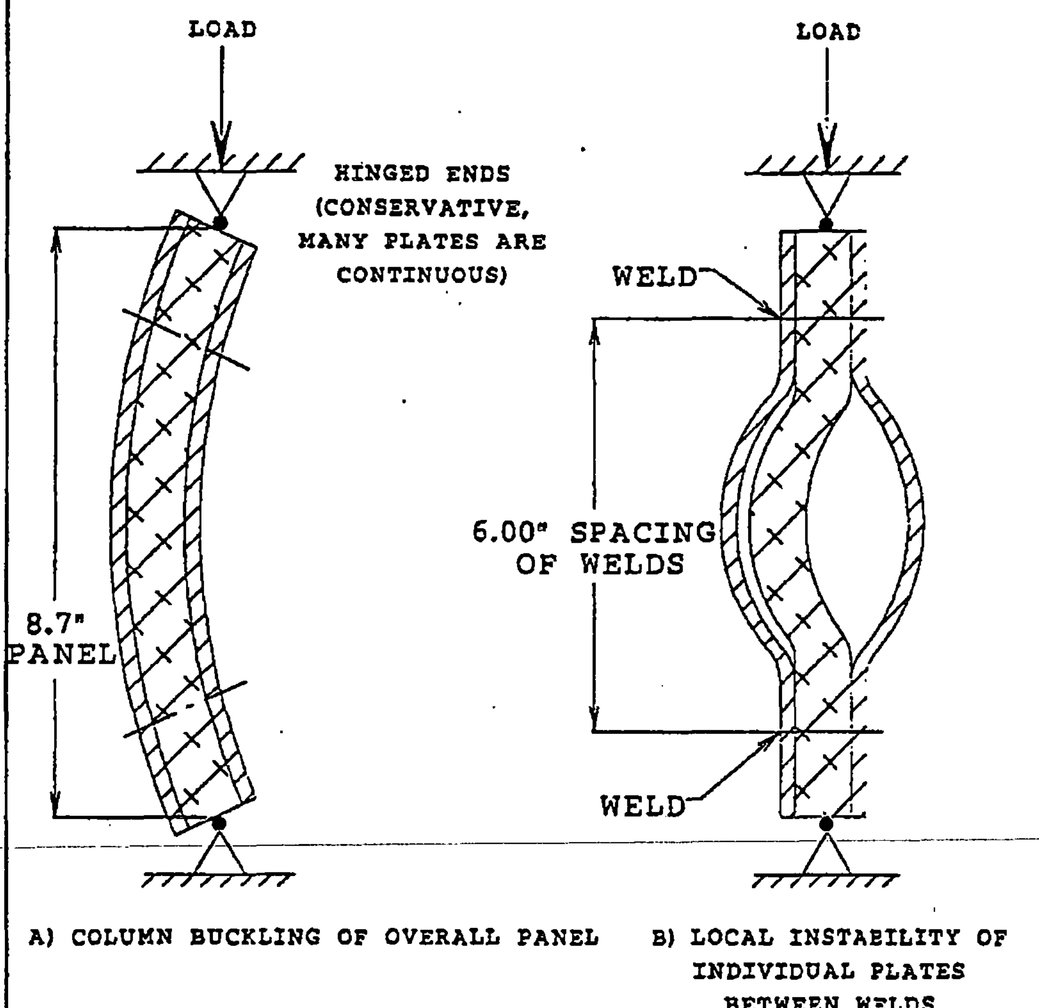


FIGURE 3B.4-8
PANEL STABILITY UNDER
COMPRESSIVE LOAD - SINGLE
ALUMINUM PLATE

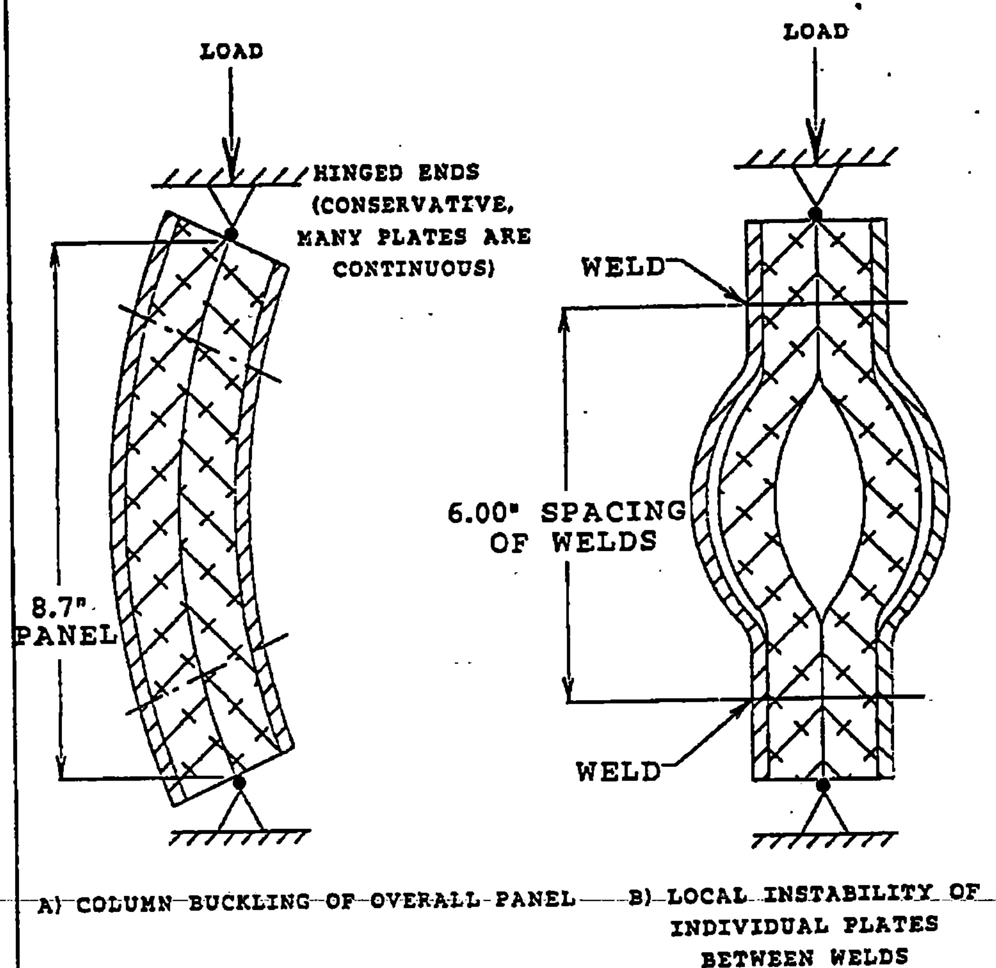
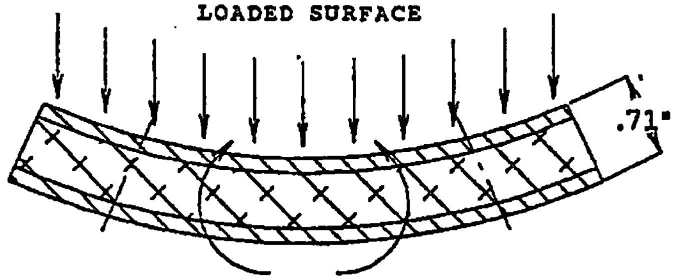


FIGURE 3B.4-9
PANEL STABILITY UNDER
COMPRESSIVE LOAD - DOUBLE
ALUMINUM PLATES



$\sigma_x = \frac{E}{1-\mu^2}\ y\ \frac{M}{D}$ (CLASSICAL BENDING OF A FLAT PLATE)

THEREFORE:

$$M = \frac{\sigma_x D (1-\mu^2)}{E y}$$

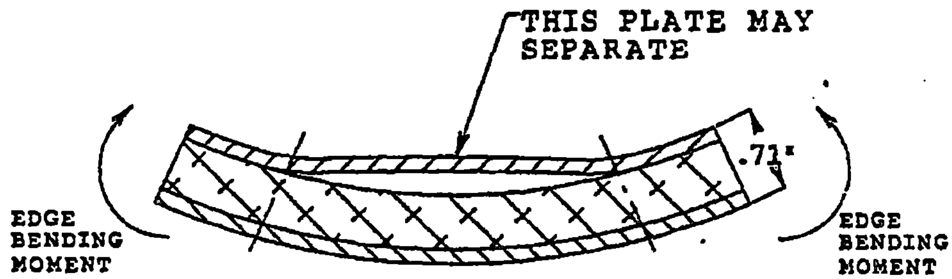
SUBSTITUTING:

$E_{304\ SST} = 26.5 \times 10^6$ PSI @ 400°F
$y = .355$ TO OUTER FIBER
$\sigma_x = S_y$ @ 400°F = 20700 PSI
$D = .8686 \times 10^6$ IN.-LB.

THE ALLOWABLE BENDING MOMENT WITH SURFACE LOADING IS:

$M_a = 1739$ IN.-LB./IN.

FIGURE 3B.4-10
PANEL STABILITY EVALUATION - BENDING MOMENT LIMIT WITH APPLIED LOAD ON COMPRESSIVE SURFACE PLATE - SINGLE ALUMINUM PLATE



$$\sigma_x = \frac{E}{1-\mu^2}\, y\, \frac{M}{D}$$

THEREFORE:

$$M = \frac{\sigma_x D (1-\mu^2)}{E\, y}$$

SUBSTITUTING:

$E_{304\ SST} = 26.5 \times 10^6$ PSI @ 400°F

$y = .355$ TO OUTER FIBER

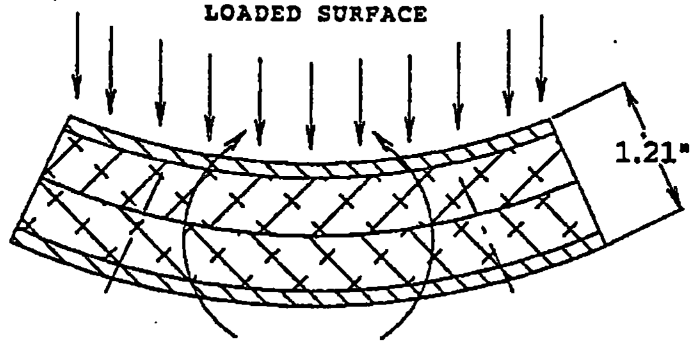
$\sigma_x = 7670$ PSI (ALLOWABLE LEVEL C STRESS IN STAINLESS PLATE TO ENSURE IT DOES NOT BUCKLE AS SKETCHED).

$D = .8686 \times 10^6$ IN.-LB.

THE ALLOWABLE BENDING MOMENT IS THEN:

$M_a = 644$ IN.-LB./IN.

FIGURE 3B.4-11
PANEL STABILITY EVALUATION
BENDING MOMENT LIMIT WITH COMPRESSION
SURFACE PLATE FREE TO SEPARATE - SINGLE
ALUMINUM PLATE



$\sigma_x = \frac{E}{1-\mu^2} \; y \; \frac{M}{D}$ (CLASSICAL BENDING OF A FLAT PLATE)

THEREFORE:

$$M = \frac{\sigma_x D (1-\mu^2)}{E y}$$

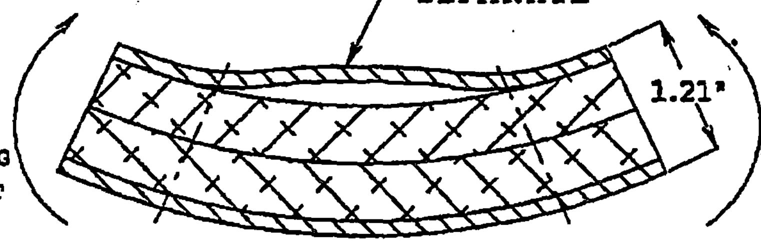
SUBSTITUTING:

$E_{304\ SST} = 26.5 \times 10^6$ PSI @ 400°F
$y = .605$ TO OUTER FIBER
$\sigma_x =$ Sy @ 400°F = 20700 PSI
$D = 4.299 \times 10^6$ IN.-LB.

THE ALLOWABLE BENDING MOMENT WITH SURFACE LOADING IS:

~~$M_a = 5051$ IN.-LB./IN.~~

FIGURE 3B.4-12
PANEL STABILITY EVALUATION - BENDING MOMENT LIMIT WITH APPLIED LOAD ON COMPRESSIVE SURFACE PLATE - DOUBLE ALUMINUM PLATES



$$\sigma_x = \frac{E}{1-\mu^2}\, y\, \frac{M}{D}$$

THEREFORE:

$$M = \frac{\sigma_x D\,(1-\mu^2)}{E\, y}$$

SUBSTITUTING:

$E_{304\ SST} = 26.5 \times 10^6$ PSI @ 400°F
y = .605 TO OUTER FIBER
σ_x = 7670 PSI (ALLOWABLE LEVEL C STRESS IN STAINLESS PLATE TO ENSURE IT DOES NOT BUCKLE AS SKETCHED)
$D = 4.299 \times 10^6$ IN.-LB.

THE ALLOWABLE BENDING MOMENT WITH SURFACE LOADING IS:

M_a = 1872 IN.-LB./IN.

FIGURE 3B.4-13
PANEL STABILITY EVALUATION
BENDING MOMENT LIMIT WITH COMPRESSION SURFACE PLATE FREE TO SEPARATE - DOUBLE ALUMINUM PLATES

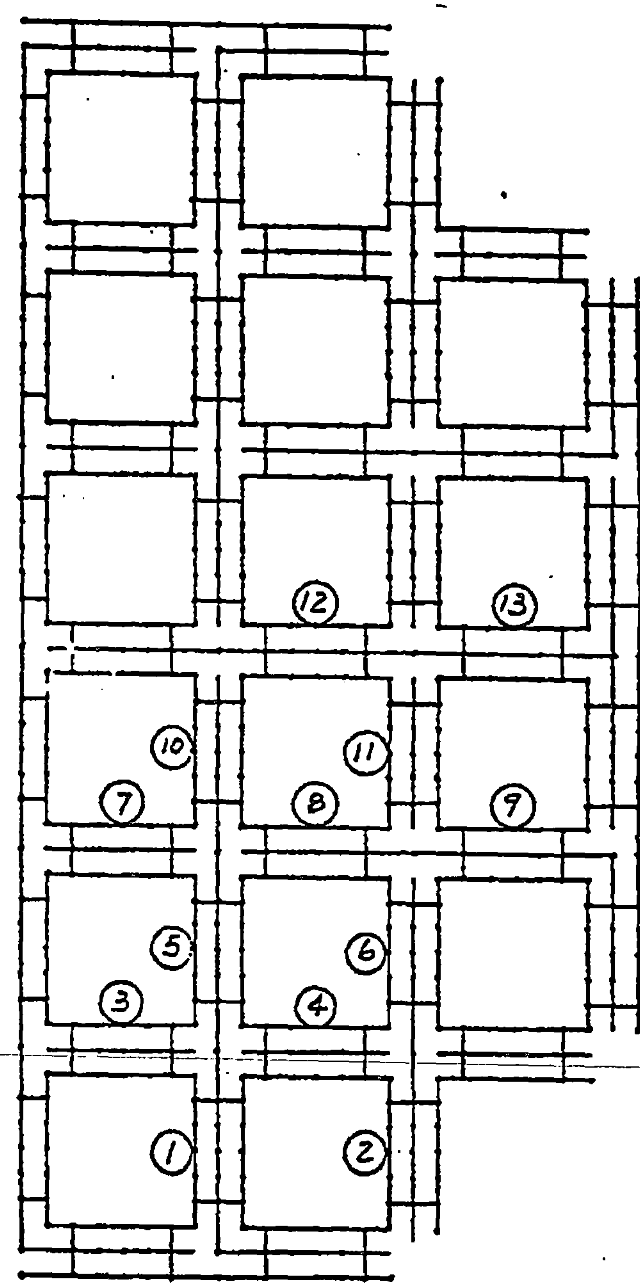


FIGURE 3B.4-14
BASKET PANEL CENTER REGION
STRESS REPORT LOCATIONS

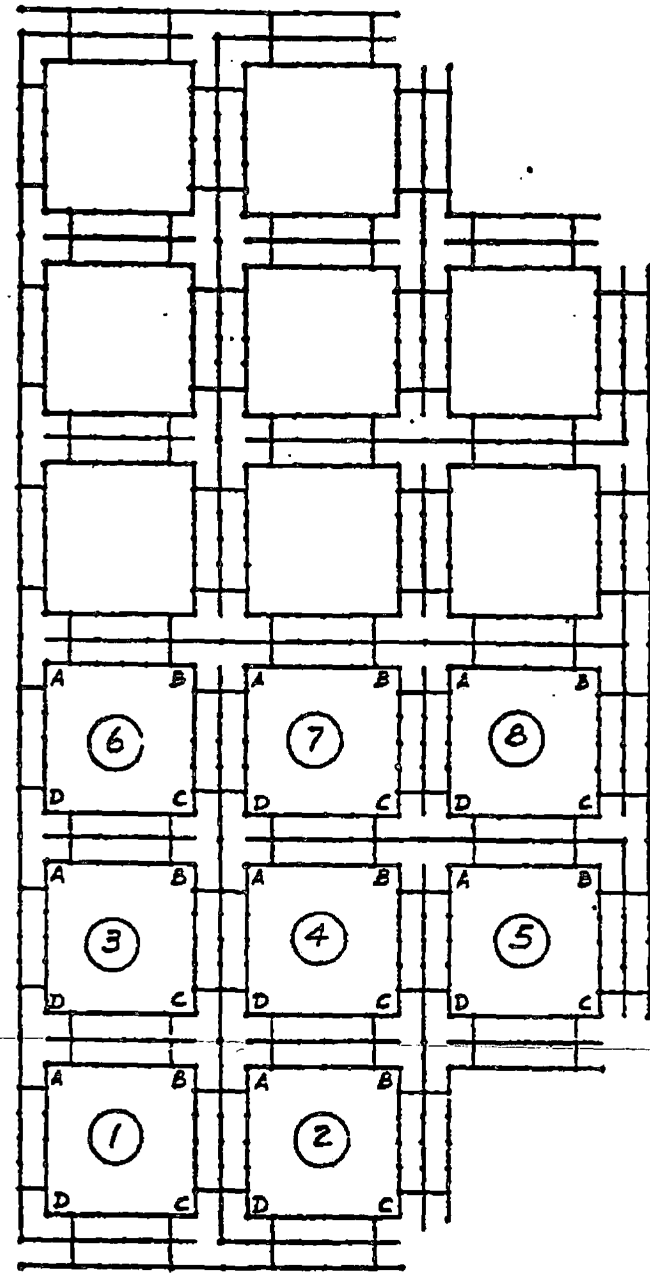


FIGURE 3B.4-15
BASKET PANEL CORNER REGION STRESS REPORT LOCATIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.4-16

FINITE ELEMENT MODEL SIMULATION FOR BOTTOM RAIL

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.4-17

FINITE ELEMENT MODEL SIMULATION FOR SIDE RAIL

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.4-18

PANEL STABILITY UNDER COMPRESSIVE LOAD

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 3B.4-19
FINITE ELEMENT MODEL SIMULATION
FOR BASKET PANEL

APPENDIX 3C

INELASTIC ANALYSIS OF THE TN-32 BASKET

3C.1 Introduction

The details of the TN-32 Basket are shown on TN Drawing Nos. 1049-70-5 and 1049-70-6. The basket structure consists of an assembly of stainless steel cells joined by fusion welded stainless steel plugs and separated by aluminum and poison plates. The stainless steel, aluminum and poison material between fuel components is effectively a sandwich panel. The panel consists of two 0.105 in. thick 304 stainless plates and one 0.5 inch thick 6061-T6 aluminum plate (except at the center cross panels, which have two 0.5 in. aluminum plates) surrounding the 0.040 in. thick poison plate. The aluminum provides the heat conduction path from the fuel assemblies to the cask cavity wall and the poison material provides the necessary criticality control.

The NRC staff requested additional analyses be performed:

- Peak amplitude of 55 G (lateral inertial loading)
- Pulse shape of an isosceles triangle
- Pulse duration of 6 millisecs.

In order to form a basis for this evaluation, equivalent static acceleration values are established by determining the maximum dynamic load factor (DLF) possible for an isosceles triangle input pulse.

Referring to NUREG/CR-3966[1], Methods for Impact Analysis of Shipping Containers, Figure 2.3 (reproduced here in Figure 3C.1-1), DLF_{max} = 1.5 for an isosceles triangle input pulse.

For completeness, Transnuclear, Inc. performed a modal analysis of the TN-32 basket. Results of this analysis, reported for reference only, showed a peak DLF of 1.35 for the TN-32 basket.

The DLF of 1.6 was uniformly applied to the analyses. This corresponds to an acceleration of 88 G. This DLF is larger than the maximum achievable under an isosceles triangle input pulse and larger than the value obtained from the modal analysis. This larger value was chosen to alleviate any concerns about the effect of slightly higher input accelerations or slightly different input pulse shapes.

The dynamic load factors are summarized in Table 3C.1-1.

Table 3C.1-1
Maximum Dynamic Load Factors

	For Isosceles Triangle (Based on Ref. 1)	Based on TN Modal Analysis	Used in Structural Analysis
Max DLF	1.5	1.35	1.6
Corresponding Acceleration	83G	74G	88G

Transnuclear, Inc. also performed a tipover analysis of the TN-32 cask. Results of this analysis, reported in Appendix 3D, showed a maximum G load of 74 should be used for the basket structure analysis. Therefore, using 88G's for structural analysis of the basket is conservative.

Elastic-plastic analyses of the TN-32 basket were performed and are presented in Appendix Sections 3C.2 and 3C.3.

Section 3C.2: 88G side impact analysis. Modeling aluminum plates elastically while allowing plastic material behavior to develop in the stainless steel plates, all material properties at 400°F temperature (maximum calculated temperature at top section of the basket is 391°F, see Figure 4.4-9).

Section 3C.3-1: 88G side impact analysis. Including support rails in the model, all materials are modeled plastically. Basket material properties at 400°F temperature and support rail material at 350°F temperature (maximum rail temperature in the hottest section is 339°F, see Table 4.1-1).

Section 3C.3-2: 52G side impact analysis. Including support rails in the model, all materials are modeled plastically. Basket material properties at 531 °F temperature (maximum calculated basket temperature in the hottest central part of basket is 527°F, see Figure 4.4-8) and support rail material at 350°F

temperature (maximum rail temperature in the hottest section is 339°F, see Table 4.1-1).

3C.2 Stress Analysis of the Basket Structure

The ANSYS[2] finite element model described in the Appendix 3B was used to perform the structural analysis with the following modifications:

- The new model has approximately four times as many elements as the previous model to ensure that the plastic behavior of the 304 stainless steel is properly represented.

- In the previous model, several of the aluminum conduction paths which consist of two 0.5" aluminum plates were represented as a single plate having equivalent bending and tensile stiffness. Both plates are included in the new model and carefully modeled to define each plate connection.

- The corner geometries have been updated to reflect current basket configuration shown in Drawings 1049-70-5 and 1049-70-6.

- The fuel assemblies are modeled by increasing the density of the contact surface of the stainless steel plate, rather than as a pressure loading.

In Appendix 3B, analyses were performed for three different basket orientations (90 °, 45 °, and 0 °). The results show that the 90 ° orientation yielded the highest stresses on the basket structure. Therefore, the structural analysis of the basket was performed for the 90° load case.

This section presents the structural analysis of the TN-32 basket in the unlikely event of cask tipover on the concrete pad. The stainless steel is modeled as a plastic material and the aluminum plates are modeled elastically. The analysis performed assumed an 88 G lateral inertial loading of the basket. The basket structure is designed to provide sufficient structural rigidity to maintain separation of the fuel assemblies and a subcritical configuration under the applied loadings. The deformations and stresses induced in the basket structure due to the applied loads are determined using the ANSYS computer program. The inertial G loads due to the fuel assemblies are distributed evenly over the contact layers of the 304 stainless steel boxes. The weight of the basket structure itself is also considered. The new basket model is shown on Figure 3C.2-1. Boundary and loading conditions used for the structural analysis are shown on Figure 3C.2-2.

Loading

An inelastic analysis requires an iterative solution and the actual load-history needs to be followed. The magnitude of the first load step is such as to produce stress near yield. The subsequent load steps are small. The inelastic analysis is extended to an inertial loading of 88 G. Following is the detail of the load step history used in the analysis:

Table 3C.2-1
Load Steps for Inelastic analysis

Load Step	No. of Iterations	Inertial Loading (G's)
1	3	35
2	7	50
3	12	55
4	19	60
5	27	70
6	35	75
7	44	80
8	53	85
9	57	88

Basket Material Properties

The material properties of the 304 stainless steel plates are taken from the ASME[3] Code, Section II, Part D. The material properties of the aluminum alloy (6061-T6/T651) are also taken from the ASME Code. These properties are listed with specific references in Chapter 3. The following accident drop case was analyzed assuming plastic behavior of the 304 stainless steel plates but elastic aluminum plate behavior. A summary of the stress-strain properties of the 304 stainless steel used for the analysis is given in Table 3C.2-2 below. This is a bilinear stress-strain relationship.

Table 3C.2-2
Mechanical Properties of SA-240 Type 304 SST (400°F)

$E = 26.5 \times 10^6$ psi
$S_m = 18{,}700$ psi
$S_y = 20{,}700$ psi
$S_u = 64{,}400$ psi

Strain (in./in.)	Stress (psi)
0.000781132	20,700
0.1	31,000
0.2	42,000
0.3	53,000
0.4	64,400

Stress Criteria

The stress criteria are taken from Section III, Appendix F of the ASME Code. The acceptance criteria for elastic analysis are provided in Tables 3B.4-1 and 2, and are reproduced below.

Table 3C.2-3
TN-32 Basket Structural Design Criteria for Level D Conditions
(Elastic Analysis)

Numerical Values of Primary Stress Intensity Limits at 400°F		
	304 SS (ksi)	6061 T6/T651 Aluminum (ksi)
Membrane Stress Intensity, P_m	44.9	12.4
Membrane Plus Bending Stress Intensity, $P_m + P_b$	64.4	17.7
Shear Stress, τ	27.0	7.4

The acceptance criteria for plastic analysis are also taken from Section III, Appendix F of the ASME Code and are provided below.

Table 3C.2-4
TN-32 Basket Structural Design Criteria for Level D Conditions
(Plastic Analysis)

Numerical Values of Primary Stress Intensity Limits at 400°F		
	304 SS (ksi)	ASME Reference
Membrane Stress Intensity, P_m	45.1	Appendix F F-1341.2a
Membrane Plus Bending Stress Intensity, $P_m + P_b$	58.0	Appendix F F-1341.2b
Shear Stress, τ	27.0	Appendix F F-1341.2c

Evaluation

Analysis using the basket system model is performed for the 90°load orientation relative to the basket plates as indicated in Figure 3C.2-2. Detailed stresses and displacements of the basket are obtained and stored for every node location for each individual load case (9 load cases). These stored results are postprocessed to printout the stresses, forces and moments at load case no. 9 (88 G) at the locations on the basket shown on Figures 3C.2-3 through 3C.2-5. The locations selected are key points that indicate the behavior of the entire basket structure. The displacement plot for the 88 G load case is shown on Figure 3C.2-6.

The panel load results from this analysis are presented in Table 3C.2-5. Their corresponding locations are shown on Figure 3C.2-4. This table shows the forces and moments for the 88 G load case. These are the panels most likely to buckle when the basket is subjected to the above lateral inertial load. These forces and moments are evaluated using the interaction equation described in Section 3B.4.3. The interaction equation for compression and bending is:

$$F/P_a + M/M_a \leq 1$$

The allowable compressive force, P_a (P_a= 7,974 lbs/in.) was determined in Section 3B.4.3.2. The allowable bending moment, M_a (M_a = 644 in.-lb/in.) was determined in Section 3B.4.3.4. The buckling interaction total, also listed in Table 3C.2-5, results in a minimum margin of safety of 0.52 for the panel location 1. Therefore the design meets the criteria with margin at a load level of 88 G's.

~~Tables 3C.2-6 lists the stresses at the corner regions and~~ Tables 3C.2-7 and 3C.2-8 list the stresses at the central regions. Their corresponding locations are shown on Figures 3C.2-3 through 3C.2-5.

Based on the results of this analysis, it is concluded that:

1. 304 Stainless Steel Plate

   The maximum membrane stress intensity at 88 G's is 15.9 ksi and occurs at location 1 of Table 3C.2-7. This stress is below the allowable stress of 45.1 ksi ($0.7S_u$) at a temperature of 400°F. The maximum membrane plus bending

stress intensity is 22.6 ksi psi and occurs at location 1 corner B (Table 3C.2-6). This stress is below the allowable stress of 58.0 ksi ($0.9S_u$) at a temperature of 400°F.

2. Shear Stress in 1/2 in. Plug Welds

   The maximum shear stress in the plug weld is 17.2 ksi at location 5 (Table 3C.2-8). This stress is below the allowable stress of 27.0 ksi ($0.42\ S_u$) at a temperature of 400°F.

3. Aluminum Plate

   The maximum membrane stress intensity due to 88 G's is 4.4 ksi and occurs at location 1 (Table 3C.2-7). This stress is below the allowable stress of 12.4 ksi ($2.4\ S_m$) at a temperature of 400°F.

   The maximum membrane plus bending stress intensity is 16.8 ksi and occurs at locations 3 and 4 (Table 3C.2-7). This stress is below the allowable stress of 17.7 ksi(S_u) at a temperature of 400°F.

4. The maximum deflection of 0.066 in. occurs in the center of the top panel. The panels deflect in the same direction. Therefore, the relative spacing between fuel assemblies remains approximately the same. This would allow the fuel assemblies to be removed after a hypothetical accident.

5. The basket plates are structurally adequate under the accident load. The plates will remain in place and maintain separation of adjacent fuel assemblies.

Table 3C.2-5
Basket Panel Loads - Compression and Bending (88G 90° Drop Orientation)

Panel Location (Figure 3C.2-4)	F_y lb/in.	M_z in-lb/in.	Interaction $F/P_a + M/M_a$	Margin to Allowable
1	5,289	≈0	0.66	0.52
2	1,759	42	0.29	2.45
5	4,258	≈0	0.53	0.89
6	2,499	29	0.36	1.78

Table 3C.2-6

Basket Panel Corner Region Stresses Under 88G Side Drop (90° Drop Orientation)

Location (Figure 3C.2-3)		Stress Intensities (ksi)		
		Membrane (P_m)	Membrane + Bending (P_m + P_b)	
		Average	Top Surface	BTM Surface
1	A	7.4	22.5	19.0
	B	8.8	15.9	22.6
	C	8.8	8.8	8.8
	D	6.6	6.4	6.9
2	A	8.5	16.7	22.5
	B	6.5	20.0	22.5
	C	2.6	2.6	8.7
	D	8.7	8.7	2.4
3	A	6.7	21.0	22.5
	B	7.6	17.6	22.1
	C	6.0	17.3	20.1
	D	6.5	18.0	21.1
4	A	6.1	12.3	21.9
	B	6.3	13.7	21.8
	C	7.8	17.3	20.2
	D	8.2	17.5	20.6
5	A	5.4	5.0	6.0
	B	7.6	5.7	12.7
	C	6.0	6.4	5.7
	D	8.6	5.5	11.9
6	A	8.1	8.6	18.6
	B	7.4	5.8	13.0
	C	6.8	17.3	21.1
	D	6.8	18.0	21.1

Table 3C.2-7
Basket Panel Center Region Stresses Under 88 G Side Drop
(90° Drop Orientation)

Location (Figure 3C.2-4)	Maximum Stress Intensities (ksi)			
	304 S.S.		Aluminum	
	P_m	$P_m + P_b$	P_m	$P_m + P_b$
1	15.9	17.0	4.4	4.4
3	8.8	18.7	.02	16.8
4	8.9	18.8	.02	16.8
7	8.9	18.8	.02	16.7
8	6.7	13.6	.04	11.8

Table 3C.2-8

Basket Panel Shear Stresses at Plug Weld Region Under 88G Side Drop (90° Drop Orientation)

Location (Figure 3C.2-5)	304 SS Plug Weld
	Shear Stress (ksi)
1	17.1
2	17.0
3	12.7
4	12.5
5	17.2
6	17.1
7	17.1
8	17.2

3C.3 Plastic Analysis of the Basket and Support Rail Structures

3C.3-1 Stress Analysis Based on Basket Material Temperature at 400°F and Support Rail Material Temperature at 350°F.

In this analysis, the basket model has been modified to allow plastic material behavior to develop in the aluminum plate (all materials are modeled plastically in the revised basket model). The aluminum plates used the following mechanical properties (bilinear stress-strain relationship) at 400°F (reference Section 3C.3-3):

E	8.7×10^3 ksi
S_y	13.3 ksi
S_u	17.7 ksi at 28% strain

The earlier analysis (Section 3C.2) assumed that the peak basket stresses due to the side impact would occur in the horizontal basket plates one compartment away from the support rails. To remove the uncertainties associated with this assumption, the basket rails were explicitly modeled with solid elements and plastic material properties. The extruded aluminum rails have a peak temperature of 339°F, as reported in Table 4.1-1. The analysis conservatively used the following mechanical properties (bilinear stress-strain relationship) of the extruded aluminum rails at 350 °F (reference Section 3C.3-4):

E	9.0×10^3 ksi
S_y	20.0 ksi
S_u	22.4 ksi at 24% strain

The new basket model including support rails is shown on Figure 3C.3-1. Boundary and loading conditions used for the structural analysis are shown on Figure 3C.3-2. The displacement plot for the 88G load case is shown on Figure 3C.3-3 for the basket and rails and Figure 3C.3-4 for the bottom rail.

To facilitate interpretation of the stress analysis results, color contour plots of stress intensities were obtained for each of the membrane and membrane plus bending stress intensities of the stainless steel and aluminum plates.

Based on the results of this analysis, it is concluded that:

1. 304 Stainless Steel Plate

   The maximum membrane stress intensity at 88 G's is 23.3 ksi as shown on Figure 3C.3-5. This stress is below the allowable stress of 45.1 ksi ($0.7S_u$) at a temperature of 400°F. The maximum membrane plus bending stress intensity is 26.8 ksi as shown on Figure 3C.3-6. This stress is below the allowable stress of 58.0 ksi ($0.9S_u$) at a temperature of 400°F.

2. Shear Stress in 1/2 in. Plug Welds

   The maximum shear stress in the plug weld is 16.5 ksi at location 5 (Figure 3C.2-5). This stress is below the allowable stress of 27.0 ksi ($0.42\ S_u$) at a temperature of 400°F.

3. Aluminum Plate

   The maximum membrane stress intensity due to 88 G's is 8.0 ksi as shown on Figure 3C.3-7. This stress is below the allowable stress of 12.4 ksi ($0.7S_u$) at a temperature of 400°F. The maximum membrane plus bending stress intensity is 15.4 ksi as shown on Figure3C.3- 8. This stress is below the allowable stress of 15.9 ksi ($0.9S_u$) at a temperature of 400°F.

4. Under the 88 G compressive load, the maximum vertical plastic deflections are -0.061", -0.057 and +0.009" at locations 1, 2, and 3 (Figure 3C.3-2) respectively. Therefore, the open dimension at locations 2 and 3 of the fuel compartment will be reduced to 8.7"-0.057"-0.009" = 8.634". This opening is greater than the cross section of the fuel assembly (8.426" x 8.426") and provides sufficient clearance for fuel removal. This is the compartment which shows the most deformation.

5. Aluminum Support Rail

   The collapse load in accordance with ASME B & PV Code, Section III, NB-3213.25 and Appendix F, F-1341.3 was calculated and plotted in Figure 3C.3-9 for the bottom support rail at location 1 (Figure 3C.3-4). As shown on Figure 3C.3-9, the collapse load for the rail is 96G and is higher than the design G load of 88.

   Additional analyses were performed to evaluate the stability of the vertical rail plates. The membrane and bending stress intensities at the locations most likely to buckle

are listed in the following table.

Location		Membrane Stress Intensity P_m (ksi)	Bending Stress Intensity P_b (ksi)
Bottom Rail (Figure 3C.3-4)	2	7.4	14.5
	3	6.2	14.3

The allowable compressive stress is 2/3 of the buckling load based on Paragraph F-1334.3 of Appendix F of the ASME Code. The critical buckling load is determined using the Euler equation:

$$P_{cr} = n \pi^2 E I/l^2$$

Where

n = the end condition constant
E = modulus of elasticity, 9.0×10^6 psi (at 350°F)
I = moment of inertia, in^4
l = length of the vertical member, inches

The rail vertical members are fixed at both ends. The theoretical value for the end condition constant is 4, but a value of 1 was used for conservatism.

The allowable compressive stresses for the locations 2 and 3 of the rail are listed in the following table.

Rail Compressive Stresses vs. Allowable Compressive Stresses

LOCATIONS	Critical Load (kips) P_{cr}	Allowable Compressive Load $P=2/3\ P_{cr}$	Allowable Compressive Stress (ksi) $F_a=P/A$	Compress. Stress f_a ANSYS Run
Bottom Rail (Fig. 3C.3-4, Location 2)	41.6	27.7	55.4	7.4
Bottom Rail (Fig. 3C.3-4, Location 3)	55.0	36.7	73.4	6.2

As indicated above, the compressive stresses from the accident loads are well below the allowable compressive stresses.

For combined axial compression and bending, equations 20 and 21 of Paragraph NF-3322.1 (e) (1) apply.

$$f_a/F_a + C_{mx}\ f_b\ /\ [1-(f_a\ /F_e)]\ F_b \leq 1$$

and

$$f_a\ /(1.4)(0.6)S_y + f_b\ /\ F_b \leq 1$$

The allowable stresses for the above equations are determined as follows:

	Allowable Stress	ASME Reference
F_a	P/A	F-1334.5(a)
F_b	1.5 S_y = 30,000 psi	F-1334.5(c)
C_{mx}	0.6	NF 3322.1(e)(1)(b)
Note	The allowable stress F_a is multiplied by 1.4 as allowed by Paragraph F-1334	

The value of F_e is calculated by the formula below per Paragraph F-1334.5(b):

$$F_e = \pi^2 E / [1.30 \times (kl/r)^2]$$

Where

k is conservatively taken as 1
1 is the free length of the member, in.
r is the radius of gyration, in.
E is the modulus of elasticity, 9.0×10^6 psi

This formula gives the following results for F_e:

Location	F_e (ksi)
Bottom rail l = 4.715", r = 0.1442" (Fig. 3C.3-4, Location 2)	63.9
Bottom Rail l = 4.1", r = 0.1442" (Fig. 3C.3-4, Location 3)	84.5

The interaction equations were evaluated for the stresses at the location 2 and 3. The highest stress combination occurs at Location 2 of the bottom rail resulting in the left hand side of Equation (2) of 0.92 which is less than 1.

Based on the results of this analysis, it was concluded that the stresses in the aluminum rails under an 88G side drop load are acceptable.

6. The basket plates and support rails are structurally adequate under the accident load. The plates will remain in place and maintain separation of adjacent fuel assemblies.

3C.3-2 Stress Analysis Based on Basket Material Temperature at 531°F and Support Rail Material Temperature at 350°F.

The SAR indicates in Figure 4.4-9 that the average temperature at the top section of the basket is about 348°F (maxi. Temperature about 391°F). The top of the basket is where the G loads from a tipover would be the highest, and therefore an analysis using a temperature of 400 °F is appropriate. The temperature in the hottest central part of the basket will average about 457 °F, but could be as high as 527°F locally for a few hours under Off Normal Conditions (Figure 4.4-8). The G load at the mid height of the basket will be half ($\approx$ 44 G) of that at the top during tipover, since impact velocity is linear with height above the pivot point.

The basket model has been rerun using mechanical properties at 531°F (bilinear stress-strain relationship) of stainless steel (ASME Section II, Part D) and aluminum (reference 3C.3-3). The mechanical properties at 350 °F (reference 3C.3-4) for the support rails were used (maximum rail temperature in the hottest section is about 339 °F). The analysis performed assumed a 52 G lateral inertial loading of the basket which conservatively bounds the approximate 44 G loading at the middle of the basket. The analysis shows that the stainless steel and aluminum plates at 531 °F are capable of withstanding the tipover accident loads.

Based on the results of this analysis, it is concluded that:

1. 304 Stainless Steel Plate

   The maximum membrane stress intensity at 52 G's is 17.2 ksi as shown on Figure 3C.3-10. This stress is below the allowable stress of 44.5 ksi ($0.7S_u$) at a temperature of 531°F. The maximum membrane plus bending stress intensity is 24.4 ksi as shown on Figure 3C.3-11. This stress is below the allowable stress of 57.2 ksi ($0.9S_u$) at a temperature of 531°F.

2. Shear Stress in 1/2 in. Plug Welds

   The maximum shear stress in the plug weld is 8.9 ksi at location 8 (Figure 3C.2-5). This stress is below the allowable stress of 26.7 ksi ($0.42\ S_u$) at a temperature of 531°F.

3. Aluminum Plate

   The maximum membrane stress intensity due to 52 G's is 3.8 ksi as shown on Figure 3C.3-12. This stress is below the allowable stress of 4.3 ksi ($0.7S_u$) at a temperature of 531 °F . The maximum membrane plus bending stress intensity is 4.7 ksi as shown on Figure 3C.3-13. This stress is below

the allowable stress of 5.6 ksi ($0.9S_u$) at a temperature of 531°F.

4. Under the 52 G compressive load, the maximum vertical plastic deflections are -0.133", -0.141", and +0.006" at locations 1, 2, and 3 (see Figure 3C.3-2) respectively. Therefore, the open dimension at locations 2 and 3 of the fuel compartment will be reduced to 8.7"-0.141"-0.006" = 8.553". This opening is greater than the cross section of the fuel assembly (8.426" X 8.426") and provides sufficient clearance for fuel removal. This is very conservative since the maximum temperature at locations 2 and 3 is about 475°F (see Figure 4.4-8) and the above deflections are calculated based on a temperature of 531 °F.

5. Aluminum Support Rail

   The temperature of the support rail remain 350 °F for this analysis. The results are provided in Section 3C.3-1.

Based on this analysis, the strength of stainless steel and aluminum at 531 °F are sufficient to accommodate the hypothetical tipover accident load in the central portion of the basket.

Based on the results of the 88 G analysis with basket plates at 400°F representing the top of the basket and the analysis performed with 52 G with basket plates at 531 °F representing the center region of the basket, it is concluded that the basket can withstand the hypothetical tipover event.

3C.3-3 Aluminum Material Properties of Basket Plates

The aluminum properties of basket plates are taken from ASME Section II, Part D (1992) and Aluminum Association "Aluminum Standards and Data" (1990)[4].

ASME Section II, Part D has the following aluminum properties:

Material	Temperature, °F					
ASME SB-209 6061-T6/T651 (Aluminum)		100	200	300	400	500
	S_y (ksi)	35.0	33.7	27.4	13.3	
	S_u (ksi)	42.0				
	E $\times 10^3$ (ksi)	10.0	9.6	9.2	8.7	8.1

Aluminum Association "Aluminum Standards and Data" has the following aluminum properties:

Material	Temperature, °F						
6061-T6/T651 (Aluminum)		75	212	300	400	500	600
	S_y (ksi)	40.0	33.2	31	15	5	2.7
	S_u (ksi)	45	42	34	19	7.5	4.6
	Elongation in 2 in., Percent	17	18	20	28	60	85

The material properties for the aluminum are taken as follows:

Use S_y minimum values at 100 °F, 200 °F, 300 °F, and 400 °F from ASME Section II, Part D.

Ratio the S_y minimum value at 500 °F from "Aluminum Standards and Data" based on $S_{y(ASME)}/S_{y(Alu.\ Standards\ and\ Data)}$ at 100 °F and is 5 X 35/40 = 4.4 ksi.

Use S_u minimum value at 100°F from ASME Section II, Part D of 42 ksi.

Obtain S_u minimum values at higher temperatures from "Aluminum Standards and Data" by ratioing $S_{u(ASME)}/S_{u(Alu.\ Standards\ and\ Data)}$ at 100 °F.

Temperature, °F	S_u (ksi) From Aluminum Standards and Data	Ratio	S_u (ksi) (minimum)
100	45.0		42.0
200	39.3	42/45	36.7
300	34.0	42/45	31.7
350	26.5	42/45	24.7
400	19.0	42/45	17.7
500	7.5	42/45	7.0
531	6.6	42/45	6.2
600	4.6	42/45	4.3

Therefore, the aluminum properties of the basket plates used for the structure analysis are as follows:

Material	Temperature, °F							
ASME SB-209 6061-T6 Aluminum		100	200	300	400	500	531	600
	S_y (ksi)	35.0	33.7	27.4	13.3	4.4	3.8	2.4
	S_u (ksi)	42.0	36.7	31.7	17.7	7.0	6.2	4.3
	E $x10^3$ (ksi)	10.0	9.6	9.2	8.7	8.1	7.8	7.4
	Elongation in 2", Percent	17	18	20	28	60	68	85

3C.3-4 Aluminum Material Properties of Support Rails

The aluminum properties of rails are also taken from ASME Section II, Part D (1992) and Aluminum Association "Aluminum Standards and Data" (1990). The following table shows the material properties used for structure analysis.

Material		Temperature, °F				
ASME SB-221 6061-T6 (Aluminum)		100	200	300	350	400
	S_y (ksi)	35.0	33.7	27.4	20.0	13.3
	S_u (ksi)	38.0	33.2	28.7	22.4	16.0
	E $x10^3$ (ksi)	10.0	9.6	9.2	9.0	8.7
	Elongation in 2", Percent	17	18	20	24	28

3C.4 References

1. NUREG/CR-3966 "Methods for Impact Analysis of Shipping Containers".

2. ANSYS Engineering Analysis System, Rev. 5.2, 1994.

3. ASME B&PV Code Section II, Part D. (1992).

4. Aluminum Association "Aluminum Standards and Data" (1990).

Figure 3C.1-1

Dynamic Load Factors vs Frequency Ratio - Reproduced From NUREG/CR-3966

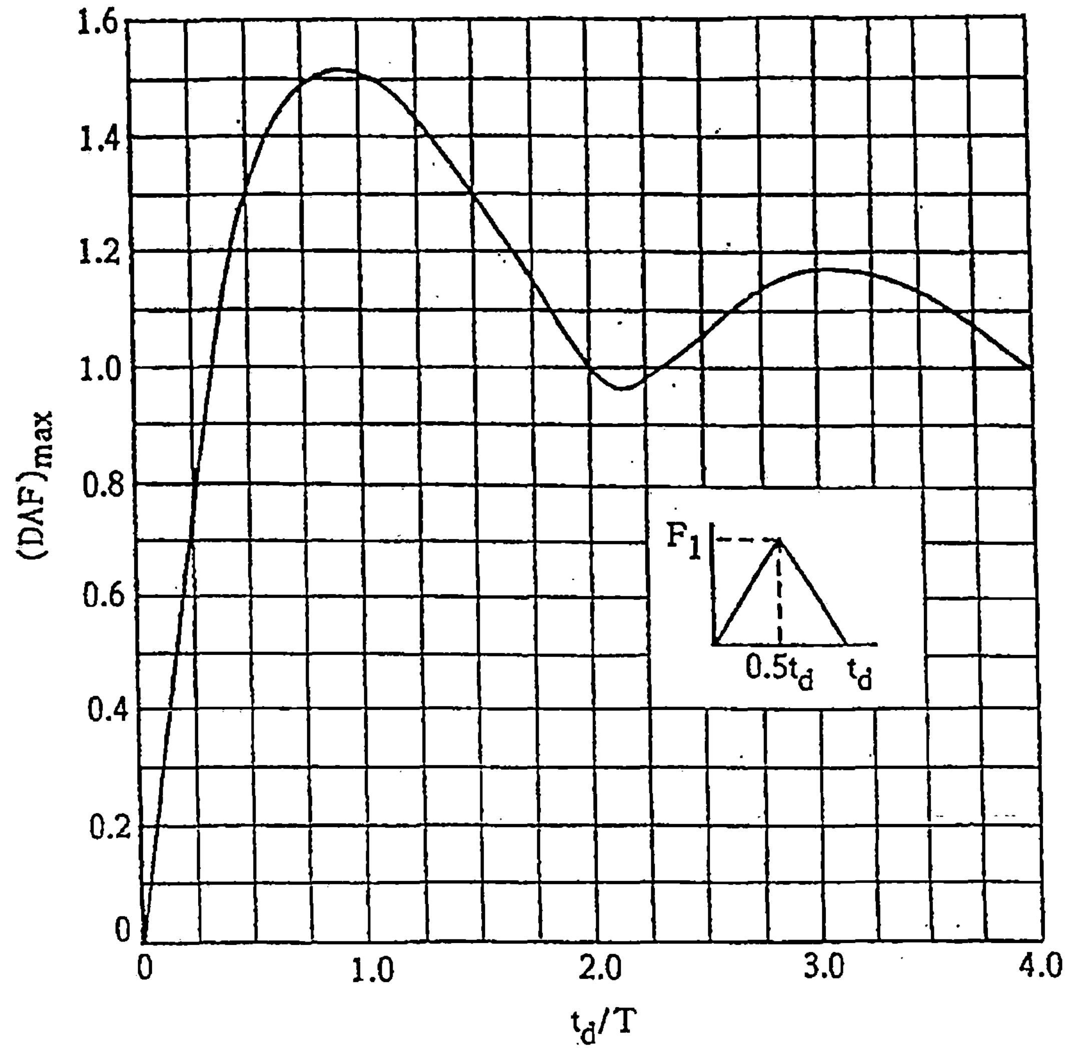


Figure 3C.2-1
Finite Element Model of the Basket Structure

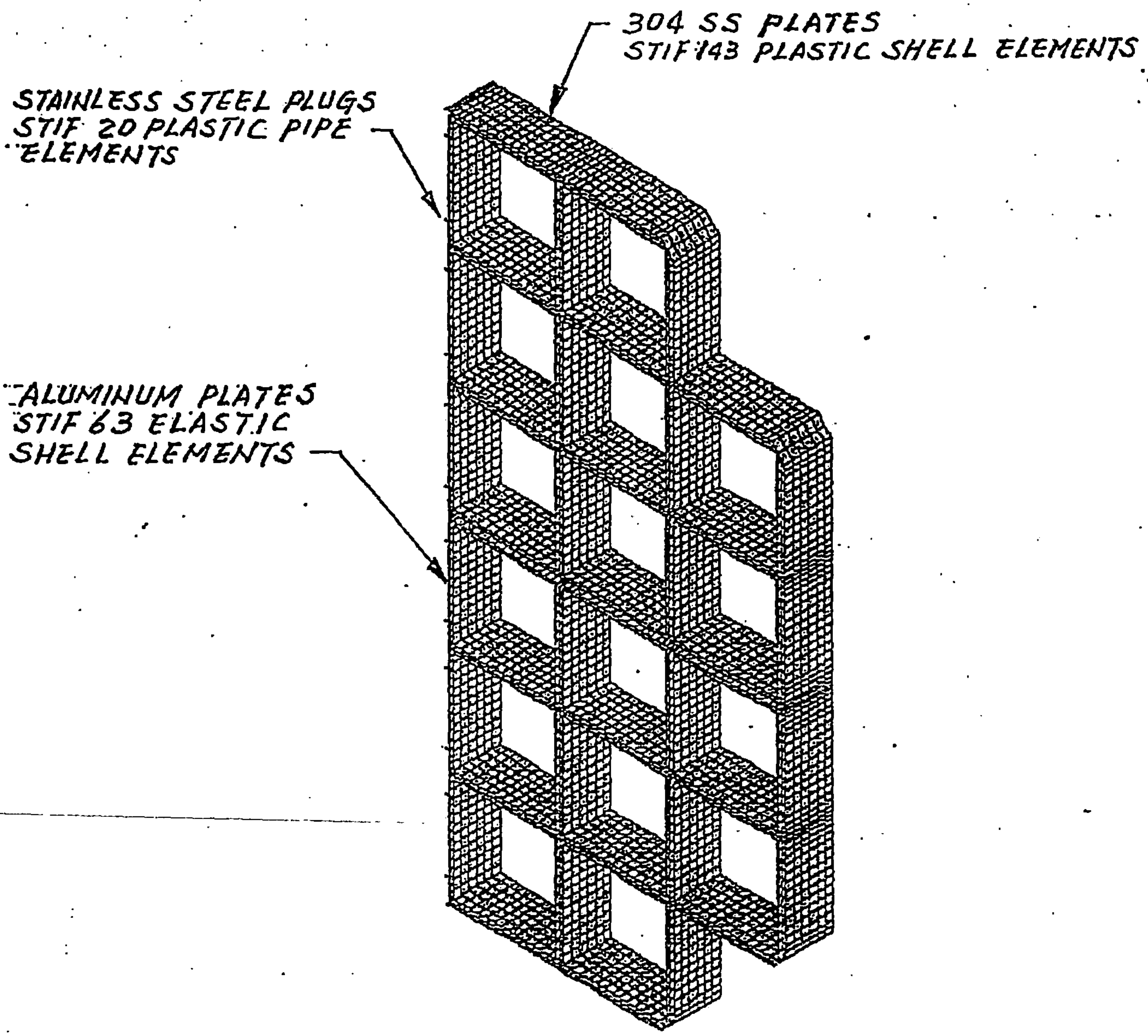


Figure 3C.2-2
Boundary and Loading Conditions for Stress Analysis of the Basket

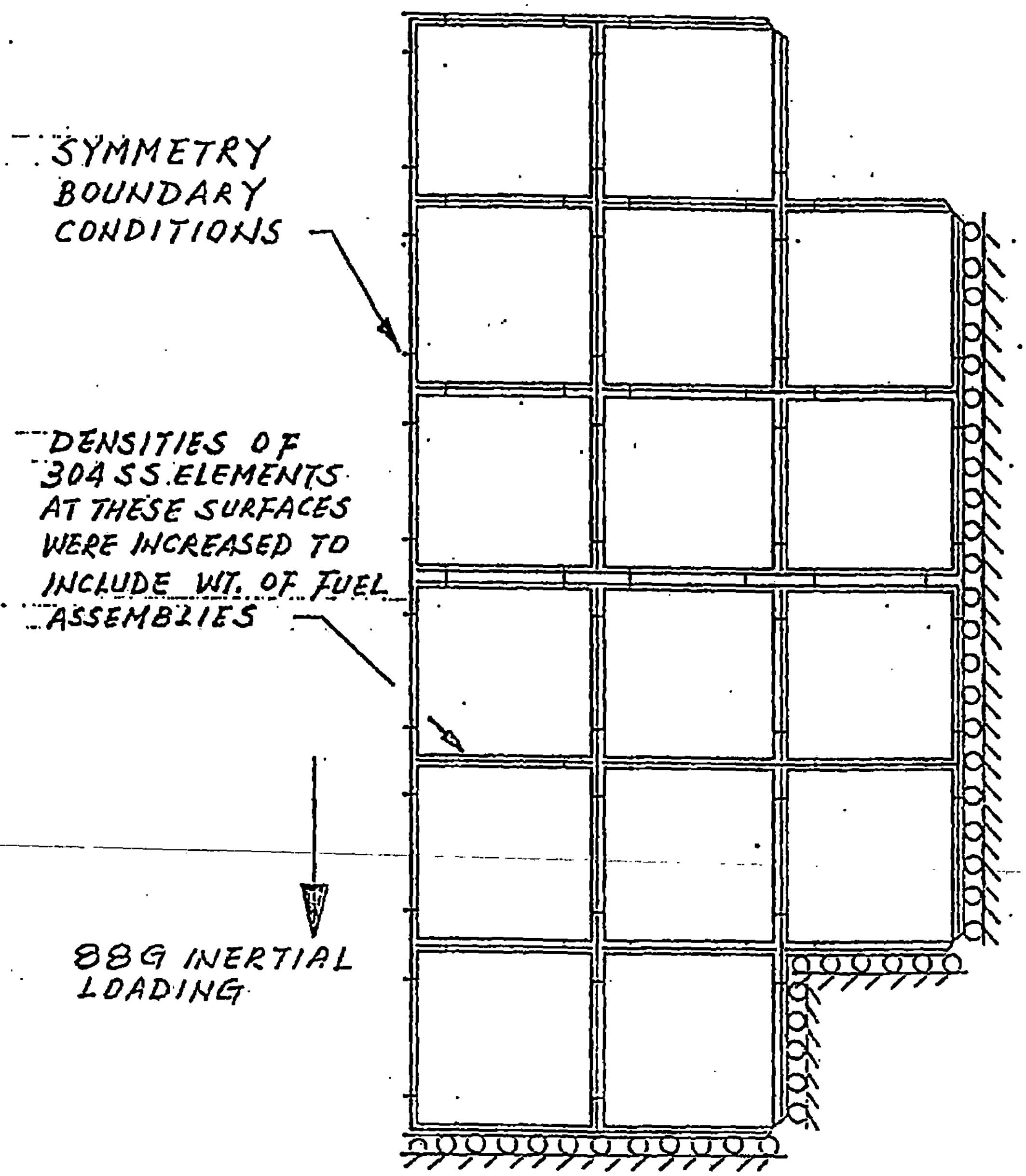
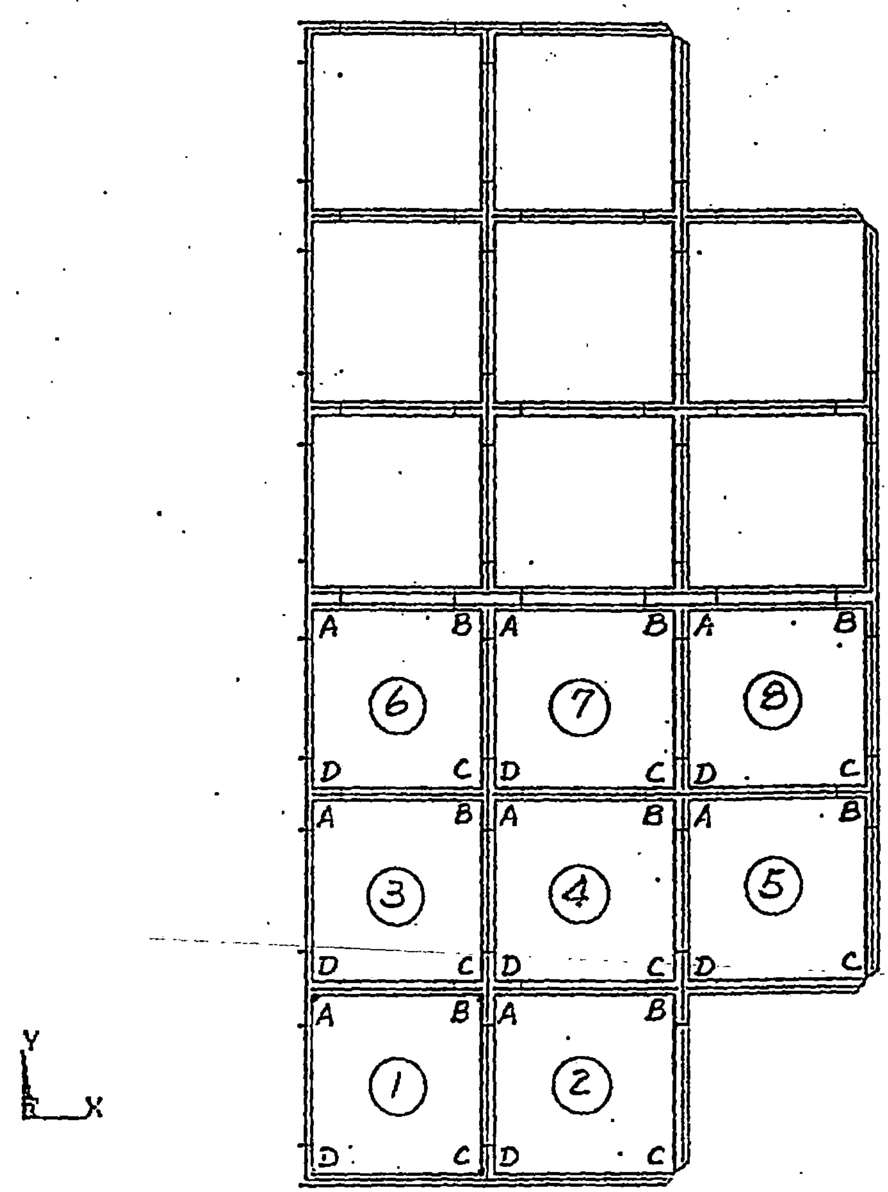
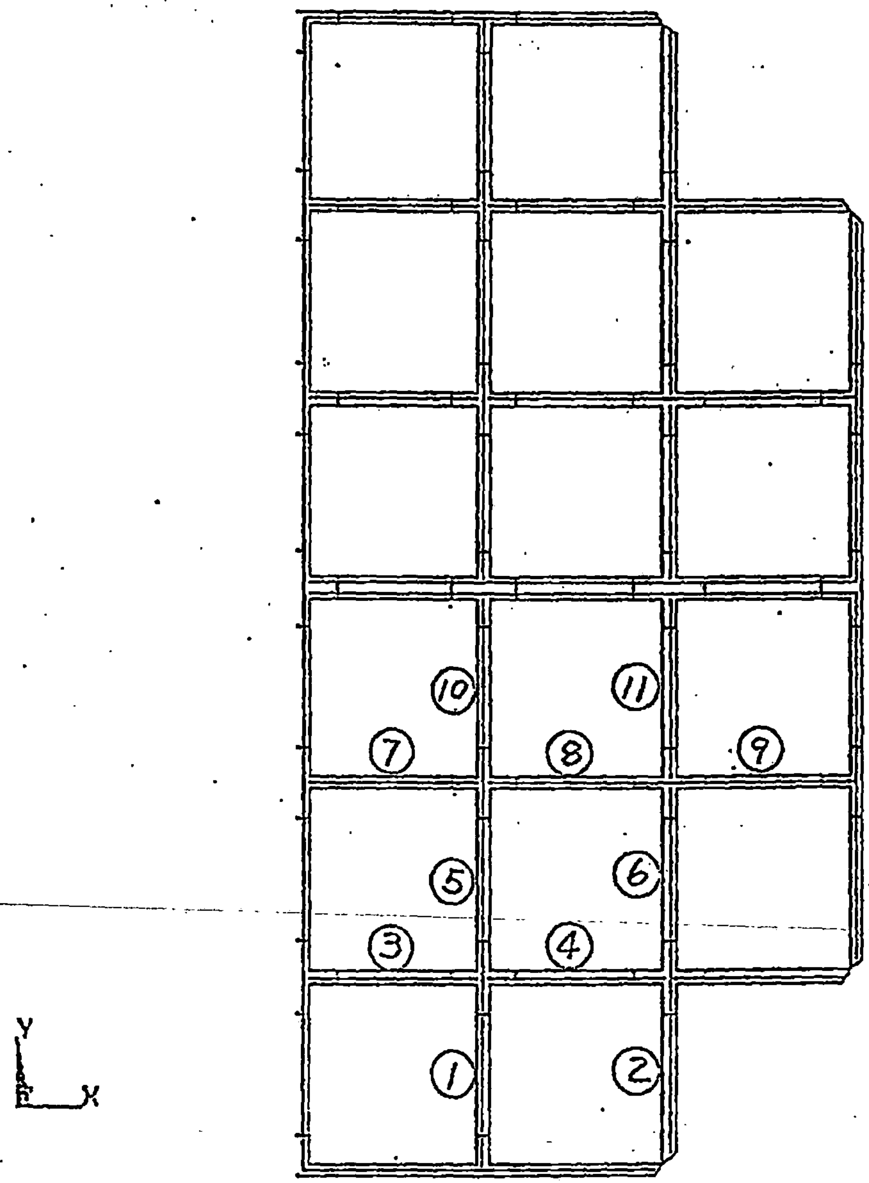


Figure 3C.2-3
Basket Panel Corner Region - Stress Report Locations



TN-32 Basket Plastic Analysis

Figure 3C.2-4
Basket Panel Center Region - Stress Report Locations



TN-32 Basket Plastic Analysis

Figure 3C.2-5
Basket Panel Plug Weld Region - Stress Report Locations

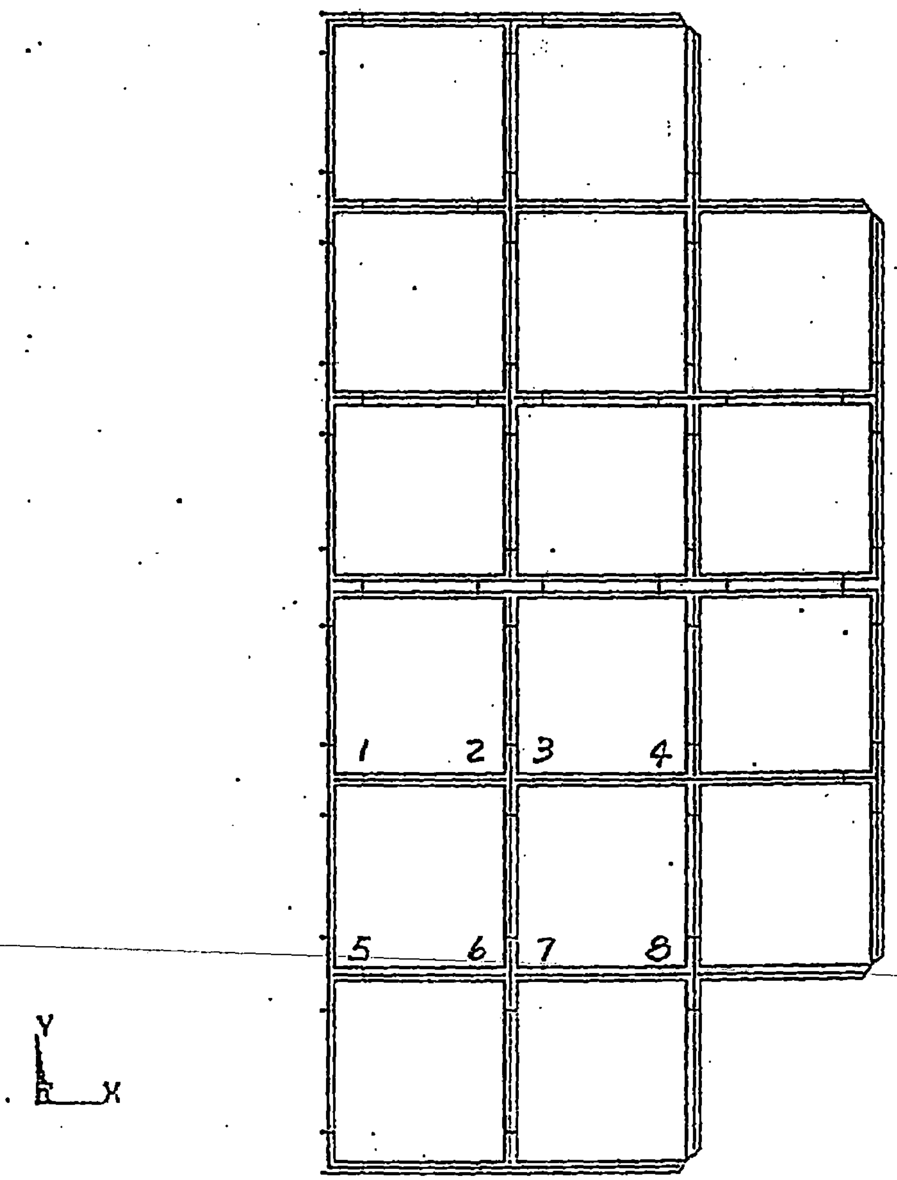


Figure 3C.2-6
Displacement Plot - 88G (90^0 Drop Orientation)

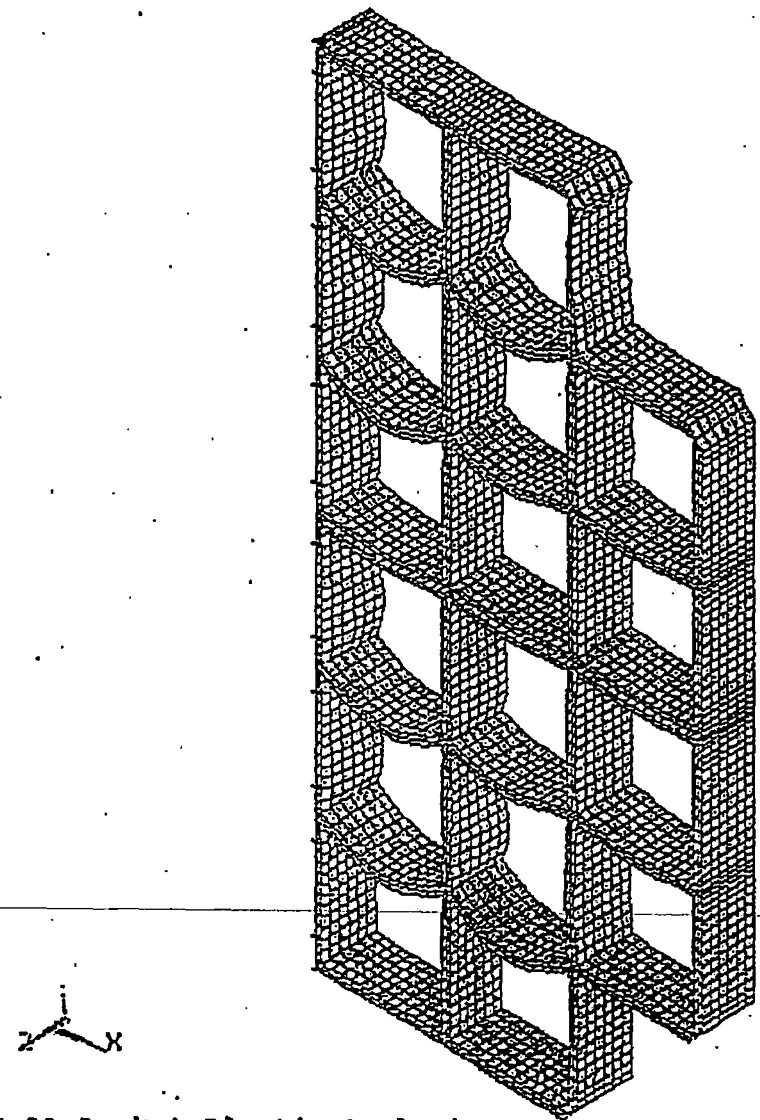


Figure 3C.3-1
Finite Element Model of the Basket and Rail Structures

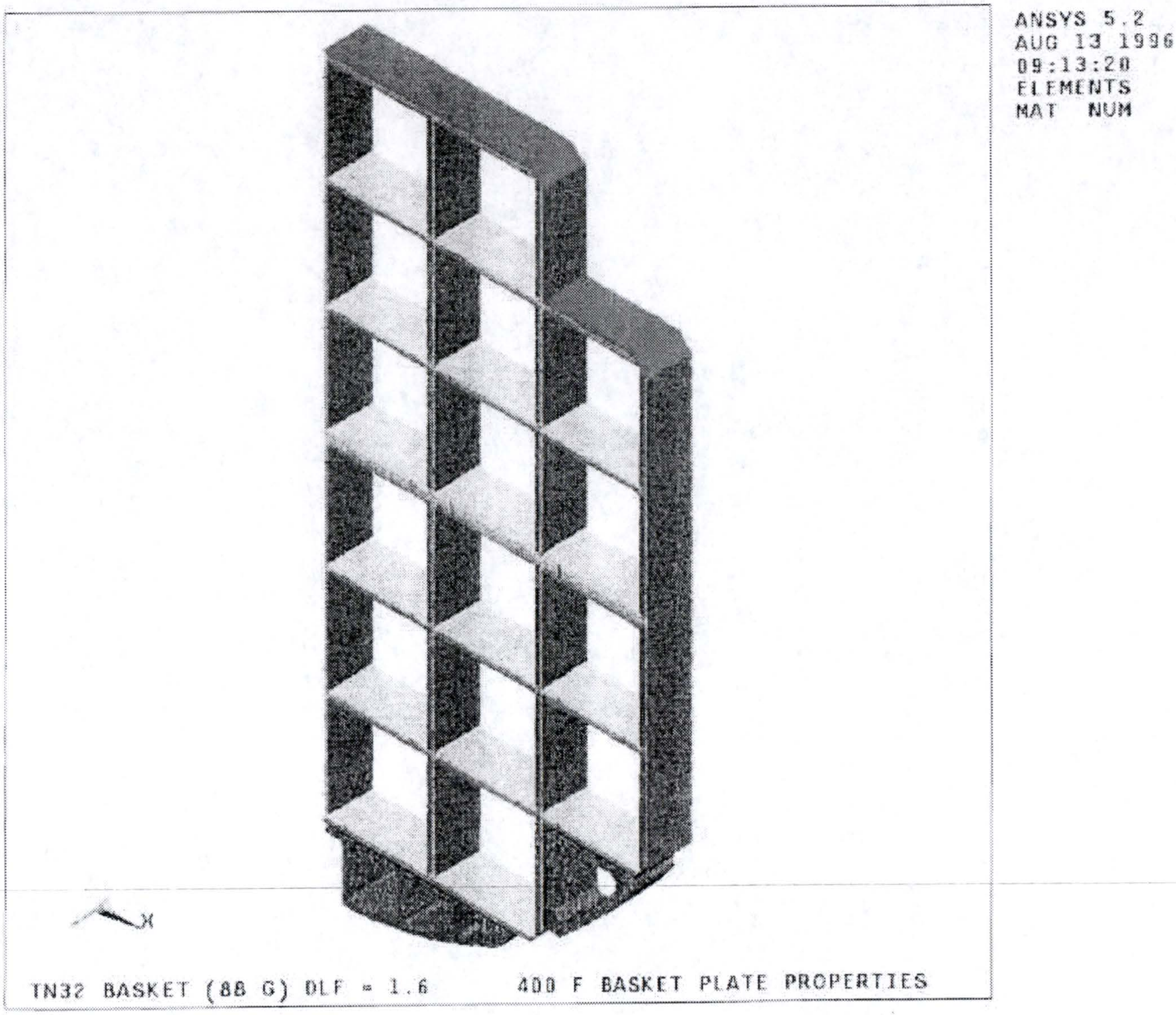


Figure 3C.3-2

Boundary and Loading Conditions for Stress Analysis of the Basket

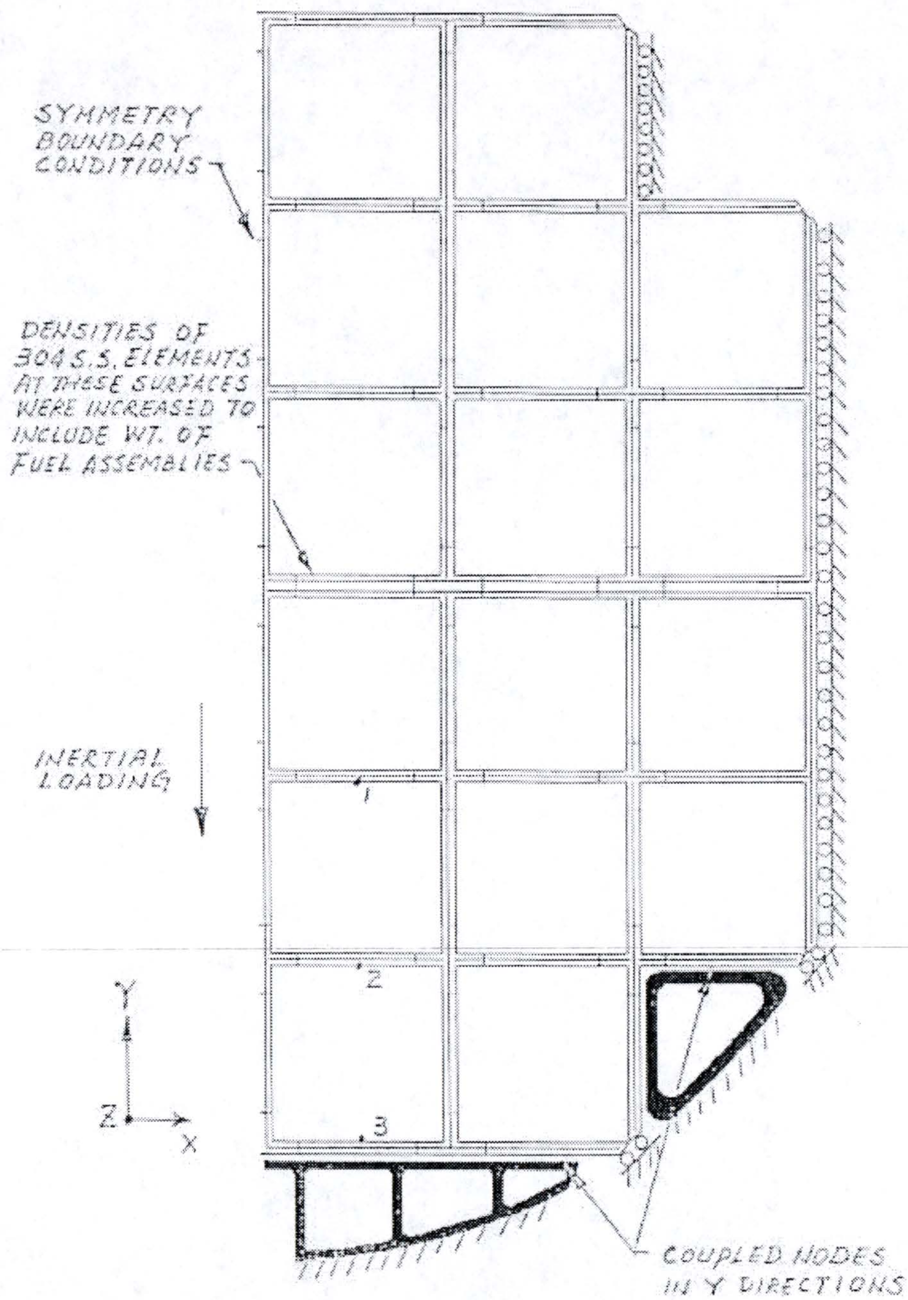


Figure 3C.3-3
Displacement Plot - Basket and Support Rails (88G-400°F)

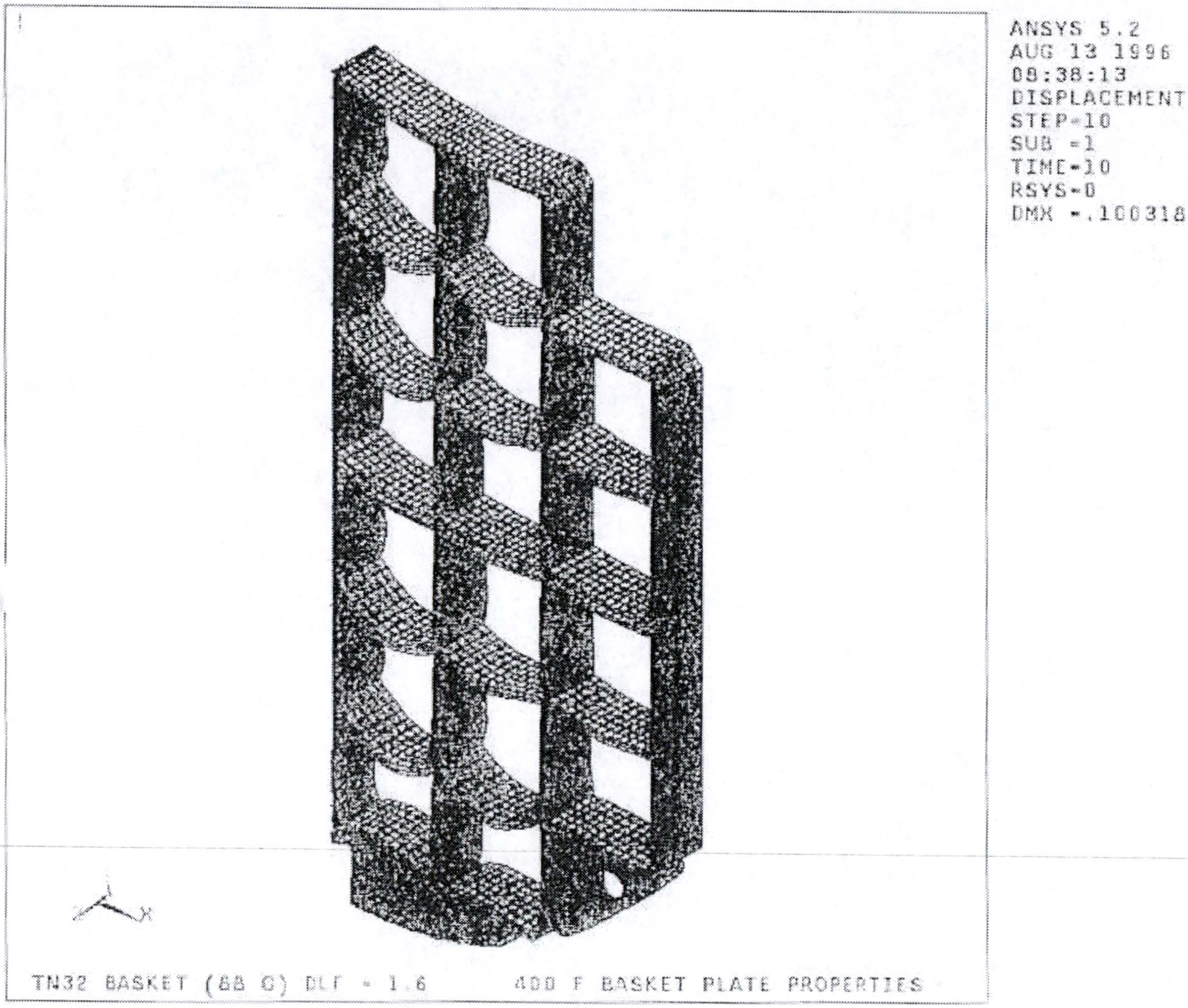


Figure 3C.3-4
Displacement Plot - Bottom Support Rails (88G-350°F)

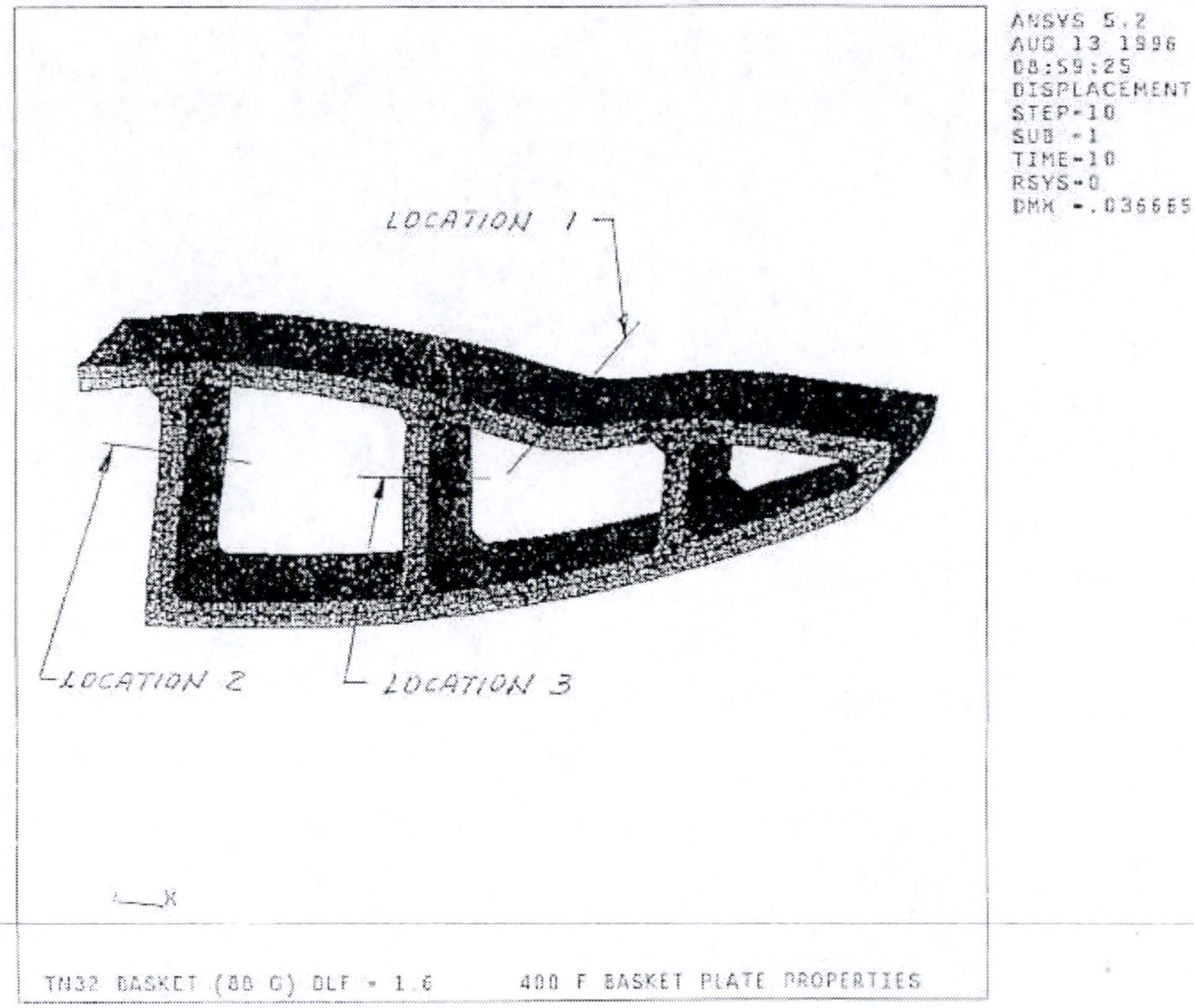


Figure 3C.3-5
Membrane Stress Intensities - 304 Stainless Steel Plate (88G-400°F)

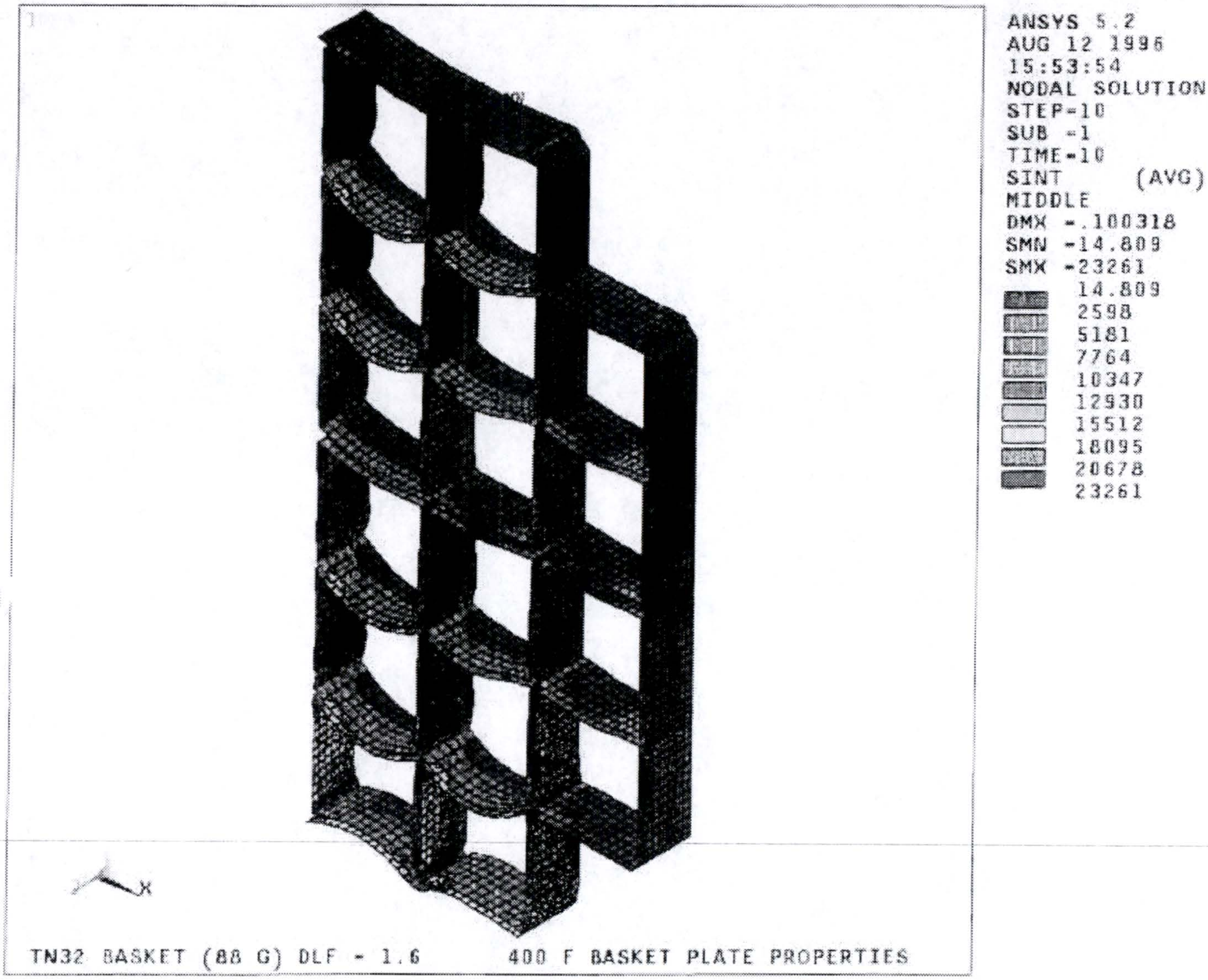


Figure 3C.3-6
Membrane Plus Bending Stress Intensities - 304 Stainless Steel Plate (88G-400°F)

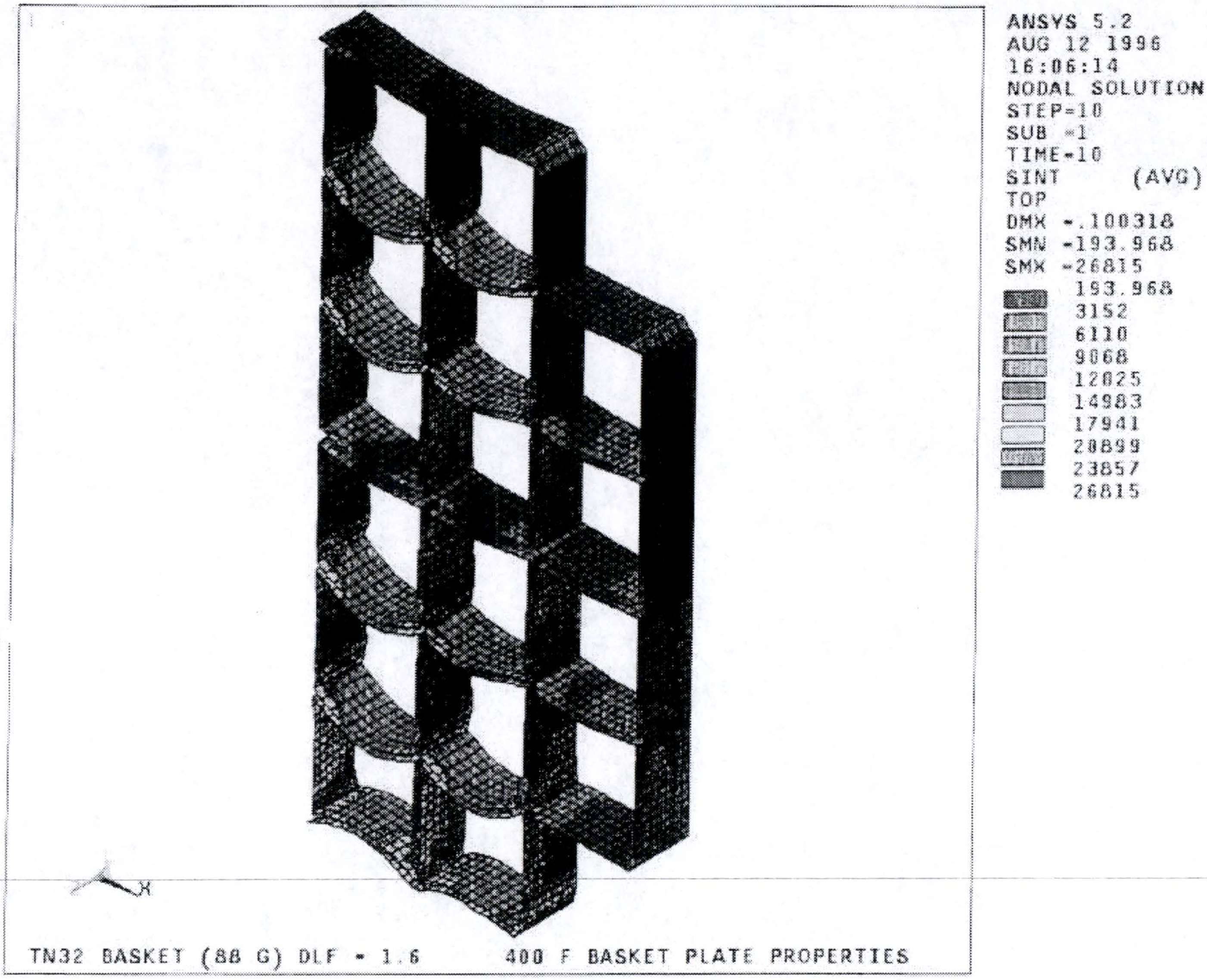


Figure 3C.3-7
Membrane Stress Intensities - Aluminum Plate (88G-400°F)

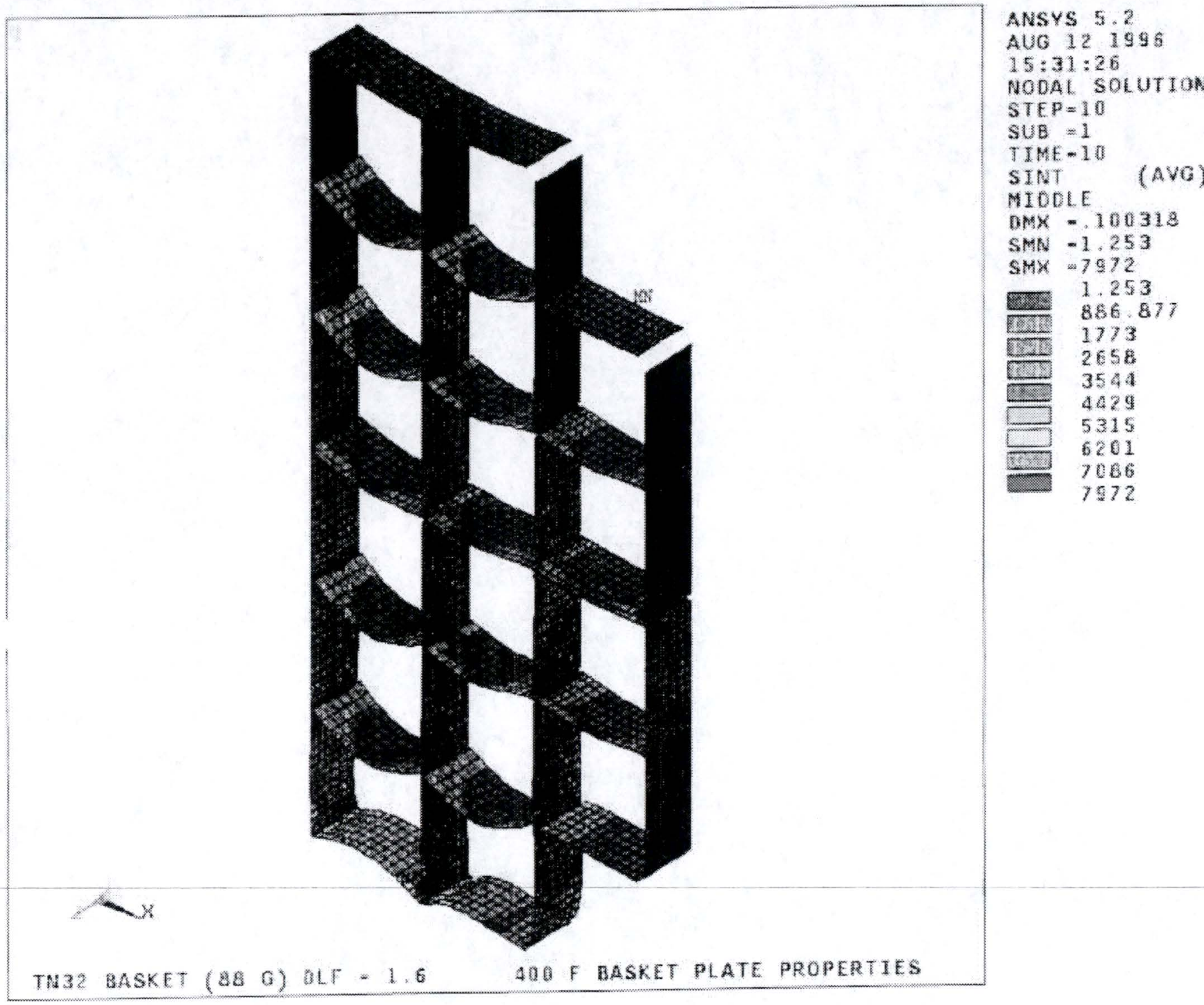


Figure 3C.3-8
Membrane Plus Bending Stress Intensities -Aluminum Plate (88G-400^{0}F)

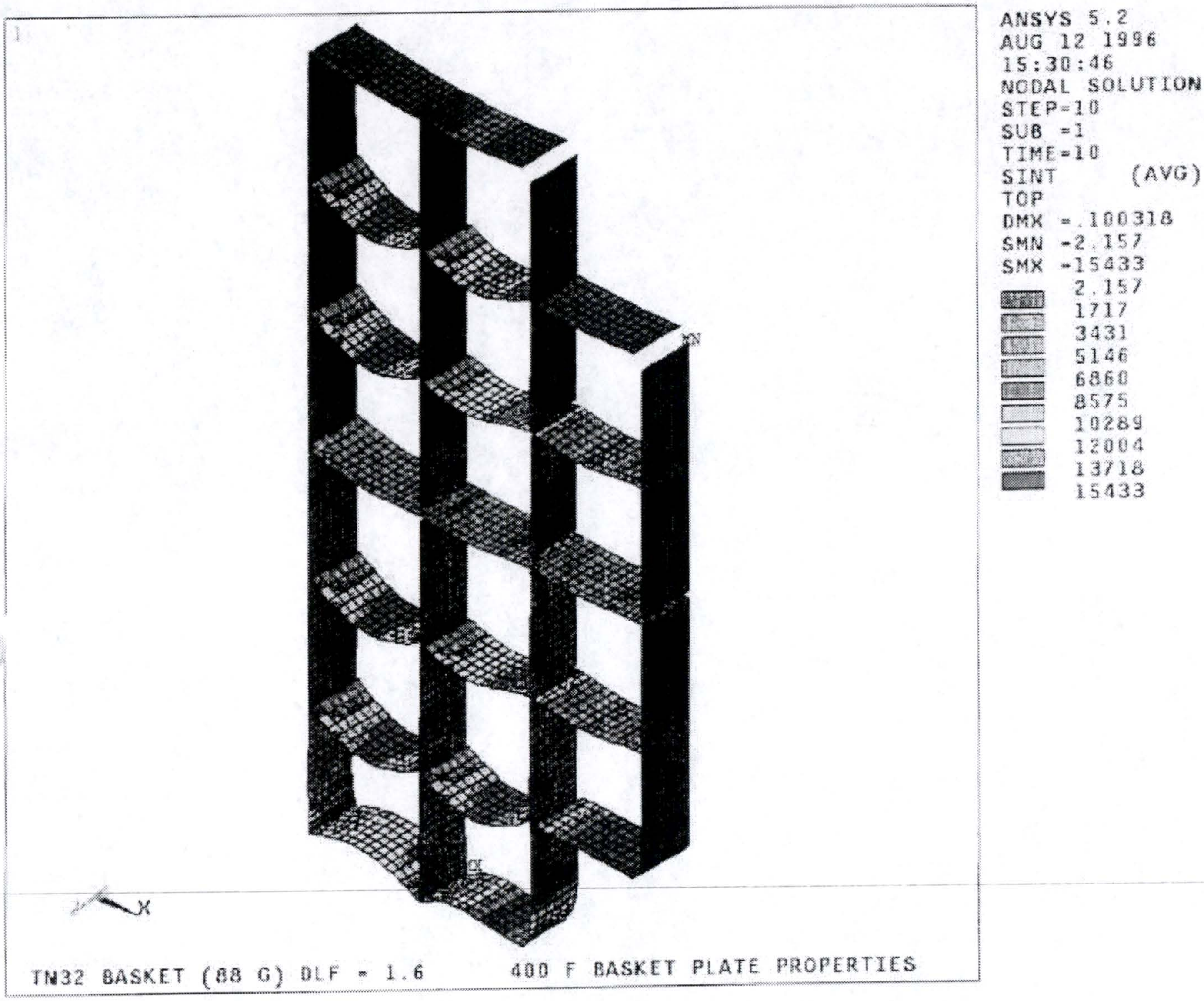


Figure 3C.3-9
Collapse Load of Bottom Support Rail

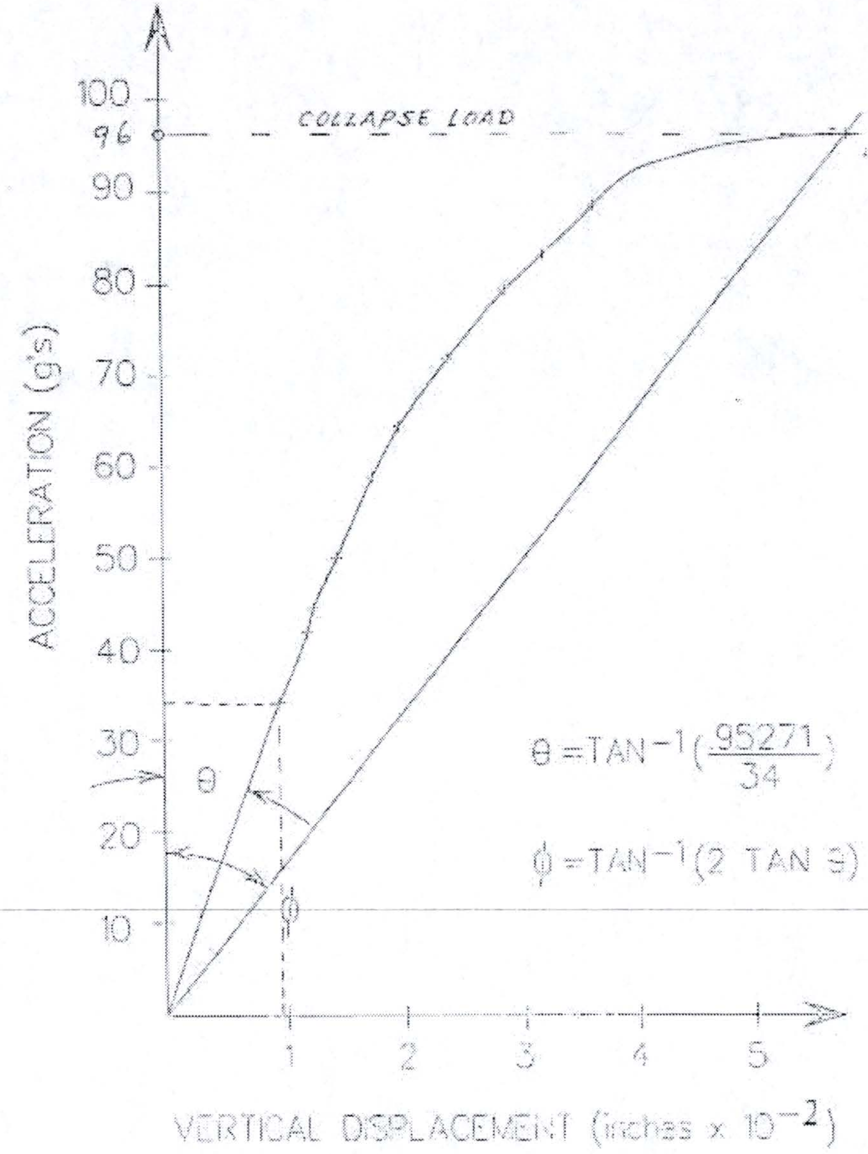


Figure 3C.3-10

Membrane Stress Intensities - 304 Stainless Steel Plate (52G-531°F)

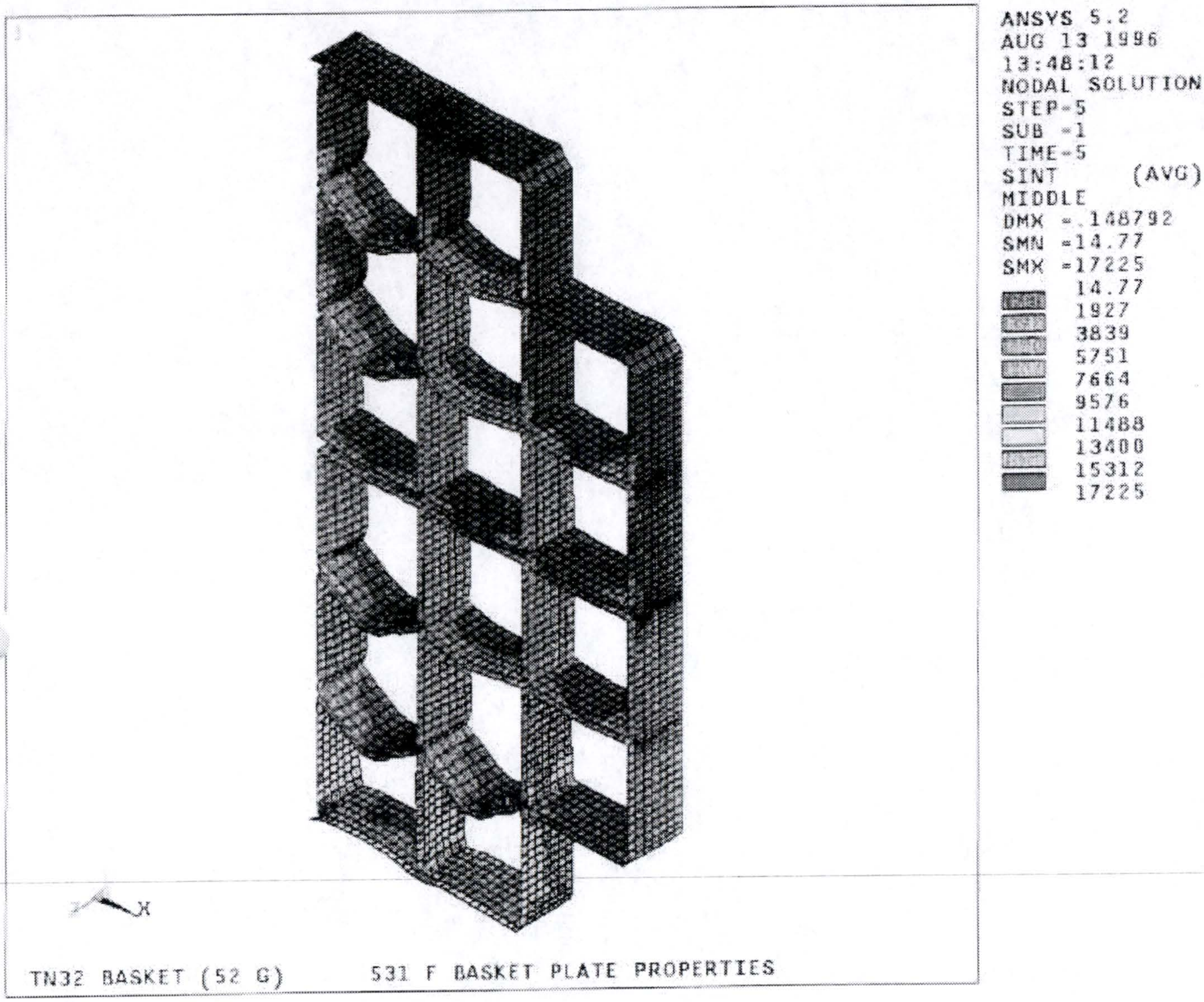


Figure 3C.3-11
Membrane Plus Bending Stress Intensities - 304 Stainless Steel Plate (52G-531°F)

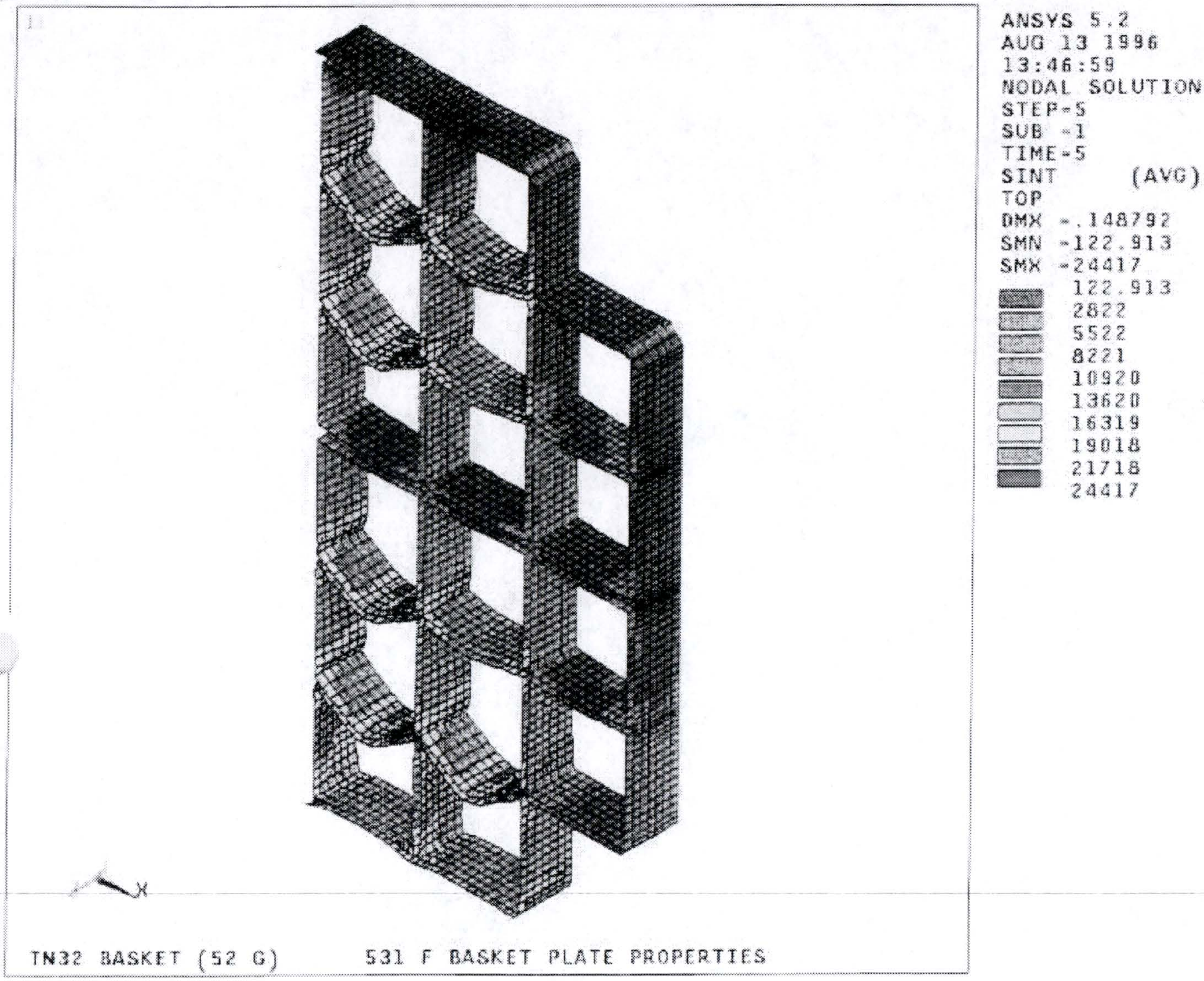


Figure 3C.3-12
Membrane Stress Intensities - Aluminum Plate (52G-531°F)

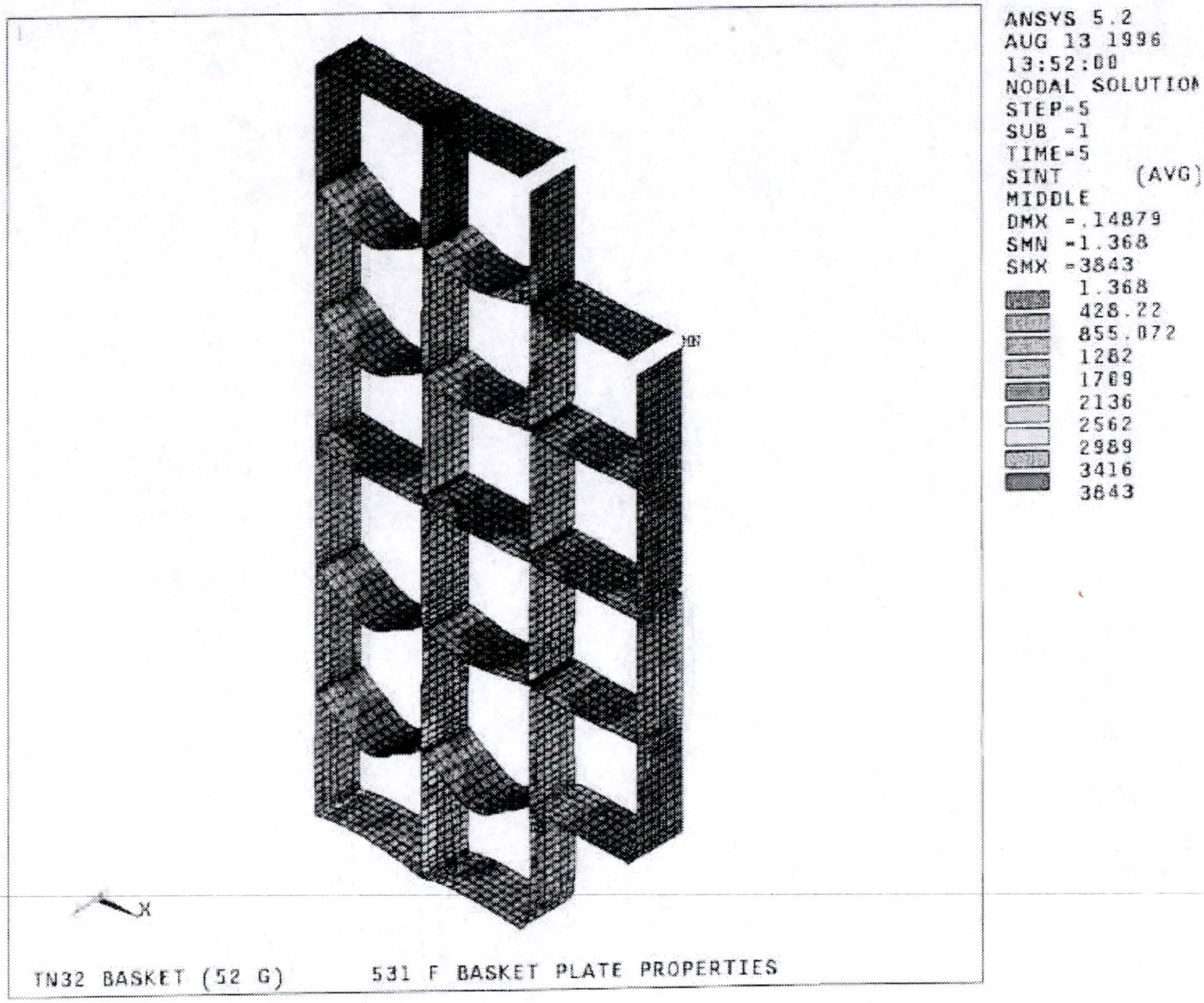
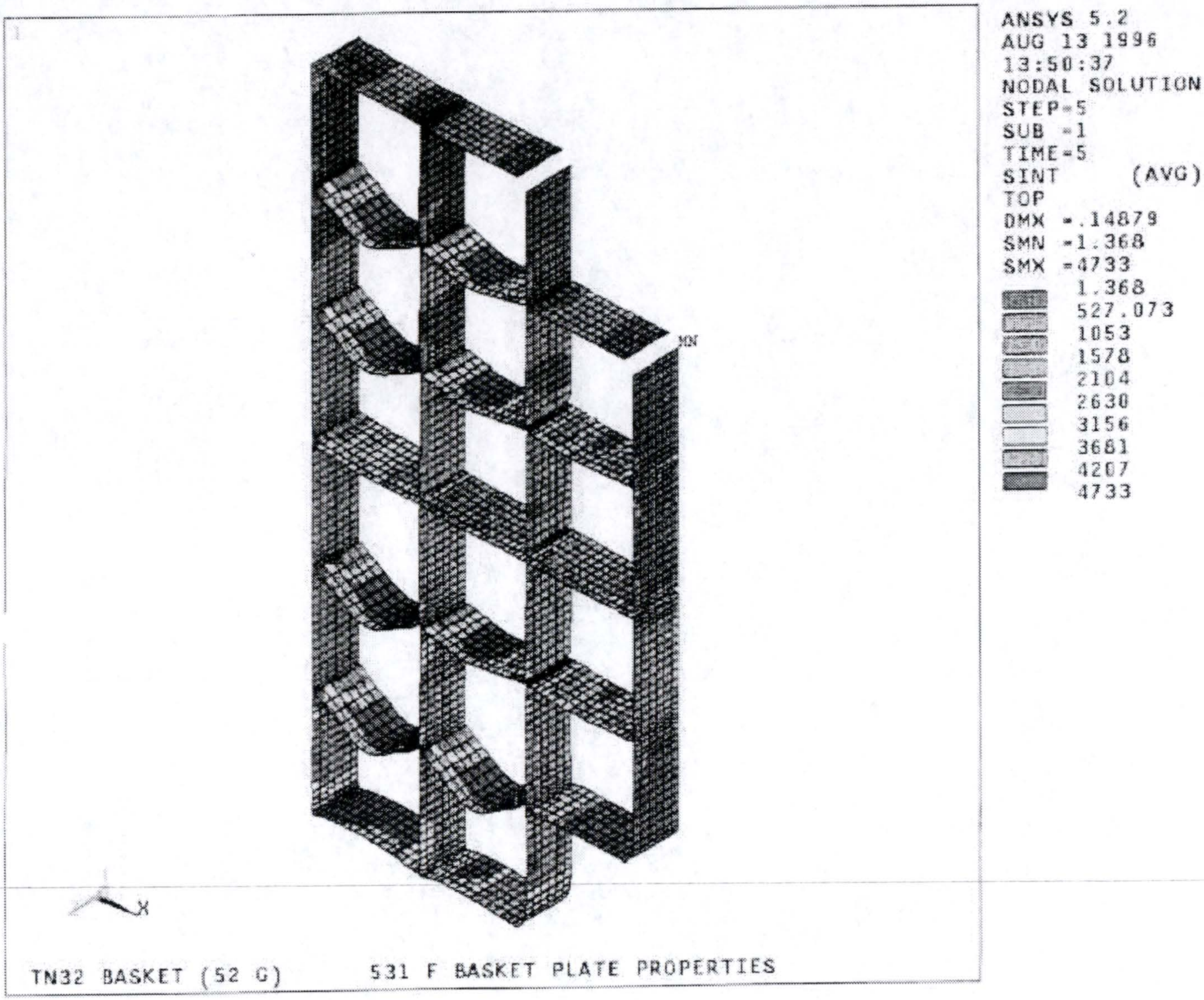


Figure 3C.3-13
Membrane Plus Bending Stress Intensities -Aluminum Plate (52G-531°F)



APPENDIX 3D

TIPOVER ANALYSIS OF TN-32 DRY STORAGE CASK

The purpose of this analysis is to determine the peak rigid body accelerations of the TN-32 storage cask due to a tipover accident. The rigid body accelerations are predicted analytically using the LS-DYNA3D explicit nonlinear dynamic analysis finite element program[1]. The methodology used in performing the analysis is based on work done at Lawrence Livermore National Labs[2] where an analysis methodology was developed and verified through comparisons with test data[3]. Benchmarking of the analyses presented herein is achieved through comparison with the Lawrence Livermore National Labs analyses as well as full scale end drop tests performed by BNFL[4].

3D.1 TN-32 Cask Tipover Model

This section describes the model used to determine the g loads during the TN-32 cask tipover.

The TN-32 finite element model is made up of four components: the cask body, the cask internals, concrete and soil. Each of these components is modeled using 3-D 8-node brick elements. The finite element models were developed in ANSYS 5.3[5] and transferred to LS-DYNA through the ANSYS-LS-DYNA interface. Modifications were made to the LS-DYNA input to add the material definition and state variables since they are not available through the ANSYS translator.

The finite element model of the TN-32 cask is developed in a similar manner to the model represented in Reference 2. The cask and basket meshes are totally independent of each other with surface-to-surface contact elements transferring load between the two components. The geometry of the cask and basket has been simplified since the purpose of the analysis is to predict the rigid body response of the cask. Features on the cask such as the trunnions, neutron shield and weather cover are neglected in terms of stiffness but their weight is lumped into the density of the cask. The geometry of the cask body used in the analysis is illustrated in Figure 3D.1-1.

Figures 3D.1-2 through 4 illustrate the finite element model of the cask, basket, concrete, and soil. Mesh sizes in this analysis are in reasonable agreement with those represented in Reference 2. Contact elements are used between the cask and concrete pad and between the concrete pad and the soil.

Boundary conditions and material properties used in the analysis are discussed in the following sections.

3D.2 Analysis Description

3D.2.1 Analysis Program

The LS-DYNA[1] finite element program was used for the analyses presented in this Supplement. Model generation was performed using the ANSYS[5] finite element program. Data filtering was performed using the DADisp[6] software.

LS-DYNA is a general purpose, explicit finite element program used to model the nonlinear dynamic response of three-dimensional models. Applications of LS-DYNA include crash worthiness, sheet metal forming, high velocity impact, explosive phenomena and drop tests.

ANSYS is a general purpose program capable of solving structural, mechanical, electrical, electromagnetic, electronic, thermal, fluid, and biomedical problems. It has extensive preprocessing (model generation), solution, postprocessing, and graphics capabilities.

DADisp is an interactive graphics worksheet which is used to manipulate data. It is a visually oriented software package for the display, management, analysis and presentation of scientific and technical data. Its filtering package is a menu-driven module for FIR and IIR digital filter design and analysis.

3D.2.2 Analysis Assumptions

Several assumptions were required to perform this analysis. These are summarized as follows:

1) Coefficient of Friction of 0.25 was assumed between all sliding surfaces.

2) Nonlinear material response of the cask internals and soil, if any, is neglected.

3) Reinforcement in the concrete pad is assumed to be 1% of the pad volume.

4) Strain rate effects on all material properties are neglected.

The use of these simplifying assumptions is justified through the comparison of the analytical results with experimental tests.

3D.2.3 Material Properties

The material properties required to perform the analysis include the modulus of elasticity (E), Poisson's ratio (ν) and material density (ρ) for the cask, internals and soil.

The concrete requires a more detailed material model since all the significant nonlinear deformations occur in the concrete. Material properties used for the concrete and soil are based on those developed at Lawrence Livermore National Laboratory[2].

Soil Properties

Reference 2 includes results of analytical simulations of cask drops onto concrete pads with varying soil elastic properties. The results of the simulations showed that the soil under the concrete pad has only a secondary effect on the initial response of the LLNL test billet, and has little effect on the peak accelerations predicted in the cask. Thus for the purpose of the TN-32 tipover analyses, the soil properties are taken from the Livermore Report[2]. The soil material properties assumed for the analyses are:

$E = 6,000$ psi

$\nu = 0.3$

$\rho = 0.225E\text{-}3$ lb-sec^2/in^4

Concrete Properties

The concrete pad is modeled using material law 16 in LS-DYNA that was developed specifically for granular type materials. The data used in the analysis was originally developed by LLNL for the Shippingport Station Decommissioning Project in 1988. This model was also used in the LLNL cask drop analyses. Material constants were input into Material Model 16 Mode II.B in DYNA. A summary of the input used in the analyses is as follows:

$\rho = 2.09675E\text{-}4$ lb-sec^2/in^4

$\nu = 0.22$

$a_0 = 1,606$ psi

$a_1 = 0.418$

$a_2 = 8.35E\text{-}5$ psi^{-1}

$b_1 = 0$

$a_{0f} = 0.0$ psi

$a_{1f} = 0.385$

Effective Plastic Strain	Scale Factor, η
0	0
0.00094	0.289
0.00296	0.465
0.00837	0.629
0.01317	0.774
0.0234	0.893
0.04034	1.0
1.0	1.0

The maximum principal stress tensile failure cutoff is set at 870 psi. Strain rate effects are neglected in the analysis. Dilger suggests in Reference 8 that the major impact of strain rate effects is in the softening part of the stress-strain curve. Since the primary purpose of these analyses is to predict peak accelerations, the strain rate effects on the material behavior can be neglected.

The pressure-volume behavior of the concrete is modeled with a tabulated pressure vs. volumetric strain rate relationship using the equation of state feature in LS-DYNA.

Volumetric strain (ε)	Pressure (psi)
0	0
-0.006	4,600
-0.0075	5,400
-0.01	6,200
-0.012	6,600
-0.02	7,800
-0.038	10,000
-0.06	12,600
-0.0755	15,000
-0.097	18,700

An unloading bulk modulus of 700,000 psi is used and is assumed to be constant at any volumetric strain (Reference 2). One percent reinforcement is assumed in the concrete pad to account for the pad reinforcement. The 1% reinforcement is also used in analyses presented in EPRI report NP-7551 (Reference 10). The material properties used for the reinforcing bar are as follows:

E = 30E6 psi

ν = 0.3

Yield Stress = 30,000 psi

Tangent Modulus = 30E4 psi

TN-32 Cask Material Properties

The same modulus of elasticity used in the LLNL Report[2] is used for the TN-32 tipover analyses. The material properties used for the casks are as follows:

$E = 30\ E6$ psi

$\nu = 0.3$

$\rho = 0.865E\text{-}3$ lb-sec^2/in^4

The density of the cask was adjusted to include the mass of those entities not explicitly modeled. The density of the cask has been adjusted so that the weight of the TN-32 cask minus the basket and fuel is 166,200 lb.

TN-32 Fuel/Basket Material Properties

The fuel and basket are modeled as a set of hollow cylinders inside the cask wall (similar manner to those models represented in Reference 2). The material properties of the fuel/basket are defined to match the correct weight and to approximate the stiffness of the basket. The cask and basket finite element model meshes are totally independent of each other with surface-to-surface contact elements transferring load between the two components. Because the cask stiffness is so much greater than the basket stiffness this is a reasonable assumption. The modulus of elasticity used for the basket is adjusted such that the fundamental frequency of the simplified basket model is approximately the same as the fundamental frequency of the detailed basket model used for stress analysis. Material properties used for the basket are as follows:

$E = 8.1E6$ psi

$\nu = 0.3$

$\rho = 0.863E\text{-}3$ lb-sec^2/in^4

The density of the basket has been adjusted to account for the weight of the fuel. The weight used for the basket plus fuel is 65,800 lb.

3D.2.4 Damping

The true damping characteristics of the cask impact event are hard to quantify. Typical values for reinforced concrete structures subjected to dynamic loads are in the 5 to 10% range (See References 13 and 14 and Figure 3D.2-1). During the drop events, the concrete, cask and soil absorb energy as a result of

damping. Since the response of the concrete is nonlinear, a single damping ratio can not be defined. In order to define a relatively uniform damping ratio over a range of frequencies, damping is defined proportional to both the stiffness and mass matrices. Known as Rayleigh damping (Reference 12), two factors can be defined relative to mass and stiffness proportional to damping to provide a range of damping. Since the damping ratio must be assumed, both an upper and lower bound ratio of damping are used in the preliminary analyses. A damping ratio of 6% was used in the final analysis, and is justified in the benchmarking analysis presented in Section 3D.4.

3D.2.5 Tipover Analysis

An angular velocity is applied to the TN-32 cask body to simulate a non-mechanistic cask tipover accident. The center of rotation is set at the edge of the cask bottom located at the center of the coordinate system as illustrated in Figure 3D.2-2. DYNA calculates the initial velocity components associated with each node for this rotational motion. The load applied to the cask is 1.729 radians/sec.

A ½ model is used in the analysis, with symmetry boundary conditions used to simulate the full structure. Non-reflecting boundaries were used around the soil non-symmetry boundaries to prevent artificial stress waves from reflecting from the boundaries of the soil. Figure 3D.2-2 also illustrates the boundary conditions used in the finite element model.

A modal analysis of the TN-32 cask was prepared using the finite element model. The first mode of vibration for the TN-32 cask is illustrated in Figure 3D.2-3. The first mode frequency for the cask is 188 Hz.

The critical damping ratio (relative to the cask response) and natural frequency of the cask are summarized in the following table:

Cask Design	Mass Damping Constant (α)	Stiffness Damping Constant (β)	Natural Frequency	Damping Ratio
TN-32	122	1.5E-5	188 Hz	6%

Figures 3D.2-4 through 3D.2-6 illustrate the results for the TN-32 tipover analysis. The plots illustrate both the displacement and Von Mises stress distribution over time and at their maximum values.

Figures 3D.2-7 and 3D.2-8 illustrate the acceleration history results from the TN-32 tipover analysis comparing the LLNL and Transnuclear data. In both analyses, the acceleration histories are averaged over the nodes on the cask lid. The following table lists the LLNL and Transnuclear analysis results.

Comparison of TN-32 Tipover Analyses

	LLNL DYNA Analysis	Transnuclear DYNA Analysis
Peak Acceleration (350 Hz Filter)	66.7 g	67 g
Duration of Pulse	0.003 sec	0.003 sec
Pulse Shape	Triangle	Triangle

Excellent correlation is achieved for the tipover analysis.

3D.2.6 Dynamic Load Factor Calculation

Since the basket is not modeled in detail in the transient dynamic analysis, it is necessary to transfer the loads from the dynamic analysis model to the detailed model of the basket. The basket structure is designed using a quasi-static analysis (using a dynamic load factor computed from the transient dynamic analysis). The dynamic load factor is a function of the rise time of the applied load, the duration of the load, the shape of the load, and the natural period of the structure. Figure 2.3 of reference 15 (reproduced in Figure 3D.2-9) shows the maximum dynamic load factor for a triangular load.

The tipover is modeled as an equivalent side drop. For the first mode shape of a side drop, the deformed shape of the central basket panels resembles a simple-simple supported beam. The frequency of the fundamental mode of vibration for the simple-simple supported beam is calculated below. Reference 16, page 369, case 6, "Single span, end supported, uniform load W", provides the following equation for the fundamental frequency:

$$f = 3.55/(5WL^3/384EI)^3$$

Where:

$W = 10.58$ lb
$L = 8.7$ in.
$E_{stainless\ steel} = 26.5 \times 10^6$ psi (304 SST at 400°F)
$E_{aluminum} = 8.7 \times 10^6$ psi (Aluminum at 400°F)
$I_{stainless\ steel} = 0.000193$ in^4
$I_{aluminum} = 0.0104$ in^4

Substituting the values given above,

$f = 118$ Hz

From Figure 3D.3-9, the dynamic load factor is calculated as follows:

t = impact duration = 0.003 sec
$T = 1/f = 1/118 = 0.0085$
$t/T = 0.003/0.0085 = 0.35$

Therefore, the dynamic load factor is approximately 1.1.

3D.3 Equivalent Side Loading on the Cask and Basket for Stress Analysis

3D.3.1 Cask Body

The tipover analysis of TN-32 results in a peak deceleration of 67g averaged through the cask lid. An equivalent side drop of 50g along the length of the cask is used to perform the stress analysis in the TN-32 SAR. This is conservative, since:

A. The tipover analysis neglects the outer shell and aluminum boxes. During the drop, these components will deform and absorb energy. Thus the actual deceleration will be less than the above calculated G loads.

B. During the tipover drop accident, the G loads vary from minimum to the maximum value along the length, from bottom end to the top surface of the lid (This corresponds to a 33.5g uniform load). A peak stress intensity of about 54,000 psi (TN-32 SAR Chapter 3, Table 3.4-6) results from the static analysis due to a 50g uniform load. The tipover dynamic analysis indicates a peak stress of about 25,000 psi (see Figure 3D.2-6). This shows that the overall effect of the assumptions made in the static analysis is very conservative and there is an approximately 50% additional margin of safety in the cask stresses.

3D.3.2 Basket

The dynamic load factor calculated from Section 3D.2.6 is about 1.1. Thus the basket structural analysis is performed by modeling the side impulse as a steady-state acceleration equal to 74g (67 × 1.1=74). The structural analysis of the basket is conservatively performed using 88g for the accident analysis (TN-32 SAR Appendix 3C).

3D.4 Benchmarking

The tipover evaluation of the TN-32 cask corresponds well with the results of the drop testing performed at Lawrence Livermore[2]. As a second validation of the dynamic model, an analysis of a 60 inch end drop was performed to simulate a full scale end drop test performed by BNFL [4]. As shown in this section, the analysis and the test results are in good agreement.

3D.4.1 BNFL End Drop Model

The analysis of the BNFL End Drop test is performed using a similar model to that used in EPRI's validation of its methodology for analysis of spent-fuel cask drop and tipover events[4]. One exception is that the concrete model is the same as used in the LLNL analysis presented in Reference 2.

Figure 3D.4-1 illustrates the geometry used in EPRI's analysis validation. Figure 3D.4-2 illustrates the finite element model used in the validation analysis. A one-quarter segment was used in the LS-DYNA analysis because of model and load symmetries. Symmetry boundary conditions are used at 0 and 90 degrees.

Material Properties

Material properties were extracted from the EPRI report with the exception of the concrete properties which are described in Section 3D.2.3.

The density of the cask is modified so that the weight of the cask matches the cask weight of 142,000 lb. Summaries of the cask and soil properties are:

E_{cask} = 30 E6 psi	E_{soil} = 82,000 psi
ν_{cask} = 0.3	ν_{soil} = 0.45
ρ_{cask} = 2.08 E-3 lb-sec²/in⁴	ρ_{soil} = 0.180 E-3 lb-sec²/in⁴

3D.4.2 BNFL Cask End Drop Analysis

The end drop analysis is performed on the 60" drop test since the cask velocity is similar to the tip velocity during the tipover event. This drop event is modeled using an equivalent initial velocity of 215 in/sec applied to the cask body. Two separate damping values are used in the analysis. A 4% and a 10% damping analysis are performed. In order to define the Rayleigh damping coefficients, a modal analysis is performed of the cask model. Figure 3D.4-3 illustrates the first mode response of the cask. The fundamental frequency of the cask is 86 Hz.

Results from the 10% damping case are illustrated in Figures 3D.4-4 and 3D.4-5. A history of the cask bottom displacement is illustrated in Figure 3D.4-4. Figure 3D.4-5 illustrates the displacement of the cask at time t = 0.01 seconds after impact. Almost all the deformation occurs in the concrete.

Results from the 4% damping case are illustrated in Figures 3D.4-6 and 3D.4-7. Figure 3D.4-6 illustrates the vertical displacement history. Figure 3D.4-7 shows the displacement distribution in the concrete.

The accelerations were computed by taking double derivatives of the displacement history in the ANSYS53 postprocessor with the second derivative scaled by 1/386 to convert from in/sec^2 to G's. These analyses resulted in peak accelerations in range of 102g to 130g.

Taking an average of the two analyses yields a damping ratio of approximately 6-8% and a peak G level of 116g which is close to the BNFL test data[4] (112-121g). A similar amount of damping is expected for the TN-32 cask tipover since most of the damping is a result of concrete damage.

3D.5 References

1. LS-DYNA3D User's Manual (Nonlinear Dynamic Analysis of Structures in Three Dimensions), August 1, 1995 Version 936, Livermore Software Technology Corporation

2. Witte, M. et. Al Evaluation of Low-Velocity Impact Testing of Solid Steel Billet onto Concrete Pads and Application to Generic ISFSI Storage Cask for Tipover and Side Drop, Lawrence Livermore National Laboratory, UCRL-ID-126295, Livermore, California. March 1997

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5. ANSYS User's Manual, Revision 5.3, Ansys Inc., P.O. Box 65, Houston, PA 15342-0065

6. DADisp Worksheet User Manual, DSP Development Corporation, March 1996

7. A. J. Sparkes, J.E. Gillard, P.A. Sims, Full-Scale Drop Tests for Benchmarking Concrete Pads for Dry Spent Fuel Storage Casks, AEA Technology, Report No. AEA-D&W-0622, July 1993

8. Ductility of Plain and Confined Concrete Under Different Strain Rates, By W.H. Dilger, ACI Journal, Jan-Feb, 1984

9. The Effect of Target Hardness on the Structural Design of Concrete Storage Pads for Spent-Fuel Casks, EPRI NP-4830, October 1986

10. Structural Design of Concrete Storage Pads for Spent-Fuel Cask, EPRI NP-7551, August 1991

11. Y.R. Rashid, R.J. James and O. Ozer, Validation of EPRI Methodology for Analysis of Cask Drop and Tipover Accidents at Spent Fuel Storage Facilities

12. Clough and Penzien, Dynamics of Structures McGraw Hill, 2nd Edition 1993

13. R.B. Matthiesen, Observations of Strong Motions From Earthquakes, ASCE Convention and Exposition, Portland, Oregon, April 1980

14. R.C. Dove, et. Al., Seismic Tests on Models of Reinforced-Concrete Category I Buildings, Structural Mechanics in Reactor Technology, SMIRT 8, Brussels, Belgium,1985

15. NUREG/CR-3966, <u>Methods For Impact Analysis of Shipping Containers</u>

16. R. J. Roark, <u>Formulas For Stress and Strain</u>, 4th Edition

Figure 3D.1-1
Weight and Dimensions of TN-32 Cask
(Weight of Trunnions, Neutron Shield, and Protective Cover are Included in the Cask)

Security-Related Information Figure Withheld Under 10 CFR 2.390.

Figure 3D.1-2
TN-32 Cask - Finite Element Model (1)

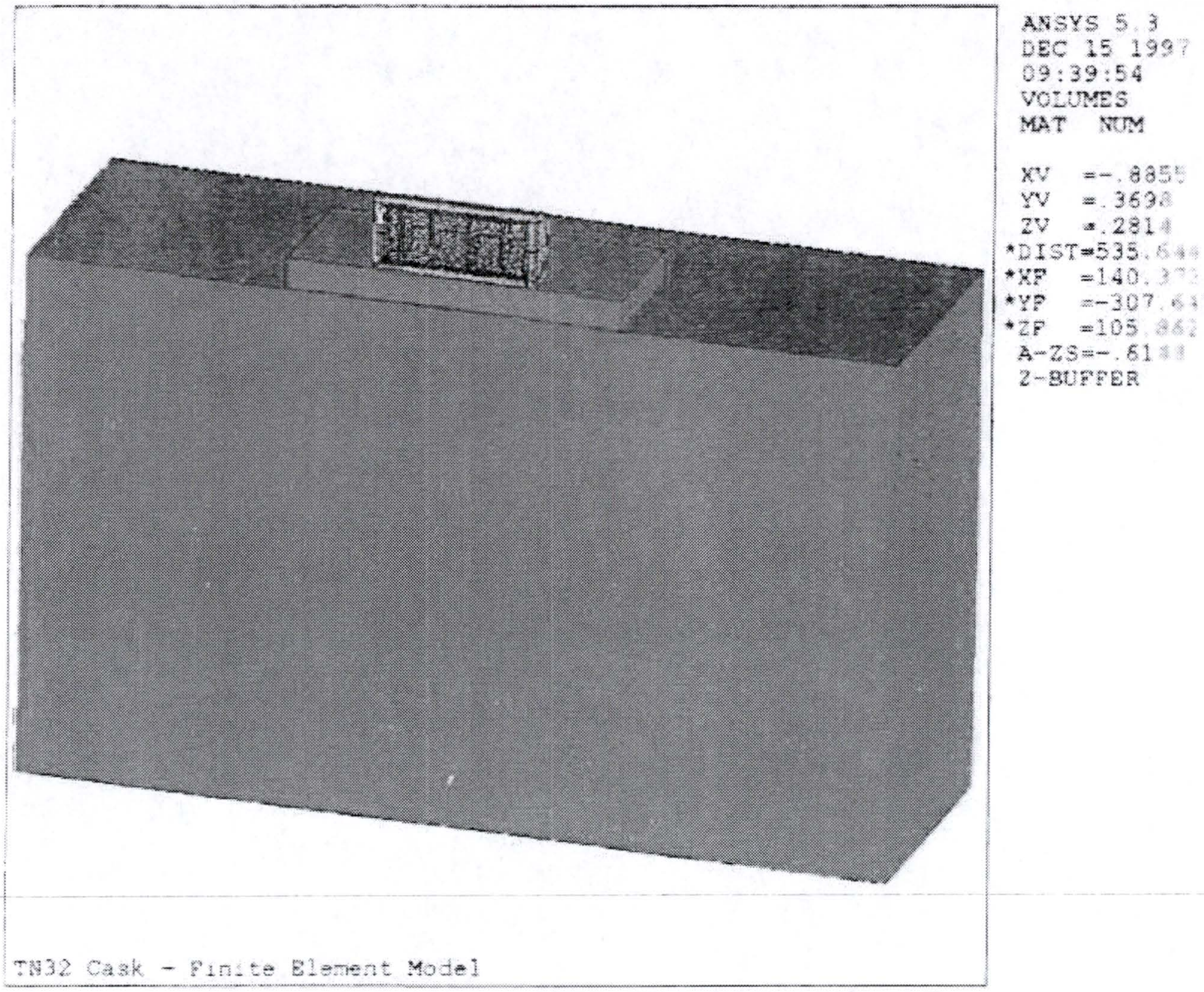


Figure 3D.1-3
TN-32 Cask - Finite Element Model (2)

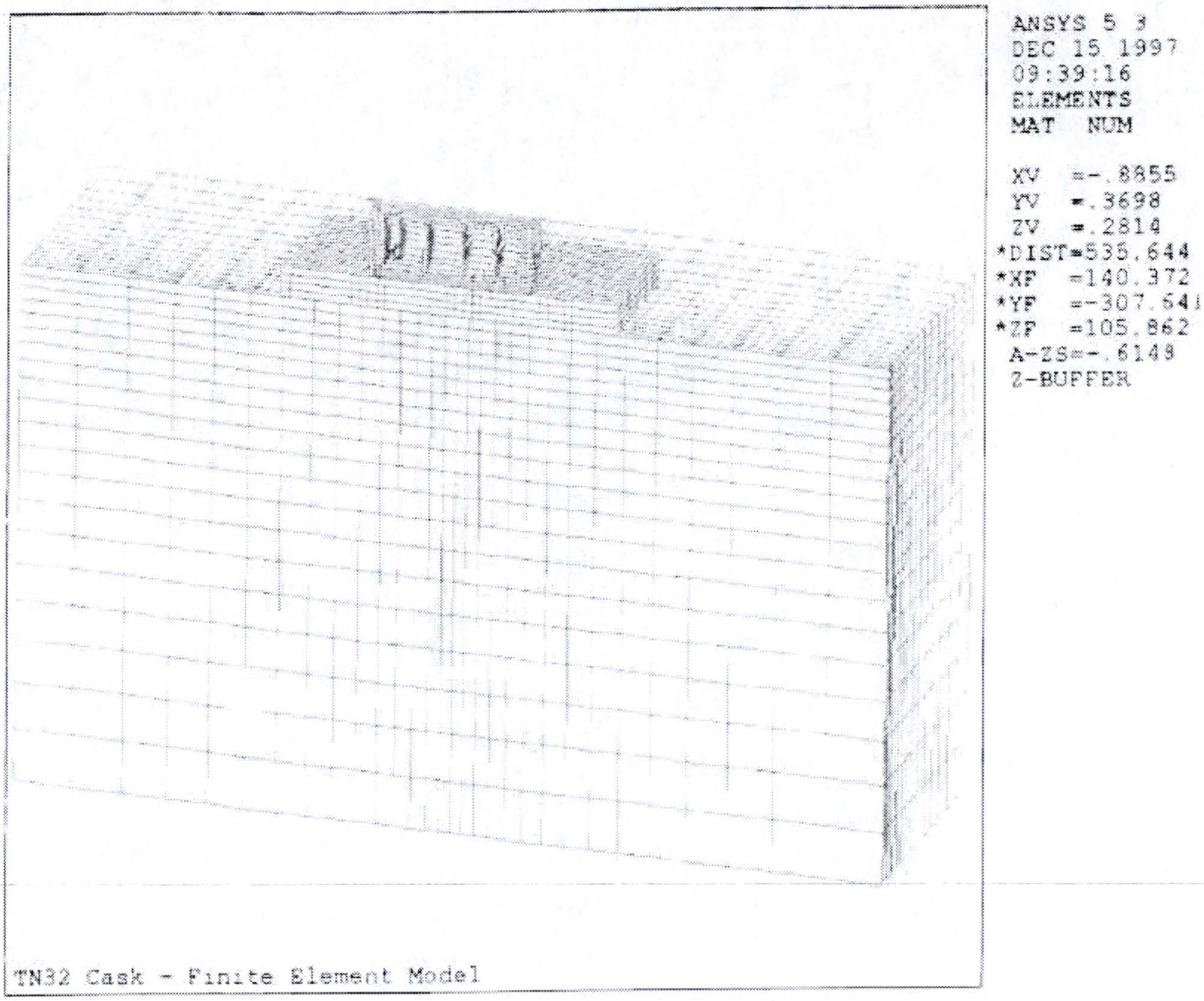
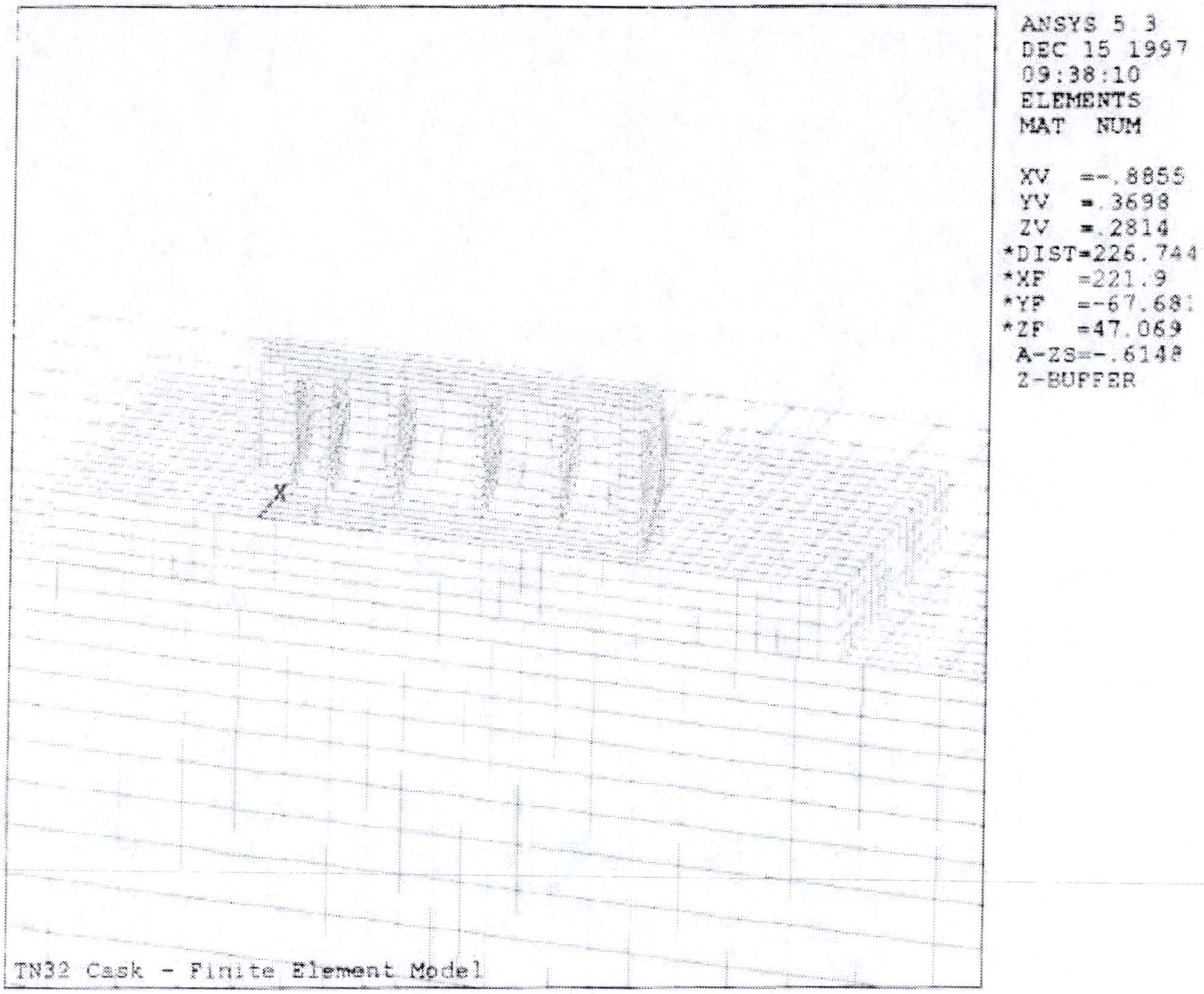
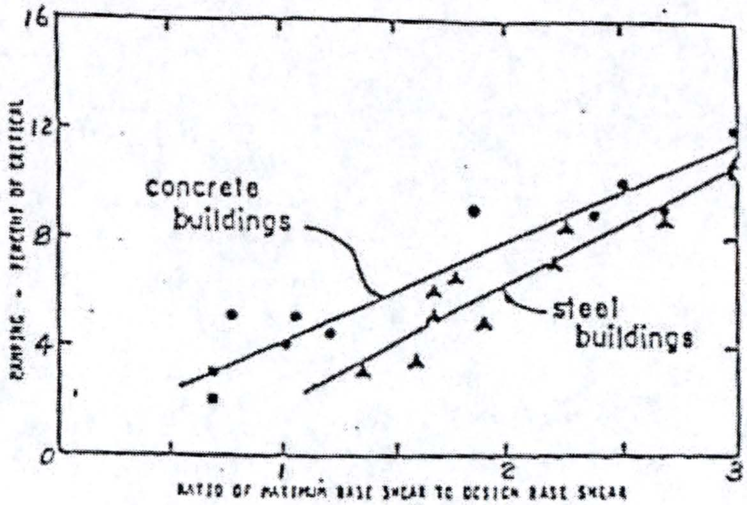


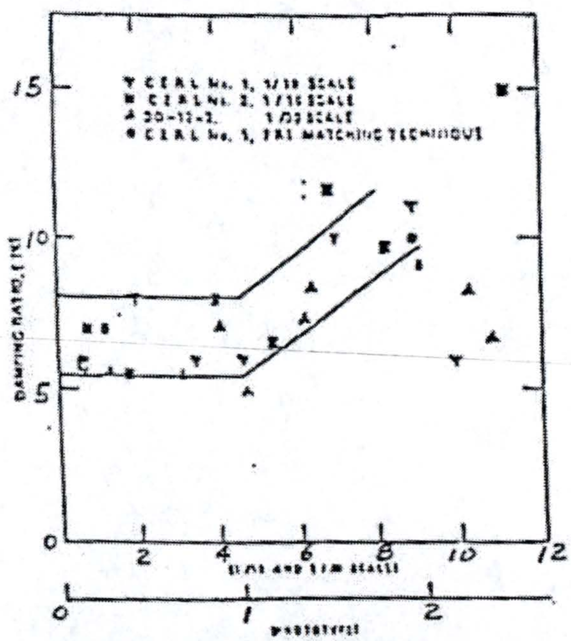
Figure 3D.1-4
TN-32 Cask - Finite Element Model (3)



<u>Figure 3D.2-1</u>
Damping Ratio Data Reproduced From References 13 and 14



Relationship of Effective First Mode Damping to Maximum Base Shear that Occured During the San Fernando Earthquake (FROM REF. 13)



Measured Damping Ratios for Reinforced Concrete Category I Buildings (FROM REF. 14)

Figure 3D.2-2
TN-32 Cask - Symmetry Boundary Conditions

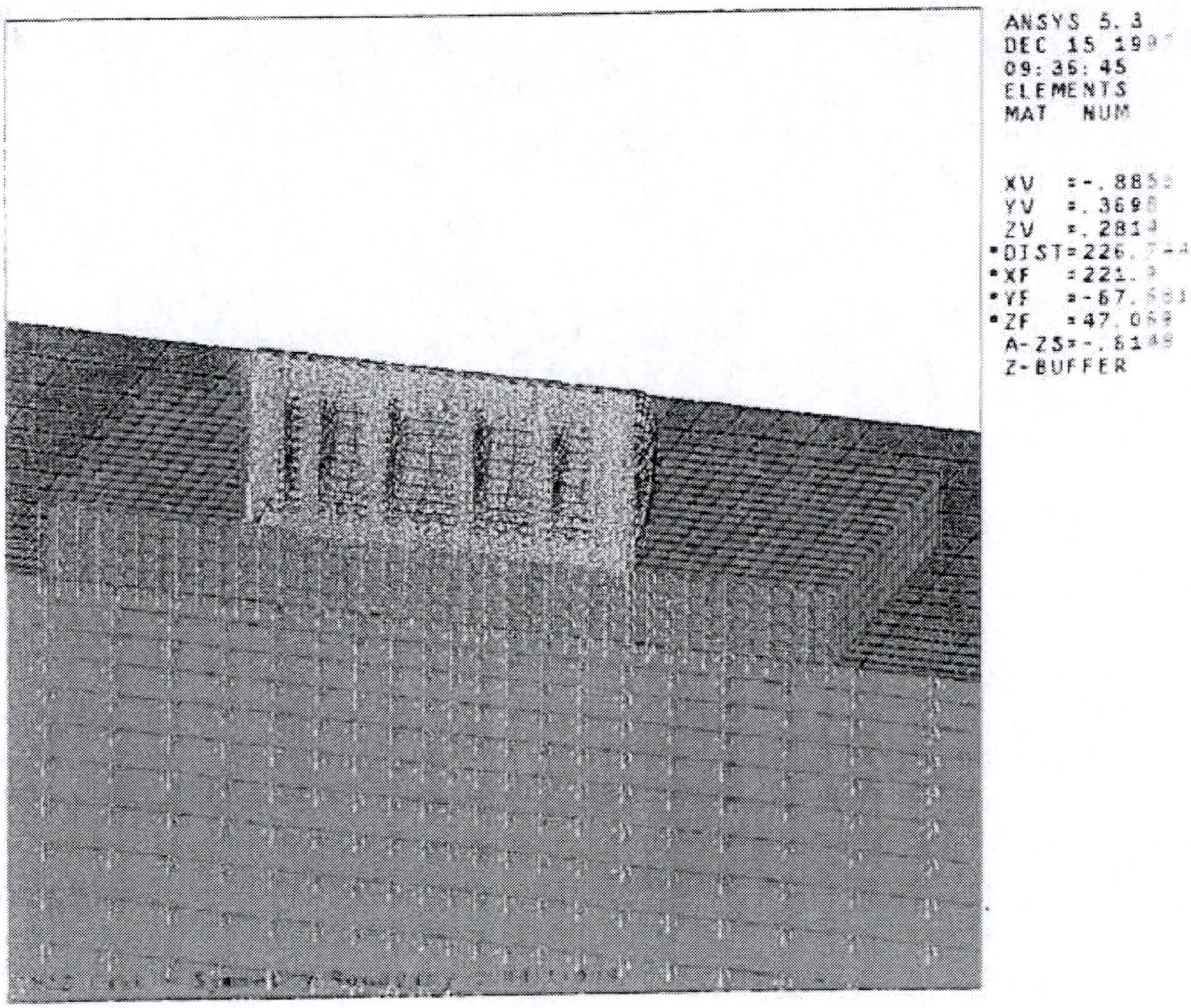


Figure 3D.2-3
TN-32 Cask - Modal Analysis

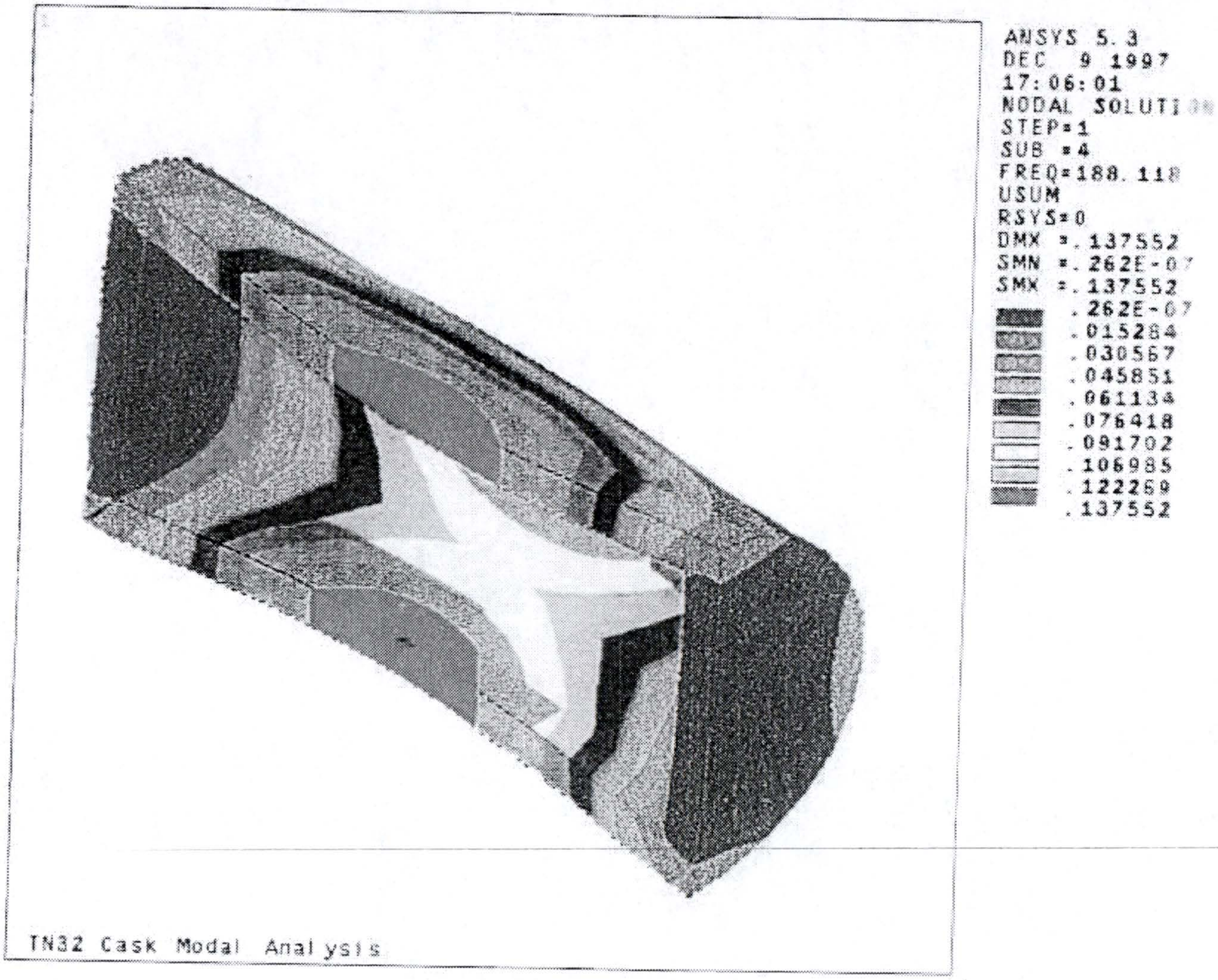


Figure 3D.2-4
TN-32 Cask Tipover Analysis - Displacement Time History

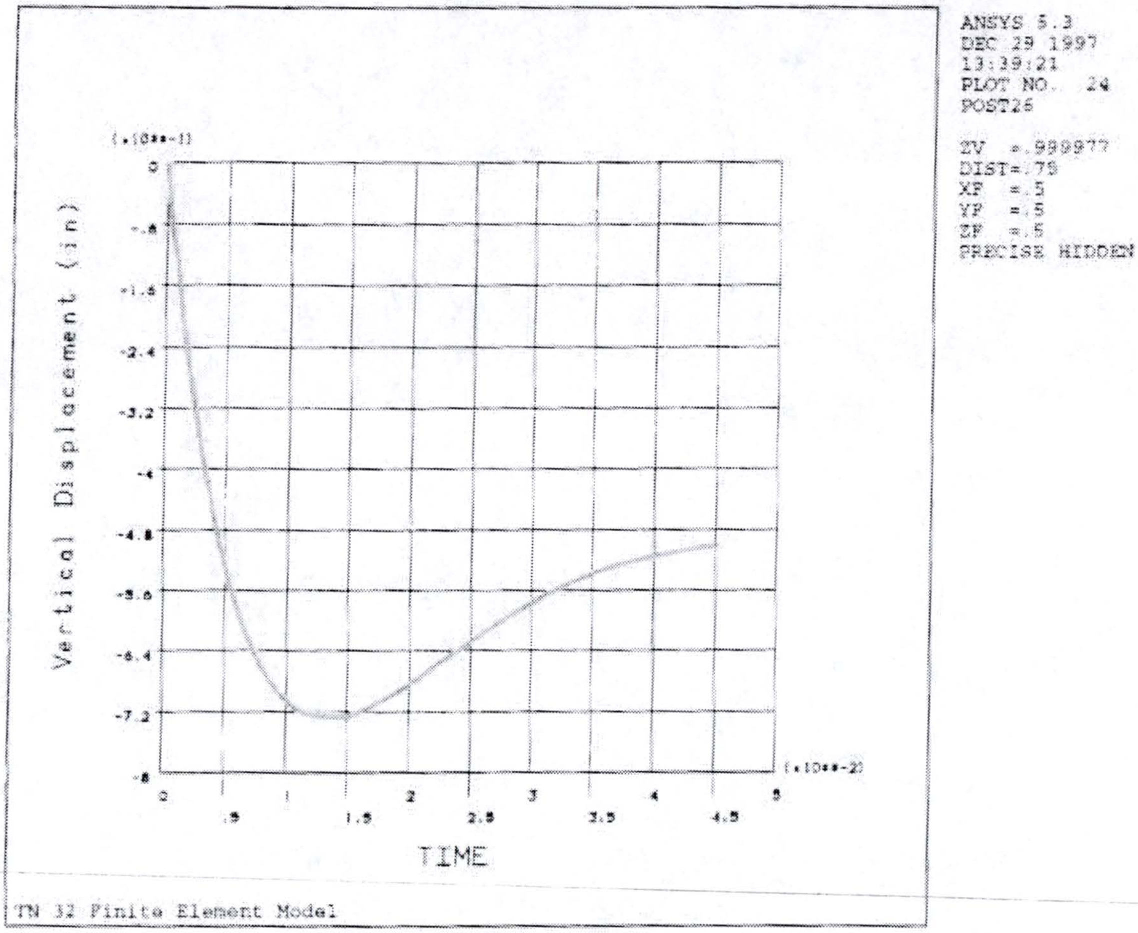


Figure 3D.2-5
TN-32 Cask Tipover Analysis - Von Mises Stress Time History

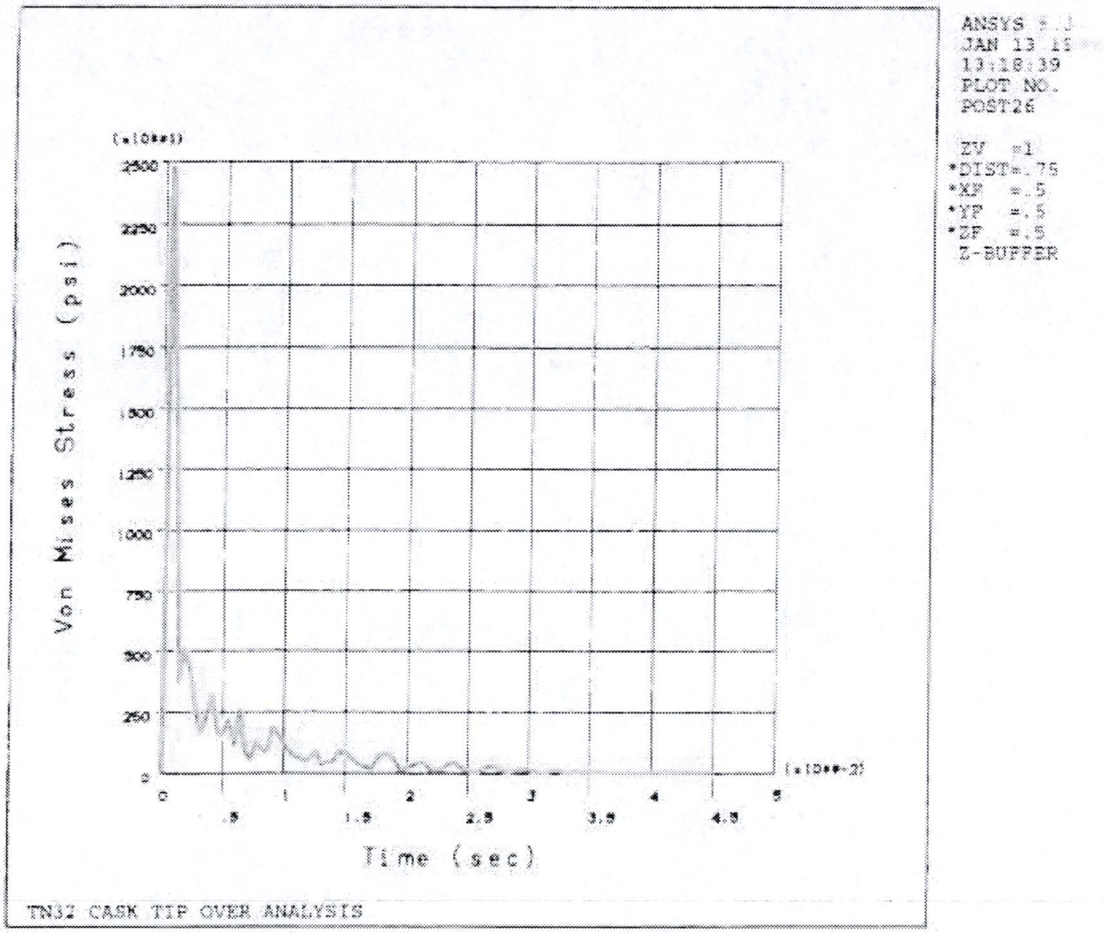


Figure 3D.2-6

TN-32 Cask Tipover Analysis - Stress Plot

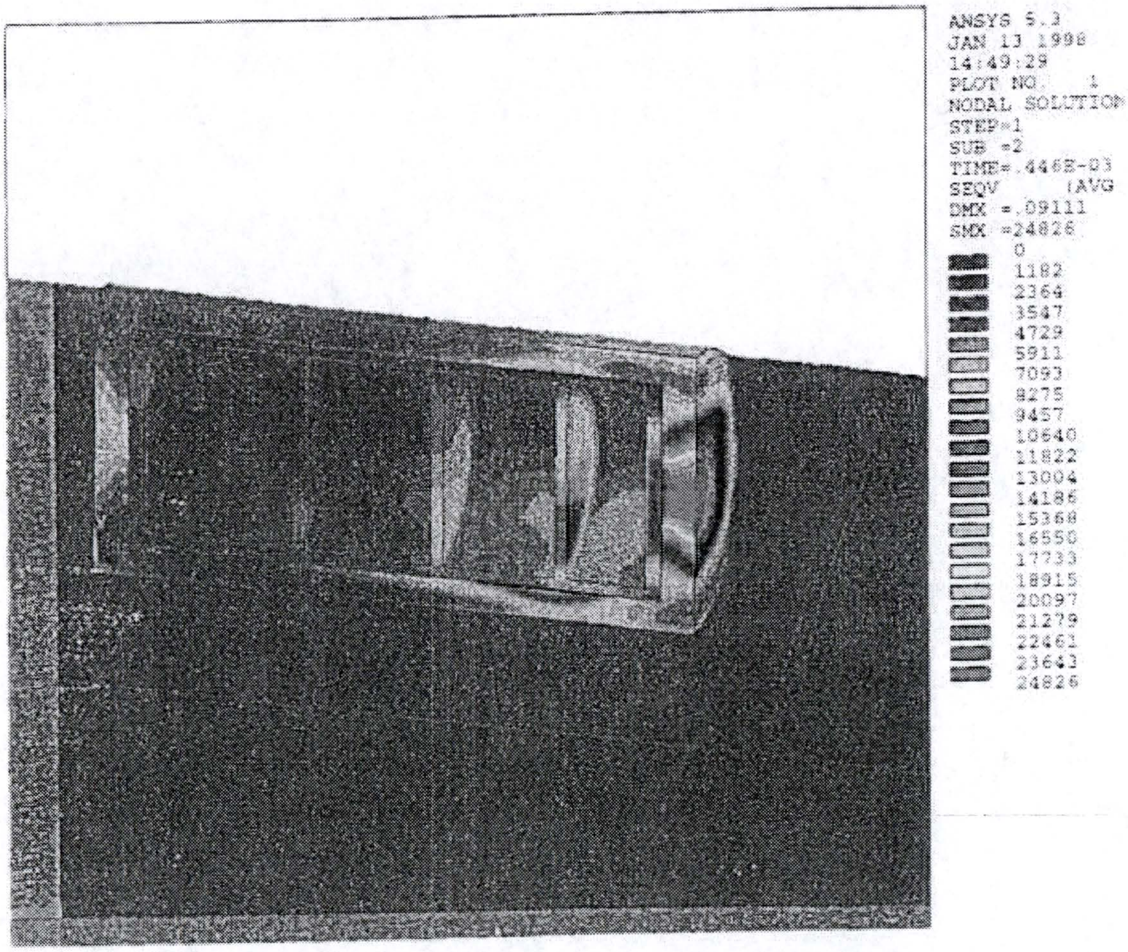


Figure 3D.2-7

TN-32 Cask Tipover Analysis - Acceleration Time History
(Max. Acceleration = 67g, Performed by Transnuclear)

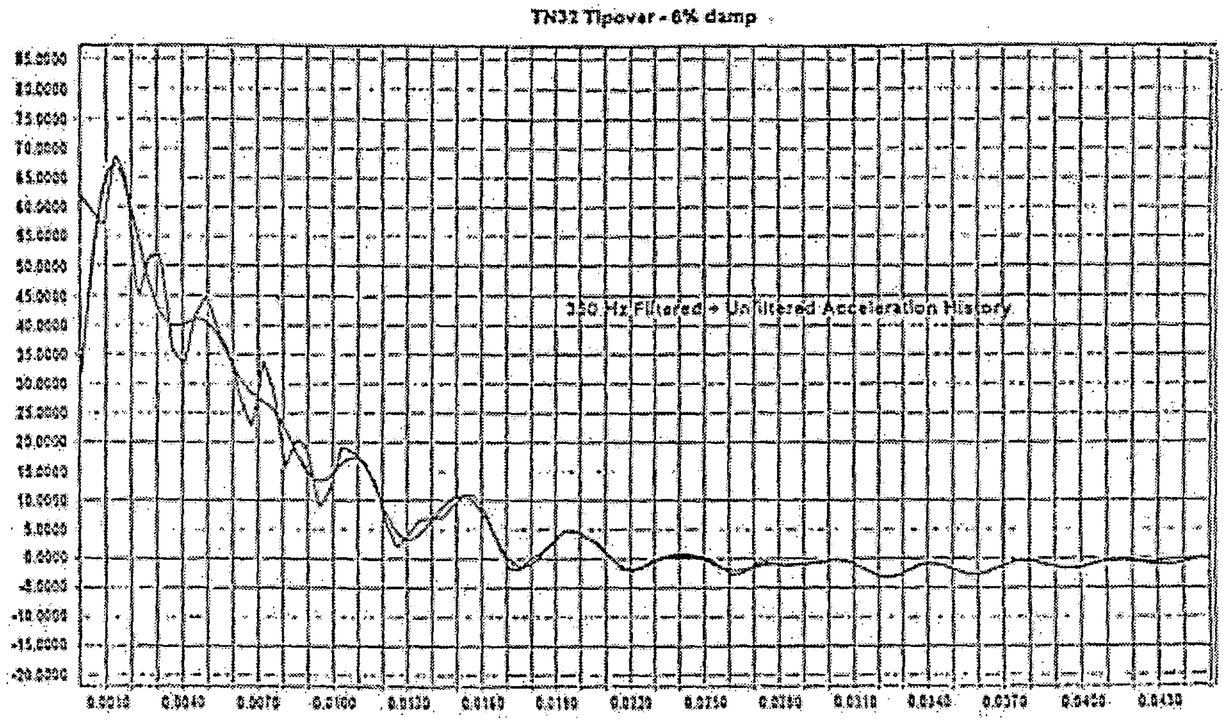


Figure 3D.2-8
Generic Cask Tipover Analysis Results, Unfiltered and Filtered at 350 Hz (Max. Acceleration = 66.7g, Performed by LLNL)

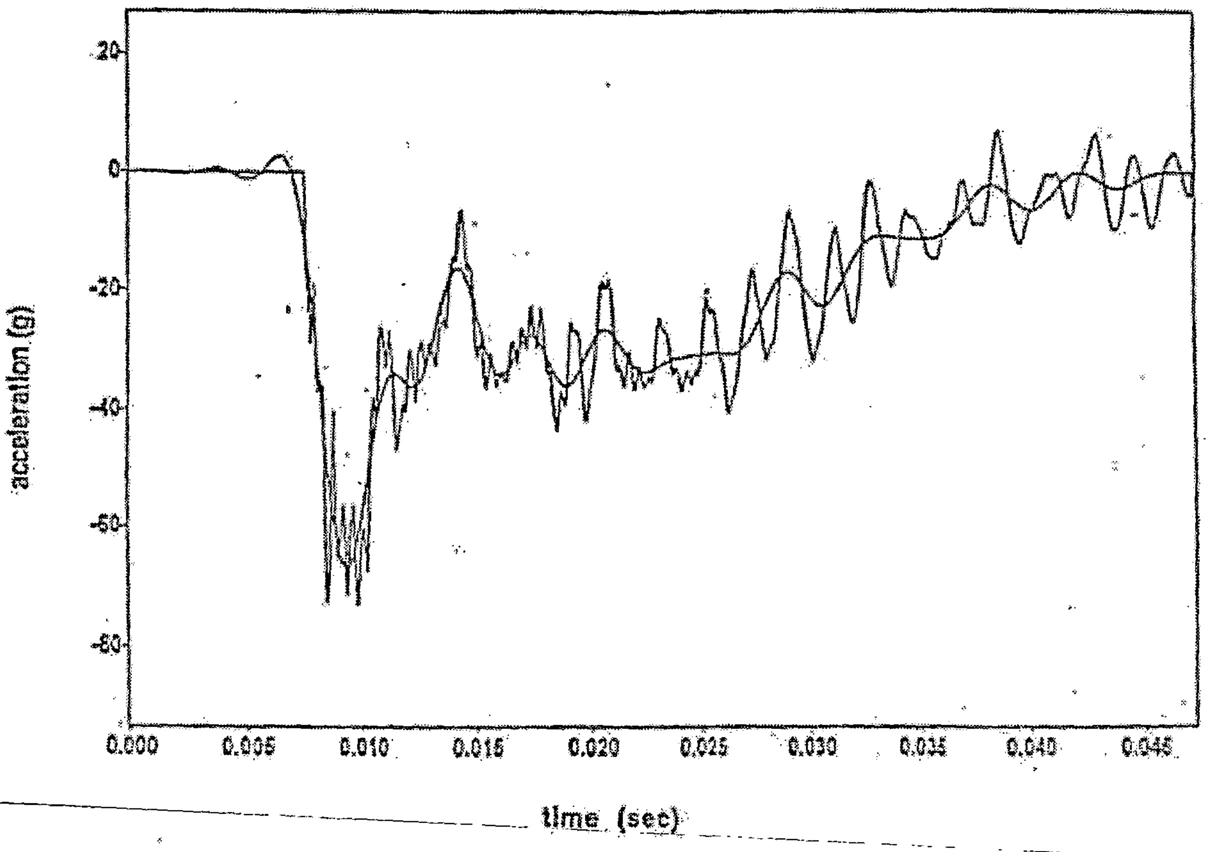


Figure 3D.2-9

Dynamic Load Factors vs. Frequency Ratio - Reproduced From NUREG/CR-3966

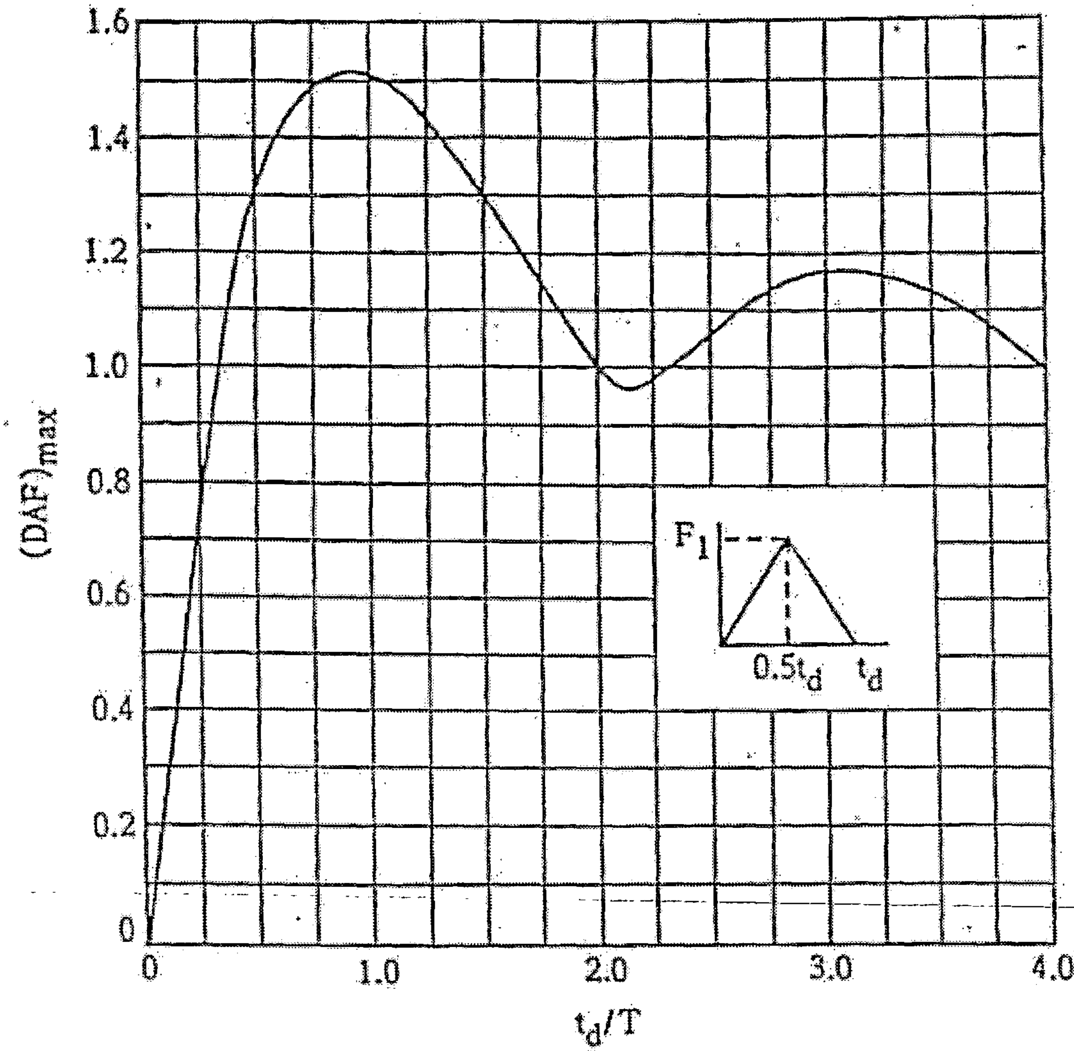


Figure 3D.4-1
Finite Element Grid for BNFL Cask Drop on Concrete Slab

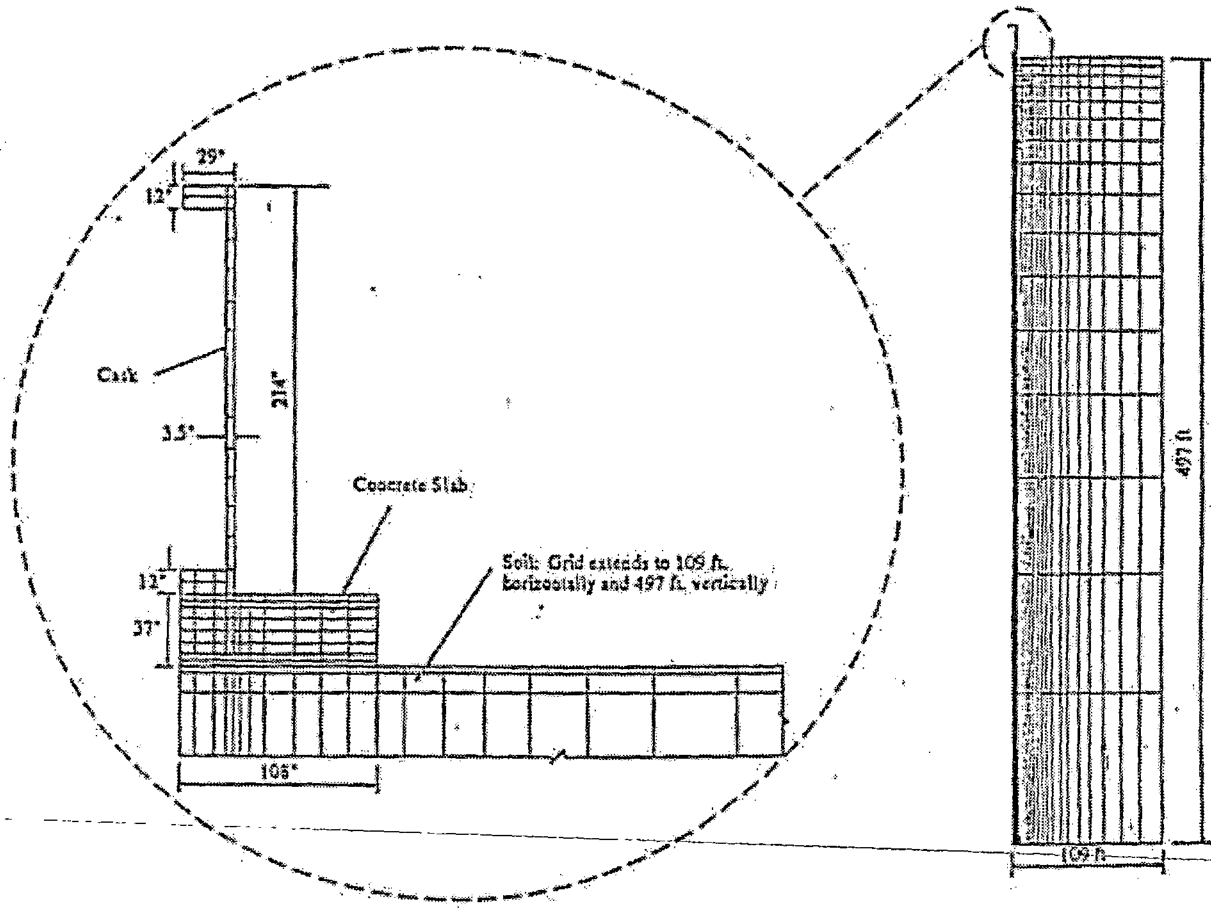


Figure 3D.4-2
Finite Element Model of BNFL Full Scale Drop Test #4

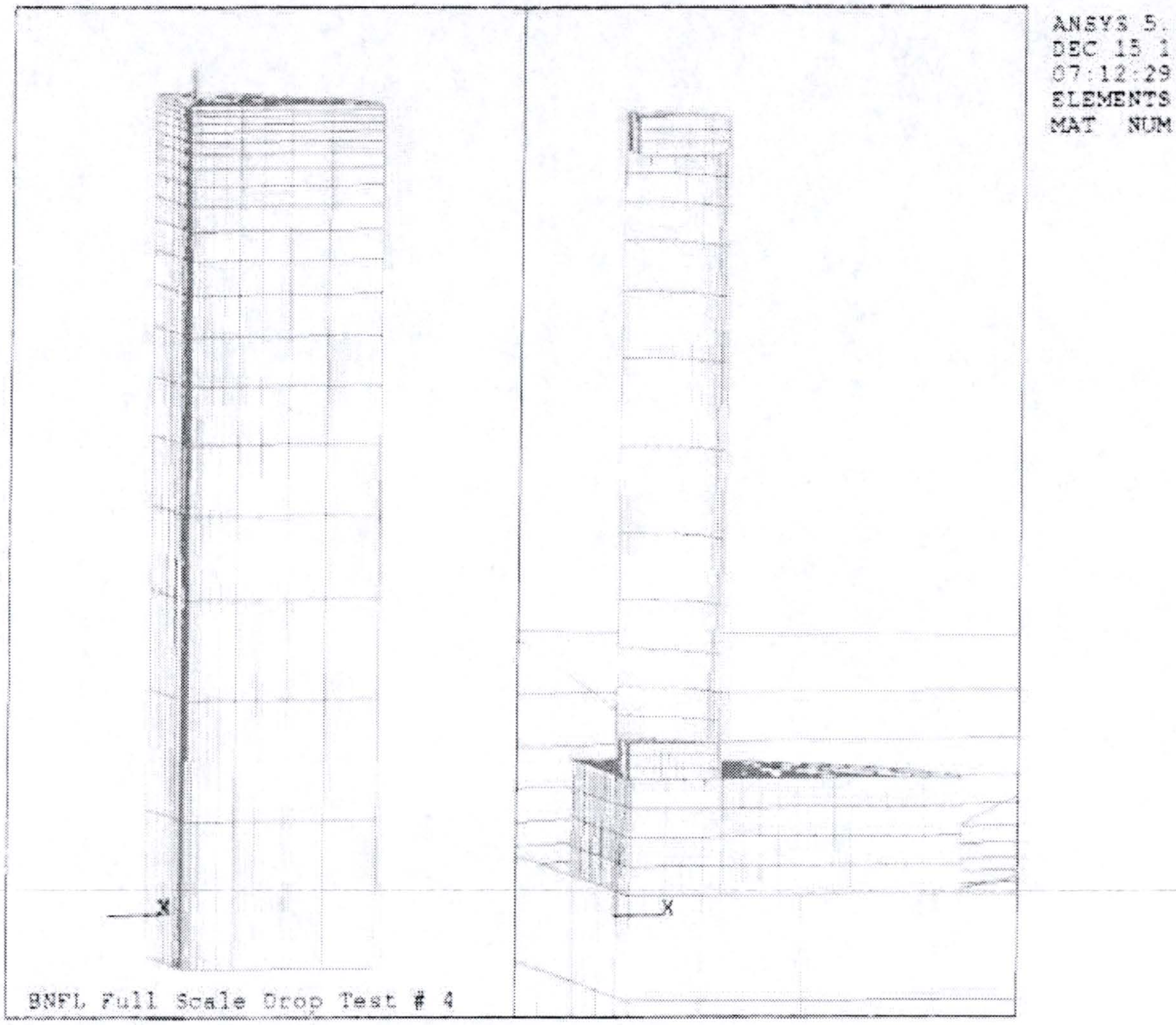


Figure 3D.4-3
BNFL Full Scale Drop Test #4 - Cask Modal Analysis

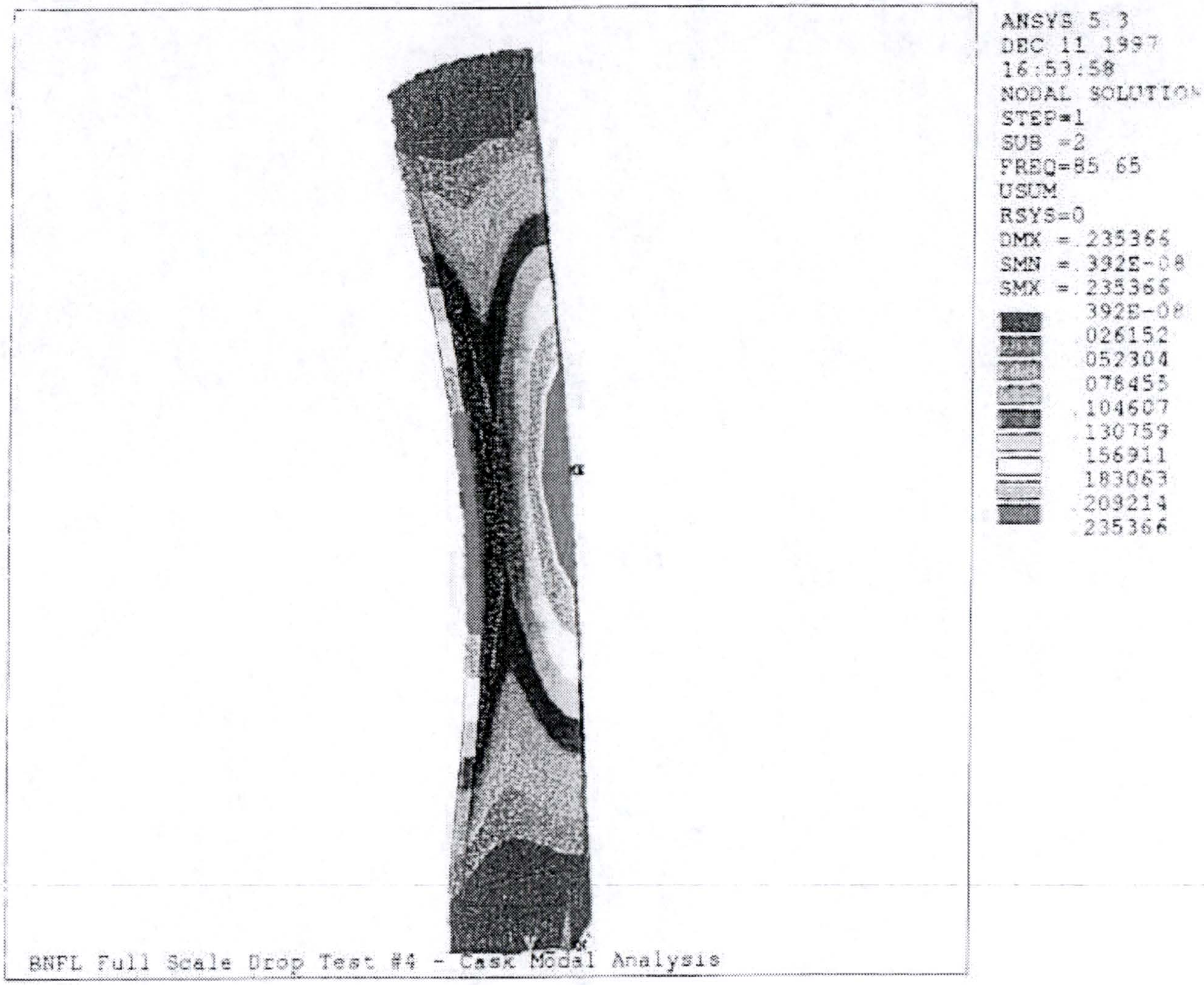


Figure 3D.4-4

BNFL Cask End Drop - Displacement Time History (10% Damping)

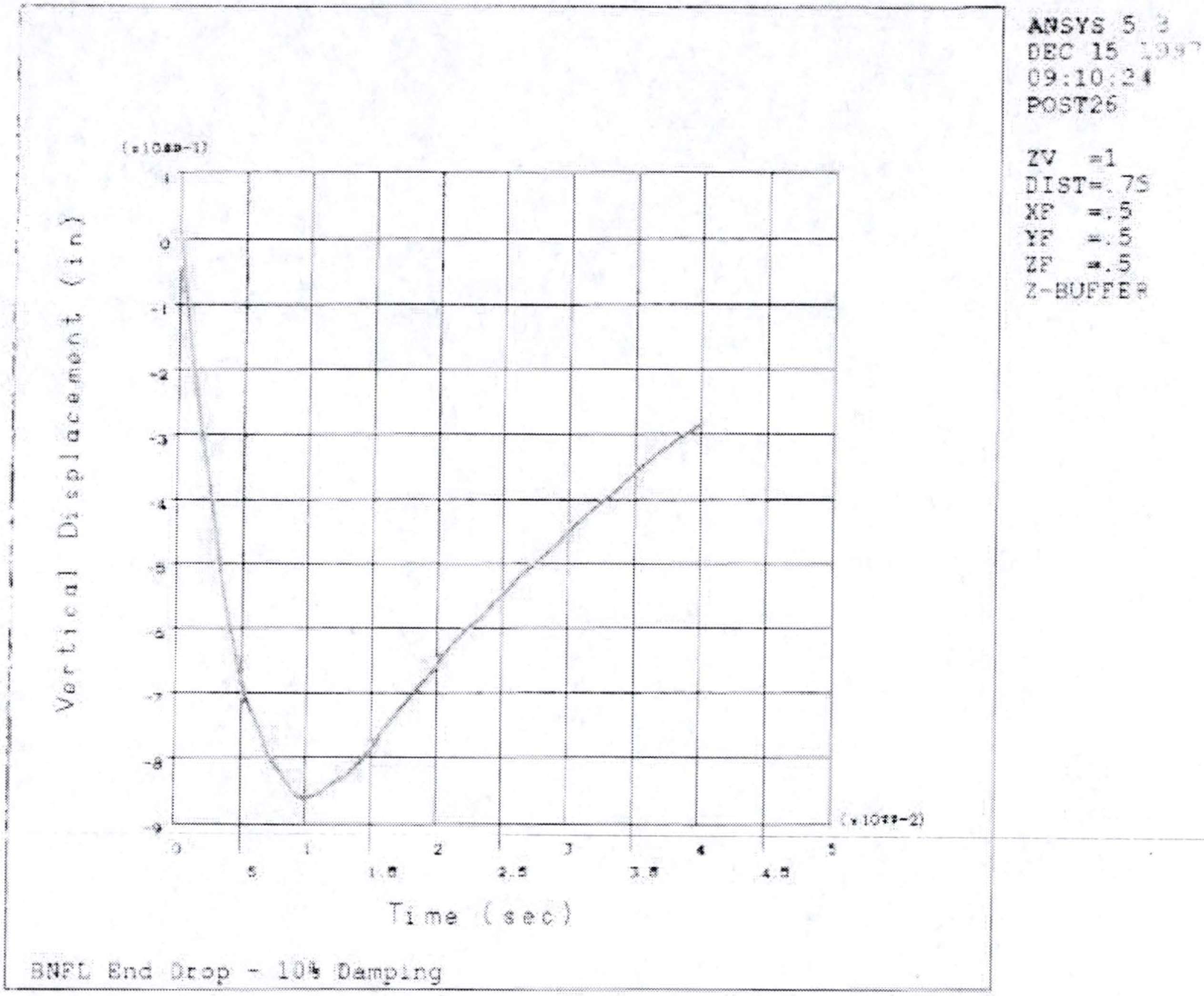


Figure 3D.4-5
BNFL Cask End Drop - Displacement Plot (10% Damping)

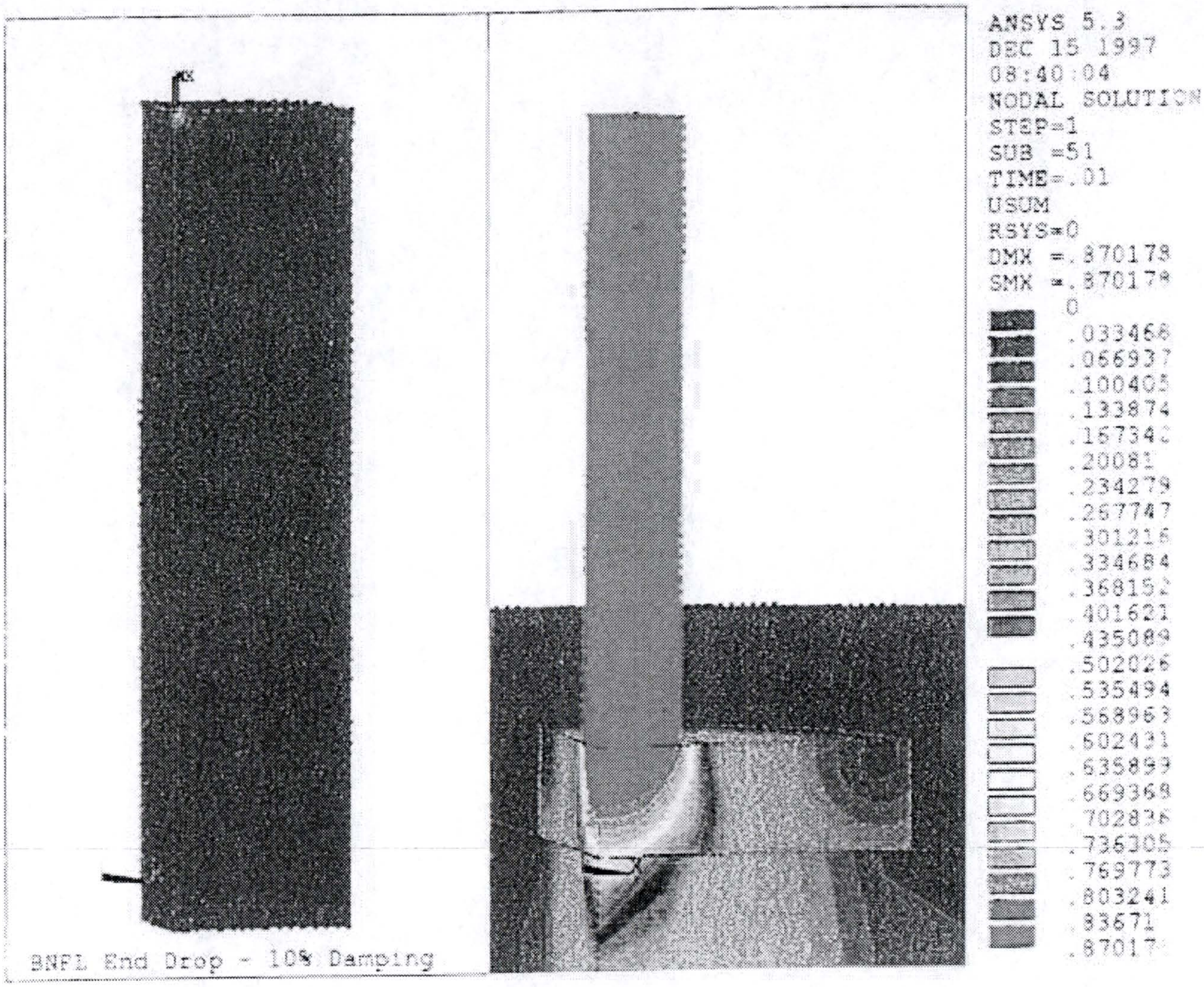


Figure 3D.4-6

BNFL Cask End Drop - Displacement Time History (4% Damping)

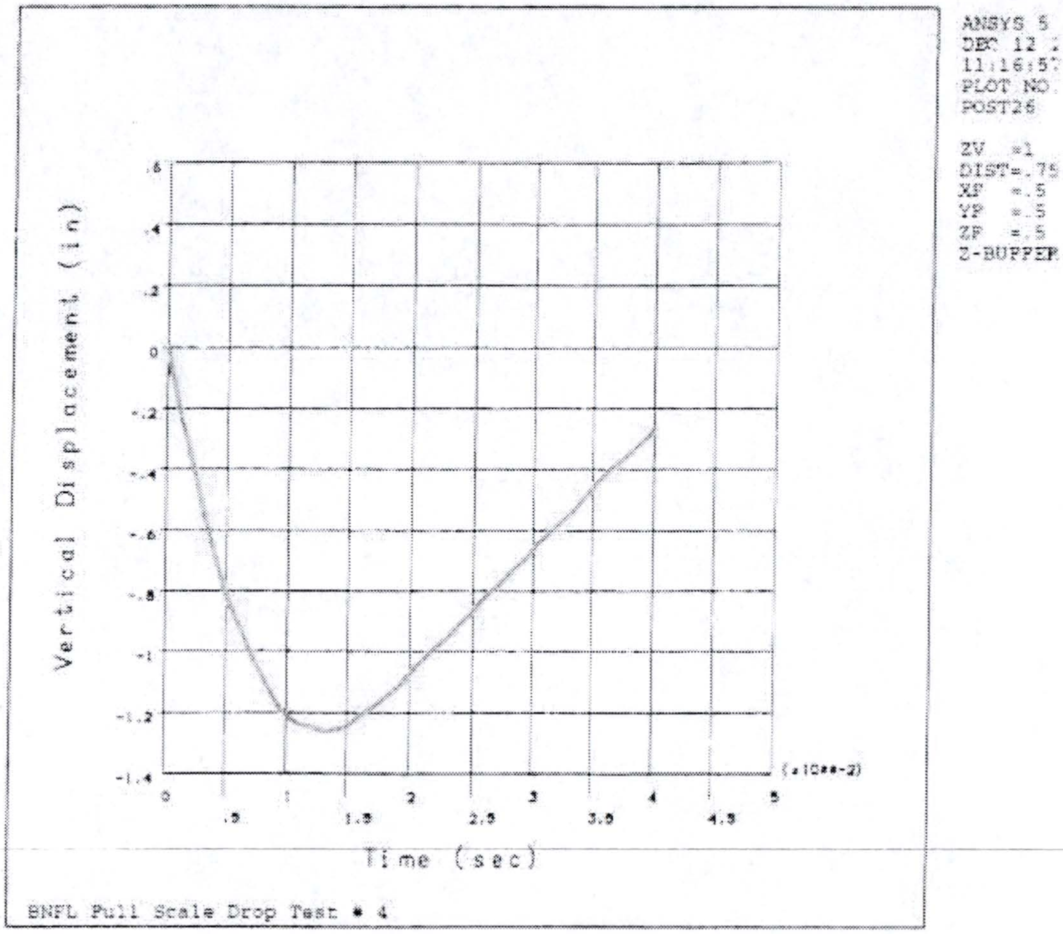
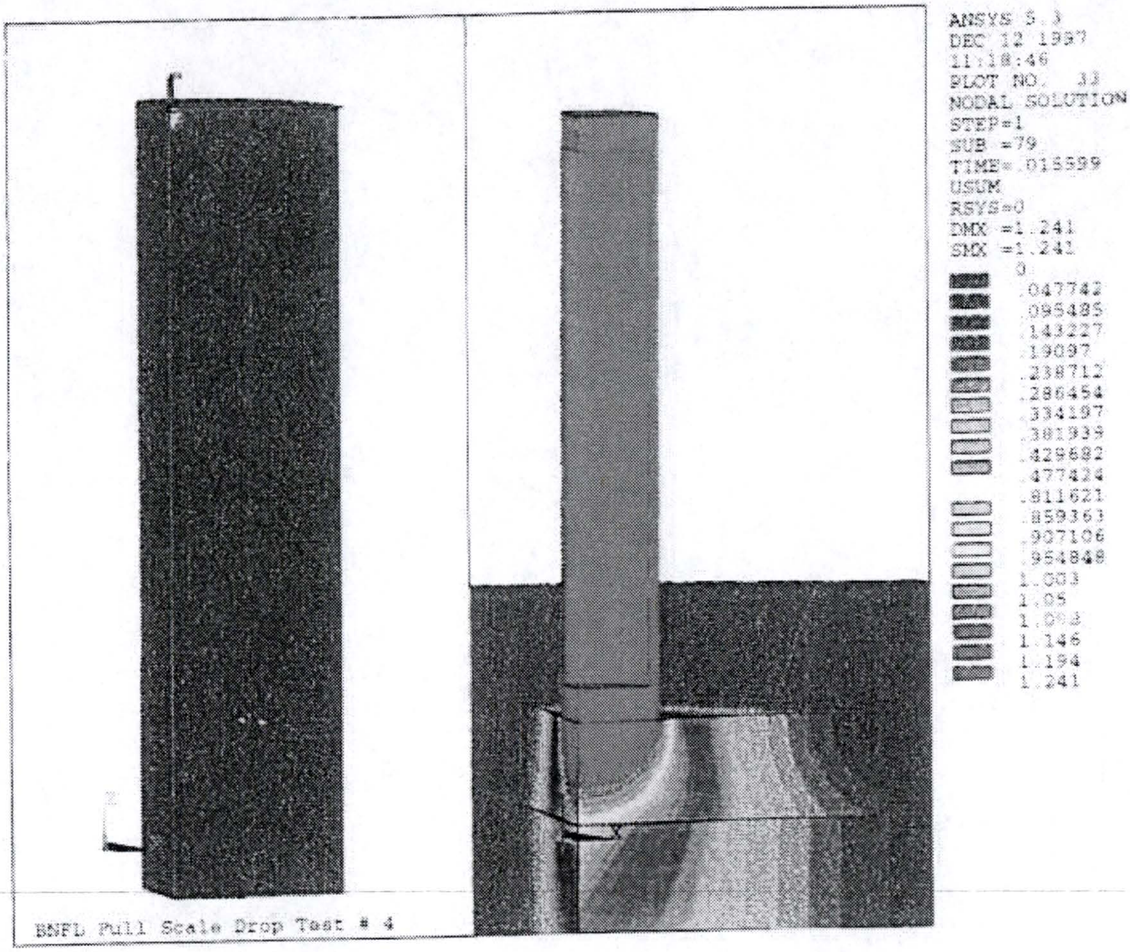


Figure 3D.4-7

BNFL Cask End Drop - Displacement Plot (4% Damping)



APPENDIX 3E

FRACTURE TOUGHNESS EVALUATION OF TN-32 CASK

3E.1 Introduction

This appendix documents the calculation of the allowable flaw sizes for TN-32 spent fuel dry storage cask confinement boundary, gamma shield, and welds. The results of this evaluation can be used to develop an appropriate inspection program and select an appropriate inspection technique to properly inspect the cask. It can also be used as an initial screening criteria to disposition any indications which are detected during inspection.

3E.1.1 Fracture Toughness Evaluation of Confinement Boundary

The TN-32 cask is designed for an ambient temperature of -20°F. It is unlikely that the confinement boundary components would reach -20°F, since the heat load of the fuel would keep the cask temperatures elevated. In addition, the ambient temperature would not be at -20°F for an extended period of time. However, if the ambient temperature were to drop to -20°F, it would remain at that temperature for only a short period of time, on the order of a few hours during the coldest part of the night. This time period would be insufficient to bring the confinement boundary components down to ambient temperature due to its large thermal mass and the heat load of the fuel.

NUREG-1536[1], " The Standard Review Plan for Dry Cask Storage Systems" specifies on Page 3-10:

> The potential for brittle fracture of some components important to safety has resulted in conditions of use that preclude transfer operations under extremely low temperature conditions. Ensure that any assumptions about internal heat generation for the brittle fracture analysis are defined on the basis of the maximum storage life and the possibility of a partial load in the cask.

Regulatory Guides 7.11[2] and 7.12[3] were written to address shipping cask confinement vessels which are subject to severe impact loads at low temperatures. Shipping casks are often shipped empty or loaded with non-fuel components.

Therefore, it is appropriate to neglect the heat load of the cask contents in determining the minimum service temperature. Unlike shipping casks, storage casks are not subject to severe impact loads at severe temperatures. Restrictions can be imposed on the casks to preclude transport to or from a storage pad during extreme cold conditions, and during storage, the casks are stationary and are shown by calculation not to tipover due to seismic loads, tornado missiles and high winds.

For casks that are built under the TN-32 Certificate of Compliance, the required Nil Ductility Transition Temperature is -80°F (T_{NDT} = LST - 60°F, conservatively assumed that the Lowest Service Temperature, LST, is -20°F). The confinement boundary components will be tested in accordance with NB-2331 of Section III[4], Division I, Subsection NB of the ASME Boiler and Pressure Vessel Code. In addition to determining the nil ductility transition temperature, charpy v-notch testing shall be performed at a temperature no greater than 60°F above the T_{NDT}. The acceptance criteria is that the material exhibit at least 35 mils lateral expansion and not less than 50 ft-lbs absorbed energy. This testing is sufficient to ensure that the confinement boundary materials will not be susceptible to brittle fracture at -20°F.

Despite the fact that the confinement boundary material meets the fracture toughness requirements of ASME Section III, Subsection NB, Transnuclear has performed a fracture mechanics evaluation of the TN-32 Dry Storage Cask confinement boundary. The work includes the following:

- Methodology
- Loadings
- Material fracture toughness
- Fracture toughness criteria
- Primary stress criteria
- Allowable flaw calculations
- Conclusions
- NDE Inspection Plan

Methodology

This section documents the calculation of the allowable flaw sizes for the TN-32 confinement boundary.

The allowable flaw sizes were calculated using linear elastic fracture mechanics (LEFM) methodology from Section XI of ASME Code[5] (1989). Flaws in the welds, if they occur, are expected to be welding defects, rather than initiated cracks. There is no active mechanism for crack initiation and growth at any of the weld locations. Thus, the calculated allowable flaw sizes can be used during fabrication and future inspections.

Loadings

The following table lists the maximum membrane and bending stresses at the confinement boundary under normal and accident conditions. Figure 3E-1 shows the selected locations on the confinement boundary numbered 1 through 7 for fracture toughness analysis. These locations were selected to be representative of the stress distribution in the confinement boundary with special attention given to areas subject to high stresses and weld locations. The maximum stress may occur at a different location for different load combinations (bolt preload, pressure, temperature, lifting load, fabrication stress, end drop, and tipover side drop).

All welds in the confinement boundary have been stress relieved. There is one longitudinal weld in the confinement shell, a circumferential weld between the flange and shell and a circumferential weld between the bottom and shell. In addition, the shell may be made from 2 courses so there may also be a circumferential weld about midway along the length of the shell. After welding, the confinement shell is stress relieved in accordance with Subsection NB requirements. Weld residual stresses will be significantly reduced due to the stress relief. Weld residual stresses are steady state secondary stresses. The ASME Code does not prescribe limits for weld residual stresses. These stresses are displacement (or strain) controlled, and are self equilibrating through the weld thickness. For the purpose of this calculation, residual stresses are considered to have a constant tensile magnitude of 8 ksi. This is similar to the value used in the evaluation of reactor pressure vessels to account for the potential for remaining residual stress after post weld heat treatment. The following table also shows the residual stresses used at each weld location. In addition

to the applied stresses, the weld residual stresses are included in the fracture toughness evaluation at the weld locations.

Summary of Stress Components
(TN-32 Confinement Boundary)

Location (Fig. 3E-1)	Normal Conditions				Accident Conditions			
	Axial Stresses (ksi)		Hoop Stresses (ksi)		Axial Stresses (ksi)		Hoop Stresses (ksi)	
	σ_m	σ_b	σ_m	σ_b	σ_m	σ_b	σ_m	σ_b
1	-1.05	0.28	-1.05	0.15	2.01	8.43	3.74	0.13
2**	-1.12	2.65	-1.12	1.00	-15.66	23.92	-5.11	7.91
3**	-3.07	2.41	-17.5	0.55	-4.48	6.33	-20.62	9.90
4**	-3.07	0.04	-12.48	0.19	-8.36	4.66	-14.50	13.33
5**	-3.07	4.63	-10.56	1.59	3.73	3.42	-14.03	7.28
6	-0.94	1.72	-11.51	0.46	3.26	0.27	-15.48	5.56
7	-0.31	2.21	-0.31	2.23	13.55	16.09	1.45	8.51

** In addition to these applied stresses, a weld residual stress of 8 ksi was added to these locations for fracture toughness evaluations.

Material Fracture Toughness

The TN-32 cask design has the following material in the confinement boundary:

- Confinement shell and bottom SA-203 Gr.D
- Confinement Flange SA-350 LF3
- Confinement lid SA-350 LF3 or SA-203 Gr.D

These alloy materials are classified as cryogenic and will provide good toughness properties at low temperature. However, for conservatism the value of K_{ID}(47 ksi$\sqrt{}$in at -20°F) was used for fracture toughness evaluation of the confinement boundary. This assumption is extremely conservative, since this K_{ID} typically is calculated based on Charpy value of 15 ft-lb at -20°F, while typical Charpy values of SA-203 Gr. D and SA-350 LF3 are 210 ft-lb and 115 ft-lb at -20°F, respectively.

Fracture Toughness Criteria

Using the rules of Section XI, IWB-3613, the limiting fracture toughness values are reduced by a factor of $\sqrt{10}$ for normal conditions and $\sqrt{2}$ for accident conditions, to define the limiting $K_{allowable}$. That is,

$K_{allowable} \leq K_{ia}/(\sqrt{10})$ = 14.86 ksi-$\sqrt{}$in. for normal conditions

$K_{allowable} \leq K_{ic}/(\sqrt{2})$ = 33.2 ksi-$\sqrt{}$in. for accident conditions

Where:

K_{ia} = the available fracture toughness based on crack arrest

K_{ic} = the available fracture toughness based on crack initiation

For conservatism, the K_{ia} value is used for fracture toughness evaluation of both the normal and accident conditions.

Primary Stress Criteria

ASME Section XI, IWB-3610 requires that any flaw evaluation include verification that the primary stress limits of ASME Code Section III continue to be met for the flawed component. The following formula conservatively assumes that the available thickness is equal to the original thickness minus the allowable flaw depth.

$$a_{all} = t(1 - S/S_{all})$$

Where:

a_{all} = allow. flaw depth based on ASME Code Sect. III limits
t = original local thickness
S = maximum calculated local stress intensity
S_{all} = allowable stress intensity per ASME Section III.

It is conservatively assumed that all stresses are pure tensile membrane stresses and that the stresses will increase linearly with decreasing wall thickness.

Allowable Flaw Size Calculation

Using the above load definitions and fracture toughness, a series of allowable flaw size calculations were performed using the Structural Integrity Associates computer program pc-CRACK™(6) (Structural Integrity Associates, pc-CRACK™ for Windows, version 3.0, March 27, 1997).

- Surface Flaws

For purpose of analysis, the postulated surface flaws are oriented in both the axial and circumferential direction. The cracks selected for each location are shown in the above table. For the confinement boundary, due to the very small t/R ratio, a single edge cracked plate (SECP) model was used.

The results of the pc-CRACK calculations are shown in the following table.

- Subsurface Flaws

The above discussion addresses the determination of allowable sizes for flaws that are connected to the surface

of the material, under a conservative set of assumptions. The bare metal or weld could also contain subsurface defects.

An evaluation of allowable subsurface defects was performed using the same linear elastic fracture mechanics technique as described above for surface defects. For this case, a center cracked panel (CCP) model was used to evaluate an assumed flaw length. The flaw must be sufficiently embedded such that treatment as a subsurface flaw is justified. In general, if a flaw is closer to the surface than 0.4 of its half-depth, it must be considered a surface flaw.

The results of the pc-CRACK calculations are shown in the following table.

Allowable Surface Flaw Depth (inches)
(TN-32 Confinement Boundary)

Location (Fig. 3E-1)	Normal Conditions		Accident Conditions	
	⊥ Axial Stress	⊥ Hoop Stress	⊥ Axial Stress	⊥ Hoop Stress
1	--- (1.41)	--- (1.41)	0.79	0.97
2	0.8	0.94	--- (0.69)	0.93 (0.69)
3	--- (0.99)	--- (0.99)	--- (1.17)	--- (1.17)
4	--- (1.28)	--- (1.28)	--- (1.09)	--- (1.09)
5	1.0	--- (1.02)	0.58	--- (1.08)
6	--- (1.26)	--- (1.26)	--- (0.97)	--- (0.97)
7	3.30	3.29	0.34	1.75

Allowable Sub-Surface Flaw Depth (inches)
(TN-32 Confinement Boundary)

Location (Fig. 3E-1)	Normal Conditions		Accident Conditions	
	⊥ Axial Stress	⊥ Hoop Stress	⊥ Axial Stress	⊥ Hoop Stress
1	--- (1.41)	--- (1.41)	1.3 (1.22)	--- (1.22)
2	1.34	--- (1.5)	1.18 (0.69)	1.36 (0.69)
3	--- (0.99)	--- (0.99)	--- (1.17)	--- (1.17)
4	--- (1.28)	--- (1.28)	--- (1.09)	--- (1.09)
5	1.34 (1.02)	--- (1.02)	1.22 (1.08)	--- (1.08)
6	--- (1.26)	--- (1.26)	--- (0.97)	--- (0.97)
7	--- (4.07)	--- (4.07)	0.77	3.16 (2.39)

Note: "---" indicates that the allowable flaw depth is not limited by fracture mechanics calculation.

( ) indicates that the allowable flaw depth is limited by primary stress criteria.

Specific conservatisms included in the above analysis are listed below:

- All factors of safety on applied stresses required by ASME Section XI (1989 Edition) were included in the evaluation.
- Weld residual stresses were treated as constant tensile stresses normal to the flaw orientation.
- Flaws were assumed to be long (infinitely long or full circumference).
- A charpy value of 15 ft-lbs at -20 °F was used for calculating the allowable stress intensity factor.

Conclusions

The results of the fracture toughness analysis show that the flaws in the confinement boundary which would result in unstable crack growth or brittle fracture are larger than those generally observed in the plate or forged steel components. Note that these allowable flaw sizes are calculated based on extremely conservative assumptions (using Charpy value of 15 ft-lb vs. typical value of 115 ft-lb for SA-350 LF3 or 210 ft-lb for SA-203 Gr. D). The actual allowable flaw sizes are at least twice those shown on the above table.

NDE Inspection Plan

The plate and forging materials used in the confinement boundary are examined by the ultrasonic methods in accordance with ASME Section III, Subsection NB, Paragraph NB-2530 and NB-2540, respectively. The external and accessible internal surfaces of the forging materials are examined by the liquid penetrant method or the magnetic particle method in accordance with paragraph NB-2546 or NB-2545.

The welds are examined by the radiographic and either the liquid penetrant or magnetic particle methods in accordance with Section III, Subsection NB, paragraphs NB-5210, NB-5220, and NB-5230. These NDE inspections ensure that any defects at or above the sizes specified in the table are detected and repaired prior to cask use for fuel storage.

The fracture toughness requirements of the lid bolts will meet the criteria of ASME Code, Section III, Division 1, Subsection NB (Para. NB-2333). Charpy v-notch testing shall be performed at -20°F. The acceptance criteria is that the material exhibit at least 25 mils lateral expansion (Table NB-2333-1).

3E.1.2 Fracture Toughness Evaluation of gamma shield

The gamma shield shell is forged from SA-266 Grade 2 material. The bottom shield plate and top shield plate (plate welded to the bottom of the lid) are constructed from either SA-266 Grade 2 material, or SA-516 Grade 70 material. The main function of the gamma shield is to provide shielding. It is not part of the confinement, and its shielding properties are not temperature dependent.

In storage, the gamma shielding is not subjected to any significant loads. The worst case loading is due to the non-mechanistic tipover. The TN-32 cask is shown not to tipover during storage due to normal, off-normal or accident events. Nevertheless, a tipover event is evaluated. If the cask were to tipover at an ambient temperature of -20°F, it would not crack due to its reasonable fracture toughness at low temperature. However, even if it were to crack, there would be no breach of confinement, since the confinement materials have exceptional fracture toughness at low temperatures.

Furthermore, if the cylindrical gamma shielding were to crack, there is no credible mechanism for the shielding to separate from itself or the confinement. In order for this to occur, the 8 inch thick shell must become completely severed, and there would need to be a sufficient axial force to overcome the frictional forces holding the confinement vessel and the gamma shielding together resulting from the shrink fit. The top shield plate is welded to the lid and is captured by the confinement vessel. Even, if it is postulated that the weld fails completely, the shield plate will still remain inside the confinement boundary and will not lose its shield capability. The one exception is the weld of the gamma shield shell to the bottom plate. In this region, if the weld were to completely fail, the bottom plate could become detached and have an impact on the shielding capability of the cask.

Preliminary charpy test data of the same material (SA-266) from a similarly sized shield shell has been provided by one of the material manufacturers for the shield shell, and the results are tabulated below.

Charpy V-Notch Test - Results for SA-266 Gr. 2

Temperature	Specimen No.	Absorbed Energy (ft-lbs) Avg. of 3 specimens
0°C (32°F)	V1	63
	V2	60
-10°C (14°F)	V3	56
	V4	50
-20°C (-4°F)	V5	45
	V6	40
-30°C (-22°F)	V7	18
	V8	20
-40°C (-40°F)	V9	17
	V10	10

The TN-32 cask is designed for an ambient temperature of -20°F. As can be seen from the materials testing, even at temperatures as low as -20°F the gamma shielding has relatively good charpy impact properties. It is unlikely that the gamma shield would reach -20°F, since the heat load of the fuel would keep the cask temperatures elevated.

Shipping casks are often shipped empty or loaded with non-fuel components. Therefore, it is appropriate to neglect the heat load of the cask contents in determining the minimum service temperature. Unlike shipping casks, storage casks are not subjected to severe impact loads at severe temperatures. During storage, the casks are stationary and do not tipover due to seismic loads, tornado missiles and high winds.

Despite the fact that the shielding material is not part of the confinement boundary and it is unlikely that the gamma shield would reach -20°F, a fracture of the gamma shield will have no safety implications. However, Transnuclear has performed a fracture mechanics evaluation of the TN-32 Dry Storage Cask gamma shield based on a service temperature of -20°F. The work includes the following:

- Methodology
- Loadings
- Material fracture toughness
- Fracture toughness criteria

- Primary stress criteria
- Allowable flaw calculations
- Conclusions
- NDE Inspection Plan

Methodology

The allowable flaw sizes were performed using linear elastic fracture mechanics (LEFM) methodology from Section XI of ASME Code Section (1989). Flaws in the welds, if they occur, are welding defects, rather than initiated cracks. There is not an active mechanism for crack initiation and growth at any of the weld locations. Thus, the calculated allowable flaw sizes can be used during fabrication.

Loadings

The following table lists the maximum membrane and bending stresses at the gamma shield under normal and accident conditions. Figure 3E-2 shows the selected locations on the gamma shield numbered 1 through 7 for fracture toughness analysis. These locations were selected to be representative of the stress distribution in the gamma shield with special attention given to areas subject to high stresses and weld locations. The maximum stress may occur at a different location for different load combinations
(bolt preload, pressure, temperature, lifting load, fabrication stress, end drop, and tipover side drop).

Summary of Stress Components
(TN-32 Gamma Shield)

Location (Figure 3E-2)	Normal Conditions				Accident Conditions			
	Axial Stresses (ksi)		Hoop Stresses (ksi)		Axial Stresses (ksi)		Hoop Stresses (ksi)	
	σ_m	σ_b	σ_m	σ_b	σ_m	σ_b	σ_m	σ_b
1[(1)]	–1.70	1.91	2.28	0.78	-1.58	1.78	2.25	0.75
2[(2)]	–1.46	0.18	-0.01	0.01	4.76	1.33	-6.08	1.04
3	0.67	0.10	2.79	0.34	$P_m + P_b + Q$ = 30.84[(3)]		$P_m + P_b + Q$ = 30.84[(3)]	
4	–0.34	3.91	4.40	3.93	$P_m + P_b + Q$ = 30.84[(3)]		$P_m + P_b + Q$ = 30.84[(3)]	
5	0.12	0.60	0.12	0.37	-4.71	3.48	2.49	1.36
6	2.68	2.50	1.69	1.52	4.17	4.00	2.43	1.67
7[(1)]	6.85	1.67	3.76	0.55	9.03	0.87	4.64	0.55

Notes:

1. In addition to these applied stresses, the weld residual stress of 8 ksi was added at these locations for fracture toughness evaluations.
2. In addition to these applied stresses, the weld residual stress of 36 ksi was added at these locations for fracture toughness evaluations.
3. This stress results from the combination of:
   - Maximum stress from dynamic impact analysis (presented in Appendix 3D) is 25.0 ksi and occurs at the lid. The maximum stress at the gamma shield is 18.5 ksi. However, 25.0 ksi is conservatively used for gamma shield fracture toughness evaluation)
   - Bolt preload stress
   - 100 psi internal pressure stress
   - Thermal stress
   - Fabrication stress

   This combined stress is modeled as a tensile membrane stress for fracture toughness evaluations.

The gamma shield welds at locations 1 and 7 are partially stress relieved. However, the lower gamma shield welded to the bottom shield plate (location 2) does not undergo stress relief. Weld residual stress is included in the calculations for all weld locations. The weld residual stress is reduced due to the stress relief at all weld locations except the weld at location 2.

Weld residual stresses are steady state secondary stresses. The ASME Code does not prescribe limits for weld residual stresses. These stresses are displacement (or strain) controlled, and are self equilibrating through the weld thickness. For the purpose of this calculation, residual stresses will be conservatively assumed to be a constant tensile magnitude of 36 ksi at location 2. This value corresponds to the minimum specified yield stress of the base material (SA-266, Gr. 2). For other welds, which have been stress relieved, it is conservatively assumed that not all of the weld residual stress is relieved during the stress relief process. A stress value of 8 ksi has been included for welds at locations 1 & 7 for fracture toughness evaluations. This is similar to the procedure used in evaluation of reactor pressure vessel to account for the potential for remaining residual stress after post weld heat treatment.

The K due to residual stresses is applied with a safety factor of 1, as recommended in ASME, Section XI, Appendix H, Paragraph H-7300. Therefore, the total K_1 (applied) is determined from membrane, bending, and residual stresses.

Material Fracture Toughness

The gamma shield shell is a forged cylinder, nominally 8 inches thick by 167.4 inches long, made from SA-266, Gr. 2 material. The welding at the top flange and bottom plate may be performed using SAW, FCAW, or SMAW processes.

The results of the Charpy testing tabulated above are used. Figure 3E-3 shows a summary of the Charpy impact data used. The actual data points are shown along with a smoothed line that connects the average values at each test temperature. This data demonstrates that a lower bound

Charpy impact value of 18 ft-lbs is appropriate for an exposure temperature of -20°F.

The Charpy impact measurement may be transformed into a fracture toughness value by using the empirical relation below (Ref.7):

$K_{id} = [5E(C_v)]^{1/2} = 51,960$ psi-(in)$^{1/2}$

Where

K_{id} = Dynamic Fracture Toughness, psi -(in)$^{1/2}$
E = Modulus of Elasticity, 30×10^6
C_v = Charpy Impact Measurement, 18 ft-lbs

For conservatism, the above calculated K_{id} was reduced by another 10% to 47 ksi-(in)$^{1/2}$ (corresponding to 15 ft-lbs charpy values at -20°F) for fracture toughness evaluations.

Both the FCAW and SMAW electrodes used in the gamma shield weldments are alloyed with manganese, nickel, chromium, and vanadium. They are essentially matching filler metals for alloys such as ASME SA-533 Gr. B, the most commonly used reactor pressure vessel steel. The higher alloy content of the FCAW and SMAW electrodes and their typical usage in applications where good toughness is required indicate that the expected fracture toughness values for the FCAW and SMAW weld fillers are as good as or better than that of the SA-266 material. Use of the fracture properties from the wrought material for locations at or near the weld joints is conservative.

Fracture Toughness Criteria

Using the rule of Section XI, IWB-3613, the limiting fracture toughness values are reduced by a factor of $\sqrt{10}$ for the normal condition and $\sqrt{2}$ for the accident condition, to define the limiting allowable $K_{allowable}$. That is,

$K_{allowable} \leq K_{ia}/(\sqrt{10}) = 14.86$ ksi-$\sqrt{in}$ for normal conditions

$K_{allowable} \leq K_{ic}/(\sqrt{2}) = 33.2$ ksi-$\sqrt{in}$ for accident conditions

Where:

K_{ia} = the available fracture toughness based on crack arrest

K_{ic} = the available fracture toughness based on crack initiation

The K_{ia} value is conservatively used for fracture toughness evaluation for both normal and accident conditions.

Primary Stress Criteria

ASME Section XI, IWB-3610 requires that any flaw evaluation include verification that the primary stress limits of ASME Code Section III continue to be met for the flawed component. The following formula is conservatively assumed that the available cross section is equal to the original thickness minus the allowable flaw depth.

$a_{all} = t(1 - S/S_{all})$

Where:

a_{all} = allowable flaw depth based on ASME Code Section III limits
t = orginal local thickness
S = maximum calculated local stress intensity
S_{all} = allowable stress intensity per ASME Section III.

All stresses are considered to be pure tensile membrane stresses and that the stresses will increase linearly with decreasing wall thickness.

Allowable Flaw Size Calculation

Using the above load definitions and fracture toughness, a series of allowable flaw size calculations was performed using the Structural Integrity Associates computer program pc-CRACK™.

- Surface Flaws

For purpose of analysis, the postulated surface flaws are oriented in both the axial and circumferential direction.
The cracks selected for each location are shown in the above table. For locations 1, 2, 5, 6, and 7, due to the

very small t/R ratio, a single edge cracked plate (SECP) model was used.

The results of the pc-CRACK calculations are shown in the following table.

- Subsurface Flaws

The above discussion addressed the determination of allowable flaw sizes for flaws that are connected to the surface of the shield shell. The shell or weld could also contain subsurface defects.

An evaluation of allowable subsurface defects was performed using the same linear elastic fracture mechanics (LEFM) techniques as were described above for surface defects. For this case, a center cracked panel (CCP) model was used to evaluate an assumed length flaw. The flaw must be sufficiently embedded such that treatment as a subsurface flaw is justified. In general, if a flaw is closer to the surface than 0.4 of its half-depth, it must be considered a surface flaw.

The results of the pc-CRACK calculations are shown in the following table.

Allowable Surface Flaw Depth (inches)
(TN-32 Gamma Shield)

Location (Fig. 3E-2)	Normal Conditions		Accident Conditions	
	⊥ Axial Stress	⊥ Hoop Stress	⊥ Axial Stress	⊥ Hoop Stress
1	0.37	0.26	0.34 (0.3)	0.34 (0.3)
2	0.33	0.29	0.29	0.29
3	--- (7.7)	2.66	0.29	0.29
4	--- (5.27)	0.80	0.29	0.29
5	6.23	--- (8.39)	--- (7.53)	3.97
6	1.47	2.31	2.08	3.14
7	0.22	0.31	0.31	0.37

Allowable Sub-Surface Flaw Depth (inches)
(TN-32 Gamma Shield)

Location (Fig. 3E-2)	Normal Conditions		Accident Conditions	
	⊥ Axial Stress	⊥ Hoop Stress	⊥ Axial Stress	⊥ Hoop Stress
1	--- (0.41)	--- (0.41)	--- (0.30)	--- (0.30)
2	0.86	0.76	0.58	0.94
3	--- (7.70)	5.85	0.71	0.71
4	5.39 (5.27)	1.89	0.71	0.71
5	--- (8.39)	--- (8.39)	--- (7.53)	7.19
6	3.35	4.66 (3.85)	4.36 (4.12)	--- (4.12)
7	0.52 (0.49)	0.64 (0.49)	0.64	--- (0.66)

Note: "---" indicates that the allowable flaw depth is not limited by fracture mechanics calculation.
( ) indicates that the allowable flaw depth is limited by primary stress criteria.

Specific conservatisms included in the above analysis are listed below:

- All factors of safety on applied stress required by ASME Section XI (1989 Edition) were included in the evaluation.
- Weld residual stresses were treated as constant tensile stresses normal to the flaw orientation. Flaws were assumed to be long (infinitely long or full circumference)
- Lower bound material properties were used.

Conclusions

The gamma shield is not part of the confinement boundary. Cracks postulated in the gamma shield will not propagate into the confinement boundary due to the geometry of the cask. If the gamma shield were to fracture along the length or around the circumference or around the weld between the gamma shield and top flange, there is no credible mechanism which would result in the gamma shielding separating from the confinement boundary. The top shield plate is welded to the lid and is captured by the confinement vessel. Therefore, if the weld were to completely fail the shield plate will still remain inside the confinement boundary and will not lose its shielding capability. Therefore, even if a fracture were to occur in the gamma shield shell or the weld between the gamma shield and top flange or top shield plate or weld between top shield plate and lid, there would be no safety significance, since confinement would be maintained, and shielding would not be impaired. The one exception is in the region of the weld of the gamma shield shell to the bottom plate. In this region, if the weld were to completely fail, the bottom plate could become detached and have an impact on the shielding capability of the cask.

NDE Inspection Plan

The results of the fracture toughness analysis shows that the flaws in the gamma shield shell and top and bottom shield plates which would result in unstable crack growth or brittle fracture are larger than those generally observed in forged steel and plate components. No special examination requirements on the gamma shield shell, top and bottom shield plates are required.

The flaw sizes in the welds which could result in brittle fracture at -20°F will be detected by NDE methods. The welds at locations 1 if it were to completely fail, would be no safety significance. Therefore, only PT or MT of the final is be specified.

If the bottom plate weld were to completely fail, the bottom plate could become detached and have an impact on the shielding capability of the cask. The minimum allowable flaw sizes for surface and subsurface are 0.29 in. and 0.58 in., respectively. Therefore, the following NDE will be used to ensure defects of the minimum flaw

sizes calculated are detected and repaired prior to used for fuel storage.

- PT or MT at weld preparation surfaces (base metal)
- PT or MT at root pass
- PT or MT for each 0.375 inches of weld
- PT or MT at final surface

The weld at location 7, if it were to completely fail, could result in a drop of the shield plug into the cask cavity. Therefore the NDE requirements specified for the location 7 weld will be the same as that specified for the location 2 weld above.

The liquid penetrant or magnetic particle method will be in accordance with Section V, Article 6 of ASME Code.

3E.1.3 References

1. NUREG-1536, Standard Review Plan for Dry Cask Storage System.

2. Regulatory Guide 7.11, Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment (Vessel With A Maximum Wall Thickness of 4 Inches)

3. Regulatory Guide 7.11, Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment (Vessel With A Maximum Wall Thickness Greater Than 4 Inches, But Not Exceeding 12 Inches).

4. ASME Code Section III, Subsection NB, 1992.

5. ASME Code Section XI, 1989.

6. Structural Integrity Associates, pc-CRACK™ for Windows, Version 3.0, March 27,1997.

7. NUREG/CR-1815, Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping containers up to four Inches Thick

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Figure 3E-1
Locations of Fracture Toughness evaluations
(TN-32 Confinement Boundary)

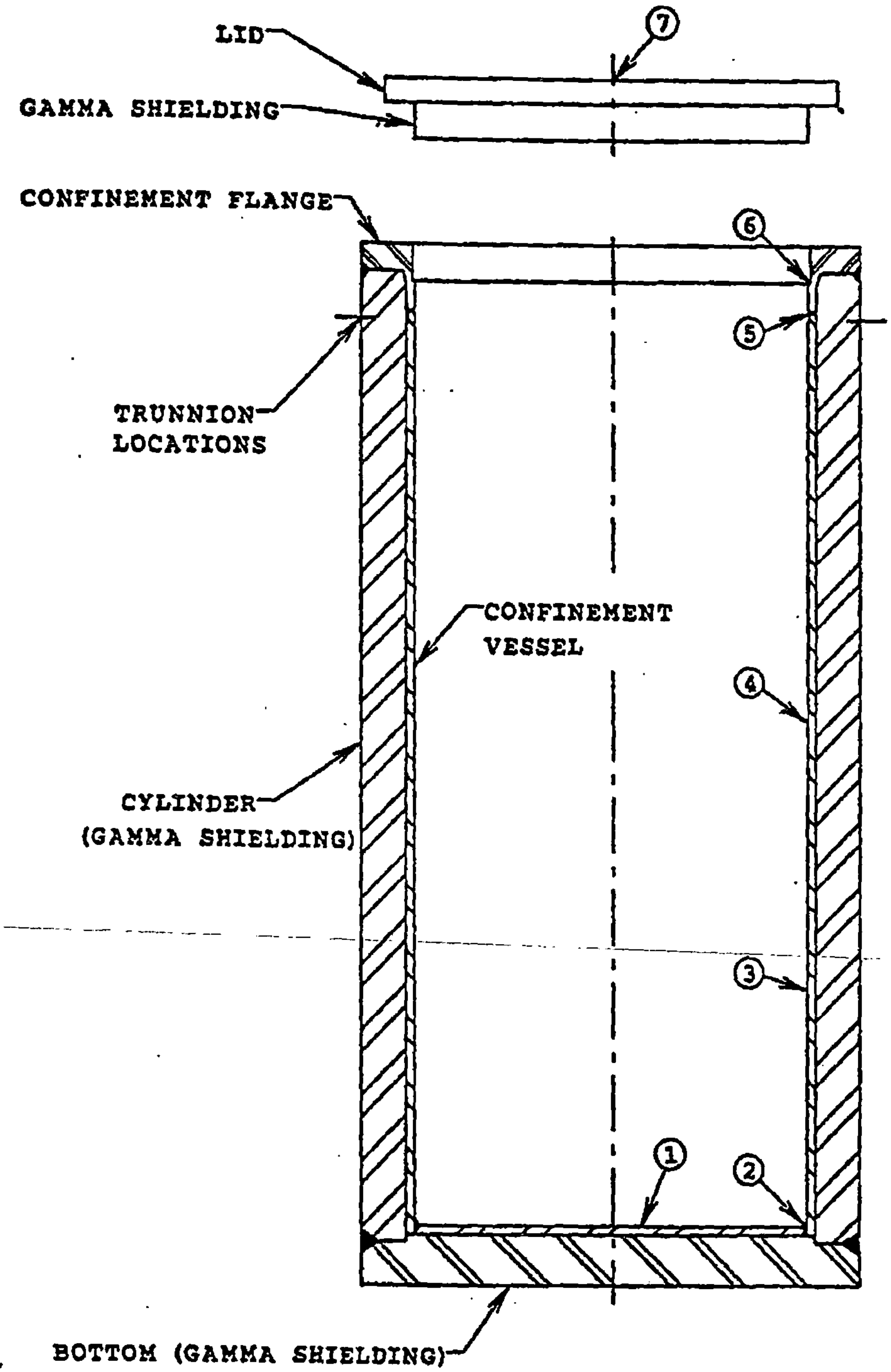


Figure 3E-2
Locations of Fracture Toughness Evaluations
(TN-32 Gamma Shield)

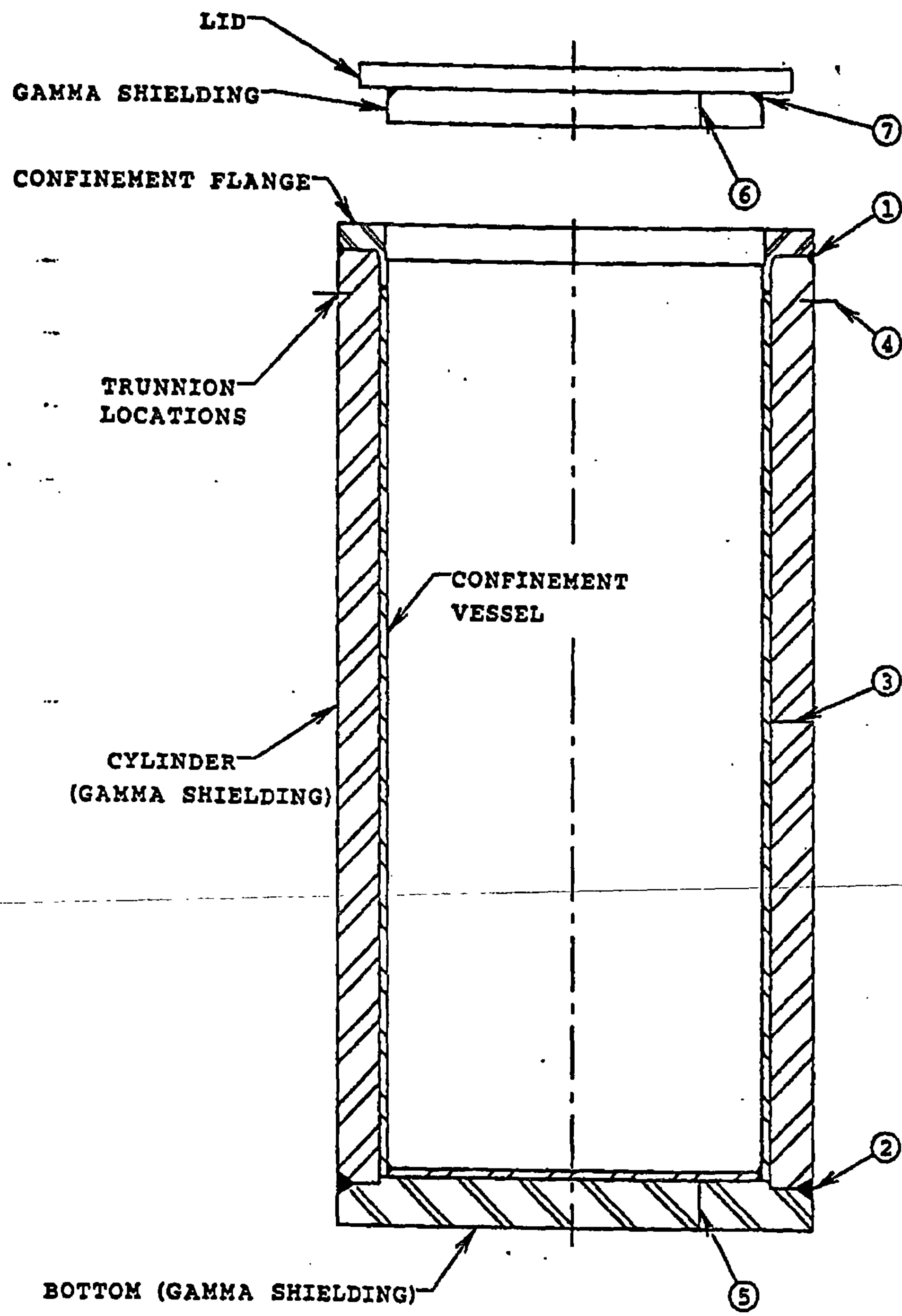
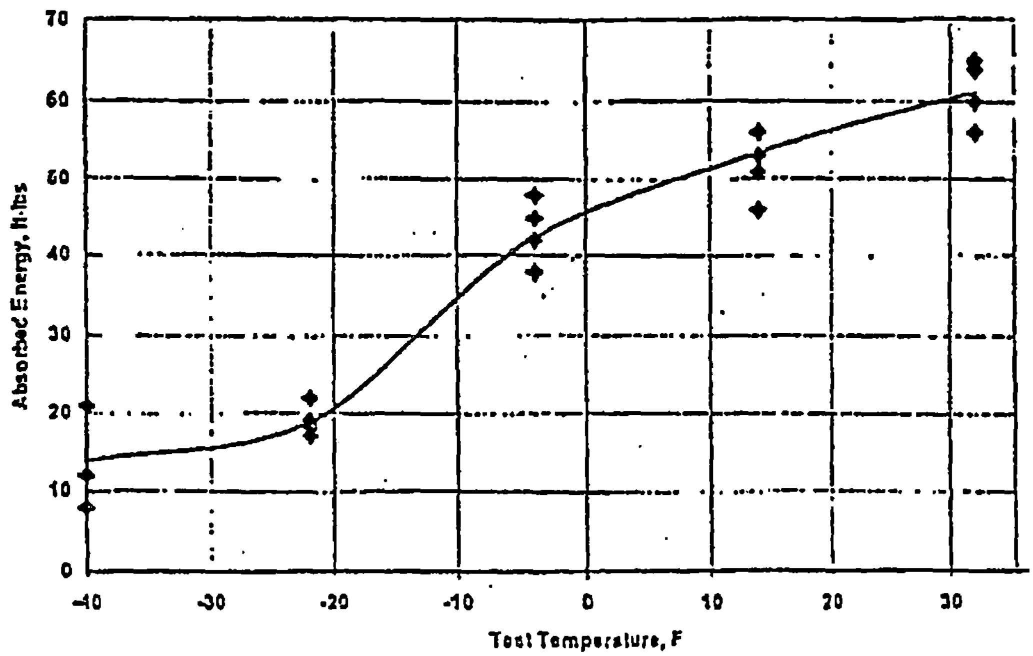


Figure 3E-3
Charpy V-Notch Test -Results for SA-266 Gr. 2



CHAPTER 4

THERMAL EVALUATION

4.1 Discussion

The TN-32 cask is designed to passively reject decay heat under normal conditions of storage, accident and loading/ unloading conditions while maintaining appropriate cask temperatures and pressures within specified limits. Objectives of the thermal analyses performed for this evaluation include:

- Determination of maximum and minimum temperatures with respect to material limits;
- Determination of temperature distributions to support the calculation of thermal stresses;
- Determination of the cask cavity temperature to support confinement pressurization calculations;
- Determination of the maximum fuel cladding temperature.

Chapter 2 presents the principal design bases for the TN-32 cask.

A significant thermal design feature of the TN-32 is the basket described in Section 1.2. The basket consists of an assembly of 32 stainless steel fuel compartments with aluminum and poison (borated aluminum) plates sandwiched between them. The compartments are plug-welded together to form the basket. The aluminum basket rails (peripheral inserts) bolted to the cavity wall provide a conduction path from the basket periphery to the cavity wall. The design of the basket allows the heat from the fuel assemblies to be conducted along the aluminum plates to the basket rails and to be dissipated to the cavity wall.

Another design feature is the conduction path created by the aluminum boxes in the neutron shielding layer described in Section 1.2. The neutron shielding is provided by a resin compound cast into long slender aluminum containers placed around the cask shell and enclosed within a smooth outer shell. By butting against the adjacent shell surfaces, the aluminum containers allow decay heat to be conducted across the neutron shield.

The TN-32 dry storage cask falls under the jurisdiction of 10CFR Part 72 when used as a component of an ISFSI. To establish

the heat removal capability, several thermal design criteria are established for the TN-32. These are:

- Confinement of radioactive material and gases is a major design requirement. Seal temperatures must be maintained within specified limits to satisfy the leak tight confinement function during normal storage conditions. An allowable temperature range of -40 to 536° F (-40 to 280° C) is set for the Helicoflex seals (double metallic O-rings) in the confinement vessel closure lid (Reference 18).

- To maintain the stability of the neutron shield resin during normal storage conditions, an allowable temperature range of -40 to 300° F (-40 to 149° C) is set for the neutron shield.

- Maximum and minimum temperatures of the confinement structural components must not adversely affect the confinement function.

- Maintaining fuel cladding integrity during storage is another design consideration. To minimize creep deformation that can occur over the storage duration, the maximum initial storage fuel cladding temperature is determined as a function of the initial fuel age using the guidelines provided by the Commercial Spent Fuel Management Program[1] (CSFM). These temperature limits are reported in Section 3.5. For normal conditions of storage, a fuel temperature limit of 328° C (622° F) has been established. During loading/unloading (including vacuum drying of the cask) and accident conditions, the fuel temperature limit is 570° C (1058° F) as recommended in Reference 11.

The ambient temperature range for normal storage is -30 to 115° F (-34 to 46° C). The cask temperature response to changes in ambient conditions will be relatively slow because the cask thermal inertia is large. Daily averaged maximum and minimum temperatures are used for the thermal evaluation.

The ambient temperature as a function of time during a peak summer-month day is shown below for a typical site (Reference 12) with a maximum ambient temperature of 115° F:

Time	12a	2a	4a	6a	8a	10a	12p	2p	4p	6p	8p	10p
Temperature, °F	82	78	75	74	85	97	103	111	115	113	100	89

The daily temperature over a 24-hour period is 94° F. For conservatism, a maximum daily averaged ambient temperature of 100° F is used for the maximum cask temperature evaluation. Similarly, for a cold winter day, the ambient temperature as a

function of time (Reference 13) is tabulated below:

Time	12a	1a	2a	3a	4a	5a	6a	7a	8a	9a	10a	11a
Temperature, °F	-24	-25	-27	-30	-29	-29	-29	-30	-28	-26	-21	-18

Time	12p	1p	2p	3p	4p	5p	6p	7p	8p	9p	10p	11p
Temperature, °F	-14	-11	-11	-10	-13	-15	-15	-16	-14	-13	-12	-11

The daily averaged temperature is -19.6 °F. The minimum daily averaged ambient temperature of -20 °F is used for the thermal evaluation.

In general, all the thermal criteria are associated with maximum temperature limits and not minimum temperatures. All materials can be subjected to the minimum average environment temperature of -20° F (-29° C) without adverse effects.

The TN-32 is analyzed based on a maximum heat load of 32.7 kW from 32 fuel assemblies with BPRAs or TPAs. The heat flux profile for a typical PWR fuel assembly with a peak power factor of approximately 1.2 and an active length of 144 in. is used. A description of the detailed analyses performed for normal storage conditions is provided in Section 4.4, accident conditions in Section 4.5, and loading/unloading conditions in Section 4.6. A summary of the results from the analyses performed for normal and fire accident conditions (maximum and minimum temperatures, with allowable range)is provided in Table 4.1-1. The thermal evaluation concludes that with this heat load, all design criteria are satisfied for normal, accident and loading/unloading conditions.

4.2 Summary of Thermal Properties of Materials

The thermal properties of materials used in the thermal analyses are reported below. The values are listed as given in the corresponding references.

a. Helium[9]
Used for: Gaps in cask cavity

Temperature °F	Thermal Conductivity Btu/hr-ft-°F
0	0.0774
200	0.1000
400	0.1206
600	0.1398

b. Carbon Steel, C-Mn-Si
Used for: Steel portions of cask

Temperature °F	Thermal Conductivity[3] Btu/hr-ft-°F	Specific Heat[3] Btu/lb-°F	Density[16] lb/in^3
100	23.9	0.110	0.284
200	24.2	0.117	
300	24.4	0.122	
400	24.2	0.128	
500	23.7	0.133	
600	23.1	0.136	
700	22.4	0.143	
800	21.7	0.148	
900	20.9	0.156	
1000	20.0	0.164	
1100	19.2	0.172	0.284

c. Aluminum, 6061 Alloy
Used for: Basket plates, basket rails (peripheral inserts)

Temperature °F	Thermal Conductivity[3] Btu/hr-ft-°F	Specific Heat[3] Btu/lb-°F	Density[15] lb/in³
100	96.9	0.215	0.098
150	98.0	0.218	
200	99.0	0.221	
250	99.8	0.223	
300	100.6	0.226	
350	101.3	0.228	
400	101.9	0.230	0.098

d. Resin - Polyester
Used for: Neutron shielding

Thermal Conductivity[4] = 0.1 Btu/hr-ft-°F

Density[4] = 0.057 lb/in.³

Specific Heat[4] = 0.31 Btu/lb-°F

e. Air[8]
Used for: Gaps in cask

Temperature °F	Thermal Conductivity Btu/hr-ft-°F	Prandtl No. Pr	Specific Vol. ft^3/lbm	Dynamic Visc. Lbm/ft-h
80	0.0152	0.708	13.79	0.0448
260	0.0194	0.694	18.39	0.0556
440	0.0233	0.688	23.00	0.0653
620	0.0269	0.690	27.60	0.0740
980	0.0333	0.705	36.81	0.0895
1340	0.0393	0.707	46.00	0.1026

f. Concrete - stone

Used for: Concrete pad

Thermal Conductivity[5] = 1.0 Btu/hr-ft-°F

Surface emissivity[6] = 0.94

g. Aluminum, 6063 Alloy
Used for: Radial neutron shielding containers

Temperature °F	Thermal Conductivity[3] Btu/hr-ft-°F	Specific Heat[3] Btu/lb-°F	Density[15] lb/in³
70	120.8	.216	0.097
100	120.3	.217	
150	119.7	.221	
200	119.1	.223	
250	118.3	.225	
300	118.3	.228	
350	117.9	.231	
400	117.6	.234	0.097

h. PWR Fuel

The fuel properties calculations are presented in Appendix 4A.
The results are tabulated below:

Temperature, °F	300	400	640	1090
Density, lb/in³	0.135			0.135
~~Specific Heat,~~ Btu/lbm-°F	~~0.058~~	~~0.065~~	~~0.072~~	~~0.078~~

Axial Direction

Temperature, °F	200	300	400	500	600	800
Thermal Conductivity, Btu/hr-ft-°F	0.804	0.850	0.894	0.937	0.979	1.062

Transverse Direction

Temperature, °F	221	300	400	505	606	805
Thermal Conductivity,	0.281	0.318	0.371	0.434	0.502	0.659

Btu/hr-ft-°F						

The effective conductivity is the lowest calculated value for the PWR fuel arrays (W14x14, W15x15 & W17x17) that may be stored at 1.02 kW per assembly and corresponds to the W17x17 assembly. This combination of heat load and conductivity bounds the combined effect of:

(a) the lower heat load (8% lower due to its lower U content) and the slightly lower effective conductivity for the W17x17 OFA assembly, and

(b) the lower heat load (11% lower due to its lower U content) and slightly lower effective conductivity for the W14x14 standard and OFA assemblies.

The analyses use interpolated values when appropriate for intermediate temperatures where the temperature dependency of a specific parameter is deemed significant. The interpolation assumes a linear relationship between the reported values.

Thermal radiation effects at the external surface of the cask are considered. The external surfaces of the TN-32 are painted white (emissivity = 0.93, solar absorptivity = 0.12-0.18, Reference 8). To account for dust and dirt, the thermal analysis uses a solar absorptivity of 0.3 and an emissivity of 0.9 for the exterior surfaces in the thermal models. After a fire, the cask surface will be partially covered in soot (emissivity = 0.95, Reference 17).

4.3 Specifications for Components

The only cask components for which a thermal technical specification is necessary are the seals. The seals used in the cask are the Helicoflex seals (double metallic O-rings). The seals will have a minimum and maximum temperature rating of -40°F and 536°F, respectively

4.4 Thermal Evaluation for Normal Conditions of Storage

The normal conditions of storage are used for the determination of the maximum fuel cladding temperature, TN-32 component temperatures, confinement pressure and thermal stresses. These steady state environmental conditions correspond to the maximum daily averaged conditions: a daily averaged ambient temperature of 100°F and the 10CFR Part 71.71(c) insolation averaged over a 24 hour period. The analyses include the effect of storing the TN-32 casks in an array that is 2 wide and infinitely long (see Figure 4.4-5).

4.4.1 Thermal Model

4.4.1.1 Analytical Model. A three-dimensional finite element computer model of the TN-32 is used to simulate heat transfer in the cask. The ANSYS computer program[7] is utilized for the analyses. This program is a large scale, general purpose finite element computer code which can perform steady state and transient three dimensional thermal analyses.

The thermal model represents the TN-32 standing vertically on the concrete pad. The model includes the geometry and material properties (Section 4.2) of the basket, the basket rails (peripheral inserts), the cask shells, the neutron shielding (resin in aluminum containers/top neutron shield), the outer shell, the lid and the concrete pad. The model simulates the thermal performance of the fuel with a homogenized material occupying the volume within the basket where the fuel is stored. This homogenized approach is based on an effective fuel conductivity model. Only the fuel rod length region is modeled. This is described in `Fuel Model' below and Appendix 4A. A quarter slice of the TN-32 is modeled with the appropriate symmetry boundary conditions. Figures 4.4-1 and 4.4-2 show sketches of radial and axial cross-sections through the model.

The basket comprises of 32 stainless steel boxes (8.70 x 8.70 x 160 in.) with typically one 0.5 in. thick aluminum and one 0.040 in. thick poison plate (borated aluminum) placed between 0.10 inch thick adjacent boxes. The boxes are held together by plug welds which pass through the aluminum and poison plates. The plug welding design causes the aluminum and poison plates to be tightly sandwiched between adjacent box sides. The basket portion of the thermal model simulates the conduction paths provided by the stainless steel fuel compartments and the aluminum plates. No credit is taken for the heat transfer paths provided by the poison plates in the cask thermal model. The decay heat from the fuel assemblies is applied directly to the elements that comprise the homogenized fuel as volumetric heat generation in the 144 inch active fuel length. As shown in

Figure 4.4-1, some aluminum plates are interrupted to allow other plates a direct conduction path to the basket periphery. As a conservative modeling approach, a nominal gap of 0.02 in. is used between the interrupted and continuous plates. This causes heat to be transferred across a gaseous medium (helium) between the two plates (or through the fuel) rather than along the more conductive stainless steel boxes sandwiching the gap.

The basket bottom and the fuel assemblies rest on the cask bottom during normal storage. No credit is taken for the direct contact of the fuel assemblies and basket with the cask bottom. Instead a 0.25 inch gap is assumed between the basket bottom and the cask bottom.

The plug weld holes in the aluminum basket plates reduce its thermal conductivity. To evaluate the effect of the holes, simple two dimensional finite element models of the plates with and without holes were developed. The analysis concluded that for the same temperature difference across symmetry boundaries, the conductivity for the basket plates is effectively reduced less than 10% with weld holes. Accordingly, the thermal conductivity for the aluminum plates is reduced 10% in the thermal model. The effective conductivity for the basket plates is based on the reduced conductivity of the 0.5 in. aluminum plates and the 0.10 in. thick stainless steel box sides.

Basket rails, bolted to the cavity wall, increase the surface area for heat dissipation while providing structural support for the basket. The thermal model assumes a nominal gap of 0.188 in. at thermal equilibrium between the periphery of the basket and the rails.

Although the rail surface bolted to the cavity wall makes surface contact with the cavity surface, a 0.01 gap is assumed between these surfaces in the thermal model. These gaps are shown in Figure 4.4-1. All heat transfer across the gaps is by gaseous conduction. Other modes of heat transfer are neglected.

The ANSYS three dimensional isoparametric thermal shell element, SHELL57, is used to simulate heat transfer along the aluminum plates and basket rails, and across helium gaps in the basket. The three dimensional isoparametric solid element, SOLID70, is used to represent the fuel, and to model gaseous conduction across gaps between the basket, basket rails and the cavity wall.

The cask body portion of the model consists of the cask bottom, the inner and outer cask body shells, the radial neutron shield (resin in aluminum containers), lid, lid neutron shield, the cask weather protective cover, and the outer shell. The cask bottom consists of an inner plate (containment) and an outer plate (gamma shielding). Although the inner and outer plates

will be in contact, a 0.125 inch gap is assumed between the plates. The lid consists of an inner plate (gamma shield) attached to an outer plate (containment). The geometry of the standard lid was compared with the type A lid. Since the overall thickness of the steel and neutron portions of the two lids with its neutron shield are the same, the temperature distribution in either lid will be similar. The geometry of the standard lid is modeled in the thermal model. Although the inner and outer plates will be in contact, a 0.010 inch gap is assumed between the inner and outer plates in the lid.

The top portion of the lid neutron shield is assigned an adiabatic boundary condition resulting is no heat dissipation from the lid neutron shield to the protective cover. The bottom portion of the lid is subjected to direct heat transfer from the top of the fuel and basket by radiation and gas conduction. As a result, temperatures in the lid and lid neutron shield regions will be conservatively bounded.

The protective cover is bolted to the cask lid as shown in Figure 4.4-2. A 0.010 inch gap is assumed at the protective cover/lid contact interface.

The inner and outer cask body shells will be assembled with an interference fit. This will assure thermal contact at the shell interface. A contact conductance of 375 Btu/hr-ft^2 is estimated for interface resistance between steel surfaces in contact[8] (air gaps). For conservatism the analysis uses a contact conductance of 200 Btu/hr-ft^2.

The neutron shielding consists of 60 long slender resin-filled aluminum containers placed between the cask body and outer steel shell. The aluminum containers butt against the shells. However, an air gap of 0.01 in. is used in the model.

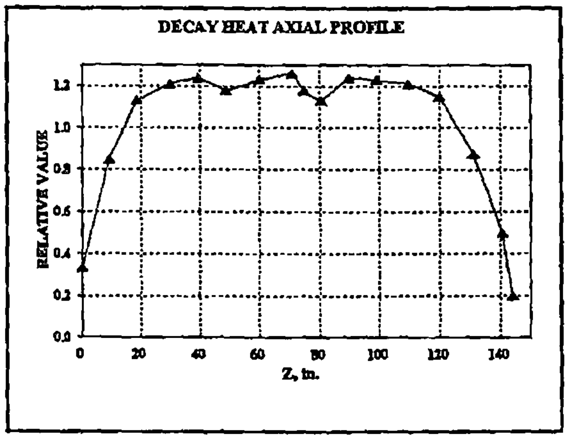
The concrete pad in the thermal model is 36 in. thick and extends 36 in. around the bottom of the cask. The bottom of the cask is assumed to be in perfect thermal contact with the concrete pad. The bottom of the pad, which is in contact with soil, is treated as a constant temperature boundary. For the normal ambient conditions, a soil temperature of 70°F is used.

The finite element model for the stainless steel shells, the protective cover flange, the resin, the air gaps and the concrete pad, are developed using SOLID70 elements. The aluminum containers for the resin and the weather protective cover are generated using SHELL57 elements.

Figure 4.4-3 shows the three-dimensional ANSYS finite element model developed. Details of the model are shown in Figure 4.4-4.

Decay Heat Load

The homogenized fuel assemblies are included in the thermal model. An axially varying decay heat load of 1.02 kW per assembly is applied to the homogenized fuel elements as volumetric heat generation. The figure below shows the predicted heat flux profile for a typical PWR fuel[4] assembly with an active length of 144 in.



Fuel Model

In the cask thermal model, the fuel is modeled as a homogenous material occupying the volumes within the basket that the fuel is stored in as in Ref. 10, Appendix II.5.4. The fuel volume length corresponds to the 151.63 inch rod length of a standard W17x17 fuel assembly. The decay heat of the fuel is applied to the homogenized fuel elements directly as volumetric heat generation in the 144 in active length of the fuel.

Although the stainless steel fuel boxes that form the fuel compartments are in good contact with the aluminum basket plates, a 0.020 inch gap is assumed between each stainless steel box side and the adjacent aluminum plate. This gap is included in the fuel model which results in lower effective fuel conductivity.

The analytical basis for the homogenization of the fuel is described in Appendix 4A. The homogenized fuel is assigned non-isotropic effective conductivities. The thermal properties for axial (from top to bottom) and transverse (side to side) conduction are listed in Section 4.2, item h.

Solar Heat Load

The maximum solar heat load is applied as a constant value to all external surfaces of the thermal model. A solar absorptivity of 0.3 is used for the painted surfaces of the cask and 0.9 for the concrete pad.

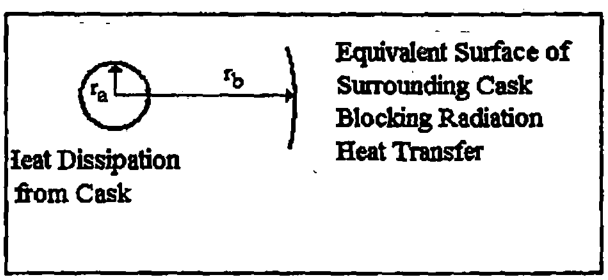
The total insolation for a 12-hour period is 1475 Btu/ft^2 for curved surfaces and 2950 Btu/ft^2 for flat surfaces per 10CFR Part 71.71(c). Since the cask has a large thermal inertia, the total insolation is averaged over a 24-hour period and applied to the cask external surface.

Heat Dissipation to the Environment

Most of the heat from the TN-32 cask is dissipated to the environment by radiation and natural convection. If the cask is stored in an array, partial radiation "blockage" occurs which reduces the overall view factor from the cask to the environment. The analyses assume that the casks will be stored in an array that is two wide and infinitely long, and placed 16 ft (nominal) (center to center) apart (Figure 4.4-5). Convection heat transfer is assumed to be unaffected. Heat transfer between casks is neglected.

To simplify the cask environment view factor calculation, the TN-32 is assumed to be a cylinder of diameter 8.2 ft and length 12.88 ft. This represents the surface dimensions for the outer shell. Based on its location in a 2 wide and infinitely long array, it is possible for 46% of the outer shell surface area to be surrounded by other casks. The radiation heat transfer for this "blocked" region can be approximated to that between two concentric cylinders with the inner radius corresponding to the cask diameter and the outer radius corresponding to the spacing between the two casks in the array. The equation for the view factor F_{2-1} for two concentric cylinders of finite length[6] is

$$F_{b-a}=\frac{1}{R}-\frac{1}{\pi R}\left\{\cos^{-1}\frac{B}{A}-\frac{1}{2L}\left[\sqrt{(A+2)^2-(2R)^2}\cos^{-1}\frac{B}{RA}+B\sin^{-1}\frac{1}{R}-\frac{\pi A}{2}\right]\right\}$$



where,

r_a = inner cylinder radius
r_b = outer cylinder radius
l = cylinder length
$R = r_b/r_a$
$L = l/r_a$
$A = L^2 + R^2 - 1$
$B = L^2 - R^2 + 1$

From the reciprocity theorem,

$$F_{a-b} = F_{b-a}(r_b/r_a)$$

The view factor from the outer surface to the environment,

$$F_{a-amb} = 1 - F_{a-b}$$

Based on an array spacing of 16 ft (nominal) and a cask diameter of 8.2 ft, an overall view factor of 0.77 is calculated between the cask and the ambient.

The heat transfer coefficient, H_r, for heat dissipation by radiation, is given by the equation:

$$H_r = G_{12}\left[\frac{\sigma(T_1^4 - T_2^4)}{T_1 - T_2}\right] Btu/hr - ft^2 - {}^\circ F$$

where,

G_{12} = the gray body exchange coefficient
= (surface emissivity) (view factor)
T_1 = ambient temperature, °R
T_2 = surface temperature, °R

For horizontal surfaces,
G_{12} = (0.9)(1) = 0.9
For the vertical blocked surfaces,
G_{12} = (0.9)(0.77) = 0.69

The thermal analysis is based on the above minimum grey body exchange coefficients calculated using empirical equations. Analyses using numerical methods could be used to calculate a smaller array spacing for the same exchange coefficients. Alternate array schemes may be used if it is shown by analysis that the minimum values for the grey body exchange coefficients are achieved.

Heat dissipation by natural convection from vertical surfaces is described by the following equation for the average Nusselt number (Reference 2):

$$\overline{N}_{u_L}=\overline{H}_c\frac{L}{k}=0.13(Gr_L Pr)^{1/3} \quad for\ Gr_L > 10^9$$

where,

Gr_L = Grashof number = $\rho^2 g\beta(T_s-T_a)L^3/\mu^2$
ρ = density, lb/ft^3
g = acceleration due to gravity, ft/sec^2
β = temperature coefficient of volume expansion, 1/R
μ = absolute viscosity, lb/ft-sec
L = characteristic length, ft
Pr = Prandtl number
H_c = natural convection coefficient

Simplifying in terms of H_c,

$$\overline{H}_c=(k)(0.13)[\rho^2 g\beta(T_s-T_a)Pr/\mu^2]^{1/3} \ Btu/hr-ft^2-{}^\circ F$$

For horizontal surfaces (per Reference 2),

$$\overline{N}_{u_L}=\overline{H}_c\frac{L}{k}=0.16(Gr_L Pr)^{1/3}$$

and

$$\overline{H}_c=(k)(0.16)[\rho^2 g\beta(T_s-T_a)Pr/\mu^2]^{1/3}$$

The total heat transfer coefficient $H_t = H_r + H_c$, is applied as a boundary condition on the outer surfaces of the finite element model.

Maximum Fuel Cladding Temperature

The finite element model of the cask includes a representation of the spent nuclear fuel that is based on a fuel effective conductivity model. The decay heat of the fuel is applied directly to the fuel elements. The fuel temperatures reported are the results of the thermal cask model analysis, which includes the homogenized fuel. As described in Appendix 4A, the homogenized fuel properties are chosen to match both the temperature drop between basket walls and fuel assembly center pin, and the effective conductivity of the fuel assemblies.

Average Cavity Gas Temperature

The cavity gas temperature is maximum at the hottest fuel cladding and minimum at the cooler surfaces in the lid region.

For simplicity and conservatism, it is assumed that the average cavity gas temperature is the average value of the maximum fuel cladding and the minimum cavity wall temperatures.

4.4.1.2 Test Model. The detailed evaluation described above ensures that the casks are capable of dissipating the design heat load. The conservative approach precludes the necessity to perform extensive thermal testing. To test the method of manufacture for the radial thermal conductance through the cask body including heat dissipated to the ambient, testing for one cask will be performed as described in Chapter 9.

4.4.2 Maximum Temperatures

A steady state thermal analysis is performed using the maximum decay heat load of 1.02 kW per assembly (32.7 kW total), 100°F ambient temperature and the maximum insolation. Figure 4.4-6 shows the temperature distribution predicted by the finite element model. The specific temperature distributions in the hottest cross-section of the model, the hottest cross-section of the basket, the top 4 in. of the basket, and the cask body are shown in Figures 4.4-7, -8, -9 and -10 respectively. A summary of the calculated cask temperatures is listed in Table 4.1-1. Additional analyses are performed using the heat loads corresponding to 10 and 20 year storage periods. The results of these evaluations are listed in Table 4.4-1.

4.4.3 Minimum Temperatures

Under the minimum daily averaged temperature condition of -20°F (-29°C) ambient, the resulting cask component temperatures will approach -20°F if no credit is taken for the decay heat load. Since the cask materials, including confinement structures and the seals, continue to function at this temperature, the minimum temperature condition has no adverse effect on the performance of the TN-32.

Temperature distributions in a minimum ambient temperature of -20°F and no insolation are performed using the heat loads corresponding to 0, 10 and 20 year storage periods. Table 4.4-2 lists the results of the analyses.

4.4.4 Maximum Internal Pressure

The maximum cask cavity internal pressure during normal conditions of storage is calculated in Chapter 7.

4.4.5 Maximum Thermal Stresses

The maximum thermal stresses during normal conditions of storage are calculated in Section 3.4.4.

4.4.6 Evaluation of Cask Performance for Normal Conditions of Storage

The thermal analysis for normal storage concludes that the TN-32 cask design meets all applicable requirements. The maximum temperatures calculated using conservative assumptions are low. The maximum temperature of any confinement structural component is less than 315°F (157°C) which has an insignificant effect on the mechanical properties of the confinement materials used. The maximum seal temperature (256°F, 124°C) during normal storage is well below the 536°F long-term limit specified for continued seal function. The maximum neutron shield temperature is below 300°F (149°C) and no degradation of the neutron shielding is expected during the storage life. The predicted maximum fuel cladding temperature is well below the allowable fuel temperature limit of 622°F (328°C). The comparison of the results with the allowable ranges is tabulated in Table 4.1-1.

4.5 Thermal Evaluation for Accident Conditions

The TN-32 casks will be stored on a concrete pad away from combustible material. Therefore, a credible fire would be very small and of short duration such as that due to a fire or explosion from a vehicle or portable crane. However a hypothetical fire accident is evaluated for the TN-32 cask based on a fuel fire, the source of fuel being that from a ruptured fuel tank of the cask transporter tow vehicle. The bounding capacity of the fuel tank is 200 gallons and the bounding hypothetical fire is an engulfing fire around the cask.

Another accident evaluation performed on the cask is the thermal response of the cask in the postulated event of it being completely buried by dirt and debris with very low thermal conductivity. The temperature-time history of the cask components during this event is reported.

4.5.1 Fire Accident Evaluation

From IAEA requirements[14], the "pool" of fuel is assumed to extend 1 meter beyond the cask surface. Based on an outer shell diameter of 98 inches, this gives a "pool" diameter of approximately 176 inches and a pool surface of 24,500 in^2. A fuel consumption rate of 0.15 in/min. was selected from a Sandia Report[15] concerning gasoline/tractor kerosene experimental burning rates. This translates into a fuel consumption rate of approximately 15.9 gal./min. Therefore, the 200 gallon of fuel will sustain a fire for about 13 minutes and hence a 15 minute fire is evaluated. The Sandia Report also reports an average flame temperature of 1550°F and an average convective heat transfer coefficient of 4.5 Btu/hr-ft^2-°F for a railroad tank car fire test. The same parameters are utilized for coupling the fire energy to the cask surface during fire accident conditions.

The fire thermal evaluation is performed primarily to demonstrate the confinement integrity of the TN-32. This is assured as long as the metallic lid seals remain below 536°F and the cavity pressure is less than 100 psig. Two models, a cross-section model and a lid seal model, are used for the evaluation.

A. Cross-section Model

The cross-section finite element model is developed using a cross-sectional slice of the finite element model for the normal storage analysis (Section 4.4.1.1). The cask components and their geometry are shown in Figure 4.5-1. Thermal properties of the materials used are listed in Section 4.2. (Thermal capacities of gases are neglected for the transient analysis.) Initial temperatures before the fire condition are established by using steady state temperatures in the hottest cross-section for normal storage conditions. All gaps in the cask body region of the model were eliminated to conservatively maximize the heat into the cask from the fire.

For the entire duration of the fire and cooldown period, the decay heat flux applied to the fuel region of the model corresponds to 1.02 kW/assy with a peaking factor of 1.2. Insolation on the outer surface of the cask is assumed during the cooldown period.

During the fire condition period (15 min.), heat absorption at the outer surface is by radiation and forced convection, and is given by the following equation:

$$q_{fire} = (H_c + H_r)(T_f - T_s)$$

where,

q_{fire} = heat flux into cask from fire, Btu/hr-ft^2
T_f = flame temperature = 1550°F
T_s = surface temperature of the cask, °F
H_c = convection heat transfer coefficient = 4.5 Btu/hr-ft^2-°F
H_r = radiation heat transfer coefficient, Btu/hr-ft^2-°F

$$H_r = (0.1714E\text{-}8)(F_s)[(E)(T_f + 460)^4 - (T_s + 460)^4]/(T_f - T_s)$$

where,
F_s = outer surface absorptivity = 0.8 (Reference 14) (This is also consistent with 10CFR71.73.)
E = flame emissivity = 0.9 (Reference 14) (This is also consistent with 10CFR71.73.)

During the cooldown period after the fire condition, heat dissipation from the outer surface is by radiation and natural convection to an ambient temperature of 100°F (as in the normal storage conditions). After a fire, the cask surface will be partially covered in soot (emissivity = 0.95, Reference 17). In order to bound the problem an emissivity of 0.9 was used for the cask external surfaces after the fire accident condition.

The results of the analysis show that no melting of the metallic cask components occurs. The peak transient temperatures in selected locations in the cask are listed in Table 4.5-1.

B. Lid-Seal Region Model

To demonstrate the integrity of the seals in the lid during the fire accident, a finite element model of the top portion of the TN-32 is developed. A comparison of the standard lid and the Type A lid was made to select the lid that would provide the peak seal temperatures during the fire accident. In the Type A lid configuration, 1.12 inch of steel is transferred from the bottom of the lid to the neutron shield, which is mounted on the top of the lid. The total mass of the lid and the neutron shield is approximately the same. Hence the geometry of the standard lid is modeled.

The model is an axisymmetric two-dimensional model and includes the geometry and material properties of the lid, resin disk, protective cover and upper region of the cask body shells. Figure 4.5-2 shows the geometry of the model. Figure 4.5-3 is an element plot of the 2-D axisymmetric ANSYS model.

The outer surfaces of the protective cover and the cask body are subjected to the heat flux from the 15 minute fire, and during the cooldown period, heat is dissipated from these surfaces to an ambient temperature of 100°F. Most of the heat transfer in the enclosure under the protective cover is by radiation in the fire condition. Hence, heat transfer in this enclosure is modeled by radiation with all surfaces being assigned an emissivity of 0.9. Near the seal region where the air gap between the lid and protective cover is small, heat conduction through air is assumed. The region where heat conduction through air is assumed is shown in Figure 4.5-3.

The initial temperature distribution before the fire condition corresponds to the maximum temperature distribution during normal storage. The effects of insolation are considered during the cooldown period. A constant decay heat load from the top of the basket and fuel to the lid is assumed as calculated for the normal storage evaluation in Section 4.4.

The results of the computer analysis show that no melting of the metallic components in the lid region occur. The maximum lid seal temperature does not exceed 380°F (194°C).

C. Conclusion

Based on the thermal analyses for the fire accident conditions, the TN-32 cask can withstand the hypothetical fire accident event without compromising its confinement integrity.

Peak seal temperature remains well below 536°F. The cavity pressure, as evaluated in Chapter 7, remains below 100 psig.

Table 4.5-1 lists the peak transient temperatures in the cask components. The peak transient fuel temperature is 647°F (342°C) and is well below the short term limit of 1058°F (570°C).

The neutron shield will off-gas during the hypothetical accident. A pressure relief valve is provided on the outer shell to prevent the pressurization of the outer shell. Shielding (Chapter 5) analyses have been performed showing acceptable consequences even if all the resin disappears.

4.5.2 Buried Cask Thermal Evaluation

The TN-32 cask dissipates heat to the environment by radiation and convection. If the cask is accidentally buried in medium that will not provide the equivalent cooling of natural convection and unrestricted radiation to the environment, component temperatures will increase to a higher steady state condition after long-term burial. Of interest is the confinement integrity which is assured as long as the metallic seals remain below 536°F (280°C) and the cavity pressure remains below 100 psig.

The TN-32 finite element model developed in Section 4.4.1.1 is modified for the buried cask analysis. A cross section model is created by selecting the nodes and elements in the hottest region along with its temperature distribution. For this analysis, the cask is assumed to be completely buried in dry soil with such poor heat transfer characteristics that it effectively insulates the cask. The resulting analysis therefore determines the time required to reach limiting temperatures for the confinement integrity.

Initial conditions before burial are established by using the steady state temperatures reported for normal conditions of storage. The transient analysis is performed with a cask heat load of 32.7 kW with a 1.2 peaking factor.

The results of the analysis show that if the cask is not uncovered within 3 hours, the neutron shield temperature will exceed the allowable value of 300°F (149°C). Thereafter, cask body temperatures will reach 536°F (280°C) about 38 hours after burial. At this time the cavity gas temperature is 644 °F (340°C). The cavity pressure at this time is calculated in Chapter 7 concludes that if all fuel fails the maximum cavity pressure will not exceed 100 psig. The fuel temperature loading/unloading limit of 1058°F (570°C) is reached about 93 hours after burial occurs.

4.6 Thermal Evaluation for Loading/Unloading Conditions

All fuel transfer operations occur when the cask is in the spent fuel pool (with the cask lid removed). The fuel is always submerged in free-flowing pool water permitting heat dissipation. After fuel loading is complete, the cask is removed from the pool, drained and dried.

The loading condition evaluated for the TN-32 would be the heatup of the cask before its cavity can be backfilled with helium. This typically occurs during the performance of the vacuum drying operation of the cask cavity. Transient thermal analyses are performed to predict the heatup time history for the cask components assuming air is in the cask cavity. Due to the low pressure in the cask, natural convection heat transfer by air is ignored.

Unloading of the cask would require the flooding of the cask prior to the removal of the fuel. A quench analysis of the fuel is performed in Chapter 3 and concludes that the total stress on the cladding as a result of this operation is below the cladding material's minimum yield stress. The pressure evaluation is presented below.

4.6.1 Pressure During Unloading of Cask

To unload the fuel from the cask, flooding of the cask cavity is required. This occurs by first releasing the pressure in the cask to atmospheric conditions followed by introducing water into the cask through the drain port and venting using the vent port. Since fuel temperatures are expected to be above 400°F, flooding of the hot cask will result in steam being generated which if not vented instantly, will result in a higher cavity pressure.

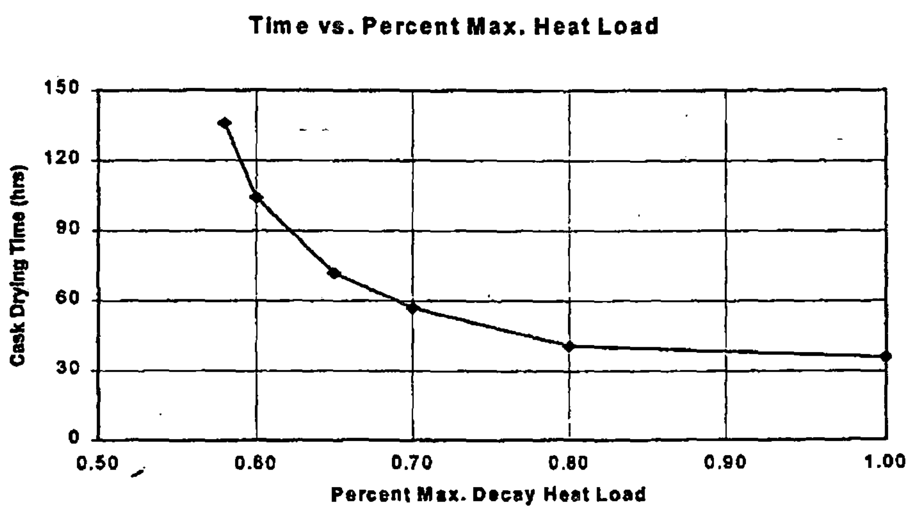
The flow rate of water into the cask during unloading is controlled such that the pressure within the cask stays below the design pressure of 100psig (114.7psia). The initial flow rate used keeps the internal pressure of the cask below 75.3psig (90psia) in the bounding event that all of the flow is evaporated. This flow rate, 0.144 lbm/s, is determined by calculating the flow rate of water vapor leaving the cask at an internal pressure of 75.3psig (90psia). By limiting the initial flow rate to 0.140 lbm/s (1.0 gpm) the steady state pressure will not exceed 75.3psig (90psia). After the steady state pressure stays below 50psig (64.7psia) for 45 minutes the flow rate can gradually be increased. In the event that the cask internal pressure increases to 75.3psig (90psia) the check valve shuts off the flow of water into the cask preventing the pressure from increasing.

4.6.2 Cask Heatup Analysis

Heatup of the cask prior to being backfilled with helium typically occurs as cask operations are being performed to drain and dry the cask. The vacuum drying of the cask generally does not reduce the pressure sufficiently to reduce the thermal conductivity of the air in the cask cavity. The TN-32 finite element model developed in Section 4.4.1.1 is modified for this transient analysis. A cross section model is created by selecting the nodes and elements in the hottest region, and by making the following modification. All gaseous heat conduction within the cask cavity is through air instead of helium. Radiation heat transfer within the cask cavity is neglected. The fuel conductivity was recalculated using air properties instead of helium. All temperatures in the cask are initially assumed to be at 115°F (the maximum spent fuel pool temperature, typically). Radiation and natural convection heat transfer is from the cask outer surface to the building environment at a temperature of 115°F. The decay heat load for the model corresponds to the 32.7 kW total heat load in the cask.

The results of the transient thermal analysis for the maximum heat load of 32.7 kW predict that the fuel cladding temperature reaches a maximum temperature of 935°F (502°C) and is well below the loading/unloading limit of 1058°F. Therefore the duration of the cask drying evolution is not constrained by the fuel cladding temperature limit.

Several transient analyses were performed at lower decay heat loads. In order to maintain cask component peak temperatures below that during fire accident conditions, the cask drying evolution can be varied between 36 hours for the design basis heat load to no limit for 56% of the design heat load. Below is a plot showing the percent maximum decay heat load versus cask drying time.



4.6.3 Pressure During Loading of Cask

The cask is vented during the draining procedure, however a small internal cask pressure is expected due to the possible boiling of water within the cask. A bounding case is considered of all the decay heat load (111,582 Btu/hr) boiling the water within the cask (heat of vaporization = 881 Btu/lbm @ 100psig, Reference 8). The rate of evaporation is less than 0.036 lbm/s. This is much less than the flow rate corresponding to the steady state pressure of 75.3psig (90psia) calculated in section 4.6.1. The cask internal pressure during draining remains well below the design pressure of 100psig.

4.7 Supplemental Information

4.7.1 Supplemental Information from References 12 & 13

Reference 12 Data

Table 8a. Hanford Air Temperature

Time	Temperature (°F)	Time	Temperature (°F)
12 a.m.	82	2 p.m.	111
2 a.m.	78	4 p.m.	115
4 a.m.	75	6 p.m.	113
6 a.m.	74	8 p.m.	100
8 a.m.	85	10 p.m.	89
10 a.m.	97	12 p.m.	82
12 p.m.	103		

Reference 13 Data

Hourly Temperature Readings

WI,14898,GREEN BAY AUSTIN STRAUBE TMPD deg. F 01/30/1951
-24 -25 -27 -30 -29 -29 -29 -30 -28 -26 -21 -18
-14 -11 -11 -10 -13 -15 -15 -16 -14 -13 -12 -11

4.8 References

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10. SAND90-2406, Sanders, T. L., et al., A Method for Determining the Spent-Fuel Contribution to Transport Cask Containment Requirements, 1992.

11. PNL-4835, Johnson et. al., Technical Basic for Storage of Zircaloy-Clad Spent Fuel in Inert Gases, Pacific Northwest Laboratory, 1983.

12. WHC-SD-TP-RPT-004, Environmental Conditions for On-Site Hazardous Material Packages, Westinghouse Hanford Company, 1992.

13. Letter from Wisconsin Electric to Transnuclear, NPL 98-0916, Local Extreme Temperatures.

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15. SAND85-0196, TTC-0659, Gregory et. al., "Thermal Measurements in a Series of Large Pool Fires," Sandia National Laboratories, 1987.

16. American Society for Metals, Metals Handbook, Ninth Edition, 1979.

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18. Helicoflex High Performance Sealing Catalog, Carbone Lorraine, Helicoflex Components Division.

TABLE 4.1-1

COMPONENT TEMPERATURES IN THE TN-32 CASK

Component	Normal Storage			Fire Accident	
	Maximum (°F)	Minimum* (°F)	Allowable Range (°F)	Peak (°F)	Allowable Range (°F)
Outer Shell	240	-20	**	945	**
Lid (Standard/Type A)	263	-20	**	438	**
Seal	256	-20	-40 to 536	380	-40 to 536
Top Neutron Shield	256	-20	-40 to 300	N/A	N/A
Radial Neutron Shield	280	-20	-40 to 300	N/A	N/A
Inner Shell	308	-20	**	375	**
Gamma Shield Shell	303	-20	**	370	**
Inner Bottom Plate	314	-20	**	***	**
Outer Bottom Plate	255	-20	**	***	**
Basket Rail	339	-20	**	398	**
Basket Plate	527	-20	**	610	**
Fuel Cladding	565	-20	622 max.	647	1058

* Assuming no credit for decay heat and a daily average ambient temperature of -20°F
** The components perform their intended safety function within the operating range.
*** Not Modeled

TABLE 4.4-1
NORMAL STORAGE CASK TEMPERATURES
AS A FUNCTION OF STORAGE TIME

LOCATION	0 yr. Storage 1.02 kw/assy		10 yr. Storage 0.66 kw/assy		20 yr. Storage 0.53 kw/assy	
Maximum Temperatures						
Seal	256°F	124°C	210°F	99°C	194°F	90°C
Outer Surface	249°F	121°C	208°F	98°C	192°F	89°C
Outer Shell	240°F	116°C	201°F	94°C	187°F	86°C
Lid	263°F	128°C	214°F	101°C	197°F	92°C
Resin (Top)	256°F	124°C	210°F	99°C	194°F	90°C
Resin (Radial)	280°F	138°C	227°F	108°C	208°F	98°C
Gamma Shield	303°F	151°C	243°F	117°C	221°F	105°C
Btm. Plt. (inner)	314°F	157°C	250°F	121°C	227°F	108°C
Btm. Plt. (outer)	255°F	124°C	212°F	100°C	196°F	91°C
Inner Shell	308°F	153°C	246°F	119°C	224°F	107°C
Basket Rail	339°F	171°C	266°F	130°C	240°F	116°C
Basket Plate	527°F	275°C	394°F	201°C	346°F	174°C
Fuel Rod	565°F	296°C	425°F	218°C	381°F	194°C
Average Temperatures						
Cavity Gas	411°F	211°C	318°F	159°C	288°F	142°C

TABLE 4.4-2
CASK TEMPERATURES AS A FUNCTION OF STORAGE TIME
(-20°F AMBIENT TEMPERATURE)

LOCATION	0 yr. Storage 1.02 kw/assy		10 yr. Storage 0.66 kw/assy		20 yr. Storage 0.53 kw/assy	
Maximum Temperatures						
Seal	146°F	63°C	98°F	37°C	79°F	26°C
Outer Surface	146°F	63°C	99°F	37°C	82°F	28°C
Outer Shell	134°F	57°C	89°F	32°C	73°F	23°C
Lid	152°F	67°C	102°F	39°C	83°F	28°C
Resin (Top)	146°F	63°C	98°F	37°C	79°F	26°C
Resin (Radial)	175°F	79°C	116°F	47°C	95°F	35°C
Gamma Shield	199°F	93°C	133°F	56°C	109°F	43°C
Btm. Plt. (inner)	215°F	102°C	145°F	63°C	119°F	48°C
Btm. Plt. (outer)	154°F	68°C	104°F	40°C	86°F	30°C
Inner Shell	205°F	96°C	137°F	58°C	111°F	44°C
Basket Rail	237°F	114°C	158°F	70°C	129°F	54°C
Basket Plate	436°F	224°C	295°F	146°C	243°F	117°C
Fuel Rod	480°F	249°C	330°F	166°C	274°F	134°C
Average Temperatures						
Cavity Gas	313°F	156°C	214°F	101°C	177°F	81°C

* The minimum TN-32 cask temperature distribution, assuming no credit is taken for decay heat, is a uniform - 20°F.

TABLE 4.5-1

MAXIMUM TRANSIENT TEMPERATURES - FIRE ACCIDENT

Location	Initial Temperature	Peak Transient Temperature
Outer Shell	240°F	945°F @ 0.250 hr.*
Fuel Cladding	565°F	647°F @ 31 hr.
Neutron Shield	280°F	929°F @ 0.255 hr.
Cavity Wall	308°F	375°F @ 2 hr.
Basket Rail	339°F	398°F @ 3 hr.
Basket Plate	527°F	610°F @ 30 hr.
Lid Seal	256°F	380°F @ 1 hr.
Avg Cavity Gas	410°F	497°F @ 22 hr.
Gamma Shield	303°F	370°F @ 2 hr.

* Time from start of fire accident

FIGURE 4.4-1

THERMAL MODEL, RADIAL CROSS SECTION

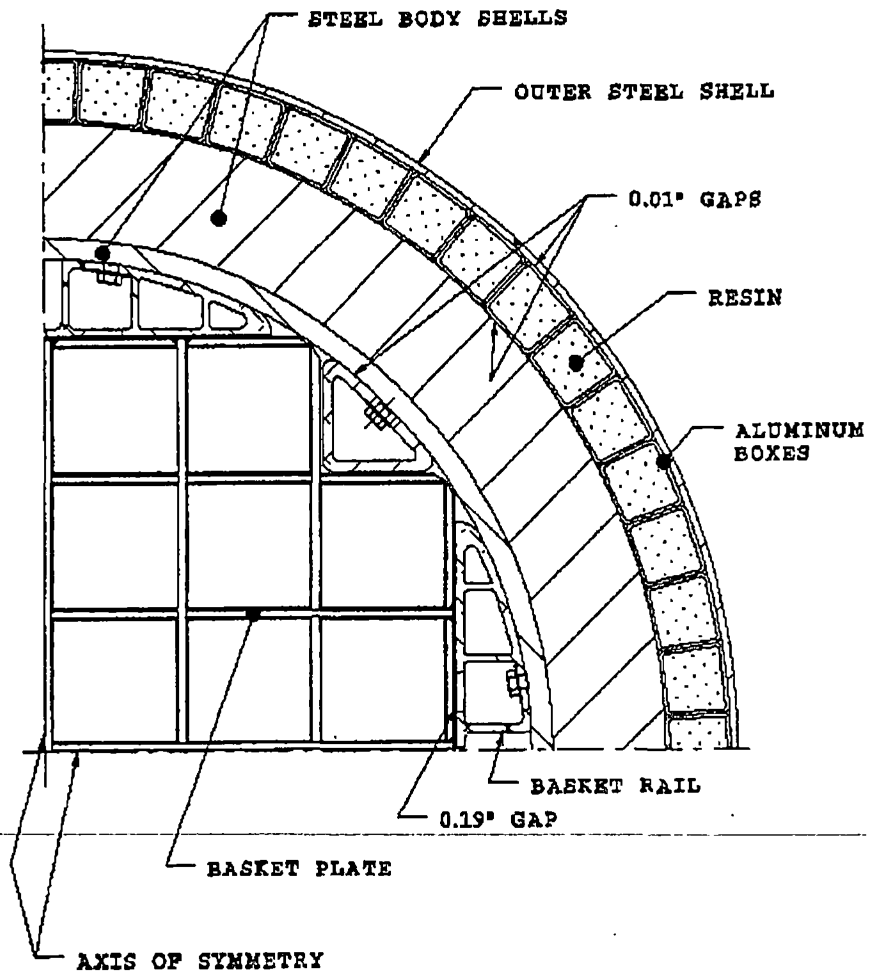


FIGURE 4.4-1
THERMAL MODEL
RADIAL CROSS SECTION

FIGURE 4.4-2

THERMAL MODEL, AXIAL CROSS SECTION

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 4.4-3

FINITE ELEMENT THERMAL MODEL

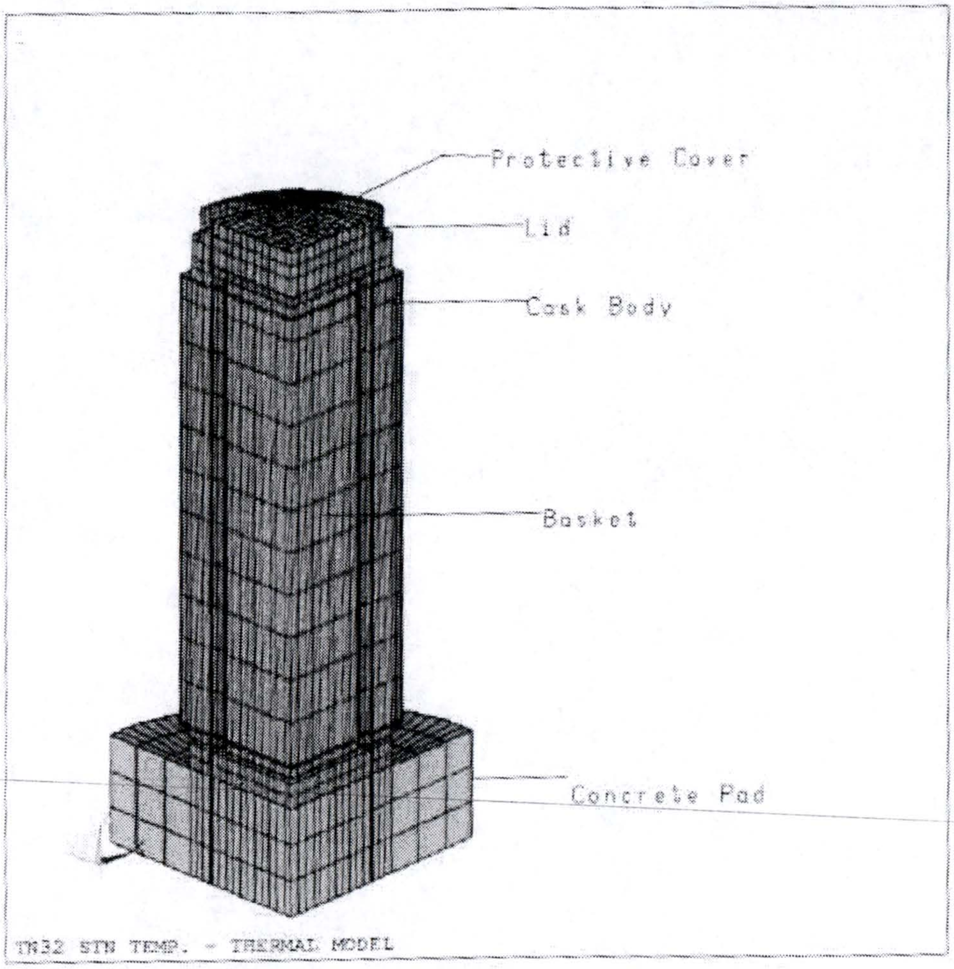


FIGURE 4.4-4

THERMAL MODEL CROSS SECTION

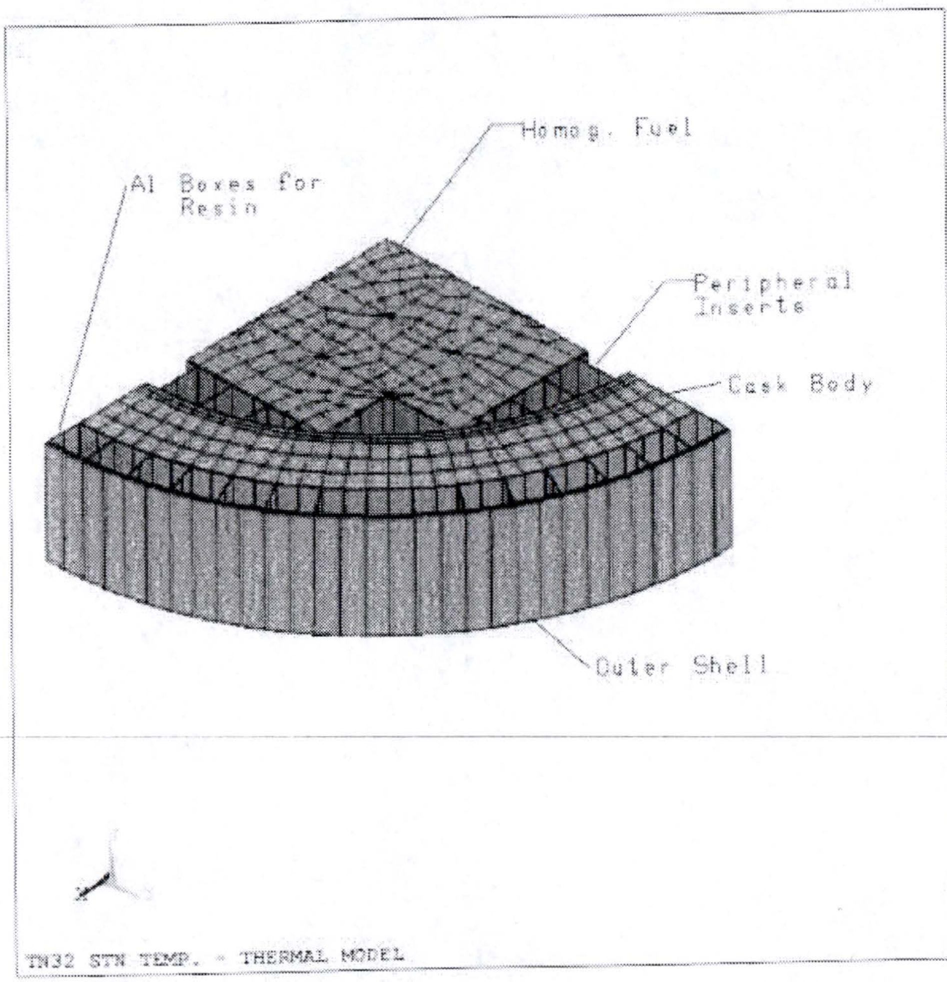


FIGURE 4.4-5

STORAGE CONFIGURATION

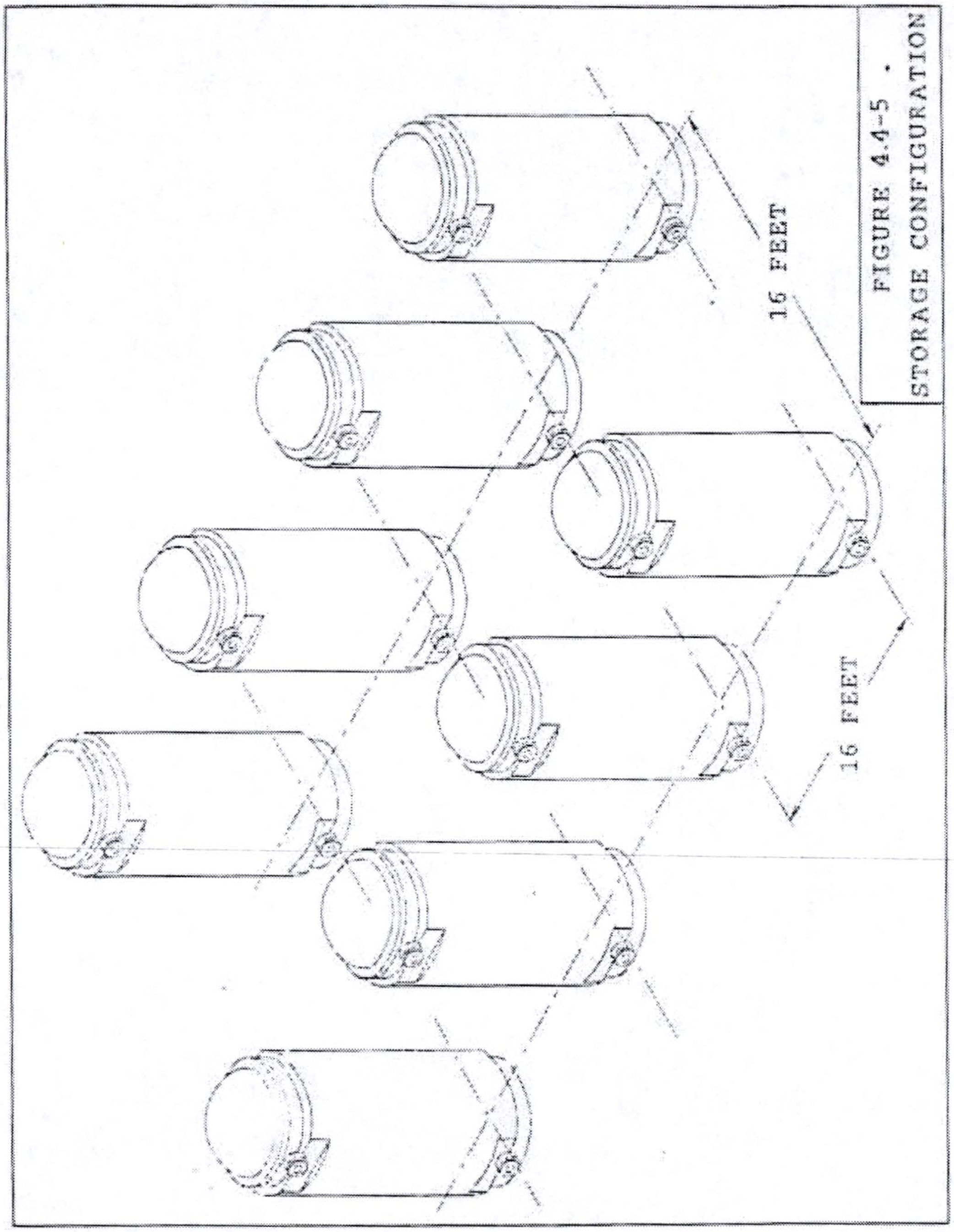


FIGURE 4.4-6

CASK TERMPERATURE DISTRIBUTION,
NORMAL STORAGE CONDITIONS

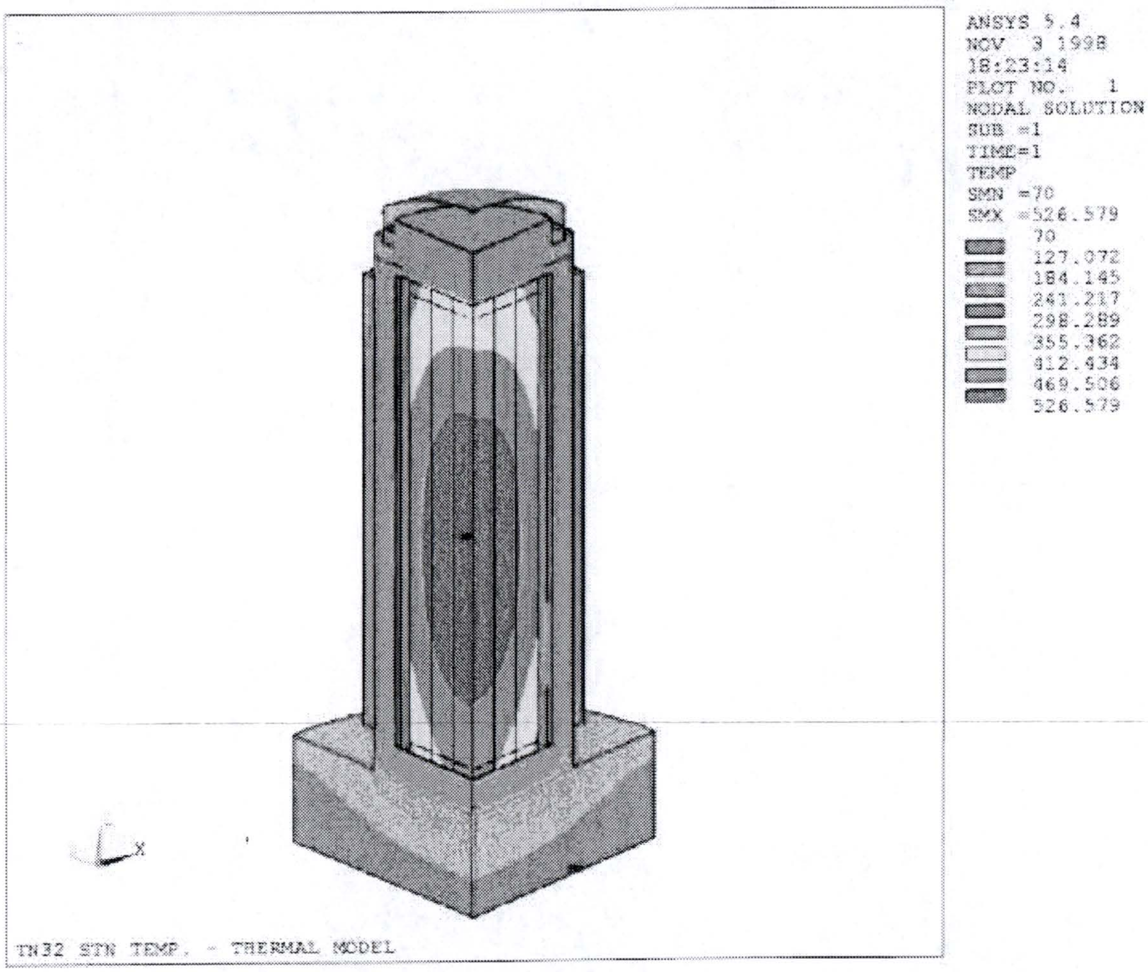


FIGURE 4.4-7

CASK TEMPERTURE DISTRIBUTION,
HOTTEST CROSS SECTION

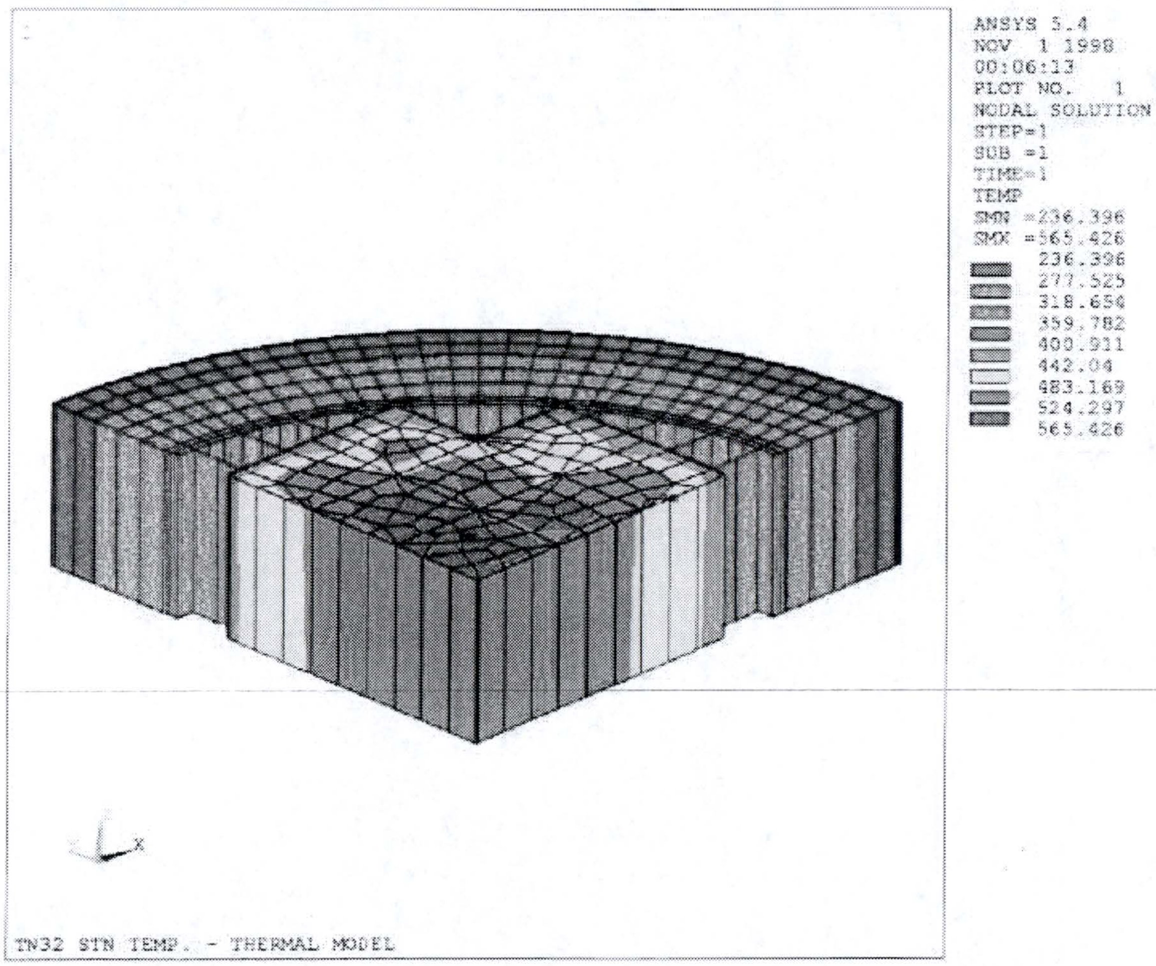


FIGURE 4.4-8

BASKET TEMPERATURE DISTRIBUTION,
HOTTEST CROSS SECTION

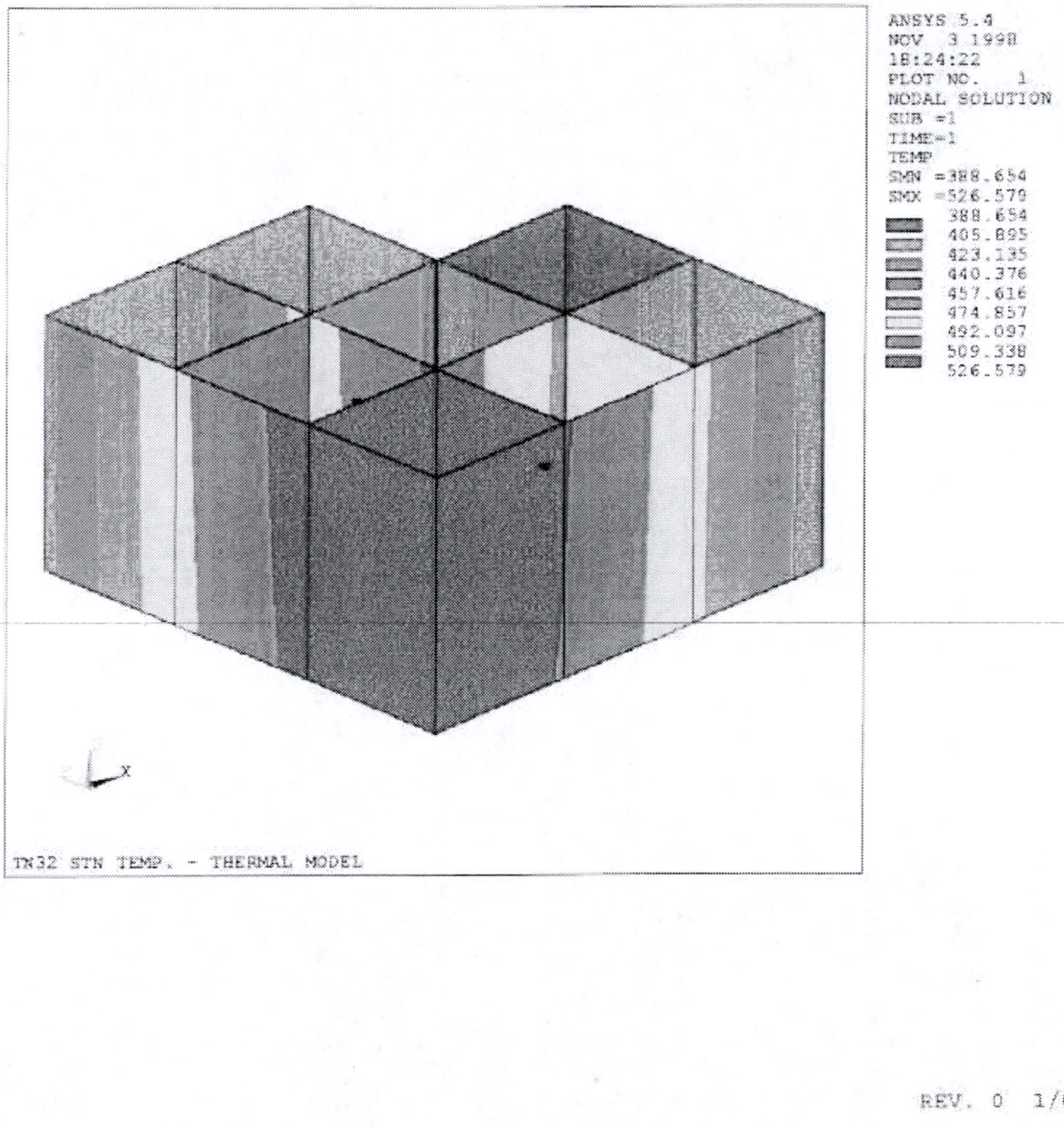


FIGURE 4.4-9

BASKET TEMPERATURE DISTRIBUTION,
TOP 4 INCHES

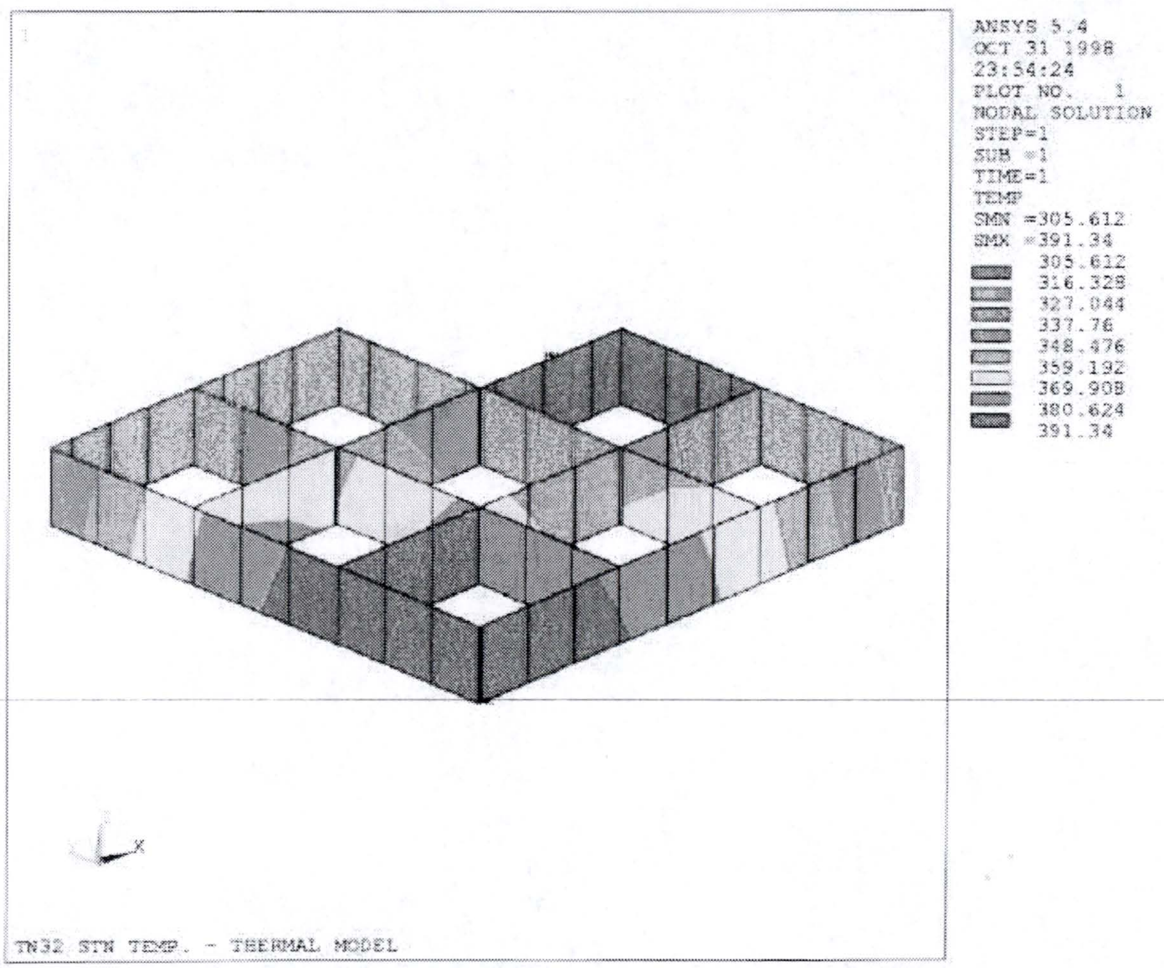


FIGURE 4.4-10

CASK BODY TEMPERATURE DISTRIBUTION

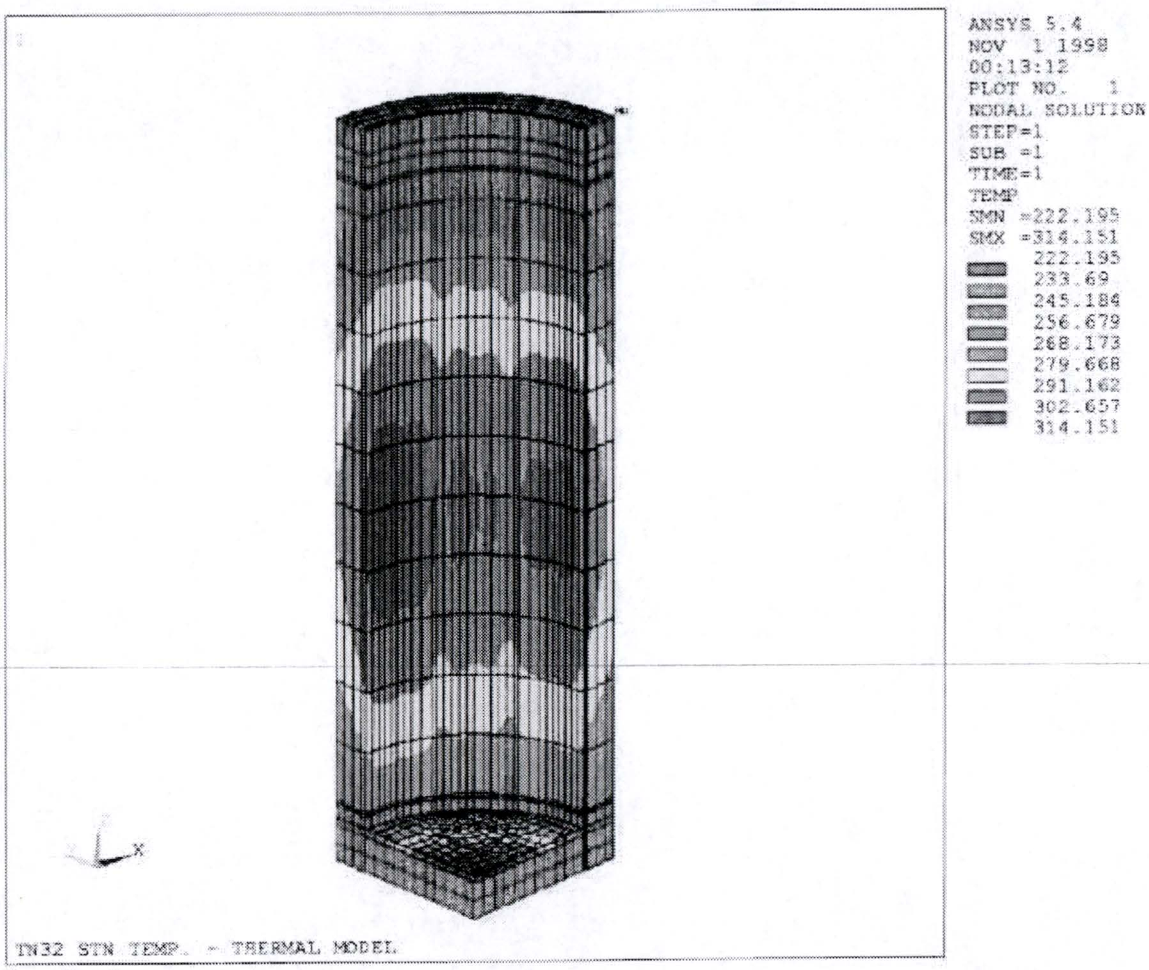


FIGURE 4.5-1

FINITE ELEMENT CROSS SECTION THERMAL MODEL
(FIRE ANALYSIS)

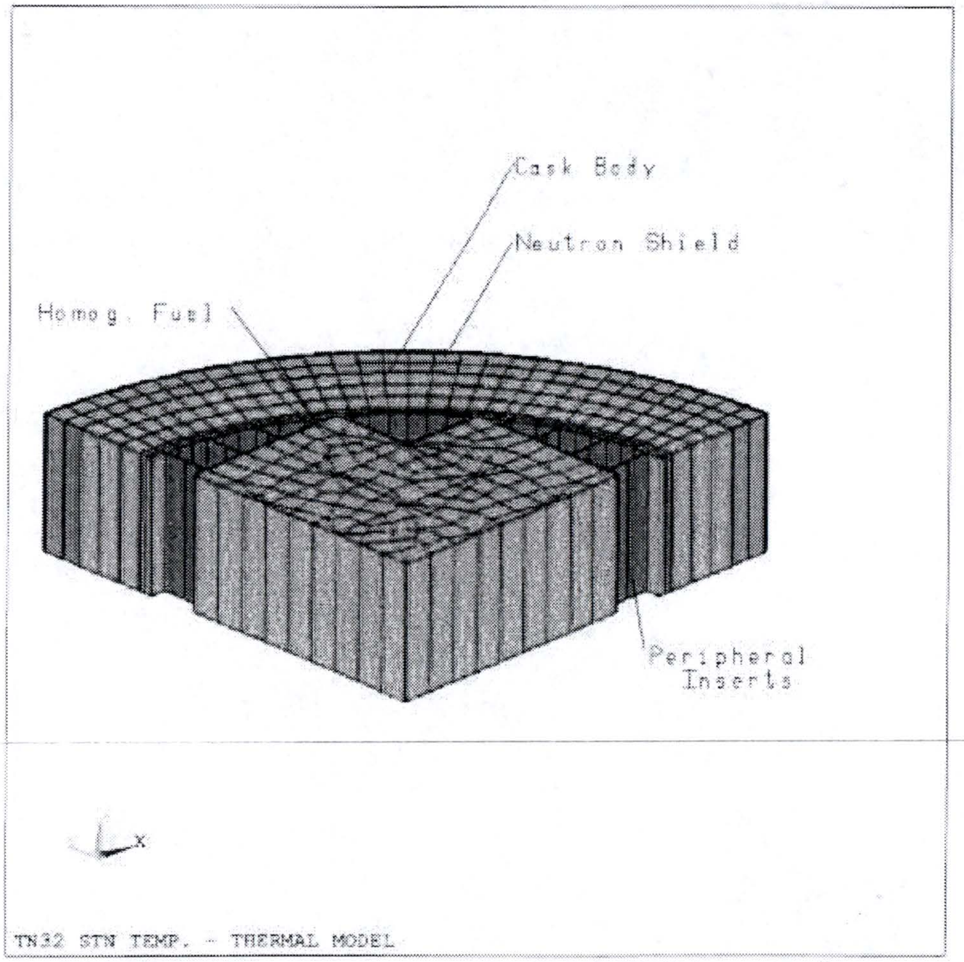


FIGURE 4.5-2

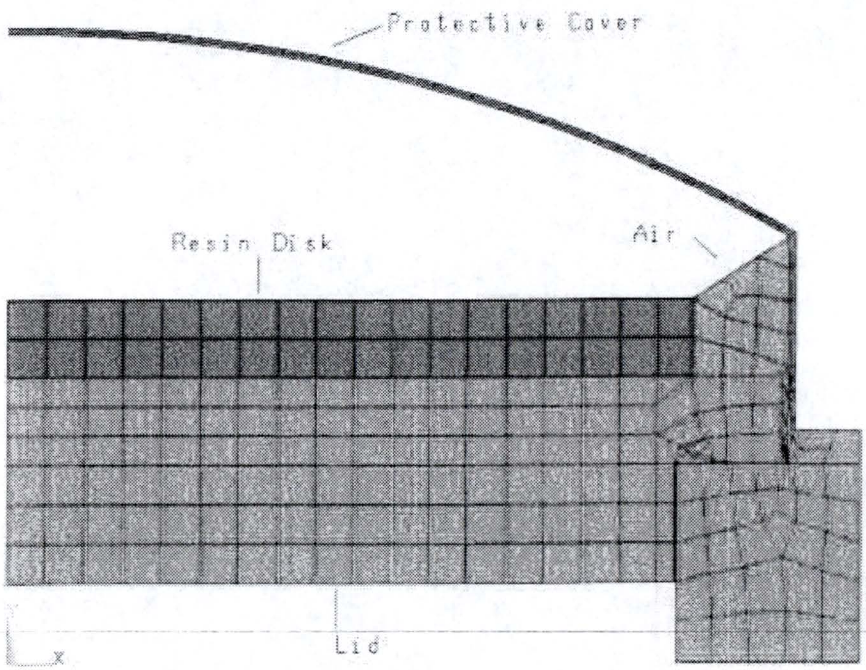
LID SEAL THERMAL MODEL

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 4.5-2
LID SEAL THERMAL MODEL
FOR FIRE ANALYSIS

FIGURE 4.5-3

FINITE ELEMENT LID SEAL THERMAL MODEL



APPENDIX 4A

EFFECTIVE THERMAL PROPERTIES OF SPENT NUCLEAR FUEL

4A.1 Discussion

In order to determine the appropriate effective fuel assembly thermal conductivity, the fuel assembly with the lowest effective thermal conductivity at the maximum heat load is selected. Use of these properties would conservatively predict bounding maximum temperatures for the TN-32.

In order to simulate the thermal performance of the fuel in the basket, the fuel's effective thermal conductivity is calculated in longitudinal and transverse directions. In the longitudinal direction, the dominant mode of heat transfer is conduction of heat through the zircaloy tubes that make up the assembly. In the transverse case, the heat transfer occurs via conduction and radiation.

Longitudinal Effective Conductivity

The longitudinal fuel effective conductivity is determined directly from the geometry and conductivities of the helium and zircaloy tubes by hand calculations. No credit is taken for the conductivity of the UO_2 pellets. No credit is taken for radiation or convection.

Transverse Effective Conductivity

No credit is taken for convection's contribution to the heat transfer within the fuel assembly region.

The transverse effective conductivity is derived using methods similar to those found in SAND90-2406, Section II.5.4[4]. In general, a fuel assembly centered within a square compartment is thermally similar to the two-dimensional problem of a uniformly heated square region with a constant thermal conductivity K_{eff}.

The thermal resistance between the stainless steel box and the adjacent aluminum plates further reduces the transverse effective conductivity. Although the stainless steel boxes are in good contact with the adjacent aluminum plates, a 0.020 inch gap is evaluated.

4A.2 Worst Case Payload

The TN-32 is designed to store 32 Westinghouse 15x15, 17x17, 17x17 OFA, 14x14 or 14x14 OFA or B&W 17x17 Mark BW spent fuel assemblies. The physical characteristics of these PWR assemblies are given in Chapter 2, Table 2.1-1. The maximum heat loads for the Westinghouse fuels are tabulated below.

Fuel Assembly	Maximum Heat Load
Westinghouse 15x15	0.980 kW
Westinghouse 17x17 Std	0.986 kW
Westinghouse 17x17 OFA	0.896 kW
Westinghouse 14x14 Std	0.876 kW
Westinghouse 14x14 OFA	0.752 kW

The worst thermal case is the fuel assembly that will result in the hottest cladding temperature for a given fuel assembly heat load. The analysis of the Westinghouse 17x17 fuel bounds the B&W Mark BW fuel.

The maximum fuel temperature is calculated using a PC BASIC code SFBTA[1,2] The temperatures of the fuel rods arranged in an assembly are calculated based on the energy transferred by thermal radiation (per the Wooton-Epstein correlation[3]) and/or thermal conduction between the rows of rods. The Wooton-Epstein correlation is based on a simplified radiative heat transfer model, which replaces the fuel rod rows with equivalent concentric tubes.

The modified Wooton-Epstein correlation is given by the equation

$$Q=\sigma C_1 F_1 A_1 [T_E^4 - T_c^4] + U A_1 [T_E - T_c] + C_2 A_1 [T_E - T_c]^s$$

where,

A_1 = Area of fuel assembly envelope
C_1 = Geometric constant (radiation)
C_2 = Empirical dimensional constant (free convection)
F_1 = Empirical constant (radiative)
Q = Heating rate of assembly
T_E = Maximum fuel cladding temperature
T_c = Cask wall temperature
U = Overall conductance coefficient
s = Empirical exponent coefficient (convection)

For square fuel rod arrays, the overall conductance is:

$$U = \left(\frac{d}{P}\right) \frac{K_g}{(P-d) + 0.215d + \frac{\pi}{4}\left(\frac{d^2}{t}\right)\left(\frac{K_g}{K_r}\right)}$$

where,
- d = Fuel rod diameter
- P = Fuel rod pitch
- K_g = Thermal conductivity for fill gas
- K_r = Thermal conductivity of fuel rod

Assuming a zero thermal convection coefficient, a comparison of the maximum fuel cladding temperature was made using the geometry data for the different fuel assemblies and the maximum decay heat load. The evaluation concluded the W17x17 fuel assembly at the maximum heat load of 0.99 kW is the bounding case.

The rod outside diameter, rod pitch, and envelope dimensions of the Mark BW fuel are all identical to the W17x17 fuel. The decay heat is 0.98 kW per assembly per Section 5.2.5. The evaluation of the W17x17 fuel for hottest cladding temperature and for effective fuel conductivity therefore bounds the Mark BW fuel.

4A.3 Summary of Thermal Properties of Materials

The thermal properties of materials used in the thermal analyses are reported below. The values listed are based on the corresponding references.

a. Thermal Conductivity of UO_2 Pellets
Ref. 5, Appendix A – Fuel Material Properties, Chapter 2

K = 5 W/m-K = 2.9 Btu/hr-ft-°F

b. Thermal Conductivity of Zircaloy
Ref. 5, Appendix B – Cladding Material Properties, Chapter 2

Temperature, °F	200	300	400	500	600	800
Thermal Conductivity, Btu/hr-ft-°F	7.86	8.28	8.68	9.06	9.44	10.20

c. Surface Emissivity of Zircaloy
Ref. 5, Appendix B – Cladding Material Properties, Chapter 2

$\varepsilon = 0.8$

d. Thermal Conductivity of Helium
Ref. 5, Appendix C – Gas Material Properties, Chapter 1

Temperature, °F	200	300	400	500	600	800
Thermal Conductivity, Btu/hr-ft-°F	0.1000	0.1104	0.1206	0.1303	0.1398	0.1580

e. Surface Emissivity of Fuel Compartment

Unpolished Stainless Steel, Ref. 6

$\varepsilon = 0.3$

The analyses use interpolated values when appropriate for intermediate temperatures where the temperature dependency of a specific parameter is deemed significant. The interpolation assumes a linear relationship between the reported values.

4A.4 Fuel Assembly Geometry

The W 17x17 fuel assembly geometry is taken from Ref. 7.

Rod Array: 17 x 17
Rod Pitch: 0.496 inch

	Fuel Rod	Guide Tubes	Instrument Tube
Number:	264	24	1
OD:	0.374 in.	0.482 in.	0.545 in.
Wall Thick.:	0.0225 in.	0.016 in.	0.015 in.
Material:	Zr 4	Zr 4	Zr 4

The instrument tube is in the center of the assembly. The location of the guide tubes can be seen in the plot of the finite element model (Figure 4A.6-1).

4A.5 Longitudinal Effective Conductivity Calculation

The helium, fuel pellet, and the zircaloy act like resistors in parallel. The contribution of the fuel pellet to the total axial conductivity is conservatively neglected. The basket opening in the TN-32 is 8.70 inches square (nominal). The equation for resistors in parallel is:

$$R_{eff} = [\ 1/R_1 + 1/R_2\ ]^{-1}$$

Substituting R = (L/KA);

$$K_{eff} = 1/A_{eff}\ [(KA)_{zirc} + (KA)_{helium}]$$

The total cross sectional area of zircaloy is:

$$A_{zircaloy} = 264 * \pi/4\ (0.374^2 - 0.329^2) + 24 * \pi/4\ (0.482^2 - 0.450^2) + \pi/4\ (0.545^2 - 0.515^2)$$

$$A_{zircaloy} = 6.5594\ in^2 + 0.5622\ in^2 + 0.0250\ in^2 = 7.147\ in^2$$

The total cross sectional area of the UO_2 fuel is given below. The diameter of the fuel pellet is 0.3225 inches(7).

$$A_{UO2} = 264 * \pi/4\ (0.3225\ in.)^2 = 21.565\ in^2$$

The total cross sectional area of the helium is taken to be the remaining area.

$$A_{helium} = (8.70\ in.)^2 - (21.565\ in^2 + 7.147\ in^2) = 46.98\ in^2$$

The effective fuel conductivity as a function of temperature in the longitudinal direction is tabulated below:

Temp.	Helium		Zircaloy		Effective Fuel	
(F)	Area (in2)	Cond. (B/hr-ft-F)	Area (in2)	Cond. (B/hr-ft-F)	Area (in2)	Cond. (B/hr-ft-F)
200	46.98	0.0996	7.147	7.8553	75.69	0.8036
300	46.98	0.1104	7.147	8.2742	75.69	0.8498
400	46.98	0.1200	7.147	8.6759	75.69	0.8937
500	46.98	0.1308	7.147	9.0652	75.69	0.9372
600	46.98	0.1404	7.147	9.4464	75.69	0.9791
800	46.98	0.1584	7.147	10.2033	75.69	1.0618

4A.6 Transverse Effective Conductivity Calculation

A two-dimensional quarter-symmetry section of a W 17x17 fuel assembly centered within a TN-32 basket compartment is modeled using ANSYS[8]. A 0.020 inch helium gap is modeled around the stainless steel box. The finite element model simulates heat transfer by radiation and conduction to the stainless steel box, and conduction across the helium gap to the perimeter of the model. Convection is not modeled. The perimeter of the model is held at a fixed temperature, and a decay heat is applied directly to the fuel pellets as volumetric heat generation. A decay heat load of 1.02 kW per assembly is used which includes the contribution from the BPRAs. The relevant result of the analysis is the maximum fuel cladding temperature.

Radiation between and within the basket walls and the fuel pins was simulated using the radiation super-element processor (AUX12). Conduction was modeled using 2-D thermal solid elements(PLANE55) to represent the helium and the fuel pellets (UO_2). The zircaloy tubes and the basket plates were modeled with 2-D conducting bar elements (LINK32), using real constant thicknesses as appropriate. The symmetry lines were meshed with 2-D thermal conducting bars (LINK32) and assigned an extremely low emissivity ($\varepsilon = 0.01$) to simulate reflection. The symmetry lines and the basket elements were used only during the super-element formulation phase (/AUX12), and were removed from the model prior to solution phase, so their conductivity and real constant values are immaterial.

A plot of the finite element model is shown in Figure 4A.6-1.

The results of this finite element model are compared to an analytical solution for a uniformly heated square region of the same size (8.70 inches) with a constant temperature at the perimeter of the square. The uniform square is assumed to have a constant conductivity. The total heat load is the same for the uniform square as for the fuel assembly model.

The effective conductivity of the fuel assembly region is taken to be that constant value which results in the same temperature drop from center to edge in the uniform square as occurs in the fuel assembly model between maximum fuel cladding and basket box.

The analytical solution for the temperature in the center of the uniform square is given below (Ref. 4, equation II-100):

$$T_c = T_o + 0.29468 \; (Q \, a^2 / K_{eff})$$

where: T_c = temperature in the center of the square

T_o = temperature on the outside (perimeter)
Q = decay heat per unit area per unit depth
a = half-length of square = ½ (8.70 in.) = 4.35 in
K_{eff} = conductivity of square region

This equation can be re-arranged to allow solution of K_{eff}. Substituting and rearranging for K_{eff},

$$K_{eff} = 0.29468 \ [\ Q\ a^2 \ / \ (T_c - T_o)\ ]$$

The fuel effective conductivity is a function of the temperature of the perimeter because the material properties are temperature dependent and radiation is strongly temperature dependent. A table associating fuel effective conductivity with temperature (i.e. - a temperature-conductivity relationship) is derived. The analysis associates K_{eff} with the average temperature, given by ½ $(T_c + T_o)$.

The results of the analyses are tabulated below. See the following pages for the temperature distribution for each case.

Temperature (F)				Conductivity
Avg.	Boundary	Maximum	ΔT	(Btu/hr-ft-F)
221	175	266	91	0.2814
301	260	341	81	0.3184
400	365	434	69	0.3713
505	475	534	59	0.4340
606	580	631	51	0.5018
805	785	824	39	0.6588

A temperature distribution for the 400°F average temperature case is shown in Figure 4A.6-2.

4A.7 Effective Specific Heat and Density Calculations

Effective Specific Heat

The effective specific heat of the fuel assembly is determined by taking a mass weighted average of the component specific heats.

Specific Heat of Zircaloy
(Ref. 5, Appendix B - Cladding Material Properties, Chap. 1)

Temperature (K)	Temperature (F)	Specific Heat (J/kg-K)	Specific Heat (Btu/lbm-F)
300	80.33	281	0.067
400	260.33	302	0.072
640	692.33	331	0.079
1090	1502.33	375	0.090

Specific Heat of UO_2
(Ref. 5, Appendix A - Fuel Material Properties, Chap. 1)

$$FCP = \frac{K_1 \theta^2 \exp(\theta/T)}{T^2[\exp(\theta/T)-1]^2} + K_2 T + \left(\frac{O/M}{2}\right)\frac{K_3 E_d}{RT^2}\exp\left(\frac{-E_d}{RT}\right) \quad \text{(Eqn. A-1.1)}$$

FCP = specific heat capacity (J/kg-K)
T = temperature (K)
O/M = oxygen to metal ratio, assumed to be 2
R = 8.3143 (J/mol-K)
θ = the Einstein temperature = 535.285
K_1 = 296.7
K_2 = 2.43E-2
K_3 = 8.745E+7
E_d = 1.577E+5

Specific Heat of UO_2

Temperature (K)	Temperature (F)	Specific Heat (J/kg-K)	Specific Heat (Btu/lbm-F)
300	80.33	236	0.056
400	260.33	266	0.063
640	692.33	296	0.071
1090	1502.33	317	0.076

$M'_{tot}C_{eff} = M'_{zir}C_{zirc} + M'_{UO2}C_{UO2}$

$A_{zircaloy} = 7.147\ in^2$ (Section 4a.5)
$A_{UO2} = 21.565\ in^2$ (Section 4a.5)
$A_{tot} = (8.70\ in.)^2 = 75.69\ in^2$

$\rho_{zirc} = 6.56\ g/cm^3 = 0.237\ lbm/in^3$ (Ref. 9)
$\rho_{UO2} = 10.96\ g/cm^3 = 0.396\ lbm/in^3$ (Ref. 9)

$M'_{zirc} = \rho_{zirc}A_{zirc} = 1.694$
$M'_{UO2} = \rho_{UO2}A_{UO2} = 8.540$
$M'_{tot} = M'_{zir} + M'_{UO2} = 10.234$

Effective Specific Heat of Fuel (Btu/lbm-F)

T (K)	T (F)	C_{zirc}	M'_{zirc} (lbm/in)	C_{UO2}	M'_{UO2} (lbm/in)	M'_{tot} (lbm/in)	C_{eff}
300	80.33	0.067	1.694	0.056	8.540	10.234	0.058
400	260.33	0.072	1.694	0.064	8.540	10.234	0.065
640	692.33	0.079	1.694	0.071	8.540	10.234	0.072
1090	1502.33	0.090	1.694	0.076	8.540	10.234	0.078

Effective Density

$V_{tot}\rho_{eff} = M'_{tot}L$

$\rho_{eff} = M'_{tot} / A_{tot} = (10.234/75.69) = 0.135\ lbm/in^3$

4A.8 Conclusions

The thermal analysis of the TN-32 cask presented in Chapter 4 is based on the following non-isotropic, temperature dependent thermal conductivities for the homogenized fuel region which were calculated in this Appendix:

Longitudinal Direction

Temperature, °F	200	300	400	500	600	800
Thermal Conductivity, Btu/hr-ft-°F	0.804	0.850	0.894	0.937	0.979	1.062

Transverse Directions

Temperature, °F	221	300	400	505	606	805
Thermal Conductivity, Btu/hr-ft-°F	0.282	0.318	0.371	0.434	0.502	0.659

The transient thermal analysis of the TN-32 cask is based on the following temperature dependent thermal specific heats, and effective densities which were calculated in this Appendix:

Temperature, °F	80.33	260.33	692.33	1502.33
Specific Heat, Btu/lbm-°F	0.058	0.065	0.072	0.078

Density, Lbm / in^3	0.135

4A.9 References

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(Revision 5)

CHAPTER 5

SHIELDING EVALUATION

5.1 Discussion and Results

Shielding for the TN-32 cask is provided mainly by the thick-walled cask body. For the neutron shielding, a borated polyester resin compound surrounds the cask body and a polypropylene disk covers the lid. Additional shielding is provided by the steel shell surrounding the resin layer and by the steel and aluminum structure of the fuel basket.

Geometric attenuation, enhanced by attenuation by air and ground, provides additional shielding for distant locations at restricted area and site boundaries. Figure 5.1-1 shows the configuration of shielding in the cask. Table 5.1-1 lists the compositions of the shielding materials.

The TN-32 is designed to store 32 Westinghouse 14 x 14 (standard or OFA), 15 x 15, and 17 x 17 (standard or OFA) or B&W 17x17 Mark BW spent fuel assemblies with or without burnable poison rod assemblies (BPRAs) and thimble plug assemblies (TPAs).

Source terms for the five Westinghouse fuel designs are calculated using the SAS2H/ORIGEN-S module of SCALE4.3[1]. The W17x17 source bounds the Mark BW 17x17, which has a slightly lower fuel mass. Each fuel assembly is modeled with a total burnup of 45,000 MWd/MTU combined with an initial minimum average enrichment of 3.5 wt% U-235 and cooling time of 7 years. These source terms are then passed through a SAS2H cask shield model for a 1-dimensional dose assessment. The source (assembly type) which provided the highest dose rate is used in the subsequent 3-dimensional shielding calculations.

Through this analysis, the Westinghouse 17x17 standard fuel array is identified as the largest fuel source. Section 5.2 describes the source specification and Section 5.3 describes the shielding analyses performed for the TN-32 cask.

An evaluation was also performed to determine the fuel assembly parameters of burnup, percent initial enrichment and cool time that would result in dose rates less than the current design basis fuel mentioned above and thus would be acceptable for storage in the TN-32 storage cask. This evaluation is described in Section 5.2.

In addition to the spent fuel, the TN-32 is capable of storing BPRAs and TPAs. BPRAs and TPAs with combinations of cumulative exposures and cooling times are permissible for storage in the TN-32 cask. The source evaluation of the BPRAs and TPAs is described in Section 5.2.

Normal and off-normal conditions are modeled with the TN-32 intact. This shielding calculation is performed using the SAS4 module of SCALE4.4[4] which is a 3-dimensional Monte Carlo method. Average dose rates on the side, top and bottom of the TN-32 cask are calculated. Maximum dose rates are also calculated above and below the radial neutron shield. Appendix 5A provides actual doses (both gamma and neutron) measured around loaded TN-32 casks.

Accident conditions assume radially, the neutron shield and steel outer shell are removed, and, axially the polypropylene disk and protective cover are removed. This evaluation bounds the accident conditions in Section 11.2. Shielding calculations for accident conditions are also performed using the SAS4 module (3-dimensional shielding analysis) of the SCALE4.4 code.

The expected maximum dose rates (for normal, off-normal, and accident conditions) from the TN-32 are provided in Table 5.1-2. The locations of the dose points are provided in Figure 5.1-2.

The direct dose from one cask at the postulated site boundary is calculated using the Monte Carlo computer code MCNP[5]. The analysis results are presented in Table 5.1-3.

Based on the shielding models developed in this chapter, the dose rate around the cask at accessible locations to personnel are presented in Chapter 10. Dose rates from cask operations are also presented in Chapter 10.

The effects of accidents on dose rates in the vicinity of the casks is discussed in Chapter 11.

5.2 Source Specification

There are five principal sources of radiation associated with cask storage that are of concern for radiation protection. These are:

1. Primary gamma radiation from spent fuel.
2. Primary neutron radiation from spent fuel.
3. Gamma radiation from activated fuel structural materials.
4. Capture gamma radiation produced by attenuation of neutrons by shielding material of the cask.
5. Neutrons produced by sub-critical fission in fuel.

The TN-32 is designed to store these fuel types: Westinghouse 14x14 standard, 14x14 optimized, 15x15, 17x17 standard and 17x17 optimized, and B&W 17x17 Mark BW. The SAS2H/ORIGEN-S modules of the SCALE code are used to generate a gamma and neutron source term for each fuel assembly type. The W17x17 source bounds the Mark BW 17x17, as described in Section 5.2.5. Each fuel assembly has an initial enrichment of 3.5 wt% U 235 and the fuel zone is irradiated at a constant specific power of 20 MW/assembly to a total burnup of 45,000 MWD/MTU. A conservative three-cycle operating history is utilized with 30 day down time for each cycle except for no down time in the last cycle.

Source terms are generated for the active fuel region, the plenum region and the end regions. Irradiation of the fuel assembly structural materials (i.e. plenum and end fittings) are included in the irradiation of the fuel zone. The fuel assembly hardware, BPRA and TPA materials and masses on a per assembly basis are listed in Table 5.2-1. Table 5.2-2 provides the material composition of fuel assembly hardware, TPA and BPRA materials. Cobalt impurities are included in the SAS2H model. In particular, the cobalt impurities in Inconel, Zircaloy and stainless steel are 0.47%, 0.001% and 0.08% respectively.[2] The masses for the materials in the top end fitting region is multiplied by 0.1 and in the plenum and bottom end fitting by 0.2.[3] These factors are used to correct for the spatial and spectral changes of the neutron flux outside of the fuel zone. The material compositions of the fuel assembly hardware are included in the SAS2H/ORIGEN-S model on a per assembly basis.

Gamma and neutron source terms are calculated for each of the five Westinghouse fuel designs. Table 5.2-3 presents the gamma and neutron source terms for a 7 year cooling time and the results of the SAS2H dose evaluation. Table 5.2.4 presents the source terms for the selected W 17x17 standard fuel assembly.

Combining the results of the source term evaluation and the 1-dimensional shielding model, the Westinghouse 17x17 standard fuel assembly is identified the most limiting source term. This fuel is used for the shielding analysis.

An evaluation was also performed to determine the fuel assembly parameters of burnup, percent initial enrichment and cool time that would result in dose rates less than the current design basis fuel mentioned above and thus would be acceptable for storage in the TN-32 storage cask. The 1-dimensional SAS2H shielding model was used for this evaluation.

The SAS2H calculation determined the contact dose rate at the midplane on the side of the cask to be 104 mrem/hr (13 neutron and 91 gamma). (Note: the Monte Carlo 3-D, SAS4 calculation showed the dose to be 153 mrem/hr.)

A series of SAS2H runs were performed for the Westinghouse 17x17 standard fuel assembly with variations in the burnup and percent initial enrichment. A description of this analysis is present in Section 5.2.4.

5.2.1 Gamma Source

Table 5.2-4 shows the total primary gamma source for the W 17 x 17 standard fuel assembly. Table 5.2-5 shows the total primary gamma source for the BPRA's and TPA's. Fission product activities and activation activities for the W 17x17 standard fuel assembly are provided in Tables 5.2-6 and 5.2-7, respectively.

The primary gamma source spectrum for the fuel, plenum, and end fittings is listed in Table 5.2-8. The primary gamma source spectrum for the TPAs and BRPAs are listed in Table 5.2-9 and 5.2-10, respectively.

The gamma source spectra are presented in the 18-group structure consistent with SCALE4 27n-18γ cross section library. The conversion of the source spectra from the default ORIGEN-S energy grouping to the SCALE 27n-18γ is performed directly through the ORIGEN-S code. The SAS2H/ORIGEN-S input file for the W17x17 standard assembly is provided in Section 5.5.

The gamma source for the fuel assembly hardware is primarily from the activation of cobalt. This activation contributes primarily to the SCALE Energy Groups 36 and 37. Based on the weight fraction of cobalt in each zone of the fuel assembly model (as adjusted by the appropriate flux ratio), the gamma source term in SCALE Energy Groups 36 and 37 are redistributed accordingly. The gamma sources for the plenum region, the top fitting region and the bottom fitting region are provided in Table 5.2-8.

The gamma source for the TPAs and BPRAs are calculated using separate SAS2H/ORIGEN-S models. The mass of the TPA/BPRA (as adjusted by the appropriate flux ratio) in each zone of the fuel assembly are included in the light elements of the SAS2H/ORIGEN-S model. (Only the mass of the TPA / BPRA is included in the source model. Fuel hardware materials are not included in these models.) The gamma source is from the activation of the metal components of these assemblies (light elements).

To determine the source term from TPAs, TPAs with 210,000 MWD/MTU cumulative exposure and 20 year cooling time are evaluated. Each TPA is within a fuel assembly with an initial enrichment of 3.5 wt% U-235 and the fuel zone is irradiated at a constant specific power of 20 MW/assembly to a total cumulative burnup of 45,000 MWD/MTU. A conservative three-cycle operating history is used with a 30 day down time for each cycle except for no down time in the last cycle. The source term results from this SAS2H / ORIGEN-S run are multiplied by the ratio of 14 cycles / 3 cycles to determine the total source from a cumulative exposure of 210,000 MWD/MTU. The gamma source and spectrum are provided in Tables 5.2-5 and 5.2-9, respectively. The activation of these components is primarily due to Co-60 and the source term apportioned between SCALE Energy groups 36 and 37. This source term was used in the shielding analysis described in Section 5.4.

To determine the permissible source for TPAs with lower exposures and shorter cooling times, the source terms from exposures of 45,000 MWD/MTU, 90,000 MWD/MTU, 135,000 MWD/MTU, and 180,000 MWD/MTW are evaluated. The amount of cooling time required such that these gamma sources are equivalent to the source presented in Table 5.2-9 is evaluated. These results are presented in Chapter 2, Figure 2.1-5. Intermediate cumulative exposures are evaluated by a straight line extrapolation between calculated values.

To determine the source term from BPRAs, BPRAs with 30,000 MWD/MTU cumulative exposure and 4 day cooling time are evaluated. Each BPRA is also within a fuel assembly with an initial enrichment of 3.5 wt% U-235 and the fuel zone is irradiated at a constant specific power of 20 MW/assembly to a total cumulative burnup of 30,000 MWD/MTU. A conservative three-cycle operating history is used with a 30 day down time for each cycle except for no down time in the last cycle.

The gamma source and spectrum are provided in Tables 5.2-5 and 5.2-10, respectively. This source term was used in the shielding analysis described in Section 5.4.

To evaluate BPRAs with greater exposures and longer cooling times, BPRA source terms are evaluated for cumulative exposures of 40,000 MWD/MTU, 50,000 MWD/MTU, and 60,000 MWD/MTU were evaluated. At these greater exposures and longer cooling times, Co-60 from the activation of components is the primary source. The amount of cooling time required such that these gamma sources are equivalent to the source presented in SCALE Energy Groups 36 and 37 (which is primarily due to Co-60 activation) of Table 5.2-10 is evaluated. These results are presented in Chapter 2, Figure 2.1-4. Intermediate cumulative exposures are evaluated by a straight line extrapolation between calculated values.

The SAS2H/ORIGEN-S input files for the TPA and BPRAs are provided in Section 5.5.

Since there are various combinations of BPRAs and TPAs, the two extremes are considered; a BPRA with 24 rods and a TPA with 24 plugs. These extremes provide the largest amount of irradiated material present in the top portion of the fuel assembly. (In the case of the BPRA this results in the largest amount of SS304 and in the case of the TPA this results in the largest amount of Inconel.) Also for this analysis, BPRAs are considered to be of SS304. Zircaloy clad BPRAs are also manufactured but their source from activation would be much less than a stainless steel BPRA. Both types of BPRAs are acceptable for loading in the TN-32 cask. Combinations of BPRAs and TPAs are also acceptable for loading in the TN-32 cask.

An axial burnup profile has been developed on the basis of exposure data provided by Virginia Power and Wisconsin Electric. Discrete peaking factors were generated and normalized to the actual exposure values. Figure 5.2-1 illustrates the design axial burnup profile versus the actual data. Table 5.2-11 provides design axial gamma peaking factors that were utilized in the SAS4 shielding model. The maximum peaking factor for the gamma source is 1.135.

The SAS4 analyses are performed with a top and bottom model, each with its own axial fuel source distribution, based on Table 5.2-11. The gamma source from the fuel zone is multiplied by a normalization factor based on the axial distribution utilized for the model. The gamma normalization factors for the top and bottom model are 0.98 and 1.06 respectively.

5.2.2 Neutron Source

Table 5.2-12 provides the total neutron source spectra for the W 17 x 17 fuel assembly. The SAS2H/ORIGEN-S code provides the neutron spectra in the SCALE 27n-18γ energy groups. Table 5.2-4 also provides the total neutron source. The SAS2H/ORIGEN-S input file for the W 17x17 fuel assembly is provided in Section 5.5.

To determine a neutron source in the spent fuel assembly, the axial burnup profile shown in Figure 5.2-1 was utilized. The neutron source is not linearly dependent with burnup, and therefore analyses were performed to determine the axial neutron source distribution. SAS2H/ORIGEN-S analyses were performed for a range of burnups from 21,600 MWD/MTU to 51,075 MWD/MTU (peak). The neutron peaking factor is determined as the ratio of the neutron source term obtained from the SAS2H/ORIGEN-S analysis to the maximum bundle average burnup neutron source. Table 5.2-11 provides the design axial neutron source distribution. The maximum peaking factor for the neutron source is 1.68. Figure 5.2-2 illustrates the neutron source distribution which was used in the SAS4 model. The normalization factors for the neutron source are 1.16 and 1.39 for the top and bottom model respectively.

5.2.3 Airborne Radioactive Material Sources

Tables 5.2-6 and 5.2-7 show the inventory of fission gases, volatile nuclides, fines and crud from each W 17x17 standard fuel assembly (these are the total curies in the fuel assembly). Most of the fission products are retained within the fuel pellet and only a small fraction is released in to the fuel rod plenums. Chapter 7 provides the confinement analysis for the TN-32. Off-normal and accident off-site airborne dose rates are also presented in Chapter 7.

5.2.4 Evaluation of Burnup, Enrichments, and Cool Time for the Fuel

As stated previously, a series of SAS2H runs were made for various combinations of % initial enrichment, burnup and decay times. Cool times were selected such that the total dose rate calculated was approximately 90% of the design basis fuel value given above. A table was generated showing the minimum cool time necessary for various combinations of burnup and bundle average enrichment and is shown in Table 2.1-3. This table is used to evaluate burnups from 15,000 MWD/MTU to 45,000 MWD/MTU and enrichments from 1.2 wt% to 4.05 wt%. The values in bold in this table are calculated values.

Since the neutron dose is a relatively small fraction of the total dose, coupled with the relatively faster reduction of gamma dose with cool time, the minimum cool time is not required to increase significantly above 7 years even for low enrichment/high burnup fuel assemblies.

Based on the calculated results (which are presented in bold type), other values may be interpolated/extrapolated based on simple logic, i.e. for the same burnup, an increase in enrichment produces a lower source. Additionally, some simple algorithms can be formulated based on the calculated values.

Enrichment

For example, comparing the ratio of neutron and gamma doses for 42, GWd/MTU, 9 year cooling time with 2.5% and 2.2% initial enrichment, the lower enrichment increases the neutron and gamma dose by factors of 1.18 and 1.06, respectively. Therefore, the dose rate increase can be predicted as a function of the enrichment by forming the ratio of the two enrichments and taking it to the power of 1.3 for neutrons and 0.45 for gammas.

$(2.5/2.2)^{1.3} = 1.18$ $\qquad (2.5/2.2)^{0.45} = 1.06$

Burnup

Comparing the ratio of the neutron and gamma doses for 3% enriched, 7 year cooled 40, 43, and 45 GWD/MTU cases, the larger burnup increases the dose by factors of 1.19 and 1.06, neutron and gamma respectively for 43 to 45 GWD/MTU and by factors of 1.35 and 1.10, neutron and gamma respectively for 40 to 43 GWD/MTU. Again, the dose rate increase can be predicted as function of burnup by forming the ratio of the two burnups and taking it to the power of 4 for neutrons and 1.3 for gammas.

$(45/43)^4 = 1.2$ $\qquad (45/43)^{1.3} = 1.06$

$(43/40)^4 = 1.34$ $\qquad (43/40)^{1.3} = 1.10$

Cool Time

Comparing the ratio of neutron and gamma doses for the following cases: 43 GWD, 2.3%, 7 and 8 years cooling; 42 GWD, 2.5%, 8 and 9 years cooling; the following values for the reduction in dose rate are predicted.

Year to Year	Neutron Factor	Gamma Factor
7 to 8	0.96	0.85
8 to 9	0.96	0.85
9 to 10	0.96	0.88
7 to 9	0.92	0.73
7 to 10	0.89	0.64

These simple algorithms were used to fill in the combinations in the table that were not explicitly calculated.

5.2.5 Comparison of Mark BW and Westinghouse 17x17 Fuels

Mark BW fuel is physically nearly identical to the Westinghouse standard 17x17 fuel, and is operated in the same reactors under identical operating conditions. The only differences are a slightly thicker cladding and a slightly smaller pellet diameter with a slightly higher density (see Table 6.2-1). The net effect is a lower stack density and overall lower fuel mass in the Mark BW fuel. The UO_2 mass in Westinghouse standard 17x17 fuel is 0.364 lb/ft, and in Mark BW fuel, 0.360 lb/ft, about 1% less.

Therefore, both the actinide and fission product inventory on a mass-specific basis will be nearly identical for the Mark BW and Westinghouse 17x17 standard fuel, given the same enrichment, cooling time, and burnup. Likewise, the axial burnup curves used for the Westinghouse fuel are appropriate for the Mark BW fuel. Because the fuel mass is about 1% smaller in the Mark BW fuel, it will have about a 1% lower fission product and actinide inventory. In turn, it will have about 1% less decay heat than the Westinghouse standard 17x17 fuel. The decay heat listed in Table 5.2-3 for the Westinghouse 17x17 standard fuel is 0.987 kW. For the Mark BW, it would be (0.360/0.364)0.987 = 0.98 kW.

The mass of hardware available in the most important zone for shielding, the top end zone, is smaller in the Mark BW fuel than the values used in this analysis for the Westinghouse fuel. The following table compares the mass of hardware in the fuel assembly top end fitting and the BPRA.

	mass, Kg	
	Westinghouse Std 17x17 (Table 5.2-1)	Mark BW
Upper end fitting		
stainless 304	6.8	5.85
Inconel	1.37	1.04
BPRA spider		
stainless 304	2.47	2.22
Inconel	0.36	0.36

The cladding weight in the Mark BW fuel will be slightly greater than that in the Westinghouse fuel, due to the increased thickness. However, cobalt impurity in Zircaloy cladding is very low, and the contribution of activated cladding to the cask dose rate is negligible compared to that of the fuel itself. The source in the spent fuel will be lower for the Mark-BW fuel as noted above.

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5.3 Model Specification

The SAS4 module of the SCALE4.4 code is used for calculating the gamma and neutron doses immediately around the cask. SAS4 is a 3-dimensional Monte Carlo based methodology. For dose rates at long distances from the cask, the MCNP code is used.

5.3.1 Description of the Radial and Axial Shielding Configuration

The differences among the three TN-32 cask designs are tabulated below.

Design	Trunnions	Lid Configuration
TN-32	Non-Single Failure Proof Top Trunnions	10.5 inch thick lid 4.0 inch polypropylene encased in 0.25 inch thick steel disk
TN-32A	Non-Single Failure Proof Top Trunnions	9.38 inch thick lid 4.0 inch polypropylene encased in 0.25 inch thick steel around the top and sides and 1.25 inch thick steel on the bottom
TN-32B	Single Failure Proof Top Trunnions	10.5 inch thick lid 4.0 inch polypropylene encased in 0.25 inch thick steel disk

With the exception of the top trunnions, the lid, and top neutron shield all other cask dimensions are the same for the three designs. Within SAS4, the model must be symmetrical around the cask midplane. Therefore, for each shielding configuration (e.g. normal, off-normal and accidents) two models must be developed; a top half model and a bottom half model.

Sections 5.3.1.1 and 5.3.1.2 describe the SAS4 radial and axial shielding models (for the vicinity immediately around the cask) developed for the TN-32 under normal, off-normal and accident conditions. Section 5.3.1.3 describes the MCNP model developed for the TN-32 at large distances from the cask.

5.3.1.1 Radial and Axial Shielding Configuration under Normal and Off-Normal Conditions of Storage

Under normal and off-normal conditions, one shielding configuration is used for the TN-32, TN-32A and TN-32B designs. The top half model is illustrated in Figures 5.3-1 through 5.3-4 and the bottom half model is illustrated in Figures 5.3-5 through 5.3-7. The dimensions of this shielding model correspond to the dimensions of the TN-32 standard design. The axial locations of the plenum and end fittings for the fuel assembly are taken from Reference 2.

The smaller non-single failure proof trunnions are used in the model since this configuration would have slightly less shielding present in the area of the trunnions.

In the Type A lid configuration, 1.12 inch of steel is transferred from the inside of the lid (the lid shielding plate) to the neutron shield which is mounted on the outside of the lid. The net thickness of shield at the top of the cask remains unchanged. As shown Figure 5.3-8, the shielding thickness beyond the perimeter of the top neutron shield is less than with the standard TN-32 lid. The total shielding thickness in this area is about equal to the radial shielding thickness near the top of the cask. Therefore the top dose rates beyond the perimeter of the neutron shield will be no higher than the radial dose rates near the top of the cask, and the shielding evaluation for the TN-32 cask with the standard lid is valid for the Type A lid.

Radial Direction Model

The fuel region is assumed to consist of uranium dioxide. The fuel cladding and steel basket are included in the homogenized fuel region. The fuel region is modeled as a cylinder with the actual cavity diameter. Subsequent regions are cylindrical shells corresponding to actual dimensions.

In the top half model, the plenum and end fittings are homogenized within their regions. The basket is included in the homogenization.

Voids are neglected within the fuel assembly itself. The voids within the cask cavity and within the protective cover are modeled.

Axial Direction Model

The axial direction model is identical to the radial direction model with the exception that the plenum and the end fittings are homogenized within their regions but the basket is neglected in the homogenization of these regions.

5.3.1.2 Radial and Axial Shielding Configuration under Hypothetical Accident Conditions of Storage

For the accident conditions, the neutron shield, the outer shell, the polypropylene disk with its steel encasement, and the protective cover are removed. To further simplify the model, the trunnions are also removed under the accident configuration. (As stated in Chapter 1, these components are not completely lost during accident conditions. These components are removed from the model to perform a bounding shielding analysis.)

Three models have been developed for accident conditions; two top half models and one bottom half model (see Figures 5.3-9, 5.3-10, and 5.3-11, respectively). The two top half models that have been developed are: one with the standard TN-32 lid (which is also used for the TN-32B) and one with the TN-32A lid. The bottom half model remains the same among the three designs.

Radial Direction Model

Similar to normal and off-normal conditions, under accident conditions, the fuel region is assumed to consist of uranium dioxide. The fuel cladding and steel basket are included in the homogenized fuel region. The fuel region is modeled as a cylinder with the actual cavity diameter. Subsequent regions are cylindrical shells corresponding to actual dimensions.

In the top half model, the plenum and end fittings are homogenized within their regions. The basket is included in the homogenization.

Voids are neglected within the fuel assembly itself. The voids within the cask cavity and within the protective cover are modeled.

Axial Direction Model

Similar to the normal and off-normal conditions, the axial direction model is identical to the radial direction model with the exception that the basket is neglected in the homogenization of the plenum and end fitting regions.

5.3.1.3 Shielding Configuration at Long Distances from the Cask

At long distances from the cask, a model was developed for MCNP. The MCNP cask model was essentially the combination of the top and bottom half models of the SAS4 analyses discussed earlier. The trunnions were not modeled because they have a negligible effect on far field doses. The cask was modeled as sitting on a concrete pad which extends 10 meters out from the cask. The ground and air were included in the model as scattering media for the neutron and gamma emissions from the cask.

Similar to the SAS4 model, the central fuel region is considered to consist of uranium dioxide. The fuel cladding, and the basket are included in the homogenized fuel region. The fuel region is modeled as a cylinder with the actual cavity diameter. Subsequent regions are cylindrical shells corresponding to actual dimensions. Three models were used which differed only in the definition of the source. One for neutron, one for gamma from the fuel and one for gamma from the fuel hardware(plenum and end fittings). The fuel inserts are not included in the MCNP analysis.

The MCNP calculated dose at far distances consists of contributions from direct, air scatter (skyshine) and ground scatter. The dose is calculated as F4 tallies in a 200 cm high by 100 cm thick air volume which is converted into a dose rate using energy dependent dose conversion factors[6].

5.3.2 Shield Regional Densities

For the SAS4 model, four source areas, shown in Table 5.2-1 are utilized: fuel zone, plenum, upper fitting and lower fitting. The sources are uniformly homogenized over the cavity diameter and the appropriate length, as shown in Figures 5.3-1 and 5.3-2.

Depending upon the source term within the cask, the regional densities are adjusted accordingly. Three basic source configurations are considered:

- 32 spent fuel assemblies loaded into the TN-32;
- 32 spent fuel assemblies with 32 Burnable Poison Rod Assemblies (24 poison rods each); or
- 32 spent fuel assemblies with 32 Thimble Plug Assemblies (24 plugs each).

The fuel basket is homogenized over the source diameter and active fuel length in the active fuel zone for both the axial and radial directions.

In the radial models, the basket is homogenized over the source diameter and the appropriate length (of the plenum and end fittings). In the axial models, the basket is neglected in the regions of the plenum and end fittings.

The radial resin and aluminum boxes are homogenized into a single composition based on the mass of each component. Dose measurements from similar designs in use have not shown dose streaming effects due to the aluminum boxes.

The material input for the SAS4 models depending upon source term are listed in Tables 5.3-1, 5.3-2, and 5.3-3. Atom densities of the materials used in the calculations are also listed in Tables 5.3-1 through 5.3-3. These atom densities were calculated in the SAS4 module of the SCALE4.3 utilizing standard compositions within SCALE4.3 and supplying appropriate densities or volume fractions.

Material and atomic densities listed in Table 5.3-1 are the basis for the material data used in the MCNP analysis.

5.4 Shielding Evaluation

Dose rates around the TN-32 are determined by choosing the most conservative source (W 17x17 Standard) and using it within a three dimensional SAS4 model. SAS4 uses XSDRNPM to calculate adjoint fluxes to derive biasing parameters for the Monte Carlo analysis (MORSE-SGC). These biasing parameters are then automatically input to MORSE-SGC. ANSI standard flux to dose factors, within SCALE, are used for the dose calculation at the selected points (Table 5.4-1). The SCALE code accounts for subcritical neutron multiplication and the generation of secondary gamma dose due to neutron interactions in the shielding materials, principally the neutron shield resin.

The shielding evaluation is performed with the TN-32 loaded with three combinations of sources:

- 32 spent fuel assemblies;
- 32 spent fuel assemblies plus 32 BPRAs (24 rods each); and
- 32 spent fuel assemblies plus 32 TPAs (24 plugs each).

The SAS4 top and bottom models were run with each of the three combinations of fuel/BPRA/TPA loadings listed above. The top model is prepared as ten separate computer runs consisting of contributions from the following sources:

- Primary gamma radiation from the active fuel region(axial and radial directions).
- Neutron radiation from the top half of the active fuel region (axial and radial directions).
- Captive gamma radiation from the top half of the active fuel region (axial and radial directions).
- Gamma radiation from activated hardware within the plenum region (axial and radial directions).
- Gamma radiation from activated hardware within the top fitting region (axial and radial directions).

Similarly, the SAS4 bottom model is prepared as eight separate computer runs consisting of contributions from the following sources:

- Primary gamma radiation from the active fuel region (axial and radial directions).
- Neutron radiation from the bottom half of the active fuel region (axial and radial directions).
- Captive gamma radiation from the bottom half of the active fuel region (axial and radial directions).
- Gamma radiation from activated hardware within the bottom fitting region (axial and radial directions).

The sources in the active fuel region (gamma, neutron, and capture gamma) are uniform radially but vary axially. The sources in the structural hardware regions (plenum, top fitting, and bottom fitting) are uniform both radially and axially.

The incremental dose rates for the BPRAs and TPAs presented in Table 5.1-2 were determined by subtracting the SAS4 runs containing the TPAs and BPRAs from the SAS4 runs with only the fuel assemblies present.

Surface detectors were placed in several radial and axial locations in order to evaluate the dose rate around the cask body. These surface detectors provide an averaged surface dose rate based on the size of the detector (surface). The surface detectors can be subdivided into segments in order to determine the location and magnitude of maximum dose rates. In particular, approximately 10 cm high detector segments were utilized above and below the radial neutron shield.

For normal conditions, the contribution of each source (from the top half model and bottom half model) to each dose point is summed to calculate the total gamma and/or neutron dose for each location. Figure 5.4-1 presents the average dose at contact, 1 m, and 2 m from surface detectors along the length of the neutron shield surface. Figures 5.4-2 and 5.4-3 presents the average dose at contact, 1 m, and 2 m from surface detectors along the diameter of the top and bottom of the cask, respectively.

For accident conditions, Figure 5.4-4 presents the average doses at contact, 1 m, and 2 m, from surface detectors along the cask body length. Figure 5.4-5 and 5.4-6 presents the average doses at contact, 1 m, and 2 m, from detectors along the standard lid and the Type A lid surfaces, respectively. For axial doses from the bottom of the cask, accident conditions are identical to normal conditions.

Dose rates at long distances from a single TN-32 loaded with thirty two design basis fuel assemblies (no BPRAs or TPAs)are evaluated with the MCNP code. The total dose rates, direct, skyshine and ground scatter are reported in Table 5.1-3.

The source term and SAS4 shielding evaluation were performed using SCALE 4.3/4.4, "Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers"[1,4] by Oak Ridge National Laboratory. The far field dose rate analysis was performed using MCNP, "MCNP4B2 Monte Carlo N-Particle Transport Code System"[5] by Los Alamos National Laboratory. SCALE4.3 is implemented on a Hewlett Packard 9000/715 Workstation. SCALE 4.4 and MCNP are implemented on Pentium based PCs using Windows NT. These program(s) have been verified in accordance with the Transnuclear quality assurance program.

Dose rate measurements have been taken on two loaded TN-32 casks. Appendix A to this chapter presents and discusses the measured data and the evaluation performed to "benchmark" this data by calculation.

Selected input for the SAS4,MCNP and SAS2H models are included in Section 5.5.

5.5 Supplemental Data

5.5.1 SAS2H/ORIGEN-S Input Files

5.5.1.1 Fuel Assembly

```
=sas2h      parm='skipcellwt'
17x17ofa-sas2.inp, 3.5 w/o U235, 45,000 MWD/MTU, 7-30 year cooling
27groupndf4   latticecell
uo2         1    0.95  900 92234 0.0294 92235 3.5 92236 0.0152
92238 96.4554 end
zircalloy  2    1.0       750   end
h2o         3  den=0.725   1.0    575     end
arbm-bormod   0.725  1  1  0  0  5000  100  3  700.0E-06  575  end
'------------------------------------------------------------------
'                mixutres of shipping cask
'------------------------------------------------------------------
ss304         4   den=0.299  end
al            4   den=0.306  end
carbonsteel  5   1.0        end
arbmtnres    1.58   5  1  0  0  5000  1.05  6012  35.13  8016
  41.73  13027  14.93   1001  5.05  6  0.896 end
al            6   0.104      end
end comp
'-------------------------------------------------------------------
'               fuel pin geometry
'-------------------------------------------------------------------
squarepitch  1.259984   0.78486  1  3  0.9144  2   0.8001  0  end
npin/assm=264  fuelength=365.76  ncycles=3   nlib/cyc=1  printlevel=10
lightel=6     inplevel=1   numholes=24  numinstr=1
ortube=0.61214  srtube=0.5715  end
power=20.0    burn=317.25   down=30    end
power=20.0    burn=317.25   down=30    end
power=20.0    burn=317.25   down=2555  end
'--------------------------------------------------------------------
'         light elements kg per assembly
'--------------------------------------------------------------------
cr 2.7433  mn 0.1503  fe  6.0047  co  0.0353  ni 4.6388  zr 101.8
'---------------------------------------------------------------------
'                   zone description of cask
'    mixt4-fuel+basket   mixt5-cask body+shell   mixt6-resin+al
'---------------------------------------------------------------------
27n-18couple  tempcask(k)=452   numzones=4   detect=5  dryfuel=yes  end
0.5    100    200    300    400
4 87.31     5 111.44    6  122.87    5  124.14
zone=1  fuelbndl=32    end
end
```

5.5.1.2 Thimble Plug Assembly

```
=sas2h      parm=(halt03,skipshipdata)
17x17tpa-top.inp, 3.5% w/o U235, 45,000 MWD/MTU, TPAs
27groupndf4   latticecell
uo2         1    0.95  900 92234 0.0294 92235 3.5 92236 0.0152
92238 96.4554 end
zircalloy  2    1.0       750   end
h2o        3  den=0.725   1.0   575     end
arbm-bormod   0.725  1  1  0  0  5000  100  3  700.0E-06  575  end
end comp
'-------------------------------------------------------------------
'                fuel pin geometry
'-------------------------------------------------------------------
squarepitch  1.25984  0.81915  1  3  0.94996  2  0.83566  0  end
'-------------------------------------------------------------------
'                assembly and cycle parameters
'--------------------------------------------------------------------
npin/assm=264  fuelength=365.76  ncycles=3  nlib/cyc=1  printlevel=6
lightel=5     inplevel=1   numholes=24  numinstr=1
ortube=0.61214  srtube=0.5715  end
power=20.0    burn=346.05   down=30    end
power=20.0    burn=346.05   down=30    end
power=20.0    burn=346.05   down=3   end
'---------------------------------------------------------------------
' light elements - TPA - top fitting zone - kg per assembly
'---------------------------------------------------------------------
cr 0.0537  mn 0.0050  fe  0.1763  co  0.0004  ni 0.0406
end
=origens
0$$   a4  21  a8  26  a10  51  71  e
1$$   1   1t
cooling to 30 years and fission product gamma reordering
3$$   21  0   1   a33 -86  e
54$$  a8  1   e   t
35$$  0   t
56$$  0   8   a13 -2   4    3   e
57**  3  e   t
cooling to 30 years and fission product gamma re-ordering
single reactor assembly
60**  4.0 7.0  30.0  365.0  1825.0  2555.0 3650.0  7300.0
65$$  a10  1    e
61**  f.1
81$$  2  51  26  1  e
82$$  f4  t
light element scale group structure - 4 days cooled
light element scale group structure - 7 days cooled
light element scale group structure - 30 days cooled
light element scale group structure - 1 year cooled
light element scale group structure - 5 years cooled
light element scale group structure - 7 years cooled
light element scale group structure - 10 year cooled
```

```
light element scale group structure - 20 year cooled
56$$  f0   t
end
```

5.5.1.3 Burnable Poison Rod Assembly

```
=sas2h      parm=(halt03,skipshipdata)
17x17bpra-plen.inp, 3.5% w/o U235, 30,000 MWD/MTU, BPRAs
27groupndf4   latticecell
uo2        1    0.95   900 92234 0.0294 92235 3.5 92236 0.0152
92238 96.4554 end
zircalloy  2    1.0        750    end
h2o        3  den=0.725   1.0    575     end
arbm-bormod   0.725  1  1  0  0  5000  100  3  700.0E-06  575  end
end comp
'------------------------------------------------------------------
'                fuel pin geometry
'------------------------------------------------------------------
squarepitch   1.25984   0.81915  1  3  0.94996  2   0.83566  0  end
'------------------------------------------------------------------
'                assembly and cycle parameters
'------------------------------------------------------------------
npin/assm=264  fuelength=365.76  ncycles=3   nlib/cyc=1  printlevel=6
lightel=5    inplevel=1   numholes=24  numinstr=1
ortube=0.61214  srtube=0.5715  end
power=20.0    burn=230.7   down=30     end
power=20.0    burn=230.7   down=30     end
power=20.0    burn=230.7   down=3    end
'------------------------------------------------------------------
' light elements - BPRAs plenum zone - kg per assembly
'------------------------------------------------------------------
cr 0.0239 mn 0.0025 fe 0.08674  co 0.000101  ni 0.01124
end
=origens
0$$   a4  21  a8  26  a10  51  71  e
1$$   1   1t
cooling to 30 years and fission product gamma reordering
3$$   21  0   1   a33 -86  e
54$$  a8  1   e   t
35$$  0   t
56$$  0   8   a13 -2   4    3   e
57**  3  e    t
cooling to 30 years and fission product gamma re-ordering
single reactor assembly
60**  4.0 7.0  30.0  365.0  1825.0  2555.0 3650.0  7300.0
65$$  a10  1   e
61**  f.1
81$$  2  51  26  1  e
82$$  f4  t
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
light element scale group structure
```

56$$ f0 t
end

5.5.2 SAS2H Input File

```
=sas2h      parm='skipcellwt'
17x17ofa-sas2.inp, 3.5 w/o U235, 45,000 MWD/MTU, 7-30 year cooling
27groupndf4   latticecell
uo2          1    0.95   900 92234 0.0294 92235 3.5 92236 0.0152
92238 96.4554 end
zircalloy  2    1.0        750    end
h2o        3   den=0.725   1.0    575     end
arbm-bormod   0.725  1  1  0  0  5000  100  3  700.0E-06  575  end
'------------------------------------------------------------------
'                 mixutres of shipping cask
'------------------------------------------------------------------
ss304         4   den=0.299   end
al            4   den=0.306   end
carbonsteel  5    1.0         end
arbmtnres    1.58   5  1  0  0  5000  1.05  6012  35.13  8016
  41.73  13027  14.93   1001  5.05  6  0.896 end
al            6   0.104      end
end comp
'-------------------------------------------------------------------
'                fuel pin geometry
'-------------------------------------------------------------------
squarepitch  1.259984   0.78486  1  3  0.9144  2   0.8001  0  end
npin/assm=264  fuelength=365.76  ncycles=3   nlib/cyc=1  printlevel=10
lightel=6     inplevel=1   numholes=24  numinstr=1
ortube=0.61214  srtube=0.5715  end
power=20.0    burn=317.25   down=30     end
power=20.0    burn=317.25   down=30     end
power=20.0    burn=317.25   down=2555   end
'--------------------------------------------------------------------
'         light elements kg per assembly
'--------------------------------------------------------------------
cr 2.7433  mn 0.1503  fe  6.0047  co  0.0353  ni 4.6388  zr 101.8
'---------------------------------------------------------------------
'                   zone description of cask
'    mixt4-fuel+basket   mixt5-cask body+shell   mixt6-resin+al
'---------------------------------------------------------------------
27n-18couple  tempcask(k)=452   numzones=4   detect=5  dryfuel=yes  end
0.5     100    200    300    400
4 87.31    5 111.44    6  122.87    5  124.14
zone=1  fuelbndl=32    end
end
```

5.5.2 SAS4 Models

5.5.2.1 Sample Input file for Active Fuel Region, Normal Conditions, Primary Gamma Dose, Top Half Model, Axial, Fuel Only

```
=sas4
□
```

```
NAT-F-AF-G1, TN-32  Normal-Axial-Top-Fuel Only-Active Fuel-Primary Gamma
□
27n-18couple infhommedium
□
'Fuel-Basket Zone
□
uo2           1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
□
zircalloy     1  den=0.376  end
inconel       1  den=0.022  end
aluminum      1  den=0.306  end
ss304         1  den=0.316  end
'Plenum  Zone (no basket)
zircalloy     2  den=0.459  end
ss304         2  den=0.159  end
'Top Fitting Zone (no basket)
inconel       3  den=0.212  end
ss304         3  den=1.052  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   4  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 5 0.89 end
carbonsteel  5  0.11  end
'Resin/Aluminum
arbmtnres     1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    6  0.896  end
al            6  0.104   end
end comp
idr=1 ity=2 izm=8 isn=8 mhw=0 frd=87.31  end
182.88  200.53 209.17 220.72 247.39 258.92 292.8 293.76  end
1       2      3      0      4      5      0     4       end
xend
tim=3000  nst=4000   nit=150  nmt=8000 sfa=1.62e17
' fr1=1.0   fr2=1.0  fr3=1.0  fr4=1.0
igo=4  isp=0  ipf=8  isd=4  end
soe  35z    1.077e-02  4.699e-02  4.523e-02  4.319e-01
 8.820e-02  9.124e-03  1.468e-02  5.372e-02
 6.586e-02  2.334e-01  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  293.76  end
bub  0.0  76.2 106.68 137.16 154.31 165.74  180.02  182.88 end
buf  1.12  1.119  1.1  1.02   0.87   0.73  0.48  0.002  end
'----------------------------------------------
'   surface detectors
'----------------------------------------------
sdl  258.82  293.76  393.76  493.76 end
sdr  0. 100.  0. 102.  0. 102.  0. 102. end
sds  10 1  10 1  10 1  10 1 end
gend
TN-32, radial calculation, primary gamma, active fuel zone
  0  0  1  20
rcc   1  0.  0.  -182.88  0.  0.   365.76    87.31
rcc   2  0.  0.  -200.53  0.  0.   401.06    87.31
rcc   3  0.  0.  -209.17  0.  0.   418.34    87.31
rcc   4  0.  0.  -220.72  0.  0.   441.44    87.31
rcc   5  0.  0.  -235.96  0.  0.   471.92   111.44
rcc   6  0.  0.  -247.39  0.  0.   494.78   100.97
```

```
rcc   7  0.  0.  -258.82  0.  0.   517.64    89.34
rcc   8  0.  0.  -292.80  0.  0.   585.60   101.92
rcc   9  0.  0.  -293.76  0.  0.   587.52   102.87
rcc  10  0.  0.  -163.57  0.  0.   327.14   122.87
rcc  11  0.  0.  -163.57  0.  0.   327.14   124.14
rcc  12  0.  0.  -393.76  0.  0.   787.52   224.14
rcc  13  0.  0.  -493.76  0.  0.   987.52   324.14
rcc  14  0.  0.  -593.76  0.  0.  1187.52   424.14
rcc  15  0.  0. -2293.76  0.  0.  4587.52  2124.14
rcc  16  0.  0. -2393.76  0.  0.  4787.52  2224.14
rcc  17  0.  0.  -202.3   0.  0.   404.6    122.87
rcc  18  0.  0.  -204.21  0.  0.   408.21   124.14
rpp  19  120.60   124.14  -30.48  30.48  -204.21  204.21
rpp  20  -124.14 -120.60  -30.48  30.48  -204.21  204.21
rpp  21  118.69   120.60  -30.48  30.48  -204.21  204.21
rpp  22  -120.60 -118.69  -30.48  30.48  -204.21  204.21
rcc  23  -131.47   0.  204.21   262.94  0.  0.   11.01
rcc  24  120.04    0.  204.21   11.43   0.  0.   5.08
rcc  25  -131.47   0.  204.21   11.43   0.  0.   5.08
  end
 ful      1
 pln      2   -1
 tpf      3   -2
 vdl      4   -3
 shd      5   -4
 lid      6   -5
 ppy      7   -6
 res     10   -5
 osh     11  -10    -5
 tv1     24
 tv2     25
 tru     23  -5   -24  -25
 bx1     19   -23
 bx2     20   -23
 st1     21   -23
 st2     22   -23
 rs1     17   -19  -21   -20  -22  -10  -5
 st3     18   -17  -19   -21  -20  -22  -11   -5
 vd2      8   -7    -6    -5
 cov      9   -8    -5
 de2     12  -11    -18   -17   -19   -20  -23  -24 -25  -9
 de3     13  -12
 de4     14  -13
 inv     15  -14
 exv     16  -15
   end
 20R1 2 1 2 1 1
 25R0
  1    2    3    1000   4    4    5    6   4   1000 1000 4   1000 1000 4   4
  6   4    1000 4    1000 1000 1000 1000 0
  0
end
```

5.5.2.2 Sample Input file for Active Fuel Region, Normal Conditions, Primary Gamma Dose, Bottom Half Model, Radial, Fuel Only

```
=sas4
□
NRB-F-AF-G, TN-32  Normal-Rad-Bottom-Fuel Only-Active Fuel-Primary Gamma
27n-18couple infhommedium
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Bottom-Basket Zone
aluminum       2  den=0.306  end
ss304          2  den=1.409  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   3  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 4 0.89 end
carbonsteel  4  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    5  0.896  end
al             5  0.104   end
end comp
idr=0 ity=2 izm=4 isn=8 mhw=0 frd=87.31  end
87.31  111.44   122.87  124.14   end
1      3        5       3     end
xend
tim=3000  nst=4000   nit=150 nmt=8000  sfa=1.62e17
' fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=11   isd=4  end
soe  35z    1.077e-02  4.699e-02  4.523e-02  4.319e-01
 8.820e-02  9.124e-03  1.468e-02  5.372e-02
 6.586e-02  2.334e-01  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  219.97  end
bub  0.0  11.43  34.29  102.87  125.73  142.88  154.31  165.74
 174.31  180.02  182.88  end
buf  1.12  1.121  1.126  1.135  1.091  1.02  0.94  0.79  0.65
 0.54  0.002  end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  111.44  124.14  224.14  324.14 end
sdr  189. 219. 0. 188.  0. 219.  0. 219. end
sds  3 12  10 0  10 0  10 0 end
gend
TN-32, radial calculation, primary gamma, active fuel zone
  0  0  1  20
rcc   1  0.  0.  -182.88  0.  0.   365.76    87.31
rcc   2  0.  0.  -193.93  0.  0.   387.86    87.31
rcc   3  0.  0.  -219.97  0.  0.   439.94   111.44
rcc   4  0.  0.  -160.28  0.  0.   320.56   122.87
rcc   5  0.  0.  -160.28  0.  0.   320.56   124.14
rcc   6  0.  0.  -319.97  0.  0.   787.52   224.14
rcc   7  0.  0.  -419.97  0.  0.   987.52   324.14
rcc   8  0.  0.  -519.97  0.  0.  1187.52   424.14
```

```
rcc   9  0.   0. -2219.97  0.   0.  4587.52  2124.14
rcc  10  0.   0. -2319.97  0.   0.  4787.52  2224.14
rcc  11  0.   0.   -186.32  0.   0.   372.64   122.87
rcc  12  0.   0.   -188.22  0.   0.   376.44   124.14
rpp  13  120.60    124.14   -30.48   30.48  -188.22  188.22
rpp  14  -124.14 -120.60   -30.48   30.48  -188.22  188.22
rpp  15  118.69    120.60   -30.48   30.48  -188.22  188.22
rpp  16  -120.60 -118.69   -30.48   30.48  -188.22  188.22
rcc  17  -131.47    0.   200.92   262.94  0.   0.   11.01
rcc  18  120.04     0.   200.92   11.43   0.   0.    5.08
rcc  19  -131.47    0.   200.92   11.43   0.   0.    5.08
  end
 ful     1
 btf     2   -1
 shd     3   -2
 res     4   -3
 osh     5   -4    -3
 tv1    18
 tv2    19
 tru    17   -3   -18  -19
 bx1    13   -17
 bx2    14   -17
 st1    15   -17
 st2    16   -17
 rs1    11   -13  -15  -14  -16  -5  -3
 st3    12   -11  -13   -15  -14  -16  -5   -3
 de2     6  -5   -12   -11   -13  -15  -14   -16  -17  -3
 de3     7  -6
 de4     8  -7
 inv     9  -8
 exv    10  -9
   end
 14R1 2 1 2 1 1
 23R0
  1    2    3    4    3    1000  1000  3  1000 1000  3  3
  4    3   1000 1000 1000 1000 0  1000 1000 1000 1000
  0
end
```

5.5.2.3 Sample Input file for Active Fuel Region, Normal Conditions, Neutron Gamma Dose, Top Half Model, Axial, Fuel Only

```
=sas4
□
NAT-F-AF-N, TN-32  Normal-Axial-Top-Fuel Only-Active Fuel-Neutron
□
27n-18couple infhommedium
□
'Fuel-Basket Zone
□
uo2           1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
□
zircalloy     1  den=0.376  end
inconel       1  den=0.022  end
aluminum      1  den=0.306  end
```

```
ss304          1  den=0.316  end
'Plenum  Zone (no basket)
zircalloy      2  den=0.459  end
ss304          2  den=0.159  end
'Top Fitting Zone (no basket)
inconel        3  den=0.212  end
ss304          3  den=1.052  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   4  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 5 0.89 end
carbonsteel  5  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    6  0.896  end
al             6  0.104   end
end comp
idr=1 ity=1 izm=8 isn=8 mhw=0 frd=87.31  end
182.88  200.53 209.17 220.72 247.39 258.92 292.8 293.76  end
1       2      3      0      4      5      0     4      end
xend
' *******  sfa is not normalized  *******
tim=3000  nst=4000   nit=150 nmt=8000 sfa=1.05e+10
'  fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=8 isd=4   end
soe   1.85e-2  2.099e-1 2.318e-1  1.309e-1
  1.774e-1  1.936e-1  3.789e-2  20z  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  293.76  end
bub  0.0 76.20 106.68 137.16 154.31 165.74 180.02 182.88 end
buf  1.6  1.595 1.48  1.09   0.55   0.25   0.04   0.002  end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  258.82  293.76  393.76  493.76 end
sdr  0. 100.  0. 102.  0. 102.  0. 102. end
sds  10 1  10 1  10 1  10 1 end
gend
TN-32, axial calculation, neutron, active fuel zone
  0  0  1  20
rcc   1  0.  0.  -182.88  0.  0.   365.76    87.31
rcc   2  0.  0.  -200.53  0.  0.   401.06    87.31
rcc   3  0.  0.  -209.17  0.  0.   418.34    87.31
rcc   4  0.  0.  -220.72  0.  0.   441.44    87.31
rcc   5  0.  0.  -235.96  0.  0.   471.92   111.44
rcc   6  0.  0.  -247.39  0.  0.   494.78   100.97
rcc   7  0.  0.  -258.82  0.  0.   517.64    89.34
rcc   8  0.  0.  -292.80  0.  0.   585.60   101.92
rcc   9  0.  0.  -293.76  0.  0.   587.52   102.87
rcc  10  0.  0.  -163.57  0.  0.   327.14   122.87
rcc  11  0.  0.  -163.57  0.  0.   327.14   124.14
rcc  12  0.  0.  -393.76  0.  0.   787.52   224.14
rcc  13  0.  0.  -493.76  0.  0.   987.52   324.14
rcc  14  0.  0.  -593.76  0.  0.  1187.52   424.14
rcc  15  0.  0. -2293.76  0.  0.  4587.52  2124.14
rcc  16  0.  0. -2393.76  0.  0.  4787.52  2224.14
rcc  17  0.  0.  -202.3   0.  0.   404.6    122.87
```

```
rcc  18  0.  0.  -204.21  0.  0.   408.21   124.14
rpp  19  120.60   124.14  -30.48  30.48  -204.21  204.21
rpp  20  -124.14 -120.60  -30.48  30.48  -204.21  204.21
rpp  21  118.69   120.60  -30.48  30.48  -204.21  204.21
rpp  22  -120.60 -118.69  -30.48  30.48  -204.21  204.21
rcc  23  -131.47   0.  204.21   262.94  0.  0.   11.01
rcc  24  120.04    0.  204.21   11.43   0.  0.   5.08
rcc  25  -131.47   0.  204.21   11.43   0.  0.   5.08
  end
 ful     1
 pln     2   -1
 tpf     3   -2
 vd1     4   -3
 shd     5   -4
 lid     6   -5
 ppy     7   -6
 res    10   -5
 osh    11  -10    -5
 tv1    24
 tv2    25
 tru    23  -5   -24  -25
 bx1    19   -23
 bx2    20   -23
 st1    21   -23
 st2    22   -23
 rs1    17   -19  -21   -20  -22  -10  -5
 st3    18   -17  -19   -21  -20  -22  -11   -5
 vd2     8   -7    -6    -5
 cov     9   -8    -5
 de2    12  -11   -18   -17   -19   -20  -23  -24 -25  -9
 de3    13  -12
 de4    14  -13
 inv    15  -14
 exv    16  -15
   end
 20R1 2 1 2 1 1
 29R0
  1    2    3    1000   4    4    5    6  4  1000 1000 4
  1000 1000 4  4  6  4    1000 4   1000 1000 1000 1000 0
  0
end
```

5.5.2.4 Sample Input file for Active Fuel Region, Normal Conditions, Neutron Gamma Dose, Bottom Half Model, Radial, Fuel Only

```
=sas4
□
NRB-F-AF-N, TN-32  Normal-Rad-Bottom-Fuel Only-Active Fuel-Neutron
□
27n-18couple infhommedium
□
'Fuel-Basket Zone
uo2           1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
zircalloy     1  den=0.376  end
inconel       1  den=0.022  end
```

```
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Bottom-Basket Zone
aluminum       2  den=0.306  end
ss304          2  den=1.409  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   3  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 4 0.89 end
carbonsteel  4  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    5  0.896  end
al             5  0.104   end
end comp
idr=0 ity=1 izm=4 isn=8 mhw=0 frd=87.31  end
87.31  111.44   122.87  124.14    end
1      3        5        3      end
xend
tim=3000  nst=4000   nit=150 nmt=8000  sfa=1.05e10
' fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=11   isd=4  end
soe   1.85e-2  2.099e-1 2.318e-1  1.309e-1
  1.774e-1  1.936e-1  3.789e-2  20z  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  219.97  end
bub  0.0  11.43  34.29  102.87  125.73  142.88  154.31  165.74
 174.31  180.02  182.88  end
buf  1.60  1.601  1.63   1.68   1.43    1.09    0.77    0.36
 0.15    0.064   0.002 end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  111.44  124.14  224.14  324.14 end
sdr  189. 219.  0. 188.  0. 219.  0. 219. end
sds  3 12  10 0  10 0  10 0 end
gend
TN-32, radial calculation, neutron, active fuel zone
  0  0  1  20
rcc   1  0.   0.   -182.88  0.   0.    365.76    87.31
rcc   2  0.   0.   -193.93  0.   0.    387.86    87.31
rcc   3  0.   0.   -219.97  0.   0.    439.94   111.44
rcc   4  0.   0.   -160.28  0.   0.    320.56   122.87
rcc   5  0.   0.   -160.28  0.   0.    320.56   124.14
rcc   6  0.   0.   -319.97  0.   0.    787.52   224.14
rcc   7  0.   0.   -419.97  0.   0.    987.52   324.14
rcc   8  0.   0.   -519.97  0.   0.   1187.52   424.14
rcc   9  0.   0. -2219.97  0.   0.   4587.52  2124.14
rcc  10  0.   0. -2319.97  0.   0.   4787.52  2224.14
rcc  11  0.   0.   -186.32  0.   0.    372.64   122.87
rcc  12  0.   0.   -188.22  0.   0.    376.44   124.14
rpp  13  120.60    124.14  -30.48  30.48  -188.22  188.22
rpp  14  -124.14 -120.60  -30.48  30.48  -188.22  188.22
rpp  15  118.69    120.60  -30.48  30.48  -188.22  188.22
rpp  16  -120.60 -118.69  -30.48  30.48  -188.22  188.22
rcc  17  -131.47    0.  200.92   262.94  0.   0.    11.01
rcc  18  120.04     0.  200.92   11.43   0.   0.    5.08
```

```
rcc  19  -131.47   0.  200.92   11.43   0.  0.   5.08
 end
 ful      1
 btf      2   -1
 shd      3   -2
 res      4   -3
 osh      5   -4    -3
 tv1     18
 tv2     19
 tru     17   -3   -18  -19
 bx1     13   -17
 bx2     14   -17
 st1     15   -17
 st2     16   -17
 rs1     11   -13  -15  -14  -16  -5  -3
 st3     12   -11  -13   -15  -14  -16  -5   -3
 de2      6  -5   -12   -11   -13  -15  -14   -16  -17  -3
 de3      7  -6
 de4      8  -7
 inv      9  -8
 exv     10  -9
   end
 14R1 2 1 2 1 1
 23R0
  1    2    3    4    3   1000  1000  3  1000 1000  3  3
  4    3   1000 1000 1000 1000 0  1000 1000 1000  0
  0
end
```

5.5.2.5 <u>Sample Input file for Active Fuel Region, Normal Conditions, Capture Gamma Dose, Top Half Model, Axial, Fuel Only</u>

```
=sas4
□
NAT-F-AF-C, TN-32  Normal-Axial-Top-Fuel Only-Active Fuel-Cap Gamma
□
27n-18couple infhommedium
□
'Fuel-Basket Zone
uo2           1  den=1.912  1.0 293.   92235 3.5   92238 96.5 end
zircalloy     1  den=0.376  end
inconel       1  den=0.022  end
aluminum      1  den=0.306  end
ss304         1  den=0.316  end
'Plenum  Zone (no basket)
zircalloy     2  den=0.459  end
ss304         2  den=0.159  end
'Top Fitting Zone (no basket)
inconel       3  den=0.212  end
ss304         3  den=1.052  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel    4  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 5 0.89 end
carbonsteel  5  0.11  end
'Resin/Aluminum
```

```
arbmtnres     1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93   6  0.896  end
al            6  0.104   end
end comp
idr=1 ity=2 izm=8 isn=8 mhw=0 frd=87.31  end
182.88  200.53 209.17 220.72 247.39 258.92 292.8 293.76  end
1      2      3      0      4      5      0     4       end
xend
' ******* sfa not normalized *********
tim=3000  nst=4000   nit=150 nmt=8000 sfa=1.05e10
'  fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=8  isd=4 end
soe   1.85e-02  2.099e-01 2.318e-01  1.309e-01
1.774e-01  1.936e-01  3.789e-02  38z  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  293.76   end
bub  0.0 76.20 106.68 137.16 154.31 165.74 180.02 182.88 end
buf  1.6  1.595 1.48  1.09   0.55   0.25   0.04   0.002  end
'-----------------------------------------------
'   surface detectors
'-----------------------------------------------
sdl  258.82  293.76  393.76  493.76 end
sdr  0. 100.  0. 102.  0. 102.  0. 102. end
sds  10 1  10 1  10 1  10 1 end
gend
TN-32, axial calculation
  0  0  1  20
rcc   1  0.   0.   -182.88  0.   0.    365.76    87.31
rcc   2  0.   0.   -200.53  0.   0.    401.06    87.31
rcc   3  0.   0.   -209.17  0.   0.    418.34    87.31
rcc   4  0.   0.   -220.72  0.   0.    441.44    87.31
rcc   5  0.   0.   -235.96  0.   0.    471.92   111.44
rcc   6  0.   0.   -247.39  0.   0.    494.78   100.97
rcc   7  0.   0.   -258.82  0.   0.    517.64    89.34
rcc   8  0.   0.   -292.80  0.   0.    585.60   101.92
rcc   9  0.   0.   -293.76  0.   0.    587.52   102.87
rcc  10  0.   0.   -163.57  0.   0.    327.14   122.87
rcc  11  0.   0.   -163.57  0.   0.    327.14   124.14
rcc  12  0.   0.   -393.76  0.   0.    787.52   224.14
rcc  13  0.   0.   -493.76  0.   0.    987.52   324.14
rcc  14  0.   0.   -593.76  0.   0.   1187.52   424.14
rcc  15  0.   0. -2293.76  0.   0.   4587.52  2124.14
rcc  16  0.   0. -2393.76  0.   0.   4787.52  2224.14
rcc  17  0.   0.   -202.3   0.   0.    404.6    122.87
rcc  18  0.   0.   -204.21  0.   0.    408.21   124.14
rpp  19  120.60   124.14  -30.48  30.48  -204.21  204.21
rpp  20  -124.14 -120.60  -30.48  30.48  -204.21  204.21
rpp  21  118.69   120.60  -30.48  30.48  -204.21  204.21
rpp  22  -120.60 -118.69  -30.48  30.48  -204.21  204.21
rcc  23  -131.47   0.  204.21   262.94  0.   0.    11.01
rcc  24  120.04    0.  204.21   11.43   0.   0.    5.08
rcc  25  -131.47   0.  204.21   11.43   0.   0.    5.08
  end
 ful      1
 pln      2   -1
 tpf      3   -2
 vd1      4   -3
```

```
shd      5   -4
lid      6   -5
ppy      7   -6
res     10   -5
osh     11  -10    -5
tv1     24
tv2     25
tru     23  -5   -24   -25
bx1     19   -23
bx2     20   -23
st1     21   -23
st2     22   -23
rs1     17   -19  -21   -20  -22  -10  -5
st3     18   -17  -19   -21  -20  -22  -11   -5
vd2      8   -7     -6     -5
cov      9   -8     -5
de2     12  -11    -18    -17    -19    -20   -23   -24  -25   -9
de3     13  -12
de4     14  -13
inv     15  -14
exv     16  -15
  end
20R1 2 1 2 1 1
29R0
 1    2    3    1000   4    4    5    6   4   1000 1000 4   1000 1000 4   4
 6   4    1000 4   1000 1000 1000 1000 0   1000 1000 1000 1000
 0
end
```

5.5.2.6 Sample Input file for Active Fuel Region, Normal Conditions, Capture Gamma Dose, Bottom Half Model, Radial, Fuel Only

```
=sas4
□
NRB-F-AF-C, TN-32  Normal-Rad-Bottom-Fuel Only-Active Fuel-Cap Gamma
27n-18couple infhommedium
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.   92235 3.5  92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Bottom-Basket Zone
aluminum       2  den=0.306  end
ss304          2  den=1.409  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel    3  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 4 0.89 end
carbonsteel   4  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    5  0.896  end
al             5  0.104   end
end comp
```

```
idr=0 ity=2 izm=4 isn=8 mhw=0 frd=87.31  end
87.31  111.44   122.87  124.14   end
1      3       5       3     end
xend
tim=3000  nst=4000   nit=150 nmt=8000  sfa=1.05e10
'fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=11  isd=4 end
soe   1.85e-2  2.099e-1 2.318e-1  1.309e-1
  1.774e-1  1.936e-1  3.789e-2  38z  end
sxy 1  -87.31  87.31  -87.31  87.31  0.0  182.88  87.32 182.88
       124.14  219.97  end
bub  0.0  11.43  34.29  102.87  125.73  142.88  154.31  165.74
 174.31  180.02  182.88  end
buf  1.60  1.601  1.63   1.68   1.43    1.09    0.77    0.36
 0.15    0.064   0.002 end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  111.44  124.14  224.14  324.14 end
sdr  189. 219.  0. 188.  0. 219.  0. 219. end
sds  3 12  10 0  10 0  10 0 end
gend
TN-32, radial calculation, neutron, active fuel zone
  0  0  1  20
rcc   1  0.  0.  -182.88  0.  0.   365.76    87.31
rcc   2  0.  0.  -193.93  0.  0.   387.86    87.31
rcc   3  0.  0.  -219.97  0.  0.   439.94   111.44
rcc   4  0.  0.  -160.28  0.  0.   320.56   122.87
rcc   5  0.  0.  -160.28  0.  0.   320.56   124.14
rcc   6  0.  0.  -319.97  0.  0.   787.52   224.14
rcc   7  0.  0.  -419.97  0.  0.   987.52   324.14
rcc   8  0.  0.  -519.97  0.  0.  1187.52   424.14
rcc   9  0.  0. -2219.97  0.  0.  4587.52  2124.14
rcc  10  0.  0. -2319.97  0.  0.  4787.52  2224.14
rcc  11  0.  0.  -186.32  0.  0.   372.64   122.87
rcc  12  0.  0.  -188.22  0.  0.   376.44   124.14
rpp  13  120.60   124.14  -30.48  30.48  -188.22  188.22
rpp  14  -124.14 -120.60  -30.48  30.48  -188.22  188.22
rpp  15  118.69   120.60  -30.48  30.48  -188.22  188.22
rpp  16  -120.60 -118.69  -30.48  30.48  -188.22  188.22
rcc  17  -131.47   0.  200.92   262.94  0.  0.   11.01
rcc  18  120.04    0.  200.92   11.43   0.  0.   5.08
rcc  19  -131.47   0.  200.92   11.43   0.  0.   5.08
  end
 ful     1
 btf     2   -1
 shd     3   -2
 res     4   -3
 osh     5   -4    -3
 tv1    18
 tv2    19
 tru    17   -3   -18  -19
 bx1    13   -17
 bx2    14   -17
 st1    15   -17
 st2    16   -17
 rs1    11   -13  -15  -14  -16  -5  -3
```

```
 st3    12   -11  -13   -15  -14  -16  -5   -3
 de2     6  -5   -12   -11   -13  -15  -14   -16  -17  -3
 de3     7  -6
 de4     8  -7
 inv     9  -8
 exv    10  -9
   end
 14R1 2 1 2 1 1
 23R0
  1    2    3    4    3   1000  1000  3  1000 1000  3  3
  4    3   1000 1000 1000 1000 0  1000 1000 1000   0
  0
end
```

5.5.2.7 Sample Input file for Plenum Region, Normal Conditions, Gamma Dose, Top Half Model, Axial, Fuel Only

```
=sas4         parm=mo
□
NAT-F-PL-G, TN-32  Normal-Axial-Top-Fuel Only-Plenum-Primary Gamma
27n-18couple infhommedium
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.   92235 3.5   92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Plenum  Zone (no basket)
zircalloy      2  den=0.459  end
ss304          2  den=0.159  end
'Top Fitting Zone (no basket)
inconel        3  den=0.212  end
ss304          3  den=1.052  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   4  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 5 0.89 end
carbonsteel  5  0.11  end
'Resin/Aluminum
arbmtnres     1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    6  0.896  end
al             6  0.104   end
end comp
idr=1 ity=2 izm=8 isn=8 mhw=2 frd=87.31  end
182.88  200.53 209.17 220.72 247.39 258.92 292.8 293.76  end
1       2      3      0      4      5      0     4      end
xend
tim=3000  nst=4000   nit=150 nmt=8000 sfa=4.95E+13
' fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=0   iso=2  isd=4   end
soe  35z   2.202e-01  7.798e-01  8z  end
sxy 2  -87.31  87.31  -87.31  87.31  182.88  200.53
   87.32 182.88   124.14  293.76  end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
```

```
sdl  258.82  293.76  393.76  493.76 end
sdr  0. 100.  0. 102.  0. 102.  0. 102. end
sds  10 1  10 1  10 1  10 1 end
gend
TN-32, axial calculation, primary gamma
  0  0  1  20
rcc   1  0.  0.  -182.88  0.  0.   365.76   87.31
rcc   2  0.  0.  -200.53  0.  0.   401.06   87.31
rcc   3  0.  0.  -209.17  0.  0.   418.34   87.31
rcc   4  0.  0.  -220.72  0.  0.   441.44   87.31
rcc   5  0.  0.  -235.96  0.  0.   471.92  111.44
rcc   6  0.  0.  -247.39  0.  0.   494.78  100.97
rcc   7  0.  0.  -258.82  0.  0.   517.64   89.34
rcc   8  0.  0.  -292.80  0.  0.   585.60  101.92
rcc   9  0.  0.  -293.76  0.  0.   587.52  102.87
rcc  10  0.  0.  -163.57  0.  0.   327.14  122.87
rcc  11  0.  0.  -163.57  0.  0.   327.14  124.14
rcc  12  0.  0.  -393.76  0.  0.   787.52  224.14
rcc  13  0.  0.  -493.76  0.  0.   987.52  324.14
rcc  14  0.  0.  -593.76  0.  0.  1187.52  424.14
rcc  15  0.  0. -2293.76  0.  0.  4587.52 2124.14
rcc  16  0.  0. -2393.76  0.  0.  4787.52 2224.14
rcc  17  0.  0.  -202.3   0.  0.   404.6   122.87
rcc  18  0.  0.  -204.21  0.  0.   408.21  124.14
rpp  19  120.60   124.14  -30.48  30.48  -204.21  204.21
rpp  20  -124.14 -120.60  -30.48  30.48  -204.21  204.21
rpp  21  118.69   120.60  -30.48  30.48  -204.21  204.21
rpp  22  -120.60 -118.69  -30.48  30.48  -204.21  204.21
rcc  23  -131.47   0.  204.21   262.94  0.  0.   11.01
rcc  24  120.04    0.  204.21   11.43   0.  0.   5.08
rcc  25  -131.47   0.  204.21   11.43   0.  0.   5.08
  end
 ful     1
 pln     2   -1
 tpf     3   -2
 vdl     4   -3
 shd     5   -4
 lid     6   -5
 ppy     7   -6
 res    10   -5
 osh    11  -10    -5
 tv1    24
 tv2    25
 tru    23  -5   -24  -25
 bx1    19   -23
 bx2    20   -23
 st1    21   -23
 st2    22   -23
 rs1    17   -19  -21   -20  -22  -10  -5
 st3    18   -17  -19   -21  -20  -22  -11   -5
 vd2     8   -7    -6    -5
 cov     9   -8    -5
 de2    12  -11   -18   -17   -19   -20  -23  -24 -25  -9
 de3    13  -12
 de4    14  -13
 inv    15  -14
 exv    16  -15
```

```
  end
·20R1 2 1 2 1 1
 29R0
  1    2    3    1000    4    4    5    6   4   1000 1000 4   1000 1000 4   4
  6  4    1000 4   1000 1000 1000 1000 0   1000 1000 1000   0
  0
end
```

5.5.2.8 Sample Input file for Top Fitting Region, Normal Conditions, Gamma Dose, Top Half Model, Radial, Fuel Only

```
=sas4
□
NRT-F-EF-G, TN-32  Normal-Radial-Top-Fuel Only-Top Fit-Primary Gamma
27n-18couple infhommedium
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Plenum-Basket Zone
zircalloy      2  den=0.459  end
aluminum       2  den=0.306  end
ss304          2  den=0.458  end
'Top Fitting-Basket Zone
inconel        3  den=0.212  end
aluminum       3  den=0.306  end
ss304          3  den=1.351  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   4  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 5 0.89 end
carbonsteel  5  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93    6  0.896  end
al             6  0.104   end
end comp
idr=0 ity=2 izm=4 isn=8 mhw=3 frd=87.31  end
87.31  111.44  12.87   124.14 end
1      4     6     4    end
xend
tim=3000  nst=4000   nit=150 nmt=8000  sfa=1.98E+14
' fr1=1.0   fr2=0.7  fr3=0.7  fr4=0.7
igo=4  isp=0  ipf=0   iso=3  isd=5  end
soe  35z   2.202e-01  7.798e-01  8z  end
sxy 3  -87.31  87.31  -87.31  87.31  200.53 209.17
   87.32 182.88   124.14  293.76  end
'---------------------------------------------
'   surface detectors
'---------------------------------------------
sdl  111.44  122.87  124.14  224.14  324.14 end
sdr  205. 236.  164. 193.  0. 164.  0. 235.  0. 235. end
sds  3 12  1 24  10 0  10 0  10 0 end
```

```
gend
TN-32, radial calculation, primary gamma, active fuel zone
  0  0  1  20
rcc   1  0.   0.  -182.88  0.   0.   365.76    87.31
rcc   2  0.   0.  -200.53  0.   0.   401.06    87.31
rcc   3  0.   0.  -209.17  0.   0.   418.34    87.31
rcc   4  0.   0.  -220.72  0.   0.   441.44    87.31
rcc   5  0.   0.  -235.96  0.   0.   471.92   111.44
rcc   6  0.   0.  -247.39  0.   0.   494.78   100.97
rcc   7  0.   0.  -258.82  0.   0.   517.64    89.34
rcc   8  0.   0.  -292.80  0.   0.   585.60   101.92
rcc   9  0.   0.  -293.76  0.   0.   587.52   102.87
rcc  10  0.   0.  -163.57  0.   0.   327.14   122.87
rcc  11  0.   0.  -163.57  0.   0.   327.14   124.14
rcc  12  0.   0.  -393.76  0.   0.   787.52   224.14
rcc  13  0.   0.  -493.76  0.   0.   987.52   324.14
rcc  14  0.   0.  -593.76  0.   0.  1187.52   424.14
rcc  15  0.   0. -2293.76  0.   0.  4587.52  2124.14
rcc  16  0.   0. -2393.76  0.   0.  4787.52  2224.14
rcc  17  0.   0.  -202.3   0.   0.   404.6    122.87
rcc  18  0.   0.  -204.21  0.   0.   408.21   124.14
rpp  19  120.60    124.14  -30.48  30.48  -204.21  204.21
rpp  20  -124.14 -120.60  -30.48  30.48  -204.21  204.21
rpp  21  118.69    120.60  -30.48  30.48  -204.21  204.21
rpp  22  -120.60 -118.69  -30.48  30.48  -204.21  204.21
rcc  23  -131.47    0.  204.21   262.94  0.  0.    11.01
rcc  24  120.04     0.  204.21    11.43  0.  0.     5.08
rcc  25  -131.47    0.  204.21    11.43  0.  0.     5.08
  end
 ful      1
 pln      2   -1
 tpf      3   -2
 vd1      4   -3
 shd      5   -4
 lid      6   -5
 ppy      7   -6
 res     10   -5
 osh     11  -10    -5
 tv1     24
 tv2     25
 tru     23  -5    -24  -25
 bx1     19   -23
 bx2     20   -23
 st1     21   -23
 st2     22   -23
 rs1     17   -19  -21   -20  -22  -10  -5
 st3     18   -17  -19   -21  -20  -22  -11    -5
 vd2      8   -7    -6    -5
 cov      9   -8    -5
 de2     12  -11    -18   -17   -19   -20  -23  -24 -25   -9
 de3     13  -12
 de4     14  -13
 inv     15  -14
 exv     16  -15
   end
 20R1 2 1 2 1 1
 25R0
```

```
 1    2    3    1000   4    4    5    6  4  1000 1000 4  1000 1000 4  4
 6  4    1000 4   1000 1000 1000 1000 0
 0
end
```

5.5.2.9 Sample Input file for Bottom Fitting Region, Normal Conditions, Gamma Dose, Bottom Half Model, Axial, Fuel Only

```
=sas4         parm=mo
□
NAB-F-EF-G, TN-32  Normal-Axial-Bottom-Fuel Only-Bottom Fitting-Pri Gamma
27n-18couple infhommedium
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.   92235 3.5  92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
aluminum       1  den=0.306  end
ss304          1  den=0.316  end
'Bottom - no basket
ss304          2  den=1.110  end
'Cask Body, Outer Shell, Polydisc shells
carbonsteel   3  1.0   end
'Polypropylene/steel disk
arbmpropylene 0.90  2 1 0 0  1001 14.3 6012  85.7 4 0.89 end
carbonsteel  4  0.11  end
'Resin/Aluminum
arbmtnres      1.58  5  1  0  0  1001  5.05  5000 1.05  6012
35.13  8016  41.73  13027  14.93   5  0.896  end
al             5  0.104   end
end comp
idr=1 ity=2 izm=3 isn=8 mhw=2 frd=87.31  end
182.88  193.93   219.97     end
1       2        3        end
xend
tim=3000  nst=4000   nit=150 nmt=8000 sfa=1.49E14
' fr1=1.0   fr2=1.0  fr3=1.0  fr4=1.0
igo=4  isp=0  ipf=0 iso=2  isd=3  end
soe  35z   2.202e-01  7.798e-01  8z  end
sxy 2  -87.31  87.31  -87.31  87.31  182.88  193.93
   87.32 182.88  124.14  219.97  end
'-------------------------------------------
'   surface detectors
'-------------------------------------------
sdl  219.97  319.97  419.97 end
sdr  0. 115. 0. 115.  0. 115. end
sds  10 1  10 1  10 1  end
gend
TN-32, axial calculation, primary gamma
  0  0  1  20
rcc   1  0.   0.  -182.88  0.  0.   365.76    87.31
rcc   2  0.   0.  -193.93  0.  0.   387.86    87.31
rcc   3  0.   0.  -219.97  0.  0.   439.94   111.44
rcc   4  0.   0.  -160.28  0.  0.   320.56   122.87
rcc   5  0.   0.  -160.28  0.  0.   320.56   124.14
rcc   6  0.   0.  -319.97  0.  0.   787.52   224.14
```

```
rcc   7  0.   0.  -419.97  0.   0.    987.52    324.14
rcc   8  0.   0.  -519.97  0.   0.   1187.52    424.14
rcc   9  0.   0. -2219.97  0.   0.   4587.52   2124.14
rcc  10  0.   0. -2319.97  0.   0.   4787.52   2224.14
rcc  11  0.   0.  -186.32  0.   0.    372.64    122.87
rcc  12  0.   0.  -188.22  0.   0.    376.44    124.14
rpp  13  120.60    124.14  -30.48  30.48  -188.22  188.22
rpp  14  -124.14 -120.60  -30.48  30.48  -188.22  188.22
rpp  15  118.69    120.60  -30.48  30.48  -188.22  188.22
rpp  16  -120.60 -118.69  -30.48  30.48  -188.22  188.22
rcc  17  -131.47    0.  200.92   262.94  0.   0.    11.01
rcc  18  120.04     0.  200.92    11.43  0.   0.     5.08
rcc  19  -131.47    0.  200.92    11.43  0.   0.     5.08
  end
 ful      1
 btf      2   -1
 shd      3   -2
 res      4   -3
 osh      5   -4    -3
 tv1     18
 tv2     19
 tru     17   -3   -18   -19
 bx1     13   -17
 bx2     14   -17
 st1     15   -17
 st2     16   -17
 rs1     11   -13   -15   -14   -16   -5   -3
 st3     12   -11   -13    -15   -14   -16   -5    -3
 de2      6  -5    -12    -11    -13   -15   -14    -16   -17   -3
 de3      7  -6
 de4      8  -7
 inv      9  -8
 exv     10  -9
   end
 14R1 2 1 2 1 1
 23R0
  1    2    3    4    3    1000   1000   3   1000 1000   3   3
  4    3   1000 1000 1000 1000 0   1000 1000 1000 1000
  0
end
```

5.5.3 Sample MCNP Input File

```
TransNuclear TN-32 cask: Far-Field model; gammas from fittings/plenum.
c    Volumetric F4 detectors used. Geometry splitting/routlette added.
c    NOTE: Dose are from "direct" + "skyshine" radiation. No Berm.
c ***********************  BLOCK 1: CELL CARDS ************************
c GEOMETRY (r-z)
c                                   (j.k.shultis 12/28/98 mod by MM 1/9/99))
c  ^z-axis
c  |                            AIR
c  |
c  |   cask                        +=+
c  |---------+                     | | berm
c  .-------+ |                     | |
c  |       | |-                    | |
```

```
c  . FUEL  | ||                       | |
c  |       | ||                       | |
c  o  ---- | || ----> r-axis          | |
c  |       | ||                       | |
c  .       | || ------------------| |---|-|---|-|---|-|---|-|---|-|-
c  |       | |-                   | |   | |   | |   | |   | |   | |
c  .-------+ |                    | |   | |   | |   | |   | |   | |
c  |---------+--------------------|-|---|-|---|-|---|-|---|-|---|-|-
c  |                              |       \
c  .                             20m       \ det vols
c  |      CONCRETE
c  .                                           SOIL
c  |
c
c ****** Cask cells
c decomposed case bottom into 10 sublayers
 110 9   -7.8212    1 -110 -209       imp:n,p=1024 $ Fe cask bot-sublayer 1
 111 9   -7.8212  110 -109  -30       imp:n,p=512  $ Fe cask bot-sublayer 2
 112 9   -7.8212  109 -108 -208       imp:n,p=256  $ Fe cask bot-sublayer 3
 113 9   -7.8212  108 -107 -207       imp:n,p=128  $ Fe cask bot-sublayer 4
 114 9   -7.8212  107 -106 -206       imp:n,p=64   $ Fe cask bot-sublayer 5
 115 9   -7.8212  106 -105 -205       imp:n,p=32   $ Fe cask bot-sublayer 6
 116 9   -7.8212  105 -104 -204       imp:n,p=16   $ Fe cask bot-sublayer 7
 117 9   -7.8212  104 -103 -203       imp:n,p=8    $ Fe cask bot-sublayer 8
 118 9   -7.8212  103 -102 -202       imp:n,p=4    $ Fe cask bot-sublayer 9
 119 9   -7.8212  102 -2   -201       imp:n,p=2    $ Fe cask bot-sublayer 10
c decompose cask side into 10 sublayers
 201 9   -7.8212  102 -122 201 -202   imp:n,p=2    $ Fe cask side-sublayer 1
 202 9   -7.8212  103 -123 202 -203   imp:n,p=4    $ Fe cask side-sublayer 2
 203 9   -7.8212  104 -124 203 -204   imp:n,p=8    $ Fe cask side-sublayer 3
 204 9   -7.8212  105 -125 204 -205   imp:n,p=16   $ Fe cask side-sublayer 4
 205 9   -7.8212  106  -13 205 -206   imp:n,p=32   $ Fe cask side-sublayer 5
 206 9   -7.8212  107  -13 206 -207   imp:n,p=64   $ Fe cask side-sublayer 6
 207 9   -7.8212  108  -13 207 -208   imp:n,p=128  $ Fe cask side-sublayer 7
 208 9   -7.8212  109  -13 208  -30   imp:n,p=256  $ Fe cask side-sublayer 8
 209 9   -7.8212  110  -13  30 -209   imp:n,p=512  $ Fe cask side-sublayer 9
 210 9   -7.8212  1    -13 209  -21   imp:n,p=1024 $ Fe cask side-sublayer 10
c decompose cask lid into 10 sublayers
 301 9   -7.8212  12 -122 -201        imp:n,p=4    $ Fe cask lid-sublayer 1
 302 9   -7.8212 122 -123 -202        imp:n,p=8    $ Fe cask lid-sublayer 2
 303 9   -7.8212 123 -124 -203        imp:n,p=16   $ Fe cask lid-sublayer 3
 304 9   -7.8212 124 -125 -204        imp:n,p=32   $ Fe cask lid-sublayer 4
 305 9   -7.8212 -13  125 -205        imp:n,p=64   $ Fe cask lid-sublayer 5
 306 9   -7.8212  13 -126 -208        imp:n,p=128  $ Fe cask lid-sublayer 6
 307 9   -7.8212 126 -127 -208        imp:n,p=256  $ Fe cask lid-sublayer 7
 308 9   -7.8212 127 -128 -208        imp:n,p=512  $ Fe cask lid-sublayer 8
 309 9   -7.8212 128 -129 -208        imp:n,p=1024 $ Fe cask lid-sublayer 9
 310 9   -7.8212 129  -14 -208        imp:n,p=1024 $ Fe cask lid-sublayer 10
c other cask cells
   3  7  -1.715    2 -5 -201          imp:n,p=1    $ bottom basket
   4  6  -1.223    7 -8 -201          imp:n,p=2    $ top plenum basket
   5  5  -1.869    8 -11 -201         imp:n,p=2    $ top fitting
c 6  8  -7.92      26 -27 2 -28       imp:n,p=2    $ ss side basket
c 7  10 -2.702     27 -201 2 -28      imp:n,p=2    $ Al side basket/rails
   8  1  -0.0013   11 -12 -201        imp:n,p=2    $ top void - part1 (air)
c 9  1  -0.0013    28 -12 26 -201 #10 imp:n,p=2    $ top void - part2 (air)
c 10  9  -7.8212   28 -19 24 -201     imp:n,p=2    $ hold down ring
```

```
 13  11 -0.90      14 -15 -25           imp:n,p=1024 $ polyprop top shield
 14  1  -0.0013    15 -16 -25           imp:n,p=1024 $ air under top cover -pt1
 15  1  -0.0013    (14 -16 25 -208):(13 -16 208 -29) imp:n,p=1024 $ air under
top cover -pt2
 16  9  -7.8212    16 -17 -30           imp:n,p=1024 $ top Fe cover - top
 17  9  -7.8212    13 -16 29 -30        imp:n,p=1024 $ top Fe cover - side
 19  9  -7.8212    21 -23 9 -10         imp:n,p=1024 $ top side-shld Fe shell
 20  9  -7.8212    22 -23 4 -9          imp:n,p=1024 $ side side-shld Fe shell
 21  9  -7.8212    21 -23 3 -4          imp:n,p=1024 $ bot side-shld Fe shell
 22  12 -1.687     21 -22 4 -9          imp:n,p=1024 $ side resin/Al shield
 23  1  -0.0013    1 -3 21 -23          imp:n,p=1024 $ air under side shld
 24  1  -0.0013    21 -23 10 -13        imp:n,p=1024 $ air above side shld -
pt1
 25  1  -0.0013    30 -23 13 -17        imp:n,p=1024 $ air above side shld -
pt2
c **** fuel regions
 40 4   -2.932    5  -40 -201          imp:n,p=1  $ FUEL region 1 (bottom)
 41 4   -2.932    40 -41 -201          imp:n,p=1  $ FUEL region 2
 42 4   -2.932    41 -42 -201          imp:n,p=1  $ FUEL region 3
 43 4   -2.932    42 -43 -201          imp:n,p=1  $ FUEL region 4
 44 4   -2.932    43 -44 -201          imp:n,p=1  $ FUEL region 5
 45 4   -2.932    44 -45 -201          imp:n,p=1  $ FUEL region 6
 46 4   -2.932    45 -46 -201          imp:n,p=1  $ FUEL region 7
 47 4   -2.932    46 -47 -201          imp:n,p=1  $ FUEL region 8
 48 4   -2.932    47 -48 -201          imp:n,p=1  $ FUEL region 9
 49 4   -2.932    48 -7  -201          imp:n,p=1  $ FUEL region 10 (top)
c ***** outside cells above/below cask
 140 2  -2.32     150 -1  -23          imp:n,p=1024 $ concrete beneath cask
 145 1  -0.0013   17 -151 -23          imp:n,p=1024 $ air above cask-pt1
c ***** cells for detector volumes and air/soil layers beyond cask
c -- cells before and at 2m detector
   600 2  -2.32     150 -1   23 -60   imp:n,p=1024 $ concrete before detector
   601 1  -0.0013   1  -53   23 -60   imp:n,p=1024 $ air before detector
   602 1  -0.0013   53 -54   23 -60   imp:n,p=1024 $ top air before detector
   603 1  -0.0013   54 -151 23 -60    imp:n,p=1024 $ top-top air before det.
c  610 2  -2.32     150  -1 60 -61    imp:n,p=1024 $ concrete beneath detector
c  611 1  -0.0013   1  -53  60 -61    imp:n,p=1024 $ air for detector
c  612 1  -0.0013   53 -54  60 -61    imp:n,p=1024 $ top air above det.
c  613 1  -0.0013   54 -151 60 -61    imp:n,p=1024 $ top-top air above det.
c -- cells before and at 3m detector
   620 2  -2.32     150 -1   60 -62   imp:n,p=1024 $ concrete before detector
   621 1  -0.0013   1  -53   60 -62   imp:n,p=1024 $ air before detector
   622 1  -0.0013   53 -54   60 -62   imp:n,p=1024 $ top air before detector
   623 1  -0.0013   54 -151  60 -62   imp:n,p=1024 $ top-top air before det.
c  630 2  -2.32     150 -1   62 -63   imp:n,p=1024 $ concrete beneath detector
c  631 1  -0.0013   1  -53   62 -63   imp:n,p=1024 $ air for detector
c  632 1  -0.0013   53 -54   62 -63   imp:n,p=1024 $ top air above det.
c  633 1  -0.0013   54 -151  62 -63   imp:n,p=1024 $ top-top air above det.
c -- cells before and at 5m detector
   640 2  -2.32     150 -1   62 -64   imp:n,p=1536 $ concrete before detector
   641 1  -0.0013   1  -53   62 -64   imp:n,p=1536 $ air before detector
   642 1  -0.0013   53 -54   62 -64   imp:n,p=1536 $ top air before detector
   643 1  -0.0013   54 -151  62 -64   imp:n,p=1536 $ top-top air before det.
c  650 2  -2.32     150 -1   64 -65   imp:n,p=1536 $ concrete beneath detector
c  651 1  -0.0013   1  -53   64 -65   imp:n,p=1536 $ air for detector
c  652 1  -0.0013   53 -54   64 -65   imp:n,p=1536 $ top air above det.
c  653 1  -0.0013   54 -151  64 -65   imp:n,p=1536 $ top-top air above det.
```

```
c -- cells before and at 7m detector
  660 2  -2.32     150 -1   64 -66   imp:n,p=1536 $ concrete before detector
  661 1  -0.0013   1  -53   64 -66   imp:n,p=1536 $ air before detector
  662 1  -0.0013   53 -54   64 -66   imp:n,p=1536 $ top air before detector
  663 1  -0.0013   54 -151  64 -66   imp:n,p=1536 $ top-top air before det.
c 670 2  -2.32     150 -1   66 -67   imp:n,p=1536 $ concrete beneath detector
c 671 1  -0.0013   1  -53   66 -67   imp:n,p=1536 $ air for detector
c 672 1  -0.0013   53 -54   66 -67   imp:n,p=1536 $ top air above det.
c 673 1  -0.0013   54 -151  66 -67   imp:n,p=1536 $ top-top air above det.
c -- cells before and at 10m detector
  680 2  -2.32     150 -1   66 -68   imp:n,p=2176 $ concrete before detector
  681 1  -0.0013   1  -53   66 -68   imp:n,p=2176 $ air before detector
  682 1  -0.0013   53 -54   66 -68   imp:n,p=2176 $ top air before detector
  683 1  -0.0013   54 -151  66 -68   imp:n,p=2176 $ top-top air before det.
c 690 2  -2.32     150 -1   68 -69   imp:n,p=2176 $ concrete beneath detector
c 691 1  -0.0013   1  -53   68 -69   imp:n,p=2176 $ air for detector
c 692 1  -0.0013   53 -54   68 -69   imp:n,p=2176 $ top air above det.
c 693 1  -0.0013   54 -151  68 -69   imp:n,p=2176 $ top-top air above det.
c -- cells before and at 20m detector
  700 3  -1.625    150 -1   68 -70   imp:n,p=3200 $ soil before detector
  701 1  -0.0013   1  -53   68 -70   imp:n,p=3200 $ air before detector
  702 1  -0.0013   53 -54   68 -70   imp:n,p=3200 $ top air before detector
  703 1  -0.0013   54 -151  68 -70   imp:n,p=3200 $ top-top air before det.
c 710 3  -1.625    150 -1   70 -71   imp:n,p=3200 $ soil beneath detector
c 711 1  -0.0013   1  -53   70 -71   imp:n,p=3200 $ air for detector
c 712 1  -0.0013   53 -54   70 -71   imp:n,p=3200 $ top air above det.
c 713 1  -0.0013   54 -151  70 -71   imp:n,p=3200 $ top-top air above det.
c -- cells before BERM centered at 20m from cask center
  720 3  -1.625    150 -1   70 -72   imp:n,p=3200 $ soil before berm
  721 1  -0.0013   1  -53   70 -72   imp:n,p=3200 $ air before berm
  722 1  -0.0013   53 -54   70 -72   imp:n,p=3200 $ top air before berm
  723 1  -0.0013   54 -151  70 -72   imp:n,p=3200 $ top-top air before be.
  730 3  -1.625    150  -1  72 -73   imp:n,p=3200 $ soil beneath no BERM
  731 1  -0.0013   1  -53   72 -73   imp:n,p=3200 $ bottom half of no BERM
  732 1  -0.0013   53 -54   72 -73   imp:n,p=3200 $ top half of no BERM
  733 1  -0.0013   54 -151  72 -73   imp:n,p=4800 $ top-top air above no BERM
c -- cells before and at 50m detector
  740 3  -1.625    150 -1   73 -74   imp:n,p=4800 $ soil before detector
  741 1  -0.0013   1  -53   73 -74   imp:n,p=4800 $ air before detector
  742 1  -0.0013   53 -54   73 -74   imp:n,p=4800 $ top air before detector
  743 1  -0.0013   54 -151  73 -74   imp:n,p=4800 $ top-top air before det.
  750 3  -1.625    150 -1   74 -75   imp:n,p=4800 $ soil beneath detector
  751 1  -0.0013   1  -53   74 -75   imp:n,p=4800 $ air for detector
  752 1  -0.0013   53 -54   74 -75   imp:n,p=4800 $ top air above det.
  753 1  -0.0013   54 -151  74 -75   imp:n,p=4800 $ top-top air above det.
c -- cells before and at 70m detector
  760 3  -1.625    150 -1   75 -76   imp:n,p=5440 $ soil before detector
  761 1  -0.0013   1  -53   75 -76   imp:n,p=5440 $ air before detector
  762 1  -0.0013   53 -54   75 -76   imp:n,p=5440 $ top air before detector
  763 1  -0.0013   54 -151  75 -76   imp:n,p=5440 $ top-top air before det.
  770 3  -1.625    150 -1   76 -77   imp:n,p=5440 $ soil beneath detector
  771 1  -0.0013   1  -53   76 -77   imp:n,p=5440 $ air for detector
  772 1  -0.0013   53 -54   76 -77   imp:n,p=5440 $ top air above det.
  773 1  -0.0013   54 -151  76 -77   imp:n,p=5440 $ top-top air above det.
c -- cells before and at 100m detector
  780 3  -1.625    150 -1   77 -78   imp:n,p=8000 $ intermed soil cell
  781 1  -0.0013   1  -53   77 -78   imp:n,p=8000 $ intermed air cell
```

```
  782 1  -0.0013  53 -54  77 -78   imp:n,p=8000 $ intermed top air cell
  783 1  -0.0013  54 -151 77 -78   imp:n,p=8000 $ intermed top-top air cell
  790 3  -1.625   150 -1  78 -79   imp:n,p=8000 $ soil before detector
  791 1  -0.0013  1  -53  78 -79   imp:n,p=8000 $ air before detector
  792 1  -0.0013  53 -54  78 -79   imp:n,p=8000 $ top air before detector
  793 1  -0.0013  54 -151 78 -79   imp:n,p=8000 $ top-top air before det.
c -- cells before and at 150m detector
  800 3  -1.625   150 -1  79 -80   imp:n,p=1.5E4 $ intermed soil cell
  801 1  -0.0013  1  -53  79 -80   imp:n,p=1.5E4 $ intermed air cell
  802 1  -0.0013  53 -54  79 -80   imp:n,p=1.5E4 $ intermed top air cell
  803 1  -0.0013  54 -151 79 -80   imp:n,p=1.5E4 $ intermed top-top air cell
  810 3  -1.625   150 -1  80 -81   imp:n,p=1.5E4 $ soil before detector
  811 1  -0.0013  1  -53  80 -81   imp:n,p=1.5E4 $ air before detector
  812 1  -0.0013  53 -54  80 -81   imp:n,p=1.5E4 $ top air before detector
  813 1  -0.0013  54 -151 80 -81   imp:n,p=1.5E4 $ top-top air before det.
c -- cells before and at 200m detector
  820 3  -1.625   150 -1  81 -82   imp:n,p=2.8E4 $ intermed soil cell
  821 1  -0.0013  1  -53  81 -82   imp:n,p=2.8E4 $ intermed air cell
  822 1  -0.0013  53 -54  81 -82   imp:n,p=2.8E4 $ intermed top air cell
  823 1  -0.0013  54 -151 81 -82   imp:n,p=2.8E4 $ intermed top-top air cell
  830 3  -1.625   150 -1  82 -83   imp:n,p=2.8E4 $ soil before detector
  831 1  -0.0013  1  -53  82 -83   imp:n,p=2.8E4 $ air before detector
  832 1  -0.0013  53 -54  82 -83   imp:n,p=2.8E4 $ top air before detector
  833 1  -0.0013  54 -151 82 -83   imp:n,p=2.8E4 $ top-top air before det.
c -- cells before and at 300m detector
  840 3  -1.625   150 -1  83 -84   imp:n,p=5.5E4 $ intermed soil cell
  841 1  -0.0013  1  -53  83 -84   imp:n,p=5.5E4 $ intermed air cell
  842 1  -0.0013  53 -54  83 -84   imp:n,p=5.5E4 $ intermed top air cell
  843 1  -0.0013  54 -151 83 -84   imp:n,p=5.5E4 $ intermed top-top air cell
  850 3  -1.625   150 -1  84 -85   imp:n,p=8.3E4 $ soil before detector
  851 1  -0.0013  1  -53  84 -85   imp:n,p=8.3E4 $ air before detector
  852 1  -0.0013  53 -54  84 -85   imp:n,p=8.3E4 $ top air before detector
  853 1  -0.0013  54 -151 84 -85   imp:n,p=8.3E4 $ top-top air before det.
c -- cells before and at 500m detector
  860 3  -1.625   150 -1  85 -86   imp:n,p=1.7E5 $ intermed soil cell
  861 1  -0.0013  1  -53  85 -86   imp:n,p=1.7E5 $ intermed air cell
  862 1  -0.0013  53 -54  85 -86   imp:n,p=1.7E5 $ intermed top air cell
  863 1  -0.0013  54 -151 85 -86   imp:n,p=1.7E5 $ intermed top-top air cell
  870 3  -1.625   150 -1  86 -87   imp:n,p=3.3E5 $ soil before detector
  871 1  -0.0013  1  -53  86 -87   imp:n,p=3.3E5 $ air before detector
  872 1  -0.0013  53 -54  86 -87   imp:n,p=3.3E5 $ top air before detector
  873 1  -0.0013  54 -151 86 -87   imp:n,p=3.3E5 $ top-top air before det.
c -- cells before and at 700m detector (2 cells before detector vol.)
  570 3  -1.625   150 -1  87 -57   imp:n,p=6.7E5   $ intermed soil cell
  571 1  -0.0013  1  -53  87 -57   imp:n,p=6.7E5   $ intermed air cell
  572 1  -0.0013  53 -54  87 -57   imp:n,p=6.7E5   $ intermed top air cell
  573 1  -0.0013  54 -151 87 -57   imp:n,p=6.7E5   $ intermed top-top air
cell
  880 3  -1.625   150 -1  57 -88   imp:n,p=1.3E6   $ intermed soil cell
  881 1  -0.0013  1  -53  57 -88   imp:n,p=1.3E6   $ intermed air cell
  882 1  -0.0013  53 -54  57 -88   imp:n,p=1.3E6   $ intermed top air cell
  883 1  -0.0013  54 -151 57 -88   imp:n,p=1.3E6   $ intermed top-top air
cell
  890 3  -1.625   150 -1  88 -89   imp:n,p=2.6E6   $ soil before detector
  891 1  -0.0013  1  -53  88 -89   imp:n,p=2.6E6   $ air before detector
  892 1  -0.0013  53 -54  88 -89   imp:n,p=2.6E6   $ top air before detector
  893 1  -0.0013  54 -151 88 -89   imp:n,p=2.6E6   $ top-top air before det.
```

```
c -- cells before and at 1000m detector (2 intermed cells before detector)
  590 3  -1.625    150 -1   89 -59   imp:n,p=5.2E6    $ intermed soil cell
  591 1  -0.0013   1  -53   89 -59   imp:n,p=5.2E6    $ intermed air cell
  592 1  -0.0013   53 -54   89 -59   imp:n,p=5.2E6    $ intermed top air cell
  593 1  -0.0013   54 -151 89 -59    imp:n,p=5.2E6    $ intermed top-top air
cell
  900 3  -1.625    150 -1   59 -90   imp:n,p=1.4E7    $ intermed soil cell
  901 1  -0.0013   1  -53   59 -90   imp:n,p=1.4E7    $ intermed air cell
  902 1  -0.0013   53 -54   59 -90   imp:n,p=1.4E7    $ intermed top air cell
  903 1  -0.0013   54 -151 59 -90    imp:n,p=1.4E7    $ intermed top-top air
cell
  910 3  -1.625    150 -1   90 -91   imp:n,p=2.8E7    $ soil before detector
  911 1  -0.0013   1  -53   90 -91   imp:n,p=2.8E7    $ air before detector
  912 1  -0.0013   53 -54   90 -91   imp:n,p=2.8E7    $ top air before detector
  913 1  -0.0013   54 -151 90 -91    imp:n,p=2.8E7    $ top-top air before det.
c
  920 3  -1.625    150 -1   91 -152  imp:n,p=2.8E7    $ soil after 1000-m
detector
  921 1  -0.0013   1  -53   91 -152  imp:n,p=2.8E7    $ air after 1000-m
detector
  922 1  -0.0013   53 -54   91 -152  imp:n,p=2.8E7    $ top air after 1000-m det
  923 1  -0.0013   54 -151 91 -152   imp:n,p=2.8E7    $ top-top air after det.
  90 0             -150:151:152      imp:n,p=0        $ problem boundary

c **********************  BLOCK 2: SURFACE CARDS ***********************
c **** Horizontal cask planes
  1   pz   -219.97       $ cask bottom - ground surface
  110 pz   -217.37       $ cask bottom - top of sublayer 10
  109 pz   -214.77       $ cask bottom - top of sublayer 9
  108 pz   -212.17       $ cask bottom - top of sublayer 8
  107 pz   -209.57       $ cask bottom - top of sublayer 7
  106 pz   -206.97       $ cask bottom - top of sublayer 6
  105 pz   -204.37       $ cask bottom - top of sublayer 5
  104 pz   -201.77       $ cask bottom - top of sublayer 4
  103 pz   -199.17       $ cask bottom - top of sublayer 3
  102 pz   -196.57       $ cask bottom - top of sublayer 2
  2   pz   -193.93       $ cask bottom - top of bot Fe plate
  3   pz   -188.22       $ side Fe jacket - outside lower bottom
  4   pz   -186.32       $ side Fe jacket - inside lower bottom
  5   pz   -182.88       $ top bottom basket/bottom of fuel
  7   pz    182.88       $ bottom of plenum basket/top of fuel
  8   pz    200.53       $ top of plenum basket
  9   pz    202.30       $ side Fe jacket - inside top
  10  pz    204.21       $ side Fe jacket - outside top
  11  pz    209.17       $ top of top fitting
  12  pz    220.72       $ cask top - bot of lid
  122 pz    223.72       $ cask top - top of sublayer 1
  123 pz    226.72       $ cask top - top of sublayer 2
  124 pz    229.72       $ cask top - top of sublayer 3
  125 pz    232.72       $ cask top - top of sublayer 4
  126 pz    238.00       $ cask top - top of sublayer 6
  127 pz    240.15       $ cask top - top of sublayer 7
  128 pz    242.31       $ cask top - top of sublayer 8
  129 pz    244.85       $ cask top - top of sublayer 9
  14  pz    247.39       $ cask top - top of lid
  13  pz    235.96       $ cask side - top of Fe side
  15  pz    258.82       $ top of polyprop on top of cask
```

```
  16  pz   292.80       $ top Fe cover - bot surface
  17  pz   293.76       $ top Fe cover - top surface
c 18  pz   266.35       $ top cover flange
c 19  pz   248.56       $ top hold down ring
c 28  pz   214.91       $ bottom hold down ring
c ***** cylindrical cask surfaces
  201 cz    87.31       $ cask wall - inner surface
  202 cz    89.31       $ cask wall - inner surface of sublayer 1
  203 cz    91.31       $ cask wall - inner surface of sublayer 2
  204 cz    93.31       $ cask wall - inner surface of sublayer 3
  205 cz    95.31       $ cask wall - inner surface of sublayer 4
  206 cz    97.31       $ cask wall - inner surface of sublayer 5
  207 cz    99.31       $ cask wall - inner surface of sublayer 6
  208 cz   101.31       $ cask wall - inner surface of sublayer 7
  209 cz   106.0        $ cask wall - inner surface of sublayer 9
  21  cz   111.44       $ cask outer surface
  22  cz   122.87       $ side Fe jacket -- inside
  23  cz   124.14       $ side Fe jacket -- outside
c 24  cz    85.73       $ inside radius of hold down ring
  25  cz    89.34       $ top polyprop disk radius
c 26  cz    87.31       $ inside radius ss basket
c 27  cz    87.31       $ inside radius Al backet/rails
  29  cz   101.92       $ inside radius top cover
  30  cz   102.87       $ outside radius top cover
c ***** surfaces for fuel regions
  40  pz  -146.30       $ top of fuel region 40
  41  pz  -109.73       $ top of fuel region 41
  42  pz   -73.15       $ top of fuel region 42
  43  pz   -36.53       $ top of fuel region 43
  44  pz    -0.0        $ top of fuel region 44
  45  pz    36.53       $ top of fuel region 45
  46  pz    73.15       $ top of fuel region 46
  47  pz   109.73       $ top of fuel region 47
  48  pz   146.30       $ top of fuel region 48
c ***** problem boundaries
 150  pz  -500.E2       $ bottom of soil (problem boundary)
 151  pz  2000.E2       $ top of air (problem boundary)
 152  cz  2000.E2       $ radial air limit (problem boundary)
c ***** surfaces for detector volumes
  53  pz   -19.97       $ top of detector volumes
  54  pz   252.03       $ top of berm
  60  cz   175.00       $ detector at  2 m - inner face  (2-m from cask
center)
c 61  cz   225.00       $ detector at  2 m - outer face
  62  cz   275.00       $ detector at  3 m - inner face
c 63  cz   325.00       $ detector at  3 m - outer face
  64  cz   475.00       $ detector at  5 m - inner face
c 65  cz   525.00       $ detector at  5 m - outer face
  66  cz   675.00       $ detector at  7 m - inner face
c 67  cz   725.00       $ detector at  7 m - outer face
  68  cz   975.00       $ detector at 10 m - inner face
c 69  cz  1025.00       $ detector at 10 m - outer face
  70  cz  1975.00       $ detector at 20 m - inner face
c 71  cz  2025.00       $ detector at 20 m - outer face
  72  cz  2000.0        $ front face of berm
  73  cz  2304.8        $ back of berm
  74  cz  4950.00       $ detector at   50 m - inner face
```

```
  75  cz  5050.00       $ detector at   50 m - outer face
  76  cz  6950.00       $ detector at   70 m - inner face
  77  cz  7050.00       $ detector at   70 m - outer face
  78  cz  9950.00       $ detector at  100 m - inner face
  79  cz  10050.0       $ detector at  100 m - outer face
  80  cz  14950.0       $ detector at  150 m - inner face
  81  cz  15050.0       $ detector at  150 m - outer face
  82  cz  19950.0       $ detector at  200 m - inner face
  83  cz  20050.0       $ detector at  200 m - outer face
  84  cz  29950.0       $ detector at  300 m - inner face
  85  cz  30050.0       $ detector at  300 m - outer face
  86  cz  49950.0       $ detector at  500 m - inner face
  87  cz  50050.0       $ detector at  500 m - outer face
  57  cz  60000.0       $ extra surface at 600 m
  88  cz  69950.0       $ detector at  700 m - inner face
  89  cz  70050.0       $ detector at  700 m - outer face
  59  cz  85000.0       $ extra surface at 850m
  90  cz  99900.0       $ detector at 1000 m - inner face
  91  cz 100100.0       $ detector at 1000 m - outer face

c ***********************  BLOCK 3: DATA CARDS ***************************
c
c
c  --- 3 volumetric cylindrical sources in cells 3,4,5 for bottom fitting,
c      plenum basket and top fitting
SDEF CEL=d1 POS=FCEL d2  AXS=0 0 1  RAD=d9  EXT=FCEL d10  ERG=d14
c -- define cells for each source
SI1 L  5  4  3                      $ cell: top fit. / plenum / bot. fitting
SP1    0.50121  0.12532  0.37589    $ relative source strengths
c -- set POS for each source
DS2 S 3 4 5                $ based on cell choosen, set distribution for POS
SI3 L 0 0 204.85           $ center for spatially sampling of source 1 (top
fit.)
SP3 1                      $ prob. distn for src 1 center
SI4 L 0 0 191.705          $ center for spatially sampling of source 2 (plenum)
SP4 1                      $ prob. distn for src 2 center
SI5 L 0 0 -188.405         $ center for spatially sampling of source 3
(bot.fit.)
SP5 1                      $ prob. distn for src 3 center
c -- set RAD for each source (must completely include cells 5, 4 or 3)
SI9  0 87.31               $ radial sampling limits for all 3 sources
SP9 -21 1                  $ radial sampling weight for all 3 sources
c -- set EXT for each source (must completely include cells 5, 4, or 3)
DS10 S 11 12 13            $ distns for sampling axially for each src
SI11  -4.32  4.32          $ axial sampling limits for src1
SP11  -21 0                $ axial sampling weight for src1
SI12  -8.825  8.825        $ axial sampling limits for src2
SP12  -21 0                $ axial sampling weight for src2
SI13  -5.525  5.525        $ axial sampling limits for src3
SP13  -21 0                $ axial sampling weight for src3
c -- gamma energy spectrum:  same for all three sources
SI14  H   1.0  1.33  1.66       $ energy bins - same for the 3 source regions
SP14      0.0  .77977  0.22023  $ bin probs.  - same for the 3 source regions
c
c
c
c ---- Detector types and locations
```

```
FC4  *** Dose in Sv per photon ***
F4:p     751 771 791 811 831 851 871 891 911
FC14  *** Dose in mrem/h ***
F14:p    751 771 791 811 831 851 871 891 911
FM14    1.426406e23   $ convert Sv/photon to mrem/h for fittings/plenum
c
c
c ---- Physics and problem control
mode p
phys:p 0  1  1
nps  7000000
c  void
c
c ------------------------------------------------------------------
c  ambient photon dose equiv. H*(10mm) Sv (from T-D1 of S&F)
c ------------------------------------------------------------------
de0     1.000E-02 1.500E-02 2.000E-02 3.000E-02 4.000E-02 5.000E-02
        6.000E-02 8.000E-02 1.000E-01 1.500E-01 2.000E-01 3.000E-01
        4.000E-01 5.000E-01 6.000E-01 8.000E-01 1.000E+00 1.500E+00
        2.000E+00 3.000E+00 4.000E+00 5.000E+00 6.000E+00 8.000E+00
        1.000E+01
df0     7.690E-14 8.460E-13 1.010E-12 7.850E-13 6.140E-13 5.260E-13
        5.040E-13 5.320E-13 6.110E-13 8.900E-13 1.180E-12 1.810E-12
        2.380E-12 2.890E-12 3.380E-12 4.290E-12 5.110E-12 6.920E-12
        8.480E-12 1.110E-11 1.330E-11 1.540E-11 1.740E-11 2.120E-11
        2.520E-11
c
c
c    ***** MATERIAL CARDS
c    **********************************************************
c     AIR: ANSI/ANS-6.4.3, Dry air;  density = 0.0012 g/cm^3
c          Composition by mass fraction
c    ***********************************************************
m1    7014       -.75519
      8016       -.23179
      6000       -.00014
     18000       -.01288
c
c    **********************************************************
c     CONCRETE: ANSI/ANS-6.4.3;   density = 2.32 g/cm^3
c               Composition by mass fraction
c    **********************************************************
m2     1001       -.0056
       8016       -.4983
      11023       -.0171
      12000       -.0024
      13027       -.0456
      14000       -.3158
      16000       -.0012
      19000       -.0192
      20000       -.0826
      26000       -.0122
c
c    ************************************************************
c     SOIL: [Jacob, Radn. Prot. Dos. 14, 299, 1986]
c           density = 1.625 g/cm^3;  Composition by mass fraction
c    ************************************************************
```

```
m3     1001  -.021
       6012  -.016
      19000  -.013
      26000  -.011
      20000  -.041
      13027  -.050
      14000  -.271
       8016  -.577
c
c     ***********************************************************
c     Fuel-Basket TN-32 Cask  (Table 5.3-1)
c          Density = 2.932 g/cm^3;  Composition by atom fraction
c     ***********************************************************
m4    92238  0.14291
      92235  0.00494
      40000  0.09981
      28000  0.02423
      26000  0.18629
      25055  0.00545
      24000  0.05470
      13027  0.18597
       8016  0.29570
c
c     ***********************************************************
c     Top Fitting TN-32 Cask (Table 5.3-1)
c          Density = 0.491 g/cm^3;  Composition by atom fraction
c     ***********************************************************
m5    26000  0.50712
      28000  0.06595
      25055  0.01483
      24000  0.14890
      40000  0.26320
c
c     ***********************************************************
c     Plenum/Basket TN-32 (Table 5.3-1)
c         Density = 1.158 g/cm^3;   Composition by atom fraction
c     ***********************************************************
m6    26000  0.34907
      28000  0.04535
      40000  0.17975
      25055  0.01021
      24000  0.10246
      13027  0.31316
c
c     ***********************************************************
c     Bottom/Basket TN-32 (Table 5.3-1)
c         Density = 1.918 g/cm^3;  Composition by atom fraction
c     ***********************************************************
m7    26000  0.48631
      28000  0.06329
      25055  0.01423
      24000  0.14285
      13027  0.23378
      40000  0.05954
c
c     ***********************************************************
c     Basket Periphery (SS304) TN-32 (Table 5.3-1)
```

```
c         Density = 7.92 g/cm^3;   Composition by atom fraction
c     ***********************************************************
m8    26000  0.68826
      25055  0.02013
      24000  0.20209
      28000  0.08952
c
c     ***********************************************************
c     Carbon Steel TN-32 (Table 5.3-1)
c         Density = 7.8212 g/cm^3;  Composition by atom fraction
c     ***********************************************************
m9    26000  0.95510
       6000  0.04490
c
c     ***********************************************************
c      Outer Basket/Rails TN-32 (Table 5.3-1)
c         Density = 2.702 g/cm^3;   Composition by atom fraction
c     ***********************************************************
m10   13027  1.00000
c
c     ***********************************************************
c     Polypropylene Disk TN-32 (Table 5.3-1)
c       Density = 0.90 g/cm^3;   Composition by atom fraction
c     ***********************************************************
m11    6012 .33480
       1001 .66520
c
c     ***********************************************************
c     Resin/Aluminum Composite for TN-32 (Table 5.3-1)
c        Density = 1.687 g/cm^3;   Composition by atom fraction
c     ***********************************************************
m12   13027  0.10331
       6012  0.24658
       8016  0.21985
       1001  0.42207
       5010  0.00164
       5011  0.00655
c
c     ***********************************************************
c     Berm (Silica + water) for ISFSI Site (SAR Page 7a-5);
c        density = 1.400 g/cm^3;  Composition by atom fraction
c     ***********************************************************
m13    14000   0.26524
        8016   0.59855
        1001   0.13621
c
c  prdmp 2j 1
c  print
□
```

5.6 References

1. SCALE4.3, "A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers." CCC-545, ORNL.

2. Croff et al, Revised Uranium-Plutonium Cycle PWR and BWR Models for the ORIGEN Computer Code.

3. Luksic, `Spent Fuel Assembly Hardware: Characterization and 10 CFR 61 Classification for Waste Disposal,' PNL-6906, UC-85, June 1989.

4. SCALE4.4, "A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers." CCC-545, ORNL.

5. MCNP4B2, "Monte Carlo N-Particle Transport Code System." Los Alamos National Laboratory, CCC-660, RSIC.

6. "Data for Use in Protection Against External Radiation," Publication 51, International Commission on Radiological Protection, Annals of the ICRP, 17, No. 2/3, Pergamon Press, Oxford, 1987.

TABLE 5.1-1

TN-32 CASK SHIELD MATERIALS

Component	Material	Density (g/cm³)	Thickness (in.)
Cask Body Wall	Carbon Steel	7.82	9.50
Lid	Carbon Steel	7.82	10.5[1]
Bottom	Carbon Steel	7.82	10.25
Resin	Polyester resin Styrene Aluminum hydrate Zinc borate	1.58	4.26
Aluminum Box	Aluminum	2.70	0.12
Outer Shell	Carbon Steel	7.82	0.50
Basket	Stainless Steel Aluminum Borated Aluminum	7.92 2.70 2.65	2 x 0.105 0.5 0.040
Protective Cover	Carbon Steel	7.82	0.38
Polypropylene Drum	Polypropylene	0.90	4.0
Polypropylene Drum Shell	Carbon Steel	7.82	0.25[2]

[1] The Type A Lid is 9.38 inches thick.

[2] The steel encasement of the polypropylene drum is 0.25 inches on the top and sides and 1.25 inch thick on the bottom.

TABLE 5.1-2
SUMMARY OF DOSE RATES
(mrem/hr)

Average Dose Rates (fuel w/o inserts)

	Cask Surface					1 meter (3 feet)		
	Side[1] above shield[3]	Side[1] along shield	Side[1] below shield[4]	Top	Bottom	Side	Top	Bottom
Normal Conditions								
Gamma	206	138	90.0	45.4	158	54.3	21.6	48.3
Neutron	131	15.3	193	6.7	340	7.9	2.6	65.2
Total	337	153	283	52.1	498	62.3	24.2	113
Accident Conditions[2]								
Gamma	-	541	-	584	158	225	309	48.3
Neutron	-	1150	-	281	340	398	90.2	65.2
Total	-	1690	-	865	498	623	399	113

(1) Average dose rates along the side of the cask, above, below and along the neutron shield.

(2) Accident " Top" dose rates are for the Type A Lid. Accident " Top" dose rates for the standard TN-32 lid (TN-32 and TN-32B) are presented in Figure 5.4-5.

(3) Maximum surface dose rates above the neutron shield are 293 mrem/hr (gamma) and 186 mrem/hr (neutron)

(4) Maximum surface dose rates below the neutron shield are 203 mrem/hr (gamma) and 324 mrem/hr (neutron)

Incremental Gamma Dose(average)for Fuel Inserts (mrem/hr)

BPRAs

Cask Surface: Radial Middle	Cask Surface: above[5] neutron shield	Cask Surface: below[6] neutron shield	Cask Surface: Top	Cask Surface: bottom	1 meter (3 feet): radial middle	1 meter (3 feet): above neutron shield	1 meter (3 feet): below neutron shield	1 meter (3 feet): top	1 meter (3 feet): bottom
30	73	21	16	9	8	-	-	8	2

TPAs

Cask Surface: Radial Middle	Cask Surface: Above neutron shield	Cask Surface: below neutron shield	Cask Surface: top	Cask Surface: bottom	1 meter (3 feet): radial middle	1 meter (3 feet): above neutron shield	1 meter (3 feet): below neutron shield	1 meter (3 feet): top	1 meter (3 feet): bottom
1	28	0	7	0	1	-	-	4	0

(5) The maximum gamma dose rate above the neutron shield with BPRA inserts is 404 mrem/hr.

(6) The maximum gamma dose rate below the neutron shield with BPRA inserts is 222 mrem/hr.

TABLE 5.1-3

DIRECT DOSE RATES AT POSTULATED SITE BOUNDARY FROM ONE CASK[1]

Distance from Source	Neutron Doses (mrem/hr)	Gamma Doses (mrem/hr)	Total Doses (mrem/hr)
100 meters	1.06E-02	2.96E-02	4.02E-02
150 meters	3.39E-03	1.04E-02	1.38E-02
200 meters	1.43E-03	4.13E-03	5.56E-03
300 meters	3.59E-04	9.44E-04	1.30E-03
500 meters	2.74E-05	9.44E-05	1.22E-04

1 No fuel inserts

TABLE 5.2-1

MATERIAL DISTRIBUTION IN WESTINGHOUSE FUEL ASSEMBLIES

	Material	Mass (kg/assembly) 14x14	15x15	17x17
Fuel Assembly				
Top Fitting				
Upper Tie Plate	SS 304	4.29	6.8	6.8
Hold Down Springs	Inconel 718	0.7	1.1	1.37
Plenum				
Cladding & Guide Tubes	Zr-4	5.1	6.1	5.5
Plenum Spring	SS 302	1.3	1.5	1.9
Fuel Zone				
Cladding & Guide Tubes	Zr-4	87.1	99.2	102.9
Grids	Zr-4	6.6		
	Inconel-718	1.4	5.9	5.9
Grid Brazing Material	Nicrobraze 50	1.2	1.2	1.2
Miscellaneous	SS 304	4.6	4.6	4.6
Bottom Fitting				
Bottom Tie Plate	SS 304	4.54	5.7	5.7
Total (Fuel assembly)		116.8	132.1	135.6
Thimble Plug Assembly				
Top Fitting				
Baseplate, yoke, holddown bar, etc	SS 304			2.468
TPA Spring	Inconel 718			0.358
Plenum				
Thimble Plugs	SS 304			3.266
Burnable Poison Rod Assembly				
Top Fitting				
Baseplate, yoke, holddown bar, etc	SS 304			2.468
BPRA Spring	Inconel 718			0.358
Plenum				
Cladding and Liner	SS 304			0.80
Fuel Zone				
Cladding and Liner	SS 304			15.0

TABLE 5.2-2

MATERIAL COMPOSITIONS FOR FUEL ASSEMBLY HARDWARE MATERIALS

Material	Element	Weight %
Zircaloy	Chromium	0.125
	Manganese	0.002
	Iron	0.225
	Cobalt	0.001
	Nickel	0.002
	Zirconium	97.911
Stainless Steel (SS 302)	Chromium	18.0
	Manganese	2.0
	Iron	69.774
	Cobalt	0.08
	Nickel	8.92
Stainless Steel (SS 304)	Chromium	19.0
	Manganese	2.0
	Iron	68.844
	Cobalt	0.08
	Nickel	8.92
Inconel 718	Chromium	18.9753
	Manganese	0.1997
	Iron	17.9766
	Cobalt	0.4694
	Nickel	51.9625
Nicrobraze 50	Chromium	14.9709
	Manganese	0.01
	Iron	0.0471
	Cobalt	0.0381
	Nickel	74.4438
	Zirconium	0.01

Data taken from Reference 2.

TABLE 5.2-3
PWR SPENT FUEL ASSEMBLY SOURCE
3.5 wt% U-235, 45,000 MWd/MTU, 7 YEARS COOLING

	14x14 OFA	14x14 Std	15x15	17x17 OFA	17x17 Std[1]
Thermal Power (W/assembly)					
Light Elements	15.4	15.1	37.9	38.3	37.6
Actinides	142	188	198	170	203
Fission Products	595	673	744	688	746
Total	752.4	876.1	979.9	896.3	986.6
Neutron Source (n/sec/assembly)	2.411E+08	3.164E+08	3.224E+08	2.754E+08	3.278E+08
Gamma Source (γ/sec/assembly)					
Light Elements	7.589E+13	7.447E+13	1.866E+14	1.891E+14	1.853E+14
Actinides	1.664E+13	2.178E+13	2.329E+13	2.026E+13	2.427E+13
Fission Products	3.867E+15	4.409E+15	4.847E+15	4.469E+15	4.870E+15
Total	3.959E+15	4.505E+15	5.057E+15	4.678E+15	5.078E+15

[1] A copy of this input file is provided in Section 5.5.

SAS2H 1-DIMENSIONAL PWR DOSE EVALUATION

	contact (124.64 cm)			1 meter (224.14 cm)		
Detector Location	neutron	gamma	total	neutron	Gamma	total
14 x 14 Optimized	10.9	65.6	77	4.43	30.8	35
14 x 14 Standard	13.8	66.6	80	5.6	31.2	37
15 x 15	13	91.4	104	5.29	42.9	48
17 x 17 Optimized	11.4	92.7	104	4.64	43.6	48
17 x 17 Standard[1]	13.2	90.5	104	5.37	42.5	48

[1] A copy of this input file is provided in Section 5.5.

TABLE 5.2-4

GAMMA AND NEUTRON RADIATION SOURCES
WESTINGHOUSE 17x17 STANDARD 3.5 wt% U-235,
45,000 MWD/MTU, 7YEAR COOLING TIME

Fission Product, Actinides, and Activation Activity (Curie/Assembly)	3.041E+05
Neutron Source (n/sec/Assembly)	3.278E+08
Fuel Zone Gamma Source (γ/sec/Assembly)	5.067E+15
Plenum Zone Gamma Source (γ/sec/Assembly)	1.548E+12
Top End Fitting Zone Gamma Source (γ/sec/Assembly)	6.191E+12
Bottom End Fitting Zone Gamma Source (γ/sec/Assembly)	4.643E+12

TABLE 5.2-5

GAMMA RADIATION SOURCES
THIMBLE PLUG ASSEMBLY AND BURNABLE POISON ROD ASSEMBLY

THIMBLE PLUG ASSEMBLY	
Plenum Zone Gamma Source (γ/sec/Assembly)	2.186E+12
Top End Fitting Zone Gamma Source (γ/sec/Assembly)	1.736E+12
BURNABLE POISON ROD ASSEMBLY	
Fuel Zone Gamma Source (γ/sec/Assembly)	2.203E+14
Plenum Zone Gamma Source (γ/sec/Assembly)	2.337E+12
Top End Fitting Zone Gamma Source (γ/sec/Assembly)	7.525E+12

TABLE 5.2-6

FISSION PRODUCT ACTIVITES
WESTINGHOUSE 17x17 STANDARD FUEL ASSEMBLY
3.5wt% INITIAL ENRICHMENT, 45,000 MWd/MTU, 7 YEAR COOLED

Security-Related Information Figure Withheld Under 10 CFR 2.390.

TABLE 5.2-7

ACTIVATION ACTIVITIES
WESTINGHOUSE 17x17 STANDARD FUEL ASSEMBLY
3.5wt% INITIAL ENRICHMENT, 45,000 MWd/MTU, 7 YEAR COOLED

Security-Related Information Figure Withheld Under 10 CFR 2.390.

TABLE 5.2-8

PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
WESTINGHOUSE 17x17 STANDARD FUEL ASSEMBLY
3.5wt% u-235, 45,000 MWd/MTU, 7 YEAR COOLING TIME

Scale Group	Energy Interval, MeV	Active Fuel Zone	Plenum Zone	Top Fitting Zone	Bottom fitting Zone
28	8.000E+00 to 1.000E+01	1.858E+05			
29	6.500E+00 to 8.000E+00	8.750E+05			
30	5.000E+00 to 6.500E+00	4.461E+06			
31	4.000E+00 to 5.000E+00	1.112E+07			
32	3.000E+00 to 4.000E+00	3.247E+09			
33	2.500E+00 to 3.000E+00	2.616E+10			
34	2.000E+00 to 2.500E+00	5.737E+11			
35	1.660E+00 to 2.000E+00	3.992E+11			
36	1.330E+00 to 1.660E+00	5.457E+13	3.408E+11	1.363E+12	1.022E+12
37	1.000E+00 to 1.330E+00	2.381E+14	1.207E+12	4.827E+12	3.620E+12
38	8.000E-01 to 1.000E+00	2.292E+14			
39	6.000E-01 to 8.000E-01	2.188E+15			
40	4.000E-01 to 6.000E-01	4.469E+14			
41	3.000E-01 to 4.000E-01	4.623E+13			
42	2.000E-01 to 3.000E-01	7.437E+13			
43	1.000E-01 to 2.000E-01	2.722E+14			
44	5.000E-02 to 1.000E-01	3.337E+14			
45	1.000E-02 to 5.000E-02	1.183E+15			

TABLE 5.2-9

PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
THIMBLE PLUG ASSEMBLY

Scale Group	Energy Interval, MeV	Plenum Zone	Top Fitting Zone
36	1.330E+00 to 1.660E+00	4.814E+11	3.823E+11
37	1.000E+00 to 1.330E+00	1.705E+12	1.354E+12

TABLE 5.2-10

PRIMARY GAMMA SOURCE SPECTRUM
SCALE 18 GROUP STRUCTURE
BURNABLE POISON ROD ASSEMBLY

SCALE Group	Energy Interval (MeV)			Active Fuel Zone	Plenum Zone	Top Fitting Zone
28	8.00E+00	to	1.000E+01	0.00E+00	0.000E+00	0.000E+00
29	6.50E+00	to	8.000E+00	0.00E+00	0.000E+00	0.000E+00
30	5.00E+00	to	6.500E+00	0.00E+00	0.000E+00	0.000E+00
31	4.00E+00	to	5.000E+00	0.00E+00	0.000E+00	0.000E+00
32	3.00E+00	to	4.000E+00	1.63E+01	1.718E-01	3.430E-01
33	2.50E+00	to	3.000E+00	6.69E+05	7.119E+03	2.810E+04
34	2.00E+00	to	2.500E+00	4.31E+08	4.590E+06	1.810E+07
35	1.66E+00	to	2.000E+00	2.14E+11	2.267E+09	8.190E+09
36	1.33E+00	to	1.660E+00	1.82E+13	1.934E+11	7.630E+11
37	1.00E+00	to	1.330E+00	6.44E+13	6.848E+11	2.700E+12
38	8.00E-01	to	1.000E+00	7.16E+13	7.587E+11	2.220E+12
39	6.00E-01	to	8.000E-01	1.44E+10	1.521E+08	5.490E+08
40	4.00E-01	to	6.000E-01	1.39E+13	1.474E+11	5.320E+11
41	3.00E-01	to	4.000E-01	4.74E+13	5.018E+11	1.130E+12
42	2.00E-01	to	3.000E-01	1.24E+11	1.316E+09	4.700E+09
43	1.00E-01	to	2.000E-01	4.63E+11	4.906E+09	1.740E+10
44	5.00E-02	to	1.000E-01	8.73E+11	9.260E+09	3.260E+10
45	1.00E-02	to	5.000E-02	3.14E+12	3.328E+10	1.170E+11

TABLE 5.2-11
AXIAL BURNUP PROFILE

Distance from Bottom of Active Fuel(cm)	Distance from Bottom of Active Fuel (in)	Gamma Profile	Neutron Peaking Factor
0.00	0	0	0.000
2.86	1.125	0.54	0.06
8.57	3.375	0.65	0.15
17.15	6.75	0.79	0.36
28.58	11.25	0.94	0.77
40.01	15.75	1.02	1.09
57.15	22.5	1.091	1.43
80.01	31.5	1.135	1.68
148.59	58.5	1.126	1.63
171.45	67.5	1.12	1.60
182.88	72	1.12	1.60
259.08	102	1.12	1.60
289.56	114	1.1	1.48
320.04	126	1.02	1.09
337.19	132.75	0.87	0.55
348.62	137.25	0.73	0.25
362.90	142.875	0.48	0.04
365.76	144	0	0.000

TABLE 5.2-12

NEUTRON SOURCE DISTRIBUTION
WESTINGHOUSE 17x17 STANDARD FUEL ASSEMBLY
3.5wt% INITIAL ENRICHMENT, 45,000 MWD/MTU, 7 YEAR COOLING TIME
TOTAL (ALPHA,N PLUS SPONTANEOUS FISSION) NEUTRON SOURCE
SCALE STRUCTURE USING SPECTRA FOR URANIUM DIOXIDE

Grp	Energy Interval (meV)			N/sec/assembly
1	6.430E+00	-	2.000E+01	6.066E+06
2	3.000E+00	-	6.430E+00	6.880E+07
3	1.850E+00	-	3.000E+00	7.598E+07
4	1.400E+00	-	1.850E+00	4.292E+07
5	9.000E-01	-	1.400E+00	5.816E+07
6	4.000E-01	-	9.000E-01	6.347E+07
7	1.000E-01	-	4.000E-01	1.242E+07
			Total	3.278E+08

TABLE 5.3-1

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL ASSEMBLIES ONLY
RADIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel/Basket	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28400	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.316	Cr	24304	6.95E-04
			Mn	25055	6.93E-05
			Fe	26304	2.37E-03
			Ni	28304	3.08E-04
Plenum/Basket	Zircaloy	0.459	Zr	40302	3.03E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.458	Cr	24304	1.01E-03
			Mn	25055	1.00E-04
			Fe	26304	3.43E-03
			Ni	28304	4.46E-04
Top Fitting/Basket	Inconel	0.212	Si	14000	1.14E-04
			Ti	22000	6.67E-05
			Cr	24404	3.68E-04
			Fe	26404	1.60E-04
			Ni	28404	1.59E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.351	Cr	24304	2.97E-03
			Mn	25055	2.96E-04
			Fe	26304	1.01E-02
			Ni	28304	1.32E-03
Bottom Fitting/Basket	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.409	Cr	24304	3.10E-03
			Mn	25055	3.09E-04
			Fe	26304	1.06E-02
			Ni	28304	1.37E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.3-1
(continued)

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL ASSEMBLIES ONLY

AXIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28404	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.316	Cr	24304	6.95E-04
			Mn	25055	6.93E-05
			Fe	26304	2.37E-03
			Ni	28304	3.08E-04
Plenum	Zircaloy	0.459	Zr	40302	3.03E-03
	SS304	0.159	Cr	24304	3.50E-04
			Mn	25055	3.49E-05
			Fe	26304	1.19E-03
			Ni	28304	1.55E-04
Top Fitting	Inconel	0.212	Si	14000	1.14E-04
			Ti	22000	6.67E-05
			Cr	24404	3.68E-04
			Fe	26404	1.60E-04
			Ni	28404	1.59E-03
	SS304	1.052	Cr	24304	2.44E-03
			Mn	25055	2.43E-04
			Fe	26304	8.32E-03
			Ni	28304	1.08E-03
Bottom Fitting	SS304	1.110	Cr	24304	2.44E-03
			Mn	25055	2.43E-04
			Fe	26304	8.32E-03
			Ni	28304	1.08E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.3-2

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL ASSEMBLIES WITH THIMBLE PLUG ASSEMBLIES
RADIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel/Basket	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28400	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.316	Cr	24304	6.95E-04
			Mn	25055	6.93E-05
			Fe	26304	2.37E-03
			Ni	28304	3.08E-04
Plenum/Basket	Zircaloy	0.459	Zr	40302	3.03E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.731	Cr	24304	1.61E-03
			Mn	25055	1.60E-04
			Fe	26304	5.48E-03
			Ni	28304	7.13E-04
Top Fitting/Basket	Inconel	0.267	Si	14000	1.43E-04
			Ti	22000	8.40E-05
			Cr	24404	4.64E-04
			Fe	26404	2.02E-04
			Ni	28404	2.00E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.733	Cr	24304	3.81E-03
			Mn	25055	3.80E-04
			Fe	26304	1.30E-02
			Ni	28304	1.69E-03
Bottom Fitting/Basket	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.409	Cr	24304	3.10E-03
			Mn	25055	3.09E-04
			Fe	26304	1.06E-02
			Ni	28304	1.37E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.3-2
(continued)

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL ASSEMBLIES WITH THIMBLE PLUG ASSEMBLIES

AXIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28404	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.316	Cr	24304	6.95E-04
			Mn	25055	6.93E-05
			Fe	26304	2.37E-03
			Ni	28304	3.08E-04
Plenum	Zircaloy	0.459	Zr	40302	3.03E-03
	SS304	0.432	Cr	24304	9.51E-04
			Mn	25055	9.47E-05
			Fe	26304	3.24E-03
			Ni	28304	4.21E-04
Top Fitting	Inconel	0.267	Si	14000	1.43E-04
			Ti	22000	8.40E-05
			Cr	24404	4.64E-04
			Fe	26404	2.02E-04
			Ni	28404	2.00E-03
	SS304	1.434	Cr	24304	3.16E-03
			Mn	25055	3.14E-04
			Fe	26304	1.07E-02
			Ni	28304	1.40E-03
Bottom Fitting	SS304	1.110	Cr	24304	2.44E-03
			Mn	25055	2.43E-04
			Fe	26304	8.32E-03
			Ni	28304	1.08E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.3-3

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL WITH BURNABLE POISON ROD ASSEMBLIES
RADIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel/Basket	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28400	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.359	Cr	24304	7.90E-04
			Mn	25055	7.87E-05
			Fe	26304	2.69E-03
			Ni	28304	3.50E-04
Plenum/Basket	Zircaloy	0.459	Zr	40302	3.03E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.511	Cr	24304	1.12E-03
			Mn	25055	1.12E-04
			Fe	26304	3.83E-03
			Ni	28304	4.98E-04
Top Fitting/Basket	Inconel	0.267	Si	14000	1.43E-04
			Ti	22000	8.40E-05
			Cr	24404	4.64E-04
			Fe	26404	2.02E-04
			Ni	28404	2.00E-03
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.733	Cr	24304	3.81E-03
			Mn	25055	3.80E-04
			Fe	26304	1.30E-02
			Ni	28304	1.69E-03
Bottom Fitting/Basket	Aluminum	0.306	Al	13027	6.83E-03
	SS304	1.409	Cr	24304	3.10E-03
			Mn	25055	3.09E-04
			Fe	26304	1.06E-02
			Ni	28304	1.37E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.3-3
(continued)

MATERIALS INPUT FOR SAS4 MODEL
TN-32 CASK - FUEL WITH BURNABLE POISON ROD ASSEMBLIES

AXIAL DIRECTION

Zone	Material	Density (g/cc)	Element/ Nuclide	SCALE Library Identifier	Atomic Number Density (atoms/barn-cm)
Fuel	UO_2	1.912	U-235	92235	1.51E-04
			U-238	92238	4.11E-03
			O	8016	8.53E-03
	Zircaloy	0.376	Zr	40302	2.48E-03
	Inconel	0.022	Si	14000	1.18E-05
			Ti	22000	6.92E-06
			Cr	24404	3.82E-05
			Fe	26404	1.66E-05
			Ni	28404	1.65E-04
	Aluminum	0.306	Al	13027	6.83E-03
	SS304	0.359	Cr	24304	7.90E-04
			Mn	25055	7.87E-05
			Fe	26304	2.69E-03
			Ni	28304	3.50E-04
Plenum	Zircaloy	0.459	Zr	40302	3.03E-03
	SS304	0.212	Cr	24304	4.67E-04
			Mn	25055	4.65E-05
			Fe	26304	1.59E-03
			Ni	28304	2.07E-04
Top Fitting	Inconel	0.267	Si	14000	1.43E-04
			Ti	22000	8.40E-05
			Cr	24404	4.64E-04
			Fe	26404	2.02E-04
			Ni	28404	2.00E-03
	SS304	1.434	Cr	24304	3.16E-03
			Mn	25055	3.14E-04
			Fe	26304	1.07E-02
			Ni	28304	1.40E-03
Bottom Fitting	SS304	1.110	Cr	24304	2.44E-03
			Mn	25055	2.43E-04
			Fe	26304	8.32E-03
			Ni	28304	1.08E-03
Cask Body	Carbon Steel	7.8212	Fe	26000	8.35E-02
			C	6012	3.93E-03
Polypropylene / Steel	Polypropylene	0.90	Fe	26000	9.18E-03
			C	6012	3.49E-02
			H	1001	6.84E-02
Resin/Aluminum	Resin (1.58 g/cc) & Aluminum (2.702 g/cc)	1.687	O	8016	2.22E-02
			Al	13027	1.10E-02
			C	6012	2.50E-02
			H	1001	4.27E-02
			B-10	5010	1.65E-04
			B-11	5011	6.63E-04

TABLE 5.4-1

PARAMETERS FOR THE SCALE 27N-18G LIBRARY

Group No	Max Energy (eV)	Flux-Dose Factor (rem/hr/ϕ)
1	2.000E+07	1.492E-04
2	6.434E+06	1.446E-04
3	3.000E+06	1.270E-04
4	1.850E+06	1.281E-04
5	1.400E+06	1.298E-04
6	9.000E+05	1.028E-04
7	4.000E+05	5.118E-05
8	1.000E+05	1.232E-05
9	1.700E+04	3.837E-06
10	3.000E+03	3.725E-06
11	5.500E+02	4.015E-06
12	1.000E+02	4.293E-06
13	3.000E+01	4.474E-06
14	1.000E+01	4.568E-06
15	3.050E+00	4.558E-06
16	1.770E+00	4.519E-06
17	1.300E+00	4.488E-06
18	1.130E+00	4.466E-06
19	1.000E+00	4.435E-06
20	8.000E-01	4.327E-06
21	4.000E-01	4.198E-06
22	3.250E-01	4.098E-06
23	2.250E-01	3.839E-06
24	1.000E-01	3.675E-06
25	5.000E-02	3.675E-06
26	3.000E-02	3.675E-06
27	1.000E-02	3.675E-06
28	1.000E+07	8.772E-06
29	8.000E+06	7.478E-06
30	6.500E+06	6.375E-06
31	5.000E+06	5.414E-06
32	4.000E+06	4.622E-06
33	3.000E+06	3.960E-06
34	2.500E+06	3.469E-06
35	2.000E+06	3.019E-06
36	1.660E+06	2.628E-06
37	1.330E+06	2.205E-06
38	1.000E+06	1.833E-06
39	8.000E+05	1.523E-06
40	6.000E+05	1.173E-06
41	4.000E+05	8.759E-07
42	3.000E+05	6.306E-07
43	2.000E+05	3.834E-07
44	1.000E+05	2.669E-07
45	5.000E+04	9.347E-07

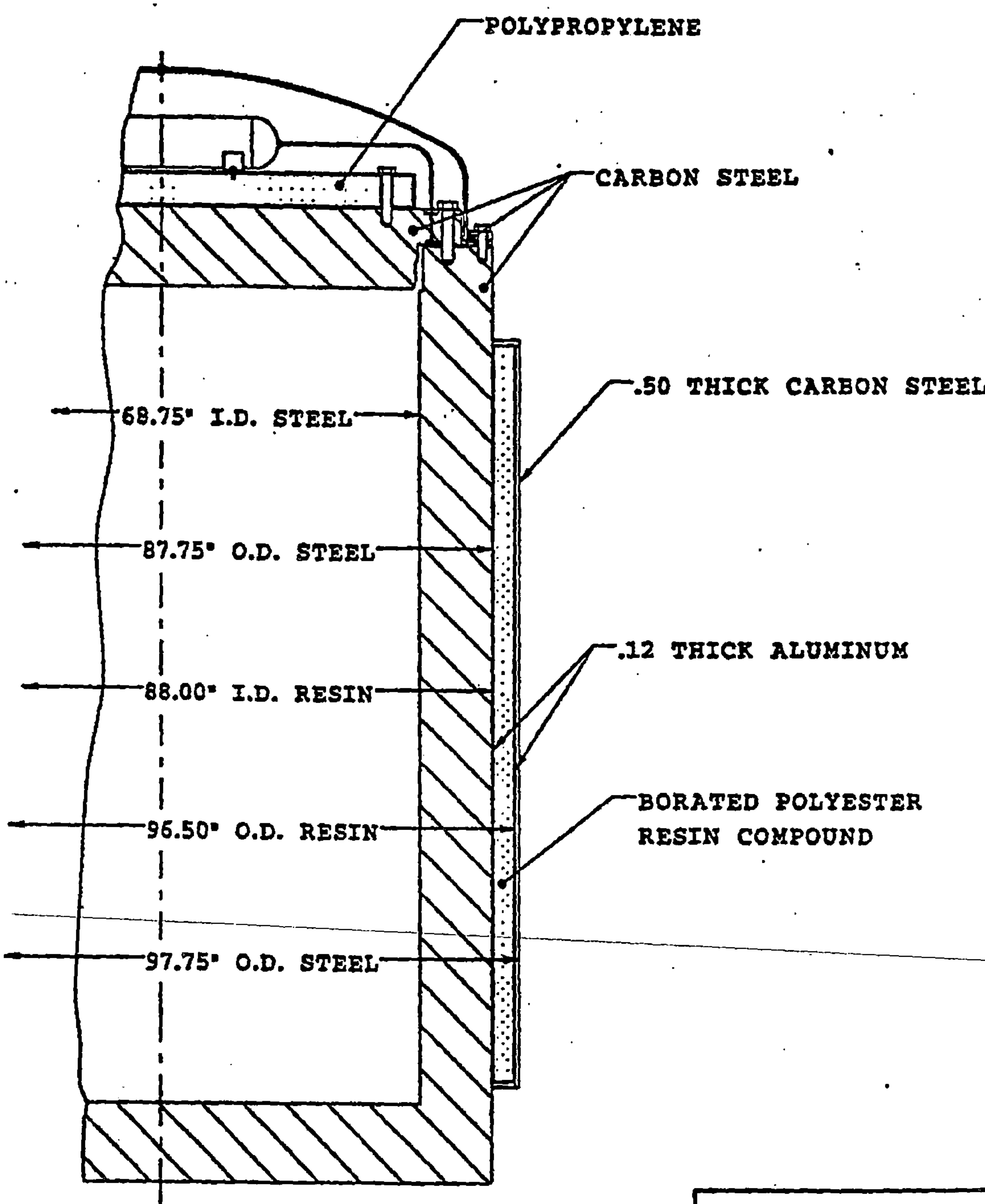


FIGURE 5.1-1
CASK SHIELDING CONFIGURATION

REV. 0 1/00

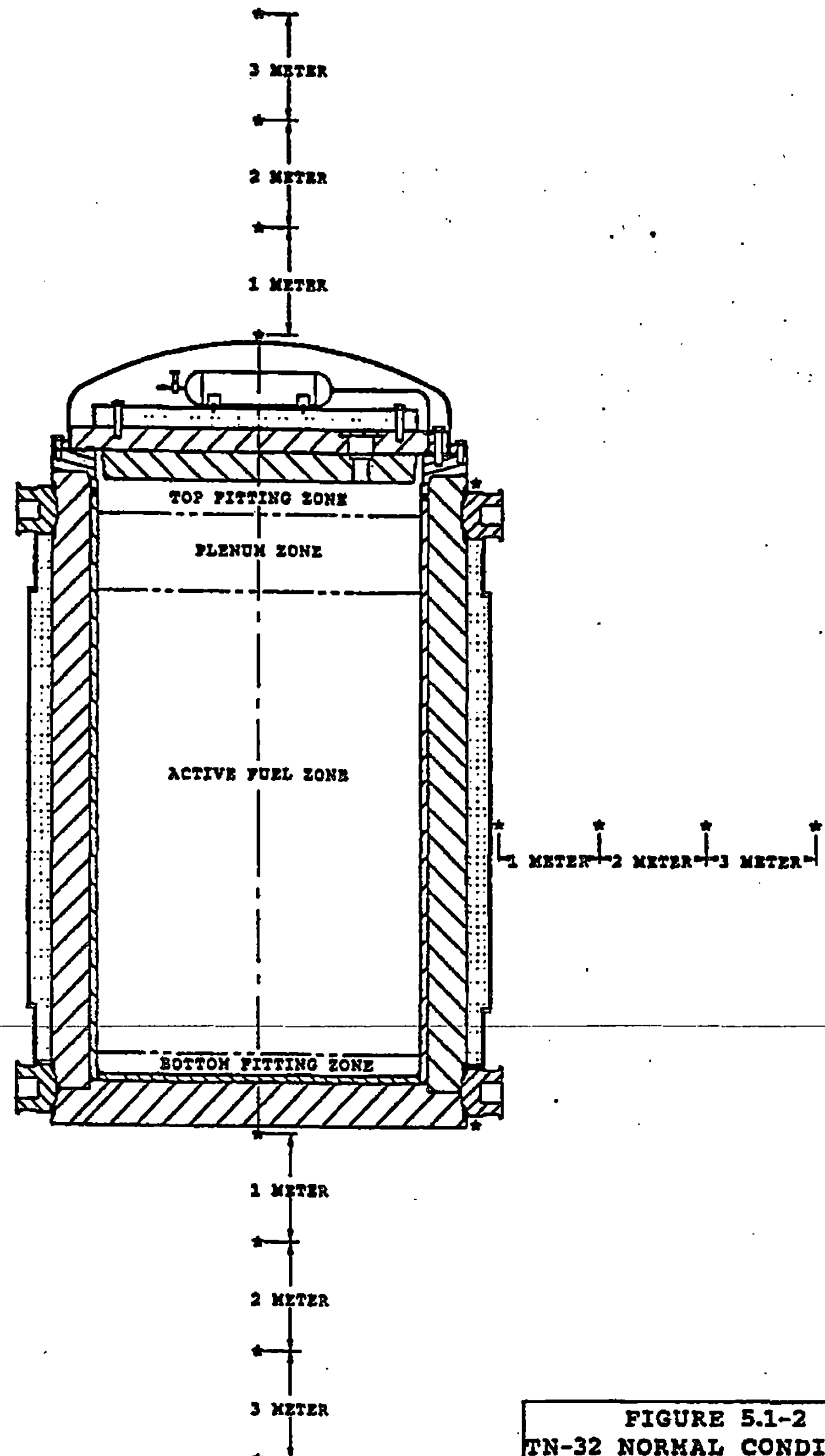
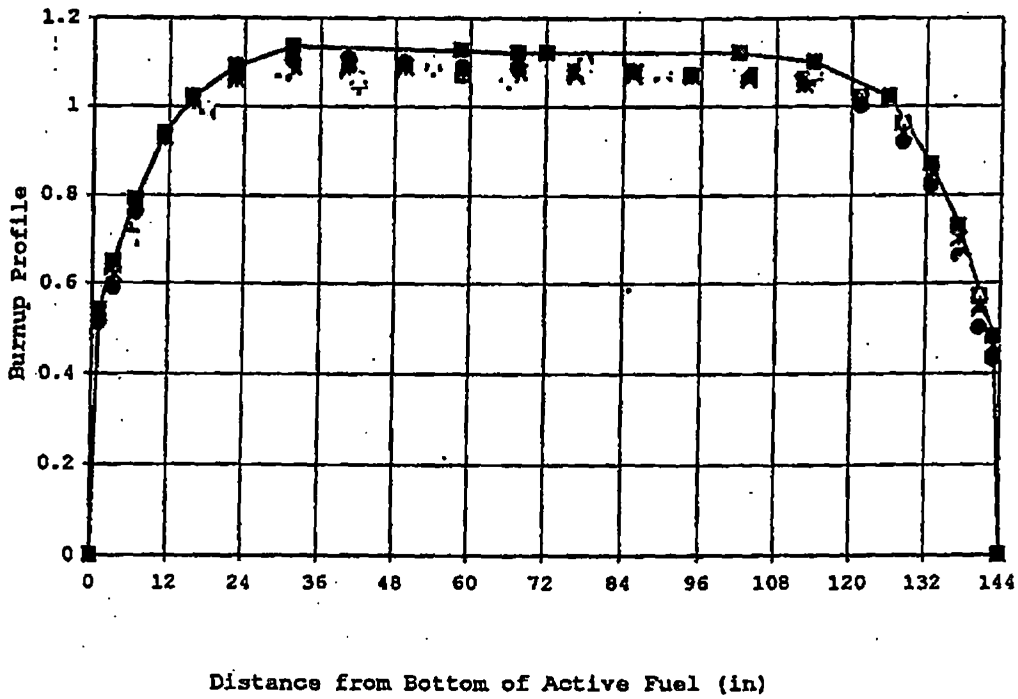


FIGURE 5.1-2
TN-32 NORMAL CONDITIONS
DOSE POINT LOCATIONS

REV. 0 1/00

FIGURE 5.2-1
AXIAL BURNUP PROFILE FOR DESIGN BASIS FUEL

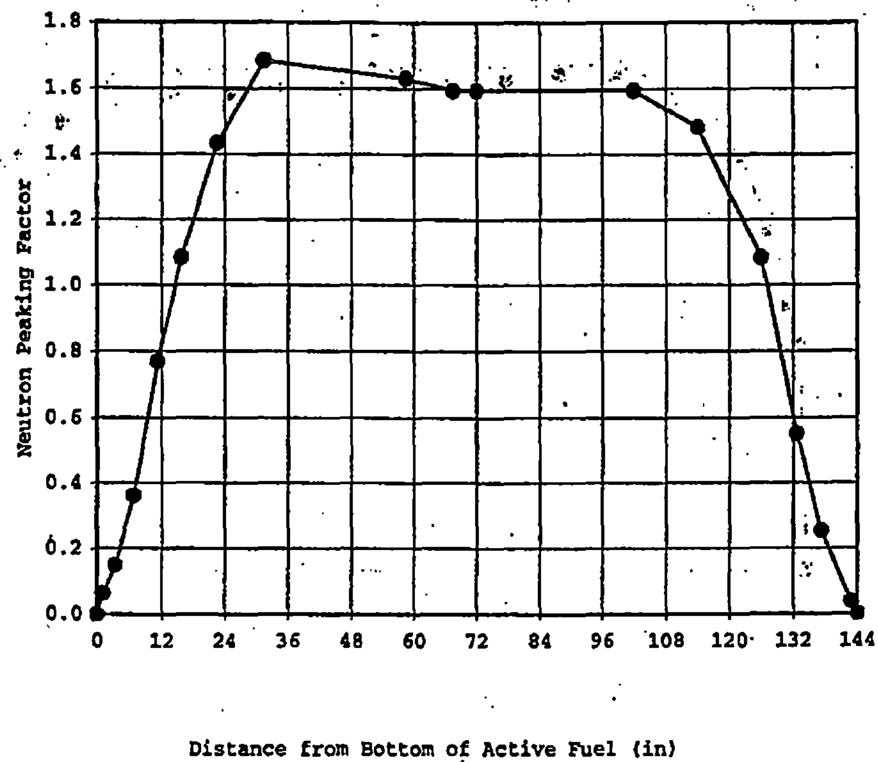


Notes:

1. Points scattered on the graph represent actual data from Virginia Power, North Anna Station and Wisconsin Electric, Point Beach Nuclear Unit

2. Solid line represents burnup profile design value.

FIGURE 5.2-2
NEUTRON SOURCE DISTRIBUTION PROFILE FOR DESIGN BASIS FUEL



Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-1
SAS4 TOP MODEL
NORMAL CONDITIONS
VIEW 90° FROM TRUNNIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-2
SAS4 TOP MODEL
NORMAL CONDITIONS
VIEW THROUGH TRUNNIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-3
SAS4 TOP MODEL
NORMAL CONDITIONS
PLANE VIEW THROUGH
TOP TRUNNIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-4
SAS4 TOP MODEL
NORMAL CONDITIONS
PLANE VIEW THROUGH
CENTER

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-5
SAS4 BOTTOM MODEL
NORMAL CONDITIONS
VIEW 90° FROM TRUNNIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-6
SAS4 BOTTOM MODEL
NORMAL CONDITIONS
VIEW THROUGH TRUNNIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-7
SAS4 BOTTOM MODEL
NORMAL CONDITIONS
PLANE VIEW THROUGH
BOTTOM TRUNNIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-8
SHIELDING AT TOP
PERIMETER WITH TYPE "A" LID

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-9
SAS4 TOP MODEL
ACCIDENT CONDITIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-10
SAS4 TOP MODEL
TYPE "A" LID
ACCIDENT CONDITIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-11
SAS4 BOTTOM MODEL
ACCIDENT CONDITIONS

REV. 0 1/00

Security-Related Information Figure Withheld Under 10 CFR 2.390.

FIGURE 5.3-12
SAS2H RADIAL MODEL

REV. 0 1/00

FIGURE 5.4-1

NORMAL CONDITIONS - RADIAL DIRECTION - MIDPLANE
AVERAGE OF TOP AND BOTTOM SAS4 RADIAL MODELS

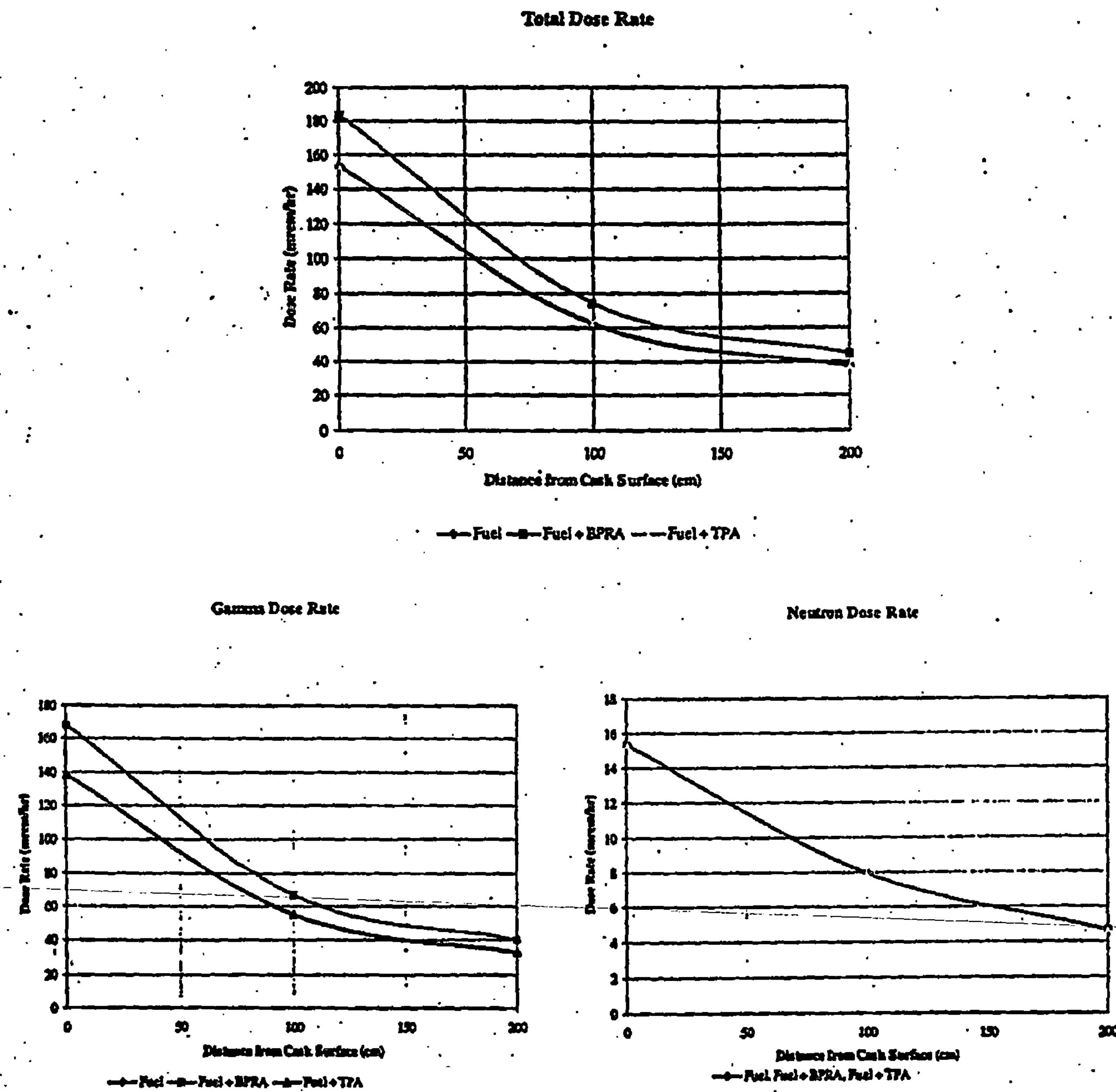
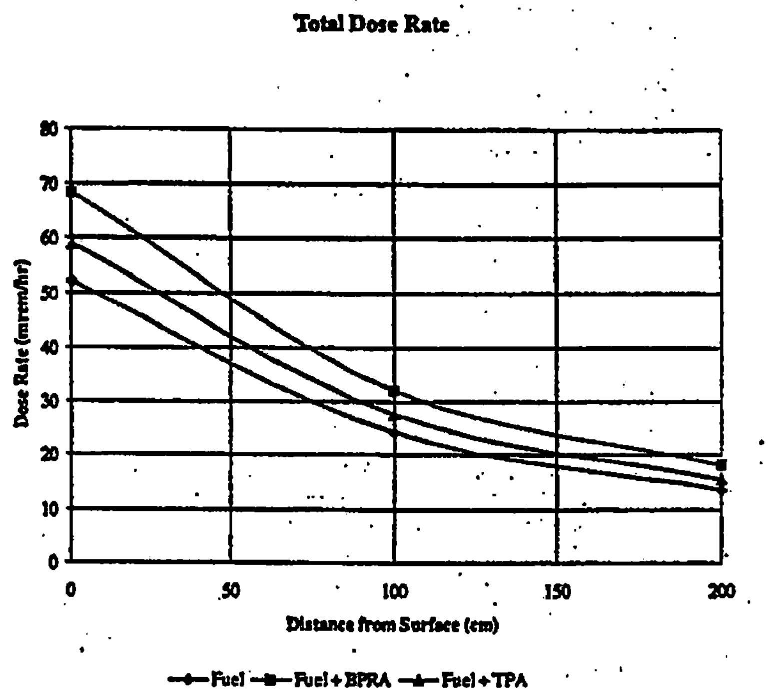
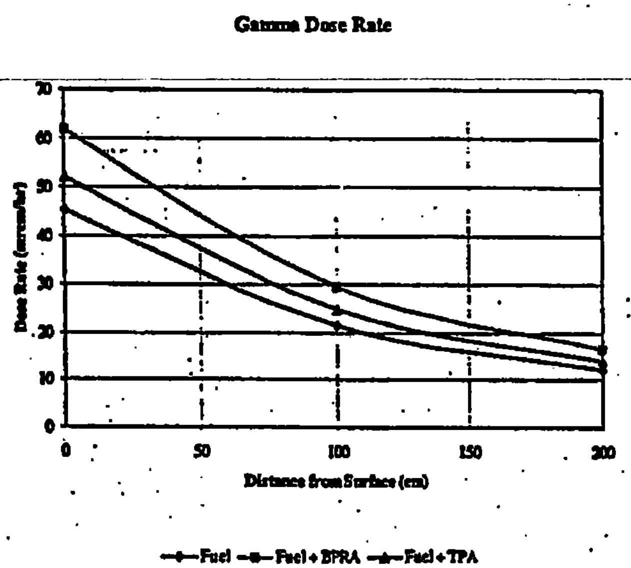


FIGURE 5.4-2

NORMAL CONDITIONS – AXIAL DIRECTION – AVERAGE TOP (STANDARD AND TYPE A LID)





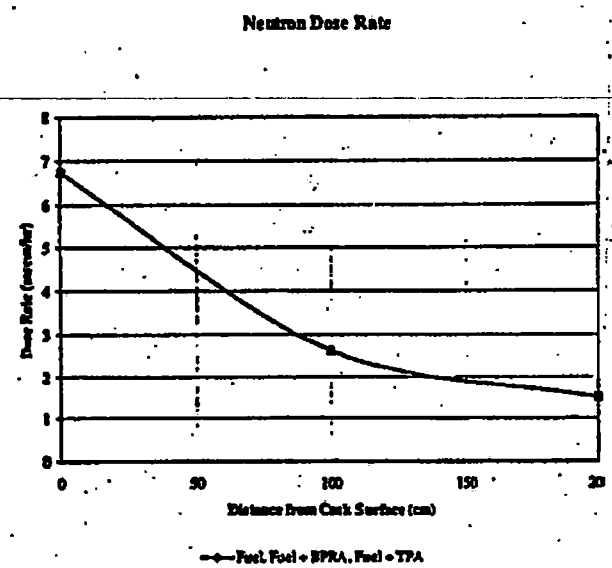
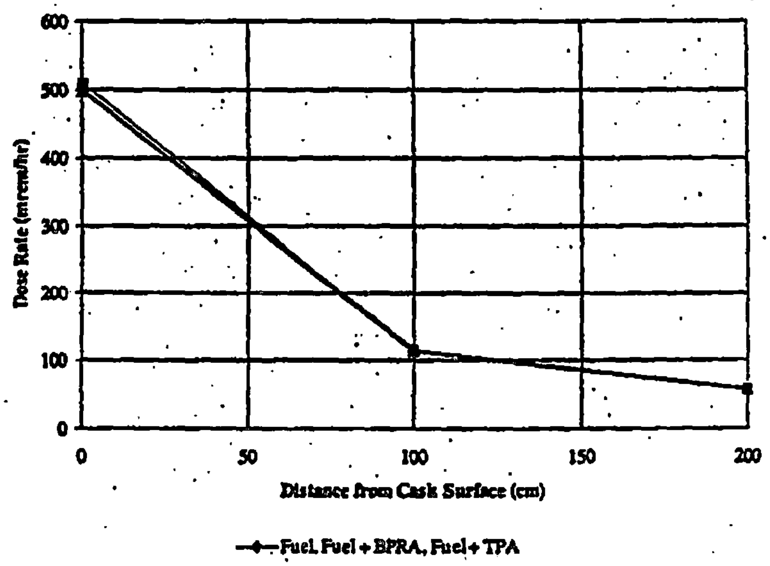


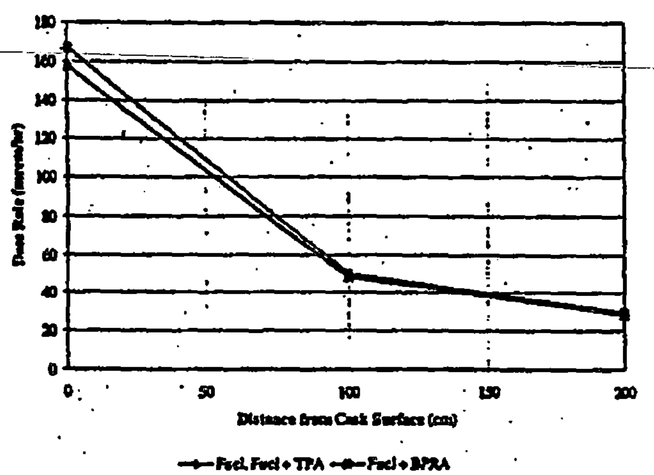
FIGURE 5.4-3

NORMAL AND ACCIDENT CONDITIONS
AXIAL DIRECTION - AVERAGE
BOTTOM

Total Dose Rate



Gamma Dose Rate



Neutron Dose Rate

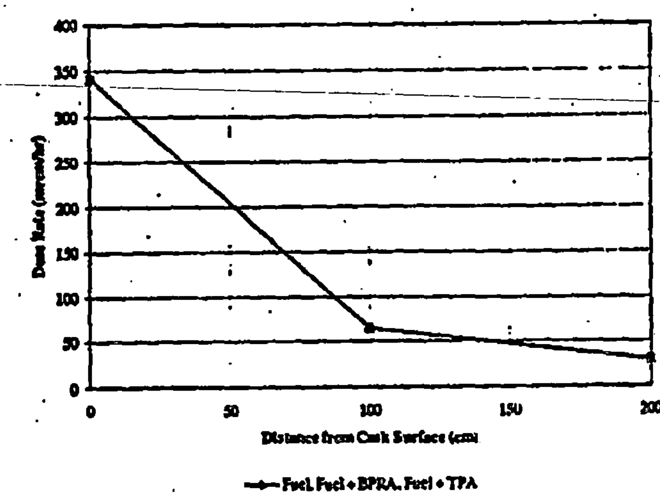
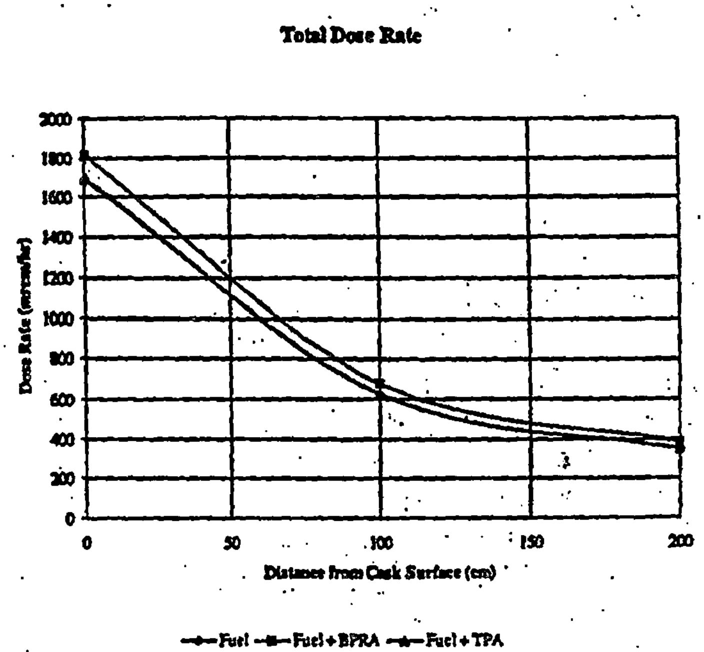
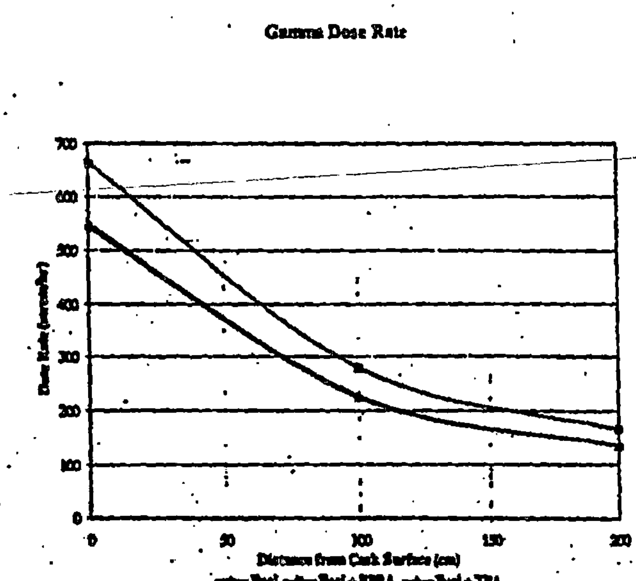


FIGURE 5.4-4

ACCIDENT CONDITIONS - RADIAL DIRECTION - MIDPLANE
AVERAGE OF TOP AND BOTTOM SAS4 RADIAL MODELS





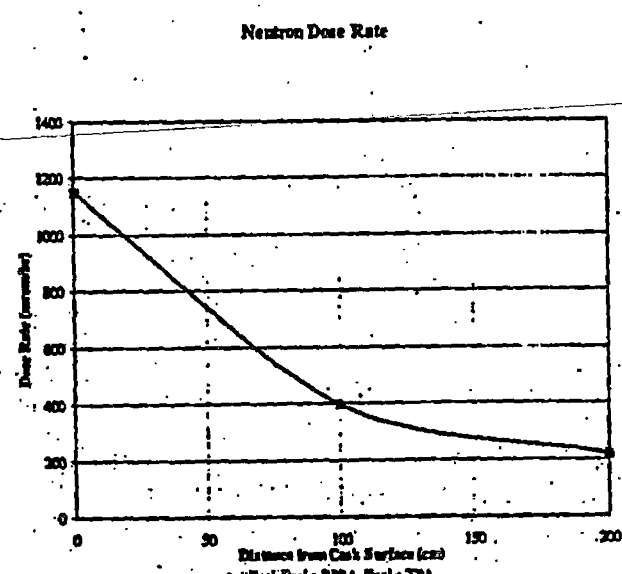
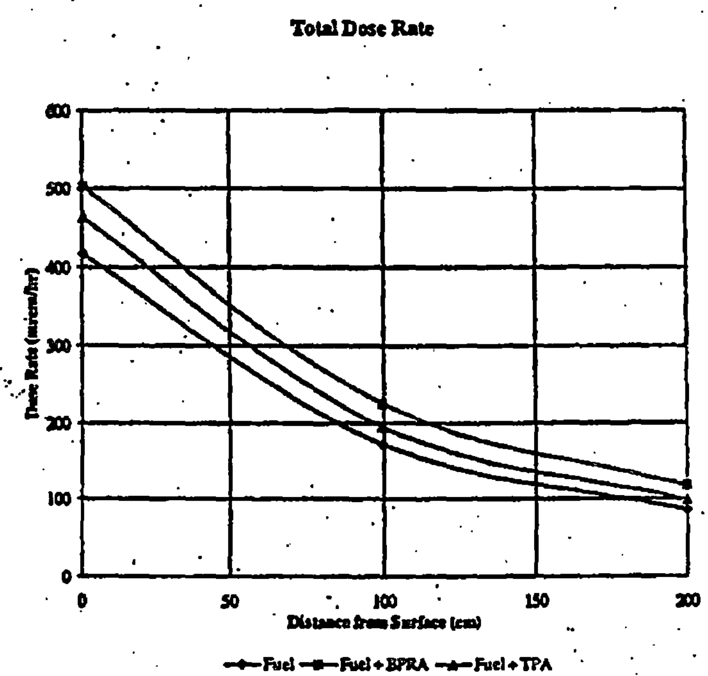
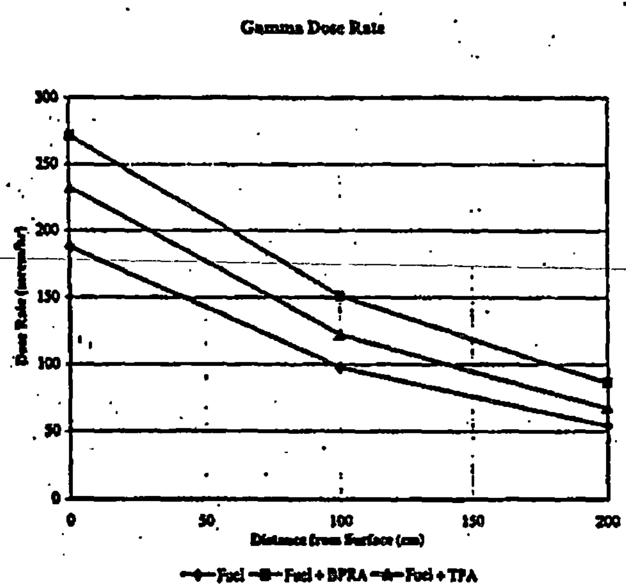


FIGURE 5.4-5

ACCIDENT CONDITIONS - AXIAL DIRECTION - AVERAGE
STANDARD LID (TN-32 and TN-32B) - TOP MODEL





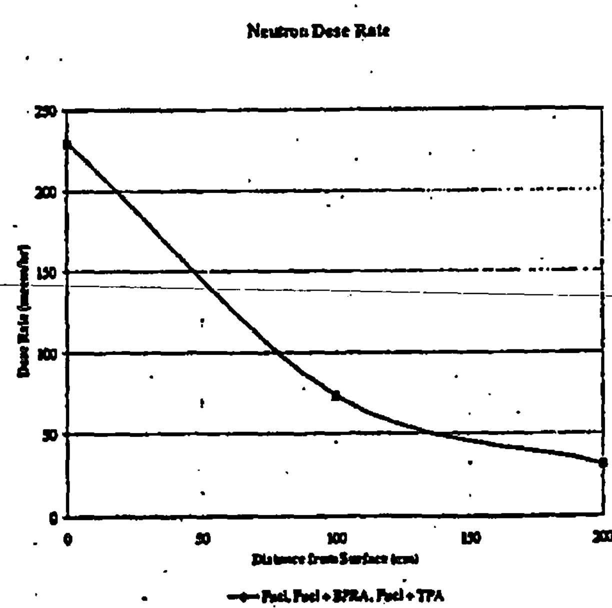
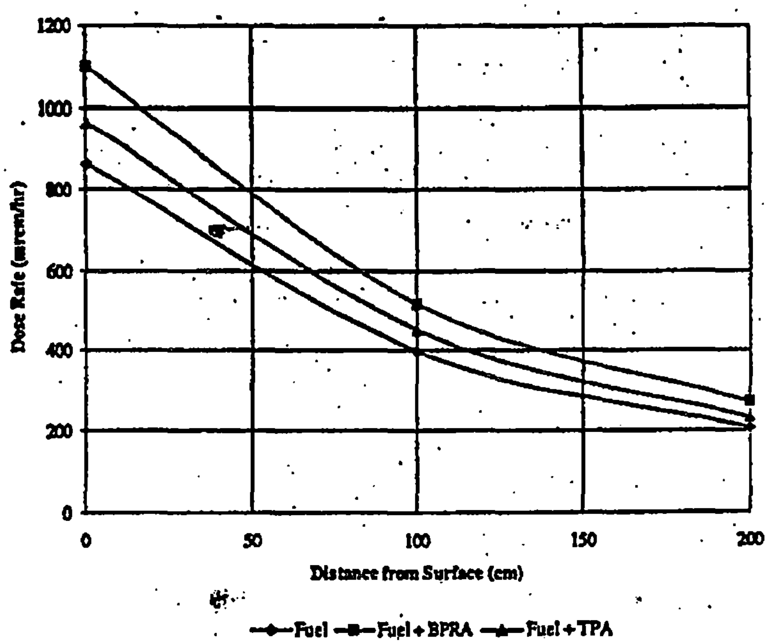


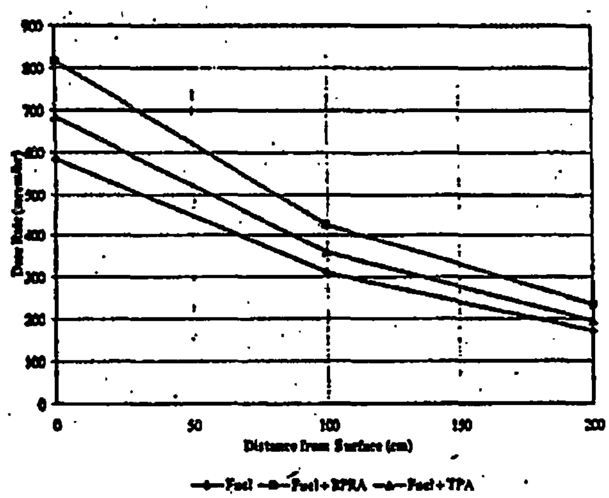
FIGURE 5.4-6

ACCIDENT CONDITIONS - AXIAL DIRECTION - AVERAGE
TYPE A LID (TN-32A) - TOP MODEL

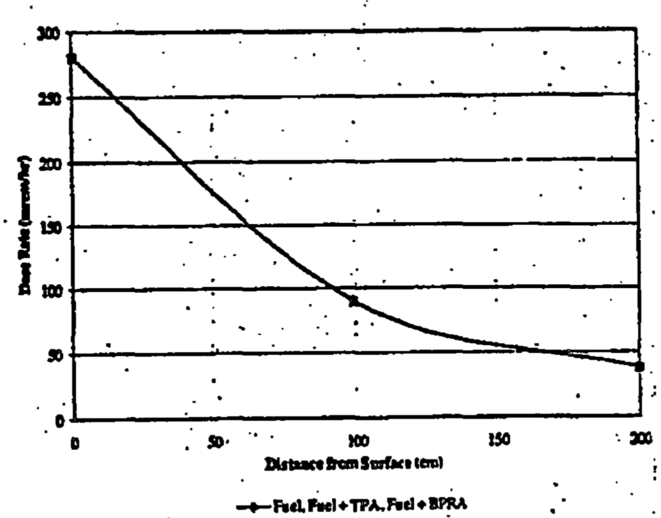
Total Dose Rate



Gamma Dose Rate



Neutron Dose Rate



APPENDIX 5A

EVALUATION OF MEASURED DOSE RATES

5A.1 Measured Dose Rates

Dose rates have been measured on two TN-32 casks which are currently stored at Virginia Power's Surry Station ISFSI. Radial gamma and neutron dose rates were measured at the cask surface,18 inches and 1 meter from the cask surface at various axial locations. The gamma dose rates were measured with a RSO-50-E instrument and the neutrons with a Ludlum "Remball". One of the casks contained spent fuel assemblies with BPRA inserts (TN-32-05) and the other cask (TN-32-07) had spent fuel without any inserts. Measurements were taken axially along the trunnion line (0°) and also at 90° from the trunnion. Figures 5A-1,5A-2, 5A-3 and 5A-4 show the measured dose rates. The neutron dose rates shown have been reduced by a factor of 2 to account for the conservative "Remball" readings. This reduction is based on a PNL report on measurements performed at Surry July 1998.

5A.2 Fuel Data

The fuel parameters for the two casks were similar except, as mentioned above, TN-32-05 contained BPRAs. The average burnup, enrichment and cool time for each cask was 35,975 MWD/MTU, 3.60%, 10.7 years and 36,300 MWD/MTU, 3.59%, and 10 years respectively. Because no BPRAs were involved, cask TN-32-07 was selected to perform a "benchmark" shielding evaluation against. The specific fuel data is shown in Table 5A-1 with the peripherally located assemblies shown in bold print. Since the peripheral assemblies strongly control the exterior dose rate, the average parameters for these assemblies was determined and source terms were prepared using these parameters of 35,000 MWD/MTU, 3.60% and 11 years cool time.

5A.3 Source Terms

A SAS2H/ORIGEN-S analysis (similar to Chapter 5) was performed using the 17x17 standard assembly with the fuel parameters listed above. Table 5A-2 lists the gamma spectra obtained from this analysis. The gamma source due to the assembly hardware, end fittings and plenum, was removed from the gamma spectrum and only the active fuel source, Table 5A-3, was conservatively used in the shielding analysis.

5A.4 Shielding Analysis

Gamma and neutron dose rates were calculated using the SAS4 shielding models, both top and bottom, utilized in Chapter 5. Primary gamma, capture gamma and neutron evaluations were made using the gamma and neutron sources calculated above. The average radial gamma and neutron doses at the surface and 1 meter from the surface in the neutron shield region were calculated and the results are shown below.

	Dose Rate (mrem/hr)	
Bottom model	contact	1 meter
Capture Gamma	6.46	2.15
Primary Gamma	43.8	17.7
Neutron	1.89	1.23
Top Model		
Capture Gamma	1.22	0.43
Primary Gamma	50.2	20.3
Neutron	4.74	1.86

Averaging the results from the top and bottom models, the calculated dose rates for the TN-32-07 cask are:

	Contact	1 meter
Gamma Dose	50.8 mrem/hr	20.3 mrem/hr
Neutron Dose	3.3 mrem/hr	1.5 mrem/hr
Total Dose	54.1 mrem/hr	21.8 mrem/hr

5A.5 Comparison of Measured and Calculated

~~From the data shown in Figures 5A-3 and 5A-4, an average~~ value can be calculated, in the resin shield area, for the measured data from the six readings each at contact and 1 meter, the following values are obtained.

	Contact	1 meter
Gamma Dose	7.0 mrem/hr	4.2 mrem/hr
Neutron Dose	10.7 mrem/hr	7.5 mrem/hr
Total Dose	17.7 mrem/hr	11.7 mrem/hr

"Correction" factors, the ratio of the calculated/measured, can be produced as shown below.

	Factor (calculated/measured)	
	contact	1 meter
Gamma Dose	7.3	4.8
Neutron Dose	0.31	0.21
Total Dose	3.1	1.9

It can be seen that the calculated gamma dose rate in the resin region is over predicted by a factor of about 7 and 5 at contact and 1 meter respectively. While the calculated neutron dose rate is under predicted by a factor of about 3 and 5 at contact and 1 meter respectively. Since the gamma makes up a larger portion of the total dose, the total calculated dose rate is still seen to be conservative by a factor of about 3 and 2 at contact and 1 meter respectively.

5A.6 Dose Above and Below Neutron Shield

In addition to the dose rates measured in the resin area, dose rates were also measured above and below the neutron shield (resin area). Calculation of dose rates in these areas using SCALE4.3 (SAS4) are difficult because point detectors must be used and meaningful results with good statistics are difficult. Therefore, it will be informative to evaluate the measured dose rates in the area above and below the neutron shield to determine their relative value (factor) compared to the average in the resin. This "factor" will be useful in predicting dose rates above and below the neutron shield for design basis fuel.

The measured dose rates for both casks will be used in this evaluation since it does not appear that the BPRAs in the fuel had a significant affect on the measured dose rates. The measured dose rates above and below the neutron shield are shown below for both casks.

Measured Dose Rates Contact (mrem/hr)

	Above Neutron Shield				Below Neutron Shield			
	Gamma		Neutron		Gamma		Neutron	
Cask	0°	90°	0°	90°	0°	90°	0°	90°
TN-32-05	12	20	35	40	6	10	23	55
TN-32-07	16	16	30	30	5	4	38	60

Cask	Measured Dose Rates 1 Meter (mrem/hr) Above Neutron Shield Gamma 0°	90°	Neutron 0°	90°	Below Neutron Shield Gamma 0°	90°	Neutron 0°	90°
TN-32-05	5	5	10	8	5	6	13	20
TN-32-07	4	4	8	9	4	4	9	20

Note: Values for 0° below shield are measured at the trunnion. Neutron dose at bottom is larger than top because of concrete reflection

If the measured dose rates above and below the neutron shield are compared to the average measured dose rate in the shield area (shown above as 7.0 and 10.7 contact gamma and neutron respectively and 4.2 and 7.5 at 1 meter), the following "factors" (above or below/center) are obtained.

Factors (above or below/midplane)
At Contact

Cask	Above Neutron Shield Gamma 0°	90°	Neutron 0°	90°	Below Neutron Shield Gamma 0°	90°	Neutron 0°	90°
TN-32-05	1.7	2.8	3.3	3.7	0.9	1.4	2.1	5.1
TN-32-07	2.3	2.3	2.8	2.8	0.7	0.6	3.6	5.6

Factors (above or below/midplane)
At 1 meter

Cask	Above Neutron Shield Gamma 0°	90°	Neutron 0°	90°	Below Neutron Shield Gamma 0°	90°	Neutron 0°	90°
TN-32-05	1.2	1.2	1.3	1.1	1.2	1.4	1.7	2.7
TN-32-07	1.0	1.0	1.1	1.2	1.0	1.0	1.2	2.7

An evaluation of the Factors determined above, gives the following observations:

At Contact:

- The largest ratio (Factor) of gamma dose above the neutron shield to average midplane dose is 2.8 while the average ratio is 2.3.
- The largest ratio of neutron dose above the neutron shield to average midplane dose is 3.7 while the average ratio is 3.2.

- The largest ratio of gamma dose below the neutron shield to average midplane dose is 1.4 while the average ratio 0.9.

- The largest ratio of neutron dose below the neutron shield to average midplane dose is 5.6 while the average ratio is 4.1.

At 1 Meter:

- The largest ratio of gamma dose above the neutron shield to average midplane dose is 1.2 while the average ratio is 1.1.

- The largest ratio of neutron dose above the neutron shield to average midplane dose is 1.3 while the average ratio is 1.2.

- The largest ratio of gamma dose below the neutron shield to average midplane dose is 1.4 while the average ratio 1.2.

- The largest ratio of neutron dose below the neutron shield to average midplane dose is 2.7 while the average ratio is 2.1.

TABLE 5A-1

FUEL DATA FOR TN-32-07

All Fuel Assemblies

	Initial Enrichment (wt% U-235)	Burnup (MWD/MTU)	Cooling Time (Days since Discharge)
	3.40	37198	2703
	3.40	38384	2703
	3.60	36536	2703
	3.60	39964	2703
	3.61	**32646**	**4729**
	3.61	**32267**	**4729**
	3.61	**30280**	**4729**
	3.61	**32824**	**4729**
	3.61	**30119**	**4729**
	3.61	**32658**	**4729**
	3.61	**35702**	**4729**
	3.61	36410	3459
	3.61	36677	3459
	3.61	37426	3459
	3.61	39431	3459
	3.61	38908	3459
	3.61	**36478**	**3459**
	3.61	38731	3459
	3.61	37305	3459
	3.61	38650	3459
	3.61	**36716**	**3459**
	3.61	38447	3459
	3.61	**37305**	**3459**
	3.61	36868	3459
	3.61	38616	3459
	3.61	38643	3459
	3.59	**36837**	**3459**
	3.59	**36377**	**3459**
	3.59	**36386**	**3459**
	3.59	**36583**	**3459**
	3.59	**37363**	**3613**
	3.60	**32611**	**3459**
average	3.59	36306	3647
max	3.61	39964	4729
min	3.40	30119	2703

Peripheral Assemblies

Initial Enrichment (wt% U-235)	Burnup (MWD/MTU)	Cooling Time (Days since Discharge)
3.61	32646	4729
3.61	32267	4729
3.61	30280	4729
3.61	32824	4729
3.61	30119	4729
3.61	32658	4729
3.61	35702	4729
3.61	36478	3459
3.61	36716	3459
3.61	37305	3459
3.59	36837	3459
3.59	36377	3459
3.59	36386	3459
3.59	36583	3459
3.59	37363	3613
3.60	32611	3459
3.60	**34572**	**4024**

35,000 MWd/MTU, 3.60 wt% initial enrichment, 4015 days (11 years) used for analysis

TABLE 5A-2

PRIMARY GAMMA SOURCE SPECTRUM
WESTINGHOUSE 17X17 ASSEMBLY
3.6 WT% U-235, 35,000 MWD/MTU, 11 YEAR COOLING TIME
(GAMMA/SEC/ASSEMBLY)

SCALE Energy Group No.	Fission Products	Actinides	Light Element	Total
28	1.31E-07	5.03E+04	0.00E+00	5.03E+04
29	9.79E-07	2.37E+05	0.00E+00	2.37E+05
30	7.69E-06	1.21E+06	0.00E+00	1.21E+06
31	2.67E-05	3.01E+06	0.00E+00	3.01E+06
32	1.60E+08	8.93E+06	1.27E-14	1.69E+08
33	1.27E+09	3.48E+08	6.68E+05	1.61E+09
34	2.38E+10	1.72E+07	4.31E+08	2.42E+10
35	8.94E+10	3.52E+07	1.55E+03	8.95E+10
36	4.39E+12	3.90E+07	1.82E+13	2.26E+13
37	4.51E+13	2.70E+08	6.43E+13	1.09E+14
38	5.57E+13	3.39E+08	6.17E+09	5.58E+13
39	1.32E+15	6.72E+08	7.62E+07	1.32E+15
40	9.26E+13	9.13E+08	2.19E+08	9.26E+13
41	2.93E+13	1.55E+10	3.46E+09	2.93E+13
42	4.58E+13	1.89E+11	2.64E+09	4.60E+13
43	1.60E+14	2.67E+11	5.31E+10	1.60E+14
44	2.04E+14	1.11E+13	2.20E+11	2.15E+14
45	7.44E+14	8.18E+12	1.12E+12	7.54E+14
Totals	2.70E+15	1.97E+13	8.39E+13	2.81E+15

TABLE 5A-3

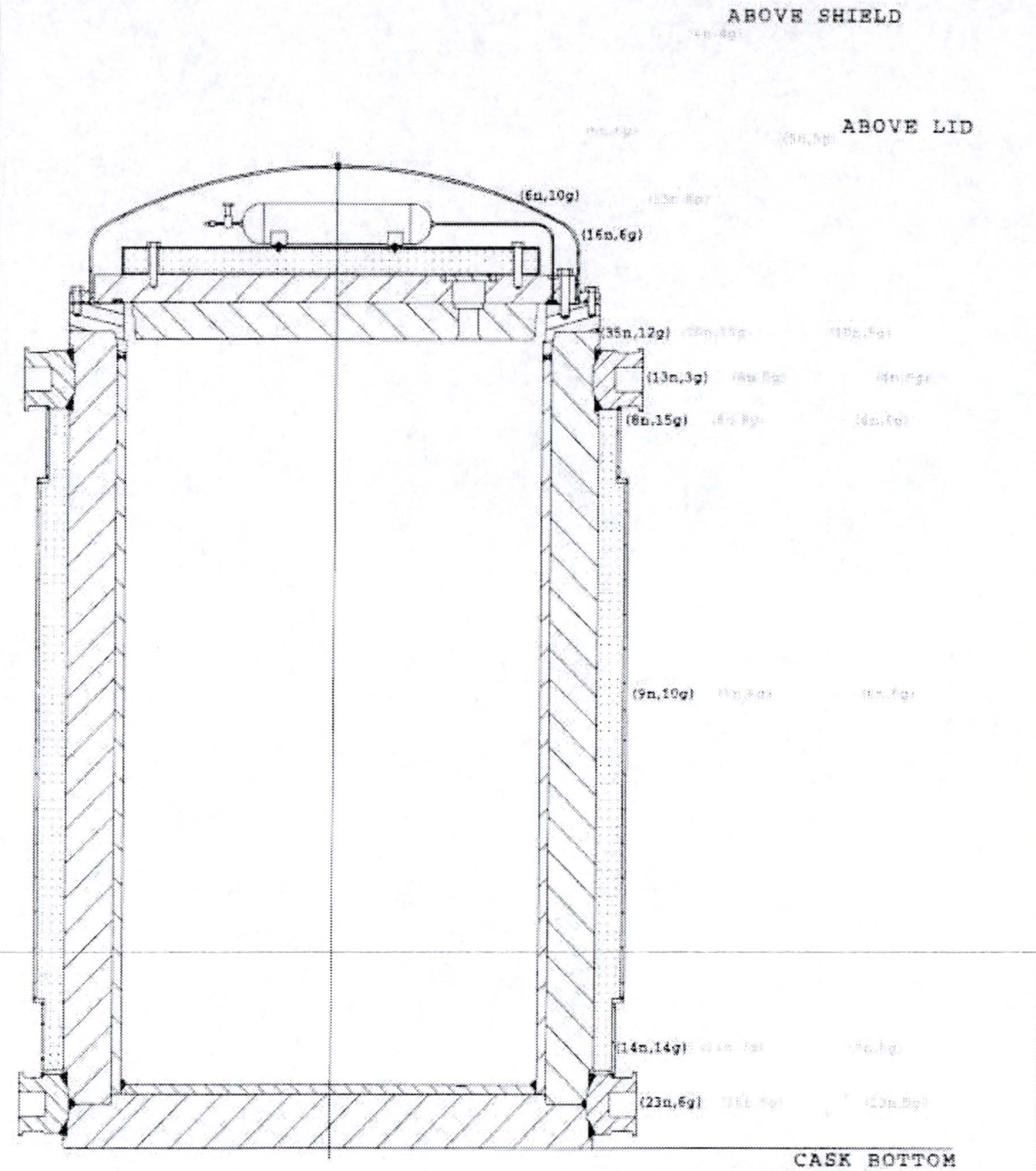
GAMMA AND NEUTRON SPECTRA FOR ACTIVE FUEL REGION
WESTINGHOUSE 17X17 ASSEMBLY
3.6 WT% U-235, 35,000 MWD/MTU, 11 YEAR COOLING TIME

GAMMA/SEC/ASSEMBLY

SCALE Energy Group No.	Fission Products	Actinides	Light Element	Total	Fractions
28	1.31E-07	5.03E+04	0.00E+00	5.03E+04	1.80E-11
29	9.79E-07	2.37E+05	0.00E+00	2.37E+05	8.46E-11
30	7.69E-06	1.21E+06	0.00E+00	1.21E+06	4.32E-10
31	2.67E-05	3.01E+06	0.00E+00	3.01E+06	1.08E-09
32	1.60E+08	8.93E+06	1.27E-14	1.69E+08	6.02E-08
33	1.27E+09	3.48E+08	6.68E+05	1.61E+09	5.76E-07
34	2.38E+10	1.72E+07	4.31E+08	2.42E+10	8.64E-06
35	8.94E+10	3.52E+07	1.55E+03	8.95E+10	3.19E-05
36	4.39E+12	3.90E+07	1.69E+13	2.13E+13	7.61E-03
37	4.51E+13	2.70E+08	5.99E+13	1.05E+14	3.75E-02
38	5.57E+13	3.39E+08	6.17E+09	5.58E+13	1.99E-02
39	1.32E+15	6.72E+08	7.62E+07	1.32E+15	4.72E-01
40	9.26E+13	9.13E+08	2.19E+08	9.26E+13	3.30E-02
41	2.93E+13	1.55E+10	3.46E+09	2.93E+13	1.04E-02
42	4.58E+13	1.89E+11	2.64E+09	4.60E+13	1.64E-02
43	1.60E+14	2.67E+11	5.31E+10	1.60E+14	5.71E-02
44	2.04E+14	1.11E+13	2.20E+11	2.15E+14	7.69E-02
45	7.44E+14	8.18E+12	1.12E+12	7.54E+14	2.69E-01
total	2.70E+15	1.97E+13	7.83E+13	2.80E+15	

NEUTRON/SEC/ASSEMBLY

SCALE Energy Group No.	Source	fraction
1	1.64E+06	1.82E-02
2	1.89E+07	2.10E-01
3	2.13E+07	2.37E-01
4	1.18E+07	1.31E-01
5	1.58E+07	1.76E-01
6	1.72E+07	1.91E-01
7	3.36E+06	3.74E-02
Total	9.00E+07	

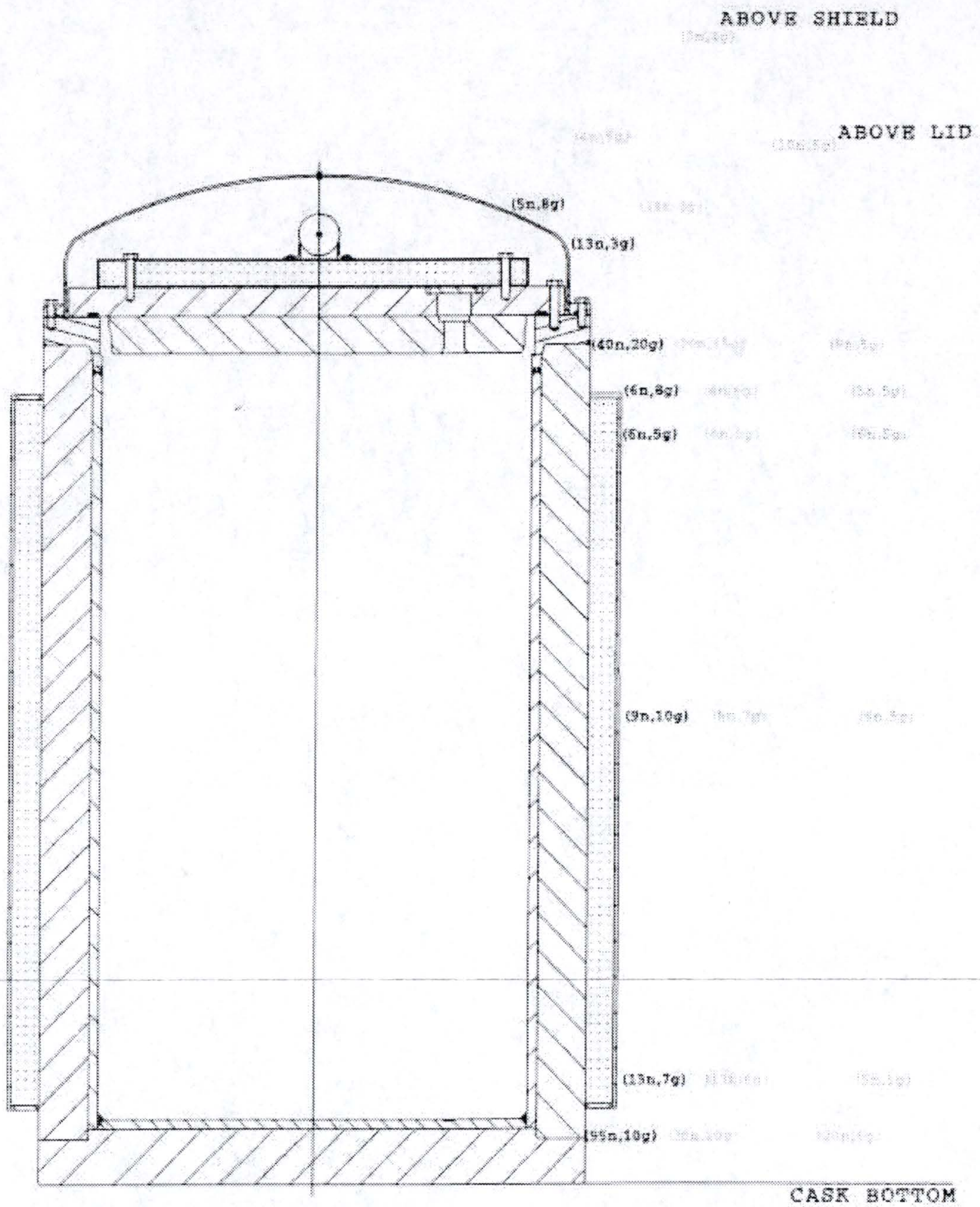


* NOTE: DOSE MEASUREMENTS ARE AT CONTACT, [illegible] AND [illegible] FROM SURFACE.

DOSE MEASUREMENTS ARE IN mrem/hr.

FIGURE 5A-1
CASK TN-32-05
DOSE MEASUREMENTS
0° FROM TRUNNIONS

REV. 0 1/00

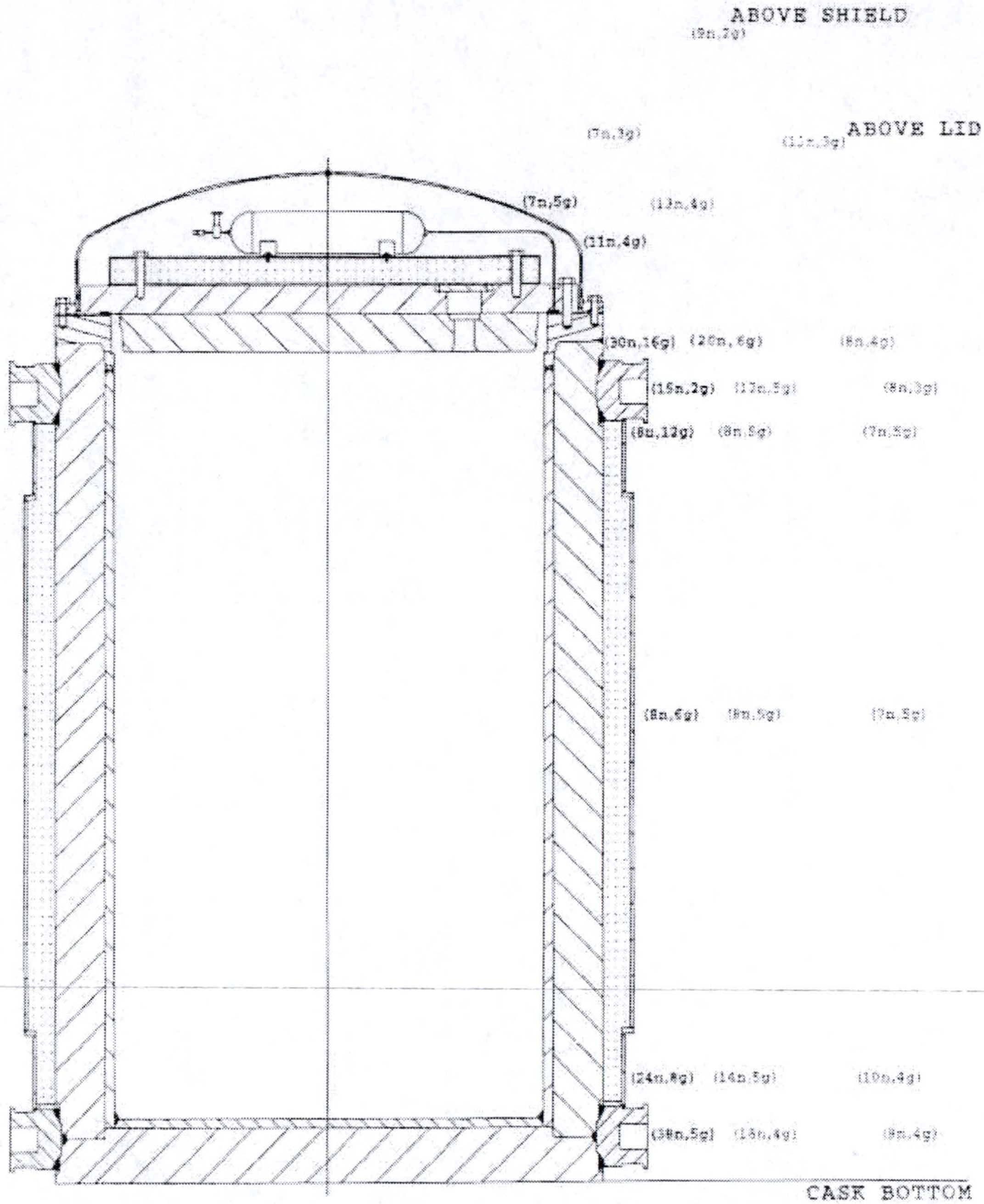


* NOTE: DOSE MEASUREMENTS ARE AT CONTACT, [illegible] AND [illegible] FROM SURFACE.

DOSE MEASUREMENTS ARE IN mrem/hr.
90° PERPENDICULAR TO TRUNNIONS

FIGURE 5A-2
CASK TN-32-05
DOSE MEASUREMENTS
90° FROM TRUNNIONS

REV. 0 1/00

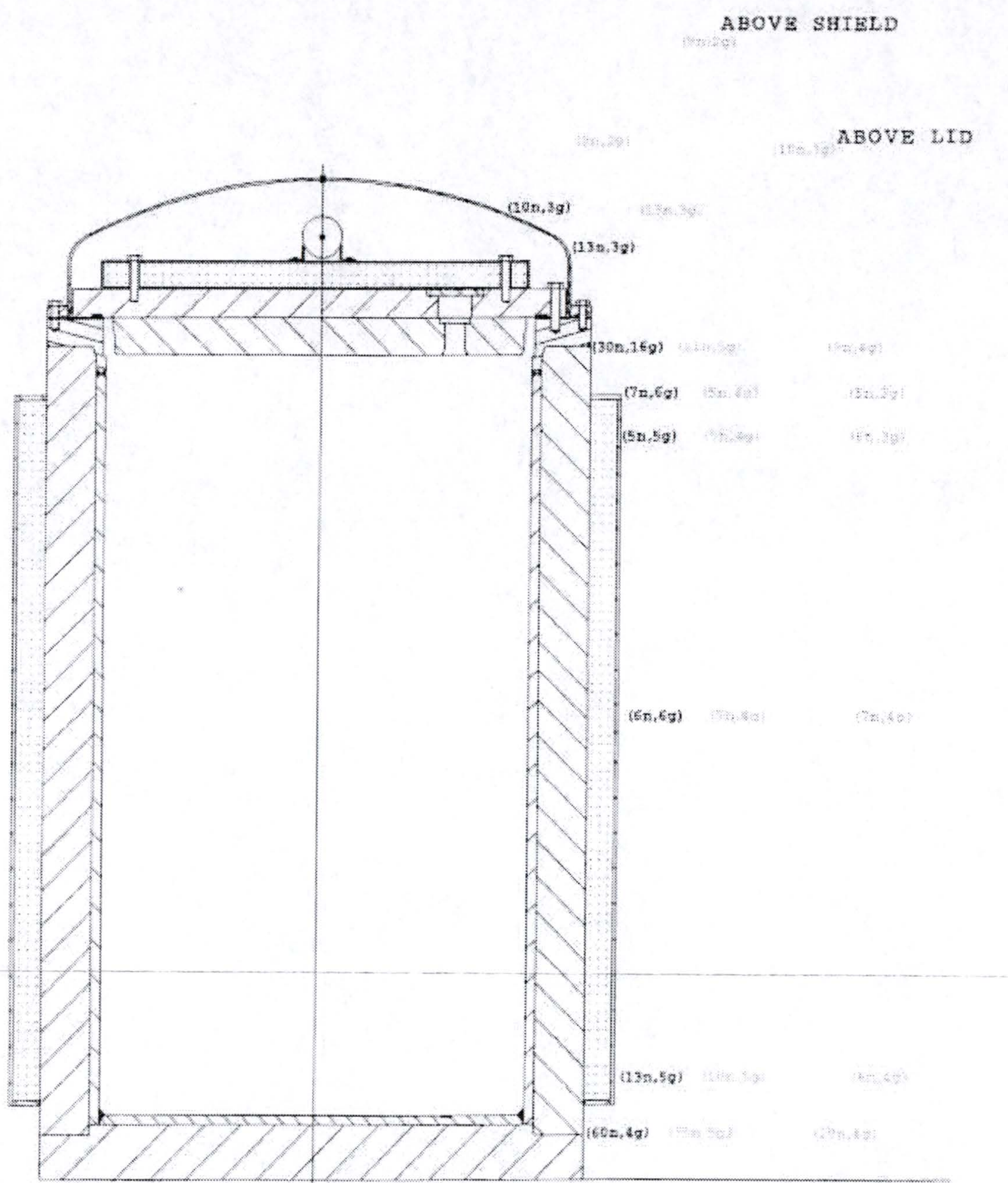


* NOTE: DOSE MEASUREMENTS ARE AT CONTACT, 18 INCHES AND 1 METER FROM SURFACE.

DOSE MEASUREMENTS ARE IN mrem/hr.

FIGURE 5A-3
CASK TN-32-07
DOSE MEASUREMENTS
0° FROM TRUNNIONS

REV. 0 1/00



* NOTE: DOSE MEASUREMENTS ARE AT CONTACT, AND FROM SURFACE.

DOSE MEASUREMENTS ARE IN mrem/hr.
90° PERPENDICULAR TO TRUNNIONS

FIGURE 5A-4
CASK TN-32-07
DOSE MEASUREMENTS
90° FROM TRUNNIONS

REV. 0 1/00

CHAPTER 6

CRITICALITY EVALUATION

6.1 Discussion and Results

Criticality control in the TN-32 is performed by the basket structural components, which maintain the relative position of the spent fuel assemblies under normal and accident conditions by the neutron absorbing plates between the basket compartments, and by dissolved boron in the spent fuel pool water. The structural analysis of the TN-32 basket is presented in Chapter 3.

The TN-32 contents are limited to the Westinghouse and B&W fuel designs listed in Chapter 2, with a maximum enrichment of 4.05 wt % U235. Fuel assemblies with or without burnable poison rod assemblies are acceptable. Criticality control does not require special loading patterns or special orientation of the fuel assemblies.

The criticality evaluation is divided into several sections:

a) Determination of the most reactive fuel configuration is provided in Section 6.4.2A. All of the design basis fuels are evaluated to determine the most reactive geometry. Placement of fuel assembles shifted off the center of the compartment cross section is also evaluated here.

b) TN-32 criticality evaluation is provided in Section 6.4.2B. The most reactive fuel is used for this evaluation. The TN-32 cask is evaluated for the following conditions, which bound normal conditions and the off-normal and accident events listed in Chapter 11:

- varied water density and partial drain-down,
- variation in critical basket dimensions,
- axial offset of active fuel and neutron absorber plates, and
- loading of a single fuel assembly with higher than TN-32 design basis enrichment,
- fresh water in the fuel pellet - cladding annulus
- postulated reduction of pin pitch due to fuel grid crushing in a tipover accident.

Appendix 6A provides a structural analysis which demonstrates that the fuel rods will remain intact under the tipover and 18 inch end drop accident conditions.

Non-uniform flooding of the basket is not evaluated because all the spaces in the basket are interconnected, and therefore this is not a credible condition.

The various effects are evaluated individually, and are combined as required to demonstrate compliance with the

requirement of 10CFR72.124 that "before a criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety."

The evaluation demonstrates that the TN-32 cask meets the requirement $k_{eff} + 2\sigma \leq$ Upper Subcritical Limit for all these conditions.

c) Benchmarking (Section 6.5). An upper subcritical limit (USL) is determined by subtracting from unity an administrative margin of 0.05, the bias determined from benchmark calculations and any modeling bias.

All calculations assume fresh fuel composition and ignore burnable poisons when evaluating burnable poison rod assemblies.

6.2 Fuel Specification

The allowable contents are listed in Chapter 2 and in the Functional and Operating Limits (Section 2.1) of the Technical Specifications provided in Chapter 12. Fuel characteristics used in the criticality calculations are listed in Table 6.2-1.

To maintain subcriticality, the maximum enrichment of the fuel must be less than or equal to 4.05 weight % U235.

Each of the fuel assembly types listed in the Technical Specifications has been evaluated in Section 6.4.2A.

The acceptable contents of the TN-32 do not include failed fuel other than fuel with hairline cracks or pinholes in the cladding. Fuel bundles from which fuel pins are missing are not allowable contents unless the missing pin is replaced by a fuel pin or dummy pin that displaces equivalent volume.

6.3 Model Specification

6.3.1 Description of Calculational Model

A 3-dimensional model of the fuel, basket, cask body, and water reflector is used as shown in Figures 6.3-1, 6.3-2 and 6.3-3. Fuel pins guide tubes, and instrument tubes are modeled individually. The top and bottom fuel hardware are modeled as pure water. The stainless steel basket compartment tubes, stainless steel bars, neutron poison plates, and gaps are modeled explicitly. Table 6.3-1 compares the model dimensions with the design dimensions.

All analyses use 2300 ppm boron in the water, except at the basket perimeter, where the aluminum rails are homogenized with 2000 ppm borated water. The lower boron concentration in the basket perimeter is conservative.

There are some minor differences between the criticality model and the actual basket design. These differences are described below. The most significant difference between the model and the actual basket is that the basket has holes in the neutron absorber plates at the location of the stainless steel plugs to which the compartment tubes are welded. See Chapter 1, drawing 1049-70-6, details A and B. The model does not include these holes. In the model, the gaps on either side of the neutron absorber plates, which under actual loading conditions will be filled with borated water, are modeled as void spaces. To evaluate the difference between the actual basket and the model, a single basket compartment with plugs was modeled with a centered fuel assembly, and reflected on 4 sides to simulate an infinite array of such cells. This model is shown in Figure 6.3-4. This model includes 2300 ppm borated water in the fuel compartment, in the gaps on either side of the neutron absorber plates, and in the clearance holes around the plugs. This model is then modified to look like the general cask model, with continuous neutron poison plates, no stainless steel plugs, and void gaps.

The model with the plugs yields $k_{eff} = 0.9467 \pm 0.0012$. The model without plugs yields $k_{eff} = 0.9461 \pm 0.0013$. Note that the k_{eff}'s here are not representative of the TN-32 cask. They are for an infinite array of compartments, and are only for comparison with each other. The results are statistically equivalent, but the 0.0006 Δk_{eff} will be treated as a modeling bias in determining the upper subcritical limit.

6.3.2 Cask Regional Densities

Materials are converted to atom densities by the Material Information Processor in the CSAS25 code sequence[1]. The mass densities supplied to the code are reported in Table 6.3-2.

The specific gravity, of borated water at 4350 ppm is given as 1.0078 in Ref 1, Section M.7.5.7, Example 2. Interpolating between sg=1.0 at 0 ppm and sg=1.0078 at 4350 ppm yields sg≈1.0045. For water density of 0.9982 g/cm^3, the corresponding density of 2300 ppm borated water is ~1.0045(0.9982)=1.0027 g/cm^3.

The neutron absorber is an alloy of aluminum and about 4.5 wt % boron, the boron being enriched to about 95 atom wt% B10. This material is subjected to the extensive acceptance testing as described in Section 9.1.7A. Therefore, the calculations take credit for 90% of the minimum specified boron 10 areal density, which is 10 mg B10/cm^2. The SCALE mixing table output lists a weight fraction of 0.0329724 for B10; using the density and thickness of the plate confirms the areal density:

$$2.693\ g/cm^3(0.0329274)0.1016\ cm = 0.0090\ g\ B10/cm^2$$

This material is not subject to degradation in the dry storage environment. It is a solid, non-friable material physically similar to its base aluminum alloy. It does not include any organic components or binders. The plates are held in place and protected from damage by the surrounding stainless steel bar and tube structure. The basket structure encloses the neutron absorber plates on all six sides.

The neutron absorber materials are exposed to borated water for a short time during fuel loading. After loading, the inert environment of the cask assures that there will be no degradation due to corrosion. Boron depletion due to neutron absorption is evaluated as follows.

Using the total scalar flux of 8.41x 10^5 n/cm^2 s at the center of the basket (see Table 14.1-1), assuming that flux to be constant and thermal, and using the thermal neutron cross section for boron 10, (3837 barn), the fraction of the original boron 10 depleted after 1000 years would be:

$$8.41x10^5\ n/cm^2\ s\ (3837x10^{-24}\ cm^2)\ 3.156x10^7\ s/year\ (1000\ year) = 1x10^{-4},$$

which is negligible. The actual flux is mostly fast and epithermal, and declining with time, so the actual depletion during dry storage will be less than the depletion calculated. Therefore, the continued efficacy of the neutron poison is assured.

6.4 Criticality Calculation

6.4.1 Calculational or Experimental Method

All calculations are performed using the CSAS25 sequence from the SCALE4.3 code system[1] with the SCALE 27-group ENDF/B-IV cross section library. Within this sequence, resonance correction based on the fuel pin cell description is performed by NITAWL using the Nordheim Integral method, and k_{eff} is determined by the KENOVa code using the Monte Carlo technique. A sufficiently large number of neutron histories is run so that the standard deviation is below 0.0020 for all calculations.

6.4.2 Fuel Loading or Other Contents Loading Optimization

A. Determination Of The Most Reactive Fuel Configuration

All fuels listed in Table 6.2-1 are evaluated with the maximum TN-32 design basis fuel enrichment, 4.05%. The fuels are analyzed with voids in the fuel pellet-cladding annulus, with and without burnable poison rod assemblies, and with fuel both centered in the compartment and shifted toward the cask vertical axis. The calculations in this section only use a density of 1.0078 g/cm^3 for 2300 ppm borated water.

Where there are variations in a reported value for a given fuel design, values are chosen for the analysis as follows:

- maximum fuel pin diameter, conservative when fuel/cladding annulus is void or borated water
- maximum active length
- minimum cladding thickness, conservative when fuel/cladding annulus is borated water; unimportant for void
- maximum guide tube diameter and maximum guide tube wall thickness for maximum displacement of borated water; except for the 14x14 OFA, the instrument tubes are modeled with the same dimensions as the guide tubes. The effect is negligible, as there is only one instrument tube per assembly.

Since no credit is taken for burnable absorbers, fuel with burnable poison rod assemblies (BPRA's), are assumed to have all guide tubes filled with aluminum instead of borated water. No credit is taken for any boron in the burnable poison rod assemblies; only the effect of borated water displacement is analyzed. It is conservatively assumed that there is no clearance between the burnable poison rod and the guide tube and that all guide tubes are filled with aluminum. This approach bounds the effect of burnable poison rods.

A typical input file is included in Section 6.6.1. The results of these calculations are listed in Table 6.4-1. The most reactive fuel lattice evaluated for the TN-32 is the

most reactive fuel lattice evaluated for the TN-32 is the Westinghouse standard 17x17 with BPRA, fuel shifted toward the cask vertical axis.

B. TN-32 Criticality Evaluation

The TN-32 is evaluated in a variety of configurations intended to bound all normal, off-normal, and accident conditions. The following conditions are evaluated individually:

- Baseline: Most reactive TN-32 design basis fuel configuration, 100% borated water density. The fuel assemblies are shifted toward the cask vertical axis until the outer pin cells contact the compartment wall. This is not a realistic configuration, but bounds all possibilities of fuel off-center in the compartment.
- The neutron absorber plates and the active fuel zone are offset by 2 inches axially. This might occur due to fuel design differences in the distance from the bottom of the fuel assembly to the beginning of the active fuel, or due to fuel pins slipping in the spacer grids during handling.
- The inside dimension of the compartment is increased and decreased 0.06 inches. All compartments move correspondingly further apart or closer together. This is greater than the dimensional tolerance on the basket tubes.
- The width of the neutron poison plate is reduced by 0.06 inch, corresponding to its dimensional tolerance. It is not necessary to evaluate the tolerance in length because it is bounded by the 2 inch axial offset condition above.
- Fresh water is placed in the annulus of all fuel rods. Although a fuel rod that develops a cladding breach in core could be saturated with non-borated water at the end of the cycle, it is unlikely that the water in the fuel pin would remain non-borated after years of storage in borated water.
- Borated water density is varied except in the homogenized basket rail/borated water zone to simulate the reduction in density that might occur during unloading operations.
- Borated water is drained down to the top of the active fuel, except in the basket rail zone. This is the most reactive configuration expected during loading and unloading, because it reduces the boron capture of reflected neutrons.

The results of these investigations are presented in Table 6.4-2. As expected physically, reduction of the neutron absorber plate width, reduction of compartment size, borated water drain-down, and inclusion of fresh water in the fuel pin annulus all cause a slight increase in k_{eff}. Optimal borated water density is found at about 95%.

These conditions are all combined for a worst case normal condition, and the borated water density is again varied from 85

to 100%, resulting in a maximum k_{eff} = 0.9264 ± 0.0009 at 90% borated water density.

To evaluate accident conditions, the worst case normal model is re-run with a single fuel assembly with enrichment in excess of the TN-32 design basis in one of the four center compartments of the basket. Fuel with 5% enrichment is assumed. This case demonstrates compliance with the requirement of 10CFR72.124 by combining at least two unlikely, independent, and concurrent changes in the conditions essential to nuclear criticality safety: worst case geometry and accidental loading of non-design basis fuel. The result is k_{eff} = 0.9315 ± 0.0009. The input file for this case is included in Section 6.6.4, and the model is shown in Figures 6.4-1 and -2.

C. Evaluation of Tipover and 18 inch Drop Accidents

Based on the structural evaluation presented in Appendix 6A, the criticality analysis assumes that under tipover and drop accident conditions, the fuel pins remain intact. In the end drop accident, the fuel rods may slide in the grid spacers until they contact the bottom plate. This condition has already been considered above by the two inch offset between the active fuel and the neutron absorber plate.

In the tipover accident, the fuel pin spacer grids may collapse, resulting in the fuel rods moving closer together. Therefore, reduced pin pitch is evaluated as the credible tipover accident configuration. The fuels are modeled with pin pitch uniformly reduced using the worst case normal model developed above and varying densities of 2300 ppm borated water. Results shown in Table 6.4-3 indicate that k_{eff} decreases uniformly with pin pitch.

D. Conclusion

ANS/ANSI-8.1[7] recommends that calculational methods used in determining criticality safety limits for applications outside reactors be validated by comparison with appropriate critical experiments. An upper subcritical limit (USL) provides a high degree of confidence that a given system is subcritical if a criticality calculation based on the system yields a multiplication factor (k_{eff}) below the USL. The upper subcritical limit is determined in Section 6.5 to be 0.9341. The analysis provided above verifies that in normal, off-normal, and accident conditions, $k_{eff} + 2\sigma \leq 0.9341$ Therefore, the fuel will remain subcritical.

6.5 Critical Benchmark Experiments

6.5.1 Benchmark Experiments and Applicability

The critical experiments and input files are taken from NUREG/CR-6361[2]. The input files are obtained from ORNL, and modified to change the cross section library to the SCALE 27 group library that is used in all the TN-32 criticality evaluations. Experiments which feature simple arrays, separator plates, steel reflector walls, water holes, borated poison plates, and dissolved boron are selected. Experiments with features that are not characteristic of the TN-32 storage cask are not used. Such features include poisons other than boron, poison rods, reflector walls other than steel, and flux traps. The 98 critical experiments chosen are listed in Tables 6.5-1 and 6.5.2.

An upper subcritical limit (USL) is determined using Method 1, "confidence band with administrative margin", described in Section 4.1.1 of NUREG/CR-6361. The administrative margin will be 0.05, and the confidence level $1-\gamma_1$ will be 0.95. It is assumed that the actual value of k_{eff} in all the experiments is exactly 1. Statistical analysis of benchmark results was performed using the PC version of the USLSTATS program, Version 1.3.4, distributed by Oak Ridge National Laboratory[2].

The characteristics water/fuel volume, hydrogen to fissile atom ratio (H/X), fuel pin pitch, and enrichment, are listed in Tables 2.1 and 3.5 of NUREG/CR-6361. One additional characteristic, boron 10 concentration in the separator plates, is calculated in Table 6.5-3. A comparison of the range of these characteristics in the experiments, and the corresponding values for the TN-32 and its contents verifies that the TN-32 falls within the range covered by the critical experiments. See Table 6.5-4.

6.5.2 Results of the Benchmark Calculations

The results of the benchmark calculations are listed in Table 6.5-1 and 6.5-2.

Seven subsets of the results are analyzed to determine if there is a trend in the bias (calculated k_{eff} -1) as a function of an experimental variable. In all subsets, the data test normal, although the sample size for the boron density is too small for this determination to be conclusive. A least mean squares linear regression is performed to fit the data of k_{eff} as a function of each independent variable, and the Pearson correlation coefficient *r* is determined. A coefficient of zero indicates no correlation, and a coefficient of $|1|$ indicates exact correlation. The results are listed in Table 6.5-4. The values of the correlation coefficient indicate that there is very little correlation between the bias and any of the experimental variables, and therefore, no discernible trend.

The minimum value of the USL from all the data sets is 0.9347, which is correlated with dissolved boron concentration as shown in Table 6.5-4. As shown in Section 6.3.1, there is a modeling bias of 0.0006 and therefore 0.9347-0.0006 = 0.9341 is the upper subcritical limit to be used for the criticality safety evaluation.

6.6 Supplemental Data

6.6.1 Sample Input File for Determination of Most Reactive Configuration

```
=CSAS25
TN32 b17shift 17x17 non-ofa / off center / 2300 ppm borated
water, 90% b10
27GROUPNDF4   LATTICECELL
UO2  1  0.95     293.  92235 4.05  92238 95.95  END
ZIRCALLOY  2  1.0  END
H2O   3   1.0   END
SS304   4   1.0   END
' BORATED H2O  2300 PPM
ARBMH3BO3  0.013253 3 1 1 0 5000 1 1001 3 8016 3 5 1.0 293  END
H2O  5  0.996340  END
' BORAL CORE  10MG/CM2 !!!NOT USED!!!
B4C    6    DEN=2.64   0.417   END
AL     6    DEN=2.64   0.583   END
CARBONSTEEL  7  1.0  END
AL      8     1.0   END
' EAGLE PICHER BORATED AL  (.040") !!!90% B10 CREDIT!!!
BORON    9    DEN=2.693    0.03811 293.    5010 86.4   5011 13.6   END
AL       9    DEN=2.693    0.96189  END
' BORATED H2O/AL HOMOG mix AT PERIPHERY !!!2000 PPM!!!
AL     10     0.303   END
ARBMH3BO3  0.01152 3 1 1 0 5000 1 1001 3 8016 3 10 0.697 293  END
H2O  10  0.69566   END
END COMP
SQUAREPITCH  1.2598  0.8192  1  5  0.9500  2  0.8357  0  END
TN32 CRITICALITY 2300 PPM BORATED H2O WITH BAL (0.040")
READ PARAM RUN=yes PLT=no TME=5000 GEN=203 NPG=2000 END PARAM
READ GEOM
BOX TYPE  1  COM=&  NEXT EIGHT BOXES ARE +X+Y QUADRANT &
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049  213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  8  1  11.9507 -12.5857  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  11.9507 -12.6365  213.04 -193.36
HOLE  33     -12.6365     0.      0.
HOLE  34     0.     -12.5857     0.
BOX TYPE  2
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  2P11.3157  213.04 -193.36
HOLE  35     -11.3665      0.      0.
CUBOID  8  1  12.5857 -12.0523  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  12.5857 -12.0523  11.9507 -12.6365  213.04 -193.36
```

```
HOLE  34    0.     -12.5857    0.
BOX TYPE  3
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  2P11.3157  213.04 -193.36
HOLE  35    -11.3665    0.      0.
CUBOID  8  1  11.3157 -11.4173  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  11.3157 -11.4173  11.9507 -12.6365  213.04 -193.36
HOLE  34    0.     -12.5857    0.
BOX TYPE  4
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  3P11.3157 -11.4173  213.04 -193.36
HOLE  36    0.     -11.3665    0.
CUBOID  8  1  11.9507 -12.5857 11.9507 -12.0523  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  11.9507 -12.0523  213.04 -193.36
HOLE  33    -12.6365    0.     0.
BOX TYPE  5
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.3157 -11.4173  213.04 -193.36
HOLE 35    -11.3665    0.     0.
HOLE  36    0.     -11.3665    0.
CUBOID  8  1  12.5857 -12.0523  11.9507 -12.0523  213.04 -193.36
BOX TYPE  6
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.3157 -11.4173  213.04 -193.36
HOLE  35    -11.3665    0.     0.
HOLE  36    0.     -11.3665    0.
CUBOID  8  1  11.3157 -11.4173  12.5857 -12.0523  213.04 -193.36
CUBOID  4  1  11.3157 -11.4173  12.8524 -12.0523  213.04 -193.36
BOX TYPE  7
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  3P11.3157 -11.4173  213.04 -193.36
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  11.9507 -12.5857  11.3157 -12.0523  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  11.3157 -12.0523  213.04 -193.36
```

```
HOLE  33    -12.6365    0.    0.
BOX TYPE  8
ARRAY  1    -11.049  -11.049    -182.88
CUBOID  3  1   10.3676  -11.049  10.3676  -11.049   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.3157 -11.4173  213.04 -193.36
HOLE  35    -11.3665    0.    0.
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  12.5857 -12.0523  11.3157 -12.0523  213.04 -193.36
CUBOID  4  1  12.5857 -12.0523  11.3157 -12.0523  213.04 -193.36
BOX TYPE  9  COM=&  NEXT EIGHT BOXES ARE +X-Y QUADRANT &
ARRAY  1    -11.049  -10.3676    -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  8  1  11.9507 -12.5857  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  12.6365 -11.9507 213.04 -193.36
HOLE  33    -12.6365   0.    0.
HOLE  34    0.    12.6365    0.
BOX TYPE  10
ARRAY  1    -11.049  -10.3676    -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  2P11.3157  213.04 -193.36
HOLE  35    -11.3665    0.    0.
CUBOID  8  1  12.5857 -12.0523  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  12.5857 -12.0523  12.6365 -11.9507  213.04 -193.36
HOLE  34    0.    12.6365    0.
BOX TYPE  11
ARRAY  1    -11.049  -10.3676    -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  2P11.3157  213.04 -193.36
HOLE  35    -11.3665    0.    0.
CUBOID  8  1  11.3157 -11.4173  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  11.3157 -11.4173  12.6365 -11.9507  213.04 -193.36
HOLE  34    0.    12.6365    0.
BOX TYPE  12
ARRAY  1    -11.049  -10.3676    -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  2P11.3157  11.4173 -11.3157  213.04 -193.36
HOLE  36    0.    11.3665    0.
CUBOID  8  1  11.9507 -12.5857  12.0523 -11.9507  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  12.0523 -11.9507  213.04 -193.36
```

```
HOLE  33    -12.6365    0.     0.
BOX TYPE  13
ARRAY  1    -11.049  -10.3676     -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.4173 -11.3157  213.04 -193.36
HOLE 35    -11.3665    0.     0.
HOLE  36    0.    11.3665    0.
CUBOID  8  1  12.5857 -12.0523  12.0523 -11.9507  213.04 -193.36
BOX TYPE  14
ARRAY  1    -11.049  -10.3676     -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.4173 -11.3157  213.04 -193.36
HOLE  35    -11.3665    0.     0.
HOLE  36    0.    11.3665    0.
CUBOID  8  1  11.3157 -11.4173  12.0523 -12.5857  213.04 -193.36
CUBOID  4  1  11.3157 -11.4173  12.0523 -12.8524  213.04 -193.36
BOX TYPE  15
ARRAY  1    -11.049  -10.3676     -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  2P11.3157  11.4173 -11.3157  213.04 -193.36
HOLE  36    0.    11.3665    0.
CUBOID  8  1  11.9507 -12.5857  12.0523 -11.3157  213.04 -193.36
CUBOID  0  1  11.9507 -12.6365  12.0523 -11.3157  213.04 -193.36
HOLE  33    -12.6365    0.     0.
BOX TYPE  16
ARRAY  1    -11.049  -10.3676     -182.88
CUBOID  3  1   10.3676  -11.049  11.049  -10.3676   213.04  -
193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  0  1  11.3157 -11.4173  11.4173 -11.3157  213.04 -193.36
HOLE  35    -11.3665    0.     0.
HOLE  36    0.    11.3665    0.
CUBOID  8  1  12.5857 -12.0523  12.0523 -11.3157  213.04 -193.36
CUBOID  4  1  12.5857 -12.0523  12.0523 -11.3157  213.04 -193.36
BOX TYPE  17  COM=& NEXT 8 BOXES ARE -X+Y QUADRANT &
ARRAY  1    -10.3676  -11.049     -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04   -193.36
CUBOID  4  1   4P11.3157 213.04   -193.36
CUBOID  8  1  12.5857 -11.9507  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507  11.9507 -12.6365  213.04 -193.36
HOLE  33    12.5857    0.     0.
HOLE  34    0.    -12.5857    0.
BOX TYPE  18
```

```
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  2P11.3157  213.04 -193.36
HOLE  35    11.3665    0.    0.
CUBOID  8  1  12.0523 -12.5857  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  12.0523 -12.5857  11.9507 -12.6365  213.04 -193.36
HOLE  34    0.    -12.5857    0.
BOX TYPE  19
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  2P11.3157  213.04 -193.36
HOLE  35    11.3665    0.    0.
CUBOID  8  1  11.4173 -11.3157  11.9507 -12.5857  213.04 -193.36
CUBOID  0  1  11.4173 -11.3157  11.9507 -12.6365  213.04 -193.36
HOLE  34    0.    -12.5857    0.
BOX TYPE  20
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  3P11.3157 -11.4173  213.04 -193.36
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  12.5857 -11.9507  11.9507 -12.0523  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507  11.9507 -12.0523  213.04 -193.36
HOLE  33    12.5857    0.    0.
BOX TYPE  21
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.3157 -11.4173  213.04 -193.36
HOLE 35    11.3665    0.    0.
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  12.0523 -12.5857  11.9507 -12.0523  213.04 -193.36
BOX TYPE  22
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.3157 -11.4173  213.04 -193.36
HOLE  35    11.3665    0.    0.
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  11.4173 -11.3157  12.5857 -12.0523  213.04 -193.36
CUBOID  4  1  11.4173 -11.3157  12.8524 -12.0523  213.04 -193.36
BOX TYPE  23
ARRAY  1     -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  3P11.3157 -11.4173  213.04 -193.36
```

```
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  12.5857 -11.9507  11.3157 -12.0523  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507 11.3157 -12.0523  213.04 -193.36
HOLE  33    12.5857    0.    0.
BOX TYPE  24
ARRAY  1    -10.3676  -11.049    -182.88
CUBOID  3  1  11.049 -10.3676 10.3676 -11.049  213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.3157 -11.4173  213.04 -193.36
HOLE  35    11.3665    0.    0.
HOLE  36    0.    -11.3665    0.
CUBOID  8  1  12.0523 -12.5857 11.3157 -12.0523  213.04 -193.36
CUBOID  4  1  12.0523 -12.5857 11.3157 -12.0523  213.04 -193.36
BOX TYPE  25   COM=& NEXT 8 BOXES ARE IN -X-Y QUADRANT &
ARRAY  1   -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  8  1  12.5857 -11.9507  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507  12.6365 -11.9507  213.04 -193.36
HOLE  33    12.5857    0.    0.
HOLE  34    0.    12.6365    0.
BOX TYPE  26
ARRAY  1   -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  2P11.3157  213.04 -193.36
HOLE  35    11.3665    0.    0.
CUBOID  8  1  12.0523 -12.5857  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  12.0523 -12.5857  12.6365 -11.9507  213.04 -193.36
HOLE  34    0.    12.6365    0.
BOX TYPE  27
ARRAY  1   -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  2P11.3157  213.04 -193.36
HOLE  35    11.3665    0.    0.
CUBOID  8  1  11.4173 -11.3157  12.5857 -11.9507  213.04 -193.36
CUBOID  0  1  11.4173 -11.3157  12.6365 -11.9507  213.04 -193.36
HOLE  34    0.    12.6365    0.
BOX TYPE  28
ARRAY  1   -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  2P11.3157 11.4173 -11.3157  213.04 -193.36
HOLE  36    0.    11.3665    0.
CUBOID  8  1  12.5857 -11.9507 12.0523 -11.9507  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507  12.0523 -11.9507  213.04 -193.36
HOLE  33    12.5857    0.    0.
BOX TYPE  29
```

```
ARRAY  1    -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.4173 -11.3157  213.04 -193.36
HOLE 35     11.3665    0.    0.
HOLE  36     0.    11.3665    0.
CUBOID  8  1  12.0523 -12.5857  12.0523 -11.9507  213.04 -193.36
BOX TYPE  30
ARRAY  1    -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.4173 -11.3157  213.04 -193.36
HOLE  35     11.3665    0.    0.
HOLE  36     0.    11:3665    0.
CUBOID  8  1  11.4173 -11.3157  12.0523 -12.5857  213.04 -193.36
CUBOID  4  1  11.4173 -11.3157  12.0523 -12.8524  213.04 -193.36
BOX TYPE  31
ARRAY  1    -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  2P11.3157 11.4173 -11.3157  213.04 -193.36
HOLE  36     0.    11.3665    0.
CUBOID  8  1  12.5857 -11.9507  12.0523 -11.3157  213.04 -193.36
CUBOID  0  1  12.6365 -11.9507  12.0523 -11.3157  213.04 -193.36
HOLE  33     12.5857    0.    0.
BOX TYPE  32
ARRAY  1    -10.3676  -10.3676   -182.88
CUBOID  3  1  11.049 -10.3676 11.049 -10.3676   213.04  -193.36
CUBOID  5  1   4P11.049  213.04  -193.36
CUBOID  4  1   4P11.3157 213.04  -193.36
CUBOID  0  1  11.4173 -11.3157  11.4173 -11.3157  213.04 -193.36
HOLE  35     11.3665    0.    0.
HOLE  36     0.    11.3665    0.
CUBOID  8  1  12.0523 -12.5857  12.0523 -11.3157  213.04 -193.36
CUBOID  4  1  12.0523 -12.5857  12.0523 -11.3157  213.04 -193.36
BOX TYPE  33   COM=& 1/2 BORATED AL VERTICAL PLATE &
CUBOID  9  1  0.0508 -0.  2P10.4775  2P182.88
BOX TYPE  34        COM=& 1/2 BORATED AL HORIZONTAL PLATE &
CUBOID  9  1  2P10.4775  0. -0.0508  2P182.88
BOX TYPE  35        COM=& BORATED AL VERTICAL PLATE &
CUBOID  9  1  2P0.0508  2P10.4775  2P182.88
BOX TYPE  36        COM= & BORATED AL PLATE HORIZONTAL &
CUBOID  9  1  2P10.4775  2P0.0508  2P182.88
BOX TYPE  37        COM=& PERIPHERAL PLATE VERTICAL &
CUBOID  8  1  1.27 -0.  2P46.7  213.04 -193.36
CUBOID  4  1  1.5367 -0.  2P46.7  213.04 -193.36
BOX TYPE  38         COM=& PERIPHERAL PLATE HORIZONTAL &
CUBOID  8  1  2P46.7  1.27 -0.  213.04 -193.36
CUBOID  4  1  2P46.7  1.5367 -0.  213.04 -193.36
BOX TYPE  39             COM=& FUEL PIN CELL &
CYLINDER  1  1  0.4096  2P182.88
```

```
CYLINDER  0  1  0.4178  2P182.88
CYLINDER  2  1  0.4750  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
BOX TYPE  40       COM=& GUIDE TUBE WITH BPRA (ALUM) &
CYLINDER  8  1  0.5715  2P182.88
CYLINDER  2  1  0.6121  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
BOX TYPE  41      COM=& 4 BOX HORIZONTAL ARRAY TOP &
ARRAY  2        -49.2252   0.  -193.36
BOX TYPE  42      COM=& 4 BOX HORIZONTAL ARRAY BOTTOM &
ARRAY  3        -49.2252  -23.368  -193.36
BOX TYPE  43     COM=& 4 BOX VERTICAL ARRAY +X &
ARRAY  4       0.    -49.4919  -193.36
BOX TYPE  44          COM=& 4 BOX VERTICAL ARRAY  -X &
ARRAY  5          -22.733     -49.4919   -193.36
BOX TYPE  45   COM=& PERIPHERAL SS PIECE  (TYPE 8 BOXES) &
CUBOID  4  1  0.2667 -0.  22.4537 -0.  213.04 -193.36
BOX TYPE  46       COM=& EMPTY GUIDE/INSTRUMENT TUBE &
CYLINDER  5  1  0.5715  2P182.88
CYLINDER  2  1  0.6121  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
GLOBAL BOX TYPE 47
ARRAY  6      -49.2252   -48.5902  -193.36
CYLINDER  10  1  87.34  213.04  -193.36
HOLE  41  0.      48.5903   0.
HOLE  42  0.     -48.5903   0.
HOLE  43     49.2253     0.     0.
HOLE  44    -49.2253     0.     0.
HOLE  37     71.9584   0.   0.
HOLE  37      -73.4951     0.     0.
HOLE  38    0.  71.9584   0.
HOLE  38      0. -73.4951    0.
HOLE  45     49.2253  49.4920    0.
HOLE  45    -49.4920  49.4920    0.
HOLE  45     49.2253 -71.9457    0.
HOLE  45    -49.4920 -71.9457    0.
CYLINDER  5  1  87.60  221.29  -193.36
CYLINDER  7  1  111.73  247.96  -219.4
REPLICATE  3  2  3*3.0  10
END GEOM
READ ARRAY
ARA=1  NUX=17 NUY=17  FILL  F39  A40 40 A43 40 A46 40 A55 40 A65
40
A88 40  A91 40 A94 40 A97 40 A100 40 A139 40 A142 40  A145 46
1B144
 END FILL
ARA=2  NUX=4 FILL  24 23 7 8  END FILL
ARA=3  NUX=4 FILL  32 31 15 16  END FILL
ARA=4  NUY=4  FILL  14 11 3 6  END FILL
ARA=5  NUY=4  FILL  30 27 19 22  END FILL
ARA=6  NUX=4 NUY=4 FILL   29 28 12 13  26 25 9 10  18 17 1 2
   21 20 4 5   END FILL
END ARRAY
READ BIAS  1D=500  2  11  END BIAS
```

```
END DATA
END
```

6.6.2 Sample Input File, TN-32 Criticality Evaluation

31 assemblies enriched 4.05%, one 5%; minimum compartment; minimum neutron absorber plate; pure water in fuel pin annulus; 95% density borated water drained down to top of active fuel; 2 inch offset between active fuel and neutron absorber plates.

```
=CSAS25
TN32 fiver95 17x17 non-ofa / off center / 2300 ppm /90% b10 / min
compartment
27GROUPNDF4    LATTICECELL
UO2  1  0.95     293.  92235 4.05  92238 95.95   END
ZIRCALLOY  2  1.0  END
H2O   3   1.0   END
SS304   4   1.0   END
' BORATED H2O  2300 PPM 95%
ARBMH3BO3  0.01252656  3 1 1 0 5000 1 1001 3 8016 3 5 1.0 293
END
H2O  5  0.9417257  END
' BORAL CORE  10MG/CM2 !!!NOT USED!!!
B4C    6   DEN=2.64  0.417  END
AL     6   DEN=2.64  0.583  END
CARBONSTEEL  7  1.0  END
AL      8     1.0  END
' EAGLE PICHER BORATED AL  (.040") !!!90% B10 CREDIT!!!
BORON    9   DEN=2.693   0.03811 293.   5010 86.4  5011 13.6  END
AL       9   DEN=2.693   0.96189  END
' BORATED H2O/AL HOMOG mix AT PERIPHERY !!!2000 PPM!!!
AL     10      0.303   END
ARBMH3BO3  0.01152 3 1 1 0 5000 1 1001 3 8016 3 10 0.697 293  END
H2O   10   0.69566   END
UO2           11  0.95    293.  92235 5  92238 95   END
END COMP
SQUAREPITCH  1.2598  0.8192  1  5  0.9500  2  0.8357  3  END
MORE DATA res=11  cylinder 0.40959999 dan(11)=0.272889 END MORE
DATA
TN32 CRITICALITY 2300 PPM BORATED H2O WITH BAL (0.040")
READ PARAM RUN=yes PLT=YES TME=5000 GEN=203 NPG=2000 END PARAM
READ GEOM
BOX TYPE  1  COM=&  NEXT EIGHT BOXES ARE +X+Y QUADRANT &
ARRAY  1     -10.9728  -10.9728    -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  8  1  11.8745 -12.5095  11.8745 -12.5095  213.04 -193.36
```

```
CUBOID 0  1  11.8745 -12.5603  11.8745 -12.5603  213.04 -193.36
HOLE  33     -12.5603    0.     0.
HOLE  34    0.    -12.5095    0.
BOX TYPE  2
ARRAY  1     -10.9728  -10.9728     -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  2P11.2395  213.04 -193.36
HOLE  35    -11.2903     0.      0.
CUBOID  8  1  12.5095 -11.9761  11.8745 -12.5095  213.04 -193.36
CUBOID  0  1  12.5095 -11.9761  11.8745 -12.5603  213.04 -193.36
HOLE  34    0.    -12.5095    0.
BOX TYPE  3
ARRAY  1     -10.9728  -10.9728     -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  2P11.2395  213.04 -193.36
HOLE  35    -11.2903     0.      0.
CUBOID  8  1  11.2395 -11.3411  11.8745 -12.5095  213.04 -193.36
CUBOID  0  1  11.2395 -11.3411  11.8745 -12.5603  213.04 -193.36
HOLE  34    0.     -12.5095    0.
BOX TYPE  4
ARRAY  1     -10.9728  -10.9728     -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  3P11.2395 -11.3411  213.04 -193.36
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  11.8745 -12.5095 11.8745 -11.9761  213.04 -193.36
CUBOID  0  1  11.8745 -12.5603  11.8745 -11.9761  213.04 -193.36
HOLE  33    -12.5603    0.     0.
BOX TYPE  5
ARRAY  1     -10.9728  -10.9728     -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  11.2395 -11.3411  213.04 -193.36
HOLE 35    -11.2903    0.    0.
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  12.5095 -11.9761  11.8745 -11.9761  213.04 -193.36
BOX TYPE  6
ARRAY  1     -10.9728  -10.9728     -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
```

```
CUBOID  5  1   4P10.9728  177.80   -193.36
CUBOID  3  1   4P10.9728  213.04   -193.36
CUBOID  4  1   4P11.2395 213.04   -193.36
CUBOID  0  1  11.2395 -11.3411  11.2395 -11.3411  213.04 -193.36
HOLE  35     -11.2903    0.    0.
HOLE  36     0.    -11.2903    0.
CUBOID  8  1  11.2395 -11.3411  12.5095 -11.9761  213.04 -193.36
CUBOID  4  1  11.2395 -11.3411  12.7762 -11.9761  213.04 -193.36
BOX TYPE  7
ARRAY  1     -10.9728  -10.9728    -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80   -193.36
CUBOID  3  1   4P10.9728  213.04   -193.36
CUBOID  4  1   4P11.2395 213.04   -193.36
CUBOID  0  1  3P11.2395 -11.3411  213.04 -193.36
HOLE  36     0.    -11.2903    0.
CUBOID  8  1  11.8745 -12.5095  11.2395 -11.9761  213.04 -193.36
CUBOID  0  1  11.8745 -12.5603  11.2395 -11.9761  213.04 -193.36
HOLE  33     -12.5603    0.    0.
BOX TYPE  8
ARRAY  1     -10.9728  -10.9728    -187.96
CUBOID  3  1   10.4438  -10.9728  10.4438  -10.9728   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80   -193.36
CUBOID  3  1   4P10.9728  213.04   -193.36
CUBOID  4  1   4P11.2395 213.04   -193.36
CUBOID  0  1  11.2395 -11.3411  11.2395 -11.3411  213.04 -193.36
HOLE  35     -11.2903    0.    0.
HOLE  36     0.    -11.2903    0.
CUBOID  8  1  12.5095 -11.9761  11.2395 -11.9761  213.04 -193.36
CUBOID  4  1  12.5095 -11.9761  11.2395 -11.9761  213.04 -193.36
BOX TYPE  9  COM=& NEXT EIGHT BOXES ARE +X-Y QUADRANT &
ARRAY  1     -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80   -193.36
CUBOID  3  1   4P10.9728  213.04   -193.36
CUBOID  4  1   4P11.2395 213.04   -193.36
CUBOID  8  1  11.8745 -12.5095  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  11.8745 -12.5603  12.5603 -11.8745 213.04 -193.36
HOLE  33     -12.5603    0.    0.
HOLE  34     0.    12.5603    0.
BOX TYPE  10
ARRAY  1     -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80   -193.36
CUBOID  3  1   4P10.9728  213.04   -193.36
CUBOID  4  1   4P11.2395 213.04   -193.36
CUBOID  0  1  11.2395 -11.3411  2P11.2395  213.04 -193.36
HOLE  35     -11.2903    0.    0.
CUBOID  8  1  12.5095 -11.9761  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  12.5095 -11.9761  12.5603 -11.8745  213.04 -193.36
```

```
HOLE  34    0.    12.5603    0.
BOX TYPE  11
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  2P11.2395  213.04 -193.36
HOLE  35    -11.2903   0.     0.
CUBOID  8  1  11.2395 -11.3411  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  11.2395 -11.3411  12.5603 -11.8745  213.04 -193.36
HOLE  34    0.    12.5603    0.
BOX TYPE  12
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  2P11.2395  11.3411 -11.2395  213.04 -193.36
HOLE  36    0.    11.2903    0.
CUBOID  8  1  11.8745 -12.5095  11.9761 -11.8745  213.04 -193.36
CUBOID  0  1  11.8745 -12.5603  11.9761 -11.8745  213.04 -193.36
HOLE  33    -12.5603    0.    0.
BOX TYPE  13
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  11.3411 -11.2395  213.04 -193.36
HOLE 35    -11.2903    0.    0.
HOLE  36    0.    11.2903    0.
CUBOID  8  1  12.5095 -11.9761  11.9761 -11.8745  213.04 -193.36
BOX TYPE  14
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  11.3411 -11.2395  213.04 -193.36
HOLE  35    -11.2903    0.    0.
HOLE  36    0.    11.2903    0.
CUBOID  8  1  11.2395 -11.3411  11.9761 -12.5095  213.04 -193.36
CUBOID  4  1  11.2395 -11.3411  11.9761 -12.7762  213.04 -193.36
BOX TYPE  15
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
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CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  2P11.2395  11.3411 -11.2395  213.04 -193.36
HOLE  36    0.    11.2903    0.
CUBOID  8  1  11.8745 -12.5095  11.9761 -11.2395  213.04 -193.36
CUBOID  0  1  11.8745 -12.5603  11.9761 -11.2395  213.04 -193.36
HOLE  33    -12.5603    0.    0.
BOX TYPE  16
ARRAY  1    -10.9728  -10.4438    -187.96
CUBOID  3  1   10.4438  -10.9728  10.9728  -10.4438   177.80  -
193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.2395 -11.3411  11.3411 -11.2395  213.04 -193.36
HOLE  35    -11.2903    0.    0.
HOLE  36    0.    11.2903    0.
CUBOID  8  1  12.5095 -11.9761  11.9761 -11.2395  213.04 -193.36
CUBOID  4  1  12.5095 -11.9761  11.9761 -11.2395  213.04 -193.36
BOX TYPE  17  COM=& NEXT 8 BOXES ARE -X+Y QUADRANT &
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  8  1  12.5095 -11.8745  11.8745 -12.5095  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745  11.8745 -12.5603  213.04 -193.36
HOLE  33    12.5095    0.    0.
HOLE  34    0.    -12.5095    0.
BOX TYPE  18
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  2P11.2395  213.04 -193.36
HOLE  35    11.2903    0.    0.
CUBOID  8  1  11.9761 -12.5095  11.8745 -12.5095  213.04 -193.36
CUBOID  0  1  11.9761 -12.5095  11.8745 -12.5603  213.04 -193.36
HOLE  34    0.    -12.5095    0.
BOX TYPE  19
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  2P11.2395  213.04 -193.36
HOLE  35    11.2903    0.    0.
CUBOID  8  1  11.3411 -11.2395  11.8745 -12.5095  213.04 -193.36
CUBOID  0  1  11.3411 -11.2395  11.8745 -12.5603  213.04 -193.36
HOLE  34    0.    -12.5095    0.
BOX TYPE  20
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
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CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  3P11.2395 -11.3411  213.04 -193.36
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  12.5095 -11.8745  11.8745 -11.9761  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745  11.8745 -11.9761  213.04 -193.36
HOLE  33    12.5095    0.    0.
BOX TYPE  21
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.2395 -11.3411  213.04 -193.36
HOLE 35    11.2903    0.    0.
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  11.9761 -12.5095  11.8745 -11.9761  213.04 -193.36
BOX TYPE  22
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.2395 -11.3411  213.04 -193.36
HOLE  35    11.2903    0.    0.
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  11.3411 -11.2395  12.5095 -11.9761  213.04 -193.36
CUBOID  4  1  11.3411 -11.2395  12.7762 -11.9761  213.04 -193.36
BOX TYPE  23
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  3P11.2395 -11.3411  213.04 -193.36
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  12.5095 -11.8745  11.2395 -11.9761  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745 11.2395 -11.9761  213.04 -193.36
HOLE  33    12.5095    0.    0.
BOX TYPE  24
ARRAY  1    -10.4438  -10.9728    -187.96
CUBOID  3  1  10.9728 -10.4438 10.4438 -10.9728  177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.2395 -11.3411  213.04 -193.36
HOLE  35    11.2903    0.    0.
HOLE  36    0.    -11.2903    0.
CUBOID  8  1  11.9761 -12.5095 11.2395 -11.9761  213.04 -193.36
CUBOID  4  1  11.9761 -12.5095 11.2395 -11.9761  213.04 -193.36
BOX TYPE  25   COM=& NEXT 8 BOXES ARE IN -X-Y QUADRANT &
ARRAY  7   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
```

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CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  8  1  12.5095 -11.8745  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745  12.5603 -11.8745  213.04 -193.36
HOLE  33    12.5095    0.     0.
HOLE  34     0.    12.5603    0.
BOX TYPE  26
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  2P11.2395  213.04 -193.36
HOLE  35    11.2903    0.    0.
CUBOID  8  1  11.9761 -12.5095  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  11.9761 -12.5095  12.5603 -11.8745  213.04 -193.36
HOLE  34     0.    12.5603    0.
BOX TYPE  27
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  2P11.2395  213.04 -193.36
HOLE  35    11.2903    0.    0.
CUBOID  8  1  11.3411 -11.2395  12.5095 -11.8745  213.04 -193.36
CUBOID  0  1  11.3411 -11.2395  12.5603 -11.8745  213.04 -193.36
HOLE  34     0.    12.5603    0.
BOX TYPE  28
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  2P11.2395 11.3411 -11.2395  213.04 -193.36
HOLE  36    0.    11.2903    0.
CUBOID  8  1  12.5095 -11.8745 11.9761 -11.8745  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745  11.9761 -11.8745  213.04 -193.36
HOLE  33    12.5095    0.    0.
BOX TYPE  29
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.3411 -11.2395  213.04 -193.36
HOLE 35    11.2903    0.    0.
HOLE  36    0.    11.2903    0.
CUBOID  8  1  11.9761 -12.5095  11.9761 -11.8745  213.04 -193.36
BOX TYPE  30
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
```

```
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.3411 -11.2395  213.04 -193.36
HOLE  35    11.2903    0.     0.
HOLE  36     0.    11.2903    0.
CUBOID  8  1  11.3411 -11.2395  11.9761 -12.5095  213.04 -193.36
CUBOID  4  1  11.3411 -11.2395  11.9761 -12.7762  213.04 -193.36
BOX TYPE  31
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  2P11.2395 11.3411 -11.2395  213.04 -193.36
HOLE  36    0.    11.2903    0.
CUBOID  8  1  12.5095 -11.8745  11.9761 -11.2395  213.04 -193.36
CUBOID  0  1  12.5603 -11.8745  11.9761 -11.2395  213.04 -193.36
HOLE  33    12.5095    0.     0.
BOX TYPE  32
ARRAY  1   -10.4438  -10.4438   -187.96
CUBOID  3  1  10.9728 -10.4438 10.9728 -10.4438   177.80  -193.36
CUBOID  5  1   4P10.9728  177.80  -193.36
CUBOID  3  1   4P10.9728  213.04  -193.36
CUBOID  4  1   4P11.2395 213.04  -193.36
CUBOID  0  1  11.3411 -11.2395  11.3411 -11.2395  213.04 -193.36
HOLE  35    11.2903    0.     0.
HOLE  36    0.    11.2903    0.
CUBOID  8  1  11.9761 -12.5095  11.9761 -11.2395  213.04 -193.36
CUBOID  4  1  11.9761 -12.5095  11.9761 -11.2395  213.04 -193.36
BOX TYPE  33  COM=& 1/2 BORATED AL VERTICAL PLATE &
CUBOID  9  1  0.050799 -0.  2P10.4013  2P182.88
BOX TYPE  34       COM=& 1/2 BORATED AL HORIZONTAL PLATE &
CUBOID  9  1  2P10.4013  0. -0.050799  2P182.88
BOX TYPE  35       COM=& BORATED AL VERTICAL PLATE &
CUBOID  9  1  2P0.050799  2P10.4013  2P182.88
BOX TYPE  36       COM= & BORATED AL PLATE HORIZONTAL &
CUBOID  9  1  2P10.4013  2P0.050799  2P182.88
BOX TYPE  37       COM=& PERIPHERAL PLATE VERTICAL &
CUBOID  8  1  1.27 -0.  2P46.3952  213.04 -193.36
CUBOID  4  1  1.5367 -0.  2P46.3952  213.04 -193.36
BOX TYPE  38        COM=& PERIPHERAL PLATE HORIZONTAL &
CUBOID  8  1  2P46.3952  1.27 -0.  213.04 -193.36
CUBOID  4  1  2P46.3952  1.5367 -0.  213.04 -193.36
BOX TYPE  39           COM=& FUEL PIN CELL &
CYLINDER  1  1  0.4096  2P182.88
CYLINDER  3  1  0.4178  2P182.88
CYLINDER  2  1  0.4750  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
BOX TYPE  40       COM=& GUIDE TUBE WITH BPRA (ALUM) &
CYLINDER  8  1  0.5715  2P182.88
CYLINDER  2  1  0.6121  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
BOX TYPE  41      COM=& 4 BOX HORIZONTAL ARRAY TOP &
ARRAY  2        -48.9204   0.  -193.36
BOX TYPE  42      COM=& 4 BOX HORIZONTAL ARRAY BOTTOM &
```

```
ARRAY  3        -48.9204  -23.2156  -193.36
BOX TYPE  43     COM=& 4 BOX VERTICAL ARRAY +X &
ARRAY  4       0.     -49.1871  -193.36
BOX TYPE  44          COM=& 4 BOX VERTICAL ARRAY  -X &
ARRAY  5         -22.5806    -49.1871   -193.36
BOX TYPE  45    COM=& PERIPHERAL SS PIECE  (TYPE 8 BOXES) &
CUBOID  4  1  0.2667 -0.  22.3013 -0.  213.04 -193.36
BOX TYPE  46       COM=& EMPTY GUIDE/INSTRUMENT TUBE &
CYLINDER  5  1  0.5715  2P182.88
CYLINDER  2  1  0.6121  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
BOX TYPE  47            COM=& FUEL PIN CELL, 5% ENRICHED &
CYLINDER  11  1  0.4096  2P182.88
CYLINDER  3  1  0.4178  2P182.88
CYLINDER  2  1  0.4750  2P182.88
CUBOID    5  1  4P0.6299  2P182.88
GLOBAL BOX TYPE 48
ARRAY  6      -48.9204   -48.2854  -193.36
CYLINDER  10  1  87.34  213.04  -193.36
HOLE  41  0.     48.2855   0.
HOLE  42  0.    -48.2855   0.
HOLE  43     48.9205     0.     0.
HOLE  44    -48.9205     0.     0.
HOLE  37     71.5012   0.   0.
HOLE  37      -73.0379     0.     0.
HOLE  38    0.  71.5012   0.
HOLE  38      0. -73.0379    0.
HOLE  45     48.92051  49.18720   0.
HOLE  45    -49.18721  49.18720   0.
HOLE  45     48.9205 -71.4885   0.
HOLE  45    -49.18720 -71.4885   0.
CYLINDER  5 1  87.60  213.04  -193.36
CYLINDER  0 1  87.60  221.29  -193.36
CYLINDER  7  1  111.73  247.96  -219.4
REPLICATE  3  2  3*3.0  10
END GEOM
READ ARRAY
ARA=1  NUX=17 NUY=17  FILL  F39  A40 40 A43 40 A46 40 A55 40 A65
40
A88 40  A91 40 A94 40 A97 40 A100 40 A139 40 A142 40  A145 46
1B144
 END FILL
ARA=2  NUX=4 FILL  24 23 7 8  END FILL
ARA=3  NUX=4 FILL  32 31 15 16  END FILL
ARA=4  NUY=4  FILL  14 11 3 6  END FILL
ARA=5  NUY=4  FILL  30 27 19 22  END FILL
ARA=6  NUX=4 NUY=4 FILL   29 28 12 13  26 25 9 10  18 17 1 2
   21 20 4 5   END FILL
ARA=7  NUX=17 NUY=17  FILL  F47  A40 40 A43 40 A46 40 A55 40 A65
40
A88 40  A91 40 A94 40 A97 40 A100 40 A139 40 A142 40  A145 46
1B144
END ARRAY
READ BIAS  ID=500  2  11  END BIAS
```

END DATA
END

6.6.3 Computer Platforms and Codes

Criticality calculations were performed using SCALE 4.3[1], "Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation for Workstations and Personal Computers" on a Hewlett Packard 9000/715 Workstation. Calculations and benchmarks were performed on the same platform.

Statistical analysis of benchmark results was performed using the PC version of the USLSTATS program, Version 1.3.4, distributed by Oak Ridge National Laboratory[2].

6.7 References

1. SCALE 4.3, A Modular Code System For Performing Standardized Computer Analyses For Licensing Evaluation, Program Package, CCC-545, ORNL.

2. NUREG/CR-6361, Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages, 1997.

3. Domestic Light Water Reactor Fuel Design Evolution, DOE/ET/47912, vol III, Sept 1981, Table 4-2.

4. Characteristics of Potential Repository Wastes, DOE/RW-0184-R1, Vol 1, July 1992, Appendix 2A.

5. Reference Core Report 17 x 17 Fuel Assembly, WCAP-9500, Westinghouse Nuclear Energy Systems, Table 4.3-1.

6. Nuclear Regulatory Commission RAI to Transnuclear dated Sept 14, 1998, question 6-3.

7. ANS/ANSI-8.1, American National Standard for Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors, 1983.

8. McGuire Nuclear Station Final Safety Analysis Report, January 1, 1998, Appendix 4

TABLE 6.2-1

Fuel Parameters for PWR Fuel

Parameter	14 x 14 Std	14 x 14 OFA	15x15	17 x 17 Std	17x17 MkBW	17x17 OFA
Enrichment, wt % U235	4.05	4.05	4.05	4.05	4.05	4.05
Active fuel length	141.2-145.2	135.2-144	142 -144	144	144	144
Pellet OD	0.3640 – 0.3674	0.3444	0.3649-0.3669	0.3225	0.3195	0.3088
Rod OD	0.422	0.400	0.422	0.374	0.374	0.360
Clad wall thickness (Zr)	0.0225-0.0243	0.0243	0.0243	0.0225	0.0240	0.0225
Rod pitch	0.556	0.556	0.563	0.496	0.496	0.496
UO_2 density (% theoretical)	95	95	95	95	96	95
No of fuel rods	179	179	204	264	264	264
No of guide/instrument tubes	16 / 1	16 / 1	21	25	25	25
Guide tube OD	0.4805-0.539	0.526	0.484-0.545	0.429-0.482	0.482	0.429-0.482
Guide tube wall (Zr)	0.017-0.034	0.017	0.015	0.016	0.016	0.016
Instrument Tube OD	0.422-0.539	0.400	0.545	0.474-0.545	0.482	0.474-0.545
Instrument Tube Wall (Zr)	0.0240-0.034	0.0235	0.015	0.015-0.016	0.016	0.015-0.016
Bottom of assembly to bottom of active fuel	3.876	na	3.873	4.176	4.5	na
Gap between bottom end plate and fuel rod	0	na	0	0.75	0	na

1. All dimensions in inches
2. Data from references 3, 4, 5, 6, and 8
3. Where there are variations for a given design, the values highlighted are chosen for the analysis. See Section 6.4.2.
4. In all cases except the 14x14 OFA model, the instrument tube is modeled with the same dimensions as the guide tube. This has no significant effect on the results.
5. For evaluation of axial offset of the active fuel and neutron poison plate, located 4.12 inches from the cask bottom

Table 6.3-1

Comparison of Design Dimensions with Criticality Model

Description	TN-32 Design	Model
compartment inside	8.70 ± 0.04	8.64 - 8.76
compartment wall	0.105	0.105
aluminum thickness	0.50	0.50
neutron absorber plate height	144	144
neutron absorber plate thickness	0.040	0.040
neutron absorber plate width	8.25 ± 0.06	8.19 - 8.25
cavity inside radius	34.38	34.38
cask wall thickness	9.50	9.50

All dimensions in inches

Table 6.3-2
Model Mass Densities

Material	Component	Density g/cm^3	Volume Fraction	Notes
Fuel	UO2	10.412	0.95	1
Cladding	ZIRCALLOY	6.56	1.0	
Water	H2O	0.9982	1.0	
Borated Aluminum	AL	2.659		
	B10	0.08867		
	B11	0.01396		
Borated water, 2300 ppm	H2O	0.98952	0.9913	2
	H3BO3	0.01319		2, 3
Basket rails/ 2000 ppm borated water	H2O	0.69441	0.69566	
	H3BO3	0.00803		3
	AL	0.8187	0.303	
Compartment tubes	SS304	7.92	1.0	
Basket plates	AL	2.702	1.0	
Containment and gamma shield	CARBONSTEEL	7.9	1.0	

Component identifiers are from the SCALE Standard Composition Library; where input is by volume fraction (percent of standard density), that fraction is listed along with the derived density

Notes:
1. U234 and U236 are ignored.
2. The 2300 ppm borated water composition is calculated:

$$g\ H_3BO\ g/cm^3\ solution = \frac{(sol'n\ density)(B\ concentration)(molecular\ wt\ H_3BO_3)}{atomic\ weight\ boron}$$

$$= (1.0027)(2300 \times 10^{-6})(61.822)/10.8126 = 0.01319$$

$$volume\ fraction\ water = \frac{[solution\ density - (g\ H_3BO_3/cm^3\ sol'n)]}{water\ standard\ density}$$

$$= (1.0027 - 0.01319) / 0.9982 = 0.9913$$

For cases with reduced density of borated water, both of these input values are multiplied by the same density factor.

3. SCALE standard boron istotopic composition, 18.431 wt% B10

Table 6.4-1
Results, Most Reactive Fuel Evaluation

Case description	k_{eff}	σ
14x14 std, no BPRA, centered in compartment	0.8373	0.0013
14x14 ofa, no BPRA, centered in compartment	0.8063	0.0013
14x14 ofa, no BPRA, shifted toward cask center	0.8133	0.0012
14x14 std, no BPRA, shifted toward cask center	0.8470	0.0013
15x15 std, no BPRA, centered in compartment	0.9068	0.0011
15x15 std, no BPRA, shifted toward cask center	0.9086	0.0012
17x17 ofa, no BPRA, centered in compartment	0.8883	0.0012
17x17 ofa, no BPRA, shifted toward cask center	0.8928	0.0011
14x14 std, with BPRA, centered in compartment	0.8361	0.0013
14x14 ofa, with BPRA, centered in compartment	0.8063	0.0014
14x14 ofa, with BPRA, shifted toward cask center	0.8173	0.0013
14x14 std, with BPRA, shifted toward cask center	0.8455	0.0013
15x15 std, with BPRA, centered in compartment	0.9123	0.0013
15x15 std, with BPRA, shifted toward cask center	0.9124	0.0012
17x17 ofa, with BPRA, centered in compartment	0.8952	0.0012
17x17 ofa, with BPRA, shifted toward cask center	0.8950	0.0009
17x17 MkBW, no BPRA, centered in compartment	0.9103	0.0012
17x17 MkBW, no BPRA, shifted toward cask center	0.9106	0.0012
17x17 MkBW, with BPRA, centered in compartment	0.9134	0.0012
17x17 MkBW, with BPRA, shifted toward cask center	0.9144	0.0009
17x17 std, no BPRA, centered in compartment	0.9121	0.0012
17x17 std, no BPRA, shifted toward cask center	0.9161	0.0012
17x17 std, with BPRA, centered in compartment	0.9137	0.0013
17x17 std, with BPRA, shifted toward cask center	0.9171	0.0009

Table 6.4-2

TN-32 Criticality Calculation Results with Most Reactive Fuel Configuration

Case	Case Description	k_{eff}	σ	$k_{eff}+2\sigma$
1	Baseline 17x17 shifted toward cask axis	0.9167	0.0008	0.9183
2	Active fuel shifted down 2 inch; offset from absorber plates	0.9170	0.0009	0.9188
3	Compartment reduced from 8.70 to 8.64 inch	0.9193	0.0009	0.9211
4	Compartment increased from 8.70 to 8.76 inch	0.9153	0.0010	0.9173
5	Neutron poison plate width reduced to 8.19 inch	0.9185	0.0009	0.9203
6	Fresh water in fuel rod annulus	0.9199	0.0009	0.9217
7	Borated water 99% density	0.9166	0.0010	0.9186
8	Borated water 95% density	0.9171	0.0009	0.9189
9	Borated water 90% density	0.9156	0.0009	0.9174
10	Borated water 75% density	0.9077	0.0010	0.9097
11	Borated water 50% density	0.8639	0.0009	0.8657
12	Borated water 25% density	0.7402	0.0008	0.7418
13	Borated water 5% density	0.5466	0.0007	0.5480
14	Borated water 1% density	0.4898	0.0007	0.4912
15	Borated water drained to top of active fuel	0.9167	0.0010	0.9187

Note: The final case in Table 6.4-1 was run with the 2300 ppm borated water density at 1.0078 g/cm^3. The baseline case here is a repeat of that case with the 2300 ppm borated water density at the correct value of 1.0027 g/cm^3. The difference is negligible.

Table 6.4-2, continued

TN-32 Criticality Calculation Results with Most Reactive Fuel Configuration

Case	Case Description	k_{eff}	σ	$k_{eff}+2σ$
16	Combined worst case normal, 100% borated water density	0.9224	0.0009	0.9242
17	Combined worst case normal, 97.5% borated water	0.9241	0.0009	0.9259
18	Combined worst case normal, 95% borated water	0.9238	0.0009	0.9256
19	Combined worst case normal, 92.5% borated water	0.9264	0.0008	0.9280
20	Combined worst case normal, 90% borated water	0.9264	0.0009	0.9282
21	Combined worst case normal, 87.5% borated water	0.9261	0.0009	0.9279
22	Combined worst case normal, 85% borated water	0.9241	0.0008	0.9257
23	Combined worst case with single 5% fuel assy, 100% borated water density	0.9312	0.0009	0.9330
24	Same, 97.5% borated water	0.9307	0.0009	0.9325
25	Same, 85% borated water	0.9310	0.0009	0.9328
26	Same, 92.5% borated water	0.9309	0.0009	0.9327
27	Same, 90% borated water	0.9314	0.0009	0.9332
28	Same, 87.5% borated water	0.9315	0.0009	0.9333
29	Same, 85% borated water	0.9299	0.0009	0.9317

Table 6.4-3
Criticality Results, Accident, Reduced Pin Pith due to Fuel Grid Damage

Case Description	k_{eff}	σ	$k_{eff}+2\sigma$
Base Case- 100% Borated water density, Pitch=1.2598 cm	0.9224	0.0009	0.9242
As Above but Pitch = 1.24 cm	0.9192	0.0009	0.9210
As Above but Pitch = 1.22 cm	0.9105	0.0010	0.9135
As Above but Pitch = 1.20 cm	0.9019	0.0009	0.9037
Base Case - 95% Borated Water Density, Pitch =1.2598 cm	0.9238	0.0009	0.9256
As Above but Pitch = 1.24 cm	0.9195	0.0009	0.9213
As Above but Pitch = 1.22 cm	0.9111	0.0009	0.9129
As Above but Pitch = 1.20 cm	0.9001	0.0009	0.9019
Base Case- 90% Borated Water Density, Pitch = 1.2598 cm	0.9264	0.0009	0.9282
As Above but Pitch = 1.24 cm	0.9188	0.0009	0.9206
As Above but Pitch = 1.22 cm	0.9095	0.0008	0.9111
As Above but Pitch = 1.20 cm	0.9003	0.0010	0.9023
Base Case - 85% Borated Water Density, Pitch = 1.2598 cm	0.9241	0.0008	0.9257
As Above but Pitch = 1.24 cm	0.9165	0.0008	0.9181
As Above but Pitch = 1.22 cm	0.9085	0.0008	0.9101
As Above but Pitch = 1.20 cm	0.8973	0.0009	0.8991

Table 6.5-1
Dissolved Boron Critical Experiments and Results with CSAS25 and 27 Group Library

case	k_{eff}	σ	B ppm
B1645SO1	0.9886	0.0011	1068
B1645SO2	0.9899	0.0011	1156
BW1231B1	0.9895	0.0014	1152
BW1231B2	0.9892	0.0011	3389
BW1273M	0.9904	0.0011	1675
BW1484A1	0.9949	0.0014	15
BW1484A2	0.9849	0.0014	72
BW1484B1	0.9932	0.0011	1037
BW1484B2	0.9899	0.0012	769
BW1484B3	0.9884	0.0012	143
BW1484S1	0.9936	0.0012	432
BW1484S2	0.9908	0.0011	514
BW1645S1	0.9849	0.0013	746
BW1645S2	0.9899	0.0012	886
BW1810F	1.0000	0.0010	1337
BW1810G	0.9899	0.0011	1776
BW1810H	0.9930	0.0011	1899
EPRU65B	0.9918	0.0013	463
EPRU75B	0.9935	0.0012	568
EPRU87B	0.9959	0.0011	286
P4267B1	0.9922	0.0013	2150
P4267B2	0.9970	0.0012	2550
P4267B3	0.9964	0.0014	1030
P4267B4	0.9904	0.0013	1820
P4267B5	0.9923	0.0012	2550

Table 6.5-2
Critical Experiment Results with CSAS25 and 27 Group Library

case	enrich	pin pitch (cm)	water / fuel volume	H/X	plate B10 (g/cm^2)	assy spacing (cm)	second assy spacing	k_{eff}	σ
ANS33AL1	4.74	1.35	2.302	138.4		5		1.0024	0.0015
ANS33AL2	4.74	1.35	2.302	138.4		2.5		1.0066	0.0016
ANS33AL3	4.74	1.35	2.302	138.4		10		1.0007	0.0015
ANS33SLG	4.74	1.35	2.302	138.4		5		0.9940	0.0016
BW1484SL	2.46	1.636	1.841	216.1		6.54		0.9891	0.0013
EPRU65	2.35	1.905	1.196	163.6				0.9880	0.0013
EPRU75	2.35	1.905	2.408	329.4				0.9951	0.0014
EPRU87	2.35	2.21	3.687	504.2				0.9961	0.0014
NSE71H1	4.74	1.35	1.804	108.3				0.9923	0.0016
NSE71H2	4.74	1.26	3.811	228.8				0.9984	0.0016
NSE71H3	4.74	2.26	7.608	456.8				0.9994	0.0015
NSE71SQ	4.74	1.26	1.823	110				0.9954	0.0016
NSE71W1	4.74	1.26	1.823	110				0.9956	0.0017
NSE71W2	4.74	1.26	1.823	110				0.9961	0.0015
P2438AL	2.35	2.032	2.918	398.7		8.67		0.9938	0.0013
P2438BA	2.35	2.032	2.918	398.7	0.067	5.05		0.9945	0.0013
P2438SLG	2.35	2.032	2.918	398.7		8.39		0.9924	0.0014
P2438SS	2.35	2.032	2.918	398.7		6.88		0.9925	0.0014
P2615AL	4.31	2.54	3.883	256.1		10.72		0.9968	0.0016
P2615BA	4.31	2.54	3.883	256.1	0.067	6.72		0.9939	0.0015
P2615SS	4.31	2.54	3.883	256.1		8.58		0.9957	0.0015
P2827SL	2.35	2.032	2.918	398.7		8.31		0.991	0.001

G								3	3
P3314AL	4.31	1.892	1.6	105.4		9.04	2.83	0.9911	0.0015
P3314BA	4.31	1.892	1.6	105.4	0.067	4.8	2.83	0.9953	0.0015
P3314BC	4.31	1.892	1.6	105.4	0.0263	3.53	2.83	0.9956	0.0016
P3314BF1	4.31	1.892	1.6	105.4	0.0263	3.6	2.83	0.9979	0.0015
P3314BF2	4.31	1.892	1.6	105.4	0.0472	4.94	2.83	0.9980	0.0015
P3314BS1	2.35	1.684	1.6	218.6	0.00456	3.86		0.9922	0.0014
P3314BS2	2.35	1.684	1.6	218.6	0.00691	3.46		0.9871	0.0014
P3314BS3	4.31	1.892	1.6	105.4	0.00456	7.23		0.9948	0.0016
P3314BS4	4.31	1.892	1.6	105.4	0.00691	6.63		0.9984	0.0015
P3314SLG	4.31	1.892	1.6	105.4		10.86	2.83	0.9965	0.0016
P3314SS1	4.31	1.892	1.6	105.4		3.38	2.83	0.9931	0.0015
P3314SS2	4.31	1.892	1.6	105.4		11.55	2.83	0.9978	0.0015
P3314SS3	4.31	1.892	1.6	105.4		4.47	2.83	0.9937	0.0015
P3314SS4	4.31	1.892	1.6	105.4		8.36	2.83	0.9918	0.0014
P3314SS5	2.35	1.684	1.6	218.6		7.8		0.9892	0.0014
P3314SS6	4.31	1.892	1.6	105.4		10.52		0.9960	0.0016
P3314W1	4.31	1.892	1.6	105.4				1.0003	0.0016

Table 6.5-2, continued

case	enrich	pin pitch (cm)	water / fuel volume	H/X	boron 10 (g/cm²)	assy spacing (cm)	second assy spacing	k_{eff}	σ
P3314W2	2.35	1.684	1.6	218.6				0.9930	0.0014
P3602BA	4.31	1.892	1.6	105.4	0.04085	8.3		0.9969	0.0015
P3602BS1	2.35	1.684	1.6	218.6		4.8		0.9950	0.0013
P3602BS2	4.31	1.892	1.6	105.4		9.83		0.9967	0.0015
P3602N11	2.35	1.684	1.6	218.6		8.98		0.9957	0.0013
P3602N12	2.35	1.684	1.6	218.6		9.58		0.9958	0.0014
P3602N13	2.35	1.684	1.6	218.6		9.66		0.9920	0.0015
P3602N14	2.35	1.684	1.6	218.6		8.54		0.9900	0.0014
P3602N21	2.35	2.032	2.918	398.7		10.36		0.9971	0.0014
P3602N22	2.35	2.032	2.918	398.7		11.2		0.9986	0.0012
P3602N31	4.31	1.892	1.6	105.4		14.87		1.0018	0.0015
P3602N32	4.31	1.892	1.6	105.4		15.74		1.0019	0.0016
P3602N33	4.31	1.892	1.6	105.4		15.87		1.0021	0.0016
P3602N34	4.31	1.892	1.6	105.4		15.84		0.9963	0.0015
P3602N35	4.31	1.892	1.6	105.4		15.45		0.9954	0.0015
P3602N36	4.31	1.892	1.6	105.4		13.82		0.9966	0.0015
P3602N41	4.31	2.54	3.883	256.1		12.89		1.0006	0.0016
P3602N42	4.31	2.54	3.883	256.1		14.12		1.0044	0.0016
P3602N43	4.31	2.54	3.883	256.1		12.44		0.9994	0.0015
P3602SS1	2.35	1.684	1.6	218.6		8.28		0.9935	0.0014
P3602SS2	4.31	1.892	1.6	105.4		13.75		0.9986	0.0015
P3926SL1	2.35	1.684	1.6	218.6		6.59		0.9906	0.0014

P3926SL2	4.31	1.892	1.6	105.4		12.97		0.9944	0.0016
P49-194	4.31	1.598	0.509	33.6				0.9951	0.0018
PAT80L1	4.74	1.6	3.807	228.6	0.0461	2		1.0000	0.0016
PAT80L2	4.74	1.6	3.807	228.6	0.0461	2		0.9936	0.0016
PAT80SS1	4.74	1.6	3.807	228.6	0.0461	2		1.0019	0.0016
PAT80SS2	4.74	1.6	3.807	228.6	0.0461	2		0.9955	0.0016
W3269SL1	2.72	1.524	1.495	156.1				0.9896	0.0015
W3269SL2	5.7	1.422	1.932	98.3				0.9997	0.0015
W3269W1	5.7	1.524	1.495	156.1				0.9929	0.0014
W3269W2	5.7	1.422	1.932	98.3				0.9981	0.0015
W3385SL1	5.74	1.422	1.933	97.6				0.9941	0.0016
W3385SL2	5.74	2.011	5.067	255.9				0.9986	0.0015

1. H/X is the atom ratio of hydrogen to U235 in the pin cell
2. Water/fuel volume ration is defined by the pin cell only

Table 6.5-3
Critical Experiments, Boron Plate Areal Density

case	material	core thickness (cm)	core density (g/cm³)	weight % boron in core	boron 10 g/cm²
P2438BA	Boral	0.509	2.49	28.7	0.0670
P2615BA	Boral	0.509	2.49	28.7	0.0670
P3314BA	Boral	0.509	2.49	28.7	0.0670
P3314BC	Boral	0.181	2.47	31.88	0.0263
P3314BF1	Boroflex	0.226	1.731	32.74	0.0236
P3314BF2	Boroflex	0.452	1.731	32.74	0.0472
P3314BS1	borated ss	0.298	7.9	1.05	0.0046
P3314BS2	borated ss	0.298	7.77	1.62	0.0069
P3314BS3	borated ss	0.298	7.9	1.05	0.0046
P3314BS4	borated ss	0.298	7.77	1.62	0.0069
P3602BA	Boral	0.292	2.5	30.36	0.0408
PAT80L1	Boral	0.43	2.6189	22.2	0.0461
PAT80L2	Boral	0.43	2.6189	22.2	0.0461
PAT80SS1	Boral	0.43	2.6189	22.2	0.0461
PAT80SS2	Boral	0.43	2.6189	22.2	0.0461

Notes:
1. Boron 10 is assumed to be 18.431 weight % of natural boron.
2. "Core" refers to the borated part of the plate. For Boral, this does not include the aluminum cladding, and for Boroflex, this does not include the plexiglas plates.

Table 6.5-4
Trend Analysis of Benchmark Results

Independent variable	range	TN-32 range	number of cases	correlation coefficient r
Pin pitch, cm	1.26 - 2.54	1.26-1.43	73	0.10
Boron areal density in separator plates, g/cm^2	0.0041 - 0.067	0.010	17	0.23
Pin cell hydrogen to U235 atom ratio (H/X)	33.6 - 504.2	114-140	73	-0.11
Pin cell water / fuel pellet volume ratio	0.509 - 7.608	1.6-2.0	73	0.30
Assembly separation, cm	2 - 15.87	2.65-4.33	55	0.26
Assembly separation using second assembly distance, cm	2 - 15.87	2.65-4.33	55	0.27
Soluble boron concentration, ppm	15-3389	2300	25	0.11
Enrichment, wt% U235	2.35-5.74	4.05	96	0.53

Independent variable, x	USL	TN-32	
		x	USL
Pin pitch, cm	$0.9364+1.2243\times10^{-3}x$	1.26	0.9379
Boron areal density in separator plates, g/cm^2	$0.9377+3.1765\times10^{-2}x$	0.010	0.9380
Pin cell hydrogen to U235 atom ratio (H/X)	$0.9392-4.0608\times10^{-6}x$	140	0.9386
Pin cell water / fuel pellet volume ratio	$0.9358+1.0398\times10^{-3}x$ $x < 6.305$	1.6	0.9375
Assembly separation, cm	$0.9365+2.5985\times10^{-4}x$	2.65	0.9372
Assembly separation using second assembly distance, cm	$0.9367+2.5336\times10^{-4}x$	2.65	0.9374
Soluble boron concentration, ppm	$0.9337+4.4305\times10^{-7}x$	2300	0.9347
Enrichment, wt% U235	$0.9308+2.0196\times10^{-3}x$	4.05	0.9390

APPENDIX 6A

EVALUATION OF FUEL UNDER ACCIDENT ACCELERATIONS

This appendix evaluates the effect of TN-32 cask impact (tipover or bottom-end drop) on the integrity of fuel rod cladding. The material properties of irradiated zircalloy cladding and the rod impact stress analysis approach are based on LLNL Report UCID-21246[1]. The fracture analysis of the fuel rod cladding is based on the ASME Code, Section XI, 1989[2]. The irradiated zircalloy fracture toughness data is obtained from ASTM Special Technical Publication 551[3]. Presented below are the analyses and results that are used to conclude that the fuel rod cladding will remain intact and retain the fuel pellets during all accident scenarios.

6A.1 Material Properties

This section establishes the basis for assuming particular material properties. The value of some of the parameters used in the analysis are temperature dependent. The maximum temperature during dry storage is not expected to exceed 575°F. Consequently, material properties will be based upon this temperature, with the expectation that the ability of the zircalloy to absorb impact loads without rupture will increase as the temperature decreases with time.

Weight Density

The weight density of both Zircalloy-2 and Zircalloy-4 is very close to the weight density of Zirconium itself. From Reference 1,

$\rho_{tube} = 0.234 \text{ lb/in}^3$

Young's Modulus

The Young's modulus for typical Zircalloy-4 PWR cladding is illustrated in Table 5 of Reference 1. Thus, at 575°F,

$E_{tube} = 11.29 \times 10^6$ psi

$E_{fuel\ pellet} = 13.7 \times 10^6$ psi (conservatively assume a lower value)

Yield Strength

The yield strength for typical Zircalloy cladding is illustrated in Table 5 of Reference 1. Thus, at 575°F,

$S_{yield\text{-}tube} = 85{,}530$ psi

6A.2 Tipover

The fuel rod side impact stresses are computed by idealizing fuel rods as continuous beams supported at each spacer grid. Continuous beam theory is used to determine the maximum bending moments and corresponding stresses in the cladding tube. The methodology used in performing the analysis is based on work done at Lawrence Livermore National Labs (Ref. 1). The fuel gas internal pressure is assumed to be present and the resulting axial tensile stress is added to the bending tensile stress due to 74G load (Appendix 3D, Section 3D.3.2). The stresses for different Westinghouse fuel assemblies are computed in Table 6A-1. It is seen that the 51,196 psi is the highest stress and occurs in 17x17OFA fuel assembly. This stress is lower than the yield strength of zircalloy (85,530 psi). It is, therefore, concluded that the fuel tube will not fail and will withstand the side drop load without excessive plastic deformations. The grid supports (spacers) are expected to crush before 74G load is developed and the actual tube stresses will be much lower than the above noted stress.

6A.3 Bottom End Drop

In case of an end drop, the inertial forces load the rod as a column having intermediate supports at each grid support (spacer). The tube limit load is that at which the fuel rod segments between the supports become unstable.

An elastic-plastic stress analysis was performed using the ANSYS Finite Element Program (Ref. 6). A three-dimensional finite element model of entire active tube length was constructed using plastic PIPE20 element for cladding tube and elastic PIPE16 element for fuel. The hinge supports were modeled at 7 grid support locations. The finite element model and support conditions for a typical tube model are shown in Figure 6A-1. The tube and fuel nodes were coupled in X, Y and Z directions. The following material properties (at 575 °F) were input as a bilinear kinematic stress-strain curve for Zircalloy cladding tube. These properties are taken from Reference 1.

Yield Strength = 85,530 psi
Ultimate Strength = 97,000 psi
Modulus of elasticity = 11.29×10^6 psi
Elongation = 1.75%
Max. elastic strain = $85530/11.29 \times 10^6 = 0.00757$ in/in
Tangent Modulus = $(97000 - 85530) / (.0175 - .00757) = 1.155 \times 10^6$ psi

For Fuel elements, Modulus of elasticity = 13.7×10^6 psi is conservatively used for analysis. The tube and fuel densities were modified to compensate for the extra tube length and the components which were not modeled.

In order to get the tube-buckling load, the large displacement option of ANSYS was used. The maximum inertia force of 200G was used. This load was applied gradually in a number of sub-steps. The analysis was continued to load sub-step till the tube model became unstable and did not converge. In each case, the lowest segment became unstable as it was supporting the entire tube and fuel weights. The last converged load sub-step was taken as the plastic instability load. The above analysis was repeated for one fuel rod of each fuel subassembly. All the input data and the resulting plastic instability loads are summarized in Table 6A-2. 70% of ANSYS plastic instability load is used as the allowable buckling load (Reference 7, Para. F-1341.4).

Since the internal pressure produces tensile stresses in the cladding, it will reduce the compressive stresses caused by the end drop impact. The pressure is therefore conservatively neglected in this analysis. From the results in Table 6A-2, it is seen that the lowest tube-buckling load of 84G occurs in W17x17 OFA and W17x17 fuel assemblies. The actual end drop impact load is 50 G (Chapter 3, Section 3A.2.3.2.2). It is, therefore, concluded that the fuel cladding tubes will not be damaged during an end drop.

Result From Hand Calculation

Alternate method #1

As an order of magnitude check, the allowable buckling load based on material properties and geometry of W17x17 OFA fuel rod is calculated below and compared to the ANSYS analysis results.

In case of a bottom end drop, the inertial forces load the rod as a column having intermediate supports at each grid support (spacer). The fuel rod cladding limit load is that at which the fuel rod segments between the supports become unstable. The segment selected for analysis is the lowest one since it must support the entire weight of the fuel rod. The length to radius-of-gyration ratio of the column is such that Euler buckling applies. The axial buckling load is computed from,

$$P_{cr} = C\pi^2 EI / L^2$$

Where: L = length of fuel rod segment between spacers
= 24 in.
E = equivalent modulus of elasticity of tube/fuel
= 12.77×10^6 psi (see below)
I = moment of inertia of the cladding and fuel
= .000305 (tube) + 0.000483 (fuel pellets)
= 0.000788 in^4

Equivalent E for Tube and Fuel,

$$E = [11.29 \times 10^6(.000305) + 13.7 \times 10^6(.000483)]/(.000788)$$

$$= 12.77 \times 10^6 \text{ psi}$$

Since the fuel rod is a continuous tube extend beyond the support grid so moments will be developed at the intermediate support. This reactive end moment will keep the end from rotating during buckling. Thus the lowest segment will have fixed end condition at top and hinged at the bottom. Reference to "Formulas for Stress and Strain" by Raymond Roark[9], Fourth Edition, Table XV indicates that for a uniform straight bar under axial load, one end hinged, and other end fixed, a constant C = 2.25 can be used for calculating the buckling load. Therefore, the allowable buckling load is,

$$P_{cr} = C\pi^2EI / l^2 = 2.25(\pi^2)(12.77 \times 10^6)(0.000788)/24^2 = 388 \text{ lbs}$$

The weight of tube/fuel is taken at the middle of the bottom column,

$$W = 5.477 \times (132/144) = 5.02 \text{ lbs}$$

Therefore, the allowable G load is:

$$G = 388/5.02 = 77$$

This value is reasonably close to the solution given by the ANSYS result (84 G).

Alternate method #2

As an alternate analysis, the critical W17x17OFA fuel rod is conservatively analyzed as a prismatic bar with both end hinged by using Euler formula:

$$P_{cr} = \pi^2EI / L^2$$

Where:
- L = length of fuel rod segment between spacers = 24 in.
- E = equivalent modulus of elasticity of tube/fuel = 12.77×10^6 psi
- I = moment of inertia of the cladding and fuel = 0.000788 in^4

$$P = (\pi^2 \times 12.77 \times 10^6 \times 0.000788)/ 24^2 = 172.4 \text{ lb.}$$

Fuel rod weight (tube and fuel pellets), W = 5.477 lb.

G load = 172.4/5.477 = 31.5 g

Experiments show that when the compressive force in a slender strut approaches this value, lateral deflection begins and increases so rapidly with increase of the compressive force that a load equal to the critical value is usually sufficient to produce complete failure of the structure (Ref.8). However, lateral constraints (spacers) on the assembly play an important role in determining the fuel rod response. These supports and continuous basket design in TN-32 cask provides a continuous lateral constraint along the length of the assembly and results in significantly less lateral displacement. Figure 6A-1 illustrates the process by which lateral deformation is limited to the width of gaps between the assembly and basket, and between rods in the assembly during an end-drop. The lateral restraints, shown in Figure 6A-1, are based on all fuel rods having the same deformation pattern, with their lateral deformation constrained by the assembly and basket. In order to study the actual deflection, moment and stress, an individual tube between two supports in W17x17 OFA assembly tube is conservatively evaluated as a simply-supported beam-column. 1G distributed transverse load (w) and varying G axial (P) load was applied so as to result in a maximum deflection equal to the complete bowing of central tube of the array due to bending plus the clearance between the basket and fuel assemblies.

The maximum deflection allowed by the clearances between tubes and between assembly and basket,

y = [(Rod pitch-Rod OD) x No. of tubes in array/2]+ Clearance between basket and assembly
= [(0.496-0.356) x 17/2] + (8.700-8.426)
= 0.5(2.38)+ 0.274
= 1.464 in.

From Ref.9, in a beam-column, the maximum deflection due to distributed transverse load 'w' and compressive axial load 'P' is given by:

$$\text{Max. } y = (-wj^2/P)[\sec(U/2) - 1 - (U^2/8)]$$

The constant distributed transverse load,

$$W = 5.477/24 = 0.2282 \text{ lb/in}$$

The compressive axial load,

$$P = 5.477G$$

G is varied in the above formula and the resulting axial loads P and transverse deflection "y" are shown in Table 6A-3. It is seen that beyond 29G axial load, the deflection begins to increase rapidly and P load corresponding to 29.4G results

in 1.487" deflection. The typical calculations of deflection, bending moment and bending stresses for this load are produced below:

$P = 29.4 \times 5.477 = 161$ lb.

Equivalent E for Tube and Fuel $= 12.77 \times 10^6$ psi

Total $I = 0.000788$ in^4

$j = (EI/P)^{0.5} = 7.905$

$U = L/j = 24/7.905 = 3.036$ radians

$y = -[0.2282(7.905)^2/161]\ [18.944 - 1 - .125(3.036)^2]$
$= 0.08857 \times 16.792$
$= 1.487$ in.

$M = wj^2(\sec U/2 - 1)$
$= 0.2282(7.905)^2[18.944-1]$
$= 255.82$ in-lb.

Therefore, the maximum bending stress is,

$S_{bending} = MC/I = 255.82 \times 0.178 / 0.000788 = 57{,}787$ psi

After the fuel rod contacts the basket ($y > 1.464$ in.), there will no additional transverse deflection or bending stresses due to increase in axial load. The additional axial G load will result in axial stress only. The combined stresses for 50G load are computed below:

Axial load $= 50 \times 5.477 = 273.85$ lb.
Section area, $A = \pi/4(0.356)^2 = 0.09954$ in^2
Axial stress $= 273.85/0.09954 = 2{,}751$ psi

Max. combined stress $= 57{,}787 + 2{,}751 = 60{,}538$ psi

This conservatively calculated stress is also less than the tube yield strength.

6A.4 Brittle Fracture Evaluation

The following section is to demonstrate that the fracture toughness of the irradiated zircalloy cladding is sufficiently high to preclude brittle fracture failure during accident conditions.

The TN-32 cask is designed for storage of intact fuel assemblies. Fuel assemblies known or suspected to have cladding defects greater than hairline cracks or pin holes shall not be loaded into TN-32's for storage. The EPRI report, reference 5, provides a definition of pin holes or

hairline cracks to include cracks of maximum width about 100µm (0.004") but whose length could be anywhere between 200-300 µm (.008" - 0.012") and several millimeters. For conservatism, the following surface flaw size is used for brittle fracture evaluation of the fuel rod cladding:

a= flaw depth = 150 µm = 0.006"
l = flaw length = 4 mm = 0.16" .

Stress intensity factor K_1 is calculated using the equation in ASME Code, Section XI, Appendix A, Article A-3000. The crack location and orientation are assumed as to be most detrimental to the rod cladding:

$$K_1 = (\sigma_m M_m + \sigma_b M_b) \sqrt{\pi} \sqrt{a/Q}$$

Where

σ_m, σ_b = membrane and bending stresses in psi

a = flaw depth

Q = flaw shape parameter as determined from Appendix A, Fig. A-3300-1

M_m = correction factor for membrane stress from Appendix A, Fig. A-3300-3

M_b = correction factor for bending stress from Appendix A, Fig. A-3300-5

It is seen from Table 6A-1, that the combined tensile stress in W17 × 17 OFA fuel rod cladding is the highest (51,196 psi). This fuel rod is, therefore, selected for a fracture evaluation.

t = cladding thickness = 0.0205 inch
a = crack depth = 0.006 inch
l = crack length = 0.16 in
a/t = 0.2926
a/l = 0.0375
zircalloy yield strength, S_y = 85,530 psi
$\sigma_m + \sigma_b) / S_y = (12,450 + 38,746)/ 85,530 \approx 0.6$
Q = 0.95
M_m = 1.45
M_b = 1.0

$$K_1 = [(12,450 \times 1.45 + 38,476 \times 1.0) (\sqrt{\pi} \times \sqrt{0.006/0.95})]$$
$$= 8,001 \text{ psi} \sqrt{in} \approx 8.0 \text{ ksi} \sqrt{in}$$

The calculated Stress Intensity Factor for the flaw should satisfy the code faulted condition criteria (ASME Code Section XI, para. IWB-3612):

$$K_1 < K_{ic} / \sqrt{2}$$

Where K_{ic} is the material fracture toughness based on fracture initiation for the corresponding crack tip temperature.

K_{ic} from Ref. 3 at 200° F (conservatively use lower temp.) = 30.0 ksi $\sqrt{in}$

Allowable fracture toughness = 30.0 / 1.414
= 21.2 ksi $\sqrt{in}$ > 8.0 ksi $\sqrt{in}$

Based on the above evaluations, it is concluded that the fracture toughness of the irradiated zircalloy cladding is sufficiently high to preclude a brittle fracture failure during accident conditions. Therefore, the fuel cladding tube will remain intact to retain the fuel pellets during the accident conditions.

6A.5 References

1. LLNL Report UCID-21246, Dynamic Impact Effects on Spent Fuel Assemblies.
2. ASME Boiler and Pressure Vessel Code, Section XI, 1989.
3. ASTM Special Technical Publication 551, Variation of Zircalloy Fracture Toughness in Irradiation, Walker and Kass.
4. PNL-6189, Recommended Temperature Limits for Dry Storage of Spent Light Water Reactor Zircalloy-Clad Fuel Rods in Inert Gas, May 1987.
5. EPRI report, 1994, Irradiation Damage to Fuel Assemblies.
6. ANSYS Engineering Analysis System User's Manual, Rev. 5.2.
7. ASME Code Section III, Division 1 Appendices, 1995.
8. Timoshenko, "Strength of Materials", Part II, 3rd Edition.
9. Roark, "Formulas for Stress and Strain", 4th Edition.

Table 6A-1

Tipover/ Side Drop Impact Stress Calculations

Tube Arrays	15 x 15	17x17[6]	17 x 17 OFA	14 x 14	14 x 14 OFA
Assembly Weight (lb)	1,525	1,533	1,446	1,345	1,195
No. of fuel rods	204	264	264	179	179
Rod Pitch (in)	0.563	0.496	0.496	0.556	0.556
Max. active fuel length (in)	144	144	144	144	144
No. of Spacers, n	7	7	7	7	7
L = length/n-1	24	24	24	24	24
Tube OD[4] in)	0.418	0.370	0.356	0.418	0.396
Clad thick. [5] (in)	0.0223	0.0205	0.0205	0.0223	0.0223
Tube ID [2] in)	0.3734	0.3290	0.3150	0.3734	0.3514
S_y (psi)	85,530	85,530	85,530	85,530	85,530
Tube E (psi)	11.29×10^6	11.29×10^6	11.29×10^6	11.29×10^6	11.29×10^6
Tube I_1, (in^4)	.000544	.000345	.0.000305	.000544	.000459
Fuel I_2, (in^4)	.000954	.000575	.0.000483	.000954	.000749
w[1] (lb/in)	0.05191	0.04033	0.03804	0.05218	0.04636
$M_{max} = 0.1058wl^2$ (in.lb)	3.1634	2.4577	2.3180	3.1799	2.8253
Total I (in^4)	0.001498	.00092	.000788	.001498	.001208
S_b = MC/I (psi) (1G)	441.4	494.2	523.6	443.7	463.1
S_b ,74G (psi)	32,664	36,571	38,746	32,834	34,269
$S_{press.}$ Psi[3]	7,338	6,919	12,450	5,128	4,842
S = S_b + $S_{press.}$ (psi)	40,002	43,490	51,196	37,962	39,111

(1) w = Assembly weight /(No. of fuel rods x Active length)

(2) Fuel OD is taken same as the tube ID.

(3) $S_{press.}$, axial stress = p x $D_{avg.}$ /4t

(4) Includes 0.004 in. reduction in cladding OD to account for water side cladding corrosion (Ref. 4).

(5) Thickness is reduced by 0.002 in. to account for corrosion (Ref. 4).

(6) Evaluation of the Westinghouse 17x17 bounds the B&W Mark BW fuel rod, which has the same outside diameter, thicker cladding, the same number of grids (spacers), and equal or lower pressurization (Table 6.2-1 and Section 7.2)

Table 6A-2
Tube Buckling Loads Due to End drop Impact

Tube Arrays	15 x 15	17x17 (2)	17 x 17 OFA	14 x 14	14 x 14 OFA
Tube length, (in.)	160	160	160	161.3	161.3
Tube active length, (in.)	144	144	144	144	144
Assembly weight (lb)	1,525	1,533	1,446	1,345	1,195
Length between spacers, (in.)	24	24	24	24	24
Tube OD (in)	0.418	0.370	0.356	0.418	0.396
Tube thickness (in)	0.0223	0.0205	0.0205	0.0223	0.0223
Tube ID (in)	0.3734	0.3290	0.3150	0.3734	0.3514
No. of fuel rods	204	264	264	179	179
Wt. fuel rod (lb)	7.475	5.807	5.477	7.514	6.676
Tube area (in^2)	0.0277	0.0225	0.0216	.0277	.0262
Fuel pellet area (in^2)	0.1095	0.0850	0.0779	0.1095	0.0970
Tube weight (lb) (1)	1.0371	0.8424	.8087	1.0455	0.9889
Fuel weight (lb)	6.438	4.965	4.668	6.468	5.688
ANSYS Plastic Instability G load	140	120	120	140	125
Buckling G Load (70%)	98	84	84	98	87.5

(1) Zircaloy Density = 0.234 $lb/in.^3$

(2) Evaluation of the Westinghouse 17x17 bounds the B&W Mark BW fuel rod, which has the same outside diameter, thicker cladding, the same number of grids (spacers), and equal or lower pressurization

Table 6A-3
TN-32 W17x17OFA Fuel Rod, Beam - Column Analysis

G Load	W	P	j	L	U	SEC(U/2)	A	B	y Deflection
10	5.477	54.77	13.5546	24	1.77061	1.57965	0.18776	0.76553	0.14374
15	5.477	82.155	11.0673	24	2.16855	2.13879	0.55096	0.34023	0.18745
20	5.477	109.54	9.58456	24	2.50402	3.19070	1.40693	0.19138	0.26926
25	5.477	136.925	8.57269	24	2.79958	5.87646	3.89675	0.12248	0.47729
26	5.477	142.402	8.40621	24	2.85503	7.00322	4.98432	0.11324	0.56444
27	5.477	147.879	8.24907	24	2.90941	8.63353	6.57544	0.10501	0.69049
28	5.477	153.356	8.10043	24	2.96280	11.2013	9.10409	0.09764	0.88896
29	5.477	158.833	7.95954	24	3.01524	15.8402	13.7038	0.09102	1.24740
29.4	5.477	161.023	7.90521	24	3.03597	18.9444	16.7923	0.08856	1.48723
29.8	5.477	163.214	7.85197	24	3.05655	23.5260	21.3582	0.08620	1.84117
30	5.477	164.31	7.82576	24	3.06679	26.7448	24.5692	0.08505	2.08983
30.2	5.477	165.405	7.79980	24	3.077	30.9687	28.7852	0.08393	2.41612
30.4	5.477	166.500	7.77410	24	3.08717	36.7553	34.5640	0.08283	2.86312
30.6	5.477	167.596	7.74865	24	3.09731	45.1687	42.9696	0.08175	3.51302
30.8	5.477	168.691	7.72345	24	3.10741	58.5225	56.3155	0.08069	4.54453
31	5.477	169.787	7.69850	24	3.11748	82.9762	80.7614	0.07966	6.43344
31.2	5.477	170.882	7.67379	24	3.12752	142.212	139.989	0.07864	11.0090

Notes:

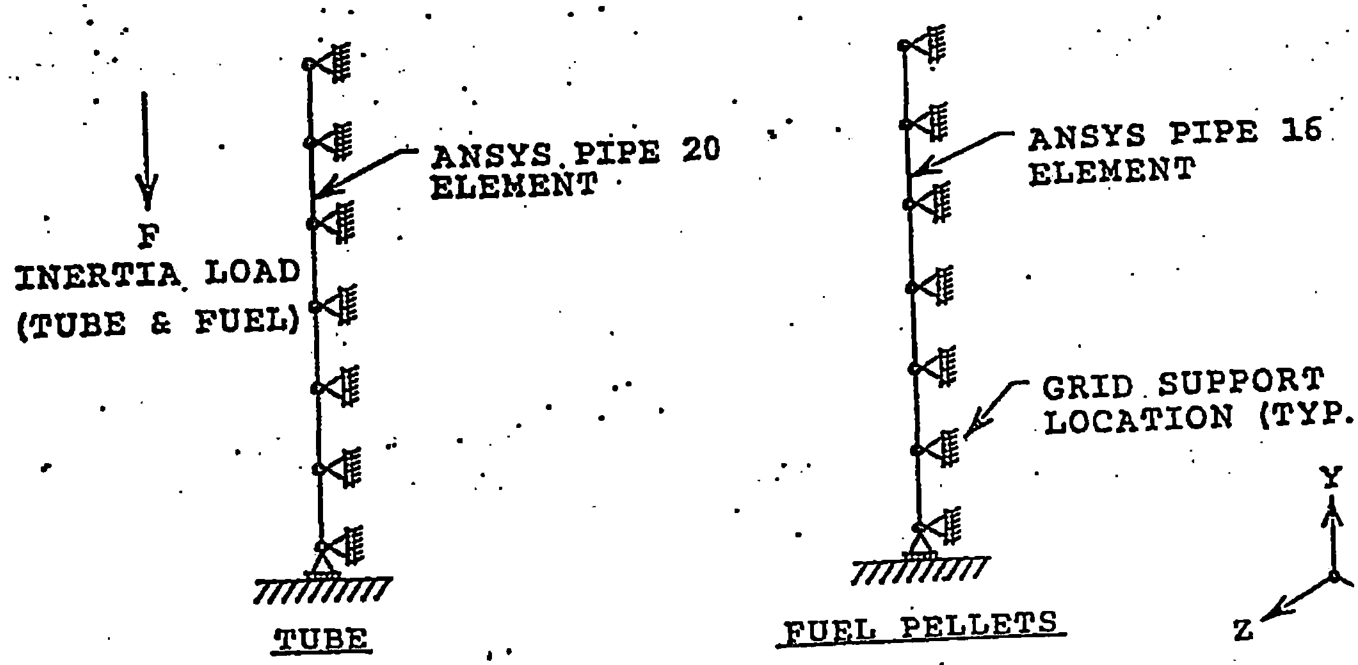
W= Tube Weight (lb)
w = W/L (lb/in)
P = Axial Force = G x W (lb)
U = L/j
A = (secU/2-1-1/8U^2)
y, deflection = B x A (in)

L = Tube span (in)

$j = (EI/P)^{0.5} = (12.77x10^6 \times .000788/P)^{0.5}$

$B=wj^2/P$

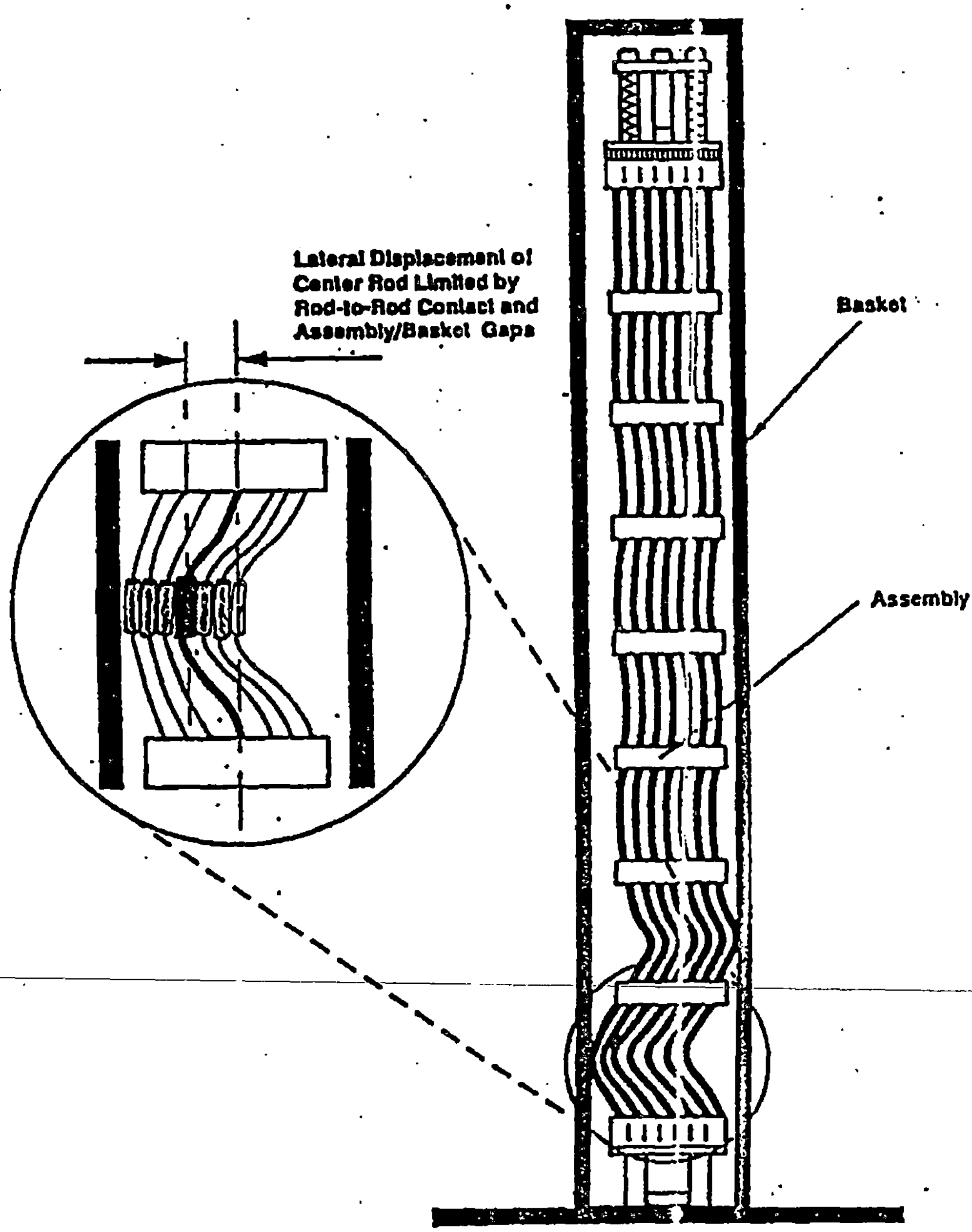
Figure 6A-1
Tube and Fuel Pellets Finite Element Model Simulation



NOTE: THE TUBE AND FUEL PELLETS NODES ARE COINCIDEN BUT ARE SHOWN SEPARATELY FOR CLARITY. THESE N ARE COUPLED IN X, Y, & Z DIRECTIONS.

Figure 6A-2

Lateral Displacement of Center Rod Limited by Rod-to-Rod Contact and Assembly/Basket Gap



Note: The type of fuel assembly shown in figure is for reference only. The purpose of this figure is to show the mode of fuel rod deflection.

CHAPTER 7

CONFINEMENT

7.1 Confinement Boundary

The confinement boundary consists of the inner shell and bottom plate, shell flange, lid outer plate, lid bolts, penetration cover plates and bolts and the inner metallic O-rings of the lid seal and the two lid penetrations (vent and drain). The confinement boundary is shown in Figure 1.2-1. The construction of the confinement boundary is shown on drawings 1049-70-1, 2 and 3 provided in Section 1.5. The confinement 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.

7.1.1 Confinement Vessel

The TN-32 confinement vessel consists of: an inner shell which is a welded, carbon steel cylinder with an integrally-welded, carbon steel bottom closure; a welded flange forging; a flanged and bolted carbon steel lid with bolts; and vent and drain covers with bolts. The overall confinement vessel length is 175.25 in. with a wall thickness of 1.5 in. The cylindrical cask cavity has a diameter of 68.75 in. and a length of 163.25 in.

The confinement shell and bottom closure materials are SA-203 Grade D and the shell flange is SA-350 Grade LF3. The confinement lid material is SA-203 Grade D or SA-350 Grade LF3.

The cask design, fabrication and testing are covered by a Quality Assurance Program which conforms to the criteria in Subpart G of 10CFR72.

The materials of construction of the confinement vessel are SA 203 Grade D and SA-350 LF3. The confinement vessel is designed to the ASME Code, Section III, Subsection NB, Article 3200. SA-203 Gr. D is not a ASME Class 1 material, but is an acceptable Class 2 (Subsection NC) material.

As stated in the Standard Review Plan, NUREG-1536[4], the NRC has accepted the use of either Subsection NB or Subsection NC of the code for containment.

SA-203 Grade D is identical to SA-203 Grade E which is a Class I material except for the following:

	Yield Strength	Tensile Strength	Elongation	S/S_m
Grade D	37 ksi	65 - 85 ksi	23% min	16.2 ksi
Grade E	40 ksi	70 - 90 ksi	21% min	23.3 ksi

The chemical content of the two grades are identical, except that Grade E restricts the carbon to 0.20 max., while Grade D further restricts the carbon content to 0.17 max. Grade D is acceptable as a Class 2 material up to 500° F.

Grade D was selected because of its ductility, since the higher strength is not required. SA-203 Grade D has better elongation than due to its lower strength is more likely to have the good fracture toughness at low temperatures.

In selecting materials for storage and transport casks, one of the major selection criteria is fracture toughness at low temperatures. Grade D was selected on this basis. There is no similar requirement for pressure vessels, as they are used at much higher temperatures.

For the SA-203 Grade D material, the allowable stress was based on S, the allowable stress for Class 2 components. This is conservative, since NB is based on S_m, which is 1/3 the tensile strength, while S is 1/4 the tensile strength. Thus there is additional margin over and above the margin required by the code for Class I materials.

The confinement vessel materials are impact tested in accordance with NB-2300 and meet the acceptance standards of NB-2330. The closure flange or other forgings comprising part of the containment boundary are examined by the ultrasonic method in accordance with paragraph NB-2542. The acceptance criteria of paragraph NB-2542.2 is applied. All external and accessible internal surfaces are examined by the liquid penetrant method or the magnetic particle method in accordance with paragraph NB-2546 or NB-2545 as applicable. The acceptance criteria of paragraph NB-2546.3 or NB-2545.3 is applied. The lid bolts, drain cover bolts and vent cover bolts are visually examined in accordance with NB-2582. The bolts are also dye penetrant examined in accordance with Paragraph NB-2584. All holes for bolts are visually examined in accordance with Paragraph NB-2582. In accordance with NB-2520, low alloy materials are magnetic particle inspected after quench and temper.

Welding materials used in containment welds or welds to containment components conform to the requirements of NB-2400 and to the material specification requirements of Section II, Part C of the ASME B&PV Code. Forgings are examined according to NB-2542, NB-2546, or NB-2545 as applicable. Temporary attachment welds to the containment boundary meet the requirements of NB-4435. Paragraph NB-4300 is applied for all confinement vessel

welds and examination and acceptance meets the requirements of NB-5210, NB-5220, NB-5320, NB-5330, NB-5340, or NB-5350 as appropriate. Stress relieving is also performed in accordance with Section III, Subsection NB.

Even though the Code is not strictly applicable to storage casks, it is the intent to follow Section III, Subsection NB of the Code as closely as possible for design and construction of the confinement vessel. The cask may, however, be fabricated by other than N-stamp holders and materials may be supplied by other than ASME Certificate Holders. Thus the requirements of NCA are not imposed. TN's quality assurance requirements, which are based on 10CFR72 Subpart G and NQA-1 are imposed in lieu of the requirements of NCA-3850. This SAR is prepared in place of the ASME design and stress reports. Surveillances are performed by TN and utility personnel rather than by an Authorized Nuclear Inspector (ANI).

The weld of the bottom inner plate to the confinement shell is a Category C, Type 2 corner weld in accordance with Figure NB-4243-1 of the ASME Code. In accordance with NB-5231, Type 2 Category C full penetration corner welded joints require the fusion zone and the parent metal beneath the attachment surface to be ultrasonically examined after welding. If this weld is performed on the confinement vessel after assembly with the outer shell, the UT inspection cannot be performed. In lieu of the UT inspection, the joint will be examined by the radiographic method and either the liquid penetrant or magnetic particle methods in accordance with the ASME Code Subsection NB.

A hydrotest is not required to be performed for this vessel. The method of manufacture precludes inspection of the confinement after the hydrotest, since it is enclosed in the gamma shielding during final machining and welding of the bottom plate. The pressure test of the completed vessel would need to be performed after installation in the gamma shielding and would not provide meaningful results. In addition, the gamma shielding supports the confinement boundary under all conditions, so a pressure test of the confinement vessel separately will not simulate actual loading conditions. The TN-32 cask is not pressure limited, as shown in Table 3A.2.3-5. All confinement welds are fully radiographed in accordance with Subsection NB requirements. The stresses due to pressure are insignificant compared to the loads due to drop or tipover events.

7.1.2 Confinement Penetrations

There are two penetrations through the confinement vessel, both in the lid. One is the drain port and the other the vent port. A double O-ring seal mechanical closure is provided for each penetration. Each penetration contains a quick connect coupling for ease of operation.

7.1.3 Seals and Welds

The confinement boundary welds consist of the circumferential welds attaching the bottom closure and the top flange to the vessel shell. Also, the longitudinal weld(s) on the rolled plate, closing the cylindrical vessel shell, and the circumferential weld(s) attaching the rolled shells together are confinement welds.

The confinement boundary welds, both circumferential and longitudinal, are full penetration welds examined volumetrically by radiograph. These welds are also liquid penetrant or magnetic particle examined. The acceptance standards are in accordance with Article NB-5000.

Stainless steel overlay welds are examined by the liquid penetrant method in accordance with Section V of the ASME Code.

Electrodes, wire, and fluxes used for fabrication comply with the applicable requirements of the ASME Code, Section II, Part C. The welding procedures, welders and weld operators must be qualified in accordance with Paragraph NB-4300 of Subsection NB.

Double metallic seals are utilized on the lid and the two lid penetrations. Helicoflex HND or equivalent seals may be used. The seals are shown in Figure 7.1-3. The internal spring and lining maintain the necessary rigidity and sealing force, and provide some elastic recovery capability. The outer aluminum jacket provides a ductile material against the sealing surfaces. The jacket also provides a connecting sheet between the inner outer seals. Holes in this sheet allow for attachment screws and for communication between the overpressure system and the space between the seals. This sheet, which is about 0.020 inch thick, has insufficient strength to transmit radial forces great enough to overcome the axial compressive forces on the seals, which are over 1000 lb/inch of seal length. Additional information on the seals is provided in Section 2.3.2. The overpressure port seal is a single metallic seal of the same design, Helicoflex HN200 or equivalent.

All TN-32 surfaces which mate with the metallic seals are stainless steel.

The use of a double seal system allows the TN-32 cask to have a pressure monitoring system of the interspace between the seals, (see Section 2.3.2). This combined cover-seal pressure monitoring system always meets or exceeds the requirement of a double barrier closure which guarantees tight, permanent containment. When the cask is placed in storage, a pressure greater than that of the cavity is set up in the gaps

(interspace) between the double metallic seals of the lid and the lid penetrations. A decrease in the pressure of the monitoring system would be signalled by a pressure transducer/switch in the over pressure system.

The lid and penetration seals described above are contained in grooves. Sealing is assured over the storage period by utilizing seals in a deformation-controlled design. The deformation of the seals is constant since bolt loads assure that the mating surfaces remain in contact. The seal deformation is set by its original diameter and the depth of the groove.

The nominal diameter of the lid seal is 6.6 mm, and the nominal groove depth is 5.6 mm. At 1 mm compression, the sealing force is 245 N/mm^2 (1399 lb/inch)[12]. The total force of the double seal is 631,600 lb. The total preload of the 48 lid bolts is 2,851,000 lb, which is greater than the combined force of the seals and internal pressure, 1,126,500 lb (Section 3A.3.1.1).

The nominal diameter of the port seals is 4.1 mm, and the nominal groove depth is 3.2 mm. At 0.9 mm compression, the sealing force is 200 N/mm^2 (1142 lb/inch). The total force of the double seal is 37,900 lb. The total preload of the 8 cover bolts is greater than the combined force of the seals and internal pressure, 39,750 lb.

The sealing force is maintained by the seal's internal spring. Due to creep, the sealing pressure decreases with increasing temperature as shown in the following table[12]. The long-term temperature limit is the point at which the sealing pressure becomes zero due to creep. The maximum normal temperature experienced by the seals in the TN-32 is 256 °F (Table 4.4-1).

Seal	$P_{124\ C}/P_{20\ C}$ (124 °C = 256 °F)	$P_{200\ C}/P_{20\ C}$ (200 °C = 392 °F)	Temperature limit
Lid, 6.6 mm	(427/670) = 60%	(250/670) = 37%	340 °C (644 °F)
Ports, 4 mm	(352/600) = 60%	(170/600) = 28%	280 °C (536 °F)

Data from Reference 12; data at 124 °C by linear interpolation

The maximum radial force on the seals is from the 5.5 atm abs overpressure system. Using the compressed seal height of 5.5 mm, this results in a force per unit seal length of about

4.5 atm gage*14.7 psi/atm*(5.6/25.4)inch = 15 lb/inch

which is negligible compared to the compressive (axial) forces of over 1000 lb/inch. Because the maximum pressure is between the two seals, the direction of this force is such that the seals are supported by the walls of the seal groove. However, the seals are designed to retain pressure in either direction.

Metallic seals are all capable of limiting leak rates to

less than 1×10^{-7} atm-cc/sec of helium. After loading, all lid and cover seals are leak tested in accordance with ANSI N14.5. The acceptable total cask leakage (both inner and outer seals combined) is 1×10^{-5} std cc/sec.

7.1.4 Closure

The confinement vessel contains an integrally-welded bottom closure and a bolted and flanged top closure, (lid). The flanged lid plate is attached to the cask body with 48 bolts. A bolt torque of 930 ± 50 ft-lbs (lubricated) is utilized to provide the required load for the metallic seals located in the lid. The closure bolt analysis is presented in Appendix 3A.3.

As previously mentioned, the lid contains two penetrations which are sealed by flanged covers fastened to the lid by 8 bolts. The bolt torque required to seal the metallic seals in the penetration covers is 60 - 65 ft-lbs (lubricated).

7.1.5 Monitoring of System Confinement

An overpressure monitoring system is part of the TN-32 design. The pressure in the monitoring system is greater than that of the cask cavity and the cask cavity pressure is greater than ambient. In this configuration, no in-leakage of air nor out-leakage of cavity gas is possible.

If a leak existed in the seals, the design of the TN-32 overpressure system is such that the leak will either be to the atmosphere or to the cask cavity. Leakage from the cask cavity past the higher pressure of the overpressure system is physically impossible.

The seals (and overpressure system)are collectively leak tested to 1×10^{-5} std cc/sec. Using the methodology of ANSI N14.5[2], an equivalent maximum hole size is estimated based upon test conditions of equivalent air leaking from 1 atm abs to 0.01 atm abs in ambient temperature conditions (77°F or 25°C) and the maximum acceptable leak of 1×10^{-5} std cc/sec. The leakage hole length is assumed to be the same as the metal seal width, 0.5 cm. The equivalent maximum hole size is calculated below.

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec at } T_u,\ P_u$$

Other definitions:

- L_u = upstream volumetric leakage rate, cc/sec = 1×10^{-5} std cc/sec (Test Leak Rate)
- F_c = coefficient of continuum flow conductance per unit pressure, cc/atm-sec
- F_m = coefficient of free molecular flow conductance per

unit pressure, cc/atm-sec

P_u = fluid upstream pressure, atm abs = 1.0 atm abs

P_d = fluid downstream pressure, atm abs = 0.01 atm abs

D = leakage hole diameter, cm

a = leakage hole length, cm = 0.5 cm (assuming leak path length is on the order of the metal seal width)

μ = fluid viscosity, cP = 0.0185 cP (from ANSI N14.5, Table B.1)

T = fluid absolute temperature, K = 298 K

M = molecular weight, g/mol = 29.0 g/mol (from ANSI N14.5, Table B.1)

P_a = average stream pressure = ½ $(P_u + P_d)$, atm abs = 0.505 atm abs

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec}$$

where:

$$F_c = (2.49 \times 10^6 \times D^4)/(a\mu) \text{ cc/atm-sec}$$
$$F_m = \{3.81 \times 10^3 \times D^3 \times (T/M)^{0.5}\} / \{aP_a\} \text{ cc/atm-sec}$$

Substituting:

$$F_c = (2.49 \times 10^6 \times D^4)/(0.5 \times 0.0185) = 2.69 \times 10^8 D^4$$
$$F_m = \{3.81 \times 10^3 \times D^3 \times (298/29.0)^{0.5}\}/\{0.5 \times 0.505) = 4.84 \times 10^4 D^3$$

$$L_u = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec}$$
$$1 \times 10^{-5} = (F_c + F_m)(1.0 - 0.01)(0.505 / 1.0)$$
$$F_c + F_m = 2 \times 10^{-5}$$

Solving the equations, the equivalent hole diameter, D, is 4.83×10^{-4} cm.

During operations, the overpressure system is initially back filled with 5.5 atm abs (66.2 psig) of Helium at standard temperature. The temperature of the helium in the O.P. tank at equilibrium is assumed to be the average of the ambient temperature (100°F) and the seal temperature (256°F, from Table 4.4-1) or 178°F (81°C). The pressure in the overpressure system at this temperature will be 6.53 atm abs (81.3 psig).

Assuming the overpressure system is leaking to the atmosphere, the leak rate is defined using the equations of ANSI N14.5:

$$L_{u,He} = (F_c + F_m)(P_u - P_d)(P_a/P_u) \text{ cc/sec}$$

$$F_c = (2.49 \times 10^6 \times D^4)/(a\mu) \text{ cc/atm-sec}$$

$$F_m = \{3.81 \times 10^3 \times D^3 \times (T/M)^{0.5}\} / \{aP_a\} \text{ cc/atm-sec}$$

$L_{u,He}$ = helium volumetric leakage rate
P_u = 6.53 atm abs
P_d = 1.0 atm abs
D = 4.83 x 10^{-4} cm
a = 0.5 cm
μ = 0.0224 cP (for helium at 354 K)
T = 354 K
M = 4.0 g/mol
P_a = ½ (P_u + P_d) = 3.77 atm abs

Substituting:

$$F_c = \{2.49E+06 \times (4.825E-04)^4\}/(0.5 \times 0.0224) = 1.21E-05$$

$$F_m = \{3.81E+03 \times (4.825E-04)^3 \times (354/4)^{0.5}\} / (0.5 \times 3.7668) = 2.14E-06$$

$$L_{u,He} = (F_c + F_m)(P_u - P_d)(P_a/P_u)$$
$$L_{u,He} = (1.21E-05 + 2.14E-06)(6.53 - 1.0)(3.77 / 6.53)$$
$$L_{u,He} = 4.53E-05 \text{ cc/sec of Helium}$$

Over the first year, the maximum volume leaked from the overpressure system is:

$$V = 4.53E-05 \text{ cc/sec} \times (365 \text{ days/yr}) \times (24 \text{ hrs/day}) \times (3600 \text{ sec/hr})$$
$$V = 1428 \text{ cc of helium at } T_u, P_u.$$

The OP system tank basically consists of a 6" diameter schedule 80 pipe (27" long) and two 6" diameter schedule 80 end caps. The volume of the tank is 835 in^3. The volume of the OP system is increased to 900 in^3 (14750 cc) to include the OP system tubing and the space between the metallic seals in the lid and penetrations. Corresponding, the pressure is reduced by the following in the first year:

$$P_{OP\ released} = P_{OP\ Sys,\ Initial} \times \{V_{released} / V_{OP\ Sys}\}$$
$$P_{OP\ released} = 6.53 \text{ atm } (1428cc / 14750cc) = 0.63 \text{ atm}$$

The overpressure system pressure is also corrected for the corresponding drop in temperature over the first year. At the end of the first year, the overpressure system pressure is 5.88 atm abs (71.7 psig). These calculations are repeated every year for the 20 year licensing period of the cask. Figure 7.1-1 illustrates the pressure drop from the overpressure system to the atmosphere. Figure 7.1-1 also illustrates the pressure drop in the cask cavity due to fuel cooling.

If a leak is to the cask cavity rather than the atmosphere, the pressure drop in the overpressure system is calculated using a downstream pressure of 2.5 atm abs, or 17.6 psig (see Section 7.2.2.1). Figure 7.1-1 also illustrates the results of this

analysis. In this scenario, the corresponding increase in the cask cavity pressure is negligible.

As shown above, the monitoring system pressure is greater than the cask cavity or atmospheric pressure assuming a leak based on the conservative initial acceptance test leak rate of 1×10^{-5} std cc/sec. Typically, metallic seals result in joints with much lower leak rates than the acceptance criteria. Therefore, no leakage will occur from the cask cavity during the storage period.

The pressure in the overpressure system will be monitored over the lifetime of the cask. To allow time to diagnose and correct any problems, the overpressure monitoring system is set to alarm if the overpressure system drops below 3.2 atm abs (32.3 psig). This alarm setpoint ensures that pressure decreases in the overpressure monitoring system are identified well before any potential out leakage from the cask cavity occurs.

7.2 Requirements for Normal Conditions of Storage

7.2.1 Release of Radioactive Material

The TN-32 dry storage cask is designed to provide storage of spent fuel for at least 40 years. The cask cavity pressure is always above ambient during the storage period as a precaution against the in-leakage of air which might be harmful to the fuel. Since the confinement vessel consists of a steel cylinder with an integrally-welded bottom closure, the cavity gas can escape only through the lid closure system. In order to ensure cask leak tightness, two systems are employed. A double barrier system for all potential lid leakage paths consisting of covers with multiple seals is utilized. Additionally, pressurization of monitored seal interspace provides a continuous positive inward and outward pressure gradient which guards against a release of the cavity gas to the environment and the admission of air to the cavity.

The cask loadings for normal conditions of storage are given in Section 2.2.5. It is shown that the seals are not disturbed by any of the loadings and thus, the cask confinement is maintained.

A gas sample may be taken utilizing the quick connect fitting in the vent port penetration to check the confinement vessel gas for radioactive material,. However, the over pressure monitoring system would have to be disabled in order to perform this test.

7.2.2 Pressurization of Confinement Vessel

7.2.2.1 Pressure under 100 °F Ambient Air Temperature, Maximum Insolation

The pressure at completion of backfill is 2.2 atm abs. The average temperature of the helium when backfilling is completed is assumed to be at 313 °F (773 °R), the same as the average cavity gas temperature under conditions of -20 °F ambient air and no solar load. The average cavity gas temperature with 100 °F ambient air and maximum solar load is 411 °F (871 °R).

2.2 atm abs (871 °R /773 °R) = 2.5 atm abs (22.1 psig)

7.2.2.2 Pressure Under 100 °F Ambient Air Temperature, Maximum Insolation, 10% Fuel Rod Failure, 10% BPRA Rod Failure

Fuel clad failure would result in an increase in cavity pressure due to free gas release of the fuel and BPRA rods. The Westinghouse 15x15 assembly contains the most free gas[3],

approximately 6.2 m^3 at STP (32 assemblies).

B&W Mark BW fuel free gas, which is not evaluated in reference 3, is bounded by the Westinghouse 15x15 fuel as follows.

The end of life pressure in the Mark BW fuel will be lower than that in the Westinghouse 17x17 fuel for the following reasons:

(a) Westinghouse 17x17 fuel is prepressurized up to 500 psi. Framatome Cogema Fuels has verified that Mark BW fuel prepressurization is less than 500 psi.

(b) The UO_2 mass in Westinghouse standard 17x17 fuel is 0.364 lb/ft, and in Mark BW fuel, 0.360 lb/ft. Therefore, for a given mass-specific burnup, the Mark BW fuel will have slightly fewer fission products than the Westinghouse 17x17.

The Mark BW fuel pellet density is 96%, compared to 95% for the Westinghouse fuel. Therefore, there will be slightly less fission gas release in the Mark BW fuel.

The diametral gap in the two fuels is the same, so the plenum volume is nearly the same. Therefore, the end of life moles of free gas in the Mark BW fuel will be the same or less than that in the Westinghouse 17x17 fuel. According to reference 3 the total free gas at 45 GWd/MTU is 939 cm^3 for the 15x15 and 648 cm^3 for the 17x17. For the analysis of internal pressurization, the Westinghouse 15x15 fuel bounds both the Westinghouse standard 17x17 fuel and the Mark BW fuel by a wide margin.

The cavity pressure from 10% of the free gas in 32 assemblies is:

Free fuel rod gas at STP (T = 492 °R, P = 1 atm abs)
= (0.1)32 assemblies(205 fuel rods/assy)939 cm^3 = 0.616 m^3

Free cavity volume = 190.4 ft^3 = 5.39 m^3

Displacement volume of BPRA = 480 in^3 = 7.866×10^{-3} m^3

Free cavity volume w/ BPRA = 5.39 m^3 - (32)(7.866×10^{-3} m^3)
= 5.14 m^3

Free fuel rod gas pressure at 411 °F (871 °R), expanded to cavity volume:

$$P_2 = P_1(T_2/T_1)(V_1/V_2)$$
$$= 1(871/492)(0.616/5.14)$$
$$= 0.21 \text{ atm } (3.12 \text{ psi})$$

Total number of p-moles in BPRAs (Ref 13)
= (0.1)(32 assemblies)(20 BPRA rods/assy)(6.59E-4 p-moles/rod)
= 0.0422 p-moles

BPRA rod gas pressure at 871 °R:

$$P_2 = \frac{nRT}{V} = \frac{(0.0422\ \text{p-moles})(1545.32\ \frac{\text{lb}_f\text{-ft}}{\text{p-mole R}})(871\ \text{R})}{(5.14\ \text{m}^3)}\left(\frac{0.3048\ \text{m}}{1\ \text{ft}}\right)^3$$

$$P_2 = 2.2\ \text{psi}$$

Total pressure = 22.1 + 3.12 + 2.17 = 27.4 psig

The maximum normal operating pressure is conservatively set at 35 psig.

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7.3 Confinement Requirements for Hypothetical Accident Conditions

7.3.1 Fission Gas Products

Table 5.2-5 lists the activity representing the fission gases, volatiles, and fines contributing more than 0.1% of the activity contained in the 32 fuel assemblies, plus iodine 129.

The releasable source term is first determined. The release fractions applied to the source term are provided below (developed from References 4, 5 and 11).

Variable	Off-Normal Conditions	Accident Conditions
Fraction of crud that spalls off rods, f_C	0.15	1.0
Fraction of Rods that develop cladding breaches, f_B	0.10	1.0
Fraction of Gases that are released due to a cladding breach, f_G	0.3	0.3
Fraction of Fines that are released due to a cladding breach, f_F	3×10^{-5}	3×10^{-5}
Fraction of Released Fines that remain airborne following a cladding breach, $f_{f,a}$ *	0.10	0.10
Fraction of Volatiles that are released due to a cladding breach, f_V	2×10^{-4}	2×10^{-4}

* 0.003% of the fuel in a rod is released from the rod during a cladding failure in the form of fines. However, only 10% of the fuel fines ejected from the rod during a cladding failure remain airborne (Reference 11).

The releasable source term also depends on the leak rate from the TN-32. Under off-normal conditions, it is assumed that the overpressure system is not functioning properly. In this case, the cask cavity gas is free to leak out at a rate of 1×10^{-5} std cc /sec. Assuming the cask cavity gas acts like helium (including the gases, volatiles, fines and crud), the leak rate is adjusted to a helium leak rate at cask cavity conditions using the equations of ANSI N14.5. This calculation is shown below.

P_u = 2.71 atm abs (off-normal cask cavity pressure, 10% fuel rod failure)
P_d = 1.0 atm abs
D = 4.83×10^{-4} cm
a = 0.5 cm
μ = 0.0280 cP (for helium at 484 K)
T = fluid absolute temp = 411°F = 484 K (cavity gas temperature, 100°F ambient)
M = 4.0 g/mol
$P_a = \frac{1}{2} (P_u + P_d)$ = 1.9 atm abs

Substituting:

F_c = 9.64E-06
F_m = 5.08E-06
$L_{u,he}$ = 1.72E-05 cc/sec of Helium for off-normal conditions

Similarly, under hypothetical accident conditions, it is assumed that the overpressure system has stopped functioning and fire conditions exist.

$L_{u,he}$ = helium volumetric leak rate
P_u = 5.0 atm abs (cask cavity pressure following fire = 73.1 psia)
P_d = 1.0 atm abs
D = 4.83 x 10^{-4} cm
a = 0.5 cm
μ = 0.0283 cP (for helium at 531 K)
T = fluid absolute temp ≈ 531 K (average cavity gas temperature following fire, 497°F)
M = 4.0
P_a = ½ (P_u + P_d) = 3.0 atm abs

Substituting into the equations of ANSI N14.5:

F_c = 9.54E-06
F_m = 3.30E-06
$L_{u,he}$ = 3.06E-05 cc/sec of Helium for hypothetical accident conditions

The releasable contents from the TN-32 during off-normal and hypothetical accident conditions are provided in Tables 7.3-1 and 7.3-2, respectively.

7.3.2 Release of Contents

Two scenarios are considered:

- Off-Normal Conditions - This condition exists over a one year period, seals are leaking at the test leak rate of 1 x 10^{-5} std cc/sec and the fraction of rods that have failed is 10%. Stability category D and 5 m/s wind speed is used for this analysis. This scenario assumes one cask is in off-normal condition at the ISFSI.

- Hypothetical Accident Conditions - This condition exists over a 30 day period, seals are leaking at the test leak rate of 1 x 10^{-5} std/cc sec, the fraction of rods that have failed is 100%, and the temperature inside the cask is comparable to the fire accident conditions. Stability category F and 1 m/s wind speed is used for this analysis.

This scenario assumes one cask is in the hypothetical accident condition at the ISFSI.

In the first scenario, the release is assumed to occur for more than a 20 minute period. The methodology of Reg Guide 1.145[6] is applied. The atmospheric diffusion from a ground level point source at 100 meters is based on the following parameters.

Wind speed = 5 meter/second

σ_y = 8 meters from Ref 6, Figure 1

σ_z = 5 meters from Ref 6, Figure 2

M = 1.1, from Ref 6, Figure 3

$\Sigma_y = M\sigma_y$ = 8.8 meters

A = is cross sectional area of the TN-32 = 12.6m²

Using the methodology of Reg Guide 1.145, $\{\chi/Q\}_{100\ meters}$ during off-normal conditions is 1.45E-03 sec/m³. Similarly, the atmospheric diffusion for 500 meters during off- normal conditions is calculated using the following parameters.

Wind speed = 5 meter/second

σ_y = 40 meters

σ_z = 20 meters

M = 1.1

$\Sigma_y = M\sigma_y$ = 44 meters

During off normal conditions $\{\chi/Q\}_{500\ meters}$ is 7.23E-05 sec/m³.

In the second scenario the release is assumed to be a short term ground level release (occurring however over a 30 day period) assuming the methodology of Regulatory Guide 1.25[7]. The atmospheric stability classification of F and a wind speed of 1 m/sec is used. The atmospheric diffusion from a ground level point source at 100 meters is calculated below.

Wind speed = 1 meter/second

σ_y = 4 meters (Ref 6, Figure 1)

σ_z = 2.3 meters (Ref 6, Figure 2)

Substituting into the equations of Reference 7:

$\chi/Q = 1 / 1 (\pi \times 4 \times 2.3)$ = 3.46E-02 sec/m³ for hypothetical accident conditions

Similarly, the atmospheric diffusion for 500 meters is:

$\{\chi/Q\}_{500\ meters}$ = 1.90E-03 sec/m³ for hypothetical accident conditions.

7.3.2.1 Dose Calculations

Dose components are calculated following the method of Regulatory Guide 1.109[8] and utilizing dose conversion factors from EPA Federal Guidance Reports Numbers 11 and 12[9,10].

To determine the committed doses (from air inhalation), the following equation is used:

$$Dose_{inhalation} = R \times \chi/Q \times Q \times DCF_{inhalation}$$

Where:

R = Inhalation Rate = 8,000 m^3/year = 2.54E-04 m^3/sec

χ/Q = Short term average centerline value of atmospheric diffusion for a ground level release (sec/m^3)

Q = amount of material released (μCi/sec)

$DCF_{inhalation}$ = Exposure Dose Conversion Factor (mrem/μCi), from reference 9.

To determine the deep doses (from air immersion), the following equation is used:

$$Dose_{air\ immersion} = \chi/Q \times Q \times DCF_{air\ immersion}$$

Where:

χ / Q = Short term average centerline value of atmospheric diffusion for a ground level release (sec/m^3)

Q = amount of material released (μCi/sec)

$DCF_{immersion}$ = Exposure Dose Conversion Factor (mrem/year per $\mu Ci/cm^3$), from ref 10

For off-normal conditions, the estimated annual airborne doses (internal and external) at 100 meters from a single TN-32 cask are provided in Table 7.3-3. The deep dose (external) and the committed dose (internal) on an organ basis and total effective dose for distances of 100 and 500 meters are summarized below:

	Dose at 100 meters (mrem/yr)	Dose at 500 meters (mrem/yr)
Gonad	3.73E-01	1.86E-02
Breast	2.83E-01	1.41E-02
Lung	4.56E+00	2.27E-01
Red Marrow	2.71E+00	1.35E-01
B. Surface	1.91E+01	9.53E-01
Thyroid	2.62E-01	1.30E-02
Remainder	1.10E+00	5.50E-02
Effective	1.92E+00	9.58E-02
Skin	3.07E-02	1.53E-03

The values presented in bold print above demonstrate that the criteria of 72.104(a) are met under off-normal conditions.

For hypothetical accident conditions, the committed doses (internal) and deep doses (external) at 100 meters from a single TN-32 cask for a 30 day exposure is provided in Table 7.3-4. The total effective dose equivalent at 100 m and 500 m from a cask is summarized below.

	Dose (mrem)	
	100 meters	500 meters
Deep Dose (external)	1.53E-01	8.42E-03
Committed Dose Equivalent (internal)	5.87E+01	3.22E+00
Total Effective Dose Equivalent	5.89E+01	3.23E+00

The committed dose equivalent to each organ plus the deep dose for a release over 30 days is presented below.

	Dose at 100 meters (mrem)	Dose at 500 meters (mrem)
Effective Deep Dose	**1.53E-01**	**8.42E-03**
Committed Dose Equivalent		
Gonad	1.21E+01	6.67E-01
Breast	7.12E+00	3.91E-01
Lung	1.12E+02	6.14E+00
R. Marrow	9.20E+01	5.05E+00
B. Surface	**6.64E+02**	**3.64E+01**
Thyroid	6.69E+00	3.67E-01
Remainder	3.33E+01	1.83E+00
TOTAL - Deep Dose plus Committed Dose Equivalent to Worst Organ (Bone Surface)	6.64E+02	3.65E+01

The criteria of §72.106(b) are met.

In addition to the design basis fuel, the burnup, initial enrichment and cooling time combinations of Table 2.1-3 were evaluated. The design basis fuel is representative of the airborne off-site doses. The most conservative case resulted in an 8% increase in the dose to the bone surface (worst organ). The acceptance criteria of 10 CFR 72 are still met.

7.3.2.2 Pressurization of the Confinement Vessel

The pressure assuming 100% fuel failure, 100% BPRA rod failure, and 100°F ambient conditions is 75.0 psig. During the fire accident condition (Section 11.2.5) the pressure increases to 83.8 psig, which is well below the 100 psi design pressure. Under the buried cask accident scenario, at seal failure (Section 4.5.2), the temperature inside the cask cavity increases to 644°F and the pressure increases to 99.0 psig.

7.3.3 Latent Seal Failure

By design the overpressure monitoring system does not immediately alarm if there is a leak in a seal or the overpressure system. The time period from when a leak begins to occur and when the overpressure system alarm is activated is dependent on the size of the leak. Two conditions which could exist within the TN-32 confinement system are:

(1) The outer seal (or the overpressure system) is leaking to the atmosphere. In this case the inner seal is intact and there is no release of the contents of the cask cavity to the atmosphere.

(2) The inner seal is leaking (or the overpressure system is leaking into the cask cavity). In this case the outer seal is still intact and there is no release of the cask cavity contents to the atmosphere.

If a latent seal leak has occurred, the tables below provide some examples of the time to alarm based on assumed leakage rates (and based on the conditions presented in Section 7.1.5).

Case 1 - Leakage of Overpressure System to the Atmosphere

Leak Rate (std cc/sec)	Estimated Time to Alarm (from Start of Latent Seal Failure)	Estimated Time to Loss of OP System Pressure (from Start of Latent Seal Failure)
1×10^{-3}	16 days	34 days
1×10^{-4}	173 days	354 days
5×10^{-5} (see Figure 7.1-2)	1 year	11 years
1×10^{-5} (see Figure 7.1-1)	9 years	over 20 years

Case 2 - Leakage of Overpressure System to Cask Cavity

Leak Rate (std cc/sec)	Estimated Time to Alarm (from Start of Latent Seal Failure)	Estimated Time to Equalize OP System Pressure with Cask Cavity Pressure (from Start of Latent Seal Failure)
1×10^{-3}	19 days	24 days
1×10^{-4}	201 days	254 days
5×10^{-5} (see Figure 7.1-2)	1.5 years	14 years
1×10^{-5} (see Figure 7.1-1)	12 years	over 20 years

As shown in the tables above, the alarm is set such that for any credible leak, there is time to evaluate the leaking condition and correct the condition provided that the overpressure system remains pressurized. This period can be extended by repressurizing the overpressure tank.

Another condition which has been considered is that a latent seal failure has occurred and the overpressure system is removed due to an accident.

(1) If the outer seal has the latent failure and the OP system is removed then there is no release of cask cavity contents to the atmosphere.

(2) If the inner seal has a latent failure and the OP system is removed then the table below provides the time before 10 CFR 72.106(b) limits will be exceeded (based on accident conditions presented in Section 7.2).

Standard Leak Rate (std cc /sec)	Time to exceed 10 CFR 72.106(b) Limits
1×10^{-3}	22 days
1×10^{-4}	223 days
5×10^{-5}	446 days
1×10^{5}	2249 days

The times above demonstrate that a latent failure up to 100 times greater than the test value could occur and recovery is possible.

The time to reach the accident release rates is dependent on the size of the leak. Due to the reliability of the metallic o-rings used in static applications, it is not considered credible that the inner seals could leak at a rate significantly higher than the test leak rate. The probability that a gross leak of an inner seal in combination with a gross leak in an outer seal or the overpressure system, such that the overpressure system could not hold pressure, is not considered a credible event.

However, if the overpressure system is not functional, the overpressure system can be replaced with a blind flange. The replacement of the overpressure system with the blind flange is described under contingency actions in Chapter 8, Section 8.4. The estimated operational dose due to this operation is provided in Chapter 10.

7.4 References

1. American Society of Mechanical Engineers, ASME Boiler And Pressure Vessel Code, Section III, Division 1 - Subsection NB, 1992.

2. ANSI N14.5-1997, "Leakage Tests on Packages for Shipment," February 1998.

3. Transnuclear, Inc., "Extended Fuel Burnup Demonstration Program Topical Report - Transport Considerations for Transnuclear Casks," DOE/ET 34014-11, White Plains, New York, December 1983.

4. NUREG-1536, "Standard Review Plan for Dry Storage Casks, Final Report," US Nuclear Regulatory Commission, Jan 1997.

5. NUREG-1617, "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel, Draft Report for Comment" US Nuclear Regulatory Commission, March 1998.

6. USNRC Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessment at Nuclear Power Plants", Rev 1 (1983).

7. USNRC Regulatory Guide 1.25, "Assumptions Used for Evaluating Accident in the Fuel Handling Storage Facility for Boiling and Pressurized Water Reactors."

8. USNRC Regulatory Guide 1.109, "Calculation of Annual Doses to Men From Routine Releases of Reactor Effluent for the Purpose of Evaluating Compliance with 10CFR50, Appendix I", Rev 1 (1977).

9. US Environmental Protection Agency Federal Guidance Report No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion," EPA-520/1-88-020, Sept, 1988.

10. US Environmental Protection Agency Federal Guidance Report No. 12, "External Exposure to Radionuclides in Air, Water, and Soil," EPA-402-R-93-081, September, 1993.

11. SAND90-2406, "A Method for Determining the Spent Fuel Contribution to Transport Cask Containment Requirements," Sandia National Laboratories, November, 1992.

12. Helicoflex Catalog ET 507 E5930.
13. Brookmire, et al, "Storage of Burnable Poison Rod Assemblies and Thimble Plug Devices in Dry Storage Casks Surry ISFSI," NE-1162, Rev. 0, May 1998.

TABLE 7.3-1

Security-Related Information Figure Withheld Under 10 CFR 2.390.

TABLE 7.3-2

TN-32 RELEASABLE SOURCE TERM FOR HYPOTHETICAL ACCIDENT CONDITIONS

Security-Related Information Figure Withheld Under 10 CFR 2.390.

TABLE 7.3-3

OFF-SITE AIRBORNE DOSES FROM OFF-NORMAL CONDITIONS AT 100M FROM THE TN-32 CASK - COMMITTED DOSES (INTERNAL)

Isotope	Gonad	Breast	Lung	R. Marrow	B. Surface	Thyroid	Remainder	Effective
H 3	4.70E-04	4.70E-04	4.70E-04	4.70E-04	4.70E-04	4.70E-04	4.70E-04	4.70E-04
CO 60	5.59E-02	2.16E-01	4.05E+00	2.02E-01	1.58E-01	1.90E-01	4.23E-01	6.94E-01
PU238	8.57E-02	3.06E-06	5.63E-02	4.65E-01	5.81E+00	2.94E-06	2.15E-01	3.24E-01
PU239	7.05E-03	2.04E-07	3.83E-03	3.74E-02	4.67E-01	2.00E-07	1.68E-02	2.57E-02
PU240	1.09E-02	3.27E-07	5.95E-03	5.82E-02	7.26E-01	3.12E-07	2.60E-02	3.99E-02
PU241	5.46E-02	2.45E-06	5.94E-04	2.69E-01	3.36E+00	9.93E-07	1.05E-01	1.79E-01
AM241	3.75E-02	3.08E-06	2.13E-02	2.01E-01	2.51E+00	1.85E-06	9.03E-02	1.39E-01
CM244	4.82E-02	3.15E-06	5.85E-02	2.85E-01	3.55E+00	3.06E-06	1.45E-01	2.03E-01
KR 85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SR 90	8.91E-03	8.91E-03	1.26E-02	1.13E+00	2.45E+00	8.91E-03	1.13E-02	2.18E-01
Y 90	2.62E-08	2.62E-08	4.71E-04	7.70E-07	7.65E-07	2.62E-08	1.96E-04	1.15E-04
RU106	3.59E-04	4.91E-04	2.87E-01	4.86E-04	4.44E-04	4.75E-04	3.31E-03	3.56E-02
RH106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
SB125	4.11E-07	4.75E-07	2.48E-05	6.11E-07	1.12E-06	3.70E-07	1.66E-06	3.77E-06
TE125M	2.22E-08	1.98E-08	2.91E-06	3.22E-07	3.30E-06	1.08E-08	1.89E-07	5.51E-07
I129	2.32E-07	5.57E-07	8.37E-07	3.73E-07	3.68E-07	4.16E-03	3.14E-07	1.25E-04
CS134	1.28E-02	1.06E-02	1.16E-02	1.16E-02	1.08E-02	1.09E-02	1.37E-02	1.23E-02
CS137	4.44E-02	3.97E-02	4.47E-02	4.20E-02	4.02E-02	4.01E-02	4.62E-02	4.37E-02
BA137M	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
CE144	4.13E-07	6.01E-07	1.37E-03	4.98E-06	8.15E-06	5.04E-07	3.30E-05	1.74E-04
PR144	4.16E-12	1.81E-11	1.62E-07	2.38E-11	2.54E-11	1.46E-11	2.42E-09	2.02E-08
PM147	1.48E-10	6.46E-10	1.39E-03	2.89E-05	3.61E-04	3.55E-10	2.80E-05	1.90E-04
EU154	7.04E-05	9.32E-05	4.76E-04	6.37E-04	3.15E-03	4.29E-05	6.80E-04	4.65E-04
EU155	9.39E-07	1.62E-06	3.14E-05	3.77E-05	4.01E-04	6.33E-07	2.93E-05	2.95E-05
Total	3.67E-01	2.76E-01	4.56E+00	2.71E+00	1.91E+01	2.55E-01	1.10E+00	1.92E+00

TABLE 7.3-3

(continued)

OFF-SITE AIRBORNE DOSES FROM OFF-NORMAL CONDITIONS AT 100M FROM THE TN-32 CASK - DEEP DOSES (EXTERNAL)

Isotope	Gonad	Breast	Lung	R. Marrow	B. Surface	Thyroid	Remainder	Effective	Skin
H 3	0.00E+00	0.00E+00	2.94E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.54E-08	0.00E+00
CO 60	5.69E-03	6.43E-03	5.74E-03	5.69E-03	8.23E-03	5.87E-03	5.55E-03	5.83E-03	6.71E-03
PU238	7.91E-11	1.53E-08	1.28E-11	2.03E-11	1.12E-10	4.84E-11	2.40E-11	5.88E-11	4.93E-10
PU239	4.23E-12	6.59E-12	2.31E-12	2.33E-12	8.27E-12	3.39E-12	2.50E-12	3.70E-12	1.62E-11
PU240	8.63E-12	1.67E-11	1.48E-12	2.24E-12	1.26E-11	5.32E-12	2.66E-12	6.44E-12	5.32E-11
PU241	2.27E-11	2.74E-11	2.04E-11	1.78E-11	6.91E-11	2.20E-11	1.92E-11	2.29E-11	3.69E-11
AM241	3.91E-09	4.87E-09	3.07E-08	2.37E-09	1.31E-08	3.56E-09	2.89E-09	3.72E-09	5.83E-09
CM244	8.25E-11	1.59E-10	8.46E-12	1.75E-11	1.05E-10	5.01E-11	2.16E-11	5.87E-11	4.67E-10
KR 85	2.06E-04	2.36E-04	2.01E-04	1.92E-04	3.88E-04	2.08E-04	1.92E-04	2.10E-04	2.33E-02
SR 90	1.04E-07	1.26E-07	8.57E-08	7.24E-08	3.03E-07	9.75E-08	8.13E-08	1.00E-07	1.22E-04
Y 90	3.77E-08	4.39E-08	3.53E-08	3.23E-08	8.86E-08	3.73E-08	3.35E-08	3.79E-08	1.25E-05
RU106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
RH106	1.65E-07	1.89E-07	1.65E-07	1.59E-07	2.81E-07	1.68E-07	1.57E-07	1.70E-07	1.78E-06
SB125	8.91E-08	1.02E-07	8.78E-08	8.42E-08	1.59E-07	9.05E-08	8.37E-08	9.09E-08	1.19E-07
TE125M	6.57E-10	9.34E-10	2.46E-10	2.05E-10	1.34E-09	5.11E-10	2.85E-10	4.99E-10	2.14E-09
I129	5.07E-09	6.99E-09	2.25E-09	1.72E-09	1.15E-08	4.05E-09	2.41E-09	3.99E-09	1.15E-08
CS134	2.87E-04	3.27E-04	2.86E-04	2.79E-04	4.66E-04	2.94E-04	2.74E-04	2.94E-04	3.67E-04
CS137	1.59E-07	1.93E-07	1.33E-07	1.14E-07	4.57E-07	1.51E-07	1.27E-07	1.54E-07	1.72E-04
BA137M	8.00E-06	9.10E-06	7.92E-06	7.72E-06	1.31E-05	8.14E-06	7.58E-06	8.14E-06	1.05E-05
CE144	5.81E-09	6.88E-09	5.24E-09	4.55E-09	1.70E-08	5.67E-09	4.92E-09	5.81E-09	1.99E-08
PR144	1.29E-08	1.46E-08	1.29E-08	1.27E-08	2.04E-08	1.33E-08	1.25E-08	1.33E-08	5.74E-07
PM147	5.29E-11	6.76E-11	3.85E-11	3.15E-11	1.54E-10	4.77E-11	3.72E-11	4.90E-11	5.73E-08
EU154	1.42E-06	1.61E-06	1.42E-06	1.39E-06	2.23E-06	1.46E-06	1.36E-06	1.46E-06	1.96E-06
EU155	2.59E-08	3.07E-08	2.31E-08	1.92E-08	8.41E-08	2.51E-08	2.15E-08	2.59E-08	3.52E-08
Total	6.19E-03	7.00E-03	6.23E-03	6.17E-03	9.10E-03	6.39E-03	6.03E-03	6.34E-03	3.07E-02

TABLE 7.3-4

OFF-SITE AIRBORNE DOSES FROM HYPOTHETICAL ACCIDENT CONDITIONS
AT 100M FROM THE TN-32 CASK
COMMITTED DOSES (INTERNAL) - mrem/30 days

Isotope	Gonad	Breast	Lung	R. Marrow	B. Surface	Thyroid	Remainder	Effective
H 3	1.64E-02	1.64E-02	1.64E-02	1.64E-02	1.64E-02	1.64E-02	1.64E-02	1.64E-02
Co 60	1.30E+00	5.02E+00	9.41E+01	4.69E+00	3.68E+00	4.42E+00	9.82E+00	1.61E+01
Pu 238	2.99E+00	1.07E-04	1.96E+00	1.62E+01	2.03E+02	1.03E-04	7.49E+00	1.13E+01
Pu 239	2.46E-01	7.12E-06	1.34E-01	1.31E+00	1.63E+01	6.97E-06	5.84E-01	8.96E-01
Pu 240	3.82E-01	1.14E-05	2.08E-01	2.03E+00	2.53E+01	1.09E-05	9.07E-01	1.39E+00
Pu 241	1.90E+00	8.54E-05	2.07E-02	9.38E+00	1.17E+02	3.46E-05	3.66E+00	6.22E+00
Am 241	1.31E+00	1.08E-04	7.41E-01	7.01E+00	8.74E+01	6.44E-05	3.15E+00	4.83E+00
Cm 244	1.68E+00	1.10E-04	2.04E+00	9.92E+00	1.24E+02	1.07E-04	5.05E+00	7.08E+00
Kr 85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sr 90	3.11E-01	3.11E-01	4.39E-01	3.95E+01	8.56E+01	3.11E-01	3.95E-01	7.61E+00
Y 90	9.13E-07	9.13E-07	1.64E-02	2.68E-05	2.67E-05	9.13E-07	6.83E-03	4.02E-03
Ru 106	1.25E-02	1.71E-02	1.00E+01	1.69E-02	1.55E-02	1.66E-02	1.15E-01	1.24E+00
Rh 106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sb 125	1.43E-05	1.66E-05	8.64E-04	2.13E-05	3.89E-05	1.29E-05	5.77E-05	1.31E-04
Te 125m	7.73E-07	6.90E-07	1.01E-04	1.12E-05	1.15E-04	3.77E-07	6.58E-06	1.92E-05
I 129	8.07E-06	1.94E-05	2.92E-05	1.30E-05	1.28E-05	1.45E-01	1.10E-05	4.36E-03
Cs 134	4.46E-01	3.71E-01	4.05E-01	4.05E-01	3.78E-01	3.81E-01	4.77E-01	4.29E-01
Cs 137	1.55E+00	1.38E+00	1.56E+00	1.47E+00	1.40E+00	1.40E+00	1.61E+00	1.52E+00
Ba 137m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ce 144	1.44E-05	2.10E-05	4.76E-02	1.73E-04	2.84E-04	1.76E-05	1.15E-03	6.08E-03
Pr 144	1.45E-10	6.32E-10	5.66E-06	8.31E-10	8.85E-10	5.10E-10	8.43E-08	7.05E-07
Pm 147	5.16E-09	2.25E-08	4.84E-02	1.01E-03	1.26E-02	1.24E-08	9.75E-04	6.63E-03
Eu 154	2.45E-03	3.25E-03	1.66E-02	2.22E-02	1.10E-01	1.50E-03	2.37E-02	1.62E-02
Eu 155	3.27E-05	5.65E-05	1.09E-03	1.31E-03	1.40E-02	2.21E-05	1.02E-03	1.03E-03
Total	1.21E+01	7.12E+00	1.12E+02	9.20E+01	6.64E+02	6.69E+00	3.33E+01	5.87E+01

TABLE 7.3-4
(continued)

OFF-SITE AIRBORNE DOSES FROM HYPOTHETICAL ACCIDENT CONDITIONS
AT 100M FROM THE TN-32 CASK
DEEP DOSES (EXTERNAL) - mrem/30 days

Isotope	Gonad	Breast	Lung	R. Marrow	B. Surface	Thyroid	Remainder	Effective	Skin
H 3	0.00E+00	0.00E+00	1.03E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E-06	0.00E+00
Co 60	1.32E-01	1.49E-01	1.33E-01	1.32E-01	1.91E-01	1.37E-01	1.29E-01	1.35E-01	1.56E-01
Pu 238	2.76E-09	5.34E-07	4.46E-10	7.06E-10	3.91E-09	1.69E-09	8.36E-10	2.05E-09	1.72E-08
Pu 239	1.47E-10	2.30E-10	8.07E-11	8.13E-11	2.88E-10	1.18E-10	8.70E-11	1.29E-10	5.66E-10
Pu 240	3.01E-10	5.82E-10	5.15E-11	7.80E-11	4.38E-10	1.85E-10	9.27E-11	2.25E-10	1.85E-09
Pu 241	7.91E-10	9.53E-10	7.13E-10	6.19E-10	2.41E-09	7.68E-10	6.70E-10	7.97E-10	1.29E-09
Am 241	1.36E-07	1.70E-07	1.07E-07	8.27E-08	4.55E-07	1.24E-07	1.01E-07	1.30E-07	2.03E-07
Cm 244	2.88E-09	5.54E-09	2.95E-10	6.08E-10	3.68E-09	1.75E-09	7.54E-10	2.05E-09	1.63E-08
Kr 85	7.19E-03	8.23E-03	7.00E-03	6.69E-03	1.35E-02	7.25E-03	6.69E-03	7.31E-03	8.11E-01
Sr 90	3.61E-06	4.40E-06	2.99E-06	2.52E-06	1.06E-05	3.40E-06	2.83E-06	3.49E-06	4.27E-03
Y 90	1.31E-06	1.53E-06	1.23E-06	1.13E-06	3.09E-06	1.30E-06	1.17E-06	1.32E-06	4.34E-04
Ru 106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Rh 106	5.75E-06	6.60E-06	5.75E-06	5.55E-06	9.78E-06	5.86E-06	5.48E-06	5.92E-06	6.20E-05
Sb 125	3.11E-06	3.56E-06	3.06E-06	2.93E-06	5.54E-06	3.15E-06	2.92E-06	3.17E-06	4.16E-06
Te 125m	2.29E-08	3.26E-08	8.56E-09	7.14E-09	4.69E-08	1.78E-08	9.95E-09	1.74E-08	7.45E-08
I 129	1.77E-07	2.44E-07	7.83E-08	6.00E-08	4.03E-07	1.41E-07	8.42E-08	1.39E-07	4.03E-07
Cs 134	1.00E-02	1.14E-02	9.97E-03	9.73E-03	1.62E-02	1.02E-02	9.55E-03	1.02E-02	1.28E-02
Cs 137	5.54E-06	6.73E-06	4.65E-06	3.97E-06	1.59E-05	5.25E-06	4.41E-06	5.38E-06	6.00E-03
Ba 137m	2.79E-04	3.17E-04	2.76E-04	2.69E-04	4.56E-04	2.84E-04	2.64E-04	2.84E-04	3.68E-04
Ce 144	2.02E-07	2.40E-07	1.83E-07	1.59E-07	5.91E-07	1.98E-07	1.72E-07	2.02E-07	6.95E-07
Pr 144	4.51E-07	5.10E-07	4.51E-07	4.44E-07	7.10E-07	4.63E-07	4.37E-07	4.63E-07	2.00E-05
Pm 147	1.84E-09	2.36E-09	1.34E-09	1.10E-09	5.37E-09	1.66E-09	1.30E-09	1.71E-09	2.00E-06
Eu 154	4.96E-05	5.63E-05	4.95E-05	4.85E-05	7.79E-05	5.08E-05	4.75E-05	5.07E-05	6.85E-05
Eu 155	9.02E-07	1.07E-06	8.04E-07	6.70E-07	2.93E-06	8.73E-07	7.50E-07	9.02E-07	1.23E-06
Total	1.50E-01	1.69E-01	1.51E-01	1.49E-01	2.22E-01	1.54E-01	1.46E-01	1.53E-01	9.91E-01

FIGURE 7.1-1

OVERPRESSURE MONITORING SYSTEM PRESSURE DROP WITH TIME
(Assuming Acceptance Test Leak Rate of 1 x 10^{-5} std cc/sec)

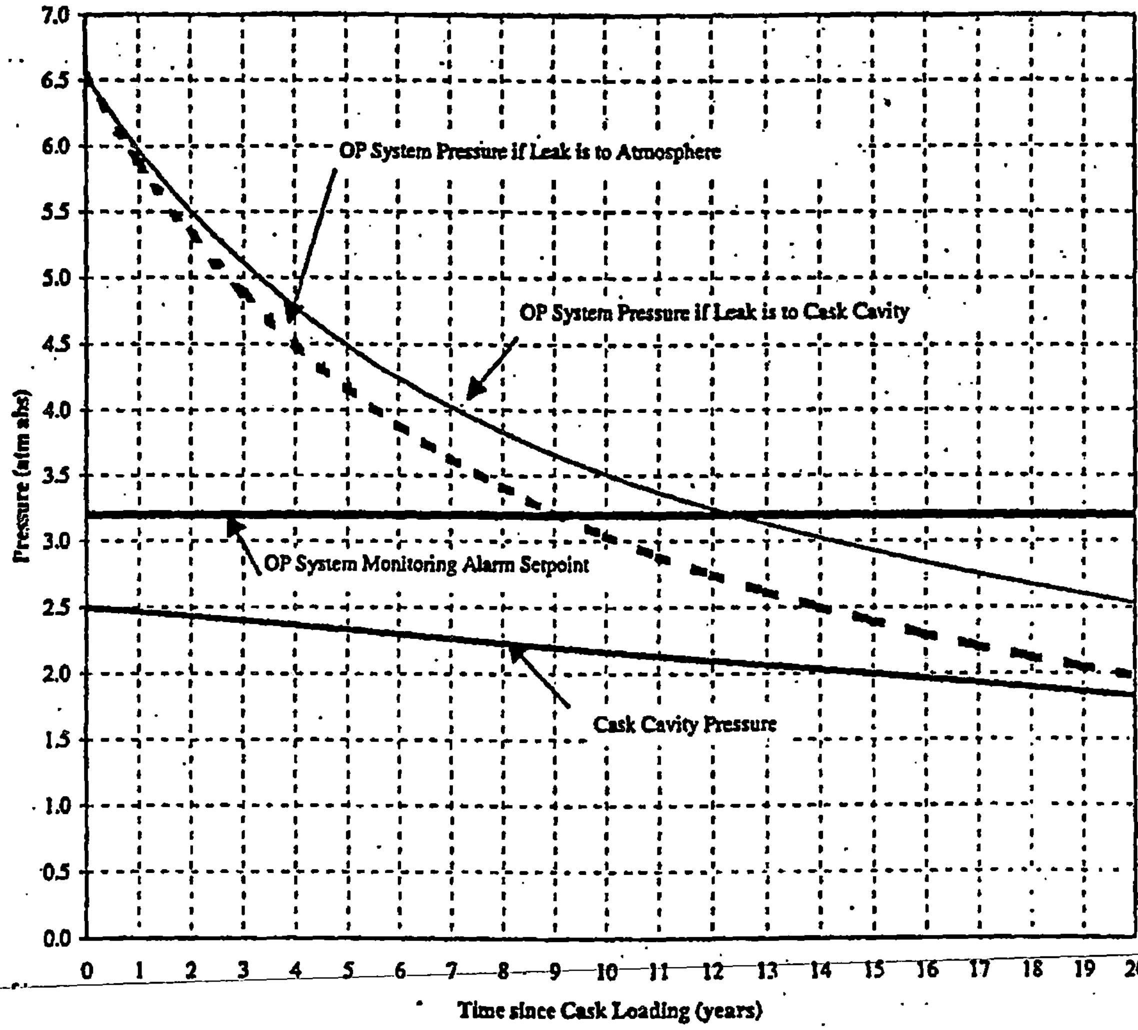


FIGURE 7.1-2

OVERPRESSURE MONITORING SYSTEM PRESSURE DROP WITH TIME
(Assuming a Latent Seal Leak Rate of 5 x 10^{-5} std cc/sec)

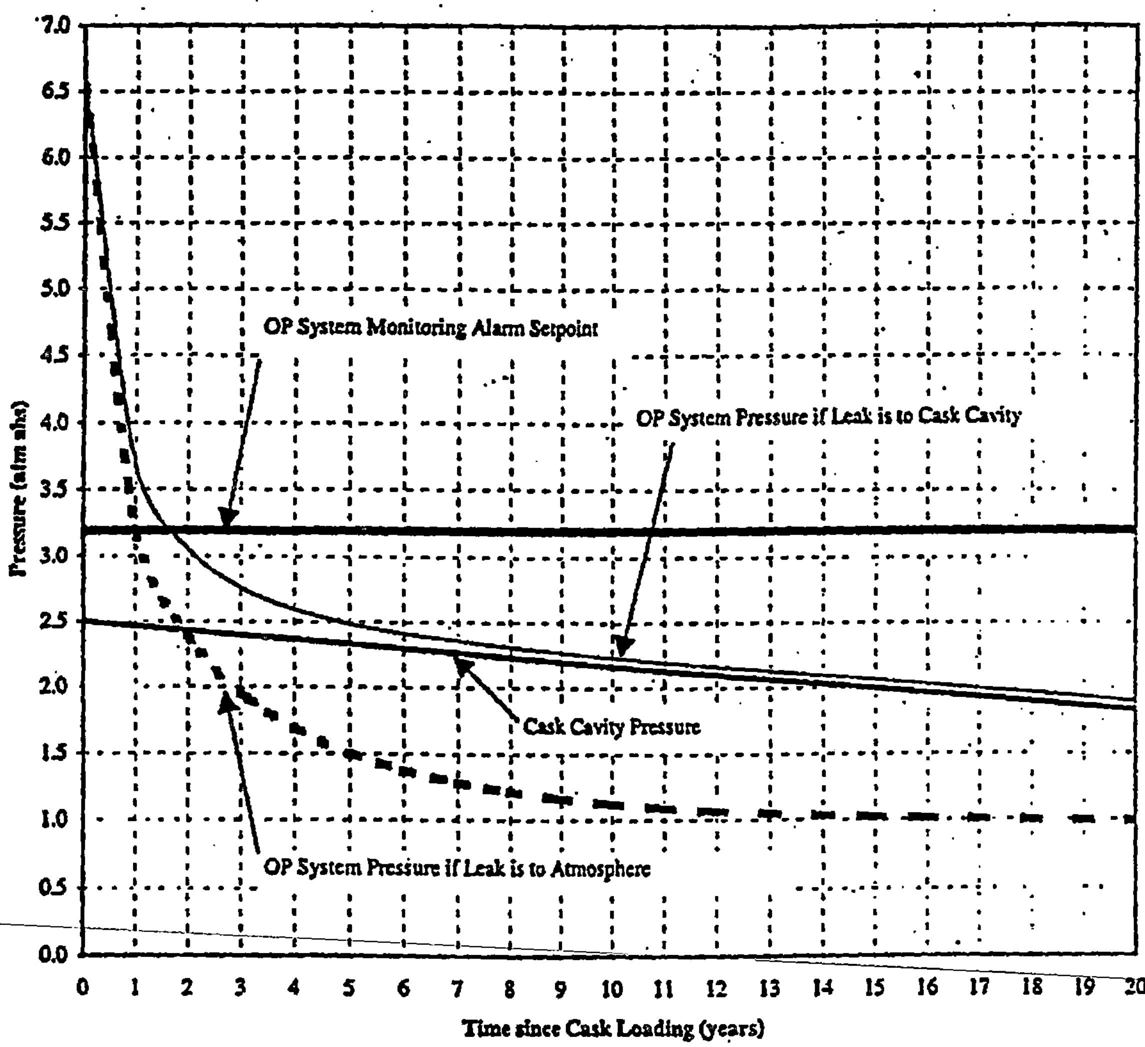
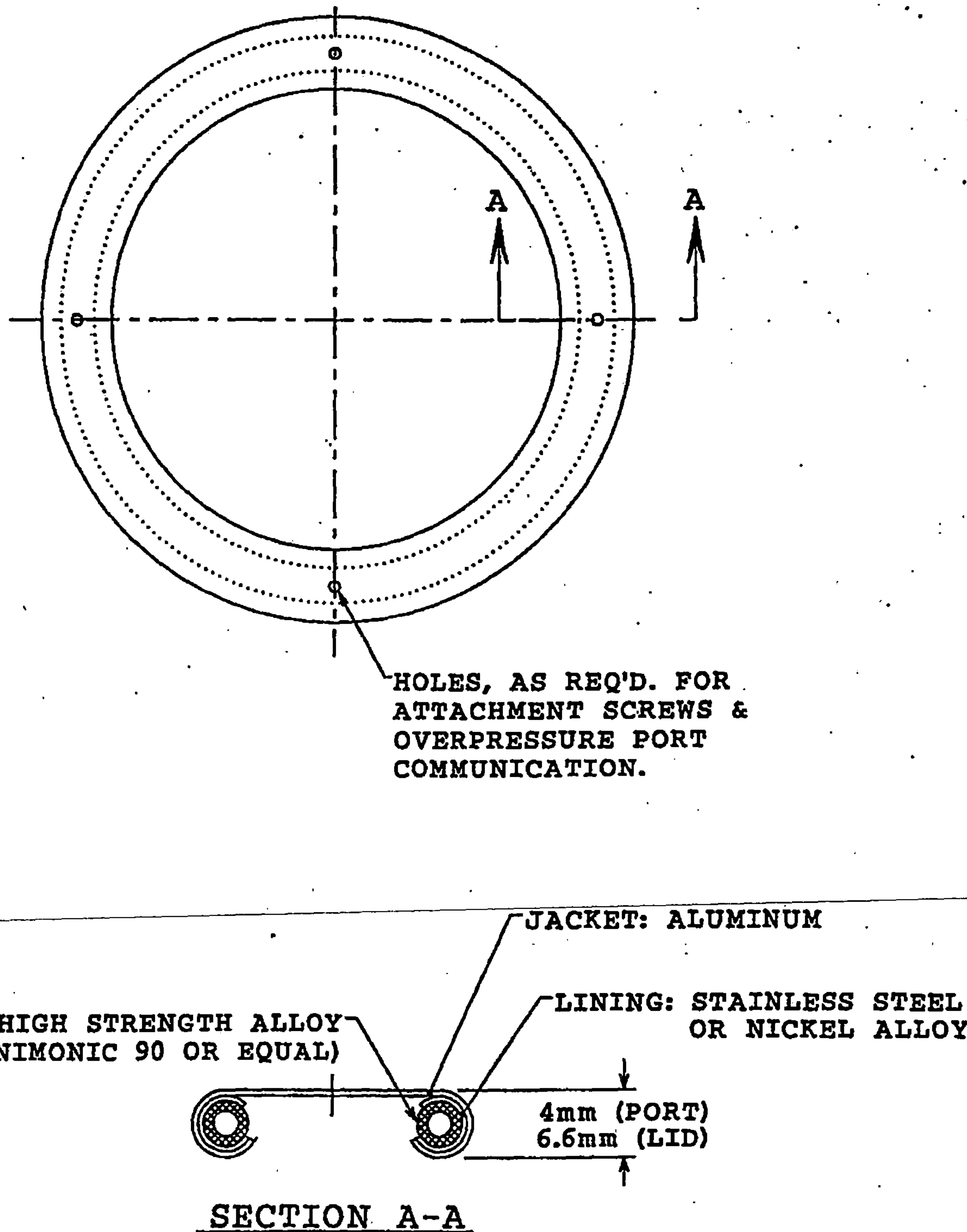


Figure 7.1-3
Lid, Vent Port, & Drain Port Metal Seals



CHAPTER 8

OPERATING PROCEDURES

This chapter outlines a representative sequence of operations to be incorporated into operating procedures for preparing, loading, testing, storing, unloading, and maintaining the TN-32 cask. Maintenance activities to be performed during the storage period are described in Chapter 9.

All procedures described herein are subject to the limitations imposed by the Technical Specifications, SAR Chapter 12.

8.1 Loading the Cask

8.1.1 General Description

This section provides a general description of the cask loading operations. More detailed steps are provided in Table 8.1-1.

The empty cask is inspected upon receipt and off loading from the delivery vehicle. The protective cover, overpressure system, top neutron shield, and lid are removed. The cask is lowered into the spent fuel pool. As it is lowered or before, the cask is filled with water having a minimum dissolved boron content of 2300 ppm. Fuel assemblies are loaded into the cask using the refueling platform main hoist fuel grapple or equivalent methods (may vary depending on plant design).

After the cask is loaded with spent fuel and the lid is placed on the cask, the cask is lifted to the pool surface, the cavity water in the cask is drained and the lid bolts are installed.

The cask is set down, decontaminated, and dried by using a vacuum system. The smooth surfaces of the cask are designed to facilitate decontamination. The lid bolts are torqued to their final required value. The cavity is filled with helium to above atmospheric pressure and the cask lid seal is leak tested. The top neutron shield is installed on the lid. The overpressure monitoring system is installed and leak tested, and the interspace between the double metallic o-rings pressurized. The external radiation levels are measured.

The protective cover is then installed and the cask is transferred to its storage location at the ISFSI. (The protective cover can be installed at the ISFSI.)

vehicle which limits the height of the cask above the ground to 18 inches. The cask is set in its storage position. The cask over pressure system is connected to the site storage cask monitoring system and a functional check of the monitoring system is performed.

8.1.2 Flow Sheets

The suggested sequence of operations to be performed in loading fuel into the TN-32 storage cask and placing the cask into storage at the ISFSI is outlined in Table 8.1-1. Some variations in this sequence may be expected as site specific procedures are developed by TN-32 owners.

Details of the number of personnel and the time required for the various operations are given in Tables 10.3-1 and -2 as part of the radiation exposure determinations discussed in Chapter 10. The data are based on Transnuclear's experience with transport and storage cask operations and will vary for an individual licensee. Temporary shielding, measures to facilitate surface decontamination, and minimization of operation time will maintain operational doses ALARA as discussed in the flow sheets.

8.1.3 Vacuum Drying System

A vacuum drying system is utilized to remove residual moisture from the cask cavity, after the cask has been drained. This method is successfully used by Transnuclear on both its transport casks and storage casks.

After a loaded cask is removed from a pool and drained, it is placed under a vacuum. After bolting the lid, residual water is removed by the following, or equivalent method:

a) Using a wand attached to the vacuum system, remove excess water from the seal areas through the passageways at the overpressure, drain, and vent ports.
b) Install the drain port cover. The quick disconnect fitting may be left in place or removed. If it is left in place, purge the space between the cover and quick disconnect fitting with helium before lowering and bolting the cover.
c) With the quick disconnect removed to improve evacuation, install a flanged vacuum connector over the vent port, purge or evacuate the helium supply lines, and evacuate the cask to 4 millibar ($4x10^{-4}$ MPa) or less. Make provision to prevent or correct icing of the evacuation lines.
d) Isolate the vacuum pump. If, in a period of 30 minutes, the pressure does not exceed 4 millibar ($4x10^{-4}$ MPa), the cask is adequately dried. Otherwise, repeat vacuum pumping until this criterion is met.

e) Backfill the evacuated cask cavity with helium (minimum 99.99% purity)to slightly above atmospheric pressure, remove the vacuum connector, and immediately install the quick disconnect fitting.
f) Attach the vacuum/backfill manifold to the fitting, purge or evacuate the helium supply lines, and re-evacuate the cask to below 100 mbar.
g) Isolate the vacuum pump, backfill the cask cavity to above atmospheric pressure with helium (minimum 99.99% purity).
h) Install the vent port cover after purging with helium between the cover and the quick disconnect. Leak test. (see Section 8.1.4).

The evacuation and backfill process is repeated if the cask cavity is exposed to the atmosphere.

8.1.4 Leak Detection

After backfill, the cask is leak tested by helium mass spectrometry by pressurizing the annular space and measuring the total leak rate of all seals, both inner and outer, including the overpressure system. This conservative leak rate must be less than the limit stated in Section 8.3. Leak test procedures make provision for cases where a quick disconnect fitting may prevent communication between the cask cavity and the inside of a port inner seal.

Failure to meet the leak test acceptance criterion requires evaluation of the leak location, for example by use of the helium mass spectrometer in the "sniffer" mode, examination of sealing surfaces, replacement of the leaking seal(s), and re-performance of the leak test. Replacement of the main lid seal requires reflooding of the cask and removal of the lid, similar to the steps described under Section 8.2.

8.1.5 Major Tools and Equipment

The following tools and equipment are normally required for loading and unloading the TN-32 casks:

- A transport frame which is used to transport the empty cask from the manufacturer's facility to the utility. The transport frame is not important to safety, since it is only used in conjunction with an empty cask.
- A spreader lift beam to connect the cask to the crane hook. The lift beam is used to remove the cask from the transport frame, to move the cask into the pool, into the processing stations such as the decontamination area and eventually to a location where the cask can be lifted by the cask transporter. This lift beam is designed and fabricated in accordance with

location where the cask can be lifted by the cask transporter. This lift beam is designed and fabricated in accordance with ANSI N14.6.[1] The load bearing components of the lift beam will be evaluated by the user under its heavy lifting program in accordance with NUREG 0612[3].

- A vertical cask transporter. The cask transporter is generally set to limit the lift height of the cask to less than 18 inches above the transport surface. The cask transporter is used to move the cask from the cask loading bay to the storage pad. The cask transporter may be self-propelled or be pulled by a tow vehicle to the ISFSI. The cask transporter is not important to safety, since the cask is analyzed to withstand a postulated 18 inch drop onto a concrete pad which is bounding for the transfer path. The cask transporter is designed to lift the cask by means of the top trunnions.
- A lid lifting system. This consists of a set of slings threaded into the top of the lid or a lifting pintle. The load bearing components of the lid lifting system will be evaluated by the user under its heavy lifting program in accordance with NUREG 0612.
- Helium mass spectrometer leak detection system including port connectors. The leak detector is designated as not important to safety, but is calibrated.
- Vacuum drying system including hoses and connectors. The vacuum drying system is not important to safety, but all gages are calibrated. The pump has adequate displacement, water vapor pumping speed, and base pressure. A two stage rotary vane pump with 75 cfm or greater displacement has been used successfully. Filters and pumping oil are periodically replaced according to manufacturer's recommendations and ALARA considerations.
- Pumps for removing water from the cask. The pumps are not important to safety.
- Calibrated torque wrenches for setting specified torque for cask bolts, screws and plugs (Not important to safety). See drawing 1049-70-1, Chapter 1, for torque requirements.
- Sockets and hex keys for removal and replacement of bolts, screws, coupling and connectors. These items are not important to safety.
- Helium cylinders and manifold with calibrated pressure gage for backfill of cask and overpressure system. These items are not important to safety.
- Alignment pins that are temporarily installed in two or more lid bolt holes during lid installation. These alignment pins are designated as not important to safety, and are removed after the lid is installed.
- • Temporary blind flange which can be used to replace the

overpressure port cover for transfer of the cask to the spent fuel pool.

8.2 Unloading the Cask

This section describes the steps required to unload a TN-32 cask. Additional measures may need to be taken if damage to the cask has occurred due to accidents.

If the TN-32 cask needs to be unloaded for any reason, the sequence of operations described in Section 8.1 and listed in Table 8.1-1 will be essentially performed in reverse. The unloading steps are provided in Table 8.2-1.

The dry cask reflood process during unloading of PWR fuel is unlikely to disperse crud into the fuel transfer pool and the pool area atmosphere, because of the tightly bound nature of PWR crud. Nonetheless, radiation monitoring is recommended during reflooding operations to minimize airborne exposure and personnel contamination hazards.

If the overpressure system is known to be leaking and no longer above cavity pressure, the cask overpressure monitoring system is disconnected and a blind flange and seal are installed at the overpressure system port before moving the cask.

The cask is moved from the ISFSI site back into the spent fuel pool building using the cask transport vehicle. The protective cover is unbolted and removed. The overpressure system is then depressurized and removed. The vent port is removed and a cavity gas sample is collected. The gas sample is analyzed and any precautions necessary are added based on the gas cavity sample results.

If degraded fuel is suspected, additional measures, appropriate for the specific conditions, are to be planned, reviewed and approved by the appropriate plant personnel, and implemented to minimize exposures to workers and radiological releases to the environment. These additional measures may include provision of filters, respiratory protection and other methods to control releases and exposures ALARA.

The helium in the cavity is depressurized to atmospheric pressure. The drain port cover is removed. The lid lifting equipment is attached, and the lid bolts are untorqued. Some of the lid bolts may be removed, but at least 6 equally spaced lid bolts should remain installed.

Fill and drain lines are connected to the lid drain and vent ports. The quick disconnect fittings may be used or they may be removed. The cask is lowered into the spent fuel pool. Water with a minimum dissolved boron content of 2300 ppm is added to

fill the cask and to gradually cool the fuel in the cask. The pressure is monitored at the cask outlet, and the flow rate of the water is controlled to limit the internal pressure to below the design limit of 100 psi. A check valve (set at 75.3 psig or below) will be installed at the inlet to the cask to prevent the cask pressure from exceeding 90 psia. The initial flow rate is 1.0 gallon per minute. Once the pressure falls below 50 psig and is maintained for a period of forty five minutes, the flow rate can be gradually increased while monitoring the pressure at the outlet. If the pressure gage reading exceeds 70 psig, close the inlet valve until the pressure falls below 50 psig. Reflooding can then be resumed. (See Chapter 4 for the supporting calculation).

The water/steam mixture from the vent port discharge may contain some radioactive material. Gases are closely monitored to determine if there is a radiological hazard and appropriately processed. A typical set up for flooding the cask is shown in Figure 8.2-1. The check valve and the monitoring of the exit pressure will ensure that the water vapor pressure generated during unloading does not exceed the cask design pressure.

When the cask is full, the fill and drain lines are removed. The cask is then lowered to the pool bottom where the lid is removed making the fuel accessible for transfer.

Provided that the TN-32 cask is within its design life, the cask can be reused after unloading. Inspection procedures will be implemented to ensure that the cask is still in its design configuration after unloading.

The TN-32 cask is designed so that it will not need to be opened after initial loading operations are completed until it is time to unload the fuel.

8.3 Surveillance and Maintenance

Chapters 9 and 12 discuss required surveillance and maintenance of the TN-32. Most required activities are very simple and do not require additional detail here. The most complex surveillance and maintenance operation is overpressure system maintenance, which is discussed below.

The term "switches" in the following refers to switches or transducers, either of which are used to monitor the pressure in the overpressure tank.

Redundant overpressure system switches are mounted on the side of the cask, and communicate with the overpressure tank via stainless steel tubing which penetrates the weather protective cover. Each switch has an isolation valve and an access valve provided for the calibration and maintenance procedure. The access valve outside port may have a capped fitting or a quick connect fitting.

To verify the functioning and calibration of the switches, a Channel Operation Test (COT) shall be performed. A helium cylinder and the appropriate manifold with a calibrated pressure gauge and a bleed down valve are required. A typical procedure outline is provided below.

a) Close the isolation valve.

b) Remove the cap from the access valve, and connect the test manifold while maintaining a slow helium purge.

c) Pressurize test manifold to about 75 psig from the helium cylinder, then isolate the helium cylinder and open the access valve.

d) Open the bleed down valve, and reduce the pressure slowly (the volume is very small, but to minimize any chance of radioactive emissions, the helium may be bled into an empty cylinder). For transducers, verify the pressure reading on the transducers against the reference gauge at a number of points. For both switches and transducers, verify that the alarm is actuated at the correct pressure.

e) Adjust the set point or calibration as required and repeat the immediately preceding step.

f) Repressurize the manifold with helium to the original system pressure (66.2 psig), close the access valve, disconnect the manifold, cap the access valve, and open the isolation valve.

g) Repeat the procedure for the second switch.

h) If replacement of a switch is required, the switch must be leak tested after installation

If there has been some reduction in system pressure, the entire overpressure system may also be re-pressurized to the original pressure (66.2 psig) by opening the isolation valve at the beginning of step f) rather than at the end.

8.4 Contingency Actions

Routine surveillance activities may trigger contingency actions as identified in the Technical Specifications. Many of these actions, such as removal of storm debris, are simple and require no further detail here. This section provides guidance in the event of a low pressure alarm from the overpressure monitoring system. The margin between the set point and the confinement pressure provides ample time as provided in the Technical Specifications to assess and correct the condition.

First determine if there is a false indication. This could be due to alarm panel malfunction or a switch failure. Exceptionally cold weather may also cause a reduction in pressure and a consequent false alarm. This may be corrected by re-pressurizing the system as discussed at the end of Section 8.3.

If the alarm appears to be due to an actual leak, first determine if there is a leak in the overpressure system. This may be done by first checking the exterior plumbing, and then, if no leak is found, by removing the weather cover, and testing the tank and the op port cover. A helium mass spectrometer system in either vacuum or sniffer mode may be used. If a leak is found, the overpressure system should be vented to atmospheric pressure. Capture the helium in an evacuated cylinder to minimize the chance of radioactive effluents, and to provide a sample for testing. The overpressure system can then be repaired, reassembled, leak tested, and repressurized. A failure of the overpressure system for a period of 30 days has been evaluated as an off normal event. This should provide sufficient time to perform any repairs and testing. A temporary blind flange may be installed on the overpressure port during the repair.

If the alarm is not false, and there is no leak in the overpressure system, there may be a leak at the lid seal or the ~~two port seals. Replacement of these seals will require~~ returning the cask to a decontamination building, the spent fuel pool area, or equivalent.

After transfer, remove the weather cover, neutron shield, and the vent port. Vent the cavity to atmospheric pressure via the quick-connect coupling in the vent port. Capture a portion of the vented gas in a sample cylinder for analysis and vent the remainder to a gaseous radwaste system. Remove the drain port cover. Inspect the sealing surfaces and replace the seals and if necessary the covers. Repressurize the cask, assemble the port

covers and leak test as in the normal sequence of loading operations (Table 8.1-1, step C-6 onward).

If after these steps, the cask still does not meet the leak tightness criterion, the lid gasket may be replaced. Proceed as for cask unloading, Section 8.2, up to the point of removing the lid. After the lid is removed, inspect the sealing surfaces, replace the seal, and reassemble the cask, proceeding in the normal sequence of loading operations (Table 8.1-1, step B-4 onward).

8.5 Preparation of the Cask

The operations required for preparing the cask for transfer are provided in Table 8.1-1, Section C and D.

The following procedural steps shall be verified before moving the cask to the storage pad:

a) The lid and penetration covers have been installed and torqued to their specified values.
b) The cask has been vacuum dried and successfully dryness tested per Section 8.1.3.
c) The cask has been leak tested to ensure that the total leakage rate of both inner and outer seals is less than 1×10^{-5} std-cm^3/sec (1.0×10^{-5} mbar-l/sec).
d) The cask cavity has been backfilled to approximately 2.2 atm abs (17.5 psig) with helium. The overpressure system has been backfilled to achieve an equilibrium pressure of about 5.5 atm abs (66.2 psig) with helium. (Note: The overpressure system may be installed at the storage site.)
e) The cask outside surfaces have been decontaminated. The surface contamination levels have been measured and do not exceed 20 dpm/100 cm^2 (alpha) or 1000 dpm/100cm^2 (beta + gamma).
f) The surface dose rates have been measured and do not exceed the technical specification limits provided in Chapter 12.

8.6 References

1. ANSI N14.6, "American National Standard for Radioactive Materials Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 kg) or More," New York, 1986.

2. ANSI N14.5, Final Draft, "Leakage Tests on Packages for Shipment of Radioactive Materials," 1997.

3. US Nuclear Regulatory Commission "Control of Heavy Loads at Power Plants", NUREG-0612, July, 1980.

TABLE 8.1-1
SEQUENCE OF OPERATIONS

A. Receiving

1. Unload empty cask and seals at plant site.

2. Inspect for shipping damage. Check for shipment completeness and cleanliness. Also verify that records for cask are complete and accurate.

3. Remove protective cover, overpressure system and top neutron shield.

4. Remove neutron shield pressure relief valve and install plug in neutron shield vent hole.

5. Remove lid bolts and lid.

6. Install lid alignment pins.

7. Steps 8 through 12 may be performed in any order.

8. Replace lid seal. Inspect the lid sealing surface. Check for defects in the seal contact areas that may prevent a proper seal. (This step may be performed at any time prior to installing lid on loaded cask).

9. Replace seals in vent, drain and overpressure port covers. Inspect the sealing surfaces. Check for defects in the seal contact areas that may prevent a proper seal. (This step may be performed at any time prior to installing covers on the loaded cask.)

10. Visually inspect the lid bolts and bolt hole threads to ensure they do not have any laps, seams, cracks or damaged threads.

11. Verify installation of a threaded plug in the vent hole of the neutron shield.

12. To minimize contaminants introduced into the spent fuel pool, rinse the interior and exterior of the cask with water if necessary.

13. Move cask to cask loading pool area.

B. Cask Loading Pool

Note: When the cask is full of water and loaded with fuel, pressure can build up within the cask due to the generation of steam. To prevent this, the cask should be vented at all times.

1. Lower cask into cask loading pool, filling the interior with borated water or pool water meeting the Technical Specification requirement for minimum boron content. The exterior of the cask and the lift beam may be rinsed with clean water immediately prior to submersion in order to facilitate decontamination.

2. Load preselected spent fuel assemblies into the basket compartments. Procedures shall be developed to ensure that the fuel loaded into the cask meets the fuel specifications.

3. Verify identity of the fuel assemblies loaded into the cask.

4. At least one lid penetration must be completely open (both cover and quick disconnect fitting removed) prior to installation of the lid. Lower lid and place on cask body flange over the alignment pins.

5. Lift cask so that the top of the cask is above the water surface and install six or more of the lid bolts hand tight.

Note: Throughout this procedure, all bolt threads are to be coated with Nuclear Grade Neolube or equivalent.

6. Using the drain port in the lid, pump water from the cask. This may be done either before or after lifting the cask out of the pool. While lifting the cask out of the pool, the cask may be rinsed with clean borated water to facilitate decontamination.

7. Disconnect drain line.

8. Move cask to the decontamination area.

TABLE 8.1-1 (continued)
SEQUENCE OF OPERATIONS

C. Decontamination Area

Note: The maximum potential for worker exposure occurs during decontamination and for operations near the lid from the time that the water in the cask is pumped out until the time the neutron shield is in place, steps C1 through C7. Exposure can be minimized by use of temporary shielding (lead "bean bags", plastic neutron shielding), by measures to facilitate decontamination, and by minimizing time and maximizing distance.

1. Decontaminate cask until acceptable surface levels are obtained.

2. Install remaining lid bolts and torque lid bolts to the value specified on Drawing 1049-70-1. This should be accomplished in multiple passes in accordance with an appropriate torquing pattern. Perform a final pass to ensure proper torque; this may be in a circular pattern.

3. Remove plug from neutron shield vent and reinstall pressure relief valve.

4. Connect the Vacuum Drying System (VDS) to the vent port and establish a vacuum to evaporate residual cavity water. Limit the rate of evacuation or provide a heat source such as heat tape on the evacuation line as necessary to prevent blockage of the line by ice.

5. Evacuate cavity to remove remaining moisture and verify dryness in accordance with Section 8.1.3.

6. Backfill cask with helium and pressurize to 2230 mbar absolute ($\pm$ 100 mbar).

7. Connect the evacuation line of a helium mass spectrometer system to the overpressure port, and helium leak test all lid and port cover seals. The acceptable total cask seal leakage (both inner and outer seals and the overpressure system) is 1×10^{-5} std-cm^3/sec (1.0×10^{-5} mbar-l/sec). The leak test shall be performed in accordance with ANSI N14.5[2]. For ports containing quick disconnects, purge the cavity below the cover with helium at a minimum flow rate of 80 cubic feet per hour for at least 20 seconds. Install the port cover. (A partial pressure of at least 50% helium will

be obtained under the cover.) The vent and drain covers should be torqued to the values specified on drawing 1049-70-1 prior to leak testing.

7A. If cask does not pass the leak test, determine source of leak. If the leak is in a vent or drain cover, remove the cover and replace the seals. Also examine the sealing surface for any obvious indication of scratches or defects. Repeat leak test.

7B. If the cask still does not pass leak test, evaluate test method or return cask to pool and replace seals.

8. Install top neutron shield.

Note: Installation of the overpressure system and protective cover could be done at a different location if restricted overhead clearances require transfer without these components in place. A temporary blind flange and metal seal will be installed on the overpressure port prior to transferring the cask without the overpressure system in place. Temporary weather protection will be provided as necessary.

9. Install overpressure system.

10. Helium leak test the overpressure system. The leak rate of the overpressure system must be combined with the inner and outer seal leak rates and not exceed 1×10^{-5} std-cm^3/sec (1.0×10^{-5} mbar-l/sec). If the acceptance criterion is not met, locate the overpressure system leak, correct it, and re-test.

TABLE 8.1-1 (continued)
SEQUENCE OF OPERATIONS

11. Pressurize the overpressure system with helium to a pressure of about 5.5 atm abs (66.2 psig).

12. Install the protective cover.

Note: steps 13 and 14 may be done at the storage pad.

13. Install pressure transducer tubing on exterior of cask, and helium leak test to point of the valve at the protective cover. The total overpressure system leak rate combined with the inner and outer seal leak rates must be 1 x 10^{-5} std-cm^3/sec (1.0 x10^{-5} mbar-l/sec) or less. If the acceptance criterion is not met, locate the overpressure system leak, correct it, and re-test.

14. Backfill the external tubing with helium to a pressure of about 5.5 atm abs (66.2 psig), and open the valve at the protective cover.

15. Verify that surface dose rates and surface contamination levels are within the limits set by the Technical Specifications.

16. Load cask on transporter.

17. Move cask to Storage Area.

D. Storage Area

1. Lower cask down onto storage pad in selected location. The casks should be positioned at least 16 feet apart between centerlines.

2. Disconnect cask transporter.

3. Connect over pressure system to monitoring panel.

4. Perform a Channel Operation Test (COT) to verify proer function of pressure switch/transducer, as described in Section 8.3

TABLE 8.2-1
SEQUENCE OF OPERATIONS - UNLOADING

A. Storage Area

1. Disconnect over pressure system from monitoring panel.

2. Position cask transporter over cask.

3. Engage lifting arms and lift cask to designated lift height.

4. Move cask to spent fuel pool building.

B. Loading Area

1. Lower cask, disconnect cask transporter and remove transporter from loading area.

2. Lift cask to decontamination area using lift beam and crane.

3. Remove neutron shield pressure relief valve and install plug in neutron shield vent hole.

4. Depressurize overpressure tank using the diaphragm valve, disconnect tubing at protective cover.

5. Remove protective cover.

6. Remove overpressure tank, overpressure port flange and top neutron shield.

7. Remove vent cover.

8. Collect a cavity gas sample through the vent port quick disconnect coupling.

9. Analyze the gas sample for radioactive material and add necessary precautions based on cavity gas sample results.

Note: If degraded fuel is suspected, additional measures, appropriate for the specific conditions, are to be planned, reviewed and approved by the designated approval authority, and implemented to minimize exposures to workers and radiological releases to the environment. These additional measures may include provision of filters, respiratory protection and other methods to control releases and exposures ALARA.

TABLE 8.2-1
SEQUENCE OF OPERATIONS - UNLOADING
(Continued)

10. Vent cavity gas through the vent port quick connect fitting until atmospheric pressure is reached. Venting to a gaseous radwaste system is recommended.

11. Remove vent port quick disconnect fitting and install the vent port adapter, which may be a flanged adapter or a ¾ inch male pipe thread. Remove the drain port cover. If it was installed during storage, the drain port quick disconnect fitting and nipple may also be removed. Install the drain port adapter to the drain port. The drain port adapter may be a fitting which mates to the drain port quick disconnect, or a 1 inch male pipe thread.

Note: The quick disconnect fittings and the pipe threads at the vent and drain ports are different sizes, and are not interchangeable.

12. Loosen lid bolts and remove all but 6 approximately equally spaced lid bolts.

13. Attach cask to crane using lift beam. Attach lid lifting equipment.

14. Attach water supply line to drain port adapter, and the vent line to the vent port adapter. (See Figure 8.2-1)

15. Ensure appropriate measures are in place to ensure proper handling of steam. Both fill and drain lines should be designed for steam at 100 psig minimum to prevent steam burns and radiation exposures due to line failure.

16. Lower cask into spent fuel pool/cask pit. The cask may be rinsed with clean water immediately prior to submersion to facilitate decontamination.

C. Cask Loading Pool

Note: In PWR spent fuel pools, significant amounts of loose fuel crud are unlikely. Evaluations should be made to determine if precautions are necessary to ensure that this particulate does not become airborne or become a radiation concern due to material floating on the surface of the water. Precautions may include enhanced filtering of the pool water during loading and unloading operations, increased ventilation and monitoring airborne contamination during all spent fuel pool activities.

TABLE 8.2-1
SEQUENCE OF OPERATIONS - UNLOADING
(Continued)

1. Begin pumping borated water or pool water meeting the Technical Specification requirement for minimum boron content into the cask through the drain port at a rate of 1 gpm while continuously monitoring exit pressure (See setup shown in Figure 8.2-1). Continue pumping at a rate of 1 gpm for at least 45 minutes. By this time, the water level in the cask will have reached the active fuel length.

2. The flow rate can then be gradually increased while monitoring the pressure at the outlet. If the pressure gage reading exceeds 70 psig, close the inlet valve until the pressure falls below 50 psig. Reflooding can then be resumed.

3. After verifying that a steady stream of water is coming from the vent line by checking for bubbles or carefully lifting the hose out of the water, take a sample for chemistry analysis.

4. When the cask is full of water, remove the hose from the drain port and the hose and vent port adapter from the vent port. Remove the remaining six lid bolts.

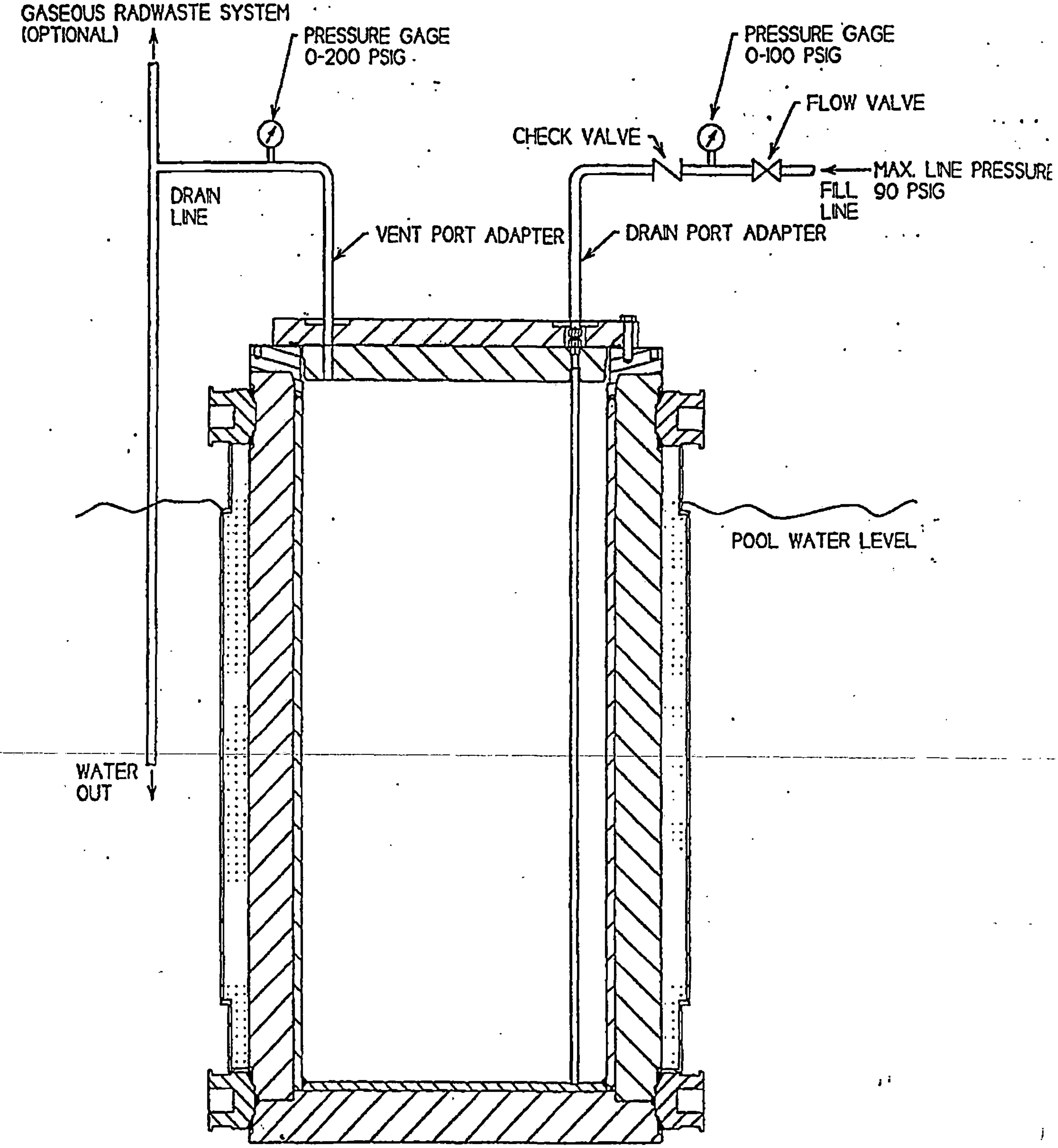
5. Lower the cask and place it on the bottom of the pool/pit. The lift beam may be rinsed with clean water immediately prior to submersion to facilitate decontamination.

6. Raise the lift beam from the cask removing the cask lid.

7. Unload spent fuel assemblies in accordance with site procedures.

FIGURE 8.2-1

TYPICAL SET-UP FOR FILLING CASK WITH WATER



CHAPTER 9

ACCEPTANCE CRITERIA AND MAINTENANCE PROGRAM

9.1 Acceptance Criteria

9.1.1 Visual Inspection

Visual inspections are performed at the Fabricator's facility to ensure that the casks conform to the drawings and specifications. The visual inspection includes verifying that all specified coatings are applied and the cask is clean and free of defects.

Upon arrival at the loading facility, the casks are again inspected to ensure that the casks have not been damaged during shipment. Visual inspections which indicate conditions which are not in conformance with the drawings and specifications will be repaired or evaluated for the effect of the condition on the safety function of the components in accordance with 10CFR72.48 by the user.

9.1.2 Structural

The structural analyses performed on the cask are presented in Chapter 3. To ensure that the cask can perform its design function, all structural materials are chemically and physically tested to ensure that the required properties are met. All welding is performed using qualified processes and qualified personnel according to the ASME Boiler and Pressure Vessel Code[1]. Base materials and welds are examined in accordance with ASME Boiler and Pressure Vessel Code requirements. NDE requirements for welds are specified on the drawings provided in Chapter 1. Weld-related NDE is performed in accordance with written and approved procedures. NDE personnel are qualified in accordance with SNT-TC-1A[2].

The confinement welds are designed, fabricated, tested and inspected in accordance with ASME B&PV Code Subsection NB. Exceptions to the Code taken regarding the containment vessel are described in Chapter 7.

Noncontainment welds are inspected to the NDE acceptance criteria of ASME B&PV Code Subsection NF. In addition the following supplementary weld inspections will be performed on the welds of the gamma shield shell to bottom shield and the lid to shield lid:

- PT or MT at weld preparation surfaces (base metal)
- PT or MT at root pass
- PT or MT for each 0.38 inches of weld
- PT or MT at final surface

Basket welding procedures are qualified in accordance with ASME Section IX. The fusion spot welds which attach the stainless steel tubes or adjacent structural shapes shall be performed using a GTAW fusion welding process based on ANSI/AWS D1.3[5]. The welding process shall produce a nugget of weld metal with a minimum 0.5 in. diameter weld shear area at the interface of the tubes and plug. A 100% visual inspection is performed to verify the normality of the weld zone. Welds located up to 24" from the openings of the basket assemblies and directly visible shall be examined by direct visual inspection. All other fusion plug welds shall be examined by a remote visual inspection using mirrors and auxiliary lighting. This inspection will verify the location, configuration and uniformity of the welds. In addition, a mechanical test of one test coupon from each welding machine is used to verify proper machine settings and operation prior to the start of each working shift. The acceptance criteria is failure of the base metal prior to failure of the weld area and a visual verification of a ½ inch diameter fused weld zone.

In addition, a bubble leak test is performed at 3 psig or greater on the resin enclosure. The purpose of this test is to identify any potential leak passages in the enclosure welds.

For the standard TN-32 and TN-32A, a load test of 1.5 times the design lift load is applied to the top trunnions in accordance with ANSI N14.6[3] for a period of ten minutes to ensure that the trunnions can perform satisfactorily. For the TN-32B, the upper trunnions are designed for nonredundant (single failure proof) lifting, and a load test of 3 times the design lift load is applied. The load is maintained for a period of ten minutes. After the load test, the trunnion welds and the bearing surfaces are examined by liquid penetrant or magnetic particle examination. Acceptance standards are in accordance with ASME Code Section III, Articles NF-5340 and NF-5350.

9.1.3 Leak Tests

Leakage tests are performed on the confinement system and overpressure system at the Fabricator's facility. These tests are usually performed using the helium mass spectrometer method. Alternative methods are acceptable, provided that the required sensitivity is achieved. The leakage tests are performed in

accordance with ANSI N14.5[4]. Personnel performing the leakage tests are qualified in accordance with SNT-TC-1A[2].

The confinement boundary permissible leakage rate is less than or equal to 1 x 10^{-5} std cm^3/sec. In order to assure the leakage rate of the confinement boundary is less than 1x 10^{-5} std cm^3/sec the total leak rate (of the inner seals and the outer seals) at standard conditions is less than 1x10^{-5} std cm^3/sec. The sensitivity of the leakage test procedure is at least 5 x 10^{-6} std cm^3/sec.

Although the overpressure system is not important to safety, it is also leak tested in accordance with ANSI N14.5. The permissible leakage rate for the overpressure system shall be less than 1 x 10^{-5} std cm^3/sec. The sensitivity of the leakage test procedure shall be no less than 5 x 10^{-6} std cm^3/sec.

9.1.4 Components

9.1.4.1 Valves

There are no valves performing a function important to safety. The TN-32 design incorporates quick-connect couplings for ease of draining and venting. However, these couplings do not form part of the confinement boundary. They are covered by bolted closures with metallic o-ring seals.

9.1.4.2 Gaskets

The lid and all confinement penetrations are sealed using double metallic o-ring seals. The inside o-ring forms part of the confinement boundary. Metallic o-rings are not temperature sensitive, and are therefore tested at room temperature. Metallic o-rings of the same type as those to be used for storage are installed for the fabrication leakage test described in Section 9.1.3. The tested o-rings are replaced before loading the cask. Upon completion of cask loading, the seals are tested as described in Section 12.1.2.5.

9.1.5 Shielding Integrity

The analyses performed to ensure shielding integrity are presented in Chapter 5.

The radial neutron shield is protected from damage or loss by the aluminum and steel enclosure. The material is a proprietary borated reinforced polymer. Additional information or the resin is provided in Appendix 9A.

The resin's primary function is neutron shielding, which is

provided primarily by its hydrogen content. The resin includes boron to reduce secondary gamma radiation which occurs when neutrons are captured by hydrogen. Variation in the boron content is not significant because the capture gammas are a small component of the external dose rate. The resin also provides some gamma shielding, which is a function of the overall resin density, but is not sensitive to composition.

The shielding performance of the material can be adequately verified by chemical analysis and verification of density. Uniformity is assured by installation process control.

The following are acceptance values for density and chemical composition for the resin. The nominal values are those used in the shielding calculations of Chapter 5, except that oxygen is 41.73% and zinc is not included in Chapter 5.

Element	nominal wt %	acceptance range (wt %)
H	5.05	-10 / + 20
B	1.05	± 20
C	35.13	± 20
Al	14.93	± 20
O+Zn (balance)	43.84	± 20

The nominal resin density used in Chapter 5 calculations is 1.58 g/cm³. However, because zinc is not included, the sum of the individual elements is only 97.89% Therefore, the minimum resin density in acceptance testing is 1.58*0.9789 = 1.547 g/cm³.

Density testing will be performed on every mixed batch of resin. Chemical analysis will be made on the first batch mixed with a given set of components, and thereafter whenever a new lot of one of the major components is introduced. Major components are aluminum oxide, zinc borate and the polyester resin, which combined make up 92% of the resin by weight.

Qualification tests of the personnel and procedure used for mixing and pouring the polyester resin used for neutron shielding are performed. Qualification testing includes verification that the chemical composition and density is achieved, and the process is performed in such a manner as to prevent large voids which would affect the shielding capability of the resin.

External dose rate surveys are performed at loading to ensure that the Technical Specification's radiation dose limits are not exceeded for each cask.

9.1.6 Thermal Acceptance

To test the method of manufacture for the radial thermal performance through the cask body, a thermal test is performed on one cask (without basket). Testing is performed to verify the radial heat transfer from the cask cavity to the ambient through the cask consisting of the inner shell, gamma shield shell, aluminum resin boxes, radial neutron shielding, and outer shell. A heat source placed within the cask cavity distributes the heat load evenly over the corresponding inner surface of the cask body. Temperature readings are taken on the inner surface of the cask and in the ambient. The appropriate cask surfaces will be insulated to minimize axial heat losses. The calculated thermal conductance is then compared to an analytically determined result. If the method of manufacture is modified for future casks, the impact of the change will be evaluated. Similar testing of a subsequent cask will be performed if the change is deemed thermally significant.

9.1.7 Neutron Absorber Tests

Material Description

The neutron absorber consists of borated aluminum containing 4.5 wt% boron which is isotopically enriched to 95 wt% B10. Because of the negligibly low solubility of boron in solid aluminum, the boron appears entirely as discrete second phase particles of AlB_2 in the aluminum matrix. The matrix is limited to any 1000 series aluminum, aluminum alloy 6063, or aluminum alloy 6351 so that no boron-containing phases other than AlB_2 are formed. Titanium may also be added to form TiB_2 particles, which are finer.

The 4.5 wt % converts to a nominal areal density of boron 10 as follows: (2.69 g BAl/cm^3)(4.5 wt% B)(95 wt%B10)(0.040 inch)(2.54 cm/inch) = 0.012 g B10/cm^2, which is intentionally slightly above the design minimum of 0.010.

The boron-containing phase is introduced into the system during the reaction of a proprietary boron-containing salt with molten aluminum. The individual AlB_2 particles range in size from 5 to 10 microns. If titanium salt is added as well, the resulting TiB_2 particles range in size from 1 to 5 microns. Both AlB_2 and TiB_2 are thermally stable at all temperatures below the melting point of the aluminum matrix. As such, the effect on the properties of the matrix aluminum alloy are those typically associated with a uniform fine dispersion of an inert equiaxed second phase.

Functional Requirements

The neutron absorber sheets serve no other function than neutron absorption; the cask safety analysis does not rely upon their thermal conductivity or mechanical strength. The basket structural components surround the sheets on all sides. The radiation and temperature environment in the cask is not sufficiently severe to damage the aluminum matrix that retains the boron-containing particles. To assure performance of the sheets' safety-related function, the only critical variable that needs to be verified is the boron 10 areal density. Because the criticality analysis takes 90% credit for the boron content, the test method used evaluates both the boron content and its uniformity.

Each neutron absorber sheet location in the basket is 8.25 inches wide by 144 inches long. The 144 inch length may be made up of more than one piece. For example, two pieces 8.25 x 72 inches may be used. Coupons the full width of the sheet (8.25 inches) will be removed between each finished sheet and at the

ends of the "stock sheet" as shown in Figure 9.1-1. The second dimension of the coupon shall be as required for neutron transmission measurements; 1 to 2 inches is adequate for the typical 1 cm diameter neutron beam.

Acceptance Testing, Neutronic

Effective boron 10 content is verified by neutron transmission testing of these coupons. The transmission through the coupons is compared with transmission through calibrated standards composed of a homogeneous boron compound without other significant neutron absorbers, for example zirconium diboride or titanium diboride. These standards are paired with aluminum shims sized to match the scattering by aluminum in the neutron absorber sheets. The transmission measurement shall be made about 1/4 to 1/3 of the distance from the end of the coupon. Thus, the random placement of the coupons in the test fixture results in testing at two locations across the sheet width as shown in Figure 9.1-1. The effective boron 10 content of each coupon, minus 3σ based on the neutron counting statistics for that coupon, must be $\geq$ 10 mg $B10/cm^2$.

In the event that a coupon fails the single neutron transmission measurement, four additional measurements may be made on the coupon, and the average of the 5 measurements, less 3σ based on the counting statistics, must be $\geq$ 10 mg $B10/cm^2$.

Macroscopic uniformity of boron-10 distribution is verified by neutron radioscopy or radiography of the coupons. The acceptance criterion is that there be uniform luminance across the coupon. This inspection shall cover the entire coupon.

Normal sampling of coupons for neutron transmission measurements and radiography/radioscopy shall be 100%. Rejection of a given coupon shall result in rejection of the contiguous sheet(s). Reduced sampling (50% - every other coupon) may be introduced based upon acceptance of all coupons in the first 25% of the lot. A rejection during reduced inspection will require a return to 100% inspection of the lot. A lot is defined as all the sheets rolled from a single casting.

Acceptance Testing, Visual

The finished sheets shall be visually examined to verify that they are free of cracks, porosity, blisters, or foreign inclusions. Removal of such defects, where possible, is permitted if the removal does not result in a dimensional non-conformance.

Justification for 90% B10 Credit

According to NUREG/CR-5661[6]

> "Limiting added neutron absorber material credit to 75% without comprehensive tests is based on concerns for potential `streaming' of neutrons due to nonuniformities. It has been shown that boron carbide granules embedded in aluminum permit channeling of a beam of neutrons between the grains and reduce the effectiveness for neutron absorption."

Furthermore

> "A percentage of neutron absorber material greater than 75% may be considered in the analysis only if comprehensive tests, capable of verifying the presence *and uniformity* of the neutron absorber, are implemented." [emphasis added]

The calculations in Chapter 6 take credit for 90% of the boron 10 in the borated aluminum. This is justified by the following considerations.

a) The coupons for neutronic inspection are removed between each finished sheet, and are the full width of the sheet. As such, they are taken from locations that are truly representative of the finished product. Coupons are also removed at the ends of the "stock sheet", where underthickness of the sheets or defects propagated from the pre-roll ingot would be most likely. The use of representative coupons for inspection is analogous to the removal of specimens from structural materials for mechanical testing.

b) Neutron radiography/radioscopy of coupons across the full width of the sheet will detect macroscopic non-uniformities in the boron 10 distribution such as could be introduced by the fabrication process. Such defects usually originate from the pre-roll ingot and propagate in the direction of rolling. For example, an ingot with a skin high in boron and a center depleted in boron will exhibit alternating bands of high and low boron concentration, which can be detected with radiography or radioscopy, parallel to the rolling direction.

c) Neutron transmission measures effective boron 10 content directly. The term "effective" is used here because if there are any of the effects noted in NUREG/CR-5661, the neutron transmission technique will measure not the physical boron 10 areal density, but a lower value. Thus, this technique by its nature screens out the microscopic non-uniformities which have been the source of the recommended 75% credit for boron 10 in criticality evaluations.

d) The use of neutron transmission and radiography/radioscopy satisfies the "and uniformity" requirement emphasized in NUREG/CR-5661 on both the microscopic and macroscopic scales.

e) The normal inspection for neutronic tests is 100%. The provisions for transition to reduced inspection and for return to normal inspection require that each new lot begin with normal inspection. This is more restrictive than the guidelines of ANSI/ASQC Z1.4[7], which allows reduced inspection to continue from lot to lot.

f) The recommendations of NUREG/CR-5661 are based upon testing of a neutron absorber with boron carbide particles averaging 85 microns. The boride particles in the borated aluminum are much finer (5-10 microns), and therefore much less subject to the neutron streaming phenomena discussed in the NUREG.

g) Visual inspection of the sheets verifies that there are no gross mechanical defects that could compromise the neutron absorber's ability to remain intact and in position in the basket.

9.2 Maintenance Program

Because of their passive nature, the storage casks will require little, if any, maintenance over the lifetime of the ISFSI. Typical maintenance tasks would involve verifying the pressure switch function and set point, verifying the pressure in the overpressure tank and repainting of some casks with corrosion-inhibiting coatings. No special maintenance techniques are necessary.

Two identical pressure tranducers/switches are used to assure a functional system through redundancy. The pressure transducers/switches are not replaced unless they are malfunctioning.

All the gaskets used for the confinement boundary are metallic o-rings. They are designed to maintain their sealing capability until the cask is reopened. If a leak is detected by a drop in pressure in the overpressure system, repairs can be made by replacing faulty components. For a drop in pressure that is consistent with the maximum allowable leak rate (see Figure 7.1-1), the overpressure system can be re-pressurized at the time of transducer/switch maintenance.

9.3 References

1. ASME Boiler and Pressure Vessel Code, Section III, 1992 Edition.

2. SNT-TC-1A, "American Society for Nondestructive Testing, Personnel Qualification and Certification in Nondestructive Testing," 1984.

3. ANSI N14.6, "American National Standard for Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds or More for Nuclear Materials," New York, 1986.

4. ANSI N14.5-1997, "American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials", February 1998

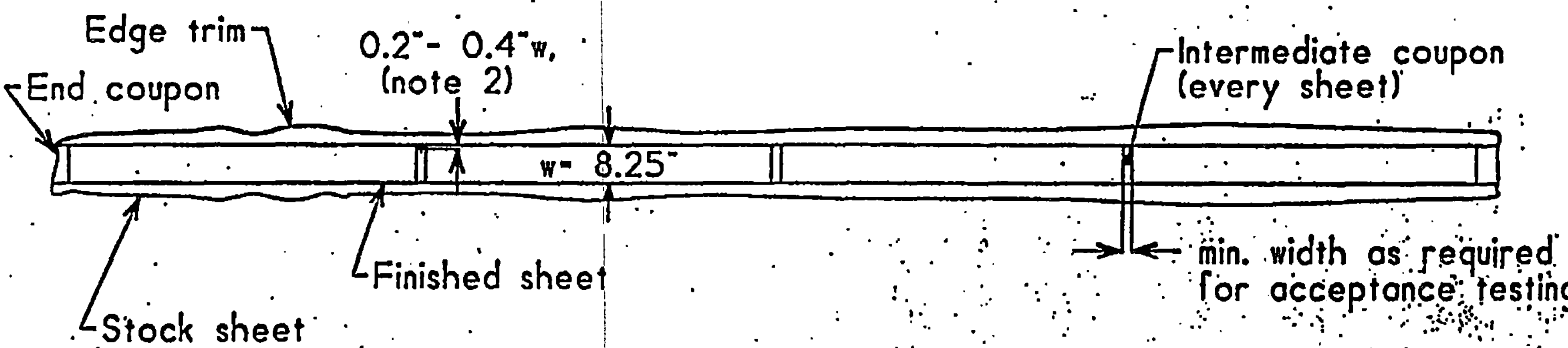
5. ANSI/AWS D1.3 Structural Welding Code - Sheet Steel.

6. NUREG/CR-5661, Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages, 1997

7. ANSI/ASQC Z1.4-1993, Sampling Procedures and Tables for Inspection by Attributes

Figure 9.1-1

TN-32 Neutron Absorber Plate Coupons, Borated Aluminum



Notes:

1. Neutron radiography/ radioscopy of entire coupon.
2. Neutron transmission measurements at this location, taken randomly from alternate edges.

APPENDIX 9A

Transnuclear TN-32 Radial Neutron Shield Material

The material is an unsaturated polyester crosslinked with styrene, with about 50 weight % mineral and fiberglass reinforcement. The components are polyester resin, styrene monomer, alpha methyl styrene, aluminum oxide, zinc borate, and chopped fiberglass.

Thermal Stability

Thermal aging tests on a material with the same components in slightly different proportions have been performed by Transnucleaire, Paris (TNP). The tests by TNP evaluate weight loss and offgassing at 125 °C (260 °F) and 155 °C (311 °F). The maximum normal temperature in the TN-32 radial neutron shield is 280 °F (138 °C) at the beginning of storage per Chapter 4 of the TN-32 SAR. A curve is interpolated at this temperature on the figure. That curve indicates an exponential weight loss that rapidly approaches a maximum value. After 106 hours, the weight loss is about 1.0%, and extrapolation of the results indicates maximum weight loss of about 1.3%. This effect diminishes rapidly with decreasing temperature, as can be seen by comparing the results at 125 and 155 °C in Figure 9A-1. An analysis of the gas released from a sample heated from 25 to 125 °C over one hour shows it to be 99.9% styrene. The results are included in the attached Table 2-2-1.

These results obtained with small samples (50 mm thick x 50 mm dia) are conservative with respect to the material in a larger enclosed form such as the TN-32 radial neutron shield, where volatile constituents must diffuse through a much greater distance to be released.

Radiation Stability

The European Organization for Nuclear Research (CERN) has published a compilation of its own testing and of prior published data on the radiation resistance of various materials. Volume Two[1] presents the results of testing, and Volume Three[2] summarizes the results and provides recommendations in Appendices 5.9 and 6. These show that while unfilled polyester has poor radiation resistance,

both mineral- and glass-filled polyester, such as used in the TN-32 radial neutron shield, are among the most radiation-resistant of thermosetting resins.

References

1. Schönbacher, et. al. , CERN 79-08, Compilation of Radiation Damage Test Data, Part II, Thermosetting and thermoplastic resins, 15 Aug 1979
2. Beynel, et. al., CERN 82-10, Compilation of Radiation Damage Test Data, Part III, Materials used around high-energy accelerators, 4 Nov 1982

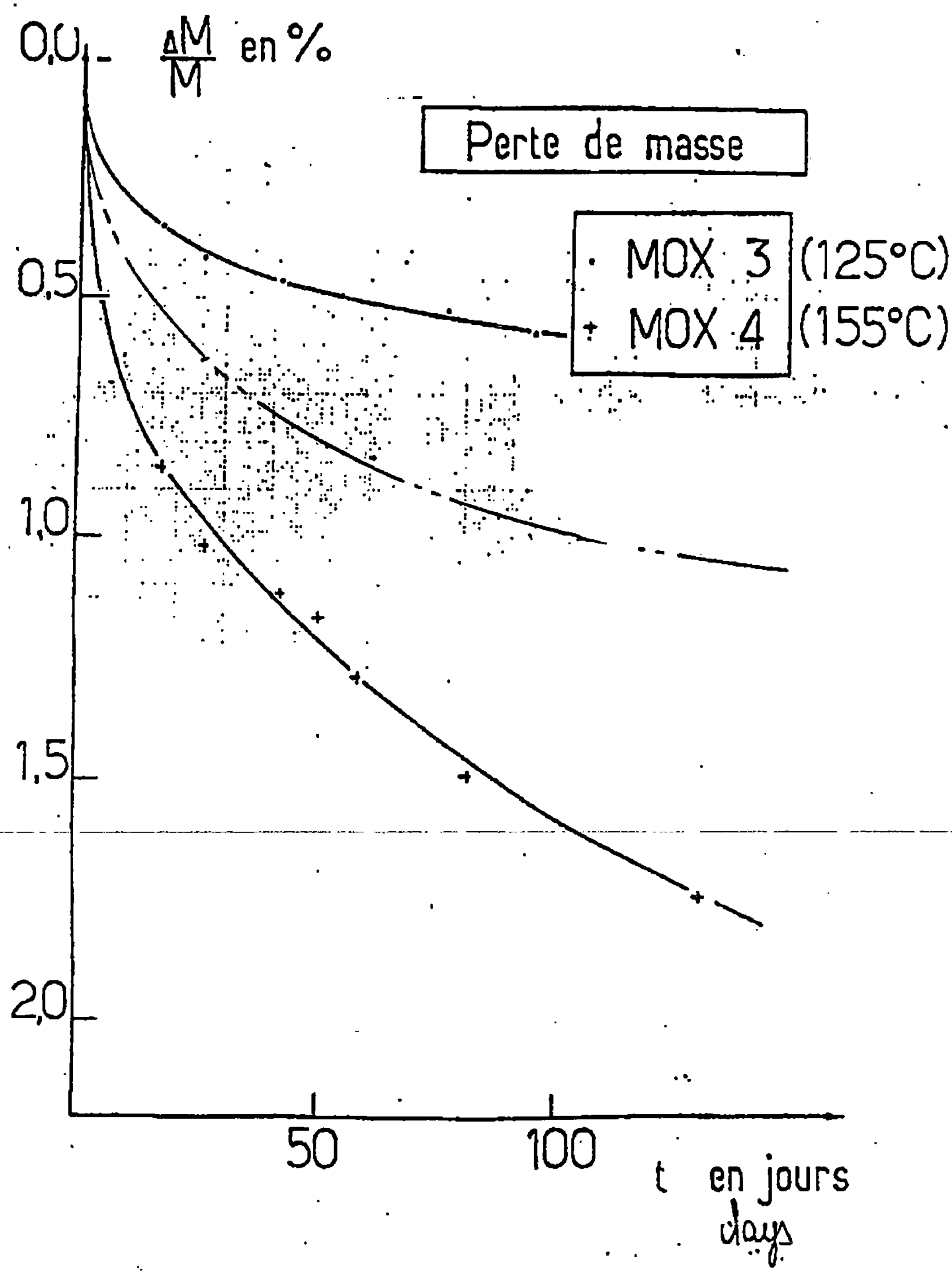
Table 9A-1

Quantitative Analysis of Gases Released from Neutron Shield Test Resin
Upon Heating from 21 to 125 °C for One Hour

Gas analyzed	Quantity (μg/g of resin)
Styrene	610
O_2	0.030
N_2	0.21
H_2	0.005
CO	0.03
CO_2	0.24
CH_4	<0.0005
C_2H_4	<0.001
C_2H_6	<0.001
C_3H_6	<0.003
C_3H_8	<0.003
iso-C_4H_{10}	<0.006
n-C_4H_{10}	<0.006
iso-C_5H_{10}	<0.02
n-C_5H_{10}	<0.02

Figure 9A-1

Weight Loss Due to Thermal Aging of Neutron Shield Test Resin



CHAPTER 10

RADIATION PROTECTION

10.1 ENSURING THAT OCCUPATIONAL RADIATION EXPOSURES ARE AS LOW AS IS REASONABLY ACHIEVABLE (ALARA)

10.1.1 Policy Considerations

A radiological protection program will be implemented at the ISFSI in accordance with requirements of 10CFR72.126.

ISFSI personnel are given training in the proper operation of the cask. This training covers operations, inspections, repair and maintenance of the cask. Proper training of the operation personnel helps to minimize exposure to radiation such that the total individual and collective exposure to personnel in all phases of operation and maintenance are kept As Low As Reasonably Achievable.

10.1.2 Design Considerations

The TN-32 dry storage cask design takes into account radiation protection considerations, which ensure that occupational radiation exposures are ALARA. The fuel will be stored dry, inside the sealed, heavily-shielded cask. The most significant radiation protection design consideration provides for heavy shielding to minimize personnel exposures. To avoid personnel exposure, the casks will not be opened nor fuel removed from the casks while at the ISFSI unless the ISFSI is specifically designed and licensed for these purposes. Storage of the fuel in the dry sealed cask eliminates the possibility of leakage of contaminated liquids. The cask is designed to prevent the leakage of any radioactive gases. The exterior of the casks will be decontaminated prior to transfer to the ISFSI, thereby minimizing exposure of personnel to surface contamination. The TN-32 cask contains no active components which require periodic maintenance or surveillance. This method of spent fuel storage minimizes direct radiation exposures and eliminates the potential for personnel contamination.

Regulatory Position 2 of Regulatory Guide 8.8[1], is incorporated into the design considerations, as described below:

- ALARA objective 2a on access control will be met by use of a fence with a locked gate that surrounds the ISFSI and prevents unauthorized access.
- Regulatory Position 2b on radiation shielding is met by the heavy shielding of the cask which minimizes personnel exposures.
- Regulatory Position 2c on process instrumentation and

controls is met by designing the instrumentation for a long service life and locating readouts in a low dose rate location.

- Regulatory Position 2d on control of airborne contaminants does not apply because no gaseous releases are expected. No significant surface contamination is expected because the exterior of the cask will be decontaminated prior to transfer to the ISFSI.

- Regulatory Position 2e on crud control is not applicable to the ISFSI because there are no systems at the ISFSI that could transport crud.

- Regulatory Position 2f on decontamination is met because the exterior of the cask is designed for decontamination. The cask is decontaminated prior to transfer to the ISFSI.

- Regulatory Position 2g on radiation monitoring does not apply because the casks are sealed. There is no need for airborne radioactivity monitoring since no airborne radioactivity is anticipated. Area radiation monitors are not required because the ISFSI will not normally be occupied.

- Regulatory Position 2h on resin treatment systems is not applicable to the ISFSI because there will be no radioactive systems containing resins.

- Regulatory Position 2i concerning other miscellaneous ALARA items is not applicable because these items refer to radioactive systems not present at the ISFSI.

10.1.3 Operational Considerations

Operational requirements for surveillance are incorporated into the design considerations in Section 10.1.2 in that the casks are stored with adequate spacing to allow ease of on site surveillance. In addition, remote annunciation is available outside the ISFSI protected area to minimize surveillance time.

The operational requirements are incorporated into the radiation protection design features described in Section 10.2 since the casks are heavily shielded to minimize occupational exposure.

The TN-32 cask is designed to be essentially maintenance free. It is a passive system without any moving parts. The double metallic O-ring design with continuous surveillance of the over pressure system guarantees that in the unlikely event of a

failure of one of the seals, adequate time is available to restore the cask leak tightness.

The only cask repair procedure that could be envisioned is replacement of a confinement seal. For this, the cask would be returned to the spent fuel pool area in order to minimize radiation exposure to personnel.

The only anticipated maintenance procedures are visual inspection, possible paint touch-up, and pressure transducer/switch maintenance.

The TN-32 cask/ISFSI contains no systems that process liquids or gases or contain, collect, store, or transport radioactive liquids or solids other than the stored spent fuel. Therefore, the ISFSI meets ALARA requirements since there are no such systems to be maintained, be repaired, or be a source of leaks.

10.2 Radiation Protection Design Features

10.2.1 Cask Design Features

The TN-32 dry storage cask has a number of design features which ensure a high degree of integrity for the confinement of radioactive materials and reduction of direct radiation exposures to levels that are as low as practical.

- The casks are loaded, sealed, and decontaminated prior to transfer to the ISFSI.
- The fuel will not be unloaded nor will the casks be opened at the ISFSI unless the ISFSI is specifically designed and licensed for these purposes.
- The fuel will be stored dry inside the casks, so that no radioactive liquid is available for leakage.
- The casks will be sealed airtight with a helium atmosphere to preclude oxidation of the fuel. The seals are double metallic O-rings to assure leak-tightness.
- The casks will be heavily shielded to reduce external dose rates. The shielding design features are discussed below.
- No radioactive material will be discharged during storage.

Shielding for the TN-32 cask is provided mainly by the thick-walled cask body. For neutron shielding, a borated polyester resin compound surrounds the cask body and a polypropylene disk covers the lid for storage. Additional shielding is provided by the steel shell surrounding the resin layer and by the stainless steel and aluminum structure of the basket. Details of the cask shielding and radioactive sources are provided in Section 5.2.

Geometric attenuation, enhanced by air and ground attenuation, provides additional "shielding" for distant locations at restricted area and site boundaries. However, the contribution of the sky shine dose must be considered for distant locations. The sky shine dose estimation is provided in the following section.

10.2.2 Radiation Dose Rates

Calculated dose rates in the immediate vicinity of the TN-32 cask are presented in Table 5.1-2 and Figure 5.4-1 and -2. Comparison of calculated and measured dose rates is presented in Appendix 5A. Direct dose rates at longer distances are presented in Table 5.1-3.

The skyshine dose from a single cask containing the design basis fuel source (without inserts, defined in Chapter 5) was calculated using the MCNP[2] code. The models for the MCNP skyshine analysis were basically the same as those utilized for the dose rates at long distances, described in section 5.3.1.3. For the skyshine analyses, an earthen berm was added to the basic long distance models. The berm was modeled as 4.2 meters high and was located 20 meters from the cask centerline. As before, three separate models were utilized, neutron, fuel gamma, and fuel hardware gamma. The tallies and dose conversion factors were the same as previously described. The MCNP calculations were performed on a Pentium PC computer under Windows NT.

Skyshine dose rates were estimated from 100 to 500 meters from a single TN-32 cask (without inserts). The results of the single cask skyshine analyses are presented in Table 10.2-1.

<u>Single cask (without inserts), skyshine plus direct</u>

The total (direct + skyshine) dose rates for a single cask are shown in Figure 10.2-1. This figure shows that for a single cask containing design basis fuel a minimum distance of approximately 250 meters is necessary to meet the 25 mrem/year limit (10 CFR 72.104).

<u>Single cask (without inserts), skyshine only</u>

If a berm is placed around the TN-32 cask, essentially reducing the direct dose to insignificant levels, 1 cask containing design basis fuel would need to be placed at an approximate distance of 150 meters from the site boundary to meet the 25 mrem/year limit.

<u>ISFSI array, skyshine only</u>

The dose rates from a typical ISFSI are evaluated based on the sky shine results from a single cask (without inserts) and assuming the presence of a berm. These results show that a minimum distance of approximately 450 meters is necessary from the ISFSI to the site boundary to meet the 25 mrem/yr limit. This value is based on the ISFSI layout of Figure 1.4-1 and the assumption that eight casks are placed at the ISFSI in the first year and two casks every year there after. Therefore, an ISFSI of 48 casks would be filled in 21 years. Figure 10.2-2 presents these results.

Dose rates at the site boundary will depended on specific ISFSI parameters such as storage array configuration, number of stored casks, characteristics of stored fuel, fuel loading patterns, site geography, etc. Each ISFSI license applicant may calculate the off-site dose rates based on site characteristics rather than the limiting design basis characteristics analyzed above. Berms, walls, or preferential loading of "cooler" fuel in the outer compartments of the cask may be used as necessary to keep the site boundary dose rate within the 25 mrem/year limit.

10.3 Estimated Onsite Collective Dose Assessment

Cask Loading Operations

Table 10.3-1 shows the estimated occupational exposures to ISFSI personnel during the loading, transport, and emplacement of the storage casks (time and manpower may vary depending on individual ISFSI practices). The task times, number of personnel required and the average distance from the cask are listed in this table.

This estimate of operational doses assumes that there is no temporary shielding used. Lead bean bags and temporary plastic neutron shielding can be used to maintain doses ALARA. Actual operations loading TN-32 casks with fuel near 40 GWD/MTU burnup and 7 year cooling has resulted in operational doses less than 15% of the dose calculated in Table 10.3-1.

The average distance for a given operation takes into account the fact that the operator may be momentarily in contact with the cask, but this time will be limited. For example, during bolting, the placement of the bolts in the holes will bring the operator in contact with the cask. While torquing the operator will be further away due to the typical length of a torque wrench handle. Similarly, for draining, vacuum drying, and leak testing, the attachment of fittings will take place closer to the cask than the operation of the pump and vacuum drying system. For decontamination, although operators will be close to the cask to take swipes, other parts of the operation will be done by hosing the cask down from further away.

For this reason, 0.5 or 1.0 meter is an appropriate average distance for these hands-on operations.

The operator's hands may be in a high dose rate location momentarily, for example when connecting couplings or vacuum fitting at the ports. This does not translate into a whole-body dose, and therefore, these localized streaming effects are not considered here.

For the operations near the lid, typically most of the operation will take place around the perimeter (corner) and a smaller portion will take place directly over the lid. A 33/67 weighted average of axial centerline and above neutron shield radial dose rates is used for these operations as described below.

Dose rates used for the operations dose estimate

Dose rates for the TN-32A are higher than for the TN-32 and TN-32B where indicated due to the 1.12 inch thinner lid; radial dose rates, and dose rates after installation of the top neutron shield are the same as for the TN-32 and TN-32B. All of the following dose rates are in mrem/hr. They include the contribution from burnable poison rod assemblies.

Water/lid: Dose rates at the cask top while the cask is still filled with water are low due to the water shielding; they are estimated at

	TN-32, TN-32B	TN-32A
0.5 meter	7γ / 3n	17γ / 3n
2 meter	2γ / 1n	5γ / 1n

After the cask is drained, and before the neutron shield is installed, dose rates at the cask lid centerline are equivalent to the accident "top" dose rates in Table 5.1-2 and Figure 5.4-5.

	TN-32, TN-32B	TN-32A
Contact	271γ / 230n	817γ / 281n
0.5 meter	211γ / 152n	622γ / 186n
1 meter	151γ / 74n	427γ / 90n
2 meter	87γ / 31n	233γ / 38n

The surface radial dose rate above the neutron shield is calculated in Table 5.1-2. Extrapolation to the points away from the surface is based upon ratios derived from measurements of loaded casks.

	TN-32, TN-32B	TN-32A
Contact	279γ / 131n	279γ / 131n
0.5 meter:	158γ / 74n	158γ / 74n
1 meter	68γ / 32n	68γ / 32n
2 meter	43γ / 20n	43γ / 20n

Lid/Corner: (prior to placement of top neutron shield) 33% axial dose rates at the cask lid centerline and 67% radial dose rate above the neutron shield:

	TN-32, TN-32B	TN-32A
0.5 meter:	179γ / 100n	311γ / 111n
1 meter	95γ / 46n	186γ / 51n
2 meter	58γ / 24n	106γ / 26n

Top/Corner (after installation of top neutron shield): use the radial dose rate above the neutron shield (table above).

	TN-32, TN-32B	TN-32A
0.5 meter:	158γ / 74n	158γ / 74n
1 meter	68γ / 32n	68γ / 32n
2 meter	43γ / 20n	43γ / 20n

Radial (midplane dose rates from Figure 5.4-1)

	TN-32, TN-32B	TN-32A
0.5 meter	117γ / 12n	117γ / 12n
1 meter:	67γ / 8n	67γ / 8n
2 meter	40γ / 5n	40γ / 5n
3 meter	27γ / 3n	27γ / 3n

Maintenance Operations

Table 10.3-2 shows the estimated design basis annual person-rem for surveillance and maintenance activities. These estimates take no credit for reduced does rates due to decay time at the ISFSI. The background dose rate at the ISFSI is estimated at 15γ/2n mrem/hr based on a distance of more than 4 meters from the nearest cask, except as noted. Dose rates are based upon the radial midplane dose rates (including the contribution from BPRAs) calculated in Chapter 5 except where noted.

Visual surveillance is based on a walk down among the casks a distance no closer than 2 meters to a single cask; background is based upon a distance of 3 meters from the neighboring cask.

For operability tests and calibration, and for unanticipated instrument repair, the worker was assumed to be located at the ~~plumbing manifold located on the cask exterior about 4 feet from~~ the ground, an average of 1 meter from the cask. Repressurization of the overpressure system may be done at the same time as calibration with little or no additional exposure.

For paint touch up, an average distance is 0.5 meter.

For major repairs to the overpressure system that would require removal of the weather protective cover, the 0.5 meter radial dose rate from the area above the radial neutron shield is used (top/corner dose rate). This dose rate is the same for the TN-32, TN-32B and TN-32A. The TN-32A has higher dose rates only after the top neutron shield is removed.

For replacement of port or lid seals, or for fuel unloading, the loading procedure dose estimate may be used for guidance, taking into account any additional decay time.

The ISFSI license applicant will evaluate the additional dose to station personnel from ISFSI operations, based on the particular storage configuration and site personnel requirements.

10.4 References

1. U.S. Nuclear Regulatory Commission, Regulatory Guide 8.8, Information Relevant to Ensuring That Occupational Exposures at Nuclear Power Stations will be As Low As Is Reasonably Achievable, Revision 3, June 1978.

2. MCNP4B2, "Monte Carlo N-Particle Transport Code System." Los Alamos National Laboratory, CCC-660, RSIC.

TABLE 10.2-1

SKY SHINE DOSE RATES AT POSTULATED SITE BOUNDARY FROM ONE CASK

Distance from Source*	Neutron (mrem/yr)	Gamma (mrem/yr)	Total [1] (mrem/yr)
100 meters	51.9	42.2	94.1
150 meters	20.1	19.9	39.9
200 meters	9.0	9.8	18.8
300 meters	2.1	2.8	4.9
500 meters	0.2	0.3	0.5

* Distance from center of cask

1.- without fuel inserts

TABLE 10.3-1

DESIGN BASIS OCCUPATIONAL EXPOSURES FOR CASK LOADING, TRANSPORT, AND EMPLACEMENT (ONE TIME EXPOSURE)

GAMMA

		No of Persons	Time (hr)	Avg Dist (m)	location	TN-32 and 32B Dose rate mrem/hr	TN-32 and 32B person-rem	TN-32A Dose rate mrem/hr	TN-32A person-rem
A. Cask Receipt									
1-12	Unloading, inspection, etc.	NO EXPOSURE OTHER THAN BACKGROUND							
B. Cask Loading Pool									
1	Lower cask into cask loading pool	NO EXPOSURE OTHER THAN BACKGROUND (POOL).							
2	Load	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
3	Verify	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
4	Lower lid	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
5	Lift cask and install some of the lid bolts hand tight	1	0.25	0.5	water/ lid	7	0.0018	17	0.0043
		1	0.5	2	water/ lid	2	0.0010	5	0.0025
6	Drain (pump) water	1	0.5	0.5	water/ lid	7	0.0035	17	0.0085
		1	1	2	water/ lid	2	0.0020	5	0.0050
7	Disconnect drain line	1	0.25	0.5	lid/ corner	179	0.0448	311	0.0778
8	Move to decontamination area	2	1	2	radial	40	0.0800	40	0.0800
C. Decontamination Area									
1	Decontaminate	2	1	1	radial	67	0.1340	67	0.1340
		1	0.5	1	lid/ corner	95	0.0475	186	0.0930
2	Install remaining lid bolts and torque	2	1	0.5	lid/ corner	179	0.3580	311	0.6220
3	Remove plug from neutron shield vent, install pressure relief valve.	1	0.25	0.5	lid/ corner	179	0.0448	311	0.0778

4	Connect the Vacuum Drying System	1	0.25	0.5	lid/ corner	179	0.0448	311	0.0778
		1	0.5	2	radial	40	0.0200	40	0.0200
5	Continue vacuum drying	1	1	1	radial	67	0.0670	67	0.0670
6	Backfill cask with helium and pressurize	1	0.25	0.5	lid/ corner	179	0.0448	311	0.0778
		2	1	2	radial	40	0.0800	40	0.0800
7	Helium leak test all lid and port cover seals	1	1	0.5	lid/ corner	179	0.1790	311	0.3110
		2	2	2	radial	40	0.1600	40	0.1600
8	Install top neutron shield.	2	0.25	0.5	top/ corner	158	0.0790	158	0.0790
9	Install overpressure system tank	2	0.5	0.5	top/ corner	158	0.1580	158	0.1580
10	Leak test OP system	2	0.5	1	top/ corner	68	0.0680	68	0.0680
11	Pressurize OP system	1	0.5	1	top/ corner	68	0.0340	68	0.0340
12	Install protective cover	2	1	0.5	top/ corner	158	0.3160	158	0.3160
13	Install exterior tubing, leak test	1	0.5	0.5	top/ corner	158	0.0790	158	0.0790
		1	1	1	radial	67	0.0670	67	0.0670
14	Backfill exterior tubing	1	0.5	1	radial	67	0.0335	67	0.0335
15	Check surface dose rate and contamination levels	2	0.5	1	radial	67	0.0670	67	0.0670
16	Load cask on transporter	2	1	2	radial	40	0.0800	40	0.0800
17	Move cask to storage area	2	3	3	radial	27	0.1620	27	0.1620

D.	Storage Area								
1	Lower cask onto storage pad	2	0.5	2	radial	40	0.0400	40	0.0400
2	Disconnect cask transporter	2	0.5	2	radial	40	0.0400	40	0.0400
3	Connect over pressure system to monitoring panel	2	1	1	radial	67	0.1340	67	0.1340
4	Check OP system function.	1	0.5	1	radial	67	0.0335	67	0.0335
						Total	2.70		3.29

TABLE 10.3-1, Continued

DESIGN BASIS OCCUPATIONAL EXPOSURES

NEUTRON & TOTAL NEUTRON + GAMMA

						TN-32 and 32B		TN-32A	
		No of Persons	Time (hr)	Avg Dist (m)	location	Dose rate mrem/hr	person-rem	Dose rate mrem/hr	person-rem
A. Cask Receipt									
1-12	Unloading, inspection, etc.	NO EXPOSURE OTHER THAN BACKGROUND							
B. Cask Loading Pool									
1	Lower cask into cask loading pool	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
2	Load	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
3	Verify	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
4	Lower lid	NO EXPOSURE OTHER THAN BACKGROUND (POOL)							
5	Lift cask and install some of the lid bolts hand tight	1	0.25	0.5	water/ lid	3	0.0008	3	0.0008
		1	0.5	2	water/ lid	1	0.0005	1	0.0005
6	Drain (pump) water	1	0.5	0.5	water/ lid	3	0.0015	3	0.0015
		1	1	2	water/ lid	1	0.0010	1	0.0010
7	Disconnect drain line	1	0.25	0.5	lid/ corner	100	0.0250	111	0.0278
8	Move to decontamination area	2	1	2	radial	5	0.0100	5	0.0100
C. Decontamination Area									
1	Decontaminate	2	1	1	radial	8	0.0160	8	0.0160
		1	0.5	1	lid/ corner	46	0.0230	51	0.0255
2	Install remaining lid bolts and torque	2	1	0.5	lid/ corner	100	0.2000	111	0.2220
3	Remove plug from neutron shield vent, install pressure relief valve.	1	0.25	0.5	lid/ corner	100	0.0250	111	0.0278

4	Connect the Vacuum Drying System	1	0.25	0.5	lid/ corner	100	0.0250	111	0.0278
		1	0.5	2	radial	5	0.0025	5	0.0025
5	Continue vacuum drying	1	1	1	radial	8	0.0080	8	0.0080
6	Backfill cask with helium and pressurize	1	0.25	0.5	lid/ corner	100	0.0250	111	0.0278
		2	1	2	radial	5	0.0100	5	0.0100
7	Helium leak test all lid and port cover seals	1	1	0.5	lid/ corner	100	0.1000	111	0.1110
		2	2	2	radial	5	0.0200	5	0.0200
8	Install top neutron shield.	2	0.25	0.5	top/ corner	74	0.0370	74	0.0370
9	Install overpressure system tank	2	0.5	0.5	top/ corner	74	0.0740	74	0.0740
10	Leak test OP system	2	0.5	1	top/ corner	32	0.0320	32	0.0320
11	Pressurize OP system	1	0.5	1	top/ corner	32	0.0160	32	0.0160
12	Install protective cover	2	1	0.5	top/ corner	74	0.1480	74	0.1480
13	Install exterior tubing, leak test	1	0.5	0.5	top/ corner	74	0.0370	74	0.0370
		1	1	1	radial	8	0.0080	8	0.0080
14	Backfill exterior tubing	1	0.5	1	radial	8	0.0040	8	0.0040
15	Check surface dose rate and contamination levels	2	0.5	1	radial	8	0.0080	8	0.0080
16	Load cask on transporter	2	1	2	radial	5	0.0100	5	0.0100
17	Move cask to storage area	2	3	3	radial	3	0.0180	3	0.0180
D.	Storage Area								
1	Lower cask onto storage pad	2	0.5	2	radial	5	0.0050	5	0.0050
2	Disconnect cask transporter	2	0.5	2	radial	5	0.0050	5	0.0050

3	Connect over pressure system to monitoring panel	2	1	1	radial	8	0.0160	8	0.0160
4	Check OP system function.	1	0.5	1	radial	8	0.0040	8	0.0040
						Total	0.92		0.96
						n+gam	3.62		4.25

TABLE 10.3-2

DESIGN BASIS ISFSI MAINTENANCE OPERATIONS
ANNUAL EXPOSURES

GAMMA

Task	Time Req'd (hr)	No of Person	Dist (m)	Dose Rate (mrem/hr)	Backgrnd (mrem/hr)	Operation Dose (rem)	Operation Frequency (/year)	Annual Dose (rem)
Visual Surveillance of Casks	0.25	1	2	40	27	0.01675	12	0.201
Instrumentation								
a. Operability & Calibration	2	2	1	67	15	0.328	1	0.328
b. Unanticipated Repairs	2	2	1	67	15	0.328	0.25	0.082
Surface Defect Repair	1	2	0.5	117	15	0.264	1	0.264
Repair under Protective Cover	8	2	0.5	158	15	2.768	0.05	0.138

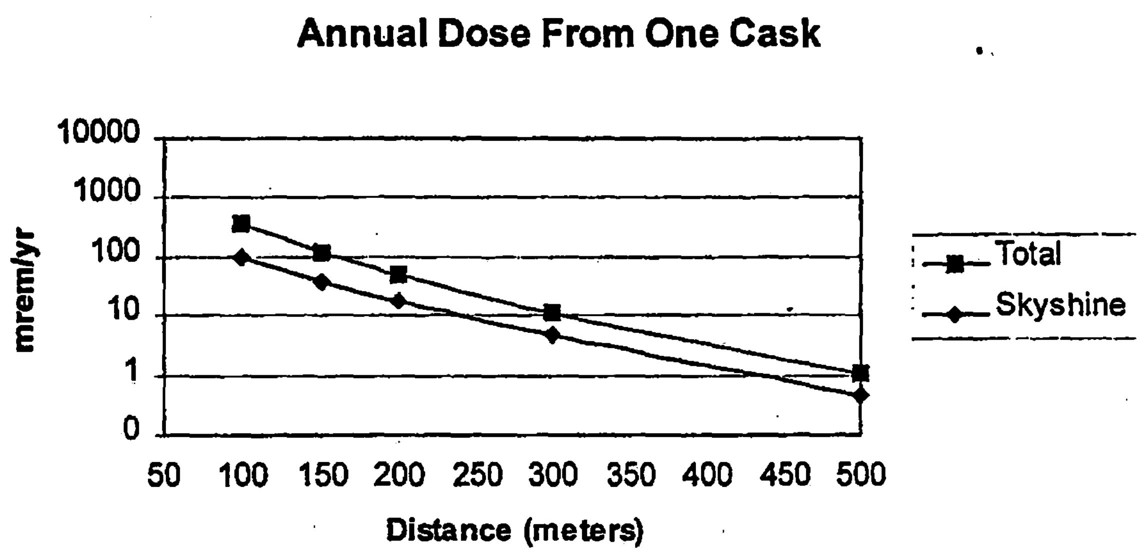
NEUTRON AND TOTAL

Task	Time Req'd (hr)	No of Person	Dist (m)	Dose Rate (mrem/hr)	Backgrnd (mrem/hr)	Operation Dose (rem)	Operation Frequency (/year)	Annual Dose (rem)	Total gamma + n (rem)
Visual Surveillance of Casks	0.25	1	2	5	3	0.002	12	0.024	0.225
Instrumentation									
a. Operability & Calibration	2	2	1	8	2	0.04	1	0.040	0.368
b. Unanticipated Repairs	2	2	1	8	2	0.04	0.25	0.010	0.092
Surface Defect Repair	1	2	0.5	12	2	0.028	1	0.028	0.292
Repair under Protective Cover	8	2	0.5	74	2	1.216	0.05	0.061	0.199

1. All dose rates assume that the TN-32 cask contains design basis fuel. No reduction of dose rate is assumed for decay time.

2. Doses are on a per cask basis.

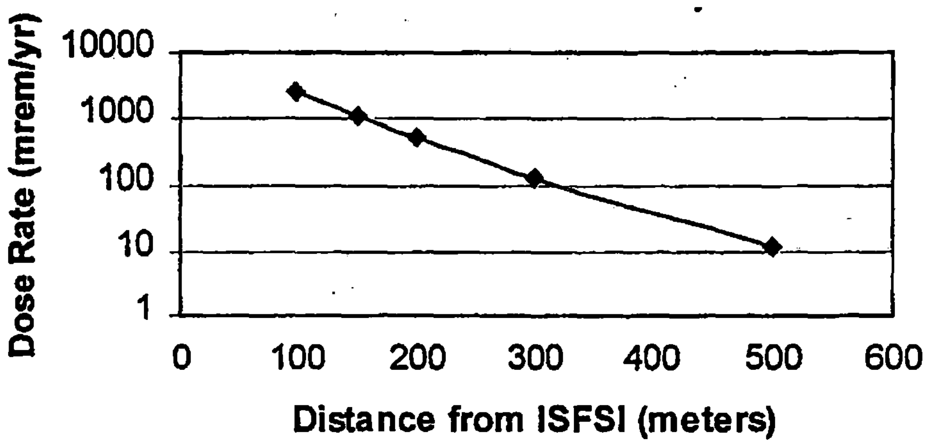
Figure 10.2-1



(no fuel inserts)

FIGURE 10.2-2

OFF-SITE SKY SHINE DOSE RATES AT POSTULATED SITE BOUNDARY
FROM A TYPICAL ISFSI



(Distance from center of nearest cask)

(no fuel inserts)

CHAPTER 11

ACCIDENT ANALYSES

This Chapter describes the postulated off-normal and accident events that might occur during storage of the TN-32 cask at an ISFSI, the potential causes of these events, their detection and consequences and the corrective course of action to be taken by ISFSI personnel.

11.1 Off-Normal Operations

Off-normal operations are design events of the second type (Design Event II) as defined in ANSI/ANS 57.9[1]. Design Event II conditions consist of that set of events that, although not occurring regularly, can be expected to occur with moderate frequency or on the order of once during a calendar year of ISFSI operation.

Two off-normal conditions have been considered with regard to the TN-32 cask: a loss of electric power or leakage in any one of the seals or the overpressure system.

11.1.1 Loss of Electric Power

A total loss of electric power is postulated. The failure could be either an open or a short to ground circuit, or any other mechanism capable of producing an interruption of power.

11.1.1.1 Postulated Cause of the Event

A loss of power to the ISFSI may occur as a result of natural phenomena, such as lightning or extreme wind, or as a result of undefined disturbances in the nonsafety-related portion of the electric power system.

If electric power is lost, the following systems would be de-energized and rendered nonfunctional:

- Area lighting
- Cask pressure monitoring instrumentation

11.1.1.2 Detection of Events

A loss of power at the ISFSI site would be detected during periodic surveillance by noting that area lighting is not operational.

11.1.1.3 Analysis of Effects and Consequences

This event has no safety or radiological consequences

because a loss of power will not affect the integrity of the storage casks, jeopardize the safe storage of the fuel, or result in radiological releases. None of the systems whose failure could be caused by this event are necessary for the accomplishment of the important to safety function of the cask. The lighting system provides no important to safety function to the cask. It does however, provide for the visual monitoring for intrusion detection as required by the ISFSI security plan. The instrumentation monitors the long-term performance of the storage casks with respect to the cask seals. None of these parameters are expected to change rapidly and their status is not dependent upon electric power.

A loss of power has no effect on the subcritical condition of the cask, cask confinement or retrievability of the fuel.

11.1.1.4 Corrective Actions

Following a loss of electric power to the ISFSI, facility maintenance personnel will be informed and will isolate the fault and restore service by conventional means. Such an operation is straightforward and routine for maintenance personnel.

11.1.1.5 Radiological Impact from Off-Normal Operations

No radiological impact from off-normal operations is postulated.

11.1.2 Cask Seal Leakage or Leakage of the Overpressure Monitoring System

The storage casks feature redundant seals in conjunction with an extremely rugged body design. Additional barriers to the release of radioactivity are presented by the sintered fuel pellet matrix and the zircaloy cladding which surrounds the fuel pellets. Furthermore, the interseal gaps are pressurized in excess of the cask cavity. The overpressure monitoring system is designated as not important to safety. Therefore a leak of the overpressure system is the most likely cause of leakage.

11.1.2.1 Postulated Cause of the Event

A combined event of failure of one of the seals or the overpressure system pressure boundary in addition to a failure of the pressure monitoring alarm system is assessed.

11.1.2.2 Detection of Event

Detection of a seal leak in addition to the loss of the pressure monitoring system would be by means of periodic calibration or testing.

11.1.2.3 Analysis of Effects and Consequences

Leaks could occur in three locations:

- In any of the inner confinement seals (lid seal, inner vent seal or inner drain seal).

  The lid and lid penetration cover bolts and seals are designed to prevent leakage during all normal, off-normal and postulated accident events. Therefore this is a very unlikely event.

  In this case the overpressure system, which has a higher pressure than the cask cavity, would leak helium into the cask cavity. Since the pressure is higher in the overpressure tank, it would prevent leakage of radioactive materials out of the cask cavity until the pressure between the overpressure tank and the cask cavity equalized. This would take several years, depending on the size of the leak. At the test leak rate, the overpressure system pressure would always exceed the cask cavity pressure, as shown in Chapter 7. Therefore no leakage of radioactive material can occur, even if the alarm were to fail. Chapter 7 also demonstrates that even if the inner seal has experienced a latent seal failure there is ample time for identifying the leak through routine surveillances.

- In any of the outer seals (lid, overpressure port cover, vent cover or drain cover)

  The lid and lid penetration cover bolts and seals are designed to prevent leakage during all normal, off-normal and postulated accident events. Therefore this is a very unlikely event.

  In this case, leakage out of the interspace to the atmosphere would occur. This would not result in release of radioactive material from the cask cavity since the inner seal is intact. Again, as demonstrated in Chapter 7, a latent seal failure of the outer seals would not result in a release of any radioactive material to the environment. There is also ample time for identifying the leak through routine surveillances.

- A leak in the overpressure system

  This is the most likely cause of a leak, since it is a non safety related component and not designed to withstand accident loadings.

  In this case two scenarios could exist:

- The overpressure system is not functioning and the inner seal is intact. In this case there is no release of radioactive material to the environment; or

- The overpressure system is not functioning and the inner seal is leaking at some rate.

In this latter case, leakage out of the interspace to the atmosphere and the cask cavity would occur. This would not result in release of radioactive material from the cask cavity until the pressure fell to the cask cavity pressure. At the test leak rate of 1×10^{-5} std cc/sec, this would not occur during the 20 year storage period.

However, a leak of this magnitude in combination with a loss of the over pressure system has been evaluated as both an off-normal and accident condition in Section 7.3.

The results of these calculations assuming off-normal conditions indicate that an individual located at the site boundary (100 m from the cask) for an entire year would receive an effective dose equivalent of 1.92 mrem, a thyroid dose of 0.262 mrem, and a bone surface dose of 19.1 mrem. These doses are below the regulatory limits of 10 CFR 72.104(a) of 2.5×10^{-1} msv (25 mrem) to the whole body, 7.5×10^{-1} msv (75 mrem) to the thyroid and 2.5×10^{-1} msv (25 mrem) to any other critical organ.

The results of these calculations assuming accident conditions indicated that at the site boundary (100m from the cask), for a 30 day release, the total effective dose equivalent is 58.9 mrem. The sum of the deep dose equivalent and the committed dose equivalent to any individual organ (the critical organ in this case is the bone surface) is 664 mrem for a 30 day release. These values are well below the limiting off site doses defined in 10 CFR 72.106(b).

Another accident condition under consideration is that the overpressure system is not functioning and the inner seal has experienced a latent seal failure. This analysis is presented in 7.3.3. This accident analysis demonstrates that a latent failure up to 100 times greater that the test value could occur and there is ample time for recovery before the limiting off site doses in 10 CFR 72.106(b) are met. The probability that a gross leak of an inner seal in combination with a gross leak in the outer seal is not considered a credible event.

11.1.2.4 Corrective Actions

The overpressure system leak would be repaired at the ISFSI

depending on the complexity of the repair, or the cask would be returned to the spent fuel pool for seal replacement. Repairs which could be performed at the ISFSI are tightening of fittings, replacement of valves or switches, localized weld repairs or replacement of components.

11.1.2.5 Radiological Impact

For the worst case, which includes loss of alarm, complete loss of the pressure differential between the cask and the overpressure system, and complete loss of the overpressure system pressure boundary, the dose rates at the site boundary would increase as stated above, but are below the regulatory limits of 10 CFR 72.104(a).

11.2 Accidents

Accidents are design events of the third and fourth type (Design Events III and IV) as defined in ANSI/ANS 57.9. Design Event III consists of that set of infrequent events that could reasonably be expected to occur during the lifetime of the ISFSI. Design Event IV consists of the events that are postulated because their consequences may result in the maximum potential impact on the immediate environs. Their consideration establishes a conservative design basis for certain systems with important confinement features. The following accidents are considered:

- An Earthquake
- Extreme Wind and Tornado Missiles
- Floods
- Explosions
- Fire
- Inadvertent Loading of a Newly Discharged Fuel Assembly
- Inadvertent Loading of a Fuel Assembly with a Higher Initial Enrichment than the Design Basis Fuel
- Hypothetical Cask Drop or Tipover
- Nonmechanistic Loss of the Confinement Barrier
- Cask Burial

11.2.1 Earthquake

11.2.1.1 Cause of Accident

The design earthquake (DE) is postulated to occur as a design basis extreme natural phenomenon.

11.2.1.2 Accident Analysis

Seismic response characteristics of the storage casks are provided in Section 2.2.3 and Appendix 3A. Results of these analyses show that the cask does not tip over or slide due to the design basis seismic event, the leak-tight integrity of the cask is not compromised and that no damage will be sustained. The basket stresses are also low and do not result in deformation that would prevent fuel from being unloaded from the cask.

11.2.1.3 Accident Dose Calculations

The DE is not capable of damaging the cask. Hence, no radioactivity is released and there is no associated dose increase due to this event.

11.2.1.4 Corrective Actions

After a design basis seismic event, the cask would be inspected for damage. Any debris would be removed. An evaluation would be performed to determine if the cask were still within the licensed design basis. The functioning of the pressure monitoring system would be confirmed and repaired if necessary. If necessary, the cask would be returned to the spent fuel pool for unloading.

11.2.2 Extreme Wind and Tornado Missiles

11.2.2.1 Cause of Accident

The extreme winds due to passage of the design tornado as defined in Section 2.2.1 are postulated to occur as an extreme natural phenomenon.

11.2.2.2 Accident Analysis

The effects and consequences of extreme winds on the casks are presented in Section 2.2.1 and Appendix 3A. Extreme winds do not result in a cask tip over or sliding of the cask. The pressure due to high winds on the surface of the cask is bounded by the assumed external pressure of 25 psi. The stresses in the cask resulting from this external pressure are presented in Appendix 3A. High winds have no effect on the leak tight integrity of the cask, and do not result in damage to the cask itself. High winds do not affect the basket or the ability to retrieve the spent fuel from the cask. The effect of tornado missiles hitting the cask has been evaluated in Section 2.2.1. These analyses show that the stresses in the cask as a result of missile impact are well below the allowable stresses for Accident(Level D) conditions. It is also shown in Section 2.2.1 that the tornado missile impact will not result in cask tipover. Local damage to the neutron shield may result from the tornado missile impact. The overpressure system could be damaged, particularly the components outside of the protective cover.

11.2.2.3 Accident Dose Calculations

Extreme winds are not capable of overturning these casks nor of damaging their seals. The overpressure system and the neutron shielding may be damaged. To determine the bounding dose, loss of neutron shielding (Section 11.2.5.3) is combined with the TEDE from the loss of one confinement barrier and 100% fuel cladding failure (Section 11.2.9.3). The resulting site boundary accident dose, 714 mrem, is below the 5 rem limit to the whole body or any organ as specified in 10 CFR 72.106(b).

11.2.2.4 Corrective Actions

After excessive high winds or a tornado, the cask will be inspected for damage. Any debris would be removed. Any damage resulting from impact with a missile would be evaluated to

determine if the cask were still within the licensed design basis. The functioning of the pressure monitoring system would be confirmed, and repaired if necessary. If necessary, the cask would be returned to the spent fuel pool for unloading.

11.2.3 Flood

11.2.3.1 Cause of Accident

Natural event.

11.2.3.2 Accident Analysis

The postulated floods and high water levels are discussed in Section 2.2.2. The analysis presented shows that the cask will withstand the external pressure due to the flood and the velocity of the flowing water will not tip or cause the cask to slide. Minor floods have no impact on the cask performance. Major floods could result in debris buildup around the casks or result in damage to the exterior of the cask or the overpressure monitoring system outside of the protective cover.

11.2.3.3 Accident Dose Calculations

The probable maximum flood is not capable of overturning the casks or of damaging their seals. Therefore, no radioactivity is released and there is no associated dose increase due to this event.

11.2.3.4 Corrective Actions

After a major flood of the ISFSI site, the cask will be inspected for damage. Any debris will be removed. Any damage resulting from the flood would be evaluated to determine if the casks were still within the licensed design basis. The functioning of the pressure monitoring system would be confirmed, and repaired if necessary.

11.2.4 Explosion

11.2.4.1 Cause of Accident

Explosion in the general vicinity.

11.2.4.2 Accident Analysis

The cask is designed to withstand 25 psi external pressure as shown in Chapter 3. The pressure generated by a credible explosion in the general vicinity of the cask is expected to be only on the order of a few psi. This would not collapse the heavy steel wall consisting of the confinement system and the gamma shield, the 0.5 inch thick steel shell surrounding the neutron resin or provide enough lateral load to tip the cask.

11.2.4.3 Accident Dose Calculations

The cask will not tip as a result of the postulated pressure wave. Accordingly, no cask damage or release of radioactivity is postulated. Since no radioactivity is released, no resultant dose increase is associated with this event.

11.2.4.4 Corrective Actions

After an explosion in the vicinity of the ISFSI site, the casks would be inspected for damage. The surfaces of the cask would potentially need to be cleaned and repainted in local areas. Any debris would be removed. If there were any damage, an evaluation would be performed to determine if the cask were still within the licensed design basis. The functioning of the pressure monitoring system would be confirmed, and repaired if necessary.

11.2.5 Fire

11.2.5.1 Cause of Accident

Combustible materials will not normally be stored at an ISFSI. Therefore, a credible fire would be very small and of short duration such as that due to a fire or explosion from a vehicle or portable crane.

However a hypothetical fire accident is evaluated for the TN-32 cask based on a fuel fire, the source of fuel being that from a ruptured fuel tank of the cask transporter tow vehicle. The bounding capacity of the fuel tank is 200 gallons and the bounding hypothetical fire is an engulfing fire around the cask.

11.2.5.2 Accident Analysis

The evaluation of the hypothetical fire event is presented in Section 4.5.1 of the SAR. The fire thermal evaluation is performed primarily to demonstrate the confinement integrity of the TN-32. This is assured as long as the metallic lid seals remain below 536°F and the cavity pressure is less than 100 psig.

Based on the thermal analyses for the fire accident conditions, the TN-32 can withstand the hypothetical fire accident event without compromising its confinement integrity. No melting of the metallic cask components occurs. Peak cask component temperatures are summarized in Table 4.5-1. The maximum seal temperature is calculated to be 380°F which is well below the temperature limit of the metallic seals. The average cavity gas temperature peaks at 497°F and the pressure increases to 83.8 psig. See Section 7.3.2.2. The pressure inside the cask cavity is well below the design pressure of 100 psig.

The neutron shield will off-gas during the hypothetical accident. A pressure relief valve is provided on the outer shell to prevent the pressurization of the outer shell. Shielding analyses have been performed showing acceptable consequences even if all the resin disappears.

11.2.5.3 Accident Dose Calculations

Local damage to the neutron shielding may result from the fire. This is bounded by removal of all the neutron shielding which is evaluated in Chapter 5. Even with this conservative assumption, the site boundary accident dose rates are below 5 rem to the whole body or any organ as specified in 10CFR72.106(b).

The offsite dose is evaluted for two accident conditions:

1) loss of radial neutron shielding
2) loss of the protective cover and top neutron shield.

A comparison of Figures 5.4-4 and 5.4-6 demonstrates that the radial case with burnable poison rod assemblies is bounding.

For accident conditions, the following assumptions are made:

a) the nearest postulated site boundary is 100 meters distant from the cask
b) the accident involves a single cask
c) the accident duration is 30 days
d) a person remains at the postulated site boundary 24 hours per day for the entire duration
e) skyshine doses are negligible compared to direct doses.

The normal condition direct dose rates (without inserts) at 100 meters are scaled by the ratio of accident to normal surface dose rates as shown in the following table. All units are mrem/hr.

	normal dose rate 100 m direct, Table 5.1-3	accident, surface Table 5.1-2	normal, surface Table 5.1-2	accident, 100 m direct mrem/hr
gamma	2.96E-02	541	138	1.16E-01
neutron	1.06E-02	1150	15.3	7.97E-01
			total	9.1E-01

The direct dose over 30 days would be 655 mrem. The background from the rest of the ISFSI would be 1/12 of the 25 mrem/year limit (10 CFR 72.104), or 2 mrem. The combined total accident dose would be 657 mrem.

11.2.5.4 Corrective Actions

After a fire, the cask would be inspected for damage. The neutron shielding material may have been damaged during the fire. A radiological survey of the cask would be performed prior to

physical inspection. The surfaces of the cask would potentially need to be cleaned and repainted in local areas. If there is any damage, an evaluation would be performed to determine if the cask were still within the licensed design basis. If the cask is no longer within the design basis, the cask will be returned to the spent fuel pool and unloaded. The top neutron shield may need to be replaced prior to putting the cask back into service. If the cask is still within the design basis, the functioning of the overpressure monitoring system would be confirmed, and repaired if necessary.

11.2.6 Inadvertent Loading of a Newly Discharged Fuel Assembly

11.2.6.1 Cause of Accident

The possibility of a spent fuel assembly, with a heat generation rate greater than 1.021 kW, being erroneously selected for storage in a cask has been considered. The cause of this accident is postulated to be an error during the loading operations, e.g., wrong assembly picked by the fuel handling crane, or a failure in the administrative controls governing the fuel handling operations.

11.2.6.2 Accident Analysis

The fuel assemblies require several years of storage in the spent fuel pool before the heat generation decays to a rate below 1.021 kW. This accident scenario postulates the inadvertent loading of an assembly not intended for storage in the storage canister, with a heat generation rate in excess of the design basis specified in Section 2.1.

In order to preclude this accident from going undetected, and to ensure that appropriate corrective actions can take place prior to the sealing of the casks, a final verification of the assemblies loaded into the casks and a comparison with fuel management records is required to assure that the correct assemblies are loaded.

These administrative controls and the records associated with them will be included in the procedures described in Chapter 8.

Appropriate and sufficient actions will be taken to ensure that an erroneously loaded fuel assembly does not remain undetected. In particular, the storage of a fuel assembly with a heat generation in excess of 1.021 kW is not considered credible in view of the multiple administrative controls. There is no thermal or shielding analysis impact since the improperly loaded cask will not get out of the water due to independent review. The loading of a higher enriched fuel assembly is evaluated as a separate accident in Section 11.2.7.

11.2.6.3 Accident Dose Calculations

The inadvertent loading of a fuel assembly not intended for storage in a storage cask is not considered to be a credible occurrence. Therefore, no resultant doses would occur.

11.2.6.4 Corrective Actions

If it has been determined that a fuel assembly which is outside the bounds of the design basis has been loaded, it shall be removed from the cask prior to removing the cask from the water.

11.2.7 Inadvertent Loading of a Fuel Assembly with a higher initial enrichment than the Design Basis Fuel

11.2.7.1 Cause of Accident

The possibility of a spent fuel assembly with an initial enrichment greater than 4.05 w/o U235 has been considered. The cause of this accident is postulated to be an error during the loading operations, e.g., wrong assembly picked by the fuel handling crane, or a failure in the administrative controls governing the fuel handling operations.

11.2.7.2 Accident Analysis

An evaluation is performed in Chapter 6 with one fuel assembly in one of the 4 center compartments with an enrichment of 5.0 w/o U235. This analysis is performed with 17x17 fuel assemblies and all of the fuel assemblies are shifted toward the cask centerline. The analysis results are presented in Table 6.4-2 and the relevant information is reproduced here.

Case Description	k_{eff}	σ	$k_{eff} + 2\sigma$
Baseline, TN-32 design basis 17x17 fuel shifted toward cask axis, 4.05% enrichment	0.9167	0.0008	0.9183
Center assembly enriched to 5% remaining fuel 4.05% enrichment 87.5% borated water density, worst case normal conditions.	0.9315	0.0009	0.9333

As shown above, in the event of one fuel assembly with higher initial enrichment than the design basis fuel being loaded into the cask, the cask remains subcritical. In order to preclude this accident from going undetected, and to ensure that appropriate corrective actions can take place prior to the sealing of the casks, a final verification of the assemblies loaded into the casks and a comparison with fuel management records is required to assure that the correct assemblies are loaded.

These administrative controls and the records associated with them will be included in the procedures described in Chapter 8.

Appropriate and sufficient actions will be taken to ensure that an erroneously loaded fuel assembly does not remain undetected. In the event that a fuel assembly with higher initial enrichment is loaded, the fuel remains subcritical.

11.2.7.3 Accident Dose Calculations

The inadvertent loading of a fuel assembly with higher initial enrichment than the design basis is prevented by administrative control. There is no resultant dose rate increase due to this condition.

11.2.7.4 Corrective Action

If it is determined that a fuel assembly has been loaded which is outside the bounds of the design basis, it shall be removed from the cask.

11.2.8 Hypothetical Cask Drop and Tipping Accidents

11.2.8.1 Cause of Accident

The stability of the TN-32 storage cask in the upright position on the ISFSI concrete storage pad is demonstrated in Section 2.2 of this SAR. The effects of tornado wind and missiles, flood water and earthquakes are described in Sections 2.2.1, 2.2.2 and 2.2.3, respectively. It is shown in those sections that the cask will not tip over under the most severe natural phenomena specified in this Safety Analysis Report.

The cask drop is postulated to occur during handling while the cask is moved onto or off of a transport vehicle. The trunnions are designed and load tested to the requirements of ANSI N14.6[2] for lifting devices. The cask will generally be handled by a specifically designed transport vehicle in a vertical orientation and not lifted higher than 18 inches. Therefore it is extremely unlikely that the cask could be dropped. Other drop events which may be postulated at a specific ISFSI site will be evaluated in accordance with 10CFR 72.212.

Therefore the cask is examined for both dropping and tipping accidents, which are hypothetical impact events that are extremely unlikely to occur.

11.2.8.2 Accident Analyses

The cask is evaluated under bottom end impact on the ISFSI storage pad after a drop from a height of 18 inches in Section

3A.2.3.2. The storage pad is generally the hardest concrete surface outside of the spent fuel storage building. The cask is oriented vertically and is not lifted higher than 18 inches once it leaves the containment building. Therefore this case is an upper bound drop event since impact onto a softer surface would result in lower cask deceleration and a lower impact force. The cask is also evaluated under a tipover event on the storage pad in Section 3A.2.3.2 even though (as demonstrated in Section 2.2) the cask can not tip over.

The analysis presented in Appendix 3A indicates that the maximum deceleration due to an 18 inch bottom end drop is 36 g's. The maximum deceleration due to a tipover accident is 23 g's.

The cask is analyzed conservatively for a 50 g vertical load simulating the end drop, and a 50 g side drop conservatively simulating the tipover.

The cask stresses reported in Tables 3A.2.5-13 through -24 are less than the 2.4 S_m containment membrane stress allowable at all locations. No additional processing is needed since this is the lowest allowable. An additional analysis of a cask tipping over and impacting a trunnion is evaluated in 3A.2.4.3. This analysis shows that the local stresses around the trunnion are acceptable, and the g loadings are less severe than the side drop analyzed in 3A.2.3.2.

The stresses in the lid bolts due to the two postulated drop accidents are presented in Section 3A.3.2. This analysis shows that the stresses in the bolts due to the accident loads are well below the allowable limit of $3S_m$ and the bolt yield strength. Therefore, confinement will not be compromised.

The stresses in the basket due to the two postulated drop accidents are presented in Appendix 3B and 3C. These analyses ~~show that the basket is structurally satisfactory under the 88 g~~ side and 50 G end loads. For the tipover event, the top of the basket was evaluated for an 88G side load and evaluated at a temperature of 400°F (Section 3C.3-1). The center of the basket is evaluated for a 52G side load at a temperature of 531°F (Section 3C.3-2).

An assessment of the fuel after a drop or tipover accident is performed in Appendix 6A. That analysis concludes that the fuel pins will remain intact. The fuel assemblies may be retrieved from the cask by returning the cask to the spent fuel pool. The Chapter 6 criticality analysis evaluates reduction of the fuel pin pitch due to grid damage in the tipover, and axial sliding of the fuel pins in the end drop. That analysis verifies that 2300 ppm borated water is adequate to maintain criticality safety during unloading after a drop or tipover accident.

11.2.8.3 Accident Dose Calculations

A cask tipover will not breach the cask confinement barrier. The bolts that retain the protective cover, the top neutron shield and the overpressure tank are not analyzed for the tipover accident, and therefore, this dose calculation will assume that they these components are removed. To determine the bounding dose, loss of neutron shielding (Section 11.2.5.3) is combined with the TEDE from the loss of one confinement barrier and 100% cladding failure (Section 11.2.9.3). The resulting site boundary accident dose, 714 mrem, is below the 5 rem limit to the whole body or any organ as specified in 10 CFR 72.106(b).

11.2.8.4 Corrective Actions

After a tipover or cask handling drop, a radiological survey would be performed. The cask would be uprighted and inspected for damage. The neutron shielding material may have been damaged due to impact. If there is any damage, an evaluation would be performed to determine if the cask were still within the licensed design basis. If the cask is no longer within the design basis, the cask will be returned to the spent fuel pool and unloaded. The neutron shield may need to be replaced prior to putting the cask back into service. If the cask is still within the design basis, the functioning of the pressure monitoring system would be confirmed, and repaired if necessary.

11.2.9 Loss of Confinement Barrier

11.2.9.1 Cause of Accident

This is a nonmechanistic type event. It is assumed that the overpressure system has stopped functioning and fire conditions exist. One set of seals is functioning. All fuel rods have failed.

11.2.9.2 Accident Analysis

Radioactive material can be released at a rate equal to the test leak rate of 1×10^{-5} std cc/sec. It is also assumed that all of the fuel rods have failed, and the temperature inside the cask is comparable to the fire accident conditions. The cask is assumed to leak at this rate for 30 days.

In this accident, the confinement function of the fuel rod cladding and one set of seals is eliminated. Heat removal and radiation shielding functions operate in the normal passive manner.

This is equivalent to breaking one cask seal barrier, removing the pressure monitoring system, failing all the cladding in all the loaded fuel assemblies (gap activity release), and

finally, failing the fuel pellets themselves. The analysis is presented in Section 7.3.2.

11.2.9.3 Accident Dose Calculations

The dose evaluation due to this postulated accident is given in Section 7.3.2.1. The total effective dose equivalent at 100 m is 58.9 mrem/30 days. The sum of the deep dose equivalent and the committed dose equivalent to any individual organ (the bone surface is the critical organ) is 664 mrem/30 days. The shallow dose equivalent to the skin is 0.99 mrem/30 days. These values are well below the limiting off site doses defined in 10 CFR 72.106.

11.2.9.4 Corrective Actions

In the event of cask leakage, the cask would be returned to the spent fuel pool and the seals would be replaced. In addition, the overpressure system would be checked to determine the cause of failure and corrective measures to prevent future recurrence would be taken. The overpressure system and pressure monitoring equipment would be repaired or replaced as necessary prior to returning the loaded cask to the ISFSI for storage.

11.2.10 Buried Cask

11.2.10.1 Cause of Accident

Earthquake or other natural phenomenon resulting in collapse of building, other structure or other manmade or earthen material onto a cask.

11.2.10.2 Accident Analysis

An evaluation was made to determine the increase in cask temperature with time assuming the cask was completely buried in a medium which will not provide the equivalent cooling of natural convection and unrestricted radiation to the environment. The details of this analysis are provided in Section 4.5.2.

The results of this analysis show that if the cask is not uncovered within 3 hours, the neutron shield temperature will exceed the allowable long term temperature limit of 300°F (149°C). The cask seal temperature will reach its 536°F (280°C) limit about 38 hours after burial. The cavity pressure, including the contribution due to 100% fuel and BPRA failure, will not exceed 100 psig at 38 hours. The fuel temperature off-normal limit of 1058° F (570°C) is reached about 93 hours after burial occurs.

11.2.10.3 Accident Dose Calculations

Provided that the cask is unburied within 3 hours, there

will be no increase in dose rate due to cask burial. After that period, slow degradation of the neutron shielding would begin to occur resulting in higher surface dose rates. At about 38 hours, the seals could reach their long term maximum temperature of 536°F (280°C). It is reasonable to assume that the cask can be unburied before temperatures are reached which would result in seal failure.

To determine the bounding dose, loss of neutron shielding (Section 11.2.5.3) is combined with the TEDE from the loss of one confinement barrier and 100% fuel cladding failure (Section 11.2.9.3). The resulting site boundary accident dose, 714 mrem, is below the 5 rem limit to the whole body or any organ as specified in 10 CFR 72.106(b).

11.2.10.4 Corrective Actions

The cask should be unburied as soon as possible to prevent release of radioactive material. The cask will be inspected for damage. The neutron shielding material may have been damaged during the burial. If there is any damage, an evaluation would be performed to determine if the cask were still within the licensed design basis. If the cask is no longer within the design basis, the cask will be returned to the spent fuel pool and unloaded. The neutron shield and all seals would need to be replaced prior to putting the cask back into service.

11.3 REFERENCES

1. American Nuclear Society, ANSI/ANS-57.9, Design Criteria for an Independent Spent Fuel Storage Installation (Dry Storage Type), 1984.

2. American National Standards Institute, ANSI N14.6, Special Lifting Devices for Shipping Containers Weighing 10,000 pounds or More, 1986.

3. Deleted.

4. Deleted.

TN-32 GENERIC TECHNICAL SPECIFICATION

TABLE OF CONTENTS

1.0 USE AND APPLICATION

1.1 Definitions

NOTE

The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
ACTIONS	ACTIONS shall be that part of a Specification that prescribes Required Actions to be taken under designated Conditions within specified Completion Times.
CHANNEL OPERATIONAL TEST (COT)	A CHANNEL OPERATIONAL TEST (COT) shall be the injection of a simulated or actual signal into the channel as close to the sensor as practicable to verify the operability of required alarm functions. The COT shall include adjustments, as necessary, of the required alarm setpoint so that the setpoint is within the required range and accuracy.
INTACT FUEL ASSEMBLY	Spent Nuclear Fuel Assemblies without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. Partial fuel assemblies, that is fuel assemblies from which fuel rods are missing, shall not be classified as INTACT FUEL ASSEMBLIES unless dummy fuel rods are used to displace an amount of water equal to or greater than that displaced by the original fuel rod(s).
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on a cask while it is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first fuel assembly is placed in the cask and end when the cask is supported by the transporter.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the Independent Spent Fuel Storage Installation (ISFSI) while a cask containing spent fuel is sitting on a storage pad within the ISFSI.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on a cask loaded with one or more fuel assemblies when it is being moved to and from the ISFSI. TRANSPORT OPERATIONS begin when the cask is first suspended from the transporter and end when the cask is at its destination and no longer supported by the transporter.
UNLOADING OPERATIONS	UNLOADING OPERATIONS include all licensed activities on a cask while fuel assemblies are being unloaded. UNLOADING OPERATIONS begin when the cask is no longer supported by the transporter and end when the last fuel assembly is removed from the cask.

1.0 USE AND APPLICATION

1.2 Logical Connectors

PURPOSE

The purpose of this section is to explain the meaning of logical connectors.

Logical connectors are used in Technical Specifications (TS) to discriminate between, and yet connect, discrete Conditions, Required Actions, Completion Times, Surveillances, and Frequencies. The only logical connectors that appear in TS are AND and OR. The physical arrangement of these connectors constitutes logical conventions with specific meanings.

BACKGROUND

Several levels of logic may be used to state Required Actions. These levels are identified by the placement (or nesting) of the logical connectors and by the number assigned to each Required Action. The first level of logic is identified by the first digit of the number assigned to a Required Action and the placement of the logical connector in the first level of nesting (i.e., left justified with the number of the Required Action). The successive levels of logic are identified by additional digits of the Required Action number and by successive indentions of the logical connectors.

When logical connectors are used to state a Condition, Completion Time, Surveillance, or Frequency, only the first level of logic is used, and the logical connector is left justified with the statement of the Condition, Completion Time, Surveillance, or Frequency.

EXAMPLES

The following examples illustrate the use of logical connectors:

EXAMPLE 1.2-1:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Verify . . . AND A.2 Restore . . .	

In this example the logical connector AND is used to indicate that when in Condition A, both Required Actions A.1 and A.2 must be completed.

1.2 Logical Connectors

EXAMPLES (continued)

EXAMPLE 1.2-2:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Stop . . . OR A.2.1 Verify . . . AND A.2.2.1 Reduce . . . OR A.2.2.2 Perform . . . OR A.3 Remove . . .	

This example represents a more complicated use of logical connectors. Required Actions A.1, A.2, and A.3 are alternative choices, only one of which must be performed as indicated by the use of the logical connector OR and the left justified placement. Any one of these three Actions may be chosen. If A.2 is chosen, then both A.2.1 and A.2.2 must be performed as indicated by the logical connector AND. Required Action A.2.2 is met by performing A.2.2.1 or A.2.2.2. The indented position of the logical connector OR indicates that A.2.2.1 and A.2.2.2 are alternative choices, only one of which must be performed.

1.0 USE AND APPLICATION

1.3 Completion Times

PURPOSE	The purpose of this section is to establish the Completion Time convention and to provide guidance for its use.
BACKGROUND	Limiting Conditions for Operation (LCOs) specify minimum requirements for ensuring safe operation of the cask. The ACTIONS associated with an LCO state Conditions that typically describe the ways in which the requirements of the LCO can fail to be met. Specified with each stated Condition are Required Action(s) and Completion Times(s).
DESCRIPTION	The Completion Time is the amount of time allowed for completing a Required Action. It is referenced to the time of discovery of a situation (e.g., equipment or variable not within limits) that requires entering an ACTIONS Condition unless otherwise specified, providing the cask is in a specified condition stated in the Applicability of the LCO. Required Actions must be completed prior to the expiration of the specified Completion Time. An ACTIONS Condition remains in effect and the Required Actions apply until the Condition no longer exists or the cask is not within the LCO Applicability. Once a Condition has been entered, subsequent subsystems, components, or variables expressed in the Condition, discovered to be not within limits, will not result in separate entry into the Condition unless specifically stated. The Required Actions of the Condition continue to apply to each additional failure, with Completion Times based on initial entry into the Condition.

1.3 Completion Times

EXAMPLES

The following examples illustrate the use of Completion Times with different types of Conditions and changing Conditions:

EXAMPLE 1.3-1:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2	12 hours 36 hours

Condition B has two Required Actions. Each Required Action has its own separate Completion Time. Each Completion Time is referenced to the time that Condition B is entered.

The Required Actions of Condition B are to complete action B.1 within 12 hours AND to complete action B.2 within 36 hours. A total of 12 hours is allowed for completing action B.1 and a total of 36 hours (not 48 hours) is allowed for completing action B.2 from the time that Condition B was entered. If action B.1 is completed within 6 hours, the time allowed for completing action B.2 is the next 30 hours because the total time allowed for completing action B.2 is 36 hours.

1.3 Completion Times

EXAMPLES (continued)

EXAMPLE 1.3-2:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One system not within limit	A.1 Restore system to within limit.	7 days
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	12 hours 36 hours

When a system is determined to not meet the LCO, Condition A is entered. If the system is not restored within 7 days, Condition B is also entered and the Completion Time clocks for Required Actions B.1 and B.2 start. If the system is restored after Condition B is entered, Condition A and B are exited, and therefore, the Required Actions of Condition B may be terminated.

1.3 Completion Times

EXAMPLES (continued)

EXAMPLE 1.3-3:

ACTIONS

---NOTE---
Separate Condition entry is allowed for each component.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Restore compliance with LCO.	4 hours
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	12 hours 36 hours

The Note above the ACTIONS Table is a method of modifying how the Completion Time is tracked. If this method of modifying how the Completion Time is tracked was applicable only to a specific Condition, the Note would appear in that Condition rather than at the top of the ACTIONS Table.

The Note allows Condition A to be entered separately for each component, and Completion Times tracked on a per component basis. When a component does not meet the LCO, Condition A is entered and its Completion Time starts. If subsequent components are determined Not to meet the LCO, Condition A is entered for each component and separate Completion Times start and are tracked for each component.

IMMEDIATE COMPLETION TIME

When "Immediately" is used as a Completion Time, the Required Action should be pursued without delay and in a controlled manner.

1.0 USE AND APPLICATION

1.4 Frequency

PURPOSE

The purpose of this section is to define the proper use and application of Frequency requirements.

DESCRIPTION

Each Surveillance Requirement (SR) has a specified Frequency in which the Surveillance must be met in order to meet the associated Limiting Condition for Operation (LCO). An understanding of the correct application of the specified Frequency is necessary for compliance with the SR.

The "specified Frequency" is referred to throughout this section and each of the Specifications of Section 3.0, Surveillance Requirement (SR) Applicability. The "specified Frequency" consists of the requirements of the Frequency column of each SR, as well as certain Notes in the Surveillance column that modify performance requirements.

Situations where a Surveillance could be required (i.e., its Frequency could expire), but where it is not possible or not desired that it be performed until sometime after the associated LCO is within its Applicability, represent potential SR 3.0.4 conflicts. To avoid these conflicts, the SR (i.e., the Surveillance or the Frequency) is stated such that it is only "required" when it can be and should be performed. With an SR satisfied, SR 3.0.4 imposes no restriction.

The use of "met" or "performed" in these instances conveys specific meanings. A Surveillance is "met" only when the acceptance criteria are satisfied. Known failure of the requirements of a Surveillance, even without a Surveillance specifically being "performed," constitutes a Surveillance not "met."

1.4 Frequency

EXAMPLES

The following examples illustrate the various ways that Frequencies are specified:

EXAMPLE 1.4-1:

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify Pressure within limit.	12 hours

Example 1.4-1 contains the type of SR most often encountered in the Technical Specifications (TS). The Frequency specifies an interval (12 hours) during which the associated Surveillance must be performed at least one time.. Performance of the Surveillance initiates the subsequent interval. Although the Frequency is stated as 12 hours, an extension of the time interval to 1.25 times the interval specified in the Frequency is allowed by SR 3.0.2 for operational flexibility. The measurement of this interval continues at all times, even when the SR is not required to be met per SR 3.0.1 (such as when the equipment is determined to not meet the LCO, a variable is outside specified limits, or the unit is outside the Applicability of the LCO). If the interval specified by SR 3.0.2 is exceeded while the cask is in a condition specified in the Applicability of the LCO, the LCO is not met in accordance with SR 3.0.1.

If the interval as specified by SR 3.0.2 is exceeded while the unit is not in a condition specified in the Applicability of the LCO for which performance of the SR is required, the Surveillance must be performed within the Frequency requirements of SR 3.0.2 prior to entry into the specified condition. Failure to do so would result in a violation of SR 3.0.4.

1.4 Frequency

EXAMPLES (continued)

EXAMPLE 1.4-2:

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify flow is within limits.	Once within 12 hours prior to starting activity AND 24 hours thereafter

Example 1.4-2 has two Frequencies. The first is a one time performance Frequency, and the second is of the type shown in Example 1.4-1. The logical connector "AND" indicates that both Frequency requirements must be met. Each time the example activity is to be performed, the Surveillance must be performed prior to starting the activity.

The use of "once" indicates a single performance will satisfy the specified Frequency (assuming no other Frequencies are connected by "AND"). This type of Frequency does not qualify for the 25% extension allowed by SR 3.0.2.

"Thereafter" indicates future performances must be established per SR 3.0.2, but only after a specified condition is first met (i.e., the "once" performance in this example). If the specified activity is canceled or not performed, the measurement of both intervals stops. New intervals start upon preparing to restart the specified activity.

2.0 Functional and Operating Limits

2.1 Fuel To Be Stored In The TN-32 Cask

The spent nuclear fuel to be stored in the TN-32 cask shall meet the following requirements:

a. Fuel shall be unconsolidated INTACT FUEL ASSEMBLIES.

b. Fuel shall be limited to fuel with zircaloy cladding.

c. Fuel types shall be limited to the fuel types below with maximum uranium content as follows:

Westinghouse 14x14 Std ZCA and ZCB:	0.4144 MTU/assy.
Westinghouse 15x15:	0.4671 MTU/assy.
Westinghouse 17x17 Std:	0.4671 MTU/assy.
Westinghouse 14x14 OFA:	0.3611 MTU/assy.
Westinghouse 17x17 OFA:	0.4282 MTU/assy.
B&W/FCF 17x17 Mark BW:	0.4632 MTU/assy.

d. Fuel may include burnable poison rod assemblies (BPRA's) having the acceptable combination of burnup and cooling time described by Figure 2.1.1-1.

e. Fuel may include thimble plug assemblies (TPA's) having the acceptable combination of burnup and cooling time described by Figure 2.1.1-2.

f. Fuel assemblies shall have the following bounding characteristics:

i. The maximum initial enrichment shall not exceed 4.05 weight percent. The determination of fuel enrichment shall not be based on average values that include low enrichment axial reflector blankets.

ii. The maximum assembly average burnup shall not exceed 45,000 MWD/MTU

iii. The minimum cooling time prior to loading shall be as specified in Table 2.1.1-1.

iv. The maximum heat load per assembly shall not exceed 1.02 kW with or without BPRA's or TPA's.

v. The fuel assembly weight with hardware shall not exceed 1533 lbs.

2.2 Functional and Operating Limits Violations

If any Functional and Operating Limit of 2.1 is violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be removed from the cask and placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within 30 days, submit a special report which describes the cause of the violation and the actions taken to restore compliance and prevent recurrence.

Table 2.1.1-1
Minimum Acceptable Cooling Time as a Function of Burnup and Initial Enrichment

Min. Init. Enrichment (% wt)(1)	Maximum Burnup (GWd/MTU)(2)																
	15	20	30	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1.2	7	7															
1.3	7	7															
1.4	7	7															
1.5	7	7	7	8	8	8	8	9									
1.6	7	7	7	7	8	8	8	9	9	9	9						
1.7	7	7	7	7	8	8	8	8	9	9	9	10					
1.8	7	7	7	7	7	8	8	8	9	9	9	10					
1.9	7	7	7	7	7	7	8	8	8	9	9	9	10	10			
2.0	7	7	7	7	7	7	8	8	8	8	9	9	9	10	10		
2.1	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10		
2.2	7	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10	
2.3	7	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10	
2.4	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9	10	10
2.5	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9	10
2.6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	10
2.7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9
2.8	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9
2.9	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9
3.0	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	9	9
3.1	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	9	9
3.2	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8
3.3	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8
3.4	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8
3.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.9	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
4.05	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

■ - not evaluated

(1) Round actual value down to next lower tenth.
(2) Round actual value up to next higher GWd/MTU.

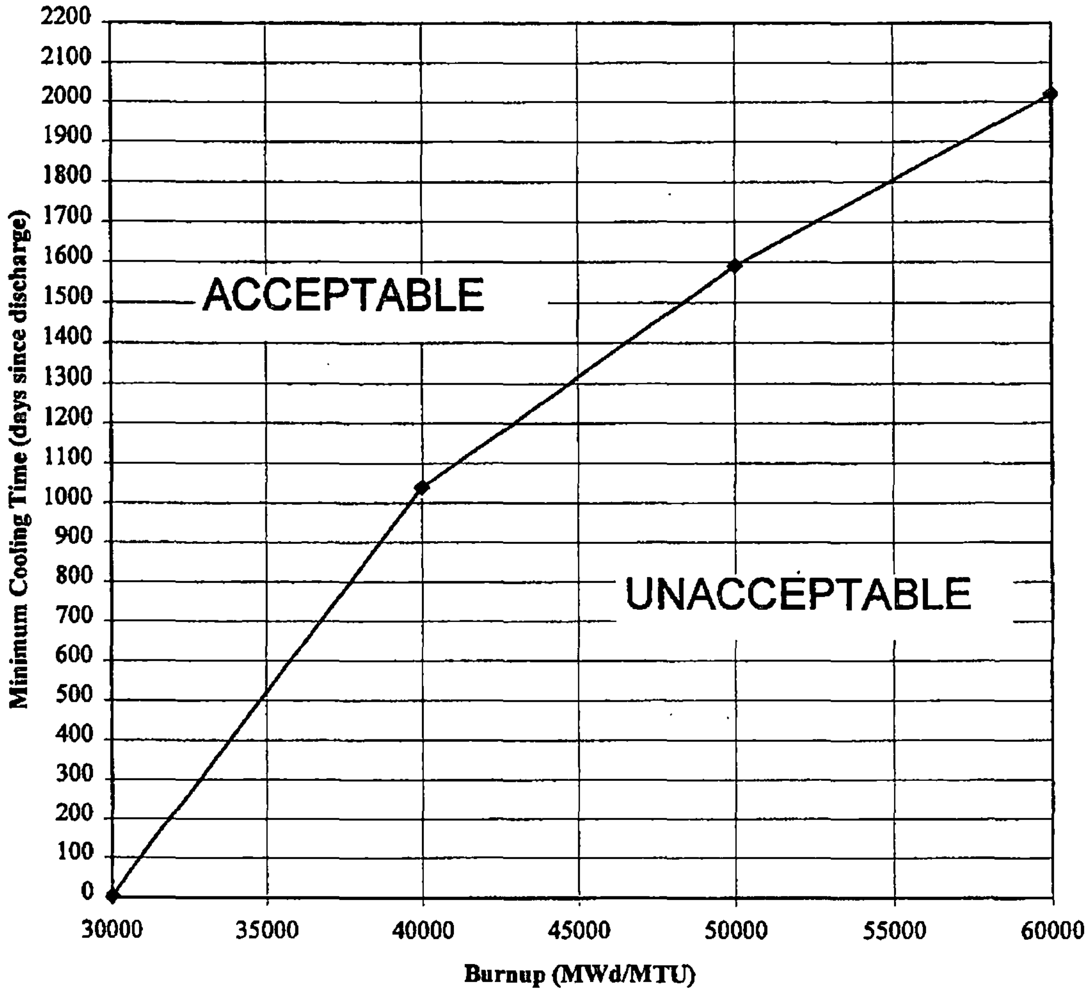


Figure 2.1.1-1
Burnable Poison Rod Assemblies (BPRAs)
Minimum Acceptable Cooling Time as a Function of Burnup

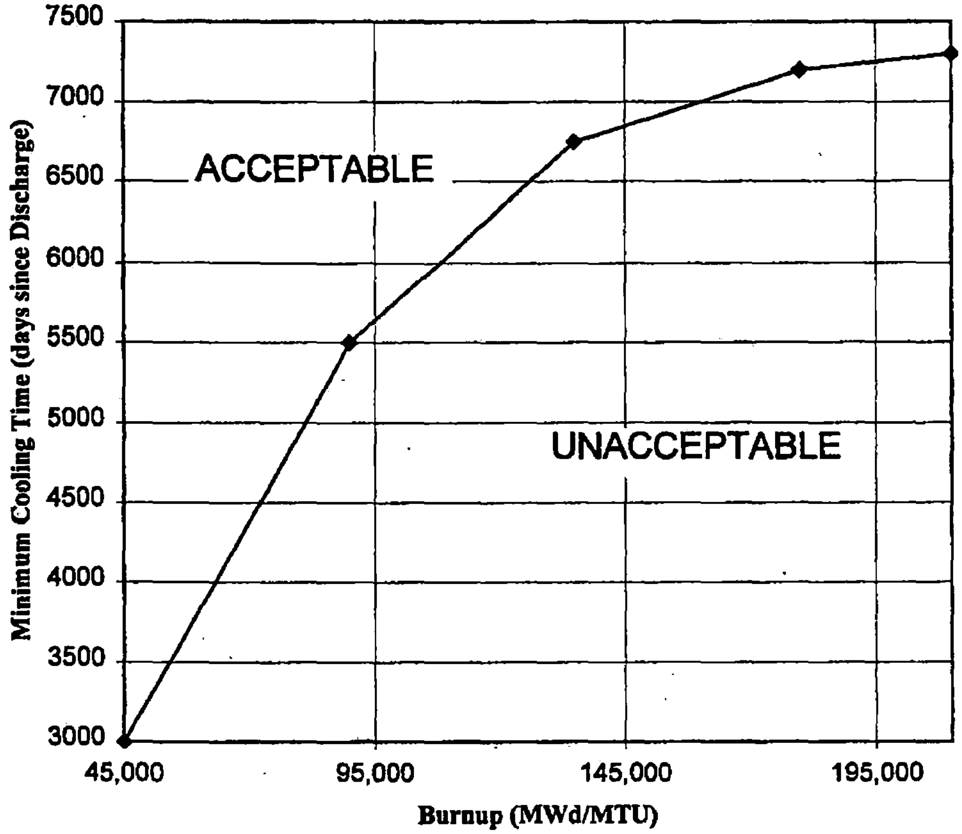


Figure 2.1.1-2
Thimble Plug Assemblies (TPAs)
Minimum Acceptable Cooling Time as a Function of Burnup

3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

LCO 3.0.1	LCOs shall be met during specified conditions in the Applicability, except as provided in LCO 3.0.2.
LCO 3.0.2	Upon discovery of a failure to meet an LCO, the Required Actions of the associated Conditions shall be met, except as provided in LCO 3.0.5. If the LCO is met or is no longer applicable prior to expiration of the specified Completion Time(s), completion of the Required Action(s) is not required, unless otherwise stated.
LCO 3.0.3	Not applicable to a cask.
LCO 3.0.4	When an LCO is not met, entry into a specified condition in the Applicability shall not be made except when the associated ACTIONS to be entered permit continued operation in the specified condition in the Applicability for an unlimited period of time. This Specification shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS, or that are related to the unloading of a cask. Exceptions to this Specification are stated in the individual Specifications. These exceptions allow entry into specified conditions in the Applicability when the associated ACTIONS to be entered allow operation in the specified condition in the Applicability only for a limited period of time.
LCO 3.0.5	Equipment removed from service or not in service in compliance with ACTIONS may be returned to service under administrative control solely to perform testing required to demonstrate it meets the LCO or that other equipment meets the LCO. This is an exception to LCO 3.0.2 for the system returned to service under administrative control to perform the testing required to demonstrate that the LCO is met.
LCO 3.0.6	Not applicable to a cask.
LCO 3.0.7	Not applicable to a cask.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

SR 3.0.1	SRs shall be met during the specified conditions in the Applicability for individual LCOs, unless otherwise stated in the SR. Failure to meet a Surveillance, whether such failure is experienced during the performance of the Surveillance or between performances of the Surveillance, shall be failure to meet the LCO. Failure to perform a Surveillance within the specified Frequency shall be failure to meet the LCO except as provided in SR 3.0.3. Surveillances do not have to be performed on equipment or variables outside specified limits.
SR 3.0.2	The specified Frequency for each SR is met if the Surveillance is performed within 1.25 times the interval specified in the Frequency, as measured from the previous performance or as measured from the time a specified condition of the Frequency is met. For Frequencies specified as "once," the above interval extension does not apply. If a Completion Time requires periodic performance on a "once per . . ." basis, the above Frequency extension applies to each performance after the initial performance. Exceptions to this Specification are stated in the individual Specifications.
SR 3.0.3	If it is discovered that a Surveillance was not performed within its specified Frequency, then compliance with the requirement to declare the LCO not met may be delayed, from the time of discovery, up to 24 hours or up to the limit of the specified Frequency, whichever is less. This delay period is permitted to allow performance of the Surveillance. If the Surveillance is not performed within the delay period, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered. When the Surveillance is performed within the delay period and the Surveillance is not met, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.
SR 3.0.4	Entry into a specified condition in the Applicability of an LCO shall not be made unless the LCO's Surveillances have been met within their specified Frequency. This provision shall not prevent entry into specified conditions in the Applicability that are required to comply with ACTIONS or that are related to the unloading of a cask.

3.1 CASK INTEGRITY

3.1.1 Cask Cavity Vacuum Drying

LCO 3.1.1 The cask cavity vacuum drying pressure shall be sustained at or below 4 mbar absolute for a period of at least 30 minutes after isolation from the pumping system.

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

-- NOTE --

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
-----NOTE----- Not applicable until SR 3.1.1.1 is performed. ----- A. Cask cavity vacuum drying pressure limit not met.	-----NOTE----- Action A.1 applies until helium is removed for subsequent operations. ----- A.1 Achieve or maintain a nominal helium environment in the cask <u>AND</u> A.2 Establish cask cavity drying pressure within limits.	12 hours 96 hours
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the cask.	7 days

C. Required Action A.2 and associated Completion Time not met.	C.1 Remove all fuel assemblies from the cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify that the equilibrium cask cavity vacuum drying pressure is brought to ≤ 4 mbar absolute for at least 30 minutes.	Once, within 24 hours of completion of cask draining.

3.1 CASK INTEGRITY

3.1.2 Cask Helium Backfill Pressure

LCO 3.1.2 The cask cavity shall be filled with helium to a pressure of 2230 mbar absolute (± 100 mbar).

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

------------------------- NOTE -------------------------
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
----------NOTE---------- Not applicable until SR 3.1.2.1 is performed. --------------------- A. Cask initial helium backfill pressure limit not met.	----------NOTE---------- Action A.1 applies until helium is removed for subsequent operations --------------------- A.1 Achieve or maintain a nominal helium environment in the cask AND A.2 Establish cask cavity backfill pressure within limits.	 6 hours 48 hours
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the cask.	7 days
C. Required Action A.2 and associated Completion Time not met.	C.1 Remove all fuel assemblies from the cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.2.1 Verify that the cask cavity helium pressure is 2230 mbar absolute (± 100 mbar).	Once, within 30 hours of completion of cask draining.

3.1 CASK INTEGRITY

3.1.3 Cask Helium Leak Rate

LCO 3.1.3 The combined helium leak rate for all closure seals shall not exceed 1.0 E-5 std cc/sec.

APPLICABILITY: During LOADING OPERATIONS.
ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
-----NOTE----- Not applicable until SR 3.1.3.1 is performed. A. Cask helium leak rate not met.	A.1 Establish cask helium leak rate within limit.	48 hours
B. Required Action A.1 and associated Completion Time are not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.3.1 Verify the cask helium leak rate is within the limit.	Once, prior to TRANSPORT OPERATIONS.

3.1 CASK INTEGRITY

3.1.4 Combined Helium Leak Rate

LCO 3.1.4 The combined helium leak rate for all closure seals and the overpressure system shall not exceed 1.0 E-5 std cc/sec.

APPLICABILITY: During STORAGE.

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
-----NOTE----- Not applicable until SR 3.1.4.1 is performed. A. Combined helium leak rate not met.	A.1 Establish combined helium leak rate within limit.	48 hours
B. Required Action A.1 and associated Completion Time are not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
-----NOTE----- This surveillance may be combined with SR 3.1.3.1. SR 3.1.4.1 Verify the combined helium leak rate is within the limit.	Once prior to TRANSPORT OPERATIONS OR Once within 48 hours of commencing STORAGE OPERATIONS.

3.1 CASK INTEGRITY

3.1.5 Cask Interseal Pressure

LCO 3.1.5 Cask interseal pressure shall be maintained at a pressure of at least 3.2 atm abs

APPLICABILITY: During STORAGE OPERATIONS.

ACTIONS

------------------------------NOTE------------------------------
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Cask interseal pressure below limit.	A.1 Reestablish cask interseal pressure above limit.	7 days
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.5.1	Verify cask interseal helium pressure above limit.	7 days
SR 3.1.5.2	Perform a CHANNEL OPERATIONAL TEST (COT) to verify proper functioning of pressure switch / transducer on cask overpressure system.	Once, within 7 days of commencing STORAGE OPERATIONS and every 36 months thereafter

3.1 CASK INTEGRITY

3.1.6 Cask Minimum Lifting Temperature

LCO 3.1.6 The loaded cask shall not be lifted if the outer surface of the cask is below -20°F.

APPLICABILITY: During TRANSPORT OPERATIONS

ACTIONS

------------------------- NOTE -------------------------
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Cask surface temperature below limit.	A.1 Lower cask to safe position	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.6.1 Verify outer surface temperature is above limit.	Once, immediately prior to lifting cask and prior to cask transfer to or from ISFSI.

3.2 CASK RADIATION PROTECTION

3.2.1 Cask Surface Contamination

LCO 3.2.1 Removable contamination on the cask exterior surfaces shall not exceed:

a. 1000 dpm / 100 cm^2 (0.2 Bq / cm^2) from beta and gamma sources, and
b. 20 dpm / 100 cm^2 (0.003 Bq / cm^2) from alpha sources.

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Removable contamination on the cask exterior surface exceeds either limit.	A.1 Decontaminate cask surfaces to below required levels.	Prior to TRANSPORT OPERATIONS

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.2.1.1 Verify that the removable contamination on the exterior surface of the cask does not exceed the specified limits.	Once, prior to TRANSPORT OPERATIONS.

3.3 CASK CRITICALITY CONTROL

3.3.1 Dissolved Boron Concentration

LCO 3.3.1 The dissolved boron concentration of the water in the spent fuel pool and the water added to the cavity of a loaded cask shall be at least 2300 ppm.

APPLICABILITY: During LOADING and UNLOADING OPERATIONS

ACTIONS

------------------------------ NOTE ------------------------------

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Dissolved boron concentration limit not met.	A.1 Suspend loading of fuel assemblies into cask.	Immediately
	AND	
	A.2 Remove all fuel assemblies from cask.	24 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.3.1.1	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the cask cavity is met using two independent measurements.	Within 4 hours prior to commencing LOADING OPERATIONS <u>AND</u> 48 hours thereafter while the cask is in the spent fuel pool or while water is in cask.
SR 3.3.1.2	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the cask cavity is met using two independent measurements.	Once, within 4 hours prior to flooding cask during UNLOADING OPERATIONS <u>AND</u> 48 hours thereafter while the cask is in the spent fuel pool or while water is in cask.

4.0 DESIGN FEATURES

The specifications in this section include the design characteristics of special importance to each of the physical barriers and to maintenance of safety margins in the cask design. The principal objective of this category is to describe the design envelope which might constrain any physical changes to essential equipment. Included in this category are the site environmental parameters which provide the bases for design, but are not inherently suited for description as LCOs.

4.1 Storage Cask

4.1.1 Criticality

The design of the storage cask, including spatial constraints on adjacent assemblies (minimum basket cell opening of 8.64 in. sq.) and the boron content of the basket material (minimum areal density equal to 10 mg B^{10}/cm^2) shall ensure that fuel assemblies are maintained in a subcritical condition with a k_{eff} of less than 0.95 under all conditions of operation.

4.1.2 Structural Performance

The cask has been evaluated for a cask tipover (equivalent to a side drop of 67 g's) and a bottom end drop resulting in an axial gravitational (g) loading of 50 g's.

4.1.3 Codes and Standards

The TN-32 cask confinement boundary is designed and fabricated in accordance with Subsection NB of the ASME Code. Exceptions to the code are listed in Table 4.1-1. The cask gamma shielding has been evaluated in accordance with Subsection NB of the ASME code with the exceptions listed in Table 4.1-1. The basket is designed in accordance with Subsection NF of the ASME Code. The basket is inspected as shown in Table 4.1-1.

Proposed alternatives to ASME Code Section III, 1992 Edition including exceptions allowed by Table 4.1-1 may be used when authorized by the Director of the Office of Nuclear Material Safety and Safeguards or Designee. The applicant should demonstrate that:

1. The Proposed alternatives would provide an acceptable level of quality and safety, or

2. Compliance with the specified requirements of ASME Code, Section III, 1992 Edition would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for exceptions in accordance with this section should be submitted in accordance with 10 CFR 72.4.

4.1.4 Helium Purity

The cask shall be filled with helium with a purity of at least 99.99%. This level of purity will ensure that the residual impurities in the cask cavity will be less than 1 mole.

4.2 Storage Pad

4.2.1 Storage Locations for Casks

Casks shall be spaced a minimum of 16 feet apart, center-to-center. This minimum spacing will ensure the proper dissipation of radiant heat energy from an array of casks as assumed in the TN-32 Safety Analysis Report.

4.2.2 Pad Properties to Limit Cask Gravitational Loadings Due to Postulated Drops

The TN-32 cask has been evaluated for cask drops onto a reinforced concrete pad. The evaluations are based on the following parameters:

Concrete thickness	36 inches (max)
Nominal concrete compressive strength	6000 psi (max)
Reinforcement Yield Strength	60,000 psi (min)
Soil Effective Modulus of Elasticity	32,600 psi (max)
Maximum drop height	18 inches

This set of limits will ensure that the g loading imposed on the cask is no more than 50 g's (cask bottom end drop).

4.3 Site Specific Parameters and Analyses

Site specific parameters and analyses that shall need verification by the system user are, as a minimum, as follows:

1. Tornado maximum wind speeds: 290 mph rotational
   70 mph translational

2. Flood levels up to 57 ft. and drag forces up to 57,160 lbs.

3. Seismic loads of up to 0.26g horizontal and 0.17g vertical , or

   Analyses to provide verification that loads associated with a design basis seismic event do not cause the cask to slide or to tip over, as follows.

   (a) For sliding analysis, a coefficient-of-friction of 0.35 is assumed and a factor-of-safety of 1.1 is used (as recommended by ANSI / ANS-57.9, Section 6.17.4.1). The following relationship of horizontal seismic acceleration to corresponding vertical seismic acceleration shall be met at any time:

$$\frac{0.35(1-g_v)}{g_h} \geq 1.1$$

   Where:

   g_h = Horizontal seismic acceleration.

   g_v = Corresponding vertical seismic acceleration.

   (b) For tipover analysis, a factor-of-safety of 1.1 is used (as recommended by ANSI / ANS-57.9, Section 6.17.4.1). The following relationship of horizontal seismic acceleration to corresponding vertical seismic acceleration shall be met at any time:

$$\frac{g_h L_v + g_v L_r}{L_r} \leq \frac{1}{1.1}$$

Where:

g_h = Horizontal seismic acceleration.

g_v = Corresponding vertical seismic acceleration.

L_v = Vertical distance from cask base to cask C. G.

L_r = Radial distance from cask base perimeter to cask C. G.

4. Average daily ambient temperatures: ≥ -20°F minimum
≤ 100°F maximum

5. The potential for fires and explosions shall be addressed, based on site-specific considerations. Fires and explosions should be bounded by the cask design bases parameters of 200 gallons of fuel (in the tank of the transporter vehicle) and an external pressure of 25 psig.

6. Supplemental Shielding: In cases where engineered features (i.e. berms, shield walls) are used to ensure that the requirements of 10 CFR 72.104(a) are met, such features are to be considered important to safety and must be evaluated to determine the applicable Quality Assurance Category.

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Table 4.1-1
TN-32 ASME Code Exceptions

<u>List of ASME Code Exceptions for TN-32 Dry Storage Cask Confinement Boundary/Gamma Shielding/Basket</u>

The cask confinement boundary is designed in accordance with the ASME Code Subsection NB. The basket was also designed in accordance with ASME Code Subsection NF. The Gamma shielding, which is primarily for shielding, but also provides structural support to the confinement boundary during drop accidents, was not designed in accordance with the code. The analysis of the gamma shielding is in accordance with Subsection NB. Inspections of the gamma shielding are performed in accordance with the ASME Code as detailed in the SAR.

Component	**Reference ASME Code/Section**	**Code Requirement**	**Exception, Justification & Compensatory Measures**
TN-32 Cask	NB-1100	Stamping and preparation of reports by the Certificate Holder	The TN-32 cask is not N stamped, nor is there a code design specification generated. A design criteria document was generated in accordance with TN's QA Program, and the design and analysis is provided in the SAR.
TN-32 Cask	NCA-3800	Quality Assurance Requirements	The Quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are imposed in lieu of NCA-3800 requirements.
Lid Bolts	NB-3232.3	Fatigue analysis of bolts	A fatigue analysis of the bolts is not performed for storage, since the bolts are not subject to significant cyclical loads.
Gamma Shielding	NB-1132.2	Non-pressure retaining structural attachments shall conform to Subsection NF	The primary function of the gamma shield is shielding, although credit is taken for the gamma shielding in the structural analysis. The welds are examined in accordance with NF acceptance criteria. A fracture toughness evaluation is presented in Appendix 3E of the SAR.
Pressure test of the confinement boundary	NB-6110	All pressure retaining components shall be pressure tested.	The TN-32 cask is not pressure limited. All confinement welds are fully radiographed. In addition, the gamma shielding supports the confinement boundary under all conditions, so a pressure test of the confinement vessel separately will not simulate actual loading conditions. If the pressure test is performed with the confinement vessel inside the gamma shield, the confinement boundary welds cannot be examined.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Confinement Vessel Material	NB-2120	Requirement materials to be ASME Class 1 material	Standard Review Plan, NUREG-1536 has accepted the use of either Subsection NB (Class 1) or NC (Class 2 or 3) of the Code for the confinement. SA-203 Gr. D is similar to SA-203 Gr. E which is a Class 1 material. The chemical content of the two grades are identical, except that Gr. E restricts the carbon to 0.20 max., while Gr. D further restricts the carbon content to 0.17 max. Gr. D is acceptable as a Class 2 material up to 500° F. Gr. D was selected because of its ductility, since the higher strength is not required. SA-203 Gr. D has better elongation than Grade E and due to its lower strength is more likely to have the good fracture toughness at low temperatures. In selecting materials for storage and transport casks, one of the major selection criteria is fracture toughness at low temperatures. Grade D was selected on this basis. There is no similar requirement for pressure vessels, as they are used at much higher temperatures. For the SA-203 Grade D material, the allowable stress was based on S, the allowable stress for Class 2 components. This is conservative, since NB is based on S_m, which is 1/3 the tensile strength, while S is 1/4 the tensile strength. Thus there is additional margin over and above the margin required by the code for Class I materials.
Weld of Lid Shield Plate to Lid	NB-4335	Impact testing of weld and heat affected zone of lid to shield plate	If two different materials are joined, the fracture toughness requirements of either may be used for the weld metal. There are no fracture toughness requirements on the shield plate, and therefore none are performed on the base metal or the heat affected zones. This weld is not subject to low temperatures, as it is inside the cask cavity. An evaluation of this weld at low temperatures is presented in Appendix 3E of the SAR.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Gamma Shielding	NB-2190	Material in the component support load path and not performing a pressure retaining function welded to pressure retaining material shall meet the requirements of NF-2000	The gamma shielding materials were procured to ASTM or ASME material specifications. Materials testing is performed in accordance with the applicable specification. Impact testing is not performed on the gamma shielding materials (including welding materials). An evaluation of the gamma shielding due to impact at low temperatures is provided in Appendix 3E of the SAR.
Confinement Vessel	NB-7000	Vessels are required to have overpressure protection	No overpressure protection is provided. Function of confinement vessel is to contain radioactive contents under normal, off normal, and accident conditions of storage. Confinement vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
Confinement Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000	TN-32 cask to be marked and identified in accordance with 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Transnuclear approved QA program.
Confinement Vessel material	NB-2000	Requires materials to be supplied by ASME approved material supplier; Quality assurance to meet NCA requirements	Material will be supplied by Transnuclear approved suppliers with Certified Material Test reports (CMTR) in accordance with NB-2000 requirements. The cask is not code stamped. The quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are imposed in lieu of the requirements of NCA-3800.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Corner weld between bottom inner plate to inner shell	NB-5231	Full penetration corner welded joints require the fusion zone and the parent metal beneath the attachment surface to be UT after welding	In lieu of the UT inspection, the joint will be examined by RT and either PT or MT methods in accordance with ASME Subsection NB requirements.
Boundary of Jurisdiction	NB-1131	The design specification shall define the boundary of a component to which another component is attached.	A code design specification was not prepared for the TN-32 cask. A TN design criteria was prepared in accordance with TN's QA program. The containment boundary is specified in Chapter 1 of the SAR.
Aluminum basket plate and rail, neutron absorber plates	NF-2120	Materials to be ASME Class 1 material	The aluminum plate strength is not used for structural analysis under normal operating loads nor the 50g accident end drop load. The aluminum plate strength is only assumed to be effective for the short duration dynamic loading from a tipover accident and for secondary thermal stress calculations. 6061-T6 is ASME code material (Class 2 or 3). The strength of the neutron absorber plates are not considered in any analysis.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Basket	NF-4000/NF-5000	Welding/NDE inspections	Basket welding procedures are qualified in accordance with ASME Section IX. Due to the unique nature of these welds, special inspections and tests were developed for these welds. These are described in Section 9.1.2 of the SAR.
Components other than the containment boundary and basket	Subsection NB		The code does not apply to components other than the containment boundary and basket. The gamma shielding has been analyzed and inspected in accordance with Subsection NB as defined at the beginning of this table.
Basket	NF-3000	Allowable Stresses	The ASME Code gives stress values up to 400°F. Stress values above 400°F are taken from "Aluminum Standards and Data", 1990. The allowable stresses used for the aluminum basket plate and rail are based on S, the allowable stress for a Class 2 or 3 component. This is conservative, since the analyses of the basket and rail are performed in accordance with the rules of Subsection NF. Subsection NF allowables are based on S_m which is 1/3 the ultimate strength, while S is ¼ the ultimate strength. Thus there is additional margin built into the analysis of the basket and rail over and above the margin required by Subsection NF for class 1 materials.

5.0 ADMINISTRATIVE CONTROLS

5.1 Training Module

Training modules shall be developed under the general licensee's training program as required by 10 CFR 72.212(b)(6). Training modules shall require a comprehensive program for the operation and maintenance of the TN-32 spent fuel storage cask and the independent spent fuel storage installation (ISFSI). The training modules shall include the following elements, at a minimum:

- TN-32 cask design (overview)
- ISFSI Facility design (overview)
- Systems, Structures, and Components Important to Safety (overview)
- TN-32 Dry Storage Cask Safety Analysis Report (overview)
- NRC Safety Evaluation Report (overview)
- Certificate of Compliance conditions
- TN-32 Technical Specifications
- Applicable Regulatory Requirements (e.g.,10 CFR72, Subpart K, 10 CFR 20, 10 CFR Part 73)
- Required Instrumentation and Use
- Operating Experience Reviews
- TN-32 Cask Operating and Maintenance procedures, including:

  Fuel qualification and loading
  Rigging and handling
  Loading Operations as described in Chapter 8 of the SAR
  Unloading Operations including reflooding as described in Chapter 8 of the SAR
  Auxiliary equipment operations and maintenance (i.e. vacuum drying, helium backfilling and leak testing, reflooding)
  Transfer operations including loading and unloading of the Transport Vehicle
  ISFSI Surveillance operations
  Radiation Protection
  Maintenance
  Security
  Off-normal and accident conditions, responses and corrective actions.

5.2 Programs

The following programs shall be established, implemented, and maintained:

5.2.1 Cask Sliding Evaluation

The TN-32 cask has been evaluated for sliding in the unlikely events of a seismic event. A static coefficient of friction of 0.35 is used in these analyses. This program provides a means for evaluating the coefficient of friction to ensure that the cask will not slide during the seismic event.

a. Pursuant to 10 CFR 72.212, this program shall evaluate the site-specific ISFSI pad configurations/conditions to ensure that the cask would not slide during the postulated design basis earthquake. The program shall conclude that the surface static friction coefficient of friction is greater than or equal to 0.35.

b. Alternatively, for site-specific ISFSI pad configurations/conditions with a lower coefficient of friction than 0.35, the program shall evaluate the site specific conditions to ensure that the TN-32 cask will not slide during the postulated design basis earthquake. The program shall also evaluate storm winds, missile impacts and flood forces to ensure that the cask will not slide such that it could result in impact with other casks or structures at the ISFSI. The program shall ensure that these alternative analyses are documented and controlled.

5.2.2 Cask Transport Evaluation Program

This program provides a means for evaluating various transport configurations and transport route conditions to ensure that the design basis drop limits are met.

a. Pursuant to 10 CFR 72.212, this program shall evaluate the site-specific transport conditions. To demonstrate compliance with Technical Specification 4.2.2, the program shall conclude that the expected lift height above the transport surface shall be less than or equal to that described by Technical Specification 4.2.2. Also, the program shall conclude that the transport route conditions (e.g., surface hardness and pad thickness) are equivalent to or less limiting than those prescribed for the typical pad surface which forms the basis for Technical Specification 4.2.2.

b. Alternatively, for site-specific transport conditions which are not encompassed by those of Technical Specification 4.2.2, the program shall evaluate the site-specific conditions to ensure that the end-drop loading does not exceed 50 g. This alternative analysis shall be commensurate with the analysis which forms the basis of Technical Specification 4.2.2 (Reference TN-32 SAR Appendix 3A). The program shall ensure that these alternative analyses are documented and controlled.

c. This program shall establish administrative controls and procedures to ensure that cask TRANSPORT OPERATIONS are conducted within the limits imposed by the Technical Specifications or the alternative analysis described above.

5.2.3 Cask Surface Dose Rate Evaluation Program

This program provides a means for ensuring that ISFSI's using TN-32 casks do not violate the requirements of 10 CFR 72 and Part 20 regarding radiation doses and dose rates.

1. As part of its evaluation pursuant to 10 CFR 72.212, the licensee shall perform an analysis to confirm that the limits of 10 CFR Part 20 and 10 CFR Part 72.104 will be satisfied under the actual site conditions and configurations considering the planned number of casks to be used and the planned fuel loading conditions.

5.2.3 Continued

2. On the basis of the analysis in TS 5.2.3.1, the licensee shall establish a set of cask surface dose rate limits which are to be applied to TN-32 casks used at the site. Limits shall establish average gamma-ray and neutron dose rates for:

   A. The top of the TN-32 cask (protective cover)
   B. The sides of the radial neutron shield,
   C. The side of the cask above the radial neutron shield, and
   D. The side of the cask below the radial neutron shield.

3. Not withstanding the limits established in TS 5.2.3.2, the dose rate limits may not exceed the values calculated in the SAR for a content of design basis fuel as follows:

   A. 60 mr/hr gamma and 10 mr/hr neutron on the top (protective cover)
   B. 170 mr/hr gamma and 20 mr/hr neutron on the sides of the radial neutron shield
   C. 280 mr/hr gamma and 140 mr/hr neutron on the side surfaces of the cask above the radial neutron shield region.
   D. 110 mr/hr gamma and 200 mr/hr neutron on the side surfaces of the cask below the radial neutron shield region.

4. Prior to transport of a TN-32 containing spent fuel to the ISFSI, the licensee shall measure the cask surface dose rates and calculate average values as described in 5.2.3.7 and 5.2.3.8.

   The measured average dose rates shall be compared to the limits established in TS 5.2.3.2 or the limits in TS 5.2.3.3, whichever are lower.

5. If the measured average surface dose rates do not meet the limits of TS 5.2.3.2 or TS 5.2.3.3, whichever are lower, the licensee shall take the following actions:

   A. Notify the U.S. Nuclear Regulatory Commission (Director of the Office of Nuclear Material Safety and Safeguards) within 30 days.
   B. Administratively verify that the correct fuel was loaded, and
   C. Perform an analysis to determine that placement of the as-loaded cask at the ISFSI will not cause the ISFSI to exceed the radiation exposure limits of 10 CFR Parts 20 and 72.

6. If the analysis in 5.2.3.5.C shows that placement of the as-loaded cask at the ISFSI will cause the ISFSI to exceed the radiation exposure limits of 10 CFR Parts 20 and 72, the licensee shall remove all fuel assemblies from the cask within 30 days of the time of cask loading.

7. The surface dose rates shall be measured at approximately the following points (see also Figure 5.2.3-1).

   A. Above the Radial Neutron Shield (A): Midway between the top of the cask body flange and the top of the radial neutron shield. At least six measurements equally spaced circumferentially.

5.2.3 Continued

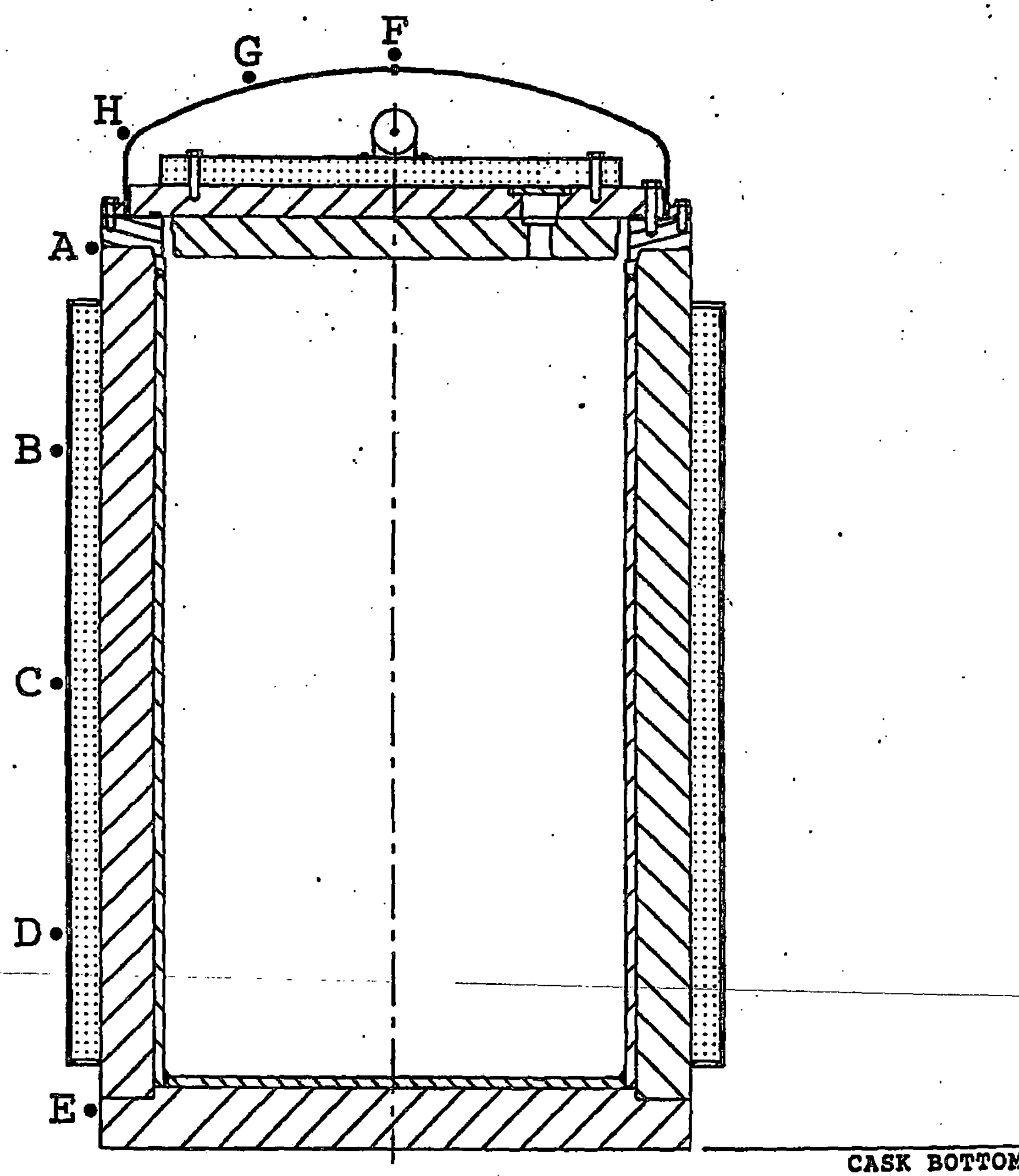
B. Sides of Radial Neutron Shield (B, C and D): one sixth, one half and five sixths of the distance from the top of the radial neutron shield. At least six measurements equally spaced circumferentially at each elevation, two of which shall be at the circumferential location of the cask trunnions. However, no measurement shall be taken directly over the trunnion.

C. Below Radial Neutron Shield (E): Midway between the bottom of the radial neutron shield and the bottom of the cask. At least six measurements equally spaced circumferentially.

D. Top of Cask (F, G and H): At the center of the protective cover, one measurement (F). Half way between the center and the knuckle at least four measurements equally spaced circumferentially (G). At the knuckle at least four measurements equally spaced circumferentially (H).

8. The average dose rates shall be determined as follows.

In each of the four measurement zones in TS 5.2.3.7, the sum of the dose rate measurements is divided by the number of measurements to determine the average for that zone. The neutron and gamma-ray dose rates are averaged separately. Uniformly spaced dose rate measurement locations are chosen such that each point in a given zone represents approximately the same surface area.



* NOTE: DOSE MEASUREMENTS ARE AT CONTACT.

FIGURE 5.2.3-1
CONTACT DOSE RATE MEASUREMENTS LOCATIONS

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TN-32 TECHNICAL SPECIFICATION BASES

TABLE OF CONTENTS

B 2.0 FUNCTIONAL AND OPERATING LIMITS

B 2.1 / B 2.2 Fuel To Be Stored In The TN-32 Cask

BASES

BACKGROUND

The cask design requires certain limits on spent fuel parameters, including fuel type, maximum allowable enrichment prior to irradiation, maximum burnup, minimum acceptable cooling time prior to storage in the cask, and physical condition of the spent fuel (i.e., intact fuel assemblies). Other important limitations are the radiological source terms from the Burnable Poison Rod Assemblies (BPRAs) and Thimble Plug Assemblies (TPAs). These limitations are included in the thermal, structural, radiological, and criticality evaluations performed for the cask.

APPLICABLE SAFETY ANALYSIS

Various analyses have been performed that use these fuel parameters as assumptions. These assumptions are included in the thermal, criticality, structural, shielding and confinement analyses. The fuel geometry is determined by the fuel type designation (i.e. 14x14 std, 14x14OFA, etc). The maximum uranium content is not generally specified for each fuel type. However, the fuel manufacturer is required to provide the uranium content for each assembly. The maximum uranium content per assembly is taken from the criticality calculations presented in Chapter 6 of the SAR. The shielding analysis is based on nominal uranium content, which is slightly less than the values specified. However, minor variations in the uranium content will have an insignificant effect on the shielding results.

Technical Specification Table 2.1.1-1 provides the minimum cooling times based on a fuel minimum initial enrichment and maximum burnup. To use the table, the minimum enrichments are rounded down and burnups are rounded up. For example, fuel with a 2.68% enrichment and a burnup of 34.2 GWd/MTU would use the 2.6% enrichment row and the 35 GWd/MTU column.

FUNCTIONAL AND OPERATING LIMITS VIOLATIONS

2.2.1 If Functional and Operating Limit 2.1 is violated, the limitations on the fuel assemblies in the cask have not been met. Actions must be taken to place the affected fuel assemblies in a safe condition. This safe condition may be established by returning the affected fuel assemblies to the spent fuel pool. However, it is acceptable for the affected fuel assemblies to remain in the cask if that is determined to be a safe condition.

2.2.2 and 2.2.3 Notification of the violation of a Functional and Operating Limit to the NRC is required within 24 hours. Written reporting of the violation must be accomplished within 30 days. This notification and written report are independent of any reports and notification that may be required by 10 CFR 72.75.

B 3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

BASES

LCOs

LCO 3.0.1, 3.0.2, 3.0.4, and 3.0.5 establish the general requirements applicable to all Specifications and apply at all times, unless otherwise stated.

LCO 3.0.1

LCO 3.0.1 establishes the Applicability statement within each individual Specification as the requirement for when the LCO is required to be met (i.e., when the cask is in the specified conditions of the Applicability statement of each Specification).

LCO 3.0.2

LCO 3.0.2 establishes that upon discovery of a failure to meet an LCO, the associated ACTIONS shall be met. The Completion Time of each Required Action for an ACTIONS Condition is applicable from the point in time that an ACTIONS Condition is entered. The Required Actions establish those remedial measures that must be taken within specified Completion Times when the requirements of an LCO are not met. This Specification establishes that:

a. Completion of the Required Actions within the specified Completion Times constitutes compliance with a Specification; and

b. Completion of the Required Actions is not required when an LCO is met within the specified Completion Time, unless otherwise specified.

There are two basic types of Required Actions. The first type of Required Action specifies a time limit in which the LCO must be met. This time limit is the Completion Time to restore a system or component or to restore variables to within specified limits. If this type of Required Action is not completed within the specified Completion Time, the cask may have to be placed in the spent fuel pool and unloaded. (Whether stated as a Required Action or not, correction of the entered Condition is an action that may always be considered upon entering ACTIONS.) The second type of Required Action specifies the remedial measures that permit continued operation of the unit that is not further restricted by the Completion Time. In this case, compliance with the Required Actions provides an acceptable level of safety for continued operation.

Completing the Required Actions is not required when an LCO is met or is no longer applicable, unless otherwise stated in the individual Specifications.

The Completion Times of the Required Actions are also applicable when a system or component is removed from service intentionally. The reasons for intentionally relying on the ACTIONS include, but are not limited to, performance of Surveillances, preventive maintenance, corrective maintenance, or investigation of operational problems. Entering ACTIONS for these reasons must be done in a manner that does not compromise safety. Intentional entry into ACTIONS should not be made for operational convenience.

BASES

LCO 3.0.2 (continued)

Individual Specifications may specify a time limit for performing an SR when equipment is removed from service or bypassed for testing. In this case, the Completion Times of the Required Actions are applicable when this time limit expires, if the equipment remains removed from service or bypassed.

When a change in specified condition is required to comply with Required Actions, the cask may enter a specified condition in which another Specification becomes applicable. In this case, the Completion Times of the associated Required Actions would apply from the point in time that the new Specification becomes applicable and the ACTIONS Condition(s) are entered.

LCO 3.0.3

This specification is not applicable to a cask. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.4

LCO 3.0.4 establishes limitations on changes in specified conditions in the Applicability when an LCO is not met. It precludes placing the cask in a specified condition stated in that Applicability (e.g., Applicability desired to be entered) when the following exist:

a. Conditions are such that the requirements of the LCO would not be met in the Applicability desired to be entered; and

b. Continued noncompliance with the LCO requirements, if the Applicability were entered, would result in the cask being required to exit the Applicability desired to be entered to comply with the Required Actions.

Compliance with Required Actions that permit continued operation of the cask for an unlimited period of time in specified condition provides an acceptable level of safety for continued operation. Therefore, in such cases, entry into a specified condition in the Applicability may be made in accordance with the provisions of the Required Actions. The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components before entering an associated specified condition in the Applicability.

The provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of LCO 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of a cask.

Exceptions to LCO 3.0.4 are stated in the individual Specifications.

Exceptions may apply to all the ACTIONS or to a specific Required Action of a Specification.

BASES

LCO 3.0.4 (continued)

Surveillances do not have to be performed on the associated equipment out of service (or on variables outside the specified limits), as permitted by SR 3.0.1. Therefore, changing specified conditions while in an ACTIONS Condition, either in compliance with LCO 3.0.4 or where an exception to LCO 3.0.4 is stated, is not a violation of SR 3.0.1 or SR 3.0.4 for those Surveillances that do not have to be performed due to the associated out of service equipment.

LCO 3.0.5

LCO 3.0.5 establishes the allowance for restoring equipment to service under administrative controls when it has been removed from service or not in service in compliance with ACTIONS. The sole purpose of this Specification is to provide an exception to LCO 3.0.2 (e.g., to not comply with the applicable Required Action(s)) to allow the performance of required testing to demonstrate:

a. The equipment being returned to service meets the LCO; or

b. Other equipment meets the applicable LCOs.

The administrative controls ensure the time the equipment is returned to service in conflict with the requirements of the ACTIONS is limited to the time absolutely necessary to perform the allowed required testing. This Specification does not provide time to perform any other preventive or corrective maintenance.

LCO 3.0.6

This specification is not applicable to a cask. The placeholder is retained for consistency with the power reactor technical specifications.

LCO 3.0.7

This specification is not applicable to a cask. The placeholder is retained for consistency with the power reactor technical specifications.

B 3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

BASES

SRs

SR 3.0.1 through SR 3.0.4 establish the general requirements applicable to all Specifications in Sections 3.1 and 3.2 and apply at all times, unless otherwise stated.

SR 3.0.1

SR 3.0.1 establishes the requirement that SRs must be met during the specified conditions in the Applicability for which the requirements of the LCO apply, unless otherwise specified in the individual SRs. This Specification is to ensure that Surveillances are performed to verify systems and components, and that variables are within specified limits. Failure to meet a Surveillance within the specified Frequency, in accordance with SR 3.0.2, constitutes a failure to meet an LCO.

Systems and components are assumed to meet the LCO when the associated SRs have been met. Nothing in this Specification, however, is to be construed as implying that systems or components meet the associated LCO when:

a. The systems or components are known to not meet the LCO, although still meeting the SRs; or

b. The requirements of the Surveillance(s) are known to be not met between required Surveillance performances.

Surveillances do not have to be performed when the cask is in a specified condition for which the requirements of the associated LCO are not applicable, unless otherwise specified.

Surveillances, including Surveillances invoked by Required Actions, do not have to be performed on equipment that has been determined to not meet the LCO because the ACTIONS define the remedial measures that apply. Surveillances have to be met and performed in accordance with SR 3.0.2, prior to returning equipment to service.

Upon completion of maintenance, appropriate post maintenance testing is required to declare equipment within its LCO. This includes ensuring applicable Surveillances are not failed and their most recent performance is in accordance with SR 3.0.2. Post maintenance testing may not be possible in the current specified conditions in the Applicability due to the necessary cask parameters not having been established. In these situations, the equipment may be considered to meet the LCO provided testing has been satisfactorily completed to the extent possible and the equipment is not otherwise believed to be incapable of performing its function. This will allow operation to proceed to a specified condition where other necessary post maintenance tests can be completed.

BASES

SR 3.0.2

SR 3.0.2 establishes the requirements for meeting the specified Frequency for Surveillances and any Required Action with a Completion Time that requires the periodic performance of the Required Action on a "once per..." interval.

SR 3.0.2 permits a 25% extension of the interval specified in the Frequency. This extension facilitates Surveillance scheduling and considers plant operating conditions that may not be suitable for conducting the Surveillance (e.g., transient conditions or other ongoing Surveillance or maintenance activities).

The 25% extension does not significantly degrade the reliability that results from performing the Surveillance at its specified Frequency. This is based on the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the SRs. The exceptions to SR 3.0.2 are those Surveillances for which the 25% extension of the interval specified in the Frequency does not apply. These exceptions are stated in the individual Specifications. The requirements of regulations take precedence over the TS. Therefore, when a test interval is specified in the regulations, the test interval cannot be extended by the TS, and the SR includes a Note in the Frequency stating, "SR 3.0.2 is not applicable".

As stated in SR 3.0.2, the 25% extension also does not apply to the initial portion of a periodic Completion Time that requires performance on a "once per..." basis. The 25% extension applies to each performance after the initial performance. The initial performance of the Required Action, whether it is a particular Surveillance or some other remedial action, is considered a single action with a single Completion Time. One reason for not allowing the 25% extension to this Completion Time is that such an action usually verifies that no loss of function has occurred by checking the status of redundant or diverse components or accomplishes the function of the equipment in an alternative manner.

The provisions of SR 3.0.2 are not intended to be used repeatedly merely as an operational convenience to extend Surveillance intervals (other than those consistent with refueling intervals) or periodic Completion Time intervals beyond those specified.

SR 3.0.3

SR 3.0.3 establishes the flexibility to defer declaring affected equipment as not meeting the LCO or an affected variable outside the specified limits when a Surveillance has not been completed within the specified Frequency. A delay period of up to 24 hours or up to the limit of the specified Frequency, whichever is less, applies from the point in time that it is discovered that the Surveillance has not been performed in accordance with SR 3.0.2, and not at the time that the specified Frequency was not met.

BASES

SR 3.0.3 (continued)

This delay period provides adequate time to complete Surveillances that have been missed. This delay period permits the completion of a surveillance before complying with Required Actions or other remedial measures that might preclude completion of the Surveillance. The basis for this delay period includes consideration of unit conditions, adequate planning, availability of personnel, the time required to perform the Surveillance, the safety significance of the delay in completing the required Surveillance, and the recognition that the most probable result of any particular Surveillance being performed is the verification of conformance with the requirements.

When a Surveillance with a Frequency based not on time intervals, but upon specified unit conditions or operational situations, is discovered not to have been performed when specified, SR 3.0.3 allows the full delay period of 24 hours to perform the Surveillance.

SR 3.0.3 also provides a time limit for completion of Surveillances that become applicable as a consequence of changes in the specified conditions in the Applicability imposed by Required Actions.

Failure to comply with specified Frequencies for SRs is expected to be an infrequent occurrence. Use of the delay period established by SR 3.0.3 is a flexibility which is not intended to be used as an operational convenience to extend Surveillance intervals.

If a Surveillance is not completed within the allowed delay period, then the equipment is considered not in service or the variable is considered outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon expiration of the delay period. If a Surveillance is failed within the delay period, then the equipment is not in service, or the variable is outside the specified limits and the Completion Times of the Required Actions for the applicable LCO Conditions begin immediately upon the failure of the Surveillance. Completion of the Surveillance within the delay period allowed by this Specification, or within the Completion Time of the ACTIONS, restores compliance with SR 3.0.1.

SR 3.0.4

SR 3.0.4 establishes the requirement that all applicable SRs must be met before entry into a specified condition in the Applicability.

This Specification ensures that system and component requirements and variable limits are met before entry in the Applicability for which these systems and components ensure safe operation of the facility.

The provisions of this Specification should not be interpreted as endorsing the failure to exercise the good practice of restoring systems or components to an appropriate status before entering an associated specified condition in the Applicability. However, in certain circumstances, failing to meet an SR will not result in SR 3.0.4 restricting a change in specified condition. When a system,

BASES

SR 3.0.4 (continued)

subsystem, division, component, device, or variable is outside its specified limits, the associated SR(s) are not required to be performed, per SR 3.0.1, which states that Surveillances do not have to be performed on such equipment. When equipment does not meet the LCO, SR 3.0.4 does not apply to the associated SR(s) since the requirement for the SR(s) to be performed is removed. Therefore, failing to perform the Surveillance(s) within the specified Frequency does not result in an SR 3.0.4 restriction to changing specified conditions of the Applicability. However, since the LCO is not met in this instance, LCO 3.0.4 will govern any restrictions that may (or may not) apply to specified condition changes.

The provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS. In addition, the provisions of SR 3.0.4 shall not prevent changes in specified conditions in the Applicability that are related to the unloading of a cask.

The precise requirements for performance of SRs are specified such that exceptions to SR 3.0.4 are not necessary. The specific time frames and conditions necessary for meeting the SRs are specified in the Frequency, in the Surveillance, or both. This allows performance of Surveillances when the prerequisite condition(s) specified in a Surveillance procedure require entry into the specified condition in the Applicability of the associated LCO prior to the performance or completion of a Surveillance. A Surveillance that could not be performed until after entering the LCO Applicability would have its Frequency specified such that it is not "due" until the specific conditions needed are met. Alternatively, the Surveillance may be stated in the form of a Note as not required (to be met or performed) until a particular event, condition, or time has been reached. Further discussion of the specific formats of SR annotation is found in Section 1.4, Frequency.

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B 3.1 CASK INTEGRITY

B 3.1.1 Cask Cavity Vacuum Drying

BASES

BACKGROUND

A cask is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A lid is then placed on the cask. Subsequent operations involve moving the cask to the decontamination area and removing water from the cask fuel cavity. After the cask lid is secured, vacuum drying of the cask cavity is performed, and the cavity is backfilled with helium. During normal storage conditions, the cask is backfilled with helium, which is a better conductor than air or vacuum, which results in lower temperatures for stored fuel and the basket.

Cavity vacuum drying is utilized to remove residual moisture from the fuel cavity after the cask has been drained of water. Any water which was not drained from the cask cavity evaporates from fuel or basket surfaces due to the vacuum. This vacuum drying operation is aided by the temperature increase due to the heat generation of the fuel.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a cask is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are uranium dioxide fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the cask in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This protective environment is accomplished by removing water from the cask cavity and backfilling the cavity with an inert gas. The failure of storage cask confinement capability is considered in the accident analysis (Reference 1).

LCO

A vacuum pressure of less than or equal to 4 mbar absolute held for 30 minutes indicates that all liquid water has evaporated and has been removed from the cask cavity. Removing water from the cask cavity helps to ensure the long term minimization of fuel clad corrosion.

APPLICABILITY

Cavity vacuum drying is performed during LOADING OPERATIONS before the cask is transported to the ISFSI storage pad. Therefore, the vacuum requirements do not apply after the cask is backfilled with helium prior to TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the internal environment of one cask is independent of the internal environment of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

BASES

ACTIONS (Continued)

A.1

The thermal analyses of the cask are performed assuming that helium is in the cask. If the cavity vacuum drying pressure limit cannot be achieved within 24 hours of completion of cask draining, the cask must be backfilled with helium (a pressure greater than 0.1 atm abs is sufficient to provide required thermal conductivity) within 12 hours. This results in the cask being backfilled with helium within 36 hours of draining the cask. ACTION A.1 requires backfilling with helium to maintain the cask in an analyzed condition, thus allowing additional time to determine the source of the vacuum drying problem.

After the cask reaches steady state conditions under air or vacuum, the fuel pin cladding short term temperature limits will not be exceeded (Reference 2). However, the temperature of the basket could increase beyond the analyzed temperature range since the thermal performance of the cask under vacuum is not as good as when filled with helium. At approximately 36 hours the cask basket materials will reach the maximum temperature for which they have been analyzed. The basket heatup calculation during vacuum drying is performed in Reference 2 and is based on design basis fuel. If the heat load is less than the design basis heat load, the temperatures would increase more slowly. At 56% of the design basis heat load, the maximum analyzed temperatures will never be reached.

Establishment of even a low pressure helium environment satisfies the helium properties described in design basis thermal analyses because thermal conductivity of gases is not pressure dependent until a high vacuum is attained. Thereby, design basis heat removal requirements will be satisfied over the period of time that it may take to remedy a leaking cask. The near-term effects of not providing a completely dried and pressurized helium atmosphere during this period are negligible. Insignificant corrosion of materials would occur during this period.

Required Action A.1 is modified by a note which allows exiting the LCO in the event that the nominal helium cask environment must be vented during subsequent actions that may be necessary to remedy the condition. For example, the helium may be vented and the LCO exited if it is discovered that residual water must be drained from the cask prior to re-commencing the vacuum drying process.

A.2

If the cavity vacuum drying pressure limit cannot be achieved, actions must be taken to meet the LCO. Failure to successfully complete cavity vacuum drying could have many causes, such as failure of the vacuum drying system, inadequate draining, ice clogging of the drain lines, or leaking of the cask seals. The 96-hour Completion Time (from the time that SR 3.1.1.1 is not met) provides ample opportunity to remedy any expected problem with the vacuum drying equipment.

B.1

If a nominal helium environment cannot be achieved or maintained in the cask within 36 hours of draining the cask, the temperatures of cask basket materials may increase beyond the analyzed condition. This could cause damage to the cask basket; however fuel temperature limits will not be exceeded. Therefore the cask will be placed back into the spent fuel pool and unloaded within 7 days. 7 days is sufficient time to reflood the cask and unload the fuel assemblies. Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore, it will be unloaded within 7 days.

BASES

ACTIONS (Continued)

C.1

If the cask cavity drying pressure limits cannot be achieved within the Completion Time of 96 hours, actions must be taken to return the cask to the spent fuel pool and unload the cask within the ensuing 30 days. Evaluation and repair to cask drying equipment may continue while preparing to unload the cask. Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 30 days.

SURVEILLANCE REQUIREMENTS

SR 3.1.1.1

Cavity dryness is demonstrated by evacuating the cavity to a high vacuum and verifying that the vacuum is held over a specified period of time. A high vacuum is an indication that the cavity is dry.

This dryness test must be performed successfully on each cask before placing in storage. The test must be performed within 24 hours of draining the cask and removing it from the spent fuel pool. This period allows sufficient time to prepare the cask and perform the test while minimizing the time the fuel is in the cask without a helium atmosphere.

REFERENCES

1. SAR Section 11.1.2 Cask Seal Leakage

2. SAR Section 4.6.2, Cask Heatup Analysis

B 3.1 CASK INTEGRITY

B 3.1.2 Cask Helium Backfill Pressure

BASES

BACKGROUND

A cask is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A lid is then placed on the cask. Subsequent operations involve moving the cask to the decontamination area and removing water from the cask fuel cavity. After the cask lid is secured, vacuum drying of the cask cavity is performed, and the cavity is backfilled with helium. During normal storage conditions, the cask is backfilled with helium, which is a better conductor than air or vacuum, which results in lower temperatures for stored fuel and the basket.

Backfilling the cask cavity with helium promotes heat transfer from the fuel and the inert atmosphere protects the fuel cladding. Providing a helium pressure greater than atmospheric pressure ensures that there will be no in-leakage of air over the life of the cask.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a cask is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are uranium dioxide fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the cask in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This is accomplished by removing water from the cask cavity and backfilling the cavity with an inert gas. The failure of storage cask confinement capability is considered in the accident analysis (Reference 1). In addition, the thermal analyses of the cask STORAGE OPERATIONS assume that the cask cavity is filled with helium.

LCO

Backfilling the cask cavity with helium at a pressure exceeding atmospheric pressure will ensure that there will be no air in-leakage into the cavity which could damage the fuel cladding over the licensed storage period. An initial helium pressure of 2230 mbar absolute (± 100 mbar) was selected to ensure that the pressure within the cask remains within the design pressure limits over the life of the cask.

BASES

APPLICABILITY

Helium backfill is performed during LOADING OPERATIONS prior to transporting the cask to the ISFSI storage pad. The helium leak rate is then measured prior to TRANSPORT OPERATIONS and STORAGE OPERATIONS.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the internal environment of one cask is independent of the internal environment of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

The thermal analyses of the cask are performed assuming that helium is in the cask. If the cask cavity helium pressure limit cannot be achieved within 30 hours of completion of cask draining, the cask must be backfilled with helium (a pressure greater than 0.1 atm abs is sufficient to provide required thermal conductivity) within 6 hours or 36 hours of draining the cask. ACTION A.1 requires backfilling with helium to maintain the cask in an analyzed condition, thus allowing additional time to determine the source of the helium backfill problem.

After the cask reaches steady state conditions under air or vacuum, the fuel pin cladding short term temperature limits will not be exceeded (Reference 2). However, the temperature of the basket could increase beyond the analyzed temperature range since the thermal performance of the cask under vacuum is not as good as when filled with helium. At approximately 36 hours the cask basket materials will reach the maximum temperature for which they have been analyzed. The basket heatup calculation during vacuum drying is performed in Reference 2 and is based on design basis fuel. If the heat load is less than the design basis heat load, the temperatures would increase more slowly. At 56% of the design basis heat load, the maximum analyzed temperatures will never be reached.

Establishment of even a low pressure helium environment satisfies the helium properties described in design basis thermal analyses because thermal conductivity of gases is not pressure dependent until a high vacuum is attained. Thereby, design basis heat removal requirements will be satisfied over the period of time that it may take to remedy a leaking cask. The near-term effects of not providing a completely dried and pressurized helium atmosphere during this period are negligible. Insignificant corrosion of materials would occur during this period.

Required Action A.1 is modified by a note which allows exiting the LCO in the event that the nominal helium cask environment must be vented during subsequent actions that may be necessary to remedy the condition.

A.2

If the initial helium backfill pressure cannot be obtained, actions must be taken to meet the LCO. The 48-hour Completion Time (from the time that SR 3.1.2.1 is not met) provides ample opportunity to remedy any expected problem with the helium backfill equipment.

BASES

ACTIONS (Continued)

B.1

If a nominal helium environment cannot be achieved or maintained in the cask within 36 hours of draining the cask, the temperatures of cask basket materials may increase beyond the analyzed condition. This could cause damage to the cask basket; however fuel temperature limits will not be exceeded. Therefore the cask will be placed back into the spent fuel pool and unloaded within 7 days. 7 days is sufficient time to reflood the cask and unload the fuel assemblies. Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 7 days.

C.1

If the cask cavity drying pressure limits cannot be achieved within the Completion Time of 48 hours, actions must be taken to return the cask to the spent fuel pool and unload the cask within the ensuing 30 days. Evaluation and repair to helium backfill equipment may continue while preparing to unload the cask. Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 30 days.

SURVEILLANCE REQUIREMENTS

3.1.2.1

The long-term integrity of the stored fuel is dependent on storage in a dry, inert environment and maintenance of adequate heat transfer mechanisms. Filling the cask cavity with helium at the initial pressure specified will ensure that there will be no air in-leakage, which could potentially damage the fuel and that the cask cavity internal pressure will remain within limits for the life of the cask.

Backfilling with helium must be performed successfully on each cask before placing in storage. The surveillance must be performed within 30 hours after draining the cask. This time is limited to ensure that the cask basket does not exceed the temperatures for which it has been analyzed. This 30-hour period is sufficient time to backfill the cask cavity with helium while minimizing the time the fuel is in the cask without the assumed thermally-conductive atmosphere.

REFERENCES

1. SAR Section 11.1.2 Cask Seal Leakage

2. SAR Section 4.6.2, Cask Heatup Analysis

B 3.1 CASK INTEGRITY

B 3.1.3 Cask Helium Leak Rate

BASES

BACKGROUND

A cask is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A lid is then placed on the cask. Subsequent operations involve moving the cask to the decontamination area and removing water from the cask fuel cavity. After the cask lid is secured, vacuum drying of the cask cavity is performed, and the cavity is backfilled with helium. During normal storage conditions, the cask is backfilled with helium, which is a better conductor than air or vacuum, which results in lower temperatures for stored fuel and the basket. Backfilling the cask cavity with helium promotes heat transfer from the fuel and the inert atmosphere protects the fuel cladding. Prior to moving the cask to the storage pad, the helium leak rate is determined to ensure that the fuel is confined.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a cask is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are uranium dioxide fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the cask in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This is accomplished by removing water from the cask cavity and backfilling the cavity with an inert gas. The failure of one of the confinement barriers is considered as an off normal condition (Reference 1). In addition, the thermal analyses of the cask STORAGE OPERATIONS assume that the cask cavity is filled with helium.

LCO

Verifying that the cask cavity is sealed by measuring the helium leak rate will ensure that the assumptions in the normal, off-normal, and accident analyses and radiological evaluations are maintained. The helium leak rate value not to exceed 1.0 E-5 std cc/sec is used in the confinement analyses presented in Chapter 7 of the SAR. This limit is based on air leakage (std-cc/sec) which requires conversion from helium leakage as appropriate.

APPLICABILITY

During LOADING OPERATIONS, the helium leak rate is required to be met when all lid bolts have had their final tensioning (torqued). Cask seal integrity is monitored during STORAGE OPERATIONS by LCO 3.1.5, Cask Interseal Pressure.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the internal environment of one cask is independent of the internal environment of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

BASES

ACTIONS (Continued)

A.1

If the helium leak rate limit is not met or is unknown due to unsatisfactory results from SR 3.1.3.1, actions must be taken to meet the LCO. The 48-hour Completion Time of Required Action A.1 provides ample time to investigate the source of the leak and reestablish the cask helium leak rate within limit.

B.1

The 30-day Completion Time of Required Action B.1 is based on engineering judgment and operating experience that any credible seal leak within the total 32-day period would not result in a significant loss of helium inventory that would affect the heat removal capability of the cask. Even in the event of a significant leak, the cask environment would not be reduced to less than one atmosphere of helium because there is no mechanism to exchange the helium in the cask with external air. Based on operational experience with transport casks, this 30-day Completion Time is sufficient to disconnect the test equipment, vent the cask, return it to the spent fuel pool, and unload the fuel.

Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 30 days.

SURVEILLANCE REQUIREMENTS

SR 3.1.3.1

A primary design consideration of the cask is that it adequately can contain radioactive material and retain an inert environment. Measuring the helium leak rate with an appropriate detector demonstrates that the confinement barrier is established and within design assumptions (Reference 2).

Measuring the helium leak rate must be performed successfully on each cask prior to placing it in storage. The surveillance must be performed within 48 hours after verifying the cask helium backfill pressure is within limits. This 48-hour period allows sufficient time to perform the surveillance while minimizing the time the fuel is in the cask without verifying that the cask is sealed.

REFERENCES

1. SAR Section 11.1.2, Cask Seal Leakage

2. SAR Section 9.1.3, Leak Tests

3. SAR Section 7.3, Confinement Requirements for Hypothetical Accident Conditions

B3.1.4 Combined Helium Leak Rate

BASES

BACKGROUND

A cask is placed in the spent fuel pool and loaded with fuel assemblies meeting the requirements of the Functional and Operating Limits. A lid is then placed on the cask. Subsequent operations involve moving the cask to the decontamination area and removing water from the cask fuel cavity. After the cask lid is secured, vacuum drying of the cask cavity is performed, and the cavity is backfilled with helium. During normal storage conditions, the cask is backfilled with helium, which is a better conductor than air or vacuum, which results in lower temperatures for stored fuel and the basket. Backfilling the cask cavity with helium promotes heat transfer from the fuel and the inert atmosphere protects the fuel cladding. Prior to moving the cask to the storage pad, the helium leak rate is determined to ensure that the fuel is confined. The overpressure system forms part of the second confinement boundary. The overpressure system may be leak tested prior to moving the cask to the storage pad or within 48 hours of moving the cask to the storage pad.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a cask is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are uranium dioxide fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the cask in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This is accomplished by removing water from the cask cavity and backfilling the cavity with an inert gas. The failure of one of the confinement barriers is considered as an off normal condition (Reference 1). In addition, the thermal analyses of the cask STORAGE OPERATIONS assume that the cask cavity is filled with helium.

LCO

Verifying that the cask cavity is sealed by measuring the helium leak rate will ensure that the assumptions in the normal, off-normal, and accident analyses and radiological evaluations are maintained. The helium leak rate value not to exceed 1.0 E-5 std cc/sec is used in the confinement analyses presented in Chapter 7 of the SAR. This limit is based on air leakage (std-cc/sec) which requires conversion from helium leakage as appropriate.

APPLICABILITY

During STORAGE OPERATIONS, the helium leak rate of the overpressure system is required to be met within 48 hours of moving the cask to the storage pad. Cask seal integrity is monitored during STORAGE OPERATIONS by LCO 3.1.5, Cask Interseal Pressure.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the internal environment of one cask is independent of the internal environment of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

BASES

ACTIONS (Continued)

A.1

If the helium leak rate limit is not met or is unknown due to unsatisfactory results from SR 3.1.4.1, actions must be taken to meet the LCO. The 48-hour Completion Time of Required Action A.1 provides ample time to investigate the source of the leak and reestablish the cask helium leak rate within limit.

B.1

The 30-day Completion Time of Required Action B.1 is based on engineering judgment and operating experience that any credible seal leak within the total 32-day period would not result in a significant loss of helium inventory that would affect the heat removal capability of the cask. Even in the event of a significant leak, the cask environment would not be reduced to less than one atmosphere of helium because there is no mechanism to exchange the helium in the cask with external air. Based on operational experience with transport casks, this 30-day Completion Time is sufficient to disconnect the test equipment, vent the cask, return it to the spent fuel pool, and unload the fuel.

Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 30 days.

SURVEILLANCE REQUIREMENTS

SR 3.1.4.1

A primary design consideration of the cask is that it adequately can contain radioactive material and retain an inert environment. Measuring the helium leak rate with an appropriate detector demonstrates that the confinement barrier is established and within design assumptions (Reference 2).

Measuring the helium leak rate must be performed successfully on each cask prior to placing it in storage. The surveillance must be performed within 48 hours of moving the cask to the storage pad. This 48-hour period allows sufficient time to perform the surveillance while minimizing the time the fuel is in the cask without verifying that the overpressure system is sealed.

A note has been added to the surveillance to state that SR 3.1.4.1 may be combined with SR 3.1.3.1. This surveillance allows the leak testing of the overpressure system while on the storage pad. However, the surveillance may be performed with the leak testing of the cask seals while in the spent fuel building.

REFERENCES

4. SAR Section 11.1.2, Cask Seal Leakage

5. SAR Section 9.1.3, Leak Tests

6. SAR Section 7.3, Confinement Requirements for Hypothetical Accident Conditions

BASES

B 3.1 CASK INTEGRITY

B 3.1.5 Cask Interseal Pressure

BASES

BACKGROUND

A cask is loaded, dried, and sealed prior to being transported to the ISFSI and placed on a storage pad. The cask is designed with redundant seals to contain the radioactive material. In addition, 10 CFR 72.122(h)(4) and 10 CFR 72.128(a)(1) state that the casks must have the capability to be continuously monitored such that the licensee will be able to determine when corrective action needs to be taken to maintain safe storage conditions. The monitoring systems provide the following features:

a. The capability to monitor interseal pressure that will indicate if cask seal integrity is compromised; and

b. Local alarms to notify the licensee that potential seal degradation has occurred.

It is necessary to verify cask seal integrity at a regular interval.

Backfilling the cask cavity with helium promotes heat transfer from the fuel and the inert atmosphere protects the fuel cladding.

APPLICABLE SAFETY ANALYSIS

The confinement of radioactivity during the storage of spent fuel in a cask is ensured by the use of multiple confinement barriers and systems. The barriers relied upon are uranium dioxide fuel pellet matrix, the metallic fuel cladding tubes in which the fuel pellets are contained, and the cask in which the fuel assemblies are stored. Long-term integrity of the fuel cladding depends on storage in an inert atmosphere. This is accomplished by removing water from the cask cavity and backfilling the cavity with an inert gas. The failure of storage cask confinement capability is considered in the accident analysis and the off-normal analysis (References 1, 2, and 3). In addition, the thermal analyses of the cask STORAGE OPERATIONS assume that the cask cavity is filled with helium.

BASES

LCO

Verifying cask interseal pressure ensures that the assumptions relating to radioactive releases in the accident analyses and radiological evaluations are maintained. Seal integrity is verified by monitoring interseal pressure indication and alarms.

APPLICABILITY

Cask interseal pressure verification is performed regularly during STORAGE OPERATIONS to confirm that the cask confinement barriers have not been compromised. During LOADING OPERATIONS, the seal integrity is verified prior to moving the cask to the ISFSI storage pads. Verification during TRANSPORT OPERATIONS is not possible as the cask is being moved. However, TRANSPORT OPERATIONS are brief and follow the verification performed during LOADING OPERATIONS and, therefore, does not represent a significant lapse in seal integrity monitoring.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the internal environment of one cask is independent of the internal environment of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If a condition is entered due to failure to meet SR 3.1.5.1 an appropriate evaluation shall be performed to investigate the cause of the low pressure condition. The 7-day period is sufficient time to perform an assessment of the condition and make repairs to the overpressure system, change out the pressure switch, if necessary, and reestablish a pressure above 3.2 atm. Reestablishing the pressure above 3.2 atm prevents leakage of radioactive material from the cask cavity. However, if the source of the low pressure is due to a leak greater than analyzed in any cask seal or the overpressure system, the leak should be repaired.

B.1

If it is determined that there is a leakage path in the cask or overpressure system, the repair should be performed in a timely manner. If the interseal pressure has been reestablished to 3.2 atm or above, no leakage of radioactive material from the cask cavity can occur. The 30-day COMPLETION TIME of REQUIRED ACTION B.1 provides ample time to implement any expected repair or unload the fuel assemblies. Once placed in the spent fuel pool with the lid removed, the fuel is provided with adequate decay heat removal facilities and an adequate borated environment to maintain the loaded fuel within limits. However, it is not intended to use the cask for indefinite storage in the spent fuel pool. Therefore it will be unloaded within 30 days.

BASES

SURVEILLANCE REQUIREMENTS

SR 3.1.5.1

After the initial leak testing is successfully performed, the cask overpressure tank pressure is routinely monitored every 7 days. This ensures that no leaks have occurred after initial testing is done. Verification of the pressure exceeding 3.2 atmospheres may be performed using alarms, pressure transducers, or other similar verification methods. Seven days is appropriate, based on the extreme improbability of developing a leak during TRANSFER and STORAGE OPERATIONS.

Cask seal integrity must be verified in accordance with 10 CFR 72.122(h)(4) and 10 CFR 72.128(a)(1). The method for verifying seal integrity is to monitor the interseal pressure. Normally, the cask seal integrity is verified using installed instrumentation that alarms or indicates. If this system is not operating on one or more casks, monitoring of seal integrity at each affected cask may be performed by alternative means.

SR 3.1.5.2

Cask seal integrity must be verified in accordance with 10 CFR 72.122(h)(4) and 10 CFR 72.128(a)(1). To ensure operability of the interseal pressure monitoring system as a remote indicator during STORAGE OPERATIONS, SR 3.1.5.2 verifies the proper functioning and setpoint of the pressure switch or transducer within 7 days of commencing STORAGE OPERATIONS. This verification is a Channel Operational Test (COT) which exercises the pressure switch by reducing the sensed pressure below the setpoint, and which verifies the accuracy of the trip setpoint within the required range. Full channel calibration over the range of the instrument is not required because the instrument provides no analog indication. Subsequent operability in-service is verified by a COT every 36 months, a reasonable period which addresses the expected drift of the instrument and the reliability of the pressure switch testing.

REFERENCES

1. SAR Section 7.3, Confinement Requirements for Hypothetical Accident Conditions
2. ~~SAR Section 11.1.2, Cask Seal Leakage~~
3. SAR Section 11.2.9, Loss of Confinement Barrier

B 3.1 CASK INTEGRITY

B 3.1.6 Cask Minimum Lifting Temperature

BASES

BACKGROUND

Minimum temperature limits for cask lifting/movement operations must be observed to avoid the potential for brittle fracture of the cask.

APPLICABLE SAFETY ANALYSIS

The containment vessel and the gamma shielding are fabricated from materials selected for their low temperature fracture toughness properties at low temperature. The fracture toughness of the cask is evaluated in SAR Appendix 3E of Chapter 3. This evaluation is based on a minimum temperature of -20°F.

The cask will generally be at a temperature higher than the ambient temperature due to the heat load of the fuel. However, for conservatism and simplicity, it is recommended that the ambient be selected as the minimum cask movement temperature. It is highly unlikely that any cask movement activity would take place at temperatures below -20°F. Nevertheless, if movement at a temperature below that specified is necessary, calculations (similar to those presented in Chapter 4 of the SAR) or direct measurements may be used to estimate the minimum cask surface temperature for any particular ambient condition.

LCO

The LCO requires that the cask not be lifted or moved if the cask outer surface temperature is below that specified.

APPLICABILITY

~~This technical specification is applicable during TRANSPORT OPERATIONS.~~

BASES

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the movement/lifting of one cask is independent of the movement/lifting of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the Surveillance Requirements are satisfied prior to the operation, the ambient temperature limits will be met. If, however, the temperature should decrease below the limit during the operation, the cask must be placed on a stable, qualified surface and the lifting / movement operation must be suspended. If the temperature limit is violated during TRANSPORT OPERATIONS, the cask must first be returned to a safe and secure location. Based on the significant margin provided in the calculation of fracture toughness, it is safe to continue TRANSPORT OPERATIONS for a short period if the ambient temperatures decrease a few degrees below the limit. For radiological and security reasons, it would be safer to transport the cask to a safe and secure area, as opposed to immediately suspending the operation and establishing temporary security and radiological controls at some temporary location until the time that ambient temperature increased above the specified value.

SURVEILLANCE REQUIREMENTS

SR 3.1.6.1

Prior to TRANSPORT OPERATIONS, the cask outer surface temperature should be verified. This temperature requirement can be met by measuring the ambient temperature prior to transport. Weather forecasts should be considered for the planned period of the TRANSPORT OPERATION.

B 3.2 CASK RADIATION PROTECTION

B 3.2.1 Cask Surface Contamination

BASES

BACKGROUND

A cask is immersed in the spent fuel pool in order to load the spent fuel assemblies. As a result, the surface of the cask may become contaminated with the radioactive material in the spent fuel pool water. This contamination is removed prior to moving the cask to the ISFSI in order to minimize radioactive contamination to personnel or the environment. This uncontaminated environment allows the ISFSI to be entered without additional radiological controls to prevent the spread of contamination and reduces personnel dose due to the spread of loose contamination or airborne contamination. This practice is consistent with ALARA principles. (Reference 1)

APPLICABLE SAFETY ANALYSIS

The radiation protection measures implemented at the ISFSI are based on the assumption that the exterior surfaces of the cask have been decontaminated. Failure to decontaminate the surfaces of the casks could lead to higher than projected occupational doses.

LCO

Removable surface contamination on the cask exterior surfaces is limited to 1000 dpm/100 cm^2 from beta and gamma sources and 20 dpm/100 cm^2 from alpha sources. These limits are based on the minimum level of activity that can be routinely detected under a surface contamination control program using direct survey methods. Experience has shown that these limits are low enough to prevent the spread of contamination to clean areas and are significantly less than the levels which would cause significant personnel skin dose.

APPLICABILITY

Verification that the cask surface contamination is less than the LCO limit is performed during LOADING OPERATIONS. This verification occurs prior to TRANSPORT OPERATIONS and STORAGE OPERATIONS, and CONDITION A is not applicable until the SURVEILLANCE REQUIREMENT (SR3.2.1.1) has been performed. Measurement of the cask surface contamination is unnecessary during TRANSPORT OPERATIONS in preparation for UNLOADING OPERATIONS, because surface contamination would have been measured prior to moving the cask to the ISFSI.

BASES

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the outer surface contamination of one cask is independent of the contamination of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the removable surface contamination of a cask that has been loaded with spent fuel is not within the LCO limits, action must be initiated to decontaminate the cask and bring the removable surface contamination within limits. The Completion Time requires that the decontamination be completed prior to TRANSPORT OPERATIONS, which will prevent the release of contamination to the environment and the ISFSI.

SURVEILLANCE REQUIREMENTS

SR 3.2.1.1

This SR verifies that the removable surface contamination on the cask is less than the limits in the LCO. The Surveillance is performed using smear surveys to detect removable surface contamination. The Frequency requires performing the verification once; following cask loading and prior to initiating TRANSPORT OPERATIONS. This Frequency is adequate to confirm that the cask can be moved to the ISFSI without spreading loose contamination, and assumes that the cask will not develop surface contamination during TRANSPORT or STORAGE OPERATIONS. Storage of the fuel in the dry, redundantly-sealed cask eliminates the possibility for leakage of contaminated liquids.

REFERENCES

1. USNRC IE Circular 81-07 dated May 14, 1981, Control of Radioactively Contaminated Materials.

B 3.3 CASK CRITICALITY CONTROL

B 3.3.1 Dissolved Boron Concentration

BASES

BACKGROUND

The casks are designed to maintain the fuel subcritical under all postulated fuel arrangements with the effective neutron multiplication factor (k_{eff}) ≤ 0.95 (Reference 1). While the cask is in the spent fuel pool or filled with borated water, additional neutron moderation is necessary to counteract neutron moderation by the water. As a result, the water must be borated to provide additional criticality control.

APPLICABLE SAFETY ANALYSIS

During LOADING OPERATIONS, the methods for criticality control rely on borated water used to fill the fuel cavity to counteract its neutron moderating effect. Maintaining the boron concentration of the water in the cask cavity at or above the Technical Specification limit prevents violation of the criticality design criterion. Criticality analyses were performed assuming the initial fuel enrichment (described in TS Section 2) with all the cavity voids filled with 2300 ppm borated water. A single cask reflected all around by 30 cm of water is used as the most reactive configuration. Analyses assume the fraction of boron-10 in the solution to be that of naturally-occurring boron. (Reference 2)

LCO

The water in the cask cavity must have a minimum boron concentration of 2300 ppm boron. The minimum boron concentration limit ensures subcritical conditions under design basis loading conditions in the cask.

BASES

APPLICABILITY

The boron concentration of the water in the cask cavity must be within its limit whenever there is water in the cavity. This condition occurs during LOADING OPERATIONS and UNLOADING OPERATIONS.

ACTIONS

The ACTIONS Table is modified by a note indicating that a separate Condition entry is allowed for each cask. This note is acceptable because the dissolved boron concentration of one cask is independent of the dissolved boron concentration of subsequent casks or adjacent casks. The Required Actions for each Condition provide appropriate compensatory actions for each cask not meeting the LCO. Subsequent casks that do not meet the LCO are governed by subsequent Condition entry and application of associated Required Actions.

A.1

If the dissolved boron concentration of the spent fuel pool is not within limit, loading of any additional fuel assemblies into the cask must be stopped. Without the required concentration of dissolved boron in the water, maintaining the subcriticality limit in all conditions can not be guaranteed. The immediate Completion Time reflects the importance of prohibiting the introduction of any potential positive reactivity addition into the cask cavity without the required boron concentration.

A.2

If the dissolved boron concentration in the cask cavity can not be brought within the limit, all fuel assemblies must be removed from the cask. This action restores the fuel assemblies to an analyzed condition in the spent fuel pool. The 24-hour Completion Time takes into consideration the time to change the boron concentration of a large spent fuel pool and the time to unload a loaded cask.

BASES

SURVEILLANCE REQUIREMENTS

SR 3.3.1.1

This SR specifically applies to LOADING OPERATIONS. The boron concentration of the spent fuel pool water and other sources of borated water is determined periodically using chemical analysis of two samples analyzed by different individuals to reduce the risk that a single error could lead to not meeting the LCO.

The requirement to verify the boron concentration within 4 hours prior to commencing LOADING OPERATIONS ensures that the water added to the cask is within the limit. The Frequency of every 48 hours thereafter while the cask is in the spent fuel pool or while the cask is filled with borated water is a reasonable amount of time to verify the boron concentration of representative samples. The Frequency is based on the operating experience that boron concentration changes occur very slowly.

SR 3.3.1.2

This SR specifically applies to UNLOADING OPERATIONS. The boron concentration is analyzed as described above. The requirement to verify the boron concentration within 4 hours prior to commencing UNLOADING OPERATIONS ensures that the water added to the cask cavity is within the limit. The Frequency of every 48 hours thereafter while the cask is in the spent fuel pool is a reasonable amount of time to verify the boron concentration of representative samples. Once the cask has been removed from the spent fuel pool, the boron concentration of the water in the cask cavity is not expected to change significantly. The Frequency is based on operating experience the boron concentration changes very slowly.

REFERENCES

1. SAR, Section 1.2.2.1, Operational Features - General Features

2. SAR, Section 6.4, Criticality Calculation

CHAPTER 13

QUALITY ASSURANCE

This chapter establishes the Quality Assurance (QA) program applied to the design, analysis, fabrication, assembly, and testing of TN-32 Storage System components that are Important to Safety as defined in Section 2.3.1 of this SAR.

All quality-related activities will be controlled under an NRC-approved quality assurance program, meeting the requirements of 10CFR72,[1] Subpart G. The licensee's QA program will be used to control activities performed by the licensee.

TN is responsible for the TN-32 Storage System as discussed in Section 1.3 of this SAR. TN implements its Quality Assurance Program for nuclear quality-related activities. The TN Quality Assurance Program is being invoked by TN to provide uniformity in the 10CFR72, Subpart G, quality program. The TN Quality Assurance Procedures are used to implement the provisions of the TN Quality Assurance Program for the nuclear quality-related activities associated with the TN-32 Storage System.

The TN Quality Assurance Program will be applied to the Important to Safety (10CFR72) components of the TN-32 Storage System and to the associated nuclear quality-related activities. In addition to compliance with 10CFR72, Subpart G, guidance for the TN Quality Assurance Procedures have been taken from Regulatory Guide 7.10[2] and from NUREG/CR-6407[3]. These quality procedures are used to establish the quality category of components, subassemblies, and piece parts according to each item's importance to nuclear safety.

The matrix in Table 13-1 shows the 10CFR72, Subpart G, criteria and the respective sections of the TN Quality Program that address the criteria.

---

[1] Title 10, U.S. Code of Federal Regulations, Part 72, (10CFR72), Licensing Requirements for the independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, 1995.

[2] Regulatory Guide 7.10, Establishing Quality Assurance Programs for Packaging Used in the Transport of Radioactive Material, U.S. Nuclear Regulatory Commission, June 1974.

[3] NUREG/CR-6407, Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety, U.S. Nuclear Regulatory Commission, February 1996.

Table 13-1 - Quality Assurance Criteria Matrix

10CFR72, Subpart G		TN Quality Assurance Manual
Section	**Criteria**	**Section**
72.142	Organization	1
72.144	Quality Assurance Program	2
72.146	Design Control	3
72.148	Procurement Document Control	4
72.150	Instructions, Procedures, and Drawings	5
72.152	Document Control	6
72.154	Control of Purchased Material, Equipment, and Services	7
72.156	Identification and Control of Material, Parts, and Components	8
72.158	Control of Special Processes	9
72.160	Licensee Inspection	10
72.162	Test Control	11
72.164	Control of Measuring and Test Equipment	12
72.166	Handling, Storage, and Shipping Control	13
72.168	Inspection, Test, and Operating Status	14
72.170	Nonconforming Materials, Parts, or Components	15
72.172	Corrective Action	16
72.174	Quality Assurance Records	17
72.176	Audits	18

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CHAPTER 14

DECOMMISSIONING

14.1 Decommissioning Considerations

The TN-32 cask design features inherent ease and simplicity of decommissioning. At the end of its service life, cask decommissioning could be performed by one of the options listed below:

- Option 1, the TN-32, including spent fuel in storage, could be shipped (by special transport license) to either a monitored retrievable storage system (MRS) or a geological repository for final disposal, or

- Option 2, the spent fuel could be removed from the TN-32 cask (either at the ISFSI site or at another off site location) and shipped in an NRC approved cask.

The first option requires that the Part 72 storage only cask be upgraded to current Part 71 regulations. Although that opportunity is beyond the bounds of this application, TN and its customers may evaluate this option on a case by case basis.

The first option does not require any decommissioning of the TN-32 cask. No residual contamination is expected to be left behind on the concrete base pad. The base pad, fence, and periphery utility structures will require no decontamination or special handling after the last cask is removed. The ISFSI pad could be demolished with normal construction techniques.

The second option would require decontamination of the TN-32 cask. The sources of contamination in the interior of the cask would primarily be contamination left from the spent fuel pool water; or crud, hot particles and fines from the spent fuel pins. This low level contamination could simply be removed with high pressure water spray. If further surface decontamination of the TN-32 is necessary, electropolishing or chemical etching can be used to remove the contaminated surface of the cask. After decontamination, the TN-32 cask could either be cut up for scrap, partially scrapped, or refurbished for reuse. Any activated metal would be shipped as low level radioactive waste to a near surface disposal facility.

Cask activation analyses have been performed to quantify the specific activities of the cask materials after years of storage. The following assumptions were made:

- the cask contains 32 design basis PWR fuel assemblies, and
- the neutron flux is assumed constant for 20 years.

The activation calculation is performed with the most conservative fuel source identified in Chapter 5 using the ORIGEN2 computer code. A radial SAS1 (one-dimensional) shielding calculation performed with the XSDRM-PM code using the source term and radial shielding thicknesses similar to Figure 5.3-12.

The total neutron fluxes are taken from a radial SAS1 (one dimensional) shielding calculation performed with the XSDRN-PM code using source term and radial shielding thicknesses similar to Figure 5.3-2. The SAS1 and the ORIGEN2 input files are provided in Section 14.2. The fluxes (determined in the SAS1 calculation) at the cask centerline, the cavity wall, the neutron shield, and the outer shell are used to irradiate the basket, the body and lid, the neutron shield, and the outer shell and protective cover, respectively. The fluxes, material compositions and masses of irradiated material are listed in Table 14.1-1. The ORIGEN2 cross section library for PWR's at a burnup of 33,000 MWD/MTU is used.

The results listed in Table 14.1-2 indicate that after 20 years irradiation and 30 days decay (to eliminate very short lived radionuclides), the total activity is less than 0.126 Ci.

To evaluate the TN-32 cask and basket for disposal, the specific activity of the isotopes listed in Tables 1 and 2 of 10 CFR 61.55 is determined and compared with the limits for Class A waste in those tables.

After the application of a surface decontamination method, the radiation levels in the cask constituents due to activation will be below the acceptable limits of Regulatory Guide 1.86[1]. The results of the calculation, shown in Table 14.1-3, show that activation of TN-32 will be far below the specific activity limits for both long and short lived nuclides for Class A waste. A detailed evaluation will be performed at the time of decommissioning to determine the appropriate mode of disposal should refurbishment not be elected.

The procedure for decommissioning TN-32 not returning to service is summarized below:

- Remove fuel in accordance with the unloading procedures of Chapter 8.

- Survey bolts, weather shield, overpressure monitoring system, top neutron shield (polyethylene disc), port covers, quick disconnect fittings, and seals. Evaluate surface contamination and determine if these items should be disposed of as non-radioactive waste or as low-level radioactive waste.

- Survey interior of TN-32 basket. Wash down the TN-32 basket inside the cask. Pump out and filter contaminated water and

cleaning agent. Survey interior of TN-32 again, decontaminate as required.

- Remove basket and rails and wash down again. Cut and crush basket for disposal as low level radioactive waste.

- Decontaminate the lid and basket rails until able to dispose of as scrap metal. If unable to achieve these levels, cut and dispose of as low level radioactive waste.

- Decontaminate the cask body. Cut the outer neutron shield shell and remove the neutron shield boxes. These are not expected to be contaminated; verify and dispose of as non-radioactive waste.

- Verify status of the cask body. It is expected that surface decontamination will be adequate, if so, dispose of the cask body as scrap metal. If unable to decontaminate to these levels, the cask body can be cut and disposed of as low level radioactive waste.

For cask refurbishment, the unloading and decontamination steps are as outlined for the scraps choices. However, the only cask discarded are consumable items, such as seals, or components damaged by the unloading. Following a comprehensive survey to confirm continued cask functionality within design basis, the TN-32 cask will be eligible for returning to spent fuel storage service.

As stated earlier under option 1, due to the leak tight design of the storage casks, no residual contamination will be left behind on the concrete base pad. No special techniques are necessary to remove the concrete pad.

The volume of waste material produced incidental to ISFSI decommissioning is expected to be limited to that necessary to accomplish surface decontamination of the casks if the spent fuel elements must be removed. No chemical or mixed waste is anticipated. Furthermore, it is estimated that the cask materials will be slightly activated as a result of their long term exposure to the relatively small neutron flux emanating from the spent fuel, and that the resultant activation level will be well below the allowable limits for general release of the casks as noncontrolled material. Therefore, it is anticipated that the casks may be decommissioned from nuclear service by surface decontamination alone, which could be performed at the utility or at any other suitable facility.

A detailed decommissioning plan will be submitted prior to the commencement of decommissioning activities. The costs of decommissioning the ISFSI are expected to represent a small and negligible fraction of the cost of decommissioning a nuclear pwer station.

14.2 Supplemental Information

14.2.1 SAS1 Input File

```
=sas1
tn32-1d-rad, calc 1066-07rv1, W17x17, 3.5%, 45 GWD/MTU, 7 year cool
27N-18COUPLE   INFHOMMEDIUM
'Fuel-Basket Zone
uo2            1  den=1.912  1.0 293.  92235 3.5  92238 96.5 end
zircalloy      1  den=0.376  end
inconel        1  den=0.022  end
al             1  den=0.306  end
ss304          1  den=0.316  end
'Plenum-Basket Zone
zircalloy      2  den=0.459  end
al             2  den=0.306  end
ss304          2  den=0.458  end
'Top Fitting - Basket Zone
inconel        3  den=0.212  end
al             3  den=0.306  end
ss304          3  den=1.351  end
'Cask Body, Outer Shell
carbonsteel    4  1.0   end
'Resin/Aluminum
arbmtnres     1.58  5  1  0  0  1001 5.05 5000 1.05 6012 35.13
8016  41.73  13027 14.93  5  0.904  end
al            5   0.096   end
end comp
end
last
tn32 gamma and neutron dose - 1 dimen analysis - radial
cylindrical
1  50.0     75    -1   0.    0.   1197.  1.856E10
1  87.31    75    -1   0.    0.   1197.  1.856E10
4  111.44   32     0
5  122.87   15     0
4  124.14    2     0
end zone
1.85e-2   2.099e-1  2.318e-1  1.309e-1  1.774e-1
1.936e-1  3.789e-2  28z  1.077e-2  4.699e-2
4.523e-2  4.319e-1  8.82e-2   9.124e-3  1.468e-2
5.372e-2  6.586e-2  2.334e-1
1.85e-2   2.099e-1  2.318e-1  1.309e-1  1.774e-1
1.936e-1  3.789e-2  28z  1.077e-2  4.699e-2
4.523e-2  4.319e-1  8.82e-2   9.124e-3  1.468e-2
5.372e-2  6.586e-2  2.334e-1
ID1=0
read xsdose
365.76
end
```

14.2.2 ORIGEN2 Input File

```
-1
-1
-1
BAS     ONE TN-32 PACKAGE
RDA     -1 = STEEL, 1% MN  (1 KG)
RDA     -2 = 304 ST STL (1 KG)
RDA     -3 = AL 6061        (1 KG)
RDA     -4 = RESIN          (1 KG)
RDA     -5 = CONTMNT STEEL (1 KG)
LIP     0 0 0
LIB     0 1 2 3 204 205 206 39 33 0 1 1
PHO     101 102 103 40
TIT     INITIAL COMP OF PACKAGE MAT'L, 1 KG EACH
INP     -1 1 -1 -1 1 1
INP     -2 1 -1 -1 1 1
INP     -3 1 -1 -1 1 1
INP     -4 1 -1 -1 1 1
INP     -5 1 -1 -1 1 1
TIT     IRRADIATION OF BASKET
MOV     -2 1 0 2997
ADD     -3 1 0 3042
HED     1  INITIAL
HED     6  30 D DECAY
BUP
IRF      1 8.42E5 1 2 5 2
IRF      2 8.42E5 2 3 5 0
IRF      3 8.42E5 3 2 5 0
IRF      4 8.42E5 2 3 5 0
IRF      5 8.42E5 3 2 5 0
IRF      6 8.42E5 2 3 5 0
IRF      7 8.42E5 3 4 5 0
IRF      8 8.42E5 4 3 5 0
IRF      9 8.42E5 3 4 5 0
IRF     10 8.42E5 4 3 5 0
IRF     11 8.42E5 3 4 5 0
IRF     12 8.42E5 4 5 5 0
IRF     13 8.42E5 5 4 5 0
IRF     14 8.42E5 4 5 5 0
IRF     15 8.42E5 5 4 5 0
IRF     16 8.42E5 4 5 5 0
IRF     17 8.42E5 5 6 5 0
IRF     18 8.42E5 6 5 5 0
IRF     19 8.42E5 5 6 5 0
IRF     20 8.42E5 6 5 5 0
DEC     30 5 6 4 4
BUP
OPTL     8 8 8 8 7 8 7 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTF     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OPTA     8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8
OUT     6 1 -1 0
TIT      IRRADIATION OF BODY AND BASKET RAILS
MOV      -1 1 0 53572
ADD      -3 1 0 1181
ADD      -5 1 0 11350
BUP
IRF      1 4.56E5 1 2 5 2
IRF      2 4.56E5 2 3 5 0
```

```
IRF      3 4.56E5 3 2 5 0
IRF      4 4.56E5 2 3 5 0
IRF      5 4.56E5 3 2 5 0
IRF      6 4.56E5 2 3 5 0
IRF      7 4.56E5 3 4 5 0
IRF      8 4.56E5 4 3 5 0
IRF      9 4.56E5 3 4 5 0
IRF     10 4.56E5 4 3 5 0
IRF     11 4.56E5 3 4 5 0
IRF     12 4.56E5 4 5 5 0
IRF     13 4.56E5 5 4 5 0
IRF     14 4.56E5 4 5 5 0
IRF     15 4.56E5 5 4 5 0
IRF     16 4.56E5 4 5 5 0
IRF     17 4.56E5 5 6 5 0
IRF     18 4.56E5 6 5 5 0
IRF     19 4.56E5 5 6 5 0
IRF     20 4.56E5 6 5 5 0
DEC     30 5 6 4 4
BUP
OUT     6 1 -1 0
TIT      IRRADIATION OF RESIN AND ALUM
MOV      -3 1 0 908
ADD      -4 1 0 4767
BUP
IRF      1 1.41E4 1 2 5 2
IRF      2 1.41E4 2 3 5 0
IRF      3 1.41E4 3 2 5 0
IRF      4 1.41E4 2 3 5 0
IRF      5 1.41E4 3 2 5 0
IRF      6 1.41E4 2 3 5 0
IRF      7 1.41E4 3 4 5 0
IRF      8 1.41E4 4 3 5 0
IRF      9 1.41E4 3 4 5 0
IRF     10 1.41E4 4 3 5 0
IRF     11 1.41E4 3 4 5 0
IRF     12 1.41E4 4 5 5 0
IRF     13 1.41E4 5 4 5 0
IRF     14 1.41E4 4 5 5 0
IRF     15 1.41E4 5 4 5 0
IRF     16 1.41E4 4 5 5 0
IRF     17 1.41E4 5 6 5 0
IRF     18 1.41E4 6 5 5 0
IRF     19 1.41E4 5 6 5 0
IRF     20 1.41E4 6 5 5 0
DEC     30 5 6 4 4
BUP
OUT     6 1 -1 0
TIT      IRRADIATION OF SHELL AND COVER
MOV      -1 1 0 4041
BUP
IRF      1 1.63E3 1 2 5 2
IRF      2 1.63E3 2 3 5 0
IRF      3 1.63E3 3 2 5 0
IRF      4 1.63E3 2 3 5 0
IRF      5 1.63E3 3 2 5 0
IRF      6 1.63E3 2 3 5 0
```

```
IRF      7 1.63E3 3 4 5 0
IRF      8 1.63E3 4 3 5 0
IRF      9 1.63E3 3 4 5 0
IRF     10 1.63E3 4 3 5 0
IRF     11 1.63E3 3 4 5 0
IRF     12 1.63E3 4 5 5 0
IRF     13 1.63E3 5 4 5 0
IRF     14 1.63E3 4 5 5 0
IRF     15 1.63E3 5 4 5 0
IRF     16 1.63E3 4 5 5 0
IRF     17 1.63E3 5 6 5 0
IRF     18 1.63E3 6 5 5 0
IRF     19 1.63E3 5 6 5 0
IRF     20 1.63E3 6 5 5 0
DEC     30 5 6 4 4
BUP
OUT     6 1 -1 0
END
4   260000 985. 250000 10.   60000  2.     140000 3.
STEEL
0
4   250000 20.  240000 190.  280000 95.   140000  7.5
SS 304
4   260000 687.5   0      0.0
SS304
0
4   120000 10.  240000 2.    290000 3.     130000  979.
AL 6061
4   140000 6.   0      0.0
AL 6061
0
4   10000  50.5 60000  351.3 80000  417.3  130000  149.3
RESIN
4   300000 21.1 50000  10.5  0      0.0
RESIN
0
4   250000 9.0  280000 37.5  260000 948.   60000 2.0
CONTMNT STEEL
4   140000 3.5  0      0.0
CONTMNT STEEL
0
```

14.3 References

1. Regulatory Guide 1.86, "Termination of Operating Licenses for Nuclear Reactors."

TABLE 14.1-1

DATA FOR TN-32 ACTIVATION ANALYSIS

Component	Flux (n/cm²/s)	Composition	Element	% wt
Body & Lid	2.37E+05	SA350LF3 and/or SA203	Mn	0.9
			Ni	3.75
			Fe	94.8
			C	0.2
			Si	0.35
Gamma Shield	2.37E+05	SA105	Mn	1.0
			Fe	98.5
			C	0.2
			Si	0.3
Outer Shell	1.63E+03	SA516 Gr 55	Mn	0.7
			Fe	99.3
Neutron Shield	1.41E+04	Polyester Resin Mixture	H	5.05
			B	1.05
			C	35.13
			O	41.73
			Al	14.93
			Zn	2.11
Fuel Basket (poison assumed as Al)	8.41E+05	SA240 (SS304)	Mn	2.0
			Cr	19.0
			Ni	9.5
			Si	0.75
			Fe	68.75
		SB-209 (Al 6061)	Si	0.6
			Mg	1.0
			Cr	0.2
			Cu	0.3
			Al	97.9

TABLE 14.1-2

RESULTS OF ORIGEN2 ACTIVATION ANALYSIS
Curies per Cask

Isotope	Basket	Body & Basket Rails	Resin & Alum	Shell & Cover	Total
Cr-51	4.598E-03	1.082E-04	2.424E-07	3.808E-08	4.7788E-03
Mn-54	5.564E-04	9.291E-03		2.081E-06	9.849E-03
Fe-55	6.105E-03	1.010E-01		2.261E-05	1.071E-01
Fe-59	1.129E-04	1.885E-03		4.222E-07	1.998E-03
Co-58	7.090E-04	5.740E-04			1.283E-03
Zn-65			1.535E-05		1.535E-05
H-3			2.713E-10		2.713E-10
C-14		2.257E-10	6.558E-10	5.021E-14	8.816E-10
Co-60	1.003E-05	7.954E-06	1.377E-09		1.799E-05
Ni-59	3.824E-06	3.096E-06			6.920E-06
Ni-63	4.393E-04	3.554E-04	2.650E-09		7.947E-04
				TOTAL:	1.259E-01

Note: Only the nuclides with activity greater than 10^{-10} curies and those listed in 10 CFR 61.55 are reported here.

TABLE 14.1-3

COMPARISON OF TN-32 ACTIVITY WITH CLASS A WASTE LIMITS

Specific Activity of Long-Lived Isotopes (10CFR61.55 Table 1)

Nuclide	Ci/m³	Limit (Ci/m³)	Volume (m³)	Component
C-14	---	80	1.51	Basket
Ni-59	2.532E-06	220		
C-14	3.088E-11	80	7.31	Body
Ni-59	4.235E-07	220		
C-14	2.006E-10	80	3.27	Resin
C-14	9.656E-14	80	0.52	Outer Shell

Specific Activity of Short-Lived Isotopes (10CFR61.55 Table 2)

Nuclide	Ci/m³ "A"	Limit (Ci/m³) "B"	A/B	Component
Co-60	6.642E-06	700	9.489E-09	Basket
Ni-63	2.909E-04	35	8.312E-06	
$T_{1/2} < 5$	8.001E-03	700	1.143E-05	
Total			1.975E-05	
Co-60	1.088E-06	700	1.554E-09	Body
Ni-63	4.862E-05	35	1.389E-06	
$T_{1/2} < 5$	1.542E-02	700	2.203E-05	
Total			2.343E-05	
H-3	8.297E-11	40	2.074E-12	Resin
Co-60	4.211E-10	700	6.016E-13	
Ni-63	8.104E-10	35	2.315E-11	
$T_{1/2} < 5$	4.694E-06	700	6.706E-09	
Total			6.732E-09	
$T_{1/2} < 5$	4.837E-05	700	6.910E-08	Shell

* - Sum of isotopes with half-life less than 5 years (Cr^{51}, Mn^{54}, Fe^{55}, Fe^{59}, Co^{58}, Zn^{65})

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 12, 2001

Mr. Mike Mason
Acting Vice President - Engineering
Transnuclear, Inc.
4 Skyline Drive
Hawthorne, NY 10532-2176

SUBJECT: AMENDMENT NO. 1 TO CERTIFICATE OF COMPLIANCE NO. 1021 FOR THE TRANSNUCLEAR, INC., TN-32 DRY STORAGE CASK

Dear Mr. Mason:

As requested by your applications dated April 23, 1999, as supplemented, and February 29, 2000, as supplemented, enclosed is Certificate of Compliance (CoC) No. 1021, Amendment No. 1, for the Transnuclear, Inc. (TN), TN-32 system. This certificate supersedes, in its entirety, CoC No. 1021, dated March 28, 2000. Changes made to the certificate are indicated by vertical lines in the right margin. As stated in the Federal Register (65 FR 75853, 12/05/00), the effective date of this certificate is February 20, 2001. The staff's Safety Evaluation Report is also enclosed. We request that you update and submit four copies of the final safety analysis report to conform to the certificate, as required by 10 CFR 72.248.

Amendment No. 1 to CoC No. 1021 constitutes U.S. Nuclear Regulatory Commission (NRC) approval of the following changes to the TN-32 system:

1. Addition of B&W/FCF 17 x 17 Mark BW assembly to TS 2.1, "Fuel to be stored in the TN-32 Cask," with revised bounding characteristics, and

2. Revised TS 4.3.3, "Site Specific Parameters and Analyses," to allow analysis for verification of allowable seismic loads.

This certificate constitutes the approval and conditions for use of the TN-32 for storage of spent nuclear fuel under the general licensing provisions of 10 CFR 72.210. A general license has been granted to all holders of licenses for nuclear power reactors issued under 10 CFR Part 50.

This letter also serves as a reminder for you to notify affected cask users of the effective date for this amendment. If you have any questions regarding this certificate amendment, please contact me or Ms. Mary Jane Ross-Lee of my staff at 301-415-8500.

Sincerely,

E. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Docket No.: 72-1021

Enclosures: 1. Certificate of Compliance No. 1021, Amendment No. 1
2. Safety Evaluation Report

cc: Mr. Keith Waldrop
Duke Energy Corp.

Mr. Paul Farron
Wisconsin Electric Power Company

CERTIFICATE OF COMPLIANCE FOR SPENT FUEL STORAGE CASKS

The U.S. Nuclear Regulatory Commission is issuing this Certificate of Compliance pursuant to Title 10 of the Code of Federal Regulations, Part 72, "Licensing Requirements for Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" (10 CFR Part 72). This certificate is issued in accordance with 10 CFR 72.238, certifying that the storage design and contents described below meet the applicable safety standards set forth in 10 CFR Part 72, Subpart L, and on the basis of the Final Safety Analysis Report (FSAR) of the cask design. This certificate is conditional upon fulfilling the requirements of 10 CFR Part 72, as applicable, and the conditions specified below.

Certificate No.	Effective Date	Expiration Date	Docket No.	Amendment No.	Amendment Effective Date	Package Identification No.
1021	04/19/00	04/19/20	72-1021	1	02/20/01	USA/72-1021

Issued To: (Name/Address)

Transnuclear, Inc.
4 Skyline Drive
Hawthorne, NY 10532

Safety Analysis Report Title

Transnuclear, Inc.
Final Safety Analysis Report for the TN-32 Dry Storage Cask
Docket No. 72-1021

CONDITIONS

This certificate is conditioned upon fulfilling the requirements of 10 CFR Part 72, as applicable, the attached Appendix A (Technical Specifications), and the conditions specified below:

1. CASK

a. Model Nos.: TN-32 (standard TN-32, TN-32A and TN-32B)

The TN-32 dry storage cask consists of a cask and basket assembly. The TN-32A is identical to the standard TN-32 except that it has a shorter lid assembly and longer cavity. The top and bottom plates on the top neutron shield are made correspondingly thicker to provide the same total shielding as the standard TN-32 design. The TN-32B is identical to the standard TN-32 except that the top lifting trunnions are single failure proof. The TN-32 is designed to contain up to 32 intact, unconsolidated pressurized water reactor (PWR) fuel assemblies.

b. Description

The cask which is being certified is described in the Safety Analysis Report (SAR) and in NRC's Safety Evaluation Report (SER) accompanying the Certificate of Compliance. The TN-32 dry storage cask was designed by Transnuclear to store irradiated PWR spent fuel assemblies at an independent spent fuel storage installation (ISFSI).

The TN-32 cask body is a right circular cylinder composed of the following components: confinement vessel with bolted lid closure, basket for fuel assemblies, gamma shield, trunnions, neutron shield, overpressure monitoring system, and weather cover.

1. b. Description (continued)

The confinement vessel consists of an inner shell which is a welded, carbon steel cylinder with an integrally-welded, carbon steel bottom closure; a welded flange forging; a carbon steel lid with closure bolts and inner metallic seal; and vent and drain covers with closure bolts and inner metallic seals.

The basket consists of an assembly of stainless steel cells which are welded together and separated by aluminum and neutron absorber plates. The aluminum provides heat conduction paths from the fuel assemblies to the cask cavity and the neutron absorber plates provide criticality control.

The gamma shield encloses the confinement vessel and consists of an independent shell and bottom plate of carbon steel and the steel shell of the neutron shield. Gamma shielding is also provided by the confinement lid.

There are four trunnions attached to the cask body. The top trunnions are used for lifting and the bottom trunnions may be used for rotating the unloaded cask.

The radial neutron shield consists of a borated polyester resin compound which surrounds the gamma shield. The resin compound is cast into long, slender aluminum containers which are enclosed in a smooth outer steel shell. The aluminum containers provide a conduction path for heat transfer from the cask body to the outer shell. Axial neutron shielding is provided by a polypropylene disk placed on the cask lid.

The overpressure monitoring system is used to monitor the pressure in the interspace between the inner and outer seals on the lid, vent, and drain port covers. The overpressure monitoring system consists of a tank filled with helium, pressure transducers or switches, and associated tubing, fittings, and valves.

The torispherical weather cover with a Viton o-ring provides weather protection for the closure lid and seal components, the top neutron shield, and the overpressure system.

The auxiliary equipment necessary for ISFSI operation is not included as part of the TN-32 cask system reviewed for a Certificate of Compliance under 10 CFR Part 72, Subpart L. Such equipment may include, but is not limited to, special lifting devices, transfer trailers or equipment, and vacuum drying/helium leak test equipment.

2. OPERATING PROCEDURES

Written operating procedures shall be prepared for cask handling, loading, unloading, movement, surveillance, and maintenance. The user's site-specific written operating procedures shall be consistent with the technical basis described in Chapter 8 of the SAR.

3. ACCEPTANCE TEST AND MAINTENANCE PROGRAM

Written cask acceptance tests and a maintenance program shall be prepared consistent with the technical basis described in Chapter 9 of the SAR.

CERTIFICATE OF COMPLIANCE
FOR SPENT FUEL STORAGE CASKS
Supplemental Sheet

4. QUALITY ASSURANCE

Activities in the areas of design, procurement, fabrication, assembly, inspection, testing, operation, maintenance, repair, modification of structures, systems and components, and decommissioning that are important to safety shall be conducted in accordance with a Commission-approved quality assurance program which satisfies the applicable requirements of 10 CFR Part 72, Subpart G, and which is established, maintained, and executed with regard to the cask system.

5. HEAVY LOADS REQUIREMENTS

Each licensed facility must ensure that cask lifting is evaluated in accordance with the existing heavy loads requirements and procedures of the licensed facility in which the lift is made. An additional safety review (under 10 CFR 50.59 or 10 CFR 72.48, if applicable) is required to show operational compliance with existing facility/site-specific heavy loads requirements. The TN-32B lifting attachments have been designed as single failure proof, and are acceptable for use at sites that require single failure proof.

6. APPROVED CONTENTS

Contents of the TN-32 system must meet the specifications given in Appendix A to this certificate.

7. DESIGN FEATURES

Features or characteristics for the site, cask, or ancillary equipment must be in accordance with Appendix A to this certificate.

8. PRE-OPERATIONAL TESTING AND TRAINING EXERCISE

A dry run training exercise of the loading, closure, handling, unloading and transfer of the TN-32 cask shall be conducted by the cask user prior to the first use of the system to load spent fuel assemblies. The dry run may be performed in an alternate step sequence from the actual procedures. The dry run shall include but is not limited to the following:

Preparation of the TN-32 cask for loading and moving the TN-32 cask into the spent fuel pool.

Selection and verification of specific fuel assemblies to ensure type conformance.

Loading a dummy fuel assembly into the TN-32 and performing appropriate independent verification.

Installation of the TN-32 lid and removal of the TN-32 cask from the spent fuel pool.

Cask draining, vacuum drying, helium backfilling, and leakage testing.

Loading the TN-32 cask onto the cask transporter.

Transferring the cask to the ISFSI.

Placement of the TN-32 cask at the ISFSI.

Unloading operations including reflooding.

9. SPECIAL REQUIREMENTS FOR CASK THERMAL TESTING

Each agent and/or subcontractor authorized by the certificate holder to complete final assembly of the TN-32 cask body fabricated under this Certificate of Compliance, shall verify the heat transfer performance of a single cask. This test shall be performed prior to the first loading of any cask assembled by that agent and/or subcontractor with a heat load equal to or greater than 23.7 kilowatts.

A letter report summarizing the test performed, measured temperature data, and the calculated results of the test shall be submitted to the NRC in accordance with 10 CFR 72.4 at least 30 days prior to use of a cask loaded with a heat load equal to or greater than 23.7 kilowatts.

Proposed modifications to the fabrication process shall be evaluated for their potential to impact the heat transfer performance of the cask body. If the modification could result in adverse impact to the heat transfer performance of the cask body, the heat transfer performance of the modified cask shall be verified by an additional thermal test, prior to loading the first modified cask with a heat load equal to or greater than 23.7 kilowatts. The results of additional thermal tests shall be retained in accordance with 10 CFR 72.234(d).

10. CHANGES TO THE CERTIFICATE OF COMPLIANCE

The holder of this certificate who desires to make changes to this certificate, which includes Appendix A (Technical Specifications), shall submit an application for amendment of the certificate.

11. AUTHORIZATION

The TN-32 system, which is authorized by this certificate, is hereby approved for general use by holders of 10 CFR Part 50 licenses for nuclear reactors at reactor sites under the general license issued pursuant to 10 CFR 72.210, subject to the conditions specified by 10 CFR 72.212, and the attached Appendix A.

FOR THE NUCLEAR REGULATORY COMMISSION

E. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Attachment: Appendix A

TN-32 GENERIC TECHNICAL SPECIFICATION

TABLE OF CONTENTS

1.0 USE AND APPLICATION

1.1 Definitions

NOTE

The defined terms of this section appear in capitalized type and are applicable throughout these Technical Specifications and Bases.

Term	Definition
ACTIONS	ACTIONS shall be that part of a Specification that prescribes Required Actions to be taken under designated Conditions within specified Completion Times.
CHANNEL OPERATIONAL TEST (COT)	A CHANNEL OPERATIONAL TEST (COT) shall be the injection of a simulated or actual signal into the channel as close to the sensor as practicable to verify the operability of required alarm functions. The COT shall include adjustments, as necessary, of the required alarm setpoint so that the setpoint is within the required range and accuracy.
INTACT FUEL ASSEMBLY	Spent Nuclear Fuel Assemblies without known or suspected cladding defects greater than pinhole leaks or hairline cracks and which can be handled by normal means. Partial fuel assemblies, that is fuel assemblies from which fuel rods are missing, shall not be classified as INTACT FUEL ASSEMBLIES unless dummy fuel rods are used to displace an amount of water equal to or greater than that displaced by the original fuel rod(s).
LOADING OPERATIONS	LOADING OPERATIONS include all licensed activities on a cask while it is being loaded with fuel assemblies. LOADING OPERATIONS begin when the first fuel assembly is placed in the cask and end when the cask is supported by the transporter.
STORAGE OPERATIONS	STORAGE OPERATIONS include all licensed activities that are performed at the Independent Spent Fuel Storage Installation (ISFSI) while a cask containing spent fuel is sitting on a storage pad within the ISFSI.
TRANSPORT OPERATIONS	TRANSPORT OPERATIONS include all licensed activities performed on a cask loaded with one or more fuel assemblies when it is being moved to and from the ISFSI. TRANSPORT OPERATIONS begin when the cask is first suspended from the transporter and end when the cask is at its destination and no longer supported by the transporter.
UNLOADING OPERATIONS	UNLOADING OPERATIONS include all licensed activities on a cask while fuel assemblies are being unloaded. UNLOADING OPERATIONS begin when the cask is no longer supported by the transporter and end when the last fuel assembly is removed from the cask.

1.0 USE AND APPLICATION

1.2 Logical Connectors

PURPOSE

The purpose of this section is to explain the meaning of logical connectors.

Logical connectors are used in Technical Specifications (TS) to discriminate between, and yet connect, discrete Conditions, Required Actions, Completion Times, Surveillances, and Frequencies. The only logical connectors that appear in TS are AND and OR. The physical arrangement of these connectors constitutes logical conventions with specific meanings.

BACKGROUND

Several levels of logic may be used to state Required Actions. These levels are identified by the placement (or nesting) of the logical connectors and by the number assigned to each Required Action. The first level of logic is identified by the first digit of the number assigned to a Required Action and the placement of the logical connector in the first level of nesting (i.e., left justified with the number of the Required Action). The successive levels of logic are identified by additional digits of the Required Action number and by successive indentions of the logical connectors.

When logical connectors are used to state a Condition, Completion Time, Surveillance, or Frequency, only the first level of logic is used, and the logical connector is left justified with the statement of the Condition, Completion Time, Surveillance, or Frequency.

EXAMPLES

The following examples illustrate the use of logical connectors:

EXAMPLE 1.2-1:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Verify . . . AND A.2 Restore . . .	

In this example the logical connector AND is used to indicate that when in Condition A, both Required Actions A.1 and A.2 must be completed.

1.2 Logical Connectors

EXAMPLES (continued)

EXAMPLE 1.2-2:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Stop . . . OR A.2.1 Verify . . . AND A.2.2.1 Reduce . . . OR A.2.2.2 Perform . . . OR A.3 Remove . . .	

This example represents a more complicated use of logical connectors. Required Actions A.1, A.2, and A.3 are alternative choices, only one of which must be performed as indicated by the use of the logical connector OR and the left justified placement. Any one of these three Actions may be chosen. If A.2 is chosen, then both A.2.1 and A.2.2 must be performed as indicated by the logical connector AND. Required Action A.2.2 is met by performing A.2.2.1 or A.2.2.2. The indented position of the logical connector OR indicates that A.2.2.1 and A.2.2.2 are alternative choices, only one of which must be performed.

1.0 USE AND APPLICATION

1.3 Completion Times

PURPOSE

The purpose of this section is to establish the Completion Time convention and to provide guidance for its use.

BACKGROUND

Limiting Conditions for Operation (LCOs) specify minimum requirements for ensuring safe operation of the cask. The ACTIONS associated with an LCO state Conditions that typically describe the ways in which the requirements of the LCO can fail to be met. Specified with each stated Condition are Required Action(s) and Completion Times(s).

DESCRIPTION

The Completion Time is the amount of time allowed for completing a Required Action. It is referenced to the time of discovery of a situation (e.g., equipment or variable not within limits) that requires entering an ACTIONS Condition unless otherwise specified, providing the cask is in a specified condition stated in the Applicability of the LCO. Required Actions must be completed prior to the expiration of the specified Completion Time. An ACTIONS Condition remains in effect and the Required Actions apply until the Condition no longer exists or the cask is not within the LCO Applicability.

Once a Condition has been entered, subsequent subsystems, components, or variables expressed in the Condition, discovered to be not within limits, will not result in separate entry into the Condition unless specifically stated. The Required Actions of the Condition continue to apply to each additional failure, with Completion Times based on initial entry into the Condition.

1.3 Completion Times

EXAMPLES

The following examples illustrate the use of Completion Times with different types of Conditions and changing Conditions:

EXAMPLE 1.3-1:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2	12 hours 36 hours

Condition B has two Required Actions. Each Required Action has its own separate Completion Time. Each Completion Time is referenced to the time that Condition B is entered.

The Required Actions of Condition B are to complete action B.1 within 12 hours AND to complete action B.2 within 36 hours. A total of 12 hours is allowed for completing action B.1 and a total of 36 hours (not 48 hours) is allowed for completing action B.2 from the time that Condition B was entered. If action B.1 is completed within 6 hours, the time allowed for completing action B.2 is the next 30 hours because the total time allowed for completing action B.2 is 36 hours.

1.3 Completion Times

EXAMPLES (continued).

EXAMPLE 1.3-2:

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. One system not within limit	A.1 Restore system to within limit.	7 days
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	12 hours 36 hours

When a system is determined to not meet the LCO, Condition A is entered. If the system is not restored within 7 days, Condition B is also entered and the Completion Time clocks for Required Actions B.1 and B.2 start. If the system is restored after Condition B is entered, Condition A and B are exited, and therefore, the Required Actions of Condition B may be terminated.

1.3 Completion Times

EXAMPLES (continued)

EXAMPLE 1.3-3:

ACTIONS

-----NOTE-----
Separate Condition entry is allowed for each component.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. LCO not met.	A.1 Restore compliance with LCO.	4 hours
B. Required Action and associated Completion Time not met.	B.1 Perform Action B.1. AND B.2 Perform Action B.2.	12 hours 36 hours

The Note above the ACTIONS Table is a method of modifying how the Completion Time is tracked. If this method of modifying how the Completion Time is tracked was applicable only to a specific Condition, the Note would appear in that Condition rather than at the top of the ACTIONS Table.

The Note allows Condition A to be entered separately for each component, and Completion Times tracked on a per component basis. When a component does not meet the LCO, Condition A is entered and its Completion Time starts. If subsequent components are determined Not to meet the LCO, Condition A is entered for each component and separate Completion Times start and are tracked for each component.

IMMEDIATE

When "Immediately" is used as a Completion Time, the COMPLETION TIME Required Action should be pursued without delay and in a controlled manner.

1.0 USE AND APPLICATION

1.4 Frequency

PURPOSE

The purpose of this section is to define the proper use and application of Frequency requirements.

DESCRIPTION

Each Surveillance Requirement (SR) has a specified Frequency in which the Surveillance must be met in order to meet the associated Limiting Condition for Operation (LCO). An understanding of the correct application of the specified Frequency is necessary for compliance with the SR.

The "specified Frequency" is referred to throughout this section and each of the Specifications of Section 3.0, Surveillance Requirement (SR) Applicability. The "specified Frequency" consists of the requirements of the Frequency column of each SR, as well as certain Notes in the Surveillance column that modify performance requirements.

Situations where a Surveillance could be required (i.e., its Frequency could expire), but where it is not possible or not desired that it be performed until sometime after the associated LCO is within its Applicability, represent potential SR 3.0.4 conflicts. To avoid these conflicts, the SR (i.e., the Surveillance or the Frequency) is stated such that it is only "required" when it can be and should be performed. With an SR satisfied, SR 3.0.4 imposes no restriction.

The use of "met" or "performed" in these instances conveys specific meanings. A Surveillance is "met" only when the acceptance criteria are satisfied. Known failure of the requirements of a Surveillance, even without a Surveillance specifically being "performed," constitutes a Surveillance not "met."

1.4 Frequency

EXAMPLES

The following examples illustrate the various ways that Frequencies are specified:

EXAMPLE 1.4-1:

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify Pressure within limit.	12 hours

Example 1.4-1 contains the type of SR most often encountered in the Technical Specifications (TS). The Frequency specifies an interval (12 hours) during which the associated Surveillance must be performed at least one time. Performance of the Surveillance initiates the subsequent interval. Although the Frequency is stated as 12 hours, an extension of the time interval to 1.25 times the interval specified in the Frequency is allowed by SR 3.0.2 for operational flexibility. The measurement of this interval continues at all times, even when the SR is not required to be met per SR 3.0.1 (such as when the equipment is determined to not meet the LCO, a variable is outside specified limits, or the unit is outside the Applicability of the LCO). If the interval specified by SR 3.0.2 is exceeded while the cask is in a condition specified in the Applicability of the LCO, the LCO is not met in accordance with SR 3.0.1.

If the interval as specified by SR 3.0.2 is exceeded while the unit is not in a condition specified in the Applicability of the LCO for which performance of the SR is required, the Surveillance must be performed within the Frequency requirements of SR 3.0.2 prior to entry into the specified condition. Failure to do so would result in a violation of SR 3.0.4.

1.4 Frequency

EXAMPLES (continued)

EXAMPLE 1.4-2:

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
Verify flow is within limits.	Once within 12 hours prior to starting activity AND 24 hours thereafter

Example 1.4-2 has two Frequencies. The first is a one time performance Frequency, and the second is of the type shown in Example 1.4-1. The logical connector "AND" indicates that both Frequency requirements must be met. Each time the example activity is to be performed, the Surveillance must be performed prior to starting the activity.

The use of "once" indicates a single performance will satisfy the specified Frequency (assuming no other Frequencies are connected by "AND"). This type of Frequency does not qualify for the 25% extension allowed by SR 3.0.2.

"Thereafter" indicates future performances must be established per SR 3.0.2, but only after a specified condition is first met (i.e., the "once" performance in this example). If the specified activity is canceled or not performed, the measurement of both intervals stops. New intervals start upon preparing to restart the specified activity.

2.0 Functional and Operating Limits

2.1 Fuel To Be Stored In The TN-32 Cask

The spent nuclear fuel to be stored in the TN-32 cask shall meet the following requirements:

a. Fuel shall be unconsolidated INTACT FUEL ASSEMBLIES.

b. Fuel shall be limited to fuel with zircaloy cladding.

c. Fuel types shall be limited to the fuel types below with maximum uranium content as follows:

Westinghouse 14x14 Std ZCA and ZCB:	0.4144 MTU/assy.
Westinghouse 15x15:	0.4671 MTU/assy.
Westinghouse 17x17 Std:	0.4671 MTU/assy.
Westinghouse 14x14 OFA:	0.3611 MTU/assy.
Westinghouse 17x17 OFA:	0.4282 MTU/assy.
B&W/FCF 17x17 Mark BW:	0.4632 MTU/assy.

d. Fuel may include burnable poison rod assemblies (BPRA's) having the acceptable combination of burnup and cooling time described by Figure 2.1.1-1.

e. Fuel may include thimble plug assemblies (TPA's) having the acceptable combination of burnup and cooling time described by Figure 2.1.1-2.

f. Fuel assemblies shall have the following bounding characteristics:

i. The maximum initial enrichment shall not exceed 4.05 weight percent. The determination of fuel enrichment shall not be based on average values that include low enrichment axial reflector blankets.

ii. The maximum assembly average burnup shall not exceed 45,000 MWD/MTU

iii. The minimum cooling time prior to loading shall be as specified in Table 2.1.1-1.

iv. The maximum heat load per assembly shall not exceed 1.02 kW with or without BPRA's or TPA's.

v. The fuel assembly weight with hardware shall not exceed 1533 lbs.

2.2 Functional and Operating Limits Violations

If any Functional and Operating Limit of 2.1 is violated, the following actions shall be completed:

2.2.1 The affected fuel assemblies shall be removed from the cask and placed in a safe condition.

2.2.2 Within 24 hours, notify the NRC Operations Center.

2.2.3 Within 30 days, submit a special report which describes the cause of the violation and the actions taken to restore compliance and prevent recurrence.

Table 2.1.1-1
Minimum Acceptable Cooling Time as a Function of Burnup and Initial Enrichment

Min. Init. Enrichment (% wt)(1)	Maximum Burnup (GWd/MTU)(2)																
	15	20	30	32	33	34	35	36	37	38	39	40	41	42	43	44	45
1.2	7	7															
1.3	7	7															
1.4	7	7															
1.5	7	7	7	8	8	8	8	9									
1.6	7	7	7	7	8	8	8	9	9	9	9						
1.7	7	7	7	7	8	8	8	8	9	9	9	10					
1.8	7	7	7	7	7	8	8	8	9	9	9	10					
1.9	7	7	7	7	7	7	8	8	8	9	9	9	10	10			
2.0	7	7	7	7	7	7	8	8	8	8	9	9	9	10	10		
2.1	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10		
2.2	7	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10	
2.3	7	7	7	7	7	7	7	7	8	8	8	9	9	9	10	10	
2.4	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9	10	10
2.5	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9	10
2.6	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	10
2.7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9
2.8	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9	9
2.9	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8	9	9
3.0	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	9	9
3.1	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	9	9
3.2	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8	8
3.3	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8
3.4	7	7	7	7	7	7	7	7	7	7	7	7	7	7	8	8	8
3.5	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
3.9	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
4.05	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7

■ - not evaluated

(1) Round actual value down to next lower tenth.
(2) Round actual value up to next higher GWd/MTU.

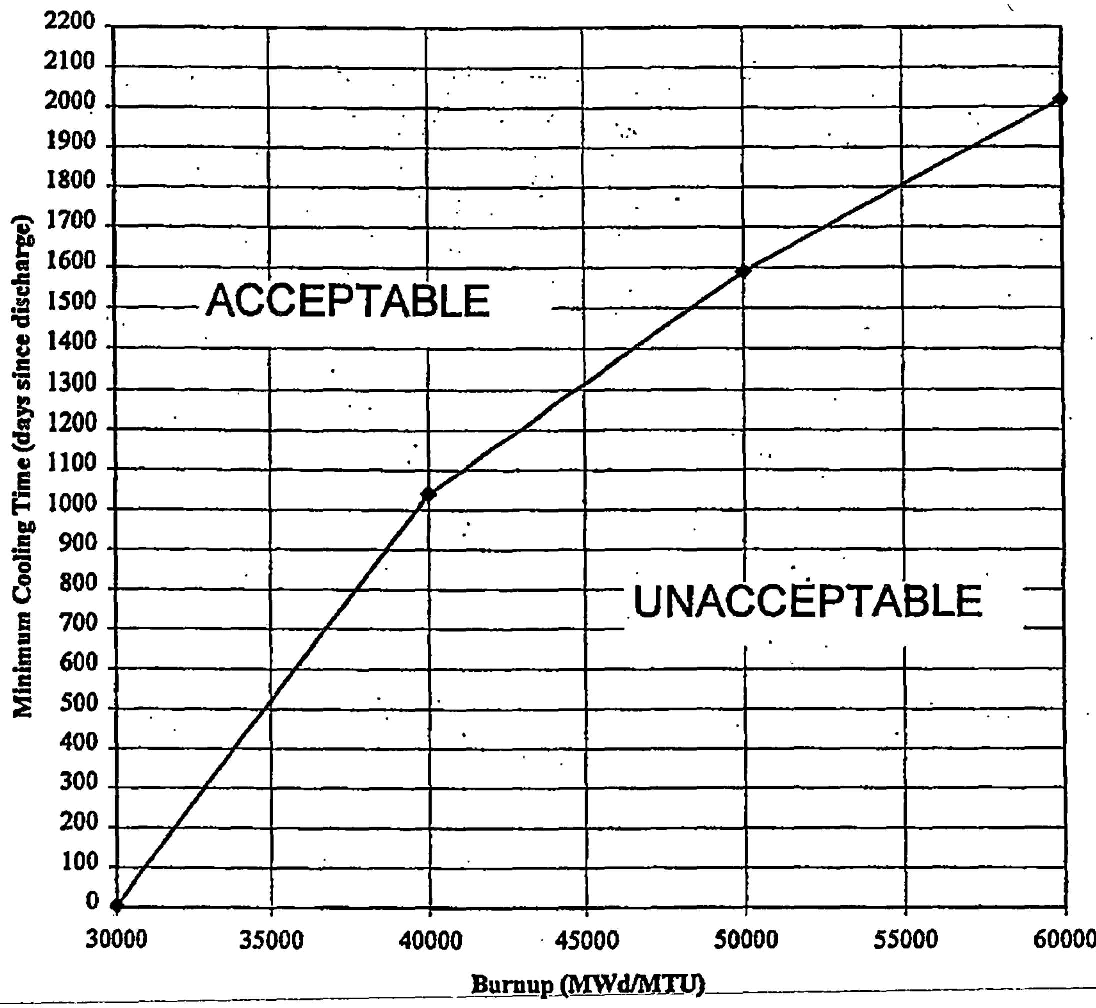

Figure 2.1.1-1
Burnable Poison Rod Assemblies (BPRAs)
Minimum Acceptable Cooling Time as a Function of Burnup

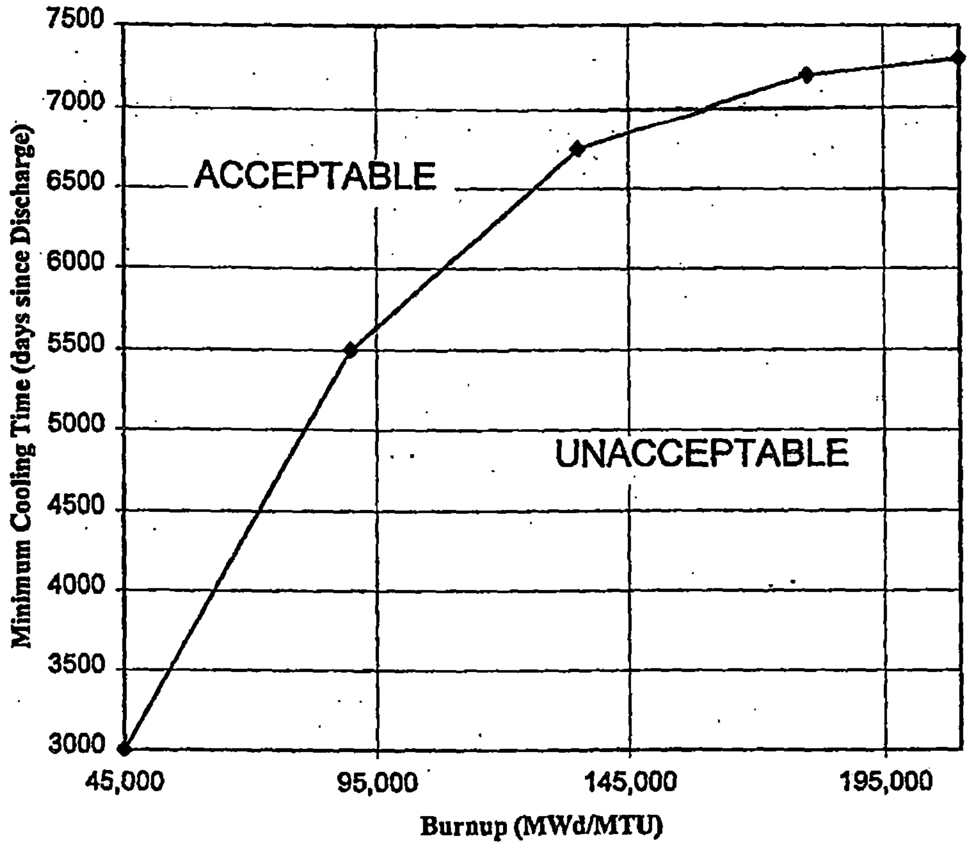

Figure 2.1.1-2
Thimble Plug Assemblies (TPAs)
Minimum Acceptable Cooling Time as a Function of Burnup

3.0 LIMITING CONDITION FOR OPERATION (LCO) APPLICABILITY

LCO 3.0.1	LCOs shall be met during specified conditions in the Applicability, except as provided in LCO 3.0.2.
LCO 3.0.2	Upon discovery of a failure to meet an LCO, the Required Actions of the associated Conditions shall be met, except as provided in LCO 3.0.5. If the LCO is met or is no longer applicable prior to expiration of the specified Completion Time(s), completion of the Required Action(s) is not required, unless otherwise stated.
LCO 3.0.3	Not applicable to a cask.
LCO 3.0.4	When an LCO is not met, entry into a specified condition in the Applicability shall not be made except when the associated ACTIONS to be entered permit continued operation in the specified condition in the Applicability for an unlimited period of time. This Specification shall not prevent changes in specified conditions in the Applicability that are required to comply with ACTIONS, or that are related to the unloading of a cask. Exceptions to this Specification are stated in the individual Specifications. These exceptions allow entry into specified conditions in the Applicability when the associated ACTIONS to be entered allow operation in the specified condition in the Applicability only for a limited period of time.
LCO 3.0.5	Equipment removed from service or not in service in compliance with ACTIONS may be returned to service under administrative control solely to perform testing required to demonstrate it meets the LCO or that other equipment meets the LCO. This is an exception to LCO 3.0.2 for the system returned to service under administrative control to perform the testing required to demonstrate that the LCO is met.
LCO 3.0.6	Not applicable to a cask.
LCO 3.0.7	Not applicable to a cask.

3.0 SURVEILLANCE REQUIREMENT (SR) APPLICABILITY

SR 3.0.1	SRs shall be met during the specified conditions in the Applicability for individual LCOs, unless otherwise stated in the SR. Failure to meet a Surveillance, whether such failure is experienced during the performance of the Surveillance or between performances of the Surveillance, shall be failure to meet the LCO. Failure to perform a Surveillance within the specified Frequency shall be failure to meet the LCO except as provided in SR 3.0.3. Surveillances do not have to be performed on equipment or variables outside specified limits.
SR 3.0.2	The specified Frequency for each SR is met if the Surveillance is performed within 1.25 times the interval specified in the Frequency, as measured from the previous performance or as measured from the time a specified condition of the Frequency is met. For Frequencies specified as "once," the above interval extension does not apply. If a Completion Time requires periodic performance on a "once per . . ." basis, the above Frequency extension applies to each performance after the initial performance. Exceptions to this Specification are stated in the individual Specifications.
SR 3.0.3	If it is discovered that a Surveillance was not performed within its specified Frequency, then compliance with the requirement to declare the LCO not met may be delayed, from the time of discovery, up to 24 hours or up to the limit of the specified Frequency, whichever is less. This delay period is permitted to allow performance of the Surveillance. If the Surveillance is not performed within the delay period, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered. When the Surveillance is performed within the delay period and the Surveillance is not met, the LCO must immediately be declared not met, and the applicable Condition(s) must be entered.
SR 3.0.4	Entry into a specified condition in the Applicability of an LCO shall not be made unless the LCO's Surveillances have been met within their specified Frequency. This provision shall not prevent entry into specified conditions in the Applicability that are required to comply with ACTIONS or that are related to the unloading of a cask.

3.1 CASK INTEGRITY

3.1.1 Cask Cavity Vacuum Drying

LCO 3.1.1 The cask cavity vacuum drying pressure shall be sustained at or below 4 mbar absolute for a period of at least 30 minutes after isolation from the pumping system.

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

----- NOTE -----

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
-----NOTE----- Not applicable until SR 3.1.1.1 is performed. ---------- A. Cask cavity vacuum drying pressure limit not met.	-----NOTE----- Action A.1 applies until helium is removed for subsequent operations. ---------- A.1 Achieve or maintain a nominal helium environment in the cask AND A.2 Establish cask cavity drying pressure within limits.	 12 hours 96 hours
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the cask.	7 days

C. Required Action A.2 and associated Completion Time not met.	C.1 Remove all fuel assemblies from the cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.1.1.1	Verify that the equilibrium cask cavity vacuum drying pressure is brought to ≤ 4 mbar absolute for at least 30 minutes.	Once, within 24 hours of completion of cask draining.

3.1 CASK INTEGRITY

3.1.2 Cask Helium Backfill Pressure

LCO 3.1.2 The cask cavity shall be filled with helium to a pressure of 2230 mbar absolute (± 100 mbar).

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

------------------------- NOTE -------------------------

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
---------NOTE--------- Not applicable until SR 3.1.2.1 is performed.	---------NOTE--------- Action A.1 applies until helium is removed for subsequent operations	
A. Cask initial helium backfill pressure limit not met.	A.1 Achieve or maintain a nominal helium environment in the cask AND A.2 Establish cask cavity backfill pressure within limits.	6 hours 48 hours
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from the cask.	7 days
C. Required Action A.2 and associated Completion Time not met.	C.1 Remove all fuel assemblies from the cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.2.1 Verify that the cask cavity helium pressure is 2230 mbar absolute (± 100 mbar).	Once, within 30 hours of completion of cask draining.

3.1 CASK INTEGRITY

3.1.3 Cask Helium Leak Rate

LCO 3.1.3 The combined helium leak rate for all closure seals shall not exceed 1.0 E-5 std cc/sec.

APPLICABILITY: During LOADING OPERATIONS.

ACTIONS

-NOTE-
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
-NOTE- Not applicable until SR 3.1.3.1 is performed. A. Cask helium leak rate not met.	A.1 Establish cask helium leak rate within limit.	48 hours
B. Required Action A.1 and associated Completion Time are not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.3.1 Verify the cask helium leak rate is within the limit.	Once, prior to TRANSPORT OPERATIONS.

3.1 CASK INTEGRITY

3.1.4 Combined Helium Leak Rate

LCO 3.1.4 The combined helium leak rate for all closure seals and the overpressure system shall not exceed 1.0 E-5 std cc/sec.

APPLICABILITY: During STORAGE.

ACTIONS

---NOTE---
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
---NOTE--- Not applicable until SR 3.1.4.1 is performed. --- A. Combined helium leak rate not met.	A.1 Establish combined helium leak rate within limit.	48 hours
B. Required Action A.1 and associated Completion Time are not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
---NOTE--- This surveillance may be combined with SR 3.1.3.1. --- SR 3.1.4.1 Verify the combined helium leak rate is within the limit.	Once prior to TRANSPORT OPERATIONS <u>OR</u> Once within 48 hours of commencing STORAGE OPERATIONS.

3.1 CASK INTEGRITY

3.1.5 Cask Interseal Pressure

LCO 3.1.5 Cask interseal pressure shall be maintained at a pressure of at least 3.2 atm abs

APPLICABILITY: During STORAGE OPERATIONS.

ACTIONS

---NOTE---
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Cask interseal pressure below limit.	A.1 Reestablish cask interseal pressure above limit.	7 days
B. Required Action A.1 and associated Completion Time not met.	B.1 Remove all fuel assemblies from cask.	30 days

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.5.1 Verify cask interseal helium pressure above limit.	7 days
SR 3.1.5.2 Perform a CHANNEL OPERATIONAL TEST (COT) to verify proper functioning of pressure switch / transducer on cask overpressure system.	Once, within 7 days of commencing STORAGE OPERATIONS and every 36 months thereafter

3.1 CASK INTEGRITY

3.1.6 Cask Minimum Lifting Temperature

LCO 3.1.6 The loaded cask shall not be lifted if the outer surface of the cask is below -20°F.

APPLICABILITY: During TRANSPORT OPERATIONS

ACTIONS

-- NOTE --

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Cask surface temperature below limit.	A.1 Lower cask to safe position	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.1.6.1 Verify outer surface temperature is above limit.	Once, immediately prior to lifting cask and prior to cask transfer to or from ISFSI.

3.2 CASK RADIATION PROTECTION

3.2.1 Cask Surface Contamination

LCO 3.2.1 Removable contamination on the cask exterior surfaces shall not exceed:

a. 1000 dpm / 100 cm^2 (0.2 Bq / cm^2) from beta and gamma sources, and
b. 20 dpm / 100 cm^2 (0.003 Bq / cm^2) from alpha sources.

APPLICABILITY: During LOADING OPERATIONS

ACTIONS

———NOTE———
Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Removable contamination on the cask exterior surface exceeds either limit.	A.1 Decontaminate cask surfaces to below required levels.	Prior to TRANSPORT OPERATIONS

SURVEILLANCE REQUIREMENTS

SURVEILLANCE	FREQUENCY
SR 3.2.1.1 Verify that the removable contamination on the exterior surface of the cask does not exceed the specified limits.	Once, prior to TRANSPORT OPERATIONS.

3.3 CASK CRITICALITY CONTROL

3.3.1 Dissolved Boron Concentration

LCO 3.3.1 The dissolved boron concentration of the water in the spent fuel pool and the water added to the cavity of a loaded cask shall be at least 2300 ppm.

APPLICABILITY: During LOADING and UNLOADING OPERATIONS

ACTIONS

------------------------------ NOTE ------------------------------

Separate Condition entry is allowed for each cask.

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. Dissolved boron concentration limit not met.	A.1 Suspend loading of fuel assemblies into cask.	Immediately
	AND	
	A.2 Remove all fuel assemblies from cask.	24 hours

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.3.1.1	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the cask cavity is met using two independent measurements.	Within 4 hours prior to commencing LOADING OPERATIONS AND 48 hours thereafter while the cask is in the spent fuel pool or while water is in cask.
SR 3.3.1.2	Verify dissolved boron concentration limit in spent fuel pool water and water to be added to the cask cavity is met using two independent measurements.	Once, within 4 hours prior to flooding cask during UNLOADING OPERATIONS AND 48 hours thereafter while the cask is in the spent fuel pool or while water is in cask.

4.0 DESIGN FEATURES

The specifications in this section include the design characteristics of special importance to each of the physical barriers and to maintenance of safety margins in the cask design. The principal objective of this category is to describe the design envelope which might constrain any physical changes to essential equipment. Included in this category are the site environmental parameters which provide the bases for design, but are not inherently suited for description as LCOs.

4.1 Storage Cask

4.1.1 Criticality

The design of the storage cask, including spatial constraints on adjacent assemblies (minimum basket cell opening of 8.64 in. sq.) and the boron content of the basket material (minimum areal density equal to 10 mg B^{10}/cm^2) shall ensure that fuel assemblies are maintained in a subcritical condition with a k_{eff} of less than 0.95 under all conditions of operation.

4.1.2 Structural Performance

The cask has been evaluated for a cask tipover (equivalent to a side drop of 67 g's) and a bottom end drop resulting in an axial gravitational (g) loading of 50 g's.

4.1.3 Codes and Standards

The TN-32 cask confinement boundary is designed and fabricated in accordance with Subsection NB of the ASME Code. Exceptions to the code are listed in Table 4.1-1. The cask gamma shielding has been evaluated in accordance with Subsection NB of the ASME code with the exceptions listed in Table 4.1-1. The basket is designed in accordance with Subsection NF of the ASME Code. The basket is inspected as shown in Table 4.1-1.

Proposed alternatives to ASME Code Section III, 1992 Edition including exceptions allowed by Table 4.1-1 may be used when authorized by the Director of the Office of Nuclear Material Safety and Safeguards or Designee. The applicant should demonstrate that:

1. The Proposed alternatives would provide an acceptable level of quality and safety, or

2. Compliance with the specified requirements of ASME Code, Section III, 1992 Edition would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

Requests for exceptions in accordance with this section should be submitted in accordance with 10 CFR 72.4.

4.1.4 Helium Purity

The cask shall be filled with helium with a purity of at least 99.99%. This level of purity will ensure that the residual impurities in the cask cavity will be less than 1 mole.

4.2 Storage Pad

4.2.1 Storage Locations for Casks

Casks shall be spaced a minimum of 16 feet apart, center-to-center. This minimum spacing will ensure the proper dissipation of radiant heat energy from an array of casks as assumed in the TN-32 Safety Analysis Report.

4.2.2 Pad Properties to Limit Cask Gravitational Loadings Due to Postulated Drops

The TN-32 cask has been evaluated for cask drops onto a reinforced concrete pad. The evaluations are based on the following parameters:

Concrete thickness	36 inches (max)
Nominal concrete compressive strength	6000 psi (max)
Reinforcement Yield Strength	60,000 psi (min)
Soil Effective Modulus of Elasticity	32,600 psi (max)
Maximum drop height	18 inches

This set of limits will ensure that the g loading imposed on the cask is no more than 50 g's (cask bottom end drop).

4.3 Site Specific Parameters and Analyses

Site specific parameters and analyses that shall need verification by the system user are, as a minimum, as follows:

1. Tornado maximum wind speeds: 290 mph rotational
   70 mph translational

2. Flood levels up to 57 ft. and drag forces up to 57,160 lbs.

3. Seismic loads of up to 0.26g horizontal and 0.17g vertical , or

   Analyses to provide verification that loads associated with a design basis seismic event do not cause the cask to slide or to tip over, as follows.

   (a) For sliding analysis, a coefficient-of-friction of 0.35 is assumed and a factor-of-safety of 1.1 is used (as recommended by ANSI / ANS-57.9, Section 6.17.4.1). The following relationship of horizontal seismic acceleration to corresponding vertical seismic acceleration shall be met at any time:

   $$\frac{0.35(1-g_v)}{g_h} \geq 1.1$$

   Where:

   g_h = Horizontal seismic acceleration.

   g_v = Corresponding vertical seismic acceleration.

   (b) For tipover analysis, a factor-of-safety of 1.1 is used (as recommended by ANSI / ANS-57.9, Section 6.17.4.1). The following relationship of horizontal seismic acceleration to corresponding vertical seismic acceleration shall be met at any time:

$$\frac{g_h L_v + g_v L_r}{L_r} \le \frac{1}{1.1}$$

Where:

g_h = Horizontal seismic acceleration.

g_v = Corresponding vertical seismic acceleration.

L_v = Vertical distance from cask base to cask C. G.

L_r = Radial distance from cask base perimeter to cask C. G.

4. Average daily ambient temperatures: ≥ -20°F minimum
≤ 100°F maximum

5. The potential for fires and explosions shall be addressed, based on site-specific considerations. Fires and explosions should be bounded by the cask design bases parameters of 200 gallons of fuel (in the tank of the transporter vehicle) and an external pressure of 25 psig.

6. Supplemental Shielding: In cases where engineered features (i.e. berms, shield walls) are used to ensure that the requirements of 10 CFR 72.104(a) are met, such features are to be considered important to safety and must be evaluated to determine the applicable Quality Assurance Category.

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Table 4.1-1
TN-32 ASME Code Exceptions

List of ASME Code Exceptions for TN-32 Dry Storage Cask Confinement Boundary/Gamma Shielding/Basket

The cask confinement boundary is designed in accordance with the ASME Code Subsection NB. The basket was also designed in accordance with ASME Code Subsection NF. The Gamma shielding, which is primarily for shielding, but also provides structural support to the confinement boundary during drop accidents, was not designed in accordance with the code. The analysis of the gamma shielding is in accordance with Subsection NB. Inspections of the gamma shielding are performed in accordance with the ASME Code as detailed in the SAR.

Component	**Reference ASME Code/Section**	**Code Requirement**	**Exception, Justification & Compensatory Measures**
TN-32 Cask	NB-1100	Stamping and preparation of reports by the Certificate Holder	The TN-32 cask is not N stamped, nor is there a code design specification generated. A design criteria document was generated in accordance with TN's QA Program, and the design and analysis is provided in the SAR.
TN-32 Cask	NCA-3800	Quality Assurance Requirements	The Quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are imposed in lieu of NCA-3800 requirements.
Lid Bolts	NB-3232.3	Fatigue analysis of bolts	A fatigue analysis of the bolts is not performed for storage, since the bolts are not subject to significant cyclical loads.
Gamma Shielding	NB-1132.2	Non-pressure retaining structural attachments shall conform to Subsection NF	The primary function of the gamma shield is shielding, although credit is taken for the gamma shielding in the structural analysis. The welds are examined in accordance with NF acceptance criteria. A fracture toughness evaluation is presented in Appendix 3E of the SAR.
Pressure test of the confinement boundary	NB-6110	All pressure retaining components shall be pressure tested.	The TN-32 cask is not pressure limited. All confinement welds are fully radiographed. In addition, the gamma shielding supports the confinement boundary under all conditions, so a pressure test of the confinement vessel separately will not simulate actual loading conditions. If the pressure test is performed with the confinement vessel inside the gamma shield, the confinement boundary welds cannot be examined.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Confinement Vessel Material	NB-2120	Requirement materials to be ASME Class 1 material	Standard Review Plan, NUREG-1536 has accepted the use of either Subsection NB (Class 1) or NC (Class 2 or 3) of the Code for the confinement. SA-203 Gr. D is similar to SA-203 Gr. E which is a Class 1 material. The chemical content of the two grades are identical, except that Gr. E restricts the carbon to 0.20 max., while Gr. D further restricts the carbon content to 0.17 max. Gr. D is acceptable as a Class 2 material up to 500° F. Gr. D was selected because of its ductility, since the higher strength is not required. SA-203 Gr. D has better elongation than Grade E and due to its lower strength is more likely to have the good fracture toughness at low temperatures. In selecting materials for storage and transport casks, one of the major selection criteria is fracture toughness at low temperatures. Grade D was selected on this basis. There is no similar requirement for pressure vessels, as they are used at much higher temperatures. For the SA-203 Grade D material, the allowable stress was based on S, the allowable stress for Class 2 components. This is conservative, since NB is based on S_m, which is 1/3 the tensile strength, while S is 1/4 the tensile strength. Thus there is additional margin over and above the margin required by the code for Class I materials.
Weld of Lid Shield Plate to Lid	NB-4335	Impact testing of weld and heat affected zone of lid to shield plate	If two different materials are joined, the fracture toughness requirements of either may be used for the weld metal. There are no fracture toughness requirements on the shield plate, and therefore none are performed on the base metal or the heat affected zones. This weld is not subject to low temperatures, as it is inside the cask cavity. An evaluation of this weld at low temperatures is presented in Appendix 3E of the SAR.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Gamma Shielding	NB-2190	Material in the component support load path and not performing a pressure retaining function welded to pressure retaining material shall meet the requirements of NF-2000	The gamma shielding materials were procured to ASTM or ASME material specifications. Materials testing is performed in accordance with the applicable specification. Impact testing is not performed on the gamma shielding materials (including welding materials). An evaluation of the gamma shielding due to impact at low temperatures is provided in Appendix 3E of the SAR.
Confinement Vessel	NB-7000	Vessels are required to have overpressure protection	No overpressure protection is provided. Function of confinement vessel is to contain radioactive contents under normal, off normal, and accident conditions of storage. Confinement vessel is designed to withstand maximum internal pressure considering 100% fuel rod failure and maximum accident temperatures.
Confinement Vessel	NB-8000	States requirements for nameplates, stamping and reports per NCA-8000	TN-32 cask to be marked and identified in accordance with 10CFR72 requirements. Code stamping is not required. QA data package to be in accordance with Transnuclear approved QA program.
Confinement Vessel material	NB-2000	Requires materials to be supplied by ASME approved material supplier; Quality assurance to meet NCA requirements	Material will be supplied by Transnuclear approved suppliers with Certified Material Test reports (CMTR) in accordance with NB-2000 requirements. The cask is not code stamped. The quality assurance requirements of NQA-1 or 10 CFR 72 Subpart G are imposed in lieu of the requirements of NCA-3800.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Corner weld between bottom inner plate to inner shell	NB-5231	Full penetration corner welded joints require the fusion zone and the parent metal beneath the attachment surface to be UT after welding	In lieu of the UT inspection, the joint will be examined by RT and either PT or MT methods in accordance with ASME Subsection NB requirements.
Boundary of Jurisdiction	NB-1131	The design specification shall define the boundary of a component to which another component is attached.	A code design specification was not prepared for the TN-32 cask. A TN design criteria was prepared in accordance with TN's QA program. The containment boundary is specified in Chapter 1 of the SAR.
Aluminum basket plate and rail, neutron absorber plates	NF-2120	Materials to be ASME Class 1 material	The aluminum plate strength is not used for structural analysis under normal operating loads nor the 50g accident end drop load. The aluminum plate strength is only assumed to be effective for the short duration dynamic loading from a tipover accident and for secondary thermal stress calculations. 6061-T6 is ASME code material (Class 2 or 3). The strength of the neutron absorber plates are not considered in any analysis.

Table 4.1-1 TN-32 ASME Code Exceptions

Component	Reference ASME Code/Section	Code Requirement	Exception, Justification & Compensatory Measures
Basket	NF-4000/NF-5000	Welding/NDE inspections	Basket welding procedures are qualified in accordance with ASME Section IX. Due to the unique nature of these welds, special inspections and tests were developed for these welds. These are described in Section 9.1.2 of the SAR.
Components other than the containment boundary and basket	Subsection NB		The code does not apply to components other than the containment boundary and basket. The gamma shielding has been analyzed and inspected in accordance with Subsection NB as defined at the beginning of this table.
Basket	NF-3000	Allowable Stresses	The ASME Code gives stress values up to 400°F. Stress values above 400°F are taken from "Aluminum Standards and Data", 1990. The allowable stresses used for the aluminum basket plate and rail are based on S, the allowable stress for a Class 2 or 3 component. This is conservative, since the analyses of the basket and rail are performed in accordance with the rules of Subsection NF. Subsection NF allowables are based on S_m which is 1/3 the ultimate strength, while S is ¼ the ultimate strength. Thus there is additional margin built into the analysis of the basket and rail over and above the margin required by Subsection NF for class 1 materials.

5.0 ADMINISTRATIVE CONTROLS

5.1 Training Module

Training modules shall be developed under the general licensee's training program as required by 10 CFR 72.212(b)(6). Training modules shall require a comprehensive program for the operation and maintenance of the TN-32 spent fuel storage cask and the independent spent fuel storage installation (ISFSI). The training modules shall include the following elements, at a minimum:

- TN-32 cask design (overview)
- ISFSI Facility design (overview)
- Systems, Structures, and Components Important to Safety (overview)
- TN-32 Dry Storage Cask Safety Analysis Report (overview)
- NRC Safety Evaluation Report (overview)
- Certificate of Compliance conditions
- TN-32 Technical Specifications
- Applicable Regulatory Requirements (e.g.,10 CFR72, Subpart K, 10 CFR 20, 10 CFR Part 73)
- Required Instrumentation and Use
- Operating Experience Reviews
- TN-32 Cask Operating and Maintenance procedures, including:

  Fuel qualification and loading
  Rigging and handling
  Loading Operations as described in Chapter 8 of the SAR
  Unloading Operations including reflooding as described in Chapter 8 of the SAR
  Auxiliary equipment operations and maintenance (i.e. vacuum drying, helium backfilling and leak testing, reflooding)
  Transfer operations including loading and unloading of the Transport Vehicle
  ISFSI Surveillance operations
  Radiation Protection
  Maintenance
  Security
  Off-normal and accident conditions, responses and corrective actions.

5.2 Programs

The following programs shall be established, implemented, and maintained:

5.2.1 Cask Sliding Evaluation

The TN-32 cask has been evaluated for sliding in the unlikely events of a seismic event. A static coefficient of friction of 0.35 is used in these analyses. This program provides a means for evaluating the coefficient of friction to ensure that the cask will not slide during the seismic event.

a. Pursuant to 10 CFR 72.212, this program shall evaluate the site-specific ISFSI pad configurations/conditions to ensure that the cask would not slide during the postulated design basis earthquake. The program shall conclude that the surface static friction coefficient of friction is greater than or equal to 0.35.

b. Alternatively, for site-specific ISFSI pad configurations/conditions with a lower coefficient of friction than 0.35, the program shall evaluate the site specific conditions to ensure that the TN-32 cask will not slide during the postulated design basis earthquake. The program shall also evaluate storm winds, missile impacts and flood forces to ensure that the cask will not slide such that it could result in impact with other casks or structures at the ISFSI. The program shall ensure that these alternative analyses are documented and controlled.

5.2.2 Cask Transport Evaluation Program

This program provides a means for evaluating various transport configurations and transport route conditions to ensure that the design basis drop limits are met.

a. Pursuant to 10 CFR 72.212, this program shall evaluate the site-specific transport conditions. To demonstrate compliance with Technical Specification 4.2.2, the program shall conclude that the expected lift height above the transport surface shall be less than or equal to that described by Technical Specification 4.2.2. Also, the program shall conclude that the transport route conditions (e.g., surface hardness and pad thickness) are equivalent to or less limiting than those prescribed for the typical pad surface which forms the basis for Technical Specification 4.2.2.

b. Alternatively, for site-specific transport conditions which are not encompassed by those of Technical Specification 4.2.2, the program shall evaluate the site-specific conditions to ensure that the end-drop loading does not exceed 50 g. This alternative analysis shall be commensurate with the analysis which forms the basis of Technical Specification 4.2.2 (Reference TN-32 SAR Appendix 3A). The program shall ensure that these alternative analyses are documented and controlled.

c. This program shall establish administrative controls and procedures to ensure that cask TRANSPORT OPERATIONS are conducted within the limits imposed by the Technical Specifications or the alternative analysis described above.

5.2.3 Cask Surface Dose Rate Evaluation Program

This program provides a means for ensuring that ISFSI's using TN-32 casks do not violate the requirements of 10 CFR 72 and Part 20 regarding radiation doses and dose rates.

1. As part of its evaluation pursuant to 10 CFR 72.212, the licensee shall perform an analysis to confirm that the limits of 10 CFR Part 20 and 10 CFR Part 72.104 will be satisfied under the actual site conditions and configurations considering the planned number of casks to be used and the planned fuel loading conditions.

5.2.3 Continued

2. On the basis of the analysis in TS 5.2.3.1, the licensee shall establish a set of cask surface dose rate limits which are to be applied to TN-32 casks used at the site. Limits shall establish average gamma-ray and neutron dose rates for:

   A. The top of the TN-32 cask (protective cover)
   B. The sides of the radial neutron shield,
   C. The side of the cask above the radial neutron shield, and
   D. The side of the cask below the radial neutron shield.

3. Not withstanding the limits established in TS 5.2.3.2, the dose rate limits may not exceed the values calculated in the SAR for a content of design basis fuel as follows:

   A. 60 mr/hr gamma and 10 mr/hr neutron on the top (protective cover)
   B. 170 mr/hr gamma and 20 mr/hr neutron on the sides of the radial neutron shield
   C. 280 mr/hr gamma and 140 mr/hr neutron on the side surfaces of the cask above the radial neutron shield region.
   D. 110 mr/hr gamma and 200 mr/hr neutron on the side surfaces of the cask below the radial neutron shield region.

4. Prior to transport of a TN-32 containing spent fuel to the ISFSI, the licensee shall measure the cask surface dose rates and calculate average values as described in 5.2.3.7 and 5.2.3.8.

   The measured average dose rates shall be compared to the limits established in TS 5.2.3.2 or the limits in TS 5.2.3.3, whichever are lower.

5. If the measured average surface dose rates do not meet the limits of TS 5.2.3.2 or TS 5.2.3.3, whichever are lower, the licensee shall take the following actions:

   A. Notify the U.S. Nuclear Regulatory Commission (Director of the Office of Nuclear Material Safety and Safeguards) within 30 days.
   B. Administratively verify that the correct fuel was loaded, and
   C. Perform an analysis to determine that placement of the as-loaded cask at the ISFSI will not cause the ISFSI to exceed the radiation exposure limits of 10 CFR Parts 20 and 72.

6. If the analysis in 5.2.3.5.C shows that placement of the as-loaded cask at the ISFSI will cause the ISFSI to exceed the radiation exposure limits of 10 CFR Parts 20 and 72, the licensee shall remove all fuel assemblies from the cask within 30 days of the time of cask loading.

7. The surface dose rates shall be measured at approximately the following points (see also Figure 5.2.3-1).

   A. Above the Radial Neutron Shield (A): Midway between the top of the cask body flange and the top of the radial neutron shield. At least six measurements equally spaced circumferentially.

5.2.3 Continued

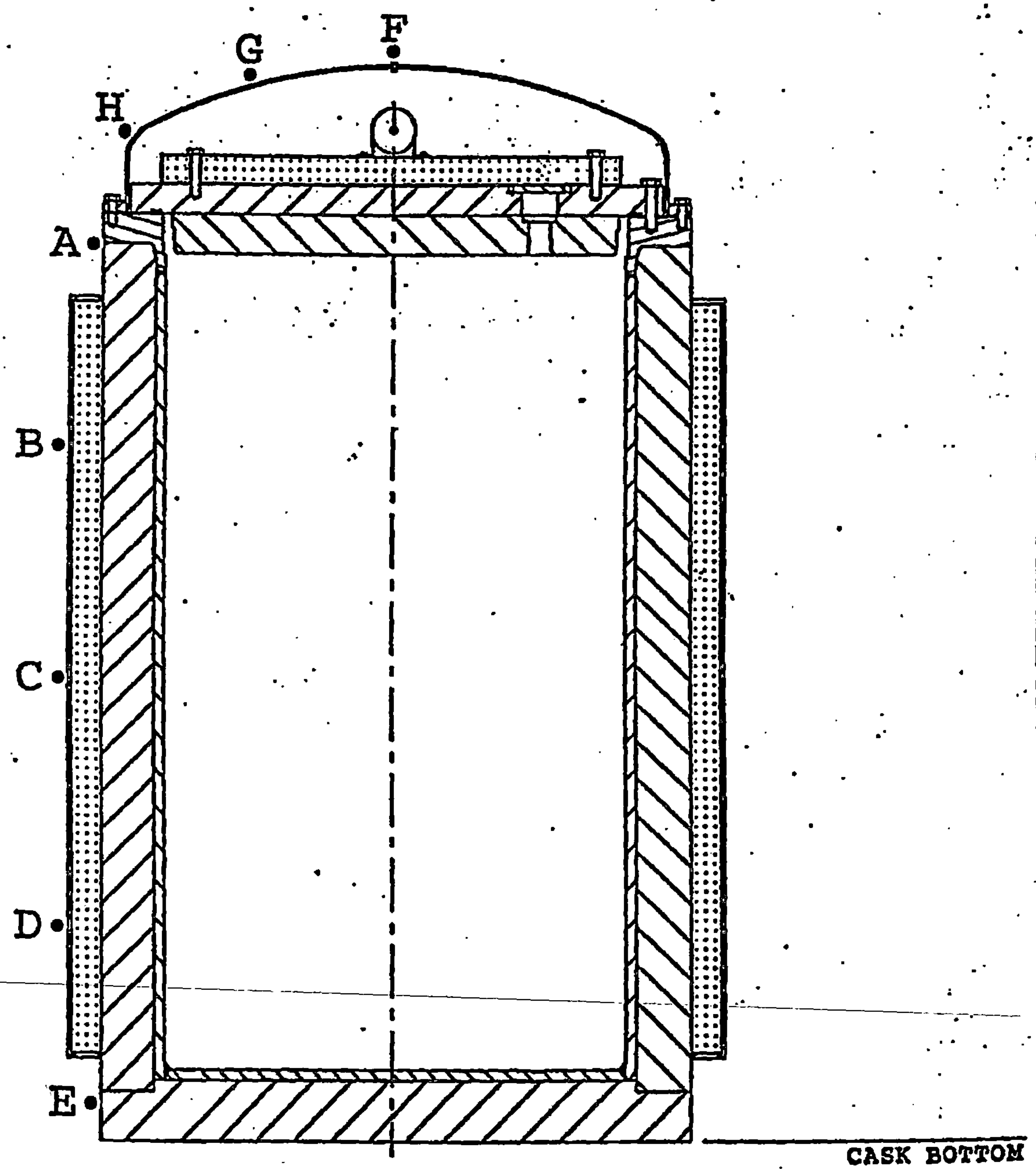
B. Sides of Radial Neutron Shield (B, C and D): one sixth, one half and five sixths of the distance from the top of the radial neutron shield. At least six measurements equally spaced circumferentially at each elevation, two of which shall be at the circumferential location of the cask trunnions. However, no measurement shall be taken directly over the trunnion.

C. Below Radial Neutron Shield (E): Midway between the bottom of the radial neutron shield and the bottom of the cask. At least six measurements equally spaced circumferentially.

D. Top of Cask (F, G and H): At the center of the protective cover, one measurement (F). Half way between the center and the knuckle at least four measurements equally spaced circumferentially (G). At the knuckle at least four measurements equally spaced circumferentially (H).

8. The average dose rates shall be determined as follows.

In each of the four measurement zones in TS 5.2.3.7, the sum of the dose rate measurements is divided by the number of measurements to determine the average for that zone. The neutron and gamma-ray dose rates are averaged separately. Uniformly spaced dose rate measurement locations are chosen such that each point in a given zone represents approximately the same surface area.



* NOTE: DOSE MEASUREMENTS ARE AT CONTACT.

FIGURE 5.2.3-1
CONTACT DOSE RATE MEASUREMENTS LOCATIONS

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION REPORT

Docket No. 72-1021
Transnuclear Storage Cask (TN-32)
Certificate of Compliance No. 1021
Revision No. 1

SUMMARY

This Safety Evaluation Report (SER) documents the review and evaluation of two amendment applications for the Transnuclear storage cask system (TN-32). By application dated April 23, 1999, as supplemented February 28 and May 22, 2000, and by application dated February 29, 2000, as supplemented April 20 and May 22, 2000, TN requested an amendment to the Certificate of Compliance No. 1021 for the TN-32 storage cask. TN requested that Mark BW fuel be incorporated into the allowable contents and that the seismic requirements be revised to allow the user some additional flexibility in storage pad design. For efficiency, the two amendments were combined for review and issuance.

The applications, as supplemented, included the necessary engineering analyses and proposed Safety Analysis Report (SAR) page changes. The proposed SAR revisions will be incorporated into the Final Safety Analysis Report (FSAR) that must be submitted within 90 days after the amendment has been approved (in accordance with 10 CFR 72.248(a)(1)).

The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed the applications, as supplemented, including the engineering analyses, proposed SAR revisions, and other supporting documents submitted with the applications. Based on the statements and representations in the applications, as supplemented, the staff concludes that the TN-32 storage cask system, as amended, meets the requirements of 10 CFR Part 72.

1.0 GENERAL INFORMATION

The applicant requested that the Mark BW 17x17 fuel (B&W/FCF 17x17 Mark BW) be added to the allowable contents for storage. The applicant also requested that the seismic requirements be revised to allow the user some additional flexibility in storage pad design. Due to the limited scope of the amendment requests, only those sections affected are addressed in this SER.

2.0 STRUCTURAL

The NRC staff review indicates that Mark BW 17x17 fuel with hardware may weigh more than the design weight (1533 lbs. per fuel assembly) for the TN-32 storage cask. However, the applicant elected to stay within the design weight by administrative controls. Technical Specification (TS) Section 2.1.f.v. and Table 2.1-1 of the SAR state that any combination of fuel and hardware which weighs more than 1533 lbs. is not acceptable for storage in the TN-32 storage cask. Therefore, storage of Mark BW 17x17 fuel in the TN-32 storage cask will not result in weight increase greater than previously analyzed.

As for the cask internal pressure, the bounding fuel authorized for storage in the TN-32 storage cask is the Westinghouse 15 x 15 fuel. This fuel bounds the Westinghouse Standard 17x17 fuel (W 17x17) which is comparable to the Mark BW 17x17 fuel. The cladding outside diameter (OD) is the same for both W 17x17 fuel and Mark BW 17x17 fuel. However, the cladding thickness is greater on the Mark BW 17x17 fuel (0.024 inch compared to 0.0225 for the W 17x17 fuel). The end of life pressure in the Mark BW 17x17 fuel is lower than that in the W 17x17 fuel for the following reasons:

(1) W 17 x 17 is prepressurized up to 500 psi, while Mark BW 17x17 fuel prepressurization is less than 500 psi.

(2)The UO_2 mass in W 17x17 is 0.364 lb/ft and in Mark BW 17x17 fuel is 0.360 lb/ft. Therefore, for a given mass-specific burnup, each Mark BW fuel assembly will have slightly fewer fission products than a W 17x17 fuel assembly.

(3)The Mark BW 17x17 fuel pellet density is 96%, compared to 95% for the Westinghouse fuel. Therefore, there will be slightly less fission gas release in the Mark BW 17x17 fuel.

By the above comparisons, the Westinghouse 15 x 15 fuel bounds the Mark BW 17x17 fuel for internal pressurization.

Based on the above, the staff concludes that the storage of Mark BW 17x17 fuel in the TN-32 storage cask will not change the structural analysis reported in the original TN-32 storage cask SAR.

The staff also reviewed the proposed change to the TS for seismic requirements. The original seismic requirements provide the horizontal and vertical seismic acceleration limits for TN-32 storage casks in a freestanding configuration. The revised seismic requirements merely express the relationship between the horizontal and vertical seismic acceleration in static equilibrium equations from which the original seismic limits were derived. To ensure against sliding and tipover, users of the TN-32 storage cask have the option to substitute the design basis seismic loads at the storage site into the two equations listed in revised Section 4.3.3. By satisfying these two equations, the TN-32 storage cask is assured of neither sliding nor tipover during the design basis earthquake at the storage site. Since the revised and the original seismic requirements are the same but expressed in different formats, the revised seismic requirements will not change the conclusions previously reached in the SER.

2.1 Materials

The inclusion of Mark BW 17x17 fuel to the fuel types that may be stored in the TN-32 storage cask does not introduce any new types of materials to the cask system. Additionally, since the burnup level of the Mark BW 17x17 fuel does not exceed an average assembly burnup of 45,000 MWD/MTU, there is no change to the loading temperature limits. The existing fuel cladding temperature limit bounds the maximum temperature limit for the Mark BW 17 x17 fuel. Consequently, this fuel would not create a new or unanalyzed galvanic or chemical reaction or

result in a cladding temperature adverse to the cladding integrity during loading, long-term storage, or design accident conditions.

Based on the above, the staff finds that inclusion of Mark BW 17x17 fuel into the TN-32 storage cask is acceptable.

3.0 THERMAL

This review assessed the specific impacts of the addition of the Mark BW 17x17 fuel to the authorized contents in the areas of (a) fuel cladding, (b) assembly thermal characteristics, and (c) cask internal pressure. The addition of the Mark BW 17x17 fuel to the authorized fuel types did not require any modification of the cask heat transfer design features or the design basis assumptions of the cask system. Consequently, the staff evaluated the general impact of the added fuel type on the cask and concluded that the basis for the cask heat transfer design features and the design basis assumptions had not been affected.

The temperatures of the fuel cladding (fission product barrier) are limited in the TN-32 storage cask for normal, off-normal, and accident conditions to protect the cladding against degradation which could lead to gross rupture. The TN-32 FSAR Revision 0[1] fuel cladding temperature limit for normal and off-normal conditions of storage is 622°F (328°C). The transient (e.g., accident and loading/unloading operations) temperature limit is 1058°F (570°C). The applicant concluded and the staff confirmed that the cladding temperature limits in effect for the currently approved fuels for the TN-32 storage cask bound the Mark BW 17x17 fuel allowable temperature limits. Therefore, use of the current cladding temperature limits for the Mark BW17x17 fuel is acceptable.

In FSAR Section 3.5.2, the applicant concluded that the quench analysis currently in effect for the Westinghouse 15x15 fuel bounded the Mark BW 17x17 fuel. The staff reviewed the information submitted by the applicant and agrees that the existing quench analysis is bounding and acceptable.

The applicant calculated a heat generation rate for the Mark BW 17x17 fuel assembly of 0.98 kW. This heat generation rate is bounded by the W 17x17 assembly heat generation rate of 0.99 kW. The applicant also clarified TS 2.1.f.iv to limit the maximum allowable heat load per assembly to less than or equal to 1.02 kW with or without burnable poison rod assemblies (BPRAs) or thimble plug devices (TPDs). The existing cask thermal analysis assumes the 1.02 kW/assembly (32.7 kW total per cask) heat generation rate and, therefore, the heat generation rate of the Mark BW 17x17 fuel is acceptable.

The applicant compared the physical characteristics of the Mark BW 17x17 fuel to the W 17x17 fuel. These assemblies have identical rod outside dimensions, pitch, and envelope dimensions. The Mark BW 17x17 fuel has about 1% less fuel mass than the W 17x17 fuel and, therefore, has a slightly lower heat generation rate as discussed above. The Mark BW 17x17 fuel also has a greater cladding thickness than the W 17x17 fuel. Based on this comparison, the applicant concluded that the effective conductivity for the W 17x17 fuel bounds the Mark BW 17x17 fuel. The staff reviewed the information submitted by the applicant and the effect of increased cladding thickness in the modified Wooton-Epstein correlation (which was used to

identify the bounding assembly type) and concluded that the W 17x17 fuel bounds the Mark BW 17x17 fuel.

In the revised SAR Section 7.2.2.2, the applicant compared the Mark BW 17x17 fuel with the W 17x17 fuel and concluded that the quantity (moles) of free gas in the Mark BW 17x17 fuel would be less than or equal to the W 17x17 fuel. This quantity of free gas is in turn bounded by the Westinghouse 15x15 fuel. Based on review and selected verifications of the information provided, the staff concludes that the Mark BW 17x17 fuel is bounded by the existing analysis and is acceptable.

4.0 SHIELDING

In the FSAR shielding analysis, the applicant established the W 17x17 fuel and associated BPRA as the content having the bounding source term and performed all subsequent calculations for that assembly type. For this amendment, the applicant showed that the source term for the W 17x17 fuel also bounds that of the Mark BW 17x17 fuel.

The Mark BW and W 17x17 fuel assemblies are physically very similar and, thus, are burned under very similar reactor operating conditions. This similarity results in nearly identical burnup profiles and actinide and fission product inventories per uranium mass for the same initial enrichment, cooling time, and burnup. Thus, the burnup profiles and source term production rates for the W 17x17 fuel can also be applied to the Mark BW 17x17 fuel.

The Mark BW fuel contains about 1% less uranium fuel mass than the Westinghouse fuel, and the source term from the active fuel will be a correspondingly 1% lower. The applicant's data also shows that the hardware in the top end fitting of the Mark BW fuel assembly has less mass than the Westinghouse fuel assembly, resulting in a smaller radioactive source term. Likewise, the BPRA spider hardware for the Mark BW fuel has less mass and, thus, a smaller source term than the Westinghouse fuel.

The one area where the Mark BW fuel assembly has greater mass than the Westinghouse fuel assembly is the fuel cladding. Since the applicant did not attempt to quantify the effect of this difference, staff performed its own calculations and estimated that the thicker Mark BW cladding has a larger mass by about 6.95 kgs of zircaloy clad per assembly. Staff further estimated that this greater mass results in a 0.1% increase in the cobalt source term in the fuel region of the assembly. The expected dose from the increase in cladding source term is more than offset by the decrease in source term from the smaller uranium fuel mass in the Mark BW fuel assemblies. Staff agrees with the applicant's conclusion that the W 17x17 fuel assembly continues to bound the shielding source term in the storage cask even when BPRAs are included.

Based on the information and representations presented by the applicant and on its own review and calculations, staff has reasonable assurance that the system can meet the regulatory shielding requirements under normal, off-normal, and accident conditions.

5.0 CRITICALITY

The applicant submitted a criticality analysis which demonstrates that storage of Mark BW 17x17 fuel in the TN-32 storage cask is bounded by the criticality safety analysis performed for the FSAR.

The Mark BW 17x17 fuel is described in SAR Table 6.2-1. There were no proposed changes to the storage cask or the spent fuel pool boron concentration requirements. The maximum assembly average burnup and initial enrichment limits are identical to the limits for the Westinghouse fuel.

The modeling assumptions used to determine the most reactive assembly are given in SAR Section 6.4.2.A. The cask and fuel assemblies are explicitly modeled. The models are identical to those previously reviewed except that the assemblies were replaced with Mark BW 17x17 fuel assemblies. For the Mark BW 17x17 fuel assembly, the active fuel length, including the natural uranium blankets, was modeled as fresh fuel (i.e., no burnup) and enriched to 4.05 wt% U-235. The applicant's results are given in Table 6.4-1 of the SAR. The applicant's calculations demonstrate that the W 17x17 fuel assembly bounds the Mark BW 17x17 fuel assembly and that the TN-32 criticality design criterion is met. The TN-32 criticality design criterion is that k_{eff}, including bias and uncertainty, $\leq$ 0.95 so that subcriticality is maintained for all credible normal, off-normal, and accident conditions. Further benchmark analysis was not performed as the previous benchmark calculations are appropriate for this system.

The applicant utilized the CSAS modules of the SCALE computer codes and the accompanying 27-group cross section library for the TN-32 storage cask analysis and the benchmark calculations. The staff agrees that these codes and cross-section sets are appropriate for this particular application and fuel system.

The staff performed confirmatory calculations using the same assumptions as those given in SAR Section 6.4.2.A. The staff's results are in close agreement with the applicant's results. For the confirmatory analysis, the staff used the CSAS modules of the SCALE version 4.4 computer code and the accompanying 44-group cross-section library. These codes are standards in the industry for performing criticality analyses and are appropriate for this particular application and fuel system.

Based on the staff's review of the information provided by the applicant and the staff's own confirmatory calculations, the staff has reasonable assurance that the TN-32 will allow safe storage of intact Mark BW 17x17 fuel assemblies and the system will remain subcritical under all credible normal, off-normal, and accident conditions.

6.0 CONFINEMENT EVALUATION

This confinement evaluation reviews the addition of the Mark BW 17x17 fuel to the allowable fuel types authorized for storage in the TN-32 storage cask. The addition of the Mark BW 17x17 fuel to the authorized fuel types did not require any modification of the cask confinement design or the design basis assumptions of the cask system.

The applicant compared the Mark BW 17x17 fuel to the approved W 17x17 fuel and concluded that the Mark BW 17x17 fuel is bounded by the W 17x17 fuel. The staff reviewed the information provided by the applicant, assessed the impact of the Mark BW fuel on the confinement design, and performed selected confirmatory calculations. The staff concluded that the Mark BW 17x17 fuel is bounded by the existing analysis and is acceptable.

7.0 CONDITIONS FOR CASK USE - OPERATING CONTROLS AND LIMITS OR TECHNICAL SPECIFICATIONS

The proposed certificate changes for this amendment are as follows:

1. TS 2.1, "Fuel to be stored in the TN-32 Cask," changed to include the B&W/FCF 17x17 Mark BW assembly and associated bounding characteristics; and

2. TS 4.3.3, "Site Specific Parameters and Analyses," changed to allow an analysis to provide verification that loads associated with a design basis seismic event do not cause the cask to slide or to tipover.

The staff has reviewed these changes, as discussed in the SER, and have found them to be acceptable.

REFERENCES

1. Transnuclear, Inc., TN-32 Dry Storage Cask Final Safety Analysis Report, Revision 0, January 2000.

CONCLUSION - EVALUATION FINDINGS

The staff has reviewed the TN-32 storage cask system amendment applications, as supplemented, including the engineering analyses, proposed SAR revisions, and other supporting documents submitted with the applications. Based on the information provided in the applications, as supplemented, the staff concludes that the TN-32 storage cask system, as amended, meets the requirements of 10 CFR Part 72.

Issued with Certificate of Compliance No. 1021, Amendment No. 1, on Feb. 12, 2001.

Serial No. 16-055
Docket No. 72-16

Attachment 5

TN-32B HBU Cask, Optional Lid Bolt Material

Attachment 5 provides supplemental information regarding optional material for the lid bolts. The material, SA-540 Gr. B23 CL 1, will be an option to the current specified bolt material SA-540 GR. B24 CL 1. Additional details are provided in letter E-44658 attached.

AREVA TN has revised drawing 19885-70-2 and calculation 19885-0203, which will be submitted under a separate cover letter due to proprietary information concerns.

North Anna Power Station ISFSI

Virginia Electric and Power Company

AREVA

March 4, 2016
E-44658

Mr. Thomas A. Brookmire
Dominion Resources Services, Inc.
5000 Dominion Blvd.
Glen Allen, VA 23060

Subject: TN-32B High Burnup Dry Storage Research Project, Optional Lid Bolt Material

Dear Mr. Brookmire:

To facilitate the fabrication of the TN-32B High Burnup (HBU) demonstration cask, AREVA-TN has revised TN drawing 19885-70-2 to add an optional material for the lid bolts (Item No. 19885-70-2-13). The material, SA-540 Gr. B23 CL 1, will be an option to the current specified bolt material SA-540 Gr. B24 CL 1. Both material grades have the same mechanical properties, as delineated in ASME/ASTM Specification SA-540/SA-540M, *Specification for Alloy Steel Bolting Materials for Special Applications*, which is contained in the ASME Boiler and Pressure Vessel (B&PV) Code, Section II, Part D. For this reason, there is no impact on the structural analyses that has been performed for the TN-32B HBU demonstration cask with the addition of this material. Additionally, AREVA-TN structural calculation 19885-0203 will be revised to incorporate this optional bolt material. Revision 1 of these AREVA-TN documents will be submitted to Dominion for the NRC's staff continuing review of the Dominion License Amendment Request (LAR) for the TN-32B HBU demonstration cask research project.

Should you have any questions or require additional information, please contact the undersigned.

Sincerely,

T. M. Edwards

Tom Edwards
Design Project Engineer

cc: Phil Lozmack (PM)
Don McGee (PM)
Rod Gooch (PM)
Adam Jones (AFS)
Gary Clark (AFS)
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Todd Young (QAS)
Project File 19885 – Outgoing Correspondence

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