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TITAN Legal Weight Truck Cask Preliminary Design Report

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Volume 1

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DISCLAIMER

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LIST OF ACRONYMS

ANS	American Nuclear Society
ANSI	American National Standards Institute
ASTM	American Society of Testing Materials
atm	Atmosphere
B&W	Babcock & Wilcox
B-Si	Boro-Silicone
BWR	Boiling Water Reactor
CE	Combustion Engineering
CFR	Code of Federal Regulations
DLF	Dynamic Load Factor
DU	Depleted Uranium
GE	General Electric
GWD	Gegawatt Days
LWR	Light Water Reactor
LWT	Legal Weight Truck
MTU	Metric Ton of Uranium
MWD/MTU	Megawatt Days per Metric Ton of Uranium
OFA	Optimized Fuel Assembly
PWR	Pressurized Water Reactor
TM	Trade Mark
Ti	Titanium
W	Westinghouse

FOREWORD

The Preliminary Design of the TITAN Legal Weight Truck (LWT) Cask System and Ancillary Equipment is presented in this document. The scope of this document includes the LWT cask with fuel baskets, impact limiters, and lifting and tiedown features; the cask support system for transportation; intermodal transfer skid; personnel barrier; and cask lifting yoke assembly. The results of the tradeoff studies and evaluations that were performed during the preliminary design are presented in Appendix A to this report.

The transporter for the LWT cask, though within the scope of work, is not included in this document because its design has not evolved to the level of a preliminary design. At the present time, the performance criteria for the transporter are being developed by another cask contractor with input from Westinghouse, and it is anticipated that the transporter detailed design specification and design will be developed by a subcontractor. In the interim, the preliminary design of the cask and support system has been based on the assumptions that 1) a double-drop, tandem axle, semi-trailer will be necessary, and 2) such a trailer can be developed within the maximum weight allocation provided by Westinghouse.

The design requirements used for the preliminary design of the LWT Cask System and Ancillary Equipment are presented in the TITAN Legal Weight Truck Cask Design Requirements document, NWD-TR-007, Revision 2. Those requirements are consistent with the Cask Physical Performance Specifications and Cask Interface Guidelines specified in the contract.

This report has been structured to follow to the maximum extent possible, the standard format and content prescribed for Part 71 applications for approval of packaging for radioactive material in the Draft Regulatory Guide 7.9, Revision 2. The exceptions to the prescribed format include the addition of subsections on the cask support system and ancillary equipment; the omission of the section on Acceptance Tests and Maintenance Program as it was considered more appropriate to address this topic at the final design stage;

and the addition of two new sections. These sections address Technical Issues Requiring NRC Resolution, and Safety/Quality Assurance Issues, and are included as Sections 8 and 9, respectively. Appendix B contains comments from the DOE preliminary design review and Westinghouse responses to those comments.

1. GENERAL INFORMATION

This section of the report presents a general description of the Westinghouse TITAN L-3/7 Legal Weight Truck Cask System and Ancillary Equipment. The cask will be used to transport either PWR or BWR spent fuel assemblies while meeting the weight and envelope restrictions for legal weight shipments by road within the U.S.

1.1 Introduction

The Westinghouse TITAN L-3/7 Legal Weight Truck (LWT) Cask is a common use cask for the shipment of either PWR or BWR spent fuel. The principal structural components of the cask body and closure lid are fabricated from Grade 9 titanium alloy. Depleted uranium (alloyed with 0.2 percent molybdenum) is used as the primary gamma shield material. A solid neutron shield, Boro-Silicone*, is provided outside the main structural boundary of the cask.

The cask is provided with a pair of interchangeable fuel baskets, one designed for PWR assemblies and the other for BWR assembles. The fuel baskets are fabricated from Type 316N stainless steel and are provided with Boral** neutron poison plates to ensure a sub-critical configuration during all postulated operating conditions.

The closure lid is bolted to the cask body. The closure lid employs the same sandwich construction using Grade 9 titanium, depleted uranium, and Boro-Silicone. The interface between the lid and the cask body is sealed using a pair of elastomeric O-ring face seals.

Removable impact limiters, made from aluminum honeycomb sheathed in Type 304 stainless steel are bolted to the cask body at each end of the cask. These impact limiters serve to limit the consequences of the Normal and Hypothetical Accident free drop events specified in 10 CFR Part 71.

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* Trademark of Reactive Experiments, Inc.
** Trademark of Brooks and Perkins

The cask is provided with penetrations and valving for seal integrity testing, venting, inerting, gas sampling, and draining the cask cavity. All the penetrations are located in the closure lid.

The LWT Cask System and ancillary equipment are designed to be compatible with manual, remote-manual, and remote-automated operation. The materials of construction and design features have been chosen to be compatible with both wet and dry loading and unloading operations and are compatible with reactor pool chemistry requirements.

The LWT cask can transport up to 3 PWR fuel assemblies or 7 BWR fuel assemblies. Authorization will be sought from the U.S. Nuclear Regulatory Commission for the shipment of the cask by road as a Type B(U), Fissile Class I package as defined in Paragraph 4 of 10 CFR Part 71.

1.2 Package Description

This section of the report presents a description of the principal design features of the LWT cask assembly.

1.2.1 Packaging

The TITAN LWT Cask is a Type B (as defined in 10 CFR Part 71) package designed to transport three PWR or seven BWR fuel assemblies. The cask can accommodate 10 year old (time since discharge from reactor core) fuel with maximum burnup values of 35,000 MWD/MTU and 30,000 MWD/MTU for PWR and BWR assemblies, respectively. Figures 1.2-1 and 1.2-2 depict the salient features of the cask assembly.

The design details of the cask assembly are provided in Westinghouse drawings 1988E42, 1988E43, and 1988E44. These drawings are included in Section 1.5. In addition, simplified sketches of the components are included with the text.

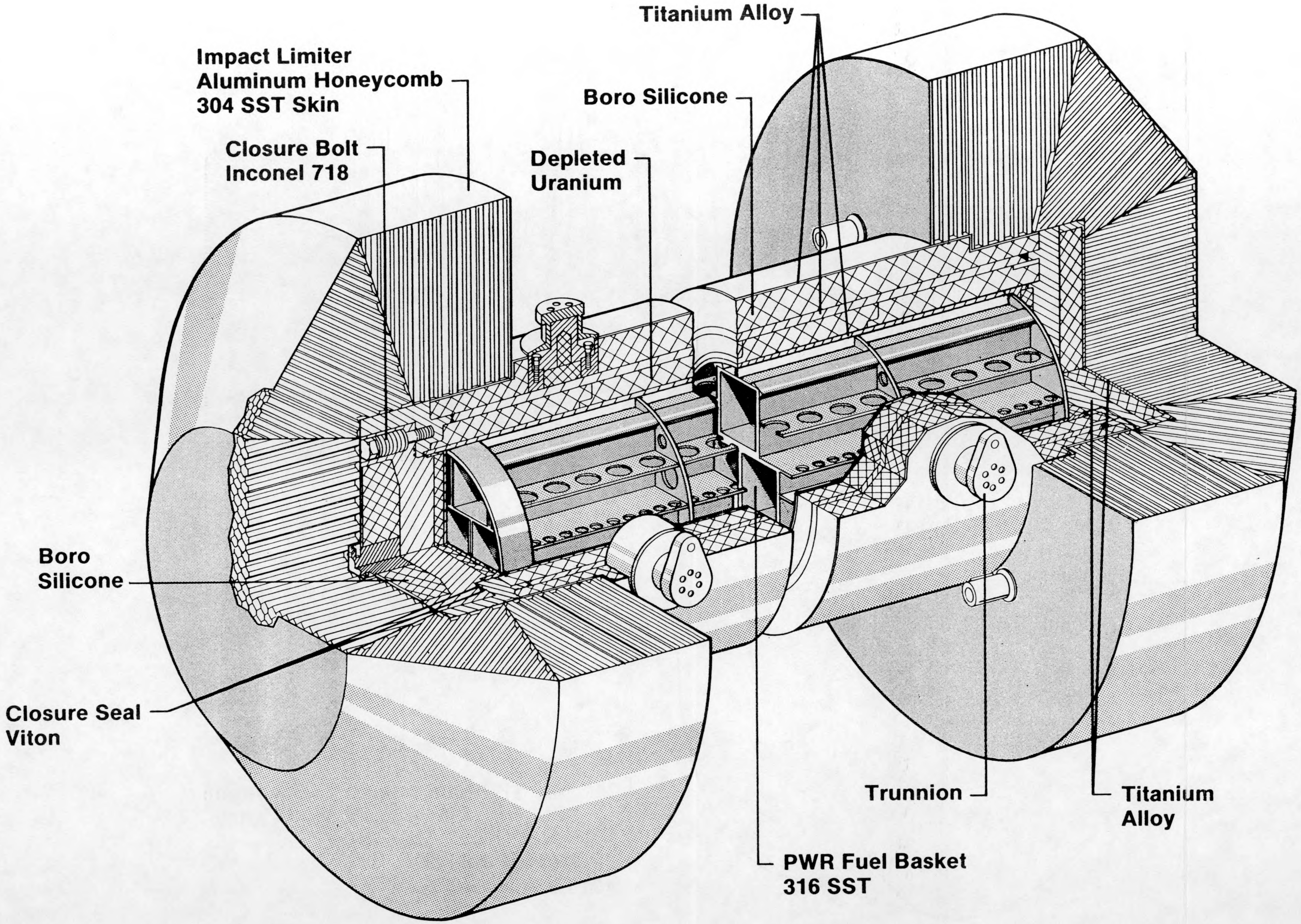

Figure 1.2-1 TITAN Legal Weight Truck Cask

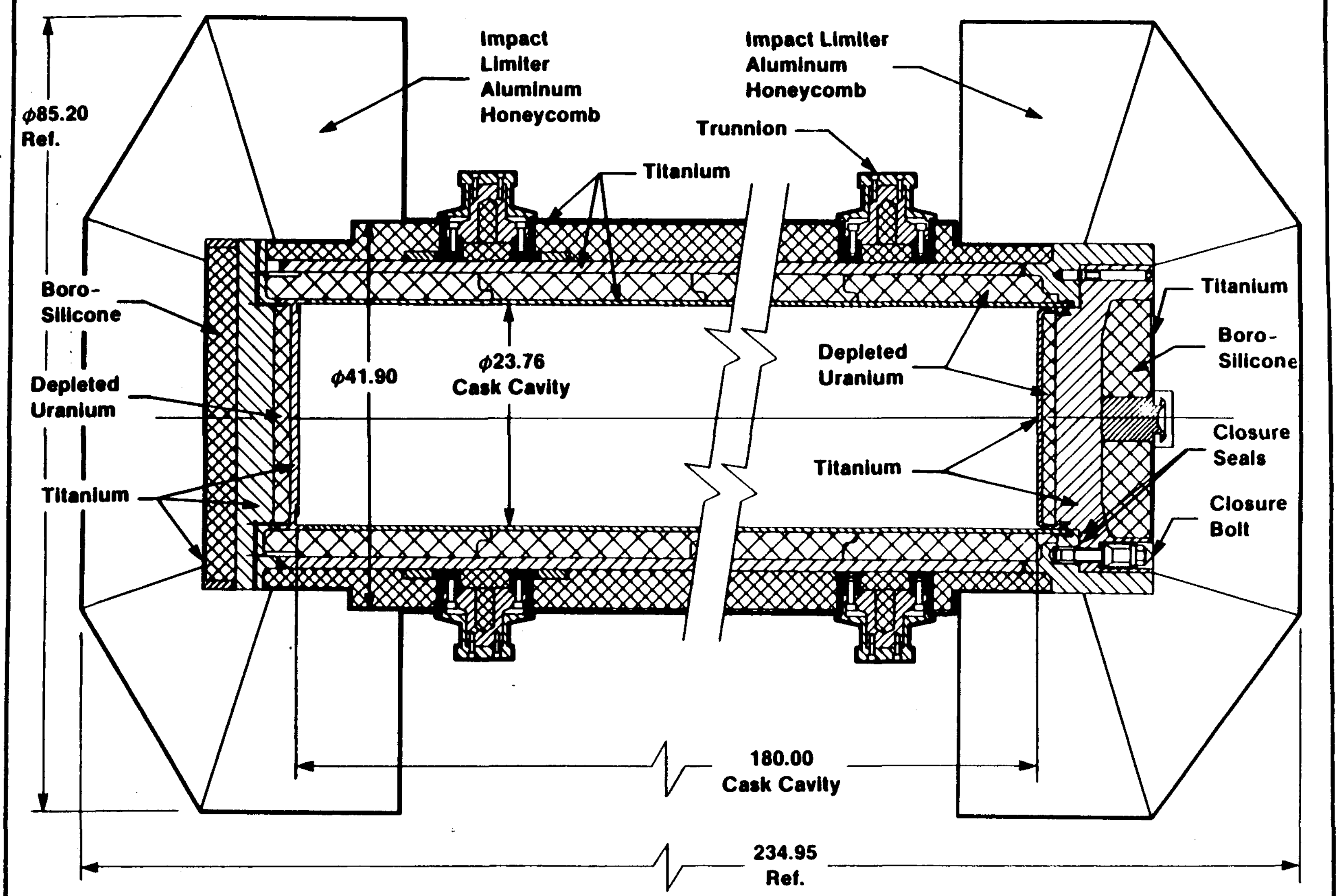

Figure 1.2-2 TITAN Legal Weight Truck Cask Cross-Section

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The LWT Cask is comprised of the following major components and features:

- Cask Body
- Trunnions
- Closure Lid
- Penetrations
- Seal Verification Test Ports
- Fuel Baskets
- Impact Limiters

Each of these cask assembly components are described below.

Cask Body

The cask body features are shown in Figures 1.2-1 and 1.2-2. Design details are provided in drawing 1988E43. The key features of the cask body construction include:

- Grade 9 titanium alloy for the principal structural components
- Depleted uranium (with 0.2 percent molybdenum) for the primary gamma shield
- Boro-Silicone for the external neutron shield.

The use of a high strength-to-weight material such as titanium alloy reduces the weight of those cask components that have to perform the structural function. This approach also permits optimal use of depleted uranium which is a more efficient gamma shield material. A cask design using a combination of high strength structural material and depleted uranium therefore provides the potential for significant increases in payload capacity. Grade 9 titanium alloy was selected for the LWT cask because of its high strength-to-weight ratio, excellent fatigue strength, fracture toughness, weldability, and cold-formability.

Depleted uranium is the most efficient gamma shield material that is readily available. It has been successfully used in transportation casks, such as the IF-300 cask.

Boro-Silicone is an elastomeric, solid neutron shield containing 1 percent Boron that has the advantages of light weight, self-extinguishing characteristics, and resiliency that will not contribute to any secondary missile formation. A technical data sheet for the material is provided in Section 1.5.

The cask body consists of a 0.5 inch thick by 23.76 inch ID Grade 9 titanium cylinder that forms the inner wall of the cask. This shell is welded to the bottom head assembly shown in Figure 1.2-3. Depleted uranium (DU) rings, which are cast and machined to the dimensions and close assembly tolerances are installed around the inner shell. The full circular rings have stepped joints to minimize radiation streaming. The thickness of DU around the cask cylindrical portion is 2.87 inches.

The cask structural boundary consists of a 1.25 inch Grade 9 titanium cylinder that fits around the DU and is welded to the upper flange. The welds joining the inner shell to the upper flange and the outer shell to the bottom head assembly are the final welds in the assembly sequence.

The cask bottom head assembly and the upper flange are shaped to provide a recess for the installation of the Boro-Silicone neutron shield. An outer sheathing of 0.19 inch thick Grade 2 titanium is welded at the ends of the cask to the upper flange and bottom head flange. The sheathing is stepped to provide for the larger Boro-Silicone thickness required in the center portion of the cask. The outer sheathing provides a cavity for pouring the Boro-Silicone and protects the neutron shield from the weather and dirt. Installation of the Boro-Silicone is performed through circular holes in the sheathing that are subsequently closed with PVC plugs. These plugs serve to vent the cavity containing the Boro-Silicone during off-gassing under the fire accident conditions.

The lifting and tiedown trunnions are secured to the cask body by bolting attached to the Grade 9 titanium housings welded to the outer 1.25 inch thick shell. Details of the trunnion design are provided later in this section.

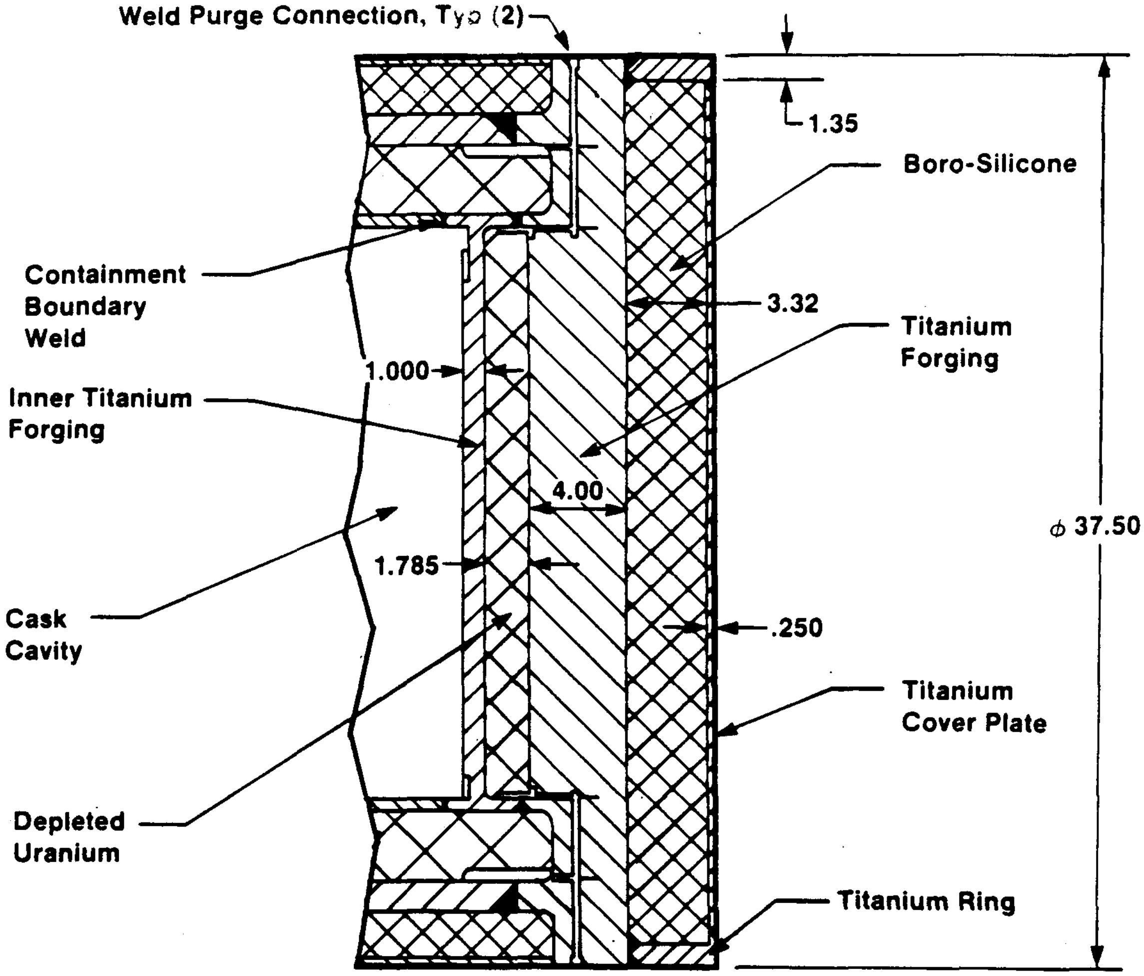

Figure 1.2-3. Bottom Head Assembly

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The bottom head assembly is of sandwich construction and includes a 1.785 inch thick cast DU plate installed between the inner 1 inch thick Grade 9 titanium plate and the outer 4 inch thick Grade 9 titanium forging. A Grade 9 titanium ring is welded to the outside of the forging to provide a cavity for installing the Boro-Silicone. A 0.25 inch thick Grade 2 titanium plate protects the neutron shielding and is welded to the Grade 9 titanium ring.

Grade 2 titanium is selected for the outer covering because it is a readily available item which does not have to be ordered through the mill as required with Grade 9 titanium components. It can be readily welded to Grade 9 titanium.

The cask body upper flange has provisions for installation of the closure lid bolting. These are discussed later in this section.

Special features are included in the design to permit purging of the back sides of all the titanium structural welds using cross-drilled holes that are plugged and welded after the welding operations. Clearances are also provided between the weld root and the DU to ensure that the DU temperatures stay below 1000°F.

Trunnions

The cask employs bolted-on Type S21800 stainless steel trunnions with replaceable wear sleeves for lifting, and tiedown of the cask to the support system. Four lifting trunnions, spaced 90° apart and in the same plane, are provided near the top end of the cask as shown in Figure 1.2-4 and drawing 1988E43. The extra pair of trunnions are designed for compatibility with redundant lifting systems.

Two trunnions are provided near the lower end of the cask, as shown in Figure 1.2-5. These trunnions are spaced 180° apart and in the same plane as two of the upper trunnions. The two lower trunnions and the pair of upper trunnions in the same plane are used to tiedown the cask to the support system.

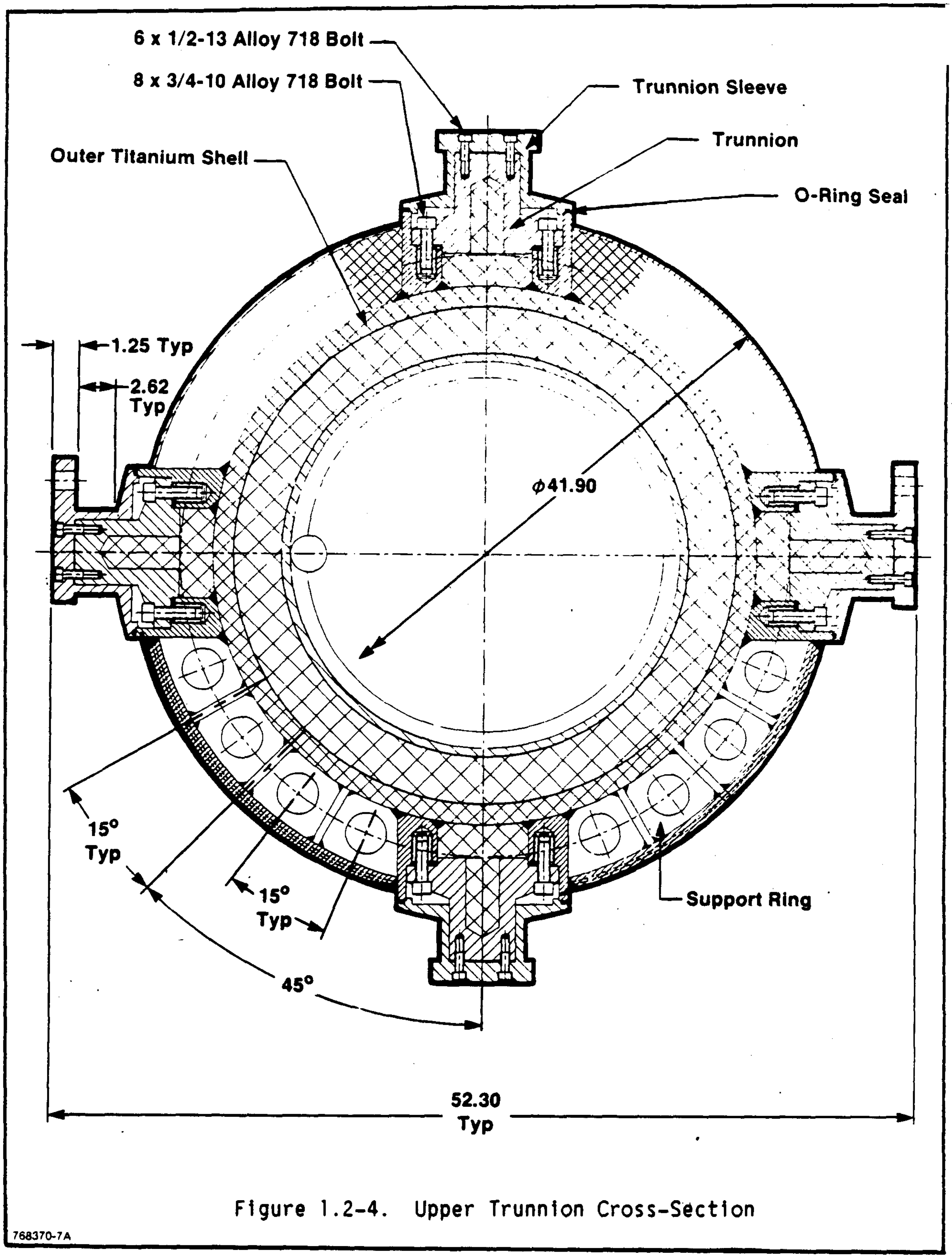

Figure 1.2-4. Upper Trunnion Cross-Section

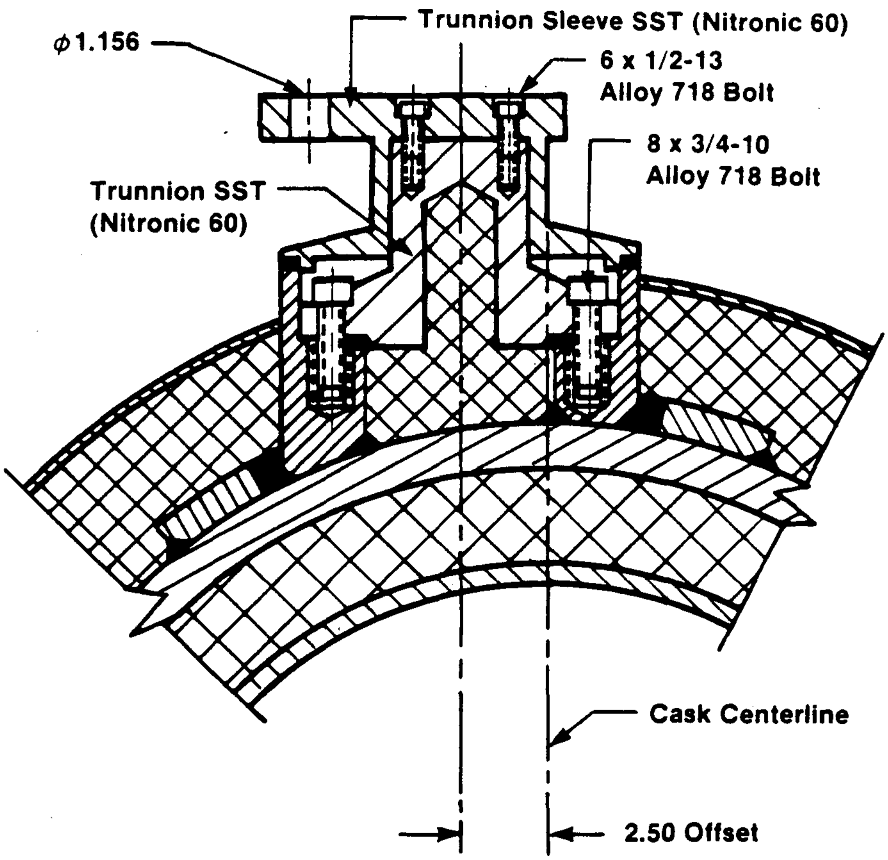

Figure 1.2-5. Lower Trunnion Cross Section

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Details of the trunnion design are shown in Figures 1.2-5 and 1.2-6. The trunnions are bolted to a Grade 9 titanium housing welded to the cask body. In the case of the lower trunnions which are designed to accept the transverse and longitudinal transportation loadings in addition to the vertical loadings, the housing is welded to a reinforcement plate which in turn is welded to the cask body. The bolts, of Alloy 718, engage with Alloy 718 threaded inserts installed in the housing.

The replaceable wear sleeves on the trunnions are made of the same high-strength, wear resistant stainless steel as the trunnions and are specially designed to permit easy replacement and to minimize weeping and seepage of water from crevices. The interface between the sleeve and the housing is sealed with a Viton O-ring seal. The sleeves are bolted to the end of the trunnion. The flanged end of the sleeves on the tiedown trunnions have a tear-drop design with lifting holes. These holes can be used for lifting the cask in the horizontal position for intermodal transfer without having to remove the impact limiters.

Figure 1.2-4 also shows the support ring that is welded to the bottom of the cask body between the upper trunnions. This ring is fabricated from Grade 9 titanium and provides a bearing surface for the cask on the support system without crushing the Boro-Silicone shield.

Closure Lid

The closure lid is fully recessed within the cask body and is fabricated from the same structural and shield materials as the cask body. The closure lid permits access to the cask cavity for fuel loading and unloading, and houses the penetrations for purging/gas sampling and draining the cavity.

The salient features of the closure lid design are shown in Figure 1.2-7. Cast and machined DU is installed in the recess between the inner 0.50 inch thick Grade 9 titanium plate and the lid forging. A recess machined at the upper end of the forging (alternatively, a cylinder will be welded to the forging to provide this recess) contains the Boro-Silicone neutron shield. A solid, Grade 9 titanium lifting pintle is welded to the top of the forging.

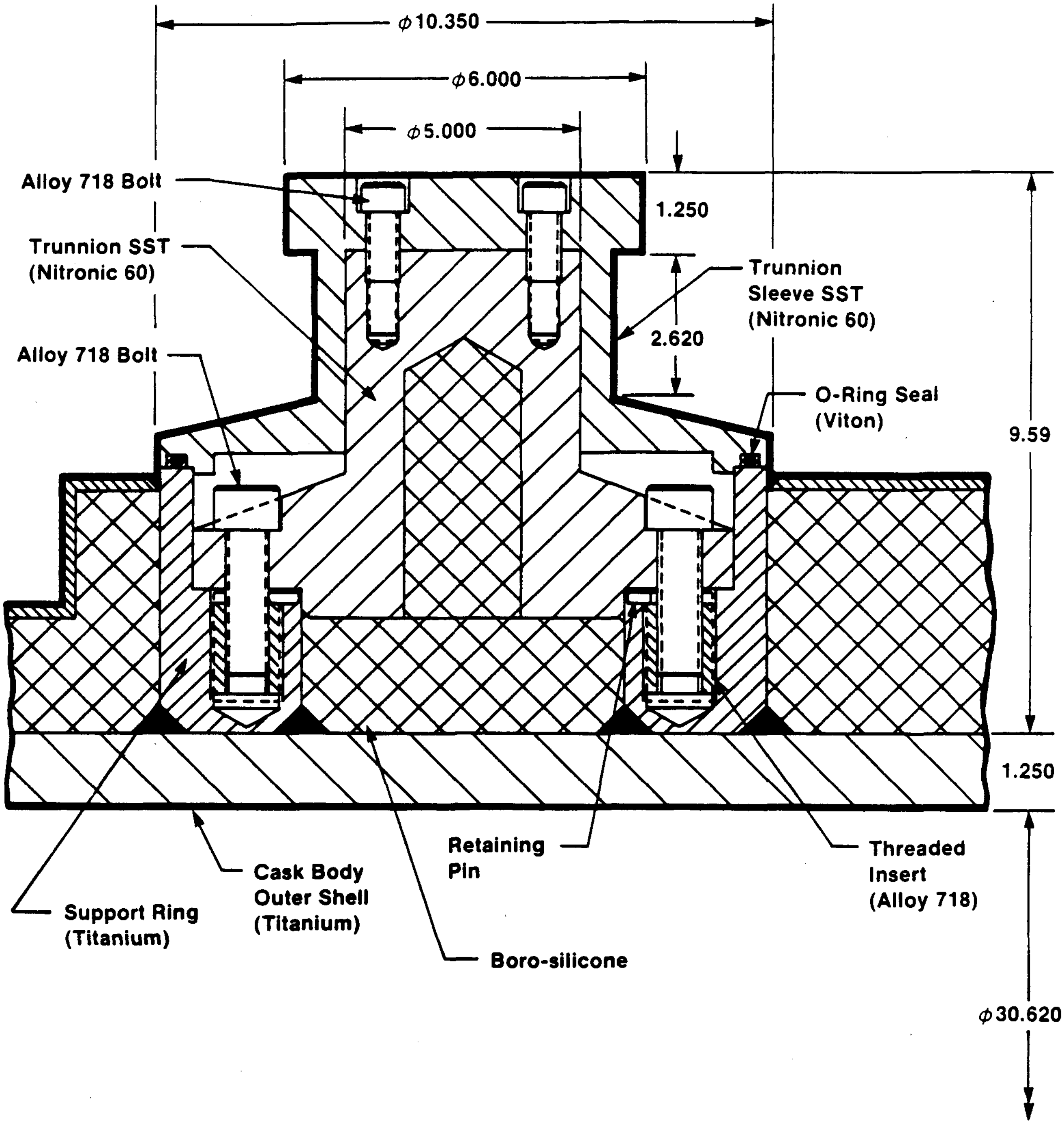

Figure 1.2-6. Typical Trunnion Detail

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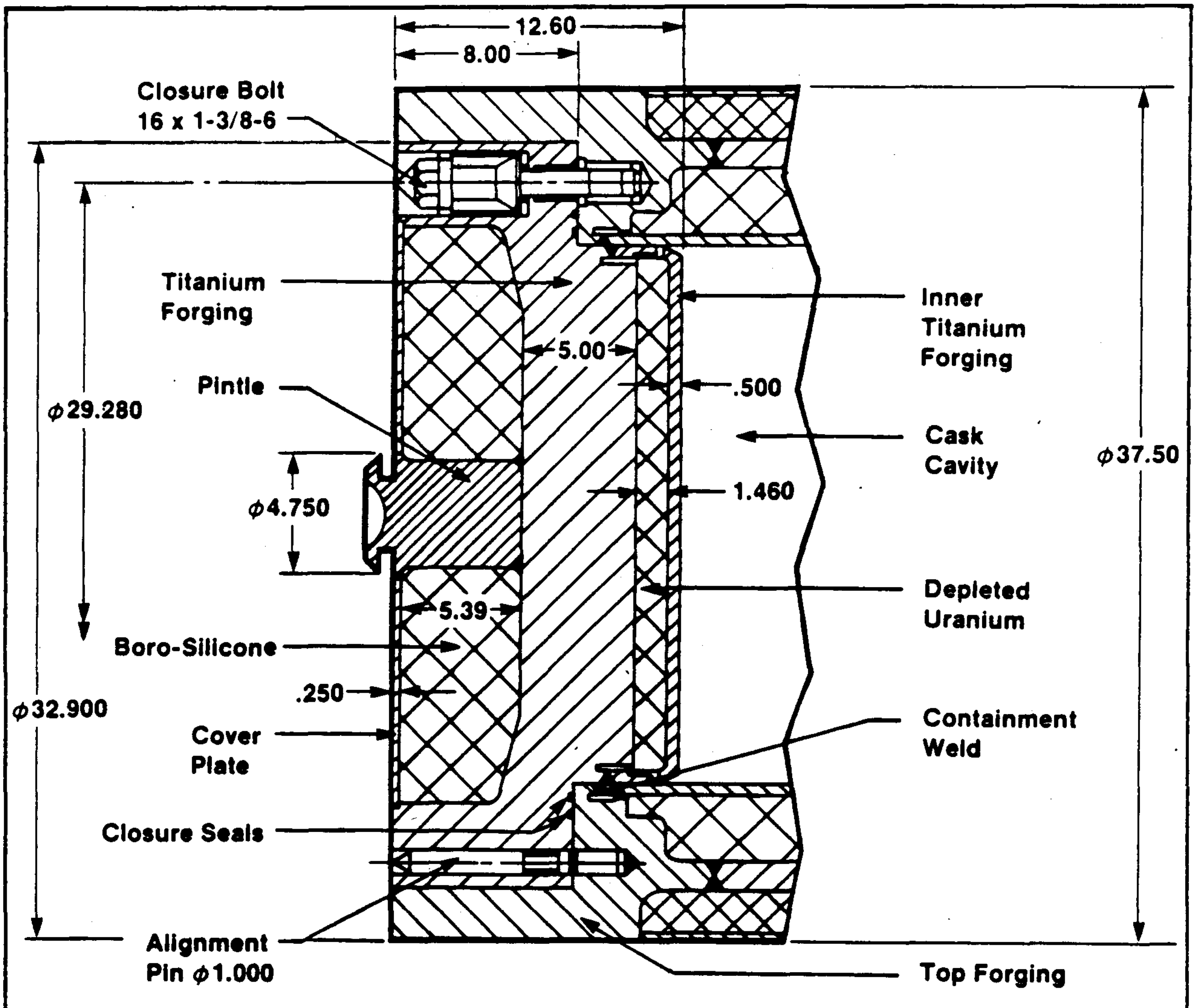

Figure 1.2-7. Cask Closure Lid

The Boro-Silicone is protected from the elements by a 0.25 inch thick Grade 2 titanium plate welded to the lid.

The closure lid is fastened to the cask body by a set of sixteen, captive, spring-loaded 1.375-6UNC, Alloy 718 bolts that are specially designed with conical heads. Key features of the bolted connection are shown in Figure 1.2-8. The bolt threads engage with a special Alloy 718 threaded insert that is installed in the cask body. The clearance between the closure lid and the cask ID is designed to be smaller than the clearance between the closure lid bolt holes and the bolts so that no direct shear loads are transferred to the bolts during drop events.

The closure lid is provided with alignment pins (one longer than the other) to simplify installation and to orient the cask lid with respect to the drain tube in the fuel basket. The lifting pintle is also provided with a key slot to ensure correct orientation especially when grappling with remote automated equipment. The interface between the cask and the closure lid is sealed by a pair of 0.25 inch diameter Viton O-ring face seals, shown in Figures 1.2-9 and 1.2-10. These seals are installed in dove-tail grooves machined in the lid. This enables ready inspection and replacement of the seals. Viton was selected from a range of candidate seal materials because of its operating temperature range (-40°F to 500°F), low permeability, and resistance to irradiation.

The O-ring seals are capable of being tested using the seal verification test port shown in Figure 1.2-10. The features of this test port are described later in this section.

<u>Penetrations</u>

The cask has two penetrations, one for purging/gas sampling, and the other for draining the cask cavity. Both these penetrations are located in the closure lid.

Figure 1.2-11 shows the basic features of the penetration for purging/gas sampling of the cask cavity. The access to the cask cavity is provided by two 0.375 inch diameter cross-drilled holes in the closure lid forging which

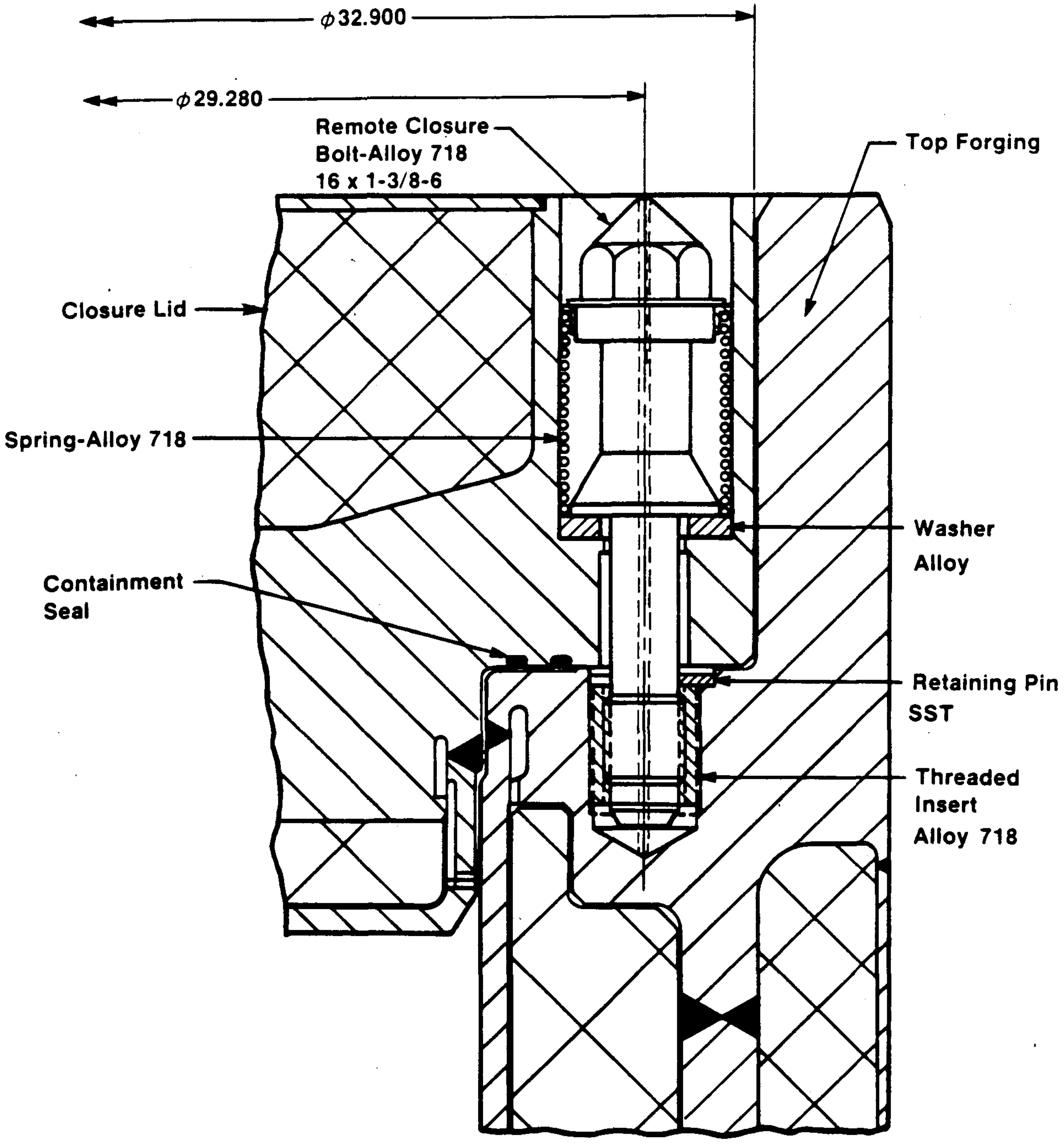

Figure 1.2-8. Closure Lid Bolt Detail

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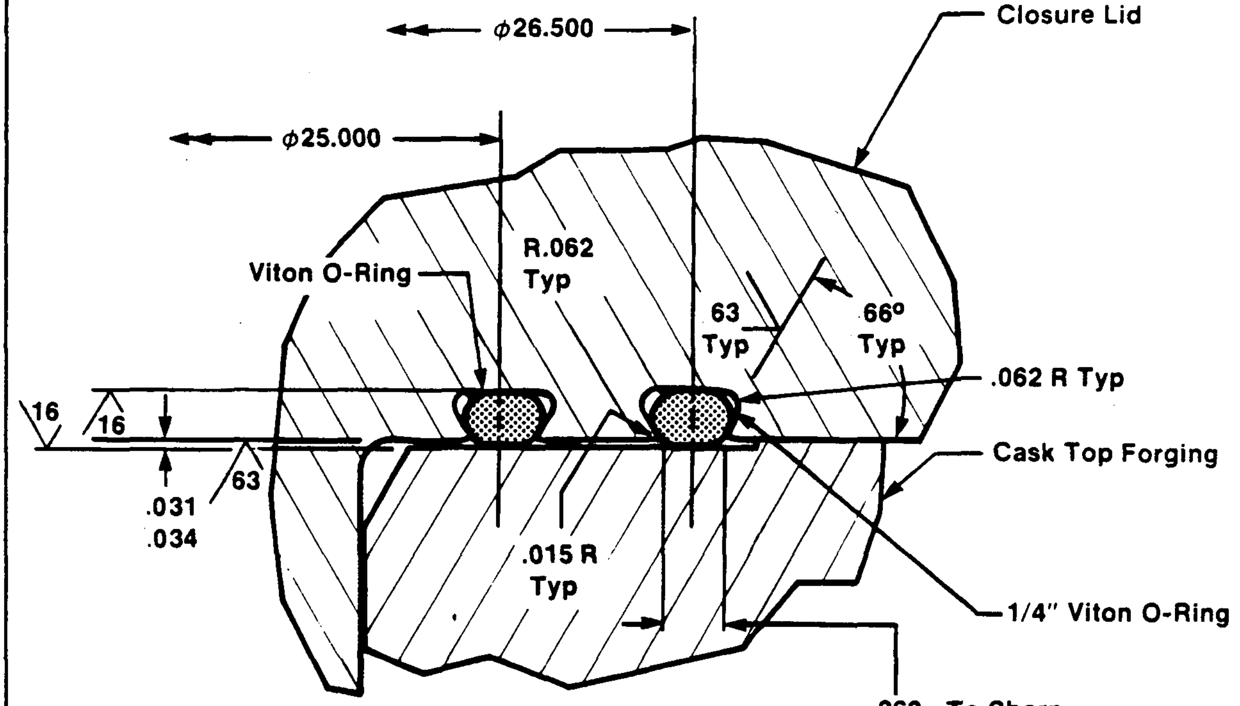

Figure 1.2-9. Closure Lid Seal Detail

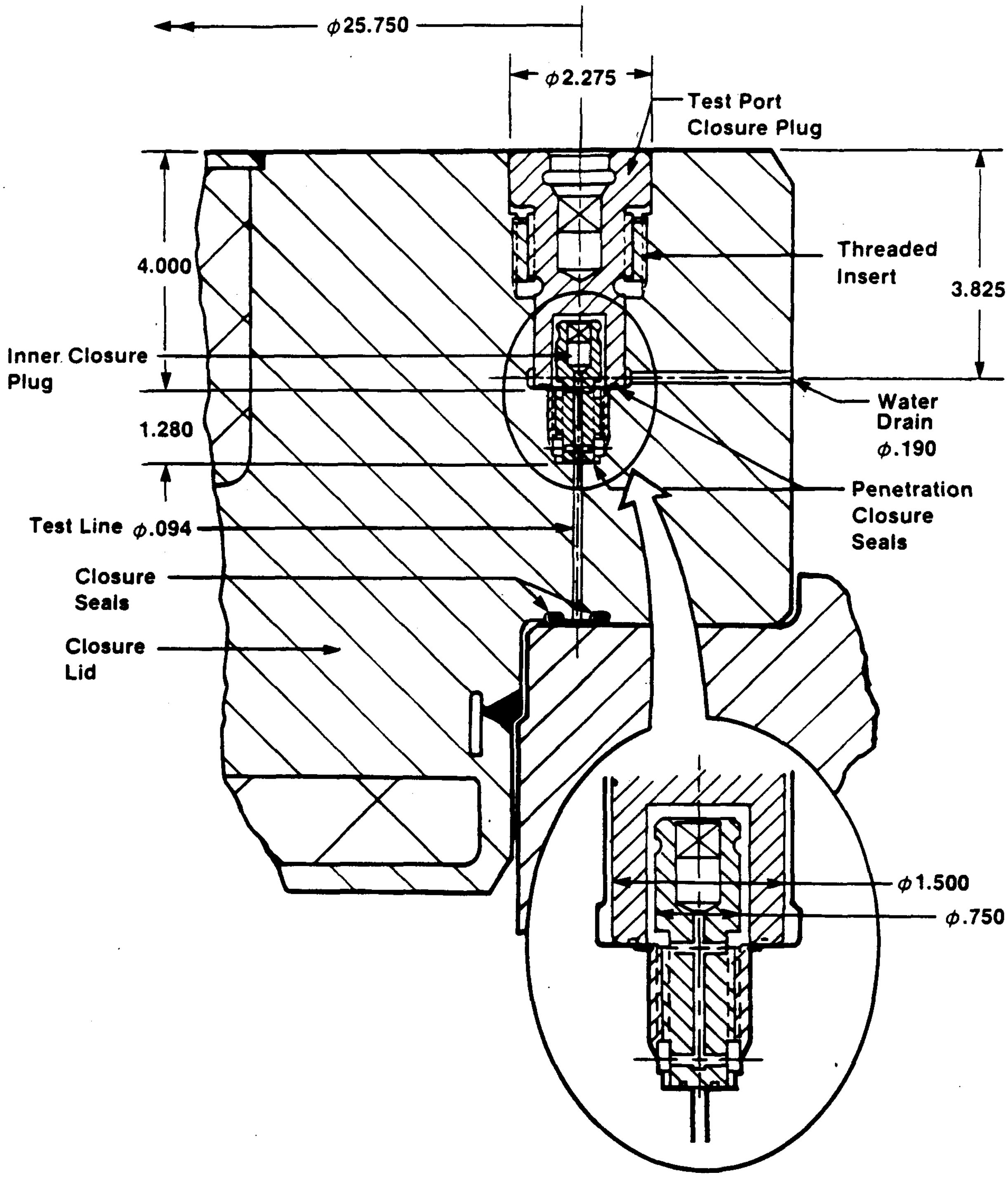

Figure 1.2-10. Closure Lid Seal and Seal Verification Test Port

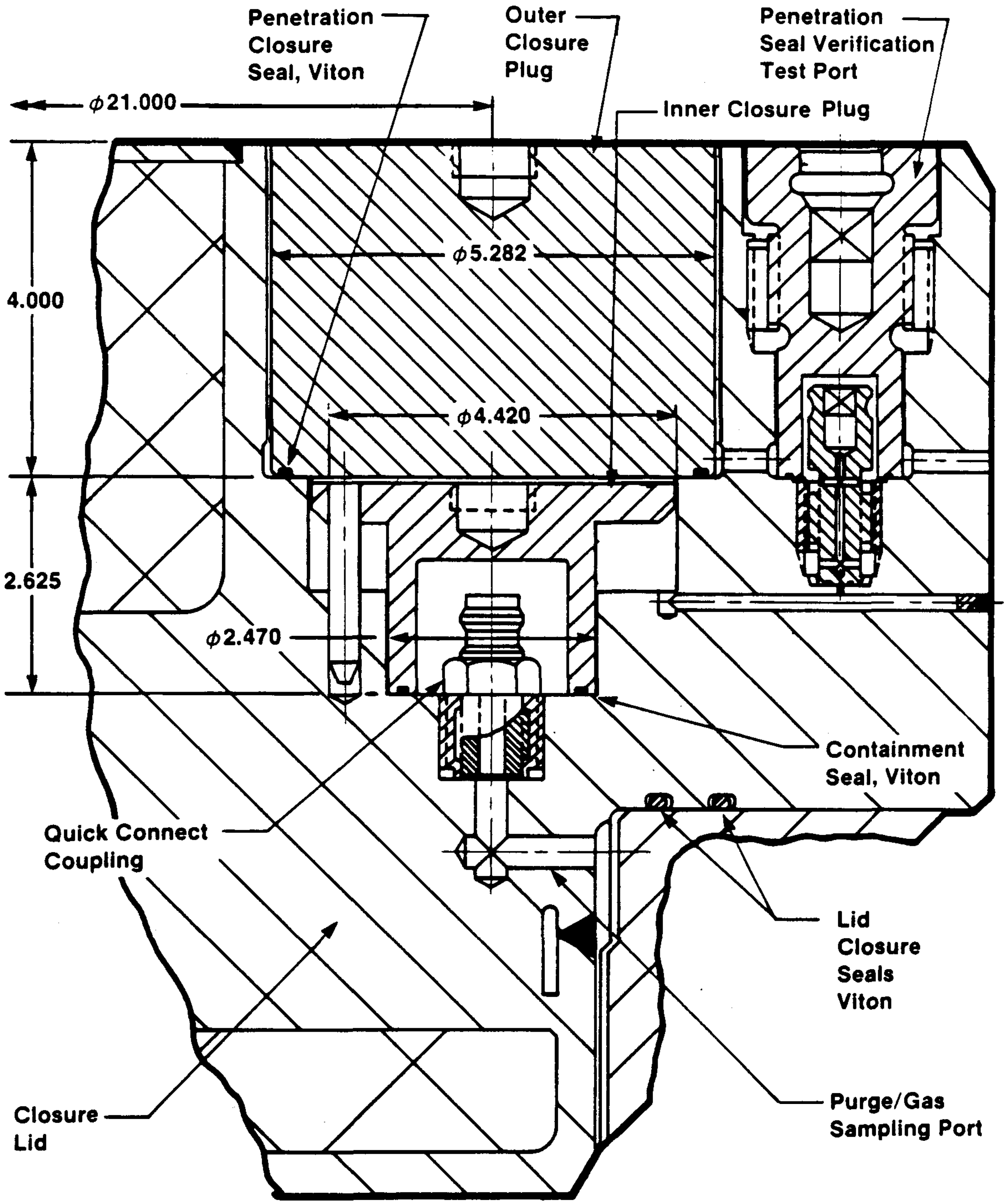

Figure 1.2-11. Purge and Gas Sampling Penetration

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connect with a male 304SS quick-disconnect coupling at one end and to the cask cavity via an axial groove in the lid cylindrical portion, at the other end. The quick-disconnect coupling is threaded into the closure lid recess and has its own O-ring seal. However, no credit is taken for this seal in meeting the requirements for double closure protection for the penetration. The quick disconnect coupling is covered by an inner closure plug which in turn is protected by an outer closure plug. Each of these plugs has its own O-ring seal made of Viton. The plugs have recessed bolting with conical heads to permit installation and removal using remote tooling. The space between the inner and outer closure plug seals is connected via cross-drilled holes in the closure lid to a seal verification test port which is described later. This seal verification test port permits verification testing of the purge/gas sampling penetration seals.

The penetration plugs are designed to maximize shielding protection and have structural sturdiness to withstand the design puncture events. The purge/gas sampling penetration also provides the capability for vacuum drying the cask cavity. Flowing gas samples can be taken by opening the drain penetration which is described below.

The drain penetration is illustrated in Figure 1.2-12, and is similar in design to the purge/gas sampling penetration in terms of components located in the closure lid. Two bolted closure plugs provide access to the 304SS male quick disconnect coupling threaded to the base of the recess in the closure lid. The coupling for the drain penetration is larger than the one used for the purge/gas sampling penetration to prevent errors in hookup. The ID of the quick disconnect coupling interfaces with a drain tube that is integral with the fuel basket and protrudes into the closure lid when the lid is seated on the cask body. The interface with the drain tube is sealed with a Viton O-ring seal that is installed in a groove in the ID of the quick disconnect coupling. A titanium boss is welded at the lower end of the penetration in the cask closure lid with a generous lead-in taper to guide the drain tube.

The angular orientation of the drain tube in the cask cavity is fixed because the fuel basket is keyed to the cask cavity. The closure lid alignment pins

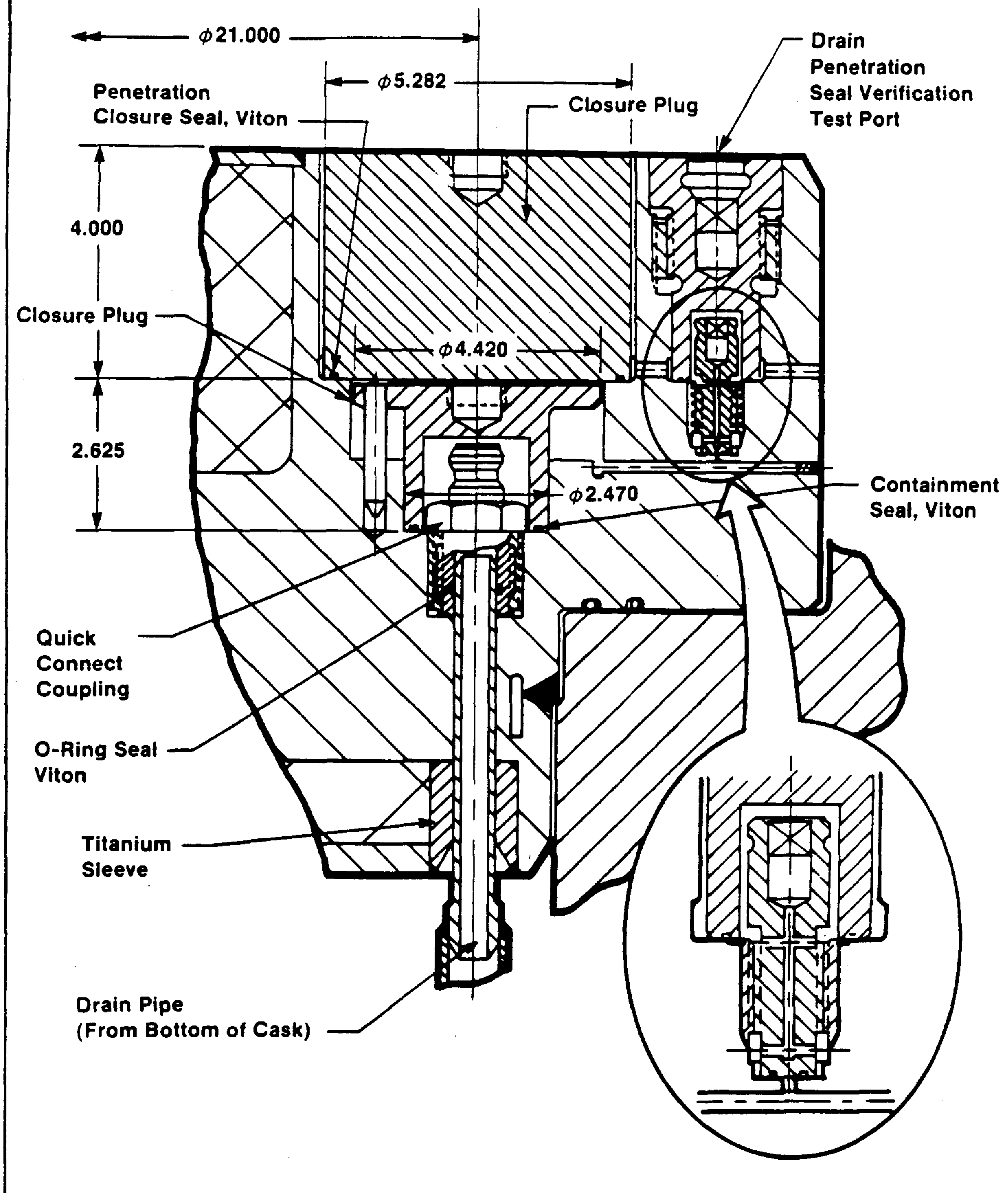

Figure 1.2-12. Drain Line Penetration

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and careful control of tolerances assure that the drain tube is properly aligned with the drain penetration.

Draining the cask cavity is accomplished by applying a positive air pressure through the purge/gas sampling penetration. The drain tube extends very close to the bottom of the cask and enables almost all the water to be forced out. The remaining water is removed by vacuum drying.

As in the case of the purge/gas sampling penetration, cross-drilled holes in the cask closure lid provide access to a seal verification test port that is used to check the integrity of the penetration seals.

The components of the cask drain penetration such as the closure plugs and quick-disconnect coupling are located in the closure lid permitting visual or remote verification of system. Removal of the closure lid also enables viewing of the drain tube.

The purge/gas sampling penetrations and the drain penetration can be used for gas circulation to permit on-site cooldown of the fuel and cask cavity prior to wet unloading operations.

<u>Seal Verification Test Ports</u>

The cask closure lid O-ring seals and each of the penetrations for venting/purging/gas sampling and draining the cask cavity is provided with means for verification of the containment integrity. This verification is performed by measuring any leakage through a seal verification test port.

The three seal verification test ports provided in the closure lid are of the same design as shown in Figure 1.2-13. The test port consists of a pair of 304SS straight-threaded closure plugs located in series inside a recess in the closure lid forging. Cross-drilled holes in the closure lid connect the test port with the space to be leak-tested (annular space between the closure lid O-ring seals, or the space between double closure O-ring seals in the penetrations). Each plug has an O-ring face seal at its lower end to meet the

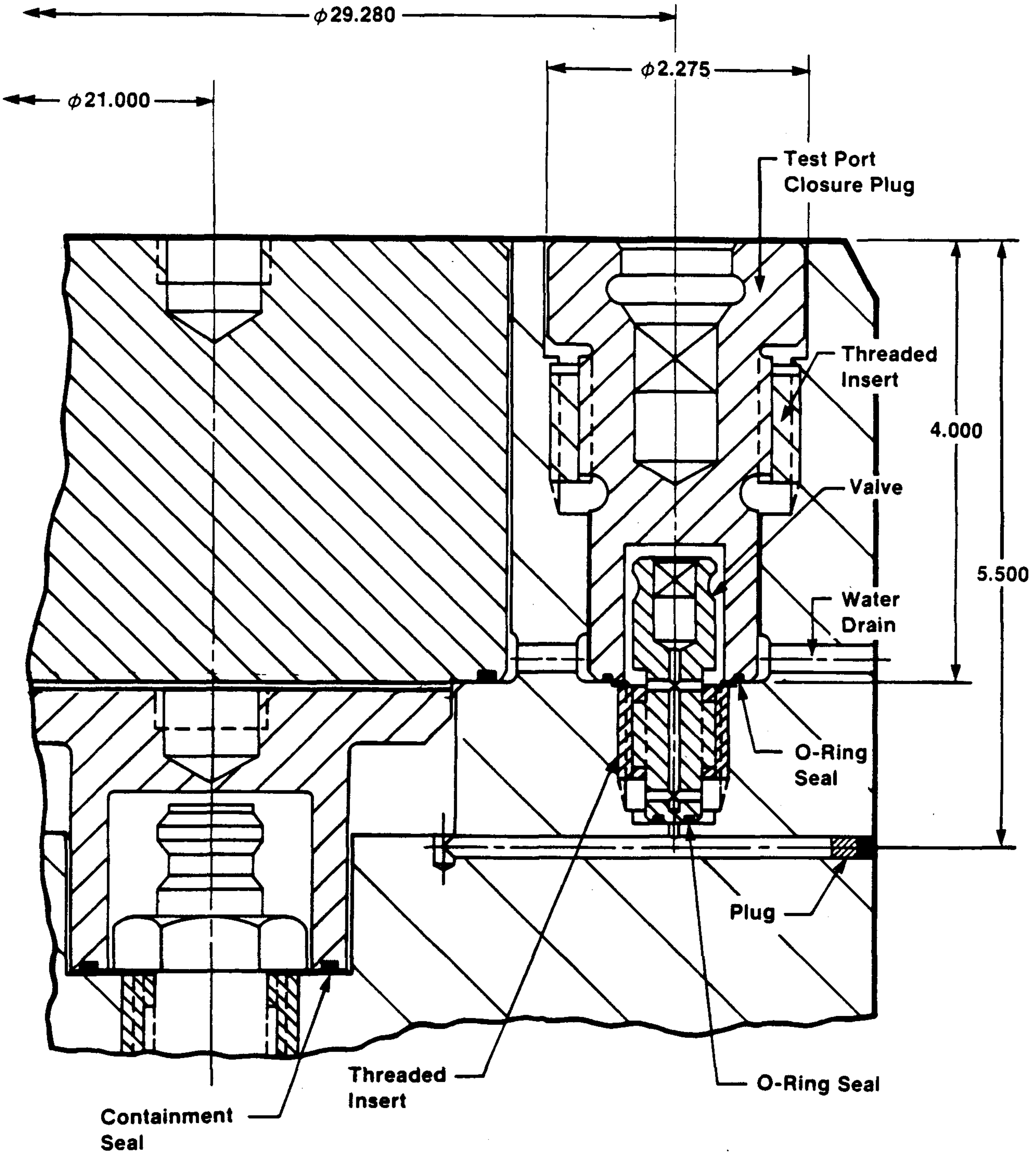

Figure 1.2-13. Seal Verification Test Port

requirement for redundant closure protection. The plugs have square holes to allow engagement of a tool to secure and loosen them. Drain holes are provided to prevent accumulation of water in the recess and eliminate hydraulic locking.

To perform the seal verification testing, the outer closure plug is removed and replaced with a special tool (not shown) that is threaded into the port. An O-ring face seal at the lower end of the tool establishes a sealed connection in the same manner as the plug that it replaced. The inner plug is then turned by a shaft in the tool to unseat the plug. This allows any leakage flow to pass through the tool into the leak testing equipment.

Fuel Baskets

The LWT cask has interchangeable fuel baskets for BWR and PWR fuel. The baskets are designed to fit within a cylindrical cask cavity that is 180 inches long and 23.76 inches in diameter. Details of the design are provided in drawings 1986E42 (BWR fuel basket) and 1988E44 (PWR fuel basket).

The salient features of the BWR fuel basket design are presented in Figures 1.2-14 through 1.2-16. The basket is of welded 316N SS construction and has seven compartments for the fuel assemblies. Each compartment is 5.90 inches square. Structural strength is provided by a system of radial and longitudinal stiffener plates that vary in thickness from 0.19 to 0.29 inches. The remaining basket components include a bottom plate (with holes that match the compartment size), a top plate and handling collar. The length and diameter of the basket have been selected to accommodate differential thermal expansion between the cask body and the basket.

The central compartment in the BWR fuel basket is provided with 0.075 inch thick Boral plates that are sandwiched between a recess milled in the walls of the compartment and a 0.031 inch thick 316 SS liner that is welded at each end to the basket structure. This liner provides structural support for the Boral and no credit is taken for the structural strength of that material. Technical information on Boral is provided in Section 1.5.

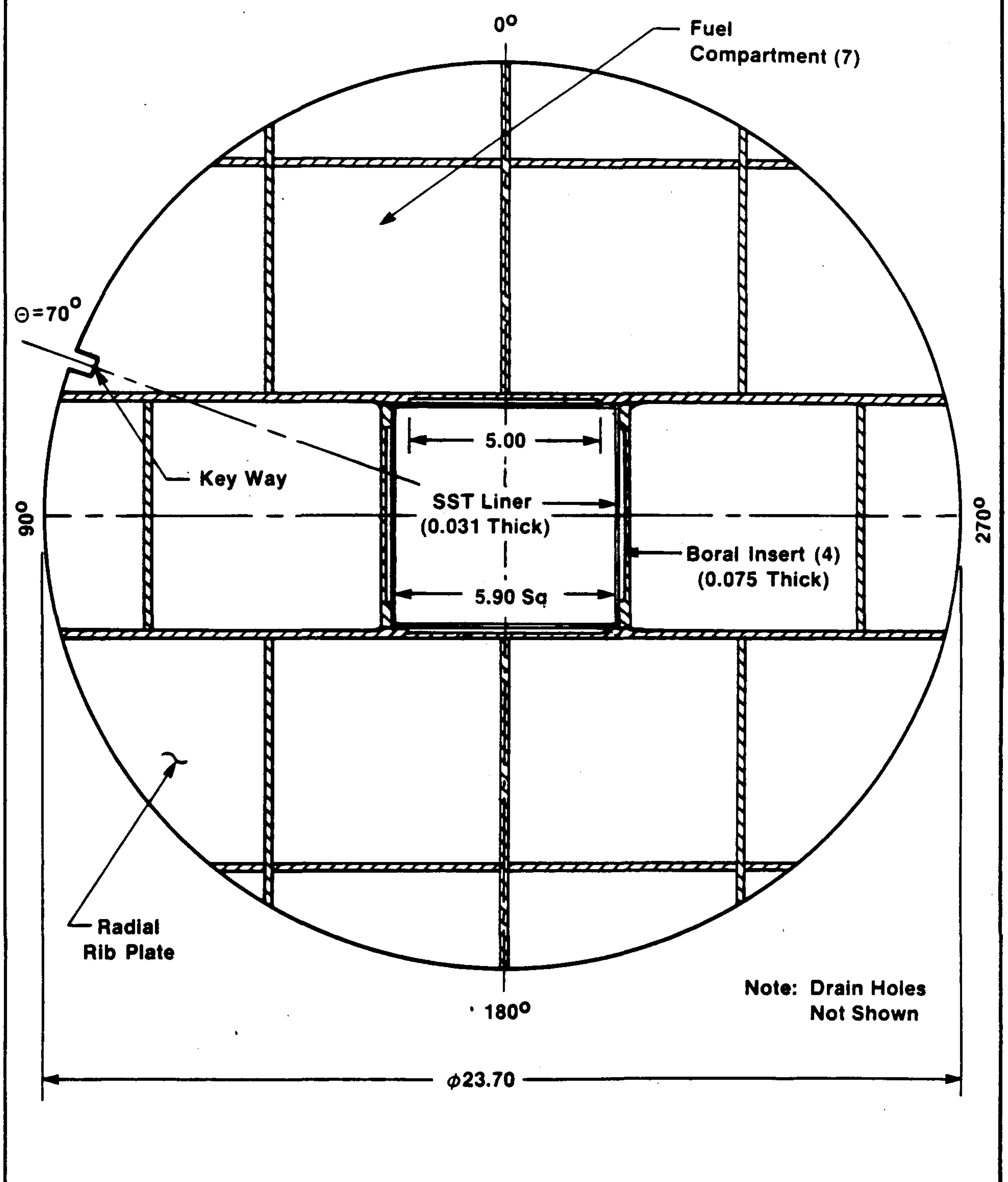

Figure 1.2-14. BWR Fuel Basket Cross-Section

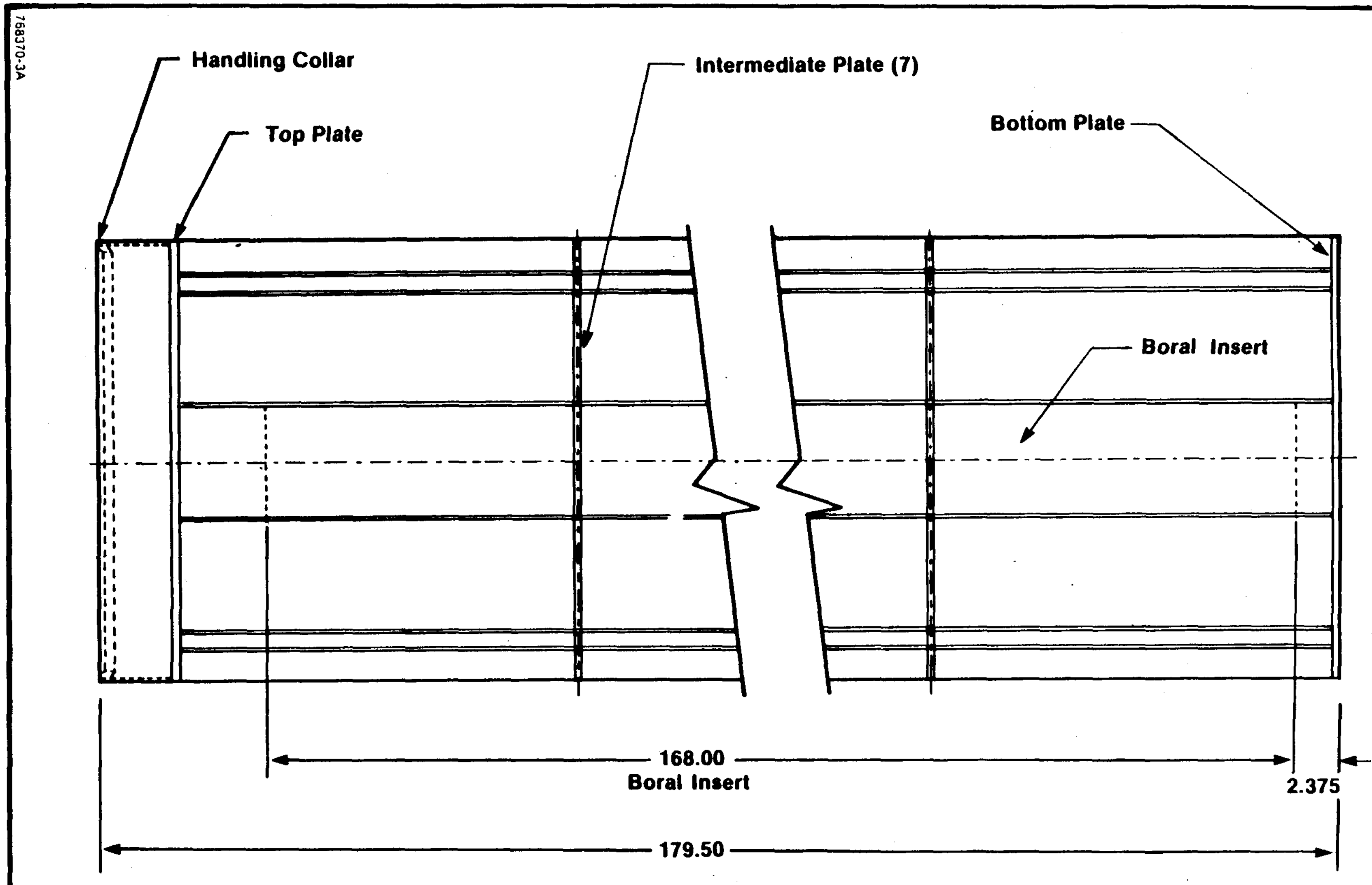

Figure 1.2-15. BWR Fuel Basket

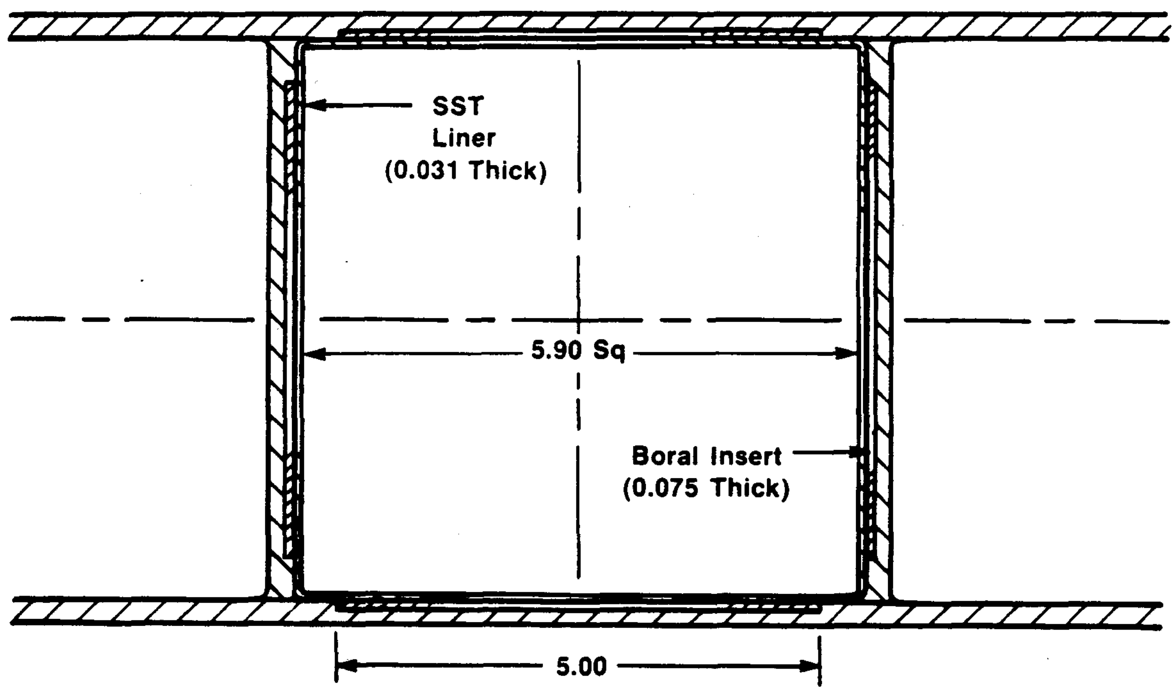

Figure 1.2-16. BWR Fuel Basket Boral Insert

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The radial stiffener plates have a keyway slot on the outer diameter. This keyway mates with a key welded to the cask ID to ensure proper radial orientation of the basket. The handling collar at the top end of the basket enables the handling of the basket for changeout using manual or remote tooling. Holes are provided in all the stiffener plates to reduce the weight of the basket and to facilitate free drainage of water.

The PWR fuel basket design is shown in Figures 1.2-17 and 1.2-18. The basic features of the design are similar to those of the BWR fuel basket. The basket has three 8.80 inch square compartments. Each compartment is provided with 0.101 inch thick Boral plates for neutron absorption that are installed in the same manner as for the BWR fuel basket. The PWR fuel baskets are provided with longitudinal stiffener bars at the outside corners of the three compartments closest to the cask ID. These bars are machined to be compatible with the cask ID profile and extend the full length of the basket.

The length of the Boral plates for both the BWR and PWR fuel baskets are designed to protect the full length of the active fuel in the assemblies while the assemblies are positioned close to the top of the basket. The Boral plates are fabricated in 168 inch lengths, eliminating the need for joints along the length of the plates.

In order to accommodate fuel assembly types of different overall lengths, the cask will be provided with aluminum Alloy 6061 spacers. The designs of these spacers for BWR and PWR fuel assemblies are shown in Figures 1.2-19 and 1.2-20, respectively.

The upper ends of the fuel compartments in the BWR and PWR fuel baskets are provided with tapers to guide the fuel into the basket. In the interests of minimizing the cask ID (and overall weight) to maximize payload capacity, these tapers are necessarily small. A more effective method of ensuring that the fuel is guided into the basket is by placing a specially designed Fuel Assembly Lead-in fixture, shown in Figure 1.2-21, on the cask body after the closure lid is removed. In addition to providing a very generous lead-in, the fixture also prevents crud from the fuel assemblies from falling on the cask closure end and simplifies decontamination.

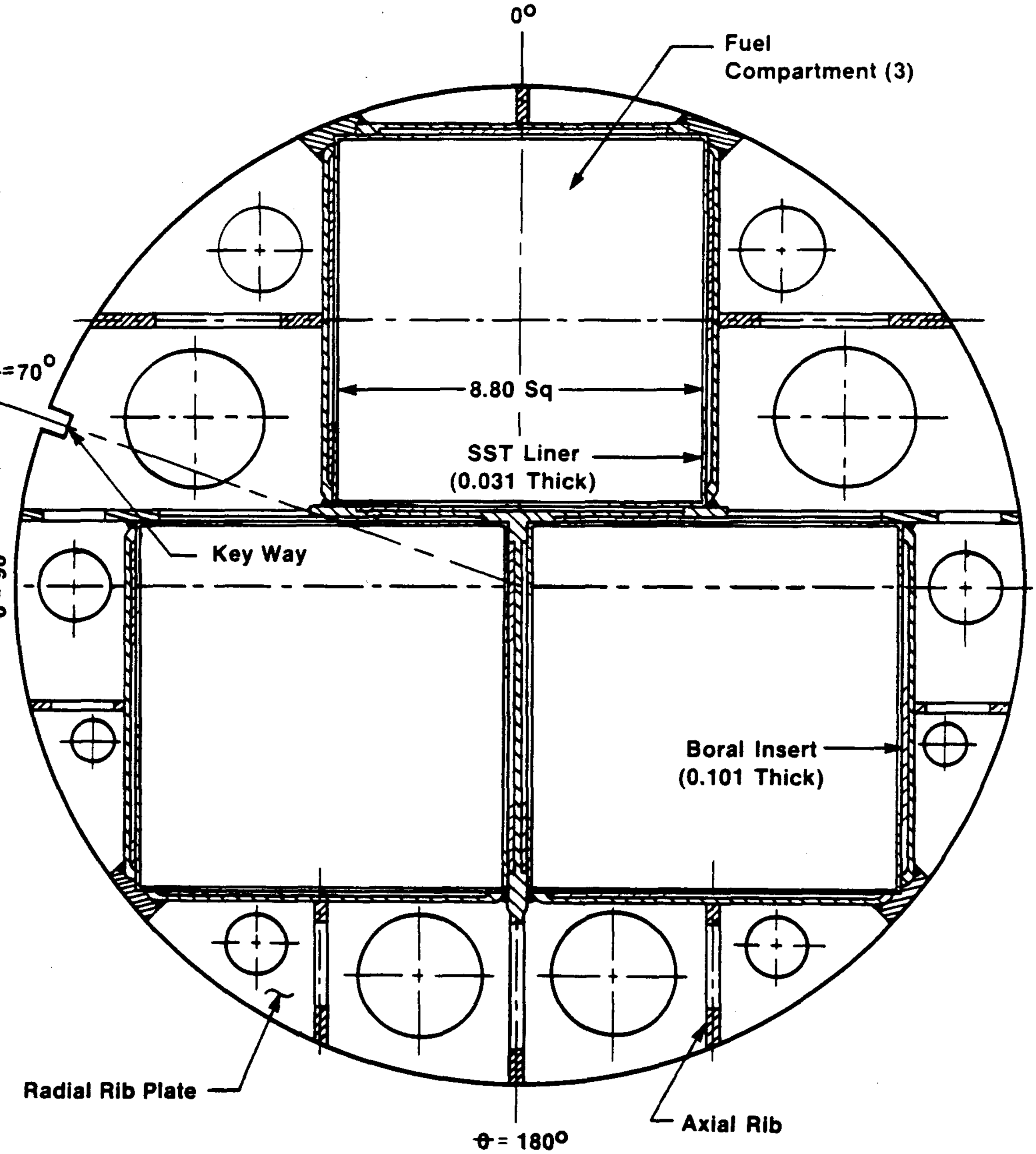

Figure 1.2-17. PWR Fuel Basket Cross-Section

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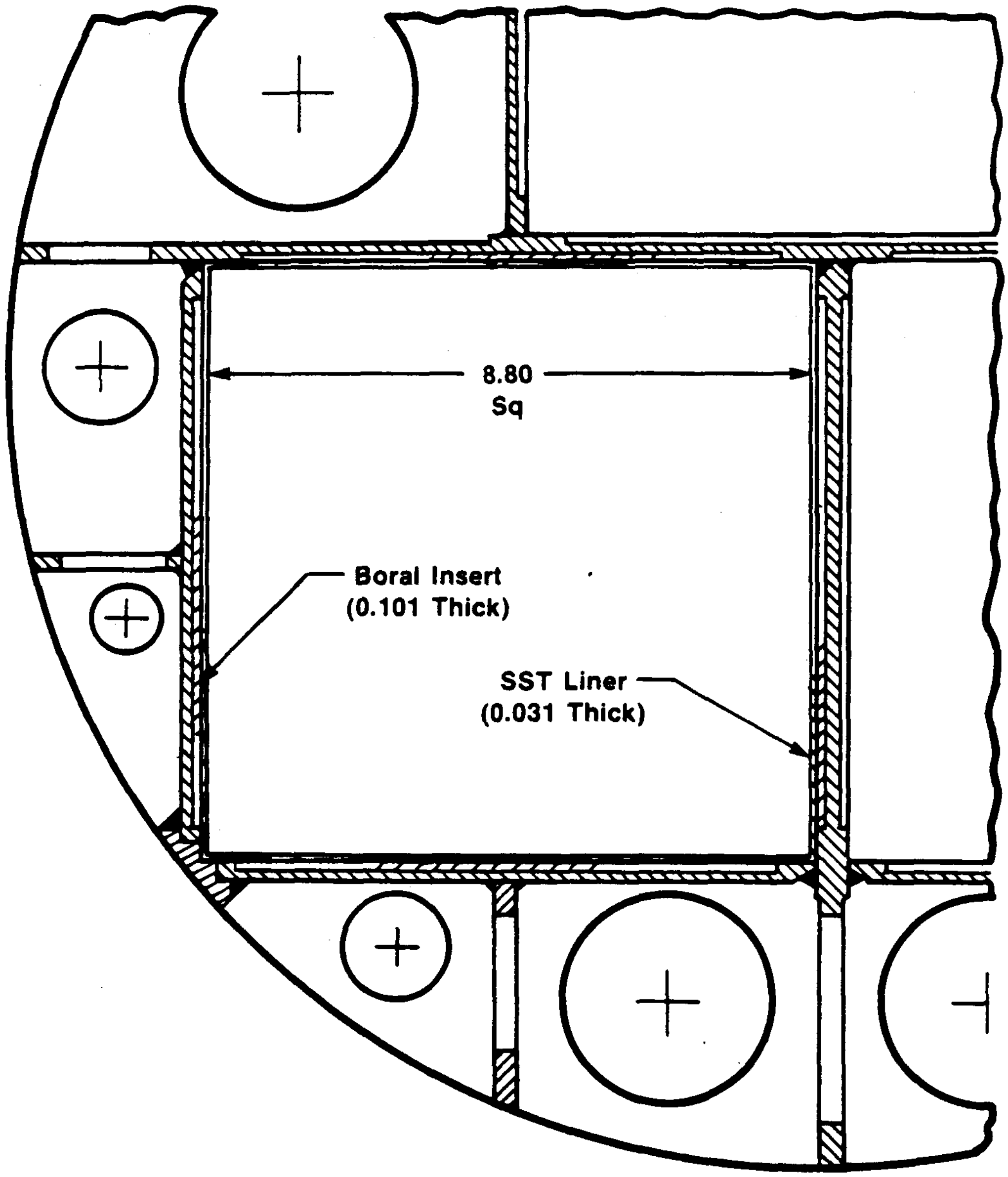

Figure 1.2-18. PWR Fuel Basket Boral Insert

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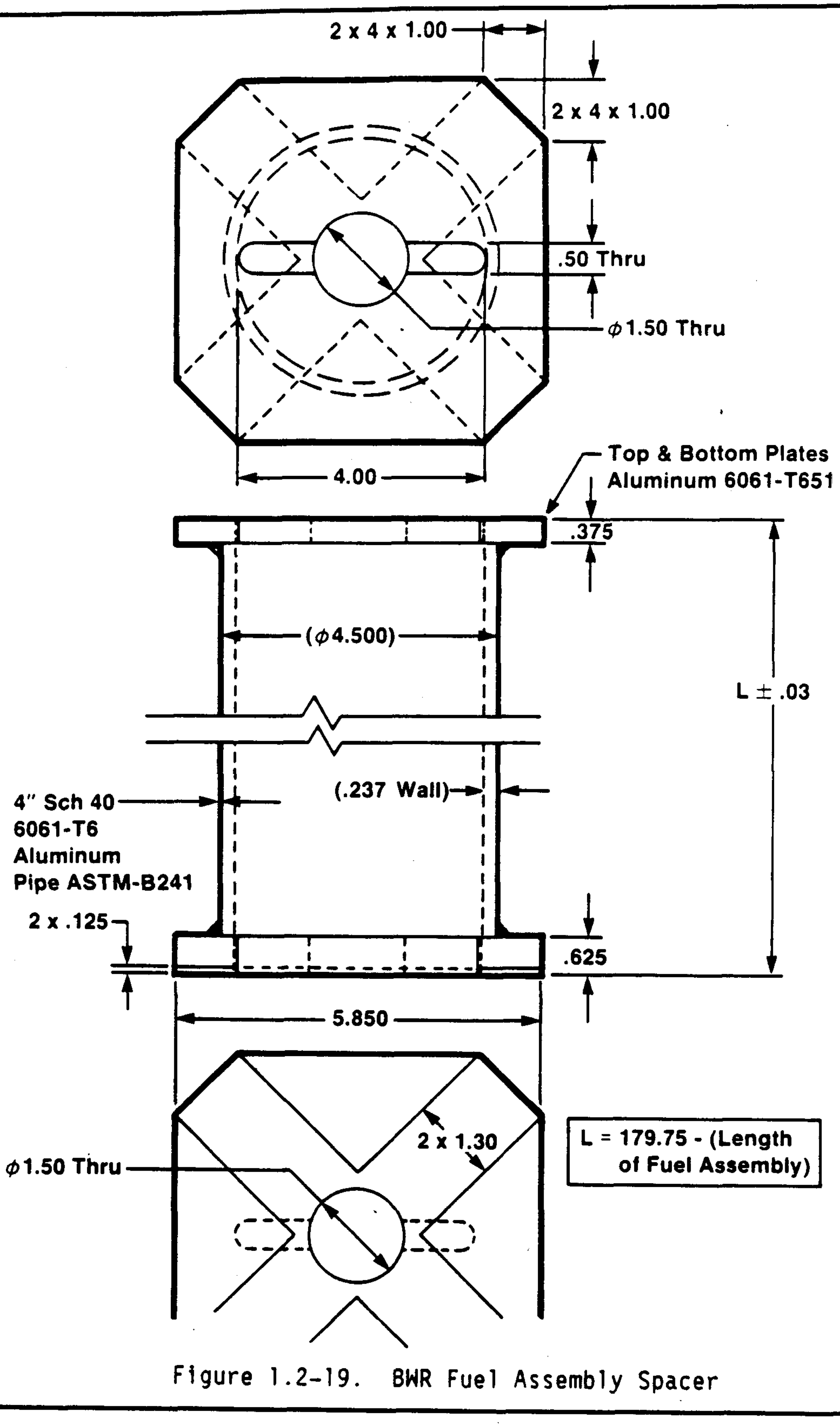

Figure 1.2-19. BWR Fuel Assembly Spacer

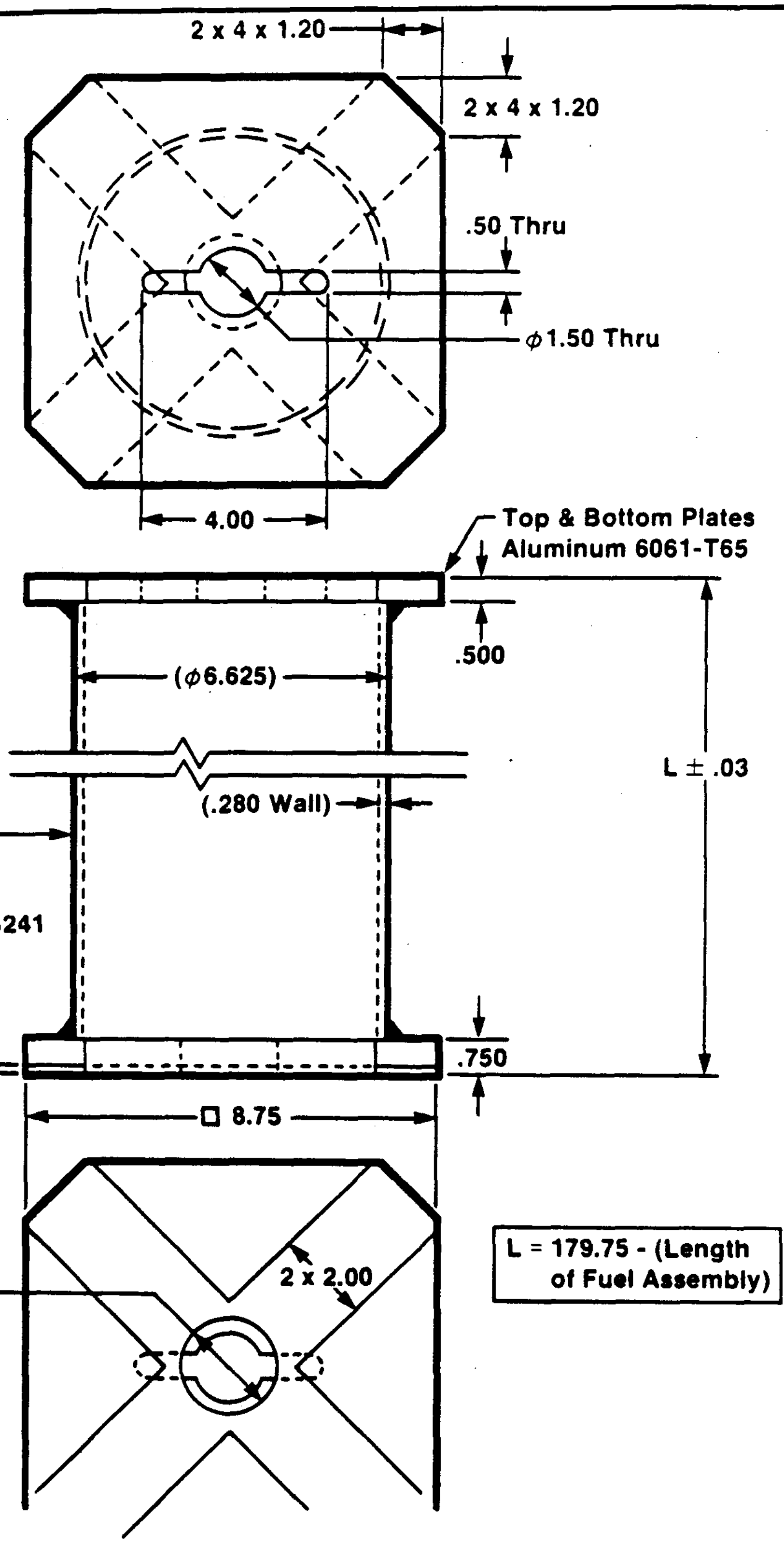

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Figure 1.2-20. PWR Fuel Assembly Spacer

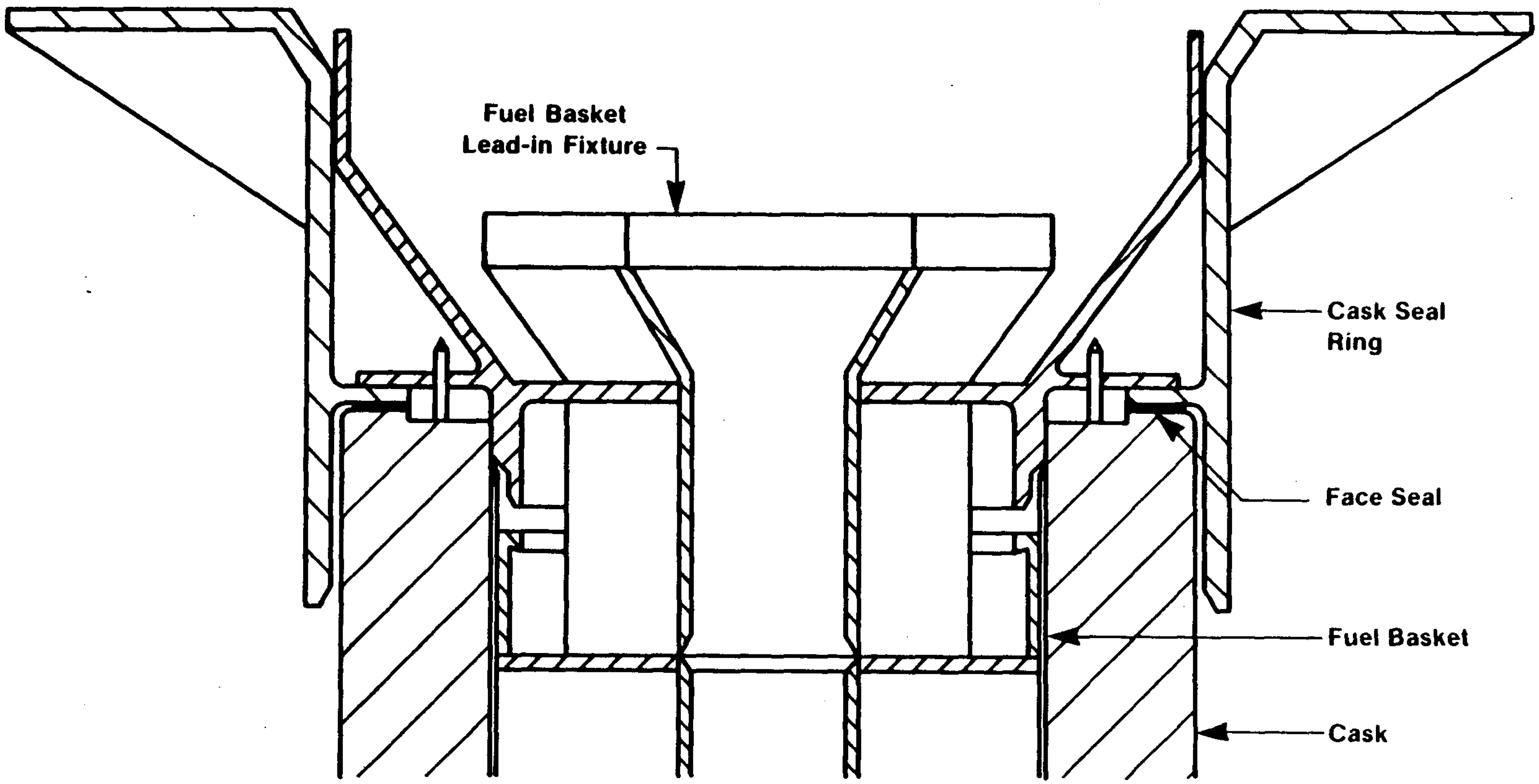

Figure 1.2-21. Fuel Assembly Lead-in Fixture

The Fuel Assembly Lead-in Fixtures will be tailored for BWR and PWR assemblies.

The removable basket design also provides the cask with versatility for accommodating special waste forms such as failed fuel and irradiated hardware using specially designed baskets for that purpose.

Impact Limiters

Impact limiters are provided at the ends of the cask to absorb the energy from the design drop accident events and to limit the deceleration loadings on the cask body. Aluminum honeycomb was selected for energy absorption service because it provides for a light-weight, compact impact limiter that is durable and essentially maintenance-free.

A schematic of the impact limiter design is shown in Figure 1.2-22. Design details are given in Drawing 1988E43. The impact limiters are constructed from aluminum Alloy 5052 honeycomb material having two different crush strengths and densities. The honeycomb panels are shaped to match the profile of the cask body and sized so that the honeycomb structure provides optimum energy absorption characteristics for different drop orientations. Honeycomb material with a density of 10.6 lb/ft^3 and 1400 psi crush strength is used at the ends of the cask and around the corners to absorb the impact energy from the end and corner drops. Honeycomb material with a density of 8.1 lb/ft^3 and 740 psi crush strength is used to absorb the impact energy from the side drop. The lower density honeycomb is used on the sides because a larger thickness is required to ensure that the cask trunnions do not contact the impact surface during the drop event.

The radial and corner regions of the impact limiter are constructed from honeycomb segments that are bonded together with an epoxy foam-type adhesive that maintains its strength over the service temperature range. The honeycomb impact limiters are encased in a 0.031 inch thick Type 304 stainless steel sheathing with welded joints. This sheathing protects the honeycomb from the elements and damage. Thicker sheathing (1/8 inch) is used along the bolting surface of the impact limiter.

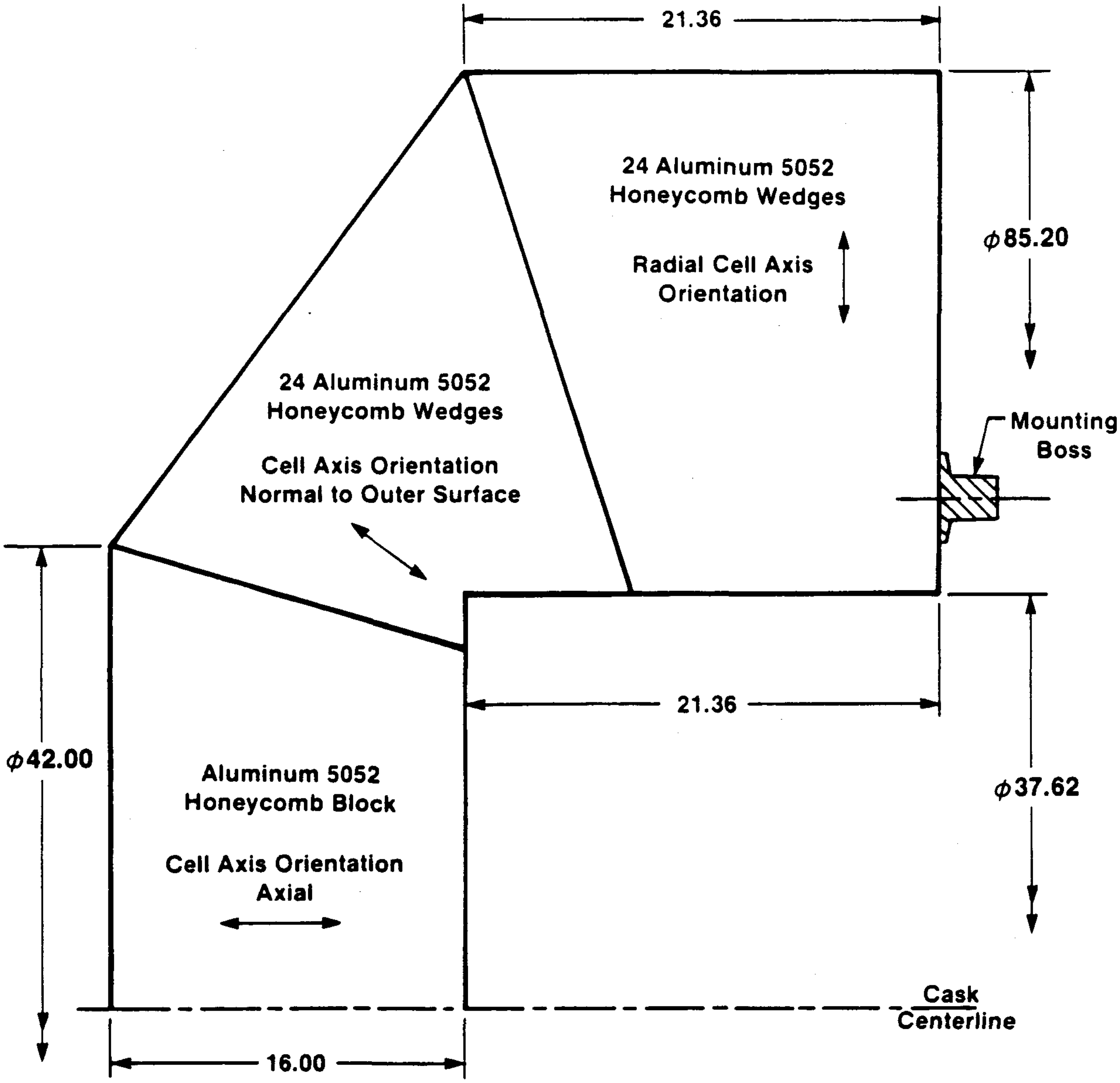

Figure 1.2-22. Impact Limiter

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Each impact limiter is secured to the cask body by four 5/8-11 UNC, Alloy 718, captive bolts. Each bolt passes through a collar attached to the cask body and engages with a special threaded receptacle welded to the impact limiter sheathing as shown in Figure 1.2-23. The bolts are spring-loaded and have conical heads to facilitate the use of remote tooling.

The impact limiter for the cask upper end is fitted with a weather seal to prevent the ingress of dirt or water into the closure lid area.

Maintainability, Reliability, and Operability Issues

The TITAN LWT Cask System has been designed to minimize maintenance requirements and to simplify those maintenance operations that will be required. Proven design features have been incorporated to maximize reliability of operation and to permit operation using manual, remote manual, and remote automated methods. These are highlighted below:

1. The innovative titanium alloy cask design maximizes payload capacity while meeting the gross vehicle weight limitations. This results in a significant reduction in operational times and associated costs.

2. The aluminum honeycomb impact limiters covered with stainless steel provide for a reliable energy absorption system that will not deteriorate in service as compared to wood and foam materials. Maintenance requirements are therefore minimal.

3. In the event of damage, the impact limiters can be readily replaced as they are secured by bolts.

4. The cask employs bolted trunnions with replaceable wear sleeves. Maintenance time for replacement of the sleeves is minimized while providing the option for replacement of the entire trunnions if required.

5. The solid elastomeric neutron shield does not require the frequent maintenance necessary with liquid neutron shields.

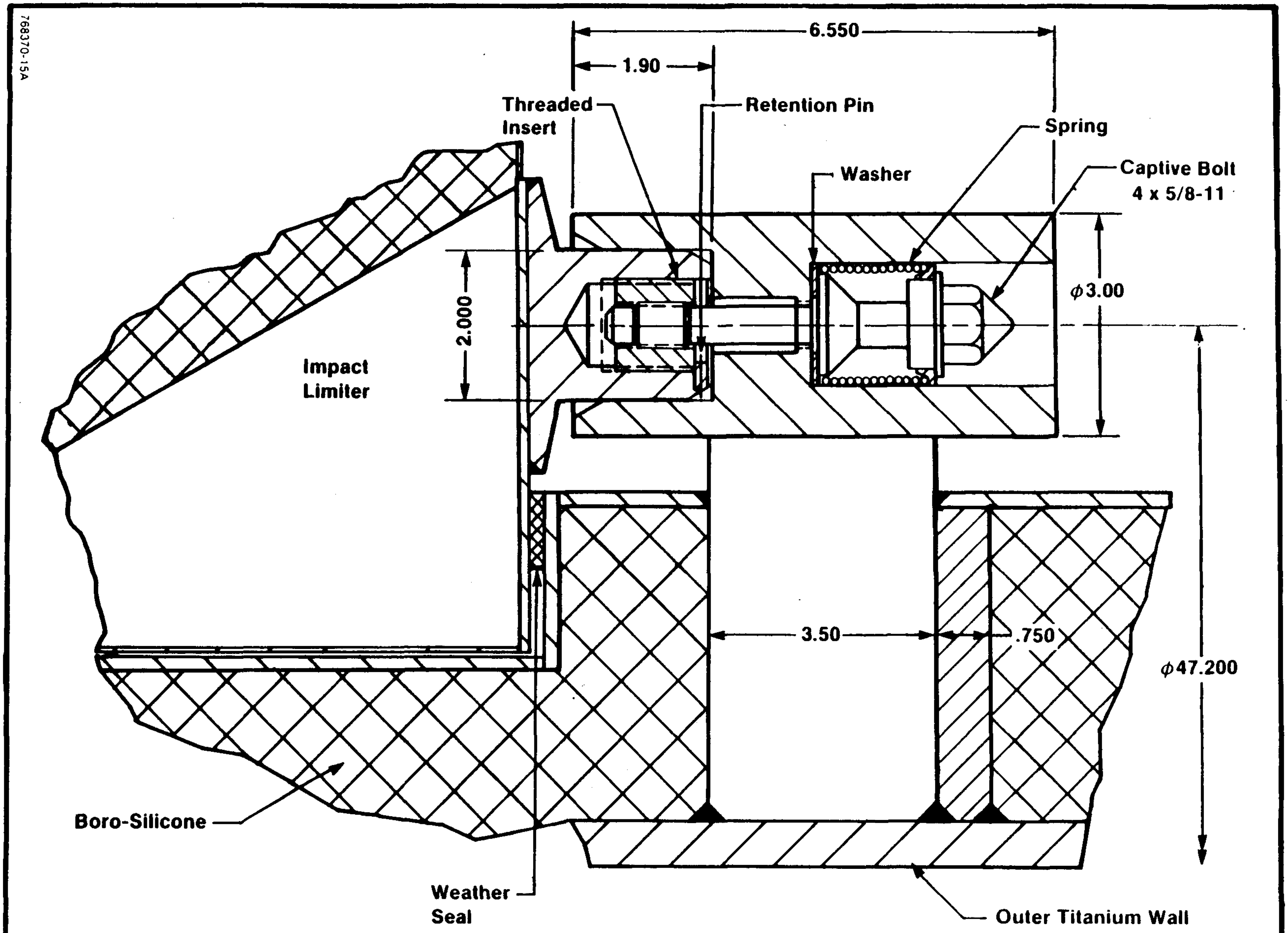

Figure 1.2-23. Impact Limiter Bolt Detail

6. Depleted uranium used as the primary gamma shield is not subject to slumping and deterioration of shielding performance in service, eliminating maintenance checks and possible repairs.

7. The replaceable wear sleeves on the trunnions are provided with weather seals to prevent ingress of pool water into the neutron shield cavity that could seep out during transport and require decontamination.

8. The upper impact limiter is provided with a weather seal to eliminate water and road dirt from entering the closure lid area. This reduces operational time required for cleanup of that area.

9. The smooth contours of the cask facilitate decontamination. Cask materials are compatible with decontamination agents.

10. The removable baskets provide the cask with operational flexibility and versatility for accommodating special fuel forms.

11. The closure lid uses a conventional bolted design that has a proven track record and ensures a high degree of reliability of the containment integrity.

12. The closure lid uses spring-loaded captive bolts with conical heads, long and short alignment pins to orient the lid in the proper manner, and visual alignment marks. These features permit operation using manual, remote manual, and remote automated methods and result in reduced operational time with any of those methods.

13. The closure lid bolt design and the interfaces between the lid and the cask body are carefully designed to ensure that the bolts do not carry loads in shear. The same principles have been applied to the design of the trunnion bolts. Reliability of the connections is therefore enhanced.

14. The closure lid is fully recessed, as are the closure lid bolts and the penetration closures. These design features provide a high degree of reliability of containment integrity under the drop and puncture accident events.

15. The closure lid seals and the penetration seals are of the face-seal design and are retained in the closure lid and the penetration closure plugs. This permits easy visual examination and replacement of the seals during cask maintenance operations.

16. The lifting and tiedown features on the cask are located in the low exposure regions of the cask to simplify operations and reduce exposure to personnel.

1.2.2 Operational Features

The TITAN LWT cask is designed for operation using manual, remote manual, and remote automated methods. The operational features have been described in the preceding sections and are discernable from the drawings provided in Section 1.5. An outline of the cask operational procedures are provided in Section 7.0. Detailed operating procedures will be included in the Technical Manual for the cask system.

1.2.3 Contents of Packaging

The TITAN LWT cask will transport spent PWR and BWR fuel assemblies from commercial nuclear power plants to an interim storage facility or a federal waste repository. The evaluations presented in support of the Preliminary Design have been based on a cask payload of intact fuel assemblies.

While the possible contents of the cask cover a variety of intact fuel assembly types, the cask has been optimized to accommodate a specific set of intact fuel assembly designs having specific burnups and age (time out of reactor). The LWT cask has been designed to accommodate the following specific types of fuel assemblies:

PWR Spent Fuels

Westinghouse Electric	17x17
Westinghouse Electric	15x15
Westinghouse Electric	14x14
Babcock & Wilcox	17x17
Babcock & Wilcox	15x15
Combustion Engineering	16x16
Combustion Engineering	14x14
Exxon Nuclear	17x17
Exxon Nuclear	15x15
Exxon Nuclear	14x14

BWR Spent Fuels

General Electric	8x8
General Electric	7x7
Exxon Nuclear	8x8
Exxon Nuclear	7x7

The specific burnup and age characteristics of the payload are:

Maximum Burnup

PWR Assemblies:	35,000 MWD/MTU
BWR Assemblies:	30,000 MWD/MTU

Fuel Age — 10 years out of reactor

The initial enrichment of the fuel used as a basis for the design of the cask ranges from 3.0 to 4.5 w/o U-235.

1.2.3.1 Maximum Payload Weight

The TITAN LWT cask is designed to carry a maximum of three (3) intact PWR assemblies or seven (7) intact BWR assemblies. The heaviest of the above listed PWR assembly designs is the Babcock & Wilcox 15x15 which has a dry weight of 1515 pounds. Three of these assemblies weigh 4545 pounds. The heaviest BWR assembly is the Exxon Nuclear 7x7 which weighs 619 pounds in the dry condition. Seven of these assemblies weigh 4335 pounds. The maximum payload weight is limited to 4550 pounds. The cask dimensions will permit all the fuel assembly types specified in the design requirements (Reference 1.2.1).

1.2.3.2 Maximum Decay Heat

The maximum decay heat in the package will be limited to 1740 thermal watts.

1.2.3.3 Maximum Curie Content

The maximum curie content of the various isotopes associated with irradiated spent fuel shall be less than 5.9×10^5. A breakdown of the curie content of the worst case PWR fuel is given in Section 5.2.

1.2.3.4 Cask Atmosphere

Prior to shipment, the cask will be dewatered and inserted with helium at 1 atmosphere.

1.2.3.5 Radiation Levels

Radiation levels will not exceed the requirements given in Paragraph 71.47 of 10 CFR Part 71 and Paragraph 173.441 of 49 CFR Part 173.

1.3 Cask Support System

The functions of the cask support system are 1) to support and secure the LWT cask on the transporter (semi-trailer) for transport, and 2) provide a pivot point for rotating the cask from its horizontal transport position to the vertical for off-loading and vice-versa.

The cask support system consists of two major components. They are 1) the front support cradle and 2) the rear support and pivot. Figure 1.3-1 shows the salient features of the support system design. Design details are provided in Drawings 1988E50, 1988E51, and 1988E52 included in Section 1.5.

The front support cradle is an Aluminum Alloy 6061 weldment fabricated from plate and I-beams. The cradle is contoured to match the circumferential profile of the cask OD with a cutout at the bottom to provide clearance for the bottom (redundant) trunnion on the cask. Two clamps are provided, one on each side of the cradle. These clamps secure the top lifting and tiedown trunnions, and are designed to provide vertical restraint for the cask. After the holddown bolts are loosened, the clamps are then swung outward to clear the trunnions.

The clamps are made of Type 304 stainless steel. Each clamp is provided with two specially designed 7/8-9 UNC captive bolts made from 17-4 PH stainless steel. With the bolts loosened, the clamps are designed to be raised to clear the trunnion flanges using a stainless steel wire bail and swing outboard where they rest in the horizontal position on brackets.

The rear support and pivot serves to provide a triaxial restraint for the cask, and permits rotation of the cask between the horizontal and vertical positions. The materials of construction are similar to those used for the front support cradle. The pivot points for the cask trunnions on the rear support are designed in the form of a U-shaped bracket with a generous lead-in angle for lowering the cask onto it. A swing-in type clamp is used to secure the bottom cask trunnions to the bracket. The clamps are locked in position with detent pins that take the vertical load in double shear. Vertical

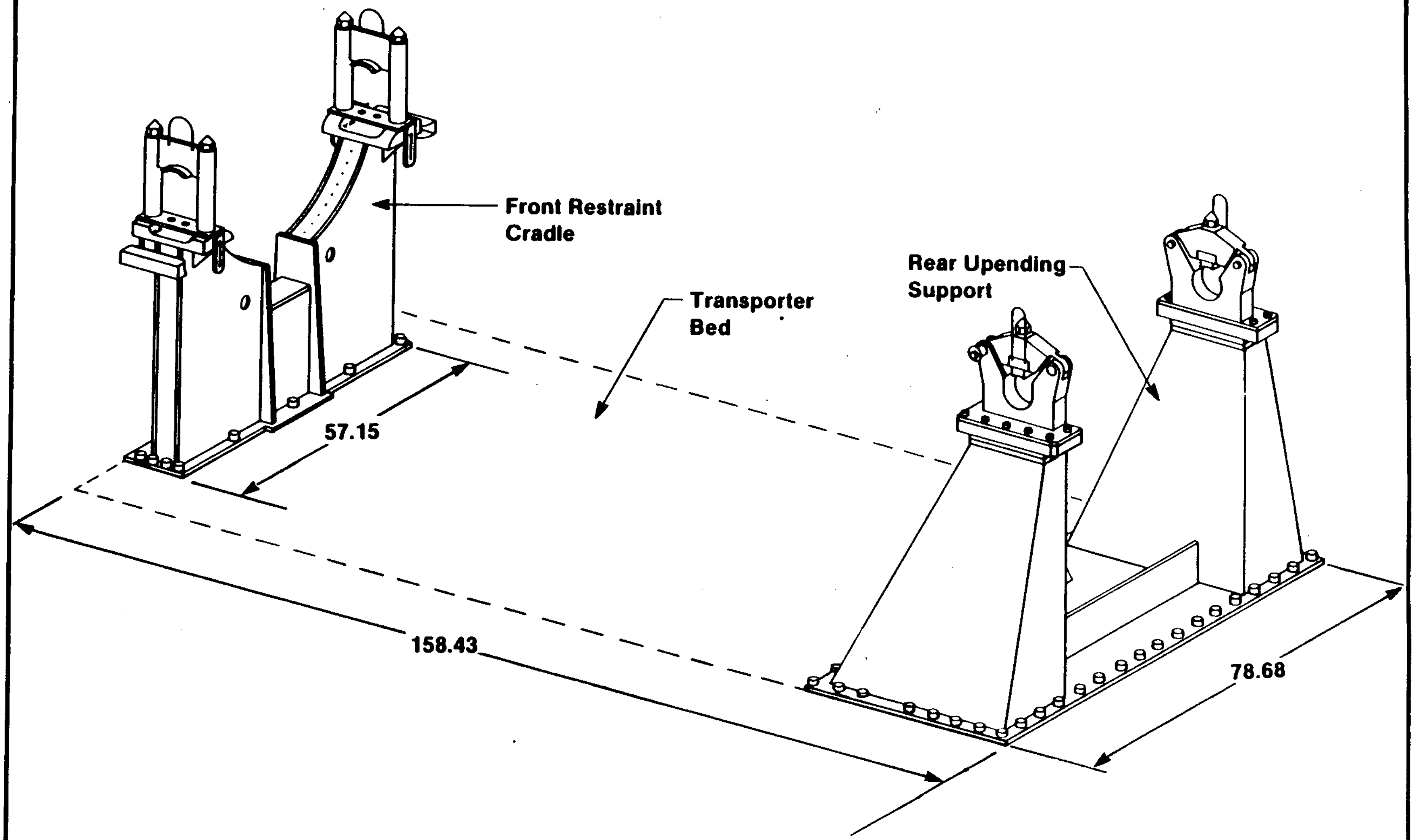

Figure 1.3-1 Cask Support System

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restraint for the trunnion is provided by a bearing pad that is loaded through a captive bolt that passes through the clamp.

The aluminum components of the front support cradle and the rear support are anodized. Both the supports are provided with bolt holes to permit bolting to the semi-trailer bed. The bolt hole pattern, shown in Drawing 1988E53, is a tentative arrangement that will be finalized as the semi-trailer design is developed.

Maintainability, Reliability, and Operability Considerations

The cask support system employs a simple and straightforward design using features that have been tried and proven for minimizing the need for frequent maintenance, providing reliable service, and to simplify operation. Those features are highlighted below:

1. The tiedown features employs engineered components and simple linkage mechanisms that have a proven record of success, contributing to a high degree of reliability.

2. The tiedown features can be directly accessed from above or from the sides of the cask. They are designed to be readily operable using manual, remote-manual, or remote-automated equipment. Key features provided for this purpose include spring-loaded captive bolts with conical heads to provide lead-in for remote tooling, use of the same bolt head sizes for both the support brackets to eliminate tool changes, and the use of appropriate supports to position the clamps in such a way that they can be easily engaged for lifting.

3. The tiedown features are located along the sides of the cask where radiation dose rates are the lowest. This simplifies manual operation while minimizing radiation exposure.

4. The front support cradle is provided with a 4-inch wide, Type 304 stainless steel sheet that is secured to the bed with recessed screws. The titanium flange on the cask bears against this stainless steel sheet which can be easily replaced when required.

5. The tiedown components are located such that they can be periodically examined for wear and tear and readily replaced if required.

6. The front support bracket has circular sleeved cutouts for access to two of the four bolts that secure the impact limiter to the cask. This access is provided for remote-manual and remote-automated tooling.

1.4 Ancillary Equipment

The ancillary equipment consists of the following:

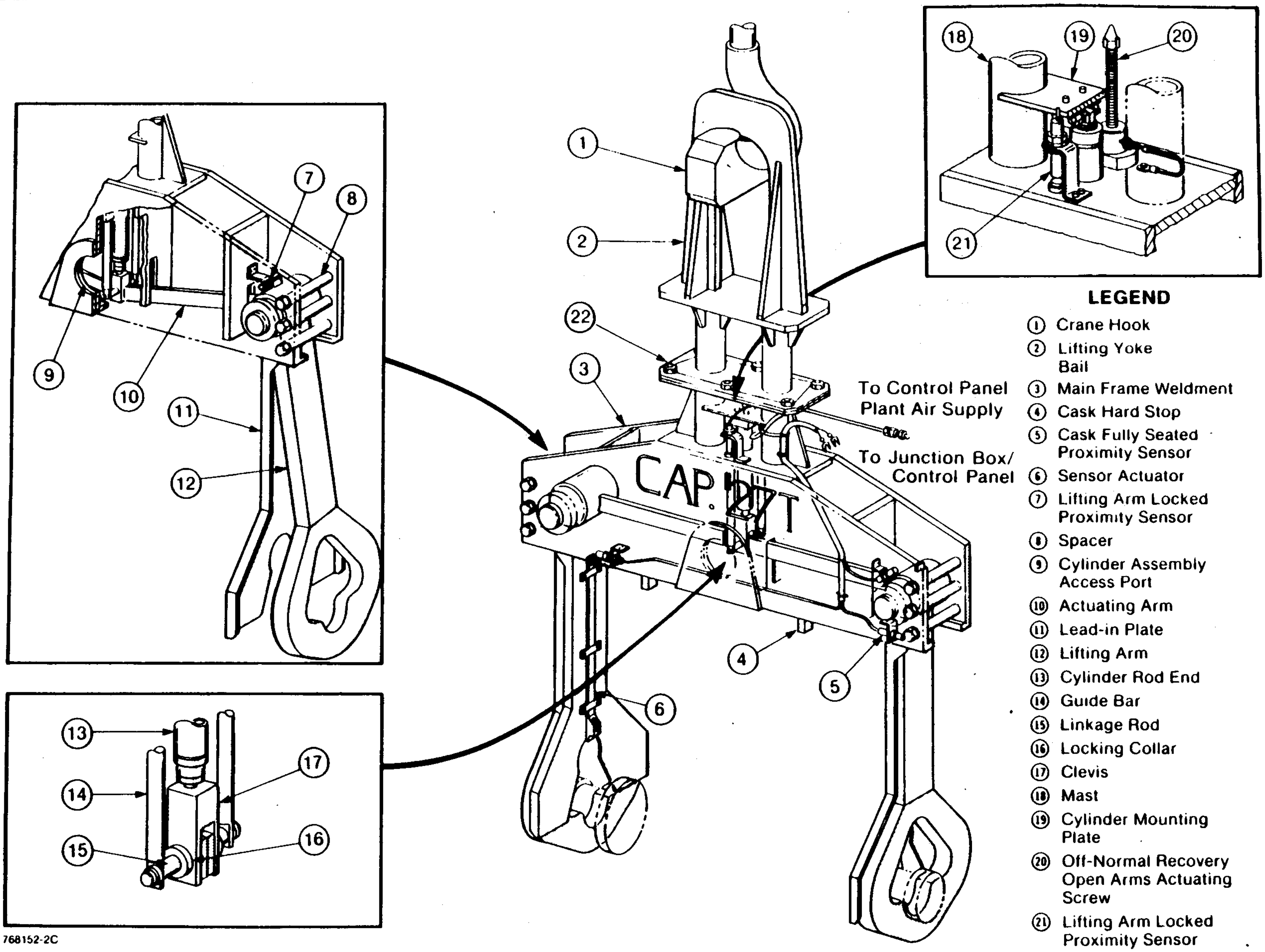
- Lifting Yoke Assembly,
- Intermodal Transfer Skid, and
- Personnel Barrier.

The following sections present the discussion of each piece of ancillary equipment listed above.

1.4.1 Lifting Yoke Assembly

The purpose of the lifting yoke assembly is to handle the cask both at the receiving facility and at those reactor sites where single-failure proof handling systems are not required.

The lifting yoke assembly is designed in accordance with ANSI-N14.6 (1978), Section 3.2 and includes the recommendations of NUREG-0612 (1980), Section 5.1.1 (4). Figure 1.4-1 shows the lifting yoke assembly. Drawing 1988E47 shows the details of the lifting yoke design.



LEGEND

1. Crane Hook
2. Lifting Yoke Bail
3. Main Frame Weldment
4. Cask Hard Stop
5. Cask Fully Seated Proximity Sensor
6. Sensor Actuator
7. Lifting Arm Locked Proximity Sensor
8. Spacer
9. Cylinder Assembly Access Port
10. Actuating Arm
11. Lead-in Plate
12. Lifting Arm
13. Cylinder Rod End
14. Guide Bar
15. Linkage Rod
16. Locking Collar
17. Clevis
18. Mast
19. Cylinder Mounting Plate
20. Off-Normal Recovery Open Arms Actuating Screw
21. Lifting Arm Locked Proximity Sensor
22. Bail/Mast Coupling Plate

Figure 1.4-1 Lifting Yoke Assembly

The lifting yoke assembly has a rated capacity of 27 tons and weighs 1321 lbs. The assembly has two vertical plates which provide for self lead-in and centering of the tool with respect to the cask top trunnions. Once aligned and centered, a pneumatic cylinder with spring return provides the actuation of the locking arms, which engage with the cask trunnions.

The linkage which is attached to the cylinder contains two vertical traveling rods. One rod provides the position indication (arms locked) to a proximity sensor. The second rod can be driven via the bolt to open the locking arms once the cask is safely set down.

The locking arms and lead in plates are attached to a welded frame which contains two masts and a bail that engages with the crane at the reactor or receiving facility. A bolted coupling is provided to facilitate bail or mast changes. The locking arms are secured to the weldment frame by a pin on each arm. The frame has provisions for attaching the pneumatic cylinder and air connections to the locking arms.

The material of construction of the lifting yoke assembly is Type 304 stainless steel with certain hardware items such as pivot pins made from 17-4 PH stainless steel for added strength and hardness. The materials were selected for corrosion resistance and ease of decontamination.

A manual override is provided to release the yoke assembly from the cask in the event of loss of pneumatic or electric power. A screw, locked in place by a detent pin is located on top of the frame (outboard of the two masts). Actuation of this screw will allow the two locking arms to be opened.

Should electric or pneumatic services be lost the tool automatically (spring return) retracts to the locked position (i.e., fail-safe position). Each of the two locking arms contains a slotted end which is designed to clear the cask trunnion flange in either the open or closed position. Position indicators (proximity switches) are used to alert the operator of the tool status. Three types of positions are measured: 1) open position (arms swung out), 2) closed position (arms swung in) and 3) tool fully seated (tool seated and centered on trunnions).

The lifting yoke assembly is designed to be compatible with the crane interfaces at both the reactor and the receiving facility for this purpose, two designs are provided for engagement with the facility crane. Figure 1.4-2 shows a single hook design and the corresponding stack-up heights with the cask. Figure 1.4-3 shows a double-hook design and the corresponding stack-up heights.

Maintainability, Reliability, and Operability Considerations

The key design features of the lifting yoke assembly that embody the principles of maintenance ease, reliability, and operational simplicity are described below:

1. The principal components are made of Type 304 stainless steel to eliminate corrosion and the need for painting. The stainless steel surfaces also permit relatively easy decontamination.

2. The lifting yoke assembly is provided with generous lead-ins and self-centering capability with position sensors to permit remote manual and remote-automated operation.

3. Operational flexibility is provided with a manual override feature that permits disengagement of the yoke assembly from the cask in the event of loss of electric or pneumatic power.

4. The pneumatic cylinder provides a simple and reliable means of actuation in a radiation environment.

5. Reliability of the tool is enhanced by the fail-safe feature in the cylinder which locks the lifting arms on the cask trunnions in the event of loss of power.

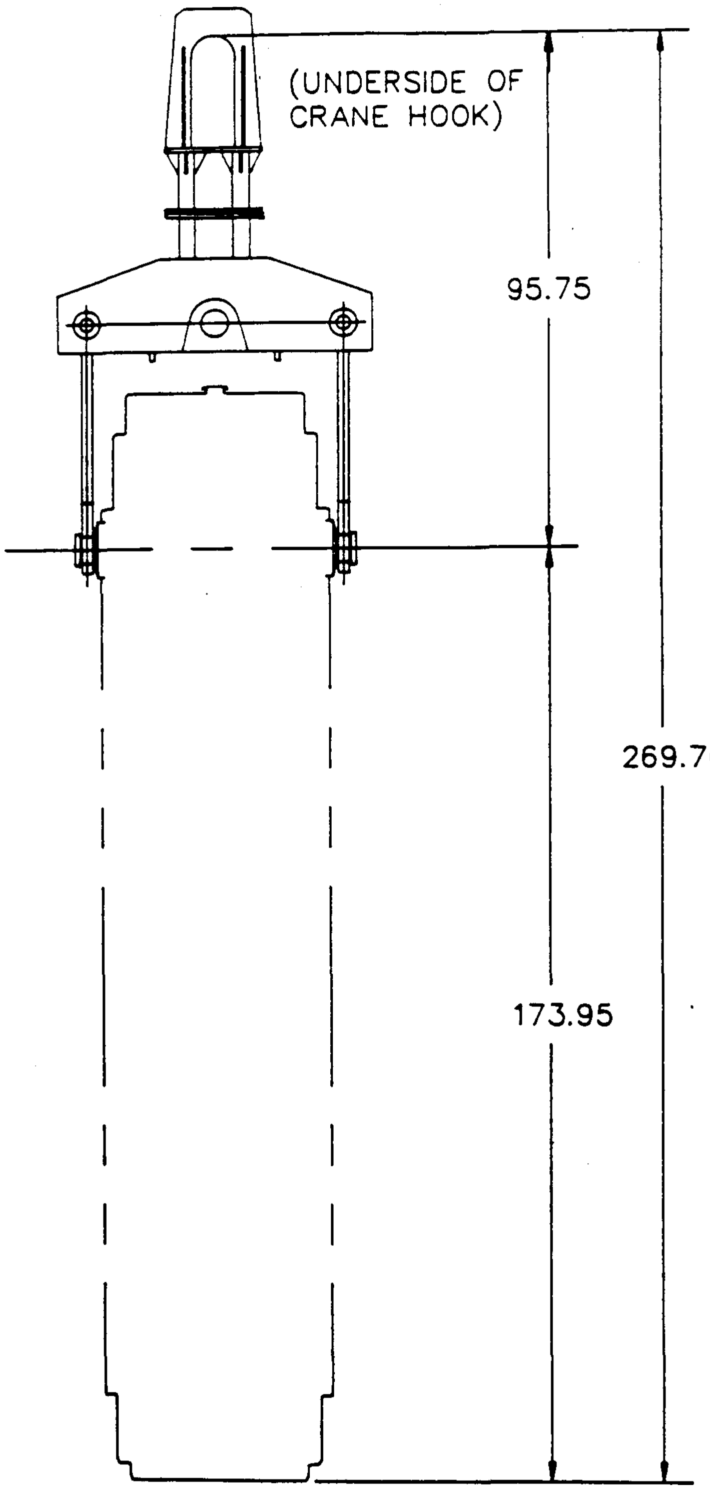


Figure 1.4-2 Lifting Yoke Assembly - Receiving Site

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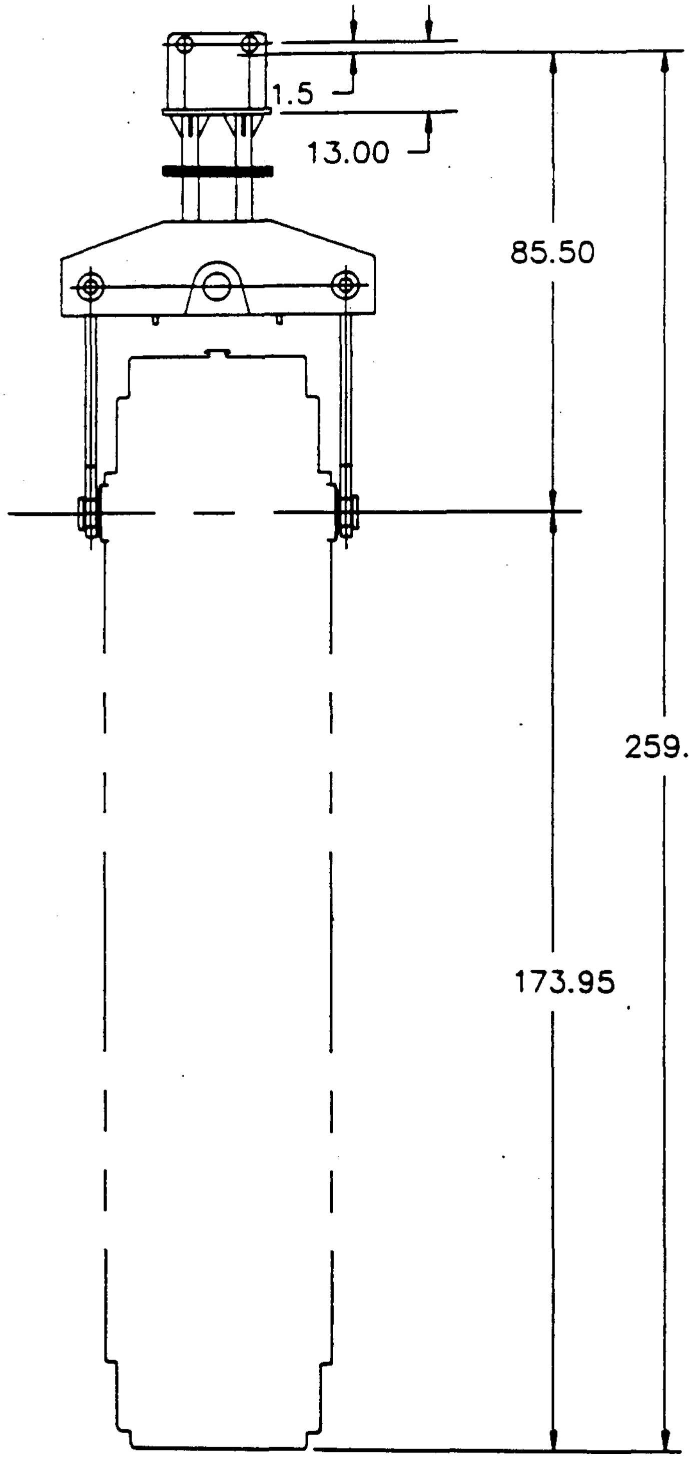

Figure 1.4-3 Lifting Yoke Assembly - Reactor Site

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1.4.2 Intermodal Transfer Skid

The purpose of the intermodal transfer skid is to provide a means for support and tiedown of the cask for transport using modes other than road, i.e., by rail or by barge. In order not to penalize the payload for normal truck shipments, the intermodal transfer skid will be shipped separately to the transfer point. The cask is brought on its transporter (semi-trailer) secured to the support system described in Section 1.3, then removed from the transporter and installed on the skid. The intermodal transfer skid, which is designed to be lifted with the cask on it, is then moved on to a railcar or barge. Optionally, depending upon the crane capabilities available at the transfer point, the intermodal transfer skid could be first placed on the railcar or barge and the cask transferred directly from the semi-trailer. As described in Section 1.2.2, the cask has provisions for lifting it in the horizontal position without having to remove the impact limiters.

Figure 1.4-4 shows the salient features of the intermodal transfer skid. Design details are provided in Drawing 1988E54. The restraint cradle and upending support features are identical to the support system used for the cask on the semi-trailer, except that the cradle and upending support are welded to an Aluminum Alloy 6061 base frame. The frame is fabricated from C8 x 8.4 and C8 x 5.4 channels and is provided with cross-bracing for structural sturdiness while minimizing weight. Four lifting eyes are attached near the corners of the frame for lifting the skid with the cask on it. The frame is provided with bolt holes for attachment to the railcar or barge deck.

The intermodal transfer skid, like the cask support system, is fully compatible with remote manual and remote automated operations. It has an estimated weight of 1790 lbs.

1.4.3 Personnel Barrier

The purpose of the personnel barrier is to limit access to the cask body, and limit rain, water spray and dirt from reaching the cask surface while permitting natural air circulation.

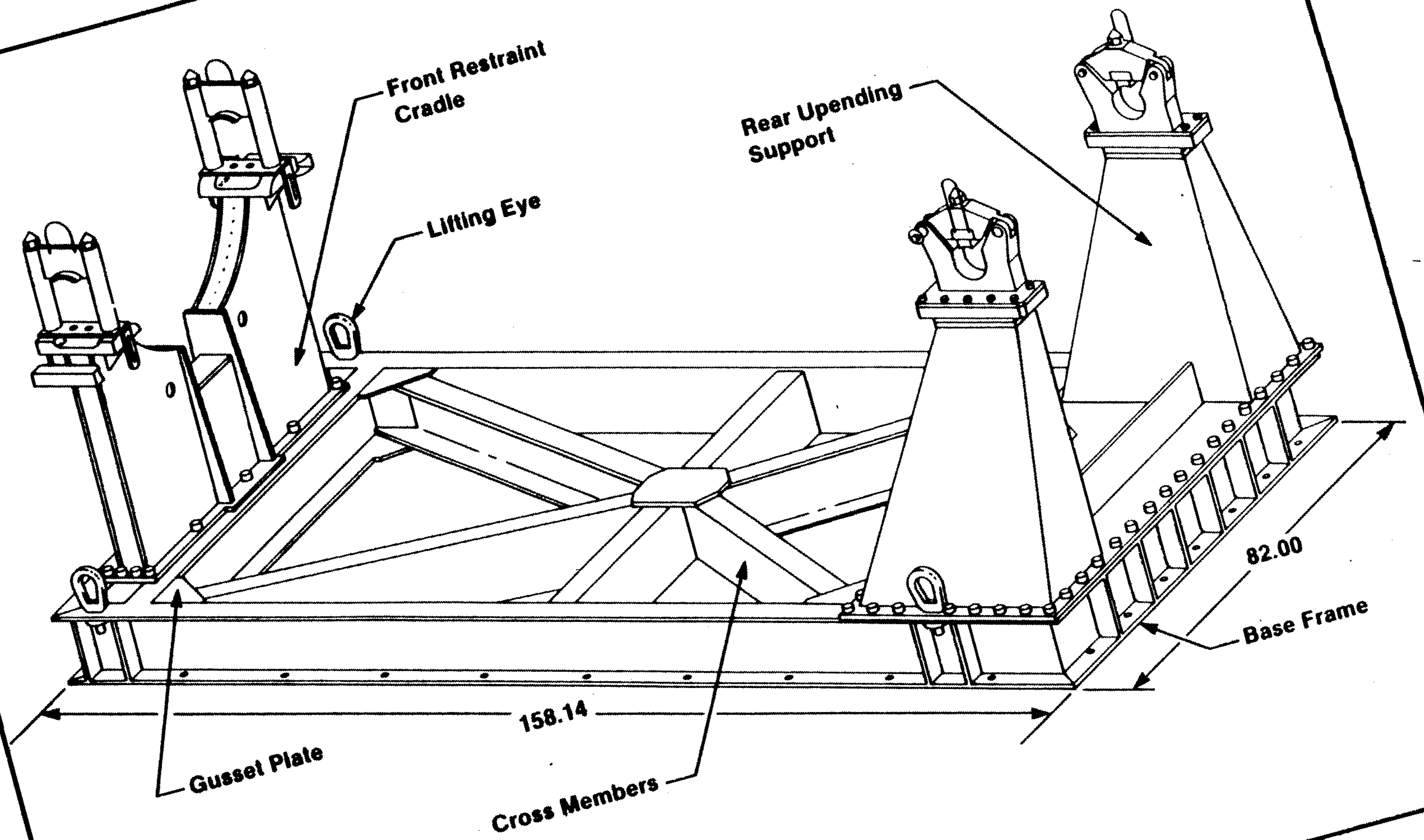

Figure 1.4-4. Intermodal Transfer Skid

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The personnel barrier is shown pictorially in Figure 1.4-5. Design details are provided in Drawing 1988E46. The personnel barrier is designed to protect the cylindrical portion of the cask that is not covered by the impact limiters. The material of construction is Aluminum Alloy 6061 (ASTM B209) to provide a light weight structure with sufficient strength to withstand transportation and handling loads. The outer skin is 0.04 inch thick sheet, except for an approximately 23 inch wide section along the entire length of the barrier on either side and above the horizontal plane through the cask centerline. That section is provided with a covering of 0.07 inch thick aluminum expanded metal sheet to provide for natural air circulation. The relatively high elevation of this expanded metal screen minimizes the possibility of road dirt from reaching the cask surface.

Structural stiffness for the personnel barrier is provided by three welded support frames and a cross-brace. Large holes are cut out in the support frame to reduce weight. The personnel barrier is secured to the semi-trailer bed by four 3/4-10 UNC captive bolts made of 17-4 PH stainless steel. Two of these bolts are located at the corners of the personnel barrier along one diagonal, while the remaining two bolts are located at the middle on either side of the structure. These bolts have conical heads to facilitate remote operation. Provision is made for the engagement of two alignment pins at the corners of the personnel barrier along the other diagonal. Installation and removal of the personnel barrier is accomplished with slings (attached to a spreader beam) that engage with two lift hooks. Four handles at the bottom end of the structure facilitates manual positioning of the personnel barrier.

The personnel barrier is 159 inches long, 94 inches wide, and 86.2 inches in height. Its estimated weight is 295 lb.

<u>Maintainability, Reliability, and Operability Considerations</u>

The following features are provided in the Personnel Barrier design to enhance maintainability and reliability and simplify operations:

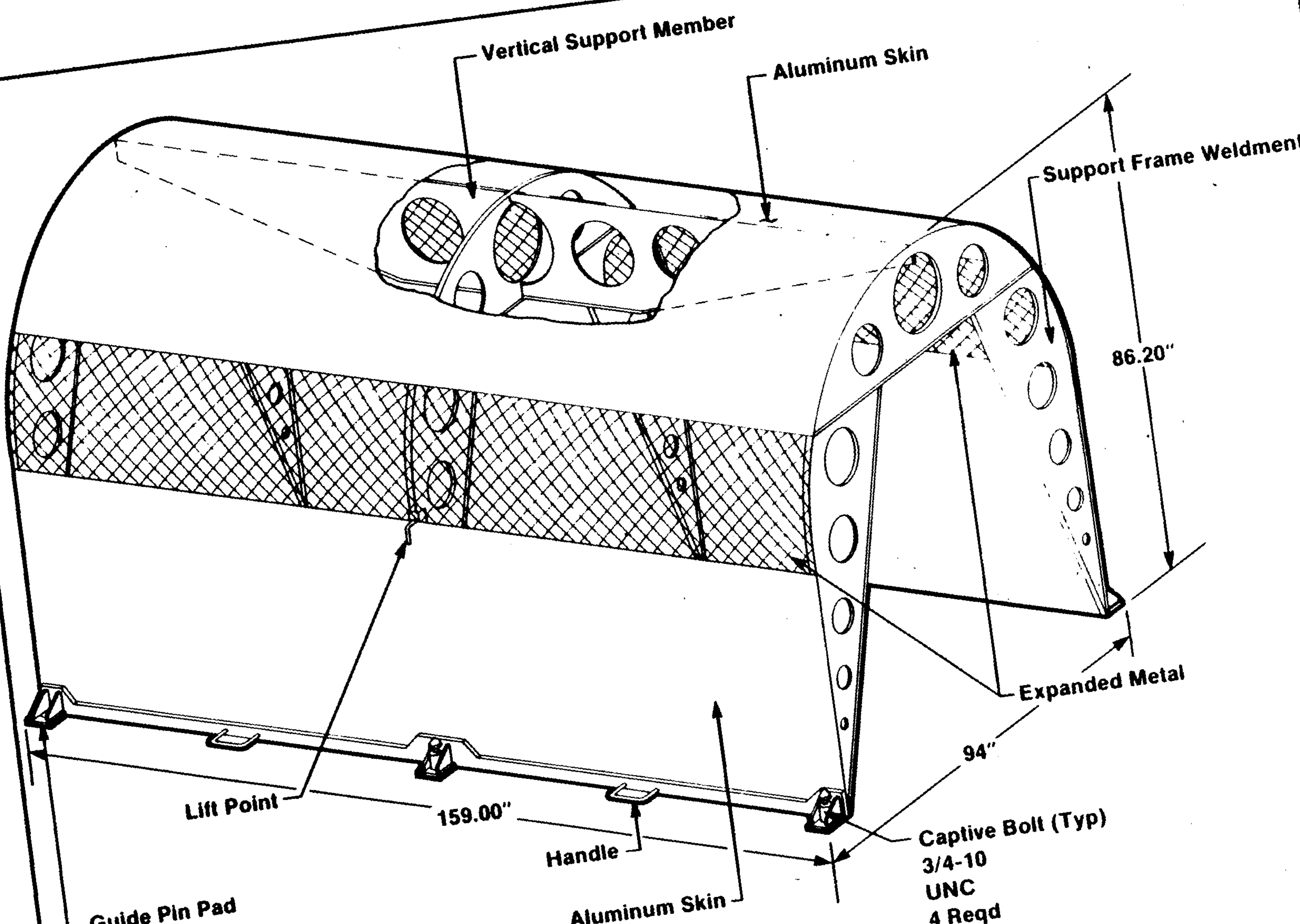

Figure 1.4-5. Personnel Barrier

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- One-piece construction provides a single, straight forward and reliable design that requires very simple operational steps for installation and removal.

- Use of aluminum provides a light-weight structure that is essentially maintenance free and requires no painting.

- Capability for remote manual and remote automated operation as provided by captive bolts with conical lead-ins, alignment pins, and lifting features that simplify installation and removal of the personnel barrier and reduce turn around time.

1.5 Appendix

1.5.1 References

1.2.1 TITAN Legal Weight Truck Cask Design Requirements, NWD-TR-007, Revision 2, Westinghouse Nuclear Waste Department, September 1989.

1.5.2 Boral Vendor Literature

This section contains vendor literature on Boral neutron absorber material used in the TITAN LWT cask.

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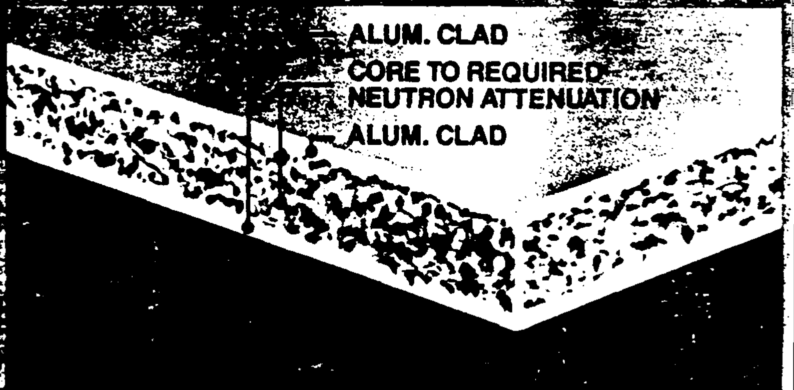
Advanced Structures Division

BORAL®

The Neutron Absorber

Product Performance

Report 624



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GENERAL

Boral is a thermal neutron poison material composed of boron carbide and the 1100 alloy aluminum. Boron carbide is a compound having a high boron content in a physically stable and chemically inert form. The 1100 alloy aluminum is a light-weight metal with high tensile strength which is protected from corrosion by a highly resistant oxide film. The two materials, boron carbide and aluminum, are chemically compatible and ideally suited for long-term use in the radiation, thermal and chemical environment of a nuclear reactor or the spent fuel containment.

Boral is an ideal neutron absorbing/shielding material because of the following reasons:

1. The content and placement of boron carbide provides a very high removal cross section for thermal neutrons.
2. Boron carbide, in the form of fine particles, is homogenously dispersed throughout the central layer of the Boral panels.
3. The boron carbide and aluminum materials in Boral are totally unaffected by long-term exposure to gamma radiation.
4. The neutron absorbing central layer of Boral is clad with permanently attached surfaces of aluminum.
5. Boral is stable, strong, durable, and corrosion resistant.

Boral is manufactured under the control and surveillance of a computer-aided Quality Assurance/Quality Control Program that conforms to the requirements of 10CFR50 Appendix B entitled, "Quality Assurance Criteria for Nuclear Power Plants".

Boral has been licensed by the USNRC for use in BWR and PWR spent fuel storage racks. Boral is also used around the world for spent fuel shipping and storage containers and for many other shielding uses including reactor control blades. For specific applications see later in this report.

Boral panels can be furnished either in the flat panel form or fabricated into a variety of geometrical shapes by standard metalworking methods and techniques. The shielding capability of Boral is assured by wet chemical analysis or neutron attenuation testing and is specified as a minimum of grams of B^{10} per square centimeter of surface area. Boral can be provided at any B^{10} loading up to 0.06 gm/sq cm as required.

BORAL MATERIAL CHARACTERISTICS

Aluminum: Aluminum is a silvery-white, ductile metallic element that is the most abundant in the earth's crust. The 1100 alloy aluminum is used extensively in cooking utensils, heat exchangers, pressure and storage tanks, chemical equipment, reflectors and sheet metal work.

It has high resistance to corrosion in industrial and marine atmospheres. Aluminum has atomic number of 13, atomic weight of 26.98, specific gravity of 2.69 and valence of 3. The physical and mechanical properties of the 1100 alloy aluminum are listed in Table 1 and 2.

TABLE 1

1100 Alloy Aluminum Physical Properties[7]

Density	0.098 lb/cu. in. 2.713 gm/cc
Melting Range	1190-1215 deg. F 643-657 deg. C
Thermal Conductivity (77 deg. F)	128 BTU/hr/sq ft/deg. F/ft 0.53 cal/sec/sq cm/deg. C/cm
Coef. of Thermal Expansion (68-212 deg. F)	13.1×10^{-6}/deg. F 23.6×10^{-6}/deg. C
Specific Heat (221 deg. F)	0.22 BTU/lb/deg. F 0.23 cal/gm/deg. C
Modulus of Elasticity	10×10^{6} psi
Tensile Strength (75 deg. F)	13,000 psi annealed 18,000 psi as rolled
Yield Strength (75 deg. F)	5,000 psi annealed 17,000 psi as rolled
Elongation (75 deg. F)	35-45% annealed 9-20% as rolled
Hardness (Brinell)	23 annealed 32 as rolled
Annealing Temperature	650 deg. F 343 deg. C

TABLE 2

Chemical Composition — Aluminum (1100 Alloy)[3]

99.00% min.	Aluminum
1.00% max.	Silicone and Iron
.05-.20% max.	Copper
.05% max.	Manganese
.10% max.	Zinc
.15% max.	others each

The excellent corrosion resistance of the 1100 alloy aluminum is provided by the protective oxide film that develops on its surface from exposure to the atmosphere or water. This film prevents the loss of metal from general corrosion or pitting corrosion and the film remains stable between a pH range of 4.5 to 8.5. More detailed corrosion data is provided later in this report.

Boron Carbide: The boron carbide contained in Boral is a fine granulated powder that conforms to ASTM C-750-80 nuclear grade Type III. The particles range in size between 60 and 200 mesh and the material conforms to the chemical composition and properties listed in Table 3.

TABLE 3

Boron Carbide Chemical Composition, Weight %

Total boron	70.0 min.
B^{10} isotopic content in natural boron	18.0
Boric oxide	3.0 max.
Iron	2.0 max.
Total boron plus total carbon	94.0 min

Boron Carbide Physical Properties

Chemical formula	B_4C
Boron content (weight)	78.28%
Carbon content (weight)	21.72%
Crystal structure	rombohedral
Density	2.51 gm./cc-0.0907 lb/cu. in.
Melting point	2450°C-4442°F
Boiling point	3500°C-6332°F
Microscopic capture cross section	600 barn

Materials Compatibility: The materials contained in Boral are compatible with all parts of a spent fuel storage system in either a boiling-water (BWR) or pressurized-water reactor (PWR) including the fuel assemblies, the cooling system, the cleanup system, the pool liner and the structures of the storage racks. This compatibility is evidenced by more than seventeen years of continuous service in both types of pool water [1][3]. None of the following materials are contained in Boral nor do they come in contact with Boral during its manufacture. Therefore Boral can not cause these materials to come in contact with the fuel assemblies:

a. Any material that contains halogens in amounts exceeding 50 ppm, including chlorinated cleaning compounds.
b. Lead
c. Mercury
d. Sulfur
e. Phosphorus
f. Zinc
g. Copper and Copper alloys
h. Cadmium
i. Tin
j. Antimony
k. Bismuth
l. Mischmetal
m. Carbon steel, e.g., wire brushes
n. Magnesium oxide, e.g., insulation
o. Neoprene or other similar gasket materials made of halogen-containing elastomers.
p. Viton
q. Saran
r. Silastic Ls-53
s. Rubber-bonded asbestos
t. TFE (Teflon) containing more than 0.75% total chlorine (glass-filled) and TFE films containing more than 0.05% total chlorine.
u. Nylon containing more than 0.07% total chlorine.
v. Polyethylene film (colored) with pigments over 50 ppm fluorine, measurable amounts of mercury or halogens, or more than 0.05% lead.
w. Grinding wheels that have been used on other than stainless steel or Inconel material.
x. Water containing more than 25 ppm halogens during any cleaning operation.
y. Any material that forms alloys or deposits on the fuel assembly.

BORAL PHYSICAL CHARACTERISTICS

Boral is a clad composite of aluminum and boron carbide. The Boral panel consists of three distinct layers. The outer layers of cladding are solid 1100 alloy aluminum. The central layer consists of a uniform aggregate of fine boron carbide particles tightly held within an aluminum alloy matrix. The boron carbide particle in the central layer averages 85 microns in diameter. The average spacial separation is 1.25 to 1.50 particle diameters. The overall thickness of Boral will vary with: B^{10} content, cladding thickness and weight percent of boron carbide in the core. These factors will also influence the mechanical properties of the sheet. Figure 1 illustrates how thickness can vary with B^{10} content, all other parameters being held constant. The actual thickness may vary from this illustration due to the previously mentioned factors or other customer technical requirements.

Dispersion Uniformity: the aluminum and boron carbide ingredients in the central core of the Boral panel are combined in powder form. The methods used to control the weight and blend the powders as well as the design and construction of the ingots necessary to produce Boral panels are patented and proprietary process of AAR Brooks & Perkins. The manufacturing methods used include a sintering process and hot rolling. The final outcome of the entire manufacturing cycle is Boral panels having boron carbide uniformly dispersed throughout the central core. The amount of boron carbide per unit area is directly related to the panel thickness.

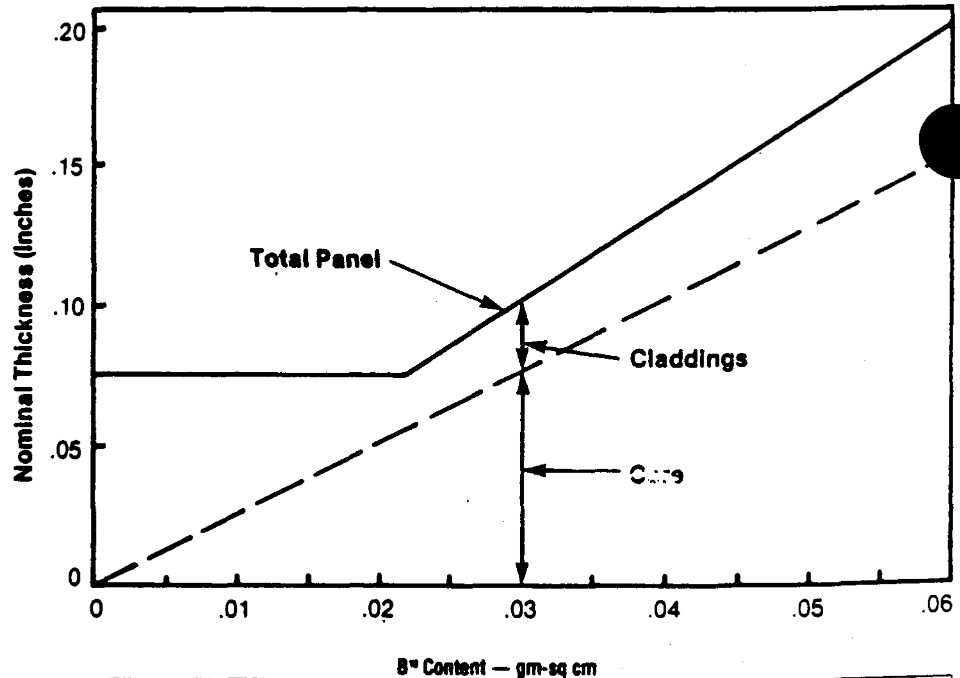
The minimum B^{10} content per unit area and the uniformity of dispersion within a panel is verified by wet chemical analysis and/or neutron attenuation testing. For details of the verification methods see AAR Brooks & Perkins Quality Assurance Procedures BP-11002-QAP and BP-11004-QAP.

The acceptance standards in the procedures are controlled by statistical data to assure the minimum requirements are achieved with 95/95 confidence level. The maximum variation in the manufacturing processes (statistical tolerance interval) over a significantly large sample size has been determined and is utilized in the establishment of acceptance criteria.

CORROSION RESISTANCE

The useful service life of Boral will exceed 40 years when in contact with the storage pool water of either a boiling-water or pressurized-water reactor. This fact is evident through laboratory testing and is supported by in-service inspections. Boral has the longest continuous, in-pool service of any thermal neutron shielding material. This excellent corrosion resistance is provid-

Figure 1: Example of Boral Thickness as Function of B^{10} Content



B10 Content	Equiv. Boron	Total Thickness Including Cladding Inches	±Tol.	mm	±Tol.
.005	.028	.075	.004	1.91	.10
.010	.056	.075	.004	1.91	.10
.015	.083	.075	.004	1.91	.10
.020	.111	.075	.004	1.91	.10
.025	.139	.085	.004	2.16	.10
.030	.167	.101	.005	2.57	.13
.035	.194	.118	.006	3.00	.15
.040	.222	.134	.006	3.40	.15
.045	.250	.151	.006	3.84	.15
.050	.278	.167	.007	4.24	.18
.055	.306	.185	.007	4.70	.18
.060	.333	.201	.009	5.11	.23

This tabulation is for Boral with thin cladding as used in high density spent fuel racks. Boral with thicker cladding, up to .040", is also available for other applications, and may be required for higher B^{10} contents.

ed by the protective film on the aluminum cladding that is an integral facing on the Boral panels. The corrosion of aluminum is negligible in fuel storage pools of either type reactor when the water quality and temperatures are maintained within normal operating limits. Typical spent fuel pool operating ranges are listed in Table 5. The boron content in the Boral will not be reduced below the specified limit during the forty or more years of exposure under those operating conditions.

In order to understand the total corrosion resistance of aluminum within the normal operating conditions of the storage pools. A discussion of that resistance must consider all forms of corrosion. A detailed discussion follows for general, galvanic, pitting, crevice, intergranular, and stress forms of corrosion.

General Corrosion: General corrosion is a uniform attack of the metal over the entire surfaces exposed to the corrosive media. General corrosion is measured by weight loss or decrease in thickness and is generally expressed in mils per year (mpy). The severity of general corrosion of aluminum depends upon the chemical nature and temperature of the electrolyte and can range from superficial etching and staining to dissolution of the metal.

Figure 2 shows a potential -pH diagram for aluminum in high purity water at 25°C (77°F). The potential for aluminum coupled with stainless steel and the limits of pH for BWR and PWR pools are shown on the diagram to be well within the passivation domain. The passivated surface of aluminum (hydrated oxide of aluminum) affords protection against corrosion in the domain shown because the coating is insoluble, non-porous and adherent to the surface of the aluminum. The protective surface formed on the aluminum (gibbsite and bayerite) is known to be stable up to 135° C (275°F)[5] and in a pH range of 4.5 to 8.5[6].

$$Al^{+++} + H_2O \rightarrow Al(OH)^{++} + H^+$$
$$2\,Al + 6\,H_2O \rightarrow Al_2O_3 \cdot 3H_2O + 6H^+ + 6 \text{ electrons}$$
$$2\,H^+ + 2 \text{ electrons} \rightarrow H_2\uparrow \qquad [5]$$

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 that coating is removed by mechanical or chemical means.

Figure 3 is also a potential-pH diagram for the aluminum-water system but at 60°C (140°F) which also shows the potential for the aluminum/stainless steel couple and the BWR and PWR limits for pH at this upper limit of temperature.

TABLE 5

Chemistry of Spent Fuel Pool Water

Reactor type	PWR	BWR
Cooling medium	*D-M water	D-M water
Boron content, ppm	0 to 2000	0
pH range	4.5 to 6.0	6.0 to 7.5
Temp range, °F	80 to 140	80 to 125
°C	26 to 60	26 to 52
Conductivity (micro mho/cm) @ 25°C	1 to 30	1
Chloride ions, ppm, max.	0.15	0.20
Fluoride ions, ppm, max.	0.10	—
Total solids, ppm, max.	1.00	0.50
Heavy metals, ppm, max.	—	0.10
Halogens, ppm, max.	0.15	—

*demineralized water

The ability of aluminum to resist corrosion from the boron ions is evident from the wide usage of aluminum in the handling of borax and in the manufacture of boric acid.[7] Aluminum storage racks with Boral plates in contact with the 800 ppm borated water showed only small amount of pitting after seventeen years in the pool.[1] These racks maintained their structural integrity and were returned to service.

Galvanic Corrosion: 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 in an electrolyte similiar to the pool water from either a BWR or PWR. There is less galvanic current flow between the aluminum-stainless steel couple than the potential difference would indicate because of the greater than normal resistance at the metal-liquid interface on stainless steel which is known as polarization.[6] It is because of this polarization characteristic that stainless steel is compatible with aluminum in all but severe marine, or high chloride, environmental conditions. Test data for aluminum coupled with 304 stainless steel in 5.0 pH water at 100°C (212°F) with flow rates ranging from 0.5 fpm to 81 fps show weight losses of 0.1 to 0.2 mpy and randomly spread pits that were not of major consequence.[8] This performance indicates a projected service life much greater than forty years.

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.[9]

Figure 2

Potential Versus pH Diagram For Aluminum-Water System At 25°C (77°F) [10]

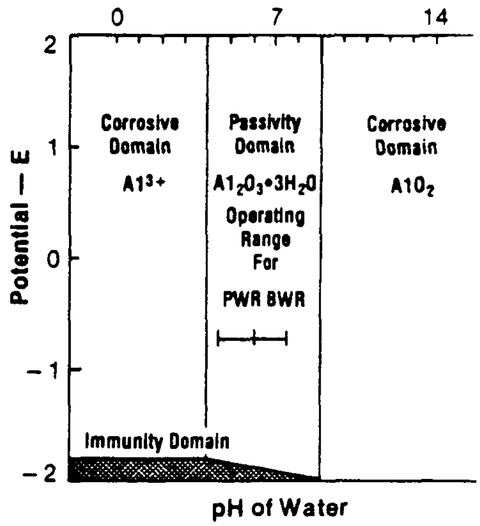
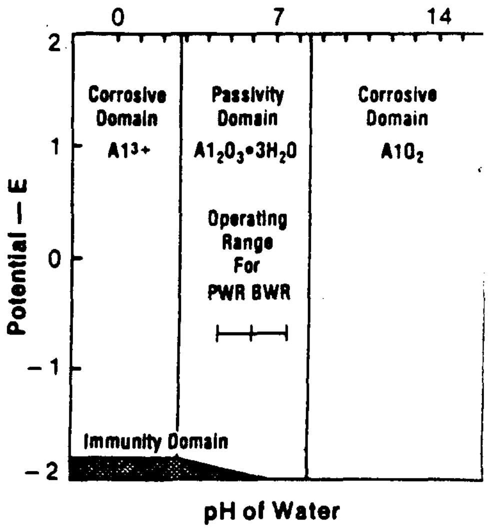


Figure 3

Potential Versus pH Diagram For Aluminum-Water System At 60°C (140°F) [5]



Pitting of aluminum has been observed when in contact with stainless steel where the electrolyte can stagnate and the conductivity of the electrolyte increases.

This pitting has not been significant in spent fuel environments and it is not likely that pitting of the aluminum would have any influence on the neutron shielding performance of the Boral.[4]

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. Testing has confirmed that after 2000 hours, under a controlled environment, the Boral and 304 stainless steel combination exhibited little or no corrosion of the aluminum cladding of the Boral. In a separate 2000 hour test at 90° to 180°C the maximum pit depth of corrosion of the Boral surface was reported at less than five mils giving a projected life much greater than forty years.[8]

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 the commercially pure aluminum (alloy 1100) and other common work hardening 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. The 1100 alloy used in Boral is not susceptable to stress corrosion and Boral is seldom, if ever, subjected to high stresses when used as a neutron shield in a spent fuel rack.

Corrosion Monitoring System: A corrosion monitoring system is a program whereby a series of surveillance samples are placed in the spent fuel pool radiation and water environment and are periodically examined for physical and chemical changes. It is important the physical configuration of the samples be carefully selected so they are representative of the construction and design of the spent fuel racks and are positioned in the pool to be exposed to representative pool conditions and radiation environment. The physical and chemical characteristics of the samples must be precisely established before insertion into the pool so accurate quantitative comparisons can be made after each exposure period The procedure for the manufacture and testing of surveillance samples recommended by AAR Brooks & Perkins is contained in Procedure No. BPS-454.

RADIATION RESISTANCE

Boral has the ability to absorb thermal neutrons from nuclear fuel assemblies without physical change or degradation of any sort from the accompanying exposure to heat and gamma radiation. This ability is attributable to the fact that Boral contains no organic nor polymeric binders which undergo extensive crosslinking and oxidative scission degradations from heat and radiation exposure. Boral utilizes an all metallic aluminum binder which is stable and unchanged under long-term gamma and neutron irradiation and heat up 540°C (1000°F).

Boral, in addition to having the longest history of use in spent fuel storage applications (since 1965), has been subjected to accelerated irradiation tests which fully support the stability of Boral under these environments. Boral test specimens have been exposed to cumulative doses of $3x10^{11}$ rads gamma and $16x10^{19}$ neutrons per sq cm in demineralized and borated water without detectable out-gassing attributable to Boral or any discernible physical changes.

Testing was performed at the Phoenix Memorial Laboratory of the University of Michigan using the Ford Nuclear Reactor.[11] The purpose of the test was to determine changes to physical and chemical properties of Boral as a result of irradiation under conditions similar to those encountered in PWR and BWR spent fuel storage pools. The data recorded during this testing effort is available upon request and includes the following:

- Total radiation exposure and residual radioactivity
- Dimensions
- Weight
- Specific gravity
- Hardness
- Mechanical strength
- Neutron attenuation
- Solution boron content, pH, conductivity, and leachable halogens

During irradiation -gas evolution rate, total volume of gas evolved, and gas composition were determined. The Boral samples were irradiated in air, demineralized water, and 2000 ppm borated water to simulate both the vented and sealed enclosure of Boral in PWR and BWR spent fuel storage environments.

The test results show conclusively there is no out-gassing from Boral when irradiated in dry air. The same was also true for boron carbide powder in a dry aluminum sample container. This clearly shows that Boral is unaffected by radiation exposure making Boral a neutron absorber that can be safely exposed while being contained in a sealed enclosure.

This characteristic of Boral -no out-gassing from irradiation -shows that the source of the evolved gases when water is in contact with Boral has to be from the water itself. There are two mechanisms by which water will evolve gases under these circumstances and only one of which requires a radiation environment. The one mechanism requiring a radiation field is the hydrolysis of the water. The disassociation of water into its hydrogen and oxygen elements also requires the presence of free radical scavengers. These could well be the boron carbide powder, impurties within the powder, impurties in the water, or surface irregularities on the Boral sample. Gases evolved by hydrolysis would be a hydrogen-oxygen gas mixture in a 2:1 ratio.

The other mechanism by which water will evolve gases is from the chemical reactions between aluminum and water. The surface of the aluminum cladding on the Boral samples is unpassivated and will allow a short term reaction with water. The gas released from the water-aluminum reaction is hydrogen as shown in the following reaction:

$$Al^{+++} + H_2O \rightarrow Al(OH)^{++} + H^+$$
$$2\,Al + 6\,H_2O \rightarrow Al_2O_3 \bullet 3H_2O + 6H^+ + 6 \text{ electrons}$$
$$2\,H^+ + 2 \text{ electrons} \rightarrow H_2\uparrow \qquad [5]$$

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 futher reaction impossible until that coating is removed by mechanical or chemical means.

The volumes and types of gases collected from the Boral in demineralized and borated water resulted from one or both of the two described mechanisms and did not result from cross linking or oxidative scission of any of the Boral materials.

In summary Boral does not out-gas or change physically or chemically as a result of exposure to gamma radiation. Water in contact with aluminum will release hydrogen chemically until the aluminum surface is passivated and water will disassociate through hydrolysis from gamma radiation. It is only necessary to provide a means for venting the hydrogen and oxygen gases if water is allowed to come in contact with Boral in spent fuel storage applications.

NEUTRON SHIELDING PERFORMANCE

The thermal neutron shielding capability of Boral is obtained from the B^{10} isotope contained within the boron carbide particles in its core. The efficiency of performance is directly related to the amount of boron carbide provided and the spacial relationship between the particles of boron carbide. Figure 4 shows the actual performance of Boral as compared to a theoretical ideal layer of B^{10} atoms. The shielding performance is measured as a neutron attenuation factor and is plotted against the surface density of B^{10} isotope in grams per square centimeter. The neutron shielding performance of Boral was unaffected after exposure to $3x10^{11}$ rads gamma and $16x10^{19}$ thermal neutrons per sq cm.

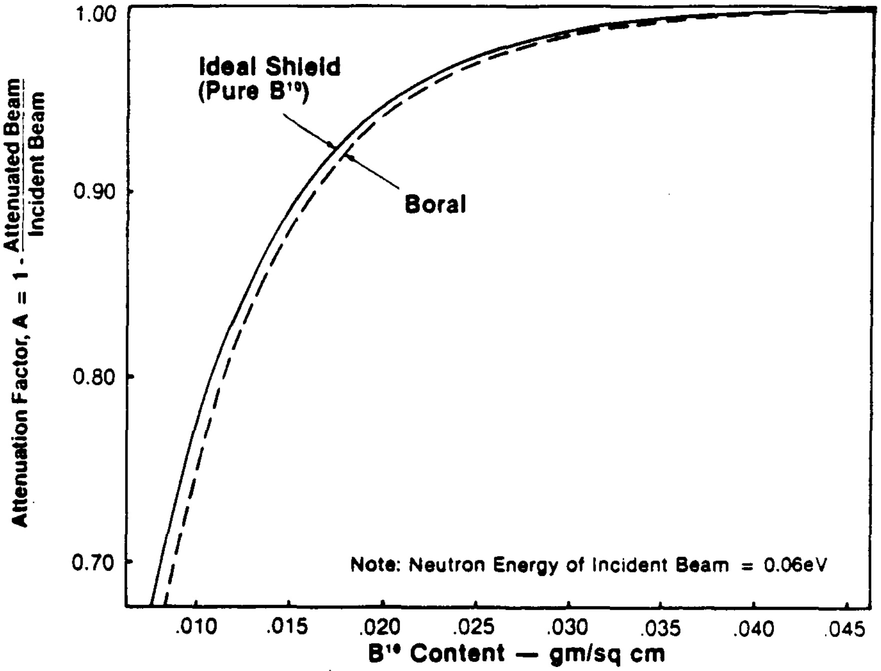
Boron and Halogen Leachability: The boron leachability and the halogen leachability was evaluated for Boral during irradiation testing conducted at the University of Michigan.[11] The test solutions were analyzed for boron and halogen contents before and after radiation exposure when sufficient solution was remaining after the test. The analysis of the test solutions showed no increase in boron or halogen that cannot be accounted for by the decrease in test solution volume or pickup of the soluble boron on the external edges of the Boral. The boron carbide is allowed to contain, by the ASTM Specification C750-80, up to a maximum of three percent (3.0%) soluble boron in the form of boric oxide (B_2O_3).

The amount of boron carbide that can come in contact with water is limited to that which is confined to the outer edges of the Boral panel. This wettable amount of boron carbide is of course influenced by the geometrical size and shape of the panel but is less than one percent (1.0%) of the total boron carbide contained therein. In any regard, the total boron content of the panel will remain above the specified minimum content in the event the total soluble boron content were somehow lost through dissolution.

Residual Activity: The residual radioactivity of the Boral was measured following the irradiation testing conducted at the University of Michigan. The activation was limited to trace amounts of impurities contained in the boron carbide and aluminum materials from which Boral is produced. The specific results are available upon request.

Figure 4

Neutron Attenuation Versus B^{10} Content



DOMESTIC INSTALLATIONS USING BORAL [12]

Pressurized Water Reactors

Plant	Utility	Water Contact	Rack Mfg.	Mfg. Year
Bellefonte 1, 2	Tennessee Valley Authority	no	Westinghouse	1981
D. C. Cook 1, 2	Indiana & Michigan Electric	no	Exxon	1979
Indian Point 3	NY Power Authority	yes	U.S. Tool & Die	1987
Maine Yankee	Maine Yankee Atomic Power	yes	PaR	1977
Salem 1, 2	Public Service Elec & Gas	no	Exxon	1980
Seabrook	New Hampshire Yankee	no	PaR	—
Sequoyah 1, 2	Tennessee Valley Authority	no	PaR	1979
Yankee Rowe	Yankee Atomic Electric	yes	B&P/PaR	1964/1983
Zion 1, 2	Commonwealth Edison Co	yes	CECo.	1980

Boiling Water Reactors

Plant	Utility	Water Contact	Rack Mfg.	Mfg. Year
Browns Ferry 1, 2, 3	Tennessee Valley Authority	yes	GE	1980
Brunswick 1, 2	Carolina Power & Light	yes	GE	1981
Clinton	Illinois Power	yes	NES	1981
Cooper	Nebraska Public Power	yes	NES	1979
Dresden 2, 3	Commonwealth Edison	yes	CECo.	1981
Duane Arnold	Iowa Elec. Light & Power	no	PaR	1979
J. A. FitzPatrick	NY Power Authority	no	PaR	1978
E. I. Hatch 1, 2	Georgia Power	yes	GE	1981
Hope Creek	Public Service Elec. & Gas	yes	PaR	1985
Humboldt Bay	Pacific Gas & Electric	yes	B&P	1986
LaCrosse	Dairyland Power	yes	PaR	1976
Limerick 1, 2	Philadelphia Electric	no	PaR	1980
Monticello	Northern States Power	yes	GE	1978
Peachbottom 2, 3	Philadelphia Electric	no	PaR	1978
Perry 1, 2	Cleveland Elec. Illuminating	no	PaR	1979
Pilgrim	Boston Edison	no	PaR	1978
Shoreham	Long Island Lighting	yes	PaR	—
Susquehanna 1, 2	Pennsylvania Power & Light	no	PaR	1979
Vermont Yankee	Vermont Yankee Atomic Power	yes	PaR/NES	1978/1986

FOREIGN INSTALLATIONS USING BORAL

France

12 PWR Plants	Electricite' de France

South Africa

Koeberg 1, 2	ESCOM

Switzerland

Beznau 1, 2	Nordostschweizerische Kraftwerke AG
Gosgen	Kernkraftwerk Gosgen-Daniken AG

Taiwan

Chin-shan 1, 2	Taiwan Power Co
Kuosheng 1, 2	Taiwan Power Co

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4. C. Czajkowski, J.R. Weeks, and S.R. Protter, "Corrosion of Structural and Poison Material in Spent Fuel Storage Pools", Paper No. 163 presented at Corrosion 81, Apr. 1981, Toronto, Canada.
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1.5.3 Boro-Silicone Shielding Material

This section contains technical data on Boro-Silicone shielding material used in the TITAN LWT cask.

BORO-SILICONE® SHIELDING

Catalog No. 237 borated silicone is fire-resistant and has a high hydrogen content. It will withstand temperatures up to 400°F (205°C) on a continuous basis.

Catalog No. 237 BORO-SILICONE® is a new formulation which now has an increased hydrogen content equivalent to 67% that of pure water. In addition, it contains one percent boron for capturing thermal neutrons and reducing capture gamma radiation. Although this is a solid material, it is quite resilient, thus minimizing any possible damage in the event of creation of secondary missiles. It is strong enough for rough handling and self-support purposes. The density of the material is 1.59 g/cc (99 lbs/cu ft). Catalog No. 237 BORO-SILICONE® is a self-extinguishing material. It is available in a variety of shapes and sizes.

TECHNICAL DATA

Properties

Hydrogen: 4.49×10^{22} atoms/cc

Boron: 0.94×10^{21} atoms/cc

Weight-Percent Boron: 1.06%

Macroscopic Thermal Neutron Cross Section, $\Sigma = 0.71 cm^{-1}$

Density: 1.59 g/cc = 99 lbs/cu ft

Recommended Temperature Limit: 400°F = 205°C

Machinability: Good

Hardness: Shore "A" Durometer Scale = 66

Flammability (ASTM D635): Self-extinguishing with glowing combustion.
Average time to self-extinguish = 0 seconds.
Average extent of burning = 0.2" (5.08mm).

Coefficient of Thermal Conductivity: 5.8×10^{-3} cal-cm/sec cm^2 °C = 1.4 BTU - ft/hr ft^2 °F

Heat Capacity (Specific Heat): 0.4 cal/g°C

Cubical Coefficient of Expansion: 5.2×10^{-4} cc/cc°C = 3×10^{-4} cu in/cu in°F

Linear Coefficient of Expansion: 1.7×10^{-4} cm/cm °C = 1×10^{-4} in/in°F

Tensile Strength (ASTM D638): 50 psi

Compressive Strength: 450 psi

Radiation Resistance, gammas: 1×10^{10} rads

Radiation Resistance, neutrons: 5×10^{18} n/cm^2

TYPICAL ELEMENTAL ANALYSIS

Element	Weight-Percent
Oxygen	46.94%
Aluminum	18.86
Silicon	17.54
Carbon	10.79
Hydrogen	4.73
Boron	1.06
Sodium	0.06
Iron	0.02

RX-237 PRODUCT DATA SHEET

1.5.4 TITAN Legal Weight Truck Cask Drawings

This section contains the applicable Westinghouse layout drawings in support of the Preliminary Design. These drawings are included in the same order in the next sub-section.

Drawing Number	Title	Sheets
1988E42	TITAN Legal Weight Truck Cask BWR Basket (Layout)	4
1988E43	TITAN Legal Weight Truck Cask (Layout)	17
1988E44	TITAN Legal Weight Truck Cask PWR Basket (Layout)	4
1988E46	TITAN Legal Weight Truck Cask Personnel Barrier	3
1988E47	TITAN Legal Weight Truck Cask Lifting Yoke Layout	6
1988E50	TITAN Legal Weight Truck Cask Support General Arrangement	2
1988E51	TITAN Legal Weight Truck Cask Front Restraint Cradle Layout	2
1988E52	TITAN Legal Weight Truck Cask Rear Upending Support Layout	2
1988E53	TITAN Legal Weight Truck Cask Supports to Trailer Bolt Pattern Layout	1
1988E54	TITAN Legal Weight Truck Cask Intermodal Transport Skid	2

2. STRUCTURAL EVALUATION

2.1 Structural Design

This section presents the structural evaluation for the TITAN LWT cask to demonstrate that the regulatory requirements for Type B packaging for the transport of radioactive material given in 10 CFR Part 71 (Reference 2.1.1) are met.

2.1.1 Discussion

The preliminary evaluation of the structural integrity of the packaging under Normal Transport Conditions and Hypothetical Accident Conditions of 10 CFR Part 71 indicates that the design will meet the criteria listed in Section 2.1.2. The packaging consists of the double-walled cask body including bottom head assembly, the cask closure lid, trunnions, fuel basket, and impact limiters. These components are described in detail in Section 1.2.1.

The cask internal cavity diameter was sized to meet the objective of transporting three PWR fuel assemblies or seven BWR assemblies. The shielding (gamma and neutron) thicknesses were determined, then the titanium wall thicknesses were chosen to resist structural loads in accordance with the design criteria. The size and crushing strength of the impact limiters incorporated into the design were selected to provide acceptable deceleration loads on the cask body in the event of specified drop accidents.

Mechanical properties of the structural materials are presented in Section 2.3. Grade 9 titanium was selected as the primary structural material. This material has a high strength-to-weight ratio, excellent fatigue strength, weldability, and corrosion resistance. The structural analysis for the cask is presented in Sections 2.6 and 2.7.

The impact limiters (described in detail in Section 1.2.1) are fabricated from an aluminum honeycomb material (Alloy 5052). The densities and crushing strengths of the honeycomb were selected to provide a minimum weight impact limiter design while limiting the cask decelerations to well below 100 g's.

The limiters are constructed of honeycomb material with two different crush strengths. The honeycomb material is oriented to provide optimum energy absorption for various loading orientations. The honeycomb segments are bonded with adhesive and covered with 0.031 inch thick Type 304 stainless steel sheet. The structural response of the impact limiters is presented in Section 2.7.

The fuel baskets for the PWR and BWR fuels are constructed of Type 316N stainless steel with Boral neutron absorber inserts. The structural analysis of the baskets is presented in Sections 2.7 and 2.10.4.

2.1.2 Design Criteria

The following design criteria were used in the structural evaluation of the LWT cask and baskets.

2.1.2.1 Design Basis Environment and Loads

The design of the LWT cask shall be based on the loading and environmental conditions defined in 10 CFR Part 71, on the submergence requirements of IAEA Safety Series 6 (Reference 2.1.2), and on expected cask handling and operating loads. Combination of loads and events shall be in accordance with Regulatory Guide 7.8 (Reference 2.1.3). Where the loads specified by Regulatory Guide 7.8 conflict with those given in the current version of 10 CFR Part 71, the latter shall be used.

2.1.2.1.1 Normal Service Loads for the Packaging

Normal Conditions of Transport

The LWT cask shall be designed to withstand each of the following Normal Conditions of Transport applied separately in accordance with 10 CFR Part 71;

a. Heat - The Normal Heat Condition shall consist of an ambient temperature of 100°F still air and insolation per Paragraph 71.71(c)(1) of 10 CFR

Part 71 together with a maximum total internal heat load of 1740 watts and maximum internal pressure.

b. Cold - The cask shall be evaluated for an ambient temperature of -40°F in still air with no insolation or internal heat load.

c. Reduced External Pressure - The effect of reduced external pressure of 3.5 psia on the cask, shall be evaluated.

d. Increased External Pressure - The effect of increased external pressure of 20 psia (5.3 psig external pressure) on the cask shall be evaluated per Paragraph 71(c)(4) of 10 CFR Part 71.

e. Vibration - The cask shall be evaluated for the vibration and shock environment normally incident to transport. The road and rail vibration and shock environment for the design of the cask shall be based on the following:

1. Road

(a) Vibration - Peak truck bed accelerations shall be as given in Table 2.1-1 (Reference 2.1.4). The number of cycles shall be based on operating for 80 hours/week, 50 weeks/year, and a 25 year lifetime.

(b) Shock - Design g-loads for the cask shall be determined from the response spectra in Figure 2.1-1. The shock frequency shall be the same as for rail given in 2.(b)(1) below.

2. Rail

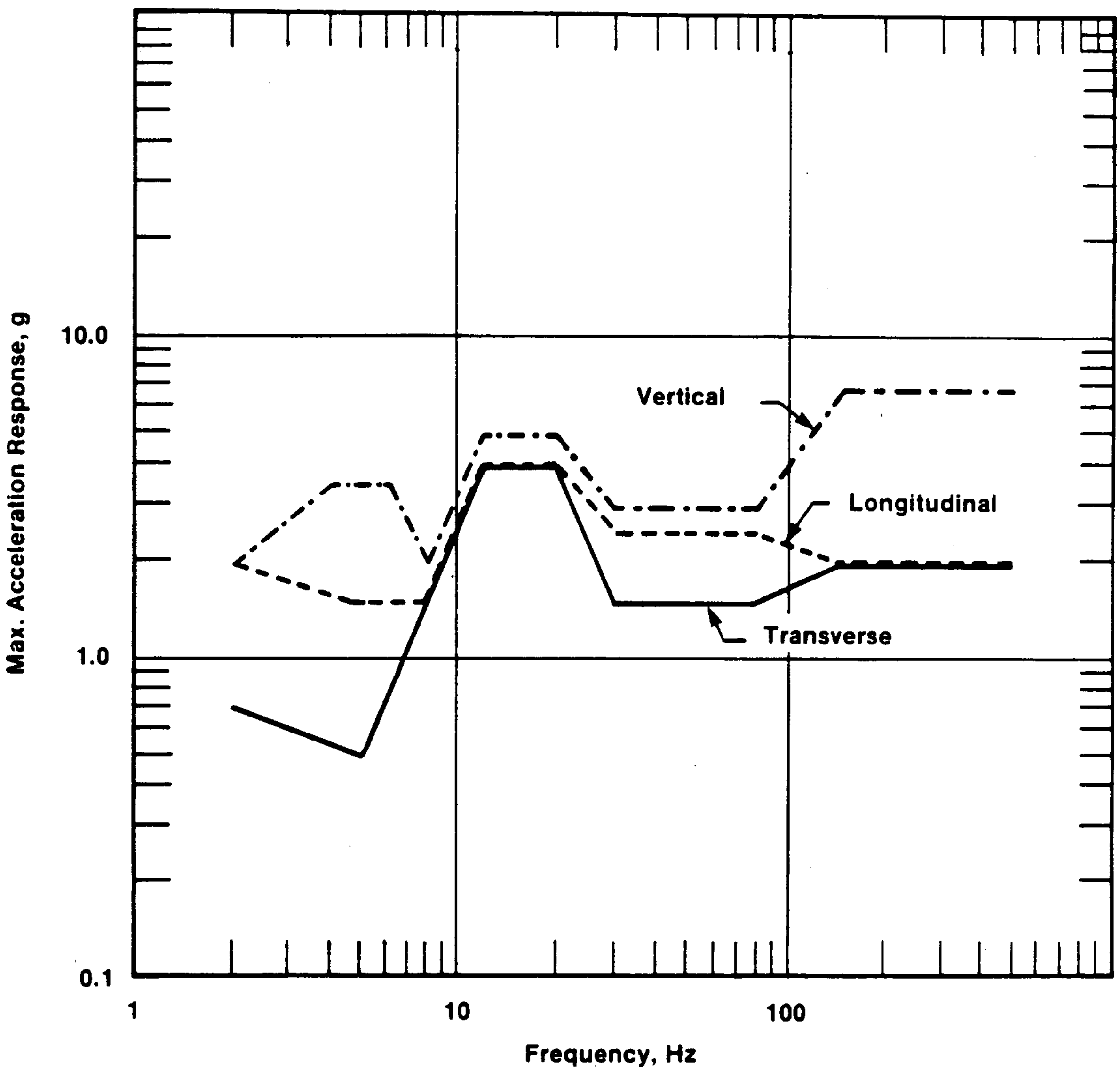
(a) Vibration - Peak cargo floor accelerations shall be as given in Table 2.1-2. The number of cycles shall be based on the same operating schedule as used for road vibration.

Table 2.1-1
Peak Vibration Accelerations of Bed of Truck
To Be Used In Fatigue Analysis

Natural Frequency* (Hz)	Peak Acceleration, g (99% Level)** Heavy Load (>20 tons) Vertical	Longitudinal	Transverse
0-5	0.6	0.3	0.2
5-10	0.3	0.2	0.2
10-20	0.4	0.3	0.3
20-40	0.3	0.1	0.3
40-120	0.6	0.2	0.2
120-700	0.6	0.1	0.2

* Package and tie-down system
** Corresponds to the 3-sigma level of a Rayleigh distribution.

(Reference 2.1.4)



(Reference 2.1.4)

Figure 2.1-1. Shock Response Envelopes for Truck Transport Loads Over 20 Tons - 3% Damping

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TABLE 2.1-2
Train Vibration Measured on Cargo Floor

Natural Frequency* (Hz)	Peak Acceleration, g (99% Level)** Heavy Load (120 tons) Vertical	Longitudinal	Transverse
0-5	0.14	0.14	0.37
5-10	0.072	0.072	0.14
10-20	0.072	0.072	0.10
20-30	0.10	0.10	0.27
30-45	0.19	0.14	0.37

* Package and Tiedown System

** Corresponds to the 3-sigma level of a Rayleigh distribution.

(Reference 2.1.5)

(b) Shock

(1) Crossings, switches, run-in and run-out; maximum acceleration levels shall be taken from Figure 2.1-2 (Reference 2.1.5). (250,000 lifetime shocks based on 25 year life, 50 trips per year, 1500 miles per trip, and 200 shock events per trip.)

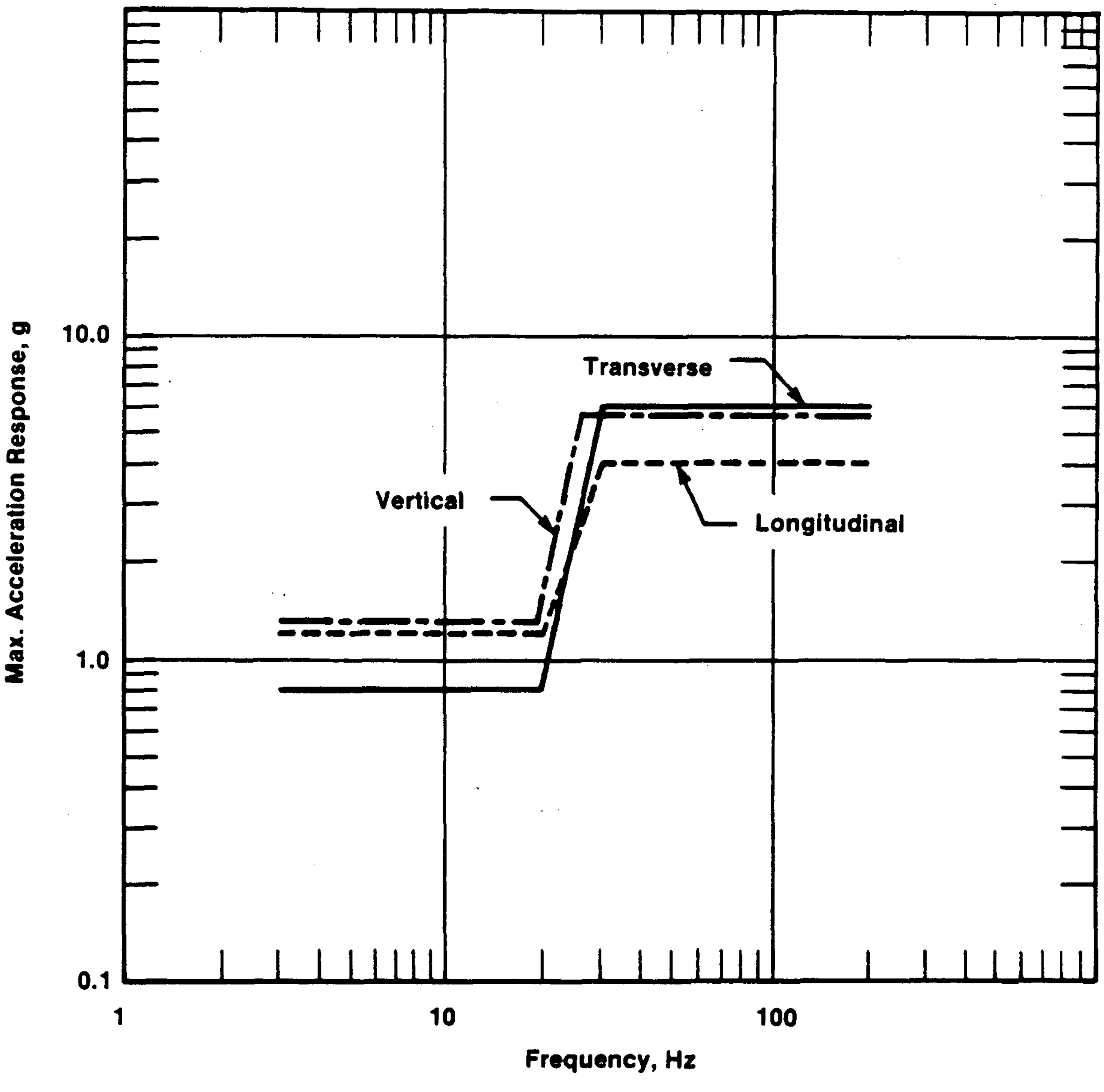
(2) Rail coupling loads shall be taken from Figure 2.1-3 with impact velocity distribution from Table 2.1-3 (Reference 2.1.5); two LWT casks per rail car. (12,500 lifetime shocks based on 25 year life, 50 trips per year, 1500 miles per trip, 10 shock events per trip.)

A structural damping factor of 0.03 (Reference 2.1.4) shall be used to evaluate the dynamic response of the cask. Higher damping factors may be considered if they can be justified.

f. Water Spray - The cask shall be designed for a water spray that simulates exposure to rainfall of approximately five cm (two inches) per hour for at least one hour.

g. Free Drop - The cask shall be evaluated for a one-foot free drop onto a flat unyielding surface. The cask shall contain the maximum weight of contents and shall strike the impact surface in a position that is expected to inflict maximum damage.

h. Penetration - The cask shall be evaluated for the impact of the hemispherical end of a 13 pound vertical steel cylinder of 1 1/4 inches diameter, dropped from a height of 40 inches onto the exposed surface of the cask which is expected to be the most vulnerable to puncture. The longitudinal axis of the cylinder shall be perpendicular to the cask surface.



(Reference 2.1.5)

Figure 2.1-2. Shock Response Envelopes for Rail Transport - 3% Damping

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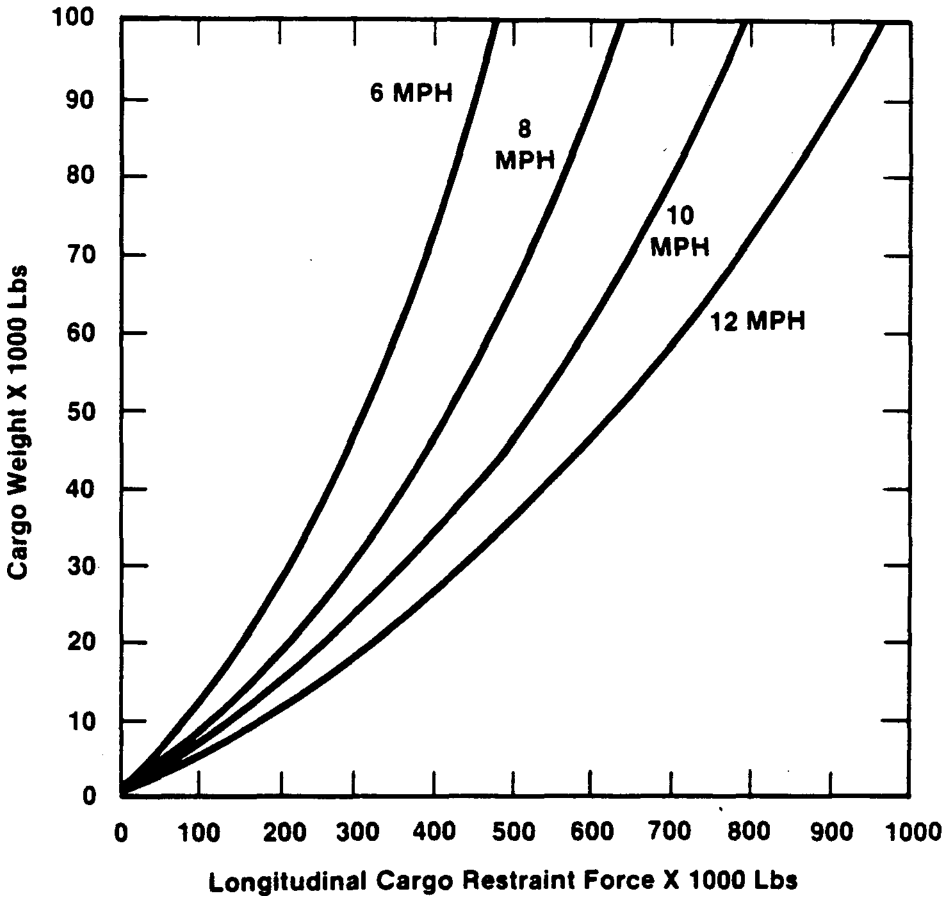

Figure 2.1-3. Cargo Weight Versus Longitudinal Cargo Restraint Force

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Table 2.1-3
Observed Impact Velocities During Rail Coupling

Observed Impact Speeds (mph)	Number Reported	Percent of Total	Cumulative Percent
5	9938	63.5	63.5
6	2831	18.1	81.6
7	1331	8.5	90.1
8	748	4.8	94.9
9	492	3.1	98.0
10	208	1.3	99.3
11	73	0.5	99.8
>11	29	0.2	100.0

(Reference 2.1.5)

OTHER SERVICE AND TEST LOADS

a. Lifting Loads - The design of the combined lifting devices which are a structural part of the cask or packaging shall be based on supporting at least three times the weight of the cask without yielding in accordance with the requirements of Paragraph 71.45(a) of 10 CFR Part 71.

b. Tie-down Loads - The design of the structural part of the cask used for tie-down shall be based on withstanding the specified transport loadings of 10 g's longitudinal, 2 g's vertical and 5 g's lateral, per Paragraph 71.45(b)(1) of 10 CFR Part 71 without yielding. The tie-down system shall also meet the requirements of 49 CFR Part 393.100 (Reference 2.1.6).

c. Other Cyclic Loads - The cask shall be evaluated for other cyclic loads, such as pressure and temperature fluctuations during the opening or closing of the cask and during loading and unloading of spent fuel.

d. Test Loads - The cask shall be capable of withstanding a pressure test at 150% of the maximum normal operating pressure, per Paragraph 71.85(b) of 10 CFR Part 71.

LOAD COMBINATION OF SERVICE LOADS

The service loads shall be combined in accordance with Table 2.1-4 which is based on References 2.1.1 and 2.1.3. Initial conditions for the Normal Conditions of Transport shall be based on the ambient temperature preceding and following the condition remaining constant at that value between -20°F and 100°F which is most unfavorable. The initial internal pressure within the containment system shall be considered to be the maximum normal pressure, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the condition is more unfavorable.

TABLE 2.1-4
LOAD COMBINATIONS FOR NORMAL CONDITIONS OF TRANSPORT AND TEST

Normal Condition	Applicable Initial Condition								
	Ambient Temperature		Insolation		Decay Heat		Internal Pressure		Fabrication Stresses
	100°F	-20°F	Max(1)	Zero	Max	Zero	Max(2)	Min	
a. Hot environment 100° ambient temperature			x		x		x		x
b. Cold environment -40°F ambient temperature				x		x		x	x
c. Reduced external pressure (0.25 atm.)	x		x		x		x		x
d. Increased External Pressure (20 psia)		x		x		x		x	x
e. Vibration & Shock Normally incident to the mode of transport	x		x		x		x		x
		x		x		x		x	x
f. Free drop	x		x		x		x		x
1 foot drop		x		x		x		x	x
g. Penetration	x		x		x		x		x
h. Lifting Loads	x		x		x		x		x
		x		x		x		x	x
i. Tie-Down Loads	x		x		x		x		x
		x		x		x		x	x
j. Loading & Unloading Loads	x			x	x				x
k. Pressure. Test Loads							(3)		

(Reference 2.1.3)

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Table 2.1-4 (Continued)
Load Combinations for Normal Conditions of Transport and Tests

Notes for Table 2.1-4

1. See Table 2.1-5 for maximum insolation data.

2. Maximum internal pressure used in evaluation of conditions shall be taken as the maximum normal operating pressure (MNOP) where the maximum normal operating pressure is defined as the maximum gauge pressure that would develop in the containment system in a period of one year under the hot environment condition, in the absence of venting.

3. The test pressure shall be taken as 1.5 x MNOP.

Table 2.1-5
Maximum Insolation Data

Form and Location of Surface	Insolation for 12 Hours Per Day
Flat surfaces transported horizontally:	
Base	None
Other surfaces	800 gcal/cm^2 (2,950 Btu/ft^2)
Flat surfaces not transported horizontally:	
Each Surface	200 gcal/cm^2 (737 Btu/ft^2)*
Curved Surfaces	400 gcal/cm^2 (1,475 Btu/ft^2)*

* Alternatively, a sine function may be used, adopting an absorption coefficient and neglecting the effects of possible reflection from neighboring objects.

(Reference: 2.1.1)

2.1.2.1.2 Hypothetical Accident Conditions

<u>CONDITIONS</u>

The TITAN LWT cask shall be evaluated for the following Hypothetical Accident Conditions in accordance with Paragraph 71.73 of 10 CFR Part 71, applied sequentially in the order listed, to determine their cumulative effect on the cask.

a. Free Drop - The cask shall be evaluated for a free drop through a distance of 30 feet onto a flat unyielding horizontal surface, and the cask shall strike the surface in a position for which maximum damage is expected. Drop orientations to be considered shall include top and bottom ends, the top and bottom corners, and side drops. Oblique drop orientations (where the cask C. G. is not directly over the point of initial impact) shall also be considered as appropriate.

b. Puncture - The cask shall be evaluated for a free drop of 40 inches onto a stationary and vertically oriented mild steel bar of 6 inches diameter with its top edge rounded to a radius of not more than 0.25 inches. The bar shall be of such a length as to cause maximum damage to the cask. The cask shall contain the maximum weight of contents and shall hit the bar in a position that is expected to inflict maximum damage.

c. Thermal - The cask shall be evaluated for a thermal condition in which the whole cask is exposed to a radiation environment of 1475°F with an emissivity coefficient of 0.90 for 30 minutes. The surface absorption coefficient of the cask shall be taken as the value that the cask may be expected to possess or 0.8, which ever is greater. The effects of solar radiation may be neglected prior to, during, and following this condition; however, convective heat input must be included, when significant, based on still, ambient air at 1475°F.

d. Immersion - In accordance with IAEA Safety Series No. 6, the cask shall be evaluated for immersion under a head of water of 200 meters for a period of not less than one hour. For test purposes an external pressure of water of 285 psig will meet this condition.

INITIAL CONDITIONS AND LOAD COMBINATIONS

Except for the water immersion test, the initial ambient air temperature before and after each condition shall be the worst case constant temperature between -20°F and 100°F. Internal heat generation from the fuel assemblies and insolation shall be considered when it is conservative to do so in accordance with Regulatory Guide 7.8 (Reference 2.1.3). The initial internal pressure within the containment system shall be taken as the maximum normal operating pressure unless a lower internal pressure consistent with the ambient temperature assumed to precede and follow the accident conditions is more unfavorable. Table 2.1-6 summarizes the loading combinations given above for the accident conditions.

2.1.2.1.3 Corrosive Environment

The cask exterior shall be capable of withstanding the effects of moisture levels and chloride concentrations caused by salted road conditions.

2.1.2.2 Structural Design Criteria and Limits

The basis for demonstrating compliance with the regulatory loadings and environmental conditions shall be 10 CFR Part 71. Regulatory Guide 7.6 (Reference 2.1.7) shall be used in conjunction with Regulatory Guide 7.8 to evaluate the structural performance of the cask.

2.1.2.2.1 Material Properties

The values for material properties, design stress intensities (S_m), and design fatigue curves for Class 1 components given in Section III, Division 1 Appendices of the ASME Boiler and Pressure Vessel Code (Reference 2.1.9) shall

TABLE 2.1-6
LOAD COMBINATIONS FOR HYPOTHETICAL ACCIDENT CONDITIONS

Accident Condition	Applicable Initial Condition								
	Ambient Temperature		Insolation		Decay Heat		Internal Pressure		Fabrication Stresses
	100°F	-20°F	Max(1)	Zero	Max	Zero	Max(2)	Min	
Free drop	x		x		x		x		x
30 foot drop		x		x		x		x	x
Puncture	x		x		x		x		x
Drop onto bar		x		x		x		x	x
Thermal Fire Accident	x		x		x		x		x
Immersion							(3)		

Notes:

1. See 10 CFR Part 71, Paragraph 71.71(c)(1).
2. Maximum internal pressure used in evaluation of conditions shall be taken as the maximum normal operating pressure (MNOP).
3. Immersion condition is independent of the other accident condition. Take internal pressure equal to zero, and external pressure equal to 285 psig.

(Reference 2.1.3)

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be used for the materials that meet the ASME specifications. For other materials, the method discussed in Article III-2000 of the Division 1 Appendices shall be used to derive design stress intensity values.

The properties of materials for the balance of the packaging shall be based on industry-recognized specifications, or standards, or on sufficient test data to justify the use of the material.

Property data shall include the effects of aging for the 25 year operating life.

2.1.2.2.2 Design Limits for Containment Structures

Regulatory Guide 7.6 and Section III, Subsection NB of the ASME B&PV Code (Reference 2.1.9) serve as the basis for design limits for all packaging containment boundaries for both the Normal Conditions of Transport and Operating loads, and for the Hypothetical Accident Conditions. These limits shall apply to the containment boundaries, bolted closure and internal fuel support basket. By satisfying these limits, the geometric form of the packaging contents will not be substantially altered and there will be no more than 5 percent reduction in the effective spacing between fuel assemblies.

<u>NORMAL CONDITIONS OF TRANSPORT AND OPERATING LOADS</u>

The following requirements shall form the basis for precluding failure of the containment structures (ductile rupture, excess strain or shakedown, fatigue, buckling and brittle fracture modes of failure) due to loadings caused by the Normal Conditions of Transport and Operating Conditions.

a. Ductile Rupture - The general primary membrane stress intensity (P_m) derived from the average value across the thickness of the section and produced by the internal pressure, gravity loads or loads necessary to satisfy the laws of equilibrium of external and internal forces, shall be limited to S_m. The local primary membrane plus primary bending stress intensity ($P_L + P_b$) shall be limited to αS_m, where α is defined as the ratio of the bending moment at full plasticity to the bending moment at yield.

b. Shakedown or Gross Unrestrained Yielding - The stress intensity, S_n, associated with the range of primary plus secondary stresses under Normal and Operating Conditions shall be less than $3S_m$. Examples of secondary stresses are:

- o general thermal stress
- o bending stress at a gross structural discontinuity, and
- o the bending stress adjacent to the point of application of an impact load.

The $3S_m$ limit given above may be exceeded if the following conditions are met (these conditions can generally be met only in cases where the thermal bending stresses are a substantial portion of the total stress):

(1) The range of stresses under Normal Conditions, excluding stresses due to stress concentrations and thermal bending stresses, yields a stress intensity, S_n, that is less than $3S_m$.

(2) The value S_a used for entering the design fatigue curve is multiplied by the factor K_e, where:

$$K_e = 1.0 \text{ for } S_n \leq 3\,S_m$$

$$= 1.0 + \frac{(1 - n)}{n(m - 1)} \left[\frac{S_n}{3S_m} - 1 \right], \text{ for } 3S_m < S_n < 3mS_m$$

$$= \frac{1}{n}, \text{ for } S_n \geq 3mS_m$$

The values of the material parameters m and n for the various classes of materials are given below:

	m	n	T_{max} °F	T_{max} °C
Low-Alloy Steel	2.0	0.2	700	371
Martensitic Stainless Steel	2.0	0.2	700	371
Carbon Steel	3.0	0.2	700	371
Austenitic Stainless Steel	1.7	0.3	800	427
Nickel-Chromium-Iron	1.7	0.3	800	427

(3) The temperatures do not exceed those listed above for the various classes of materials.

(4) The ratio of the minimum specified yield strength of the material to the minimum specified ultimate strength is less than 0.8.

c. Fatigue - The fatigue requirements of NB-3222.4 of the ASME B&PV Code shall be met for all Normal Conditions where the primary plus secondary stress intensity, excluding peak stresses, does not exceed $3S_m$. If the combined stress exceeds $3S_m$, the criteria given in Paragraph (b.) above may be used. The alternating stress, S_{alt}, used to enter the fatigue curves given in the ASME Code or other appropriate references shall be based on the maximum ranges of primary plus secondary plus peak stresses at a point for all the Normal Conditions. Peak stresses include stresses at local structural discontinuities and surface stresses adjacent to the point of application of a punching load. Appropriate stress concentration factors for structural discontinuities shall be used. A value of 4 shall be used in regions where this factor is unknown.

d. Buckling - For containment boundary structures subjected to Normal Transport and Operating loads, compressive stresses shall be limited to 33% of the buckling stress of the structure in order to preclude structural instability.

e. Brittle Fracture - The containment boundaries shall be designed so that unstable crack growth is precluded. Those containment boundary components constructed from materials that do not undergo a brittle-to-ductile transition with increasing temperature, such as austenitic stainless steel or titanium alloys, will not be limited with respect to use at low temperature. The criterion for acceptance of alloy steel components subjected to Normal Transport loadings shall be based upon a Lowest Service Temperature (LST) of -40°F, and the material's nil-ductility transition (NDT) temperature as determined by a drop weight test per ASTM E-208. The margin required between the NDT temperature and the LST shall be a minimum of 30°F. Bolting materials, which cannot be tested per ASTM E-208, shall meet the requirement that two out of three Charpy V-notch tests per ASTM E23 at a temperature of -50°F, or lower, shall exhibit energies greater than or equal to 20 ft-lbs.

A summary of the structural limits that shall be used for the containment structures, closure bolts, and fuel support basket is presented in Table 2.1-7.

HYPOTHETICAL ACCIDENT CONDITIONS

The following requirements shall form the basis for precluding failure of the containment structures (ductile rupture, extreme total stress range, buckling and brittle fracture) due to loadings caused by the Hypothetical Accident Conditions.

a. Ductile Rupture - The general primary membrane stress intensity (P_m) shall be less than or equal the lesser value of 2.4 S_m or 0.7 times the minimum ultimate strength (S_u) of the material and the local primary membrane plus primary bending stress intensity ($P_L + P_b$) shall be less than or equal to the lesser value of 3.6 S_m or S_u. The primary membrane stress for closure bolts shall be limited to the lesser of S_y or 0.7 S_u, and primary membrane plus bending stress shall be limited to S_u.

Table 2.1-7

Allowable Structural Limits for Containment Structures

Stress Category	Containment and Basket Structures	
	Normal Conditions	Accident Conditions
General Primary Membrane (P_m)	S_m (1)	lesser of: 2.4 S_m 0.7 S_u
Local Primary Membrane + Bending ($P_L + P_b$)	1.5 S_m (2)	lesser of: 3.6 S_m S_u
Range of Primary + Secondary Stresses	3.0 S_m (3)	No limit
Fatigue (S_{alt}) = $S_P/2$	$\Sigma\, n/N \leq 1.0$	No limit
Extreme Stress Range(4)	Not Applicable	2 S_a @ 10 cycles
Bearing Stress	S_y	S_y for seal surfaces S_u elsewhere
Primary Shear Stress	0.6 S_m	lesser of: 1.44 S_m 0.42 S_u
Buckling	3.0 Design Factor	1.5 Design Factor

Stress Category	Closure Bolts Allowable Stresses	
	Normal Conditions	Accident Conditions
General Primary Membrane (P_m)	2 S_m (5)	Lesser of: S_y 0.7 S_u
Local Primary Membrane & Bending ($P_L + P_b$)	3 S_m	S_u

Note: (1) Where S_m is the structural allowable as defined by the ASME Code, Section III, for Class 1 components.

(2) For rectangular cross-sections.
(3) Except as modified in the writeup.
(4) Surface stresses adjacent to the point of application of a punching load shall be treated as peak stresses.
(5) Where S_m is the structural allowable as defined by the ASME Code, Section III, for Class 1 bolts.

b. Extreme Total Stress Range - In accordance with Regulatory Guide 7.6 (Reference 2.1.7), the maximum range of primary-plus-secondary-plus-peak stress intensity ($P_L + P_b + Q + F$) between the initial state and worst accident condition shall be less than 2 S_a where S_a is the stress from the appropriate ASME design fatigue curve taken at 10 cycles.

c. Buckling - For containment boundary structures subjected to the Hypothetical Accident Conditions, compressive stresses shall be limited to 67% of the buckling stress.

d. Brittle Fracture - Same limitations as for the Normal Transport and Operating conditions.

A summary of the structural limits that shall be used for the containment structures, fuel support basket and closure bolts is presented in Table 2.1-7.

2.1.2.2.3 Balance of Packaging Structures

Allowable stresses for Normal and Hypothetical Accident conditions are presented in Table 2.1-8 and the special design limits provided in this section shall be used for the non-containment structural components such as lifting and tie-down trunnions, the cask outer shell, shielding and the impact limiter. The critical components and welds of the lifting and tiedown devices attached to the cask and the cask outer shell shall also be evaluated for fatigue using shock and vibration loads normally incident to transport. Fatigue limits in Section III of the ASME Code shall be used. Equivalent fatigue analysis methods may be used for materials not in Section III.

LIFTING DEVICES ATTACHED TO THE CASK

The acceptance criteria for lifting devices attached to the cask are provided in Table 2.1-8. These "non-containment" allowables shall be utilized in conjunction with a load factor of three (3) on any expected operational lifting loads, per Paragraph 71.45(a) of 10 CFR Part 71. These devices shall also be designed so that failure of any lifting device under excess load would

Table 2.1-8

Allowable Structural Limits for Non-Containment Structures[1]

Stress Category	Allowable Stresses Under Max. Loadings	Max. Loadings Accident Conditions
General Primary Membrane Stress Intensity (P_m)	S_y	Greater of: 0.7 S_u S_y
Local Primary Membrane + Bending Stress Intensity ($P_L + P_b$)	Greater of: 1.5 S_m S_y	S_u
Range of Primary + Secondary Stress Intensity	Greater of: 3.0 S_m 2.0 S_y	No Limit
Bearing Stress	S_y	S_u
Pure Primary Shear Stress	Greater of: 0.6 S_m 0.6 S_y	Greater of: 0.6 S_y 0.42 S_u
Fatigue	(2)	No Limit
Buckling	3.0 Design Factor	1.5 Design Factor

Stress Category	Non-Containment Fastener Allowable Stresses Normal Conditions	Accident Conditions
General Primary Membrane (P_m)	Greater of: 2.0 S_m[3] S_y	Greater of: S_y 0.7 S_u
Local Primary Membrane + Bending ($P_L + P_b$)	Greater of: 3.0 S_m S_y	S_u

Notes: (1) See notes on Table 2.1-7 for explanation of nomenclature.
(2) Use fatigue limits given in Section III of the ASME Code.
(3) S_m is bolt allowable for this application.

not impair the ability of the cask to meet the requirements of 10 CFR Part 71. Any other structural part of the cask which could be used to lift the cask shall be capable of being rendered inoperable for lifting the cask during transport.

TIE-DOWN DEVICES OR TRUNNIONS ATTACHED TO THE CASK

The acceptance criteria for tie-down devices or trunnions attached to the cask are provided in Table 2.1-8. These allowables shall be utilized in conjunction with a static load applied to the center of gravity of the cask having a vertical component of two times the maximum weight of the cask with its contents, a horizontal component along the direction in which the cask travels of 10 times the maximum weight, and a horizontal component in the transverse direction of 5 times the weight of the cask and its contents. Any other structural part of the cask that could be used to tie-down the cask shall be capable of being rendered inoperable. Each tie-down device which is a structural part of the cask shall be designed so that failure of the device under excessive load would not cause failure of the cask.

CASK OUTER SHELL

The cask outer shell shall be designed to contain the shielding and to withstand the Normal Conditions of Transport and Hypothetical Accident Conditions to the extent required to continue to provide protection of the containment boundaries during these events. To achieve this protection, the non-containment allowables shown in Table 2.1-8 shall be used for the outer shell.

SHIELDING

The shielding shall be designed to remain sufficiently intact in order that it satisfy its shielding function.

IMPACT LIMITER

The impact limiters shall be allowed to exceed yield for all conditions. The acceptance criterion for all impact related loads within the impact limiters is that no cask "hard point" shall come into contact directly with the impact surface.

2.1.2.3 Structural Design Criteria and Limits for Support and Tiedown Systems

2.1.2.3.1 Material Properties

The properties of materials for the support and tie-down systems and for the intermodal transfer skid shall be based on industry-recognized specifications or standards, or on sufficient test data to justify the use of the material.

2.1.2.3.2 Design Limits for Support and Tiedown Systems

The acceptance stress criteria under the normal travel loads for the support and tie-down structures that are not a part of the cask or package, shall be taken in accordance with the ASME B&PV Code, Subsection NF, Design Rules for Linear Type, Class 1 Supports, or with the AISC Manual for Steel Construction (Reference 2.1.10), or with the Aluminum Construction Manual (Reference 2.1.11). The stress criteria for the maximum non-accident loads shall be taken in accordance with Table 2.1-9. These allowables shall be utilized in conjunction with static loads applied to the center of gravity of the cask having magnitudes equal to the cask weight times the g-loadings given in Section 3.1, Part II, of Reference 2.7.3.

The critical components and attachment welds for the support and tie-down structures shall be evaluated for fatigue using the vibration and shock loads normally incident to transport and the fatigue limits given in Section VIII of the ASME Code. Equivalent fatigue analysis methods may be used for materials not in Section VIII.

Table 2.1-9
Allowable Structural Limits for Support and Tie-down Structures Under Maximum Non-Accident Transportation Conditions

Stress Category	Allowable Stresses
Primary Membrane Stress Intensity	S_y
Primary Membrane plus Bending Stress Intensity	Greater of: 1.5S (Note 1) S_y
Range of Primary Plus Secondary Stress Intensity	Greater of: 3.0S $2.0S_y$
Bearing Stress	$1.5\ S_y$
Pure Shear Stress	Greater of: 0.6S $0.6S_y$
Fatigue	(2)
Buckling	3.0 Design Factor

Note: (1) Where S is the structural allowable as defined by the ASME B&PV Code for Class 2/3 Components.
(2) Use fatigue limits given in Section VIII of the ASME Code. Equivalent fatigue analysis methods may be used for materials not in Section VIII.

(Reference: 2.1.8)

2.1.2.3.3 Design Limits for the Intermodal Transfer Skid

The design limits for the Intermodal Transfer Skid for normal travel loads shall be taken in accordance with the ASME B&PV Code,Subsection NF, Design Rules for Linear Type, Class 1 Supports or with the AISC Manual for Steel Construction (Reference 2.1.10), or with the Aluminum Construction Manual, except for lifting devices. The acceptance criteria for lifting structures or components for the skid or for maximum non-accident transportation loads are provided in Table 2.1-9. These allowables shall be utilized in conjunction with a load factor of three (3) on any expected lifting loads.

2.2 Weights and Centers of Gravity

The weight of the LWT cask including a breakdown of the major components is provided in Table 2.2-1. The center of gravity is very close to the geometric center as the cask is for all practical purposes symmetric in configuration.

2.3 Mechanical Properties of Materials

The LWT cask will be fabricated primarily from Grade 9 titanium material. Depleted uranium will be sandwiched between the titanium plates and shells and will serve as the primary shielding material. The cask impact limiters will be constructed of aluminum honeycomb. High strength bolts made from Alloy 718 will be used in the closure. The general arrangement drawings presented in Section 1.5 define the specific material used for each component of the cask.

Table 2.3-1 presents material properties for the Grade 9 titanium material. The material strength data given in this table are based on a series of tests performed by the RMI Corporation and is the basis of a proposed ASME B&PV Section III Code Case which has been submitted by Westinghouse to the ASME (Appendix 2.10.5).

Grade 9 titanium is covered by several industry and military specifications. These include ASTM (listed on Table 2.3-1), Aerospace Metals Standards (published by Battelle Columbus Division), and the Aerospace Structural Materials Handbook. The properties of Grade 9 have been well characterized in these specifications and in References 2.3.1 thru 2.3.3. To support this

Table 2.2-1

Cask Weight

	Component	Weight * with PWR Fuel	Weight ** with BWR Fuel
1.0	Top Impact Limiter	1,235 lbs	1,235 lbs
2.0	Cask		
	2.1 Closure Lid	1,819 lbs	1,819 lbs
	2.2 Bottom Head Assembly	1,421 lbs	1,421 lbs
	2.3 Inner Shell	1,148 lbs	1,148 lbs
	2.4 Depleted Uranium(1)	30,128 lbs	30,128 lbs
	2.5 Outer Shell	3,747 lbs	3,747 lbs
	2.6 Boro-Silicone	4,835 lbs	4,835 lbs
	2.7 Outer Skin	722 lbs	722 lbs
	2.8 Trunnions	699 lbs	699 lbs
3.0	Basket	1,685 lbs	1,575 lbs
4.0	Bottom Impact Limiter	1,235 lbs	1,235 lbs
5.0	Payload	4,550 lbs	4,480 lbs
	TOTAL CASK WEIGHT	53,224 lbs	53,044 lbs

* 3 PWR Fuel Assemblies
** 7 BWR Fuel Assemblies

(1) The existing design based on which the structural analysis has been performed uses a depleted uranium thickness of 2.87 inches for the cask cylindrical portion. Shielding evaluations show that a 0.1 inch reduction in thickness is possible while still meeting the 2 meter dose rate limit. The weights reported above are based on this reduced shielding thickness.

Table 2.3-1

Mechanical Properties of Grade 9 Titanium

Applicable Material Specifications	Temp °F	Strength (ksi) Yield S_y	Ultimate S_u	Allowables S_m(2)	S(2)	Elastic Modulus (10^6psi)	Coeff. of Thermal Expansion (10^6 in/in/°F) (3)
ASTM							
B265(1)	RT	70	90.0	30.0	22.5	15.0	--
B348							
B381	100	67.9	87.3	30.0	22.5	14.75	--
B337							
B338	200	61.6	79.2	29.0	21.8	14.5	5.34
B363	300	55.3	72.0	26.4	19.8	---	--
	400	49.7	63.9	23.4	17.6	12.4	5.37
	500	44.8	57.6	21.1	15.8		--
	600	41.3	54.9	20.1	15.1		5.48

(1) The inclusion of Grade 9 titanium material in this ASTM specification is in process.
(2) S_m allowable in accordance with ASME B&PV Code, Section III for Class 1 components; S in accordance with Section III for Class 2/3 components.
(3) Ti-3Al-2.5V Seamless Engineering Guide, Second Edition, Sandvik Special Metals Corp. (Reference 2.3.3).

material data base, additional basic materials testing is planned to develop elevated temperature information on tensile, fatigue and creep rupture strengths, and on fracture toughness of the base material and weldments. Of all the specifications, the proposed ASME B&PV Code Section III Code Case for Grade 9 titanium is the most significant and, when approved, will form the single reference document for those material properties included in it.

Depleted uranium, containing 0.2 percent Mo, will be used for the gamma shielding. Typical properties of this depleted uranium alloy are provided in Table 2.3-2. For the structural evaluation of the cask, the strength of the depleted uranium will be ignored if it contributes to the overall strength of the cask.

The cask impact limiters will be constructed of aluminum honeycomb with two different core densities and crush strengths. Type 304 SS skin covers the honeycomb surfaces. The end portion will use 1400 psi crush strength honeycomb, and the circular side skirts will use 750 psi crush strength material. A deviation from the nominal crush strengths of 10% is conservatively assumed for the preliminary design of the cask. The transition zone between the end and side skirt segments will be constructed of 1400 psi crush honeycomb. The dynamic crush strength of the honeycomb is a function of the impact velocity and is usually higher than the static crush strength listed above. For preliminary design, an increase of 25% over the nominal static value was used as the dynamic crush strength for an impact velocity of 44 fps (terminal velocity for a 30 foot drop). This assumption will be confirmed by tests. The honeycomb in the impact limiters will be precrushed such that they respond essentially as perfectly elastic-plastic bodies. A typical crush strength-deflection curve for honeycomb is shown in Figure 2.3-1.

From the curve it can be seen that honeycomb which is not precrushed or in which the contact area has not been reduced will exhibit a peak stress at impact. This peak can be eliminated by precrushing and by proper design of the impact limiter honeycomb. The resulting crush strength- deflection curve for the honeycomb is that of a perfectly elastic-plastic material with the maximum crush strength equal to the critical crush strength of the honeycomb.

Table 2.3-2

Typical Properties of Depleted Uranium Alloy Containing 0.2% Mo

Physical Properties	
Density (lbs/in^3)	0.679
Thermal Properties	
Conductivity (BTU/Hr-ft-°F)	9.2
Coeff. of Thermal Expansion (10^{-6}in/in-°F)	
200 °F	8.23
300 °F	8.5
400 °F	8.75
Mechanical Properties	
Ultimate Tensile Strength (psi)	70-100,000
Yield Strength (psi)	40-60,000
Elongation (% in 2 inches)	3-7
Reduction in Area (%)	2-7
Modulus of Elasticity (psi)	$24x10^6$
Poisson's Ratio	0.21
Shear Modulus (psi)	$12x10^6$
Hardness Rockwell B	85-100

Reference 2.3.4

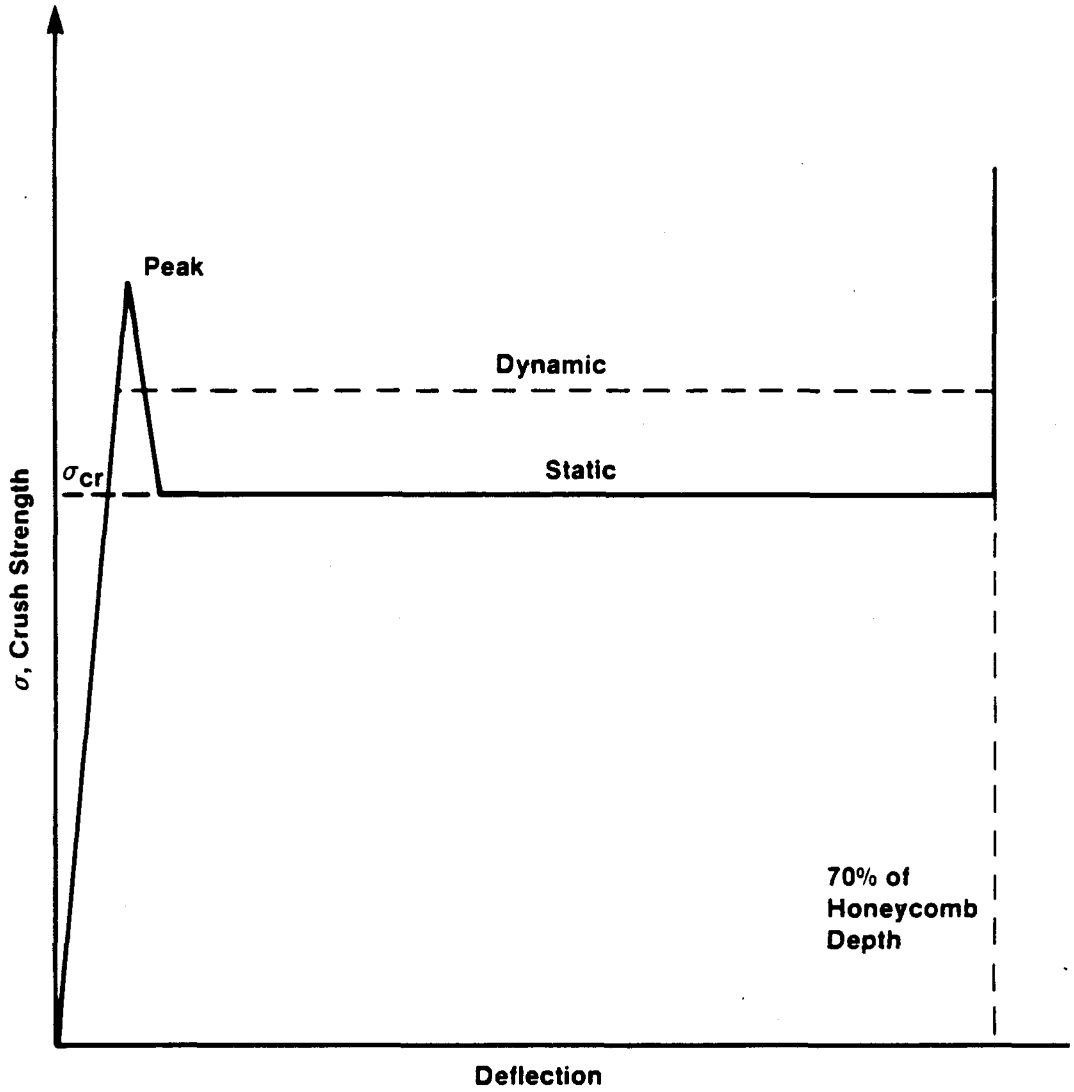


Figure 2.3-1. Crush Strength-Deflection Curve for Honeycomb

The maximum crush deflection of the honeycomb is approximately 70% of the honeycomb cell depth (where the honeycomb locks up). The impact limiter is designed to preclude honeycomb crushes of greater than 70%. The figure also shows that the dynamic crush strength of the honeycomb is greater than its static crush strength.

The circumferential portion of the honeycomb impact limiter consists of a honeycomb ring or skirt made up of twenty-four 15° segments. The centerline of the cells of each 15° segment line up radially with respect to the center of the cask. 15° segments were chosen as a reasonable and practical approximation of an ideal honeycomb configuration where all honeycomb cells would be radial. Adjacent segments are bonded to an aluminum skin that separates them. This skin provides a surface to bond the honeycomb and a mechanism for transferring the load between segments.

The energy absorbed by the impact limiter is the sum of the energy absorbed by each segment. The stress normal to the plane of crushing is a function of the type of honeycomb and the angle of crush. Manufacturers usually provide honeycomb properties that are normal to or in the direction of the honeycomb cells. GA and Sandia (Reference 2.3.5) have developed an empirical procedure for calculating σ_n, which is the stress normal to the plane of crushing, for loads applied at angles other than the axis parallel to the honeycomb cells. The method is based on the criterion that the stress components in the honeycomb cannot exceed the strength of the honeycomb, or

$$\sigma_{cr} = \sqrt{\sigma_y^2 + 4\,\sigma_x^2} \tag{1}$$

where

σ_{cr} = manufacturer's crush strength of honeycomb, in direction of cells,

σ_y = compressive stress in the direction of the honeycomb cells, or $\sigma_n \cos\alpha$,

σ_x = stress normal to the direction of the honeycomb cells or $\sigma_n \sin\alpha$,

σ_n = honeycomb stress normal to the plane of crushing, and

α = angle between the normal to the plane of crushing and cell direction.

Therefore, the effective crush stress can be found by rewriting the above equation, or

$$\sigma_n = \frac{\sigma_{cr}}{\sqrt{\cos^2 \alpha + 4 \sin^2 \alpha}} \qquad (2)$$

The total force exerted by a honeycomb impact limiter is equal to the sum of the forces exerted by each honeycomb segment, or

$$F = \sum_{i=1}^{n} \sigma_{n_i} A_i \qquad (3)$$

where

F = total force exerted by the impact limiter

σ_{n_i} = stress normal to the plane of crushing in the i^{th} honeycomb segment, and

A_i = crush area of the i^{th} honeycomb segment, and

n = number of honeycomb segments that have been partially or fully crushed.

The crushed area can be calculated using the geometry of the impact limiter and is a function of the deflected shape or crush depth of the impact limiter. Therefore, the load-deflection curve of the impact limiter can be obtained by calculating the crush area as a function of crushed depth or deflection, by computing σ_{ni} for each segment of honeycomb, and by determining the force using equation (3).

The crush area geometries for the cask impact limiter as a function of impact crush and angle of drop orientation were calculated using a CAD 3D solid modeling technique. An example is shown in Figure 2.3-2. The figure shows the impact limiter as a solid model with 15° segments for a 45° angle drop to a crushing depth of 8 inches. The resulting crush area of the various honeycomb segments are shown along with the calculated areas using the solid model. These areas used with the calculated stresses normal to the plane of crushing in the honeycomb segments gives the honeycomb impact limiter crushing force. Tables 2.10-1 thru 2.10-8 in Appendix 2.10.2 give the resulting segment crush areas, normal crushing stress for each segment, and resulting impact limiter force as a function of impact limiter crush deflection for 0°, 15°, 30°, 45°, 60°, 75°, 90° and C.G. over corner drop orientations, respectively. The resulting impact limiter static load-deflection curves plotted from these tables are shown on Figure 2.3-3. These curves scaled upward by 25% to account for honeycomb dynamic crush strengths are used for the one foot and 30 foot drop analyses.

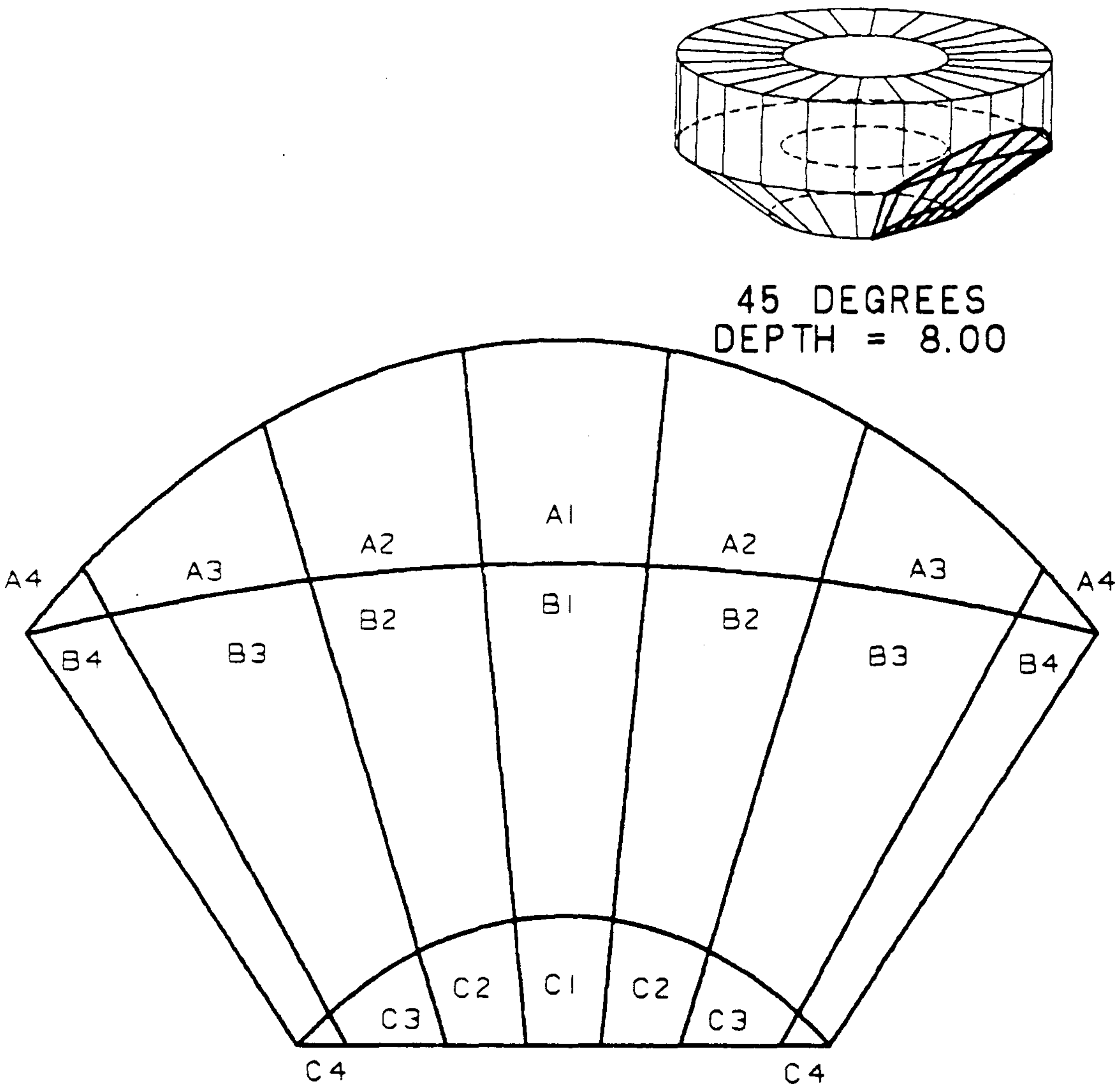
ASME SA-637, Alloy 718 fasteners will be used on the closure. This material has a minimum tensile strength of 185 ksi and a minimum yield strength of 150 ksi. The material is included in the ASME B&PV Code, Section III for use with Class 1 components. The design allowables for Alloy 718 bolting material used in the design of the cask are listed in Table 2.3-3.

2.4 General Standards For All Packages

This section describes how the LWT cask meets the general standards for all packages.

2.4.1 Minimum Package Size

This section is not applicable since the smallest overall dimension is greater than 4 inches.



ZONE	AREA	ZONE	AREA	ZONE	AREA
A1	121.51	B1	138.10	C1	32.79
A2	109.74	B2	149.24	C2	30.26
A3	69.08	B3	187.99	C3	20.54
A4	6.38	B4	85.81	C4	2.38

Figure 2.3-2. Honeycomb Impact Limiter Load-Deflection Calculations

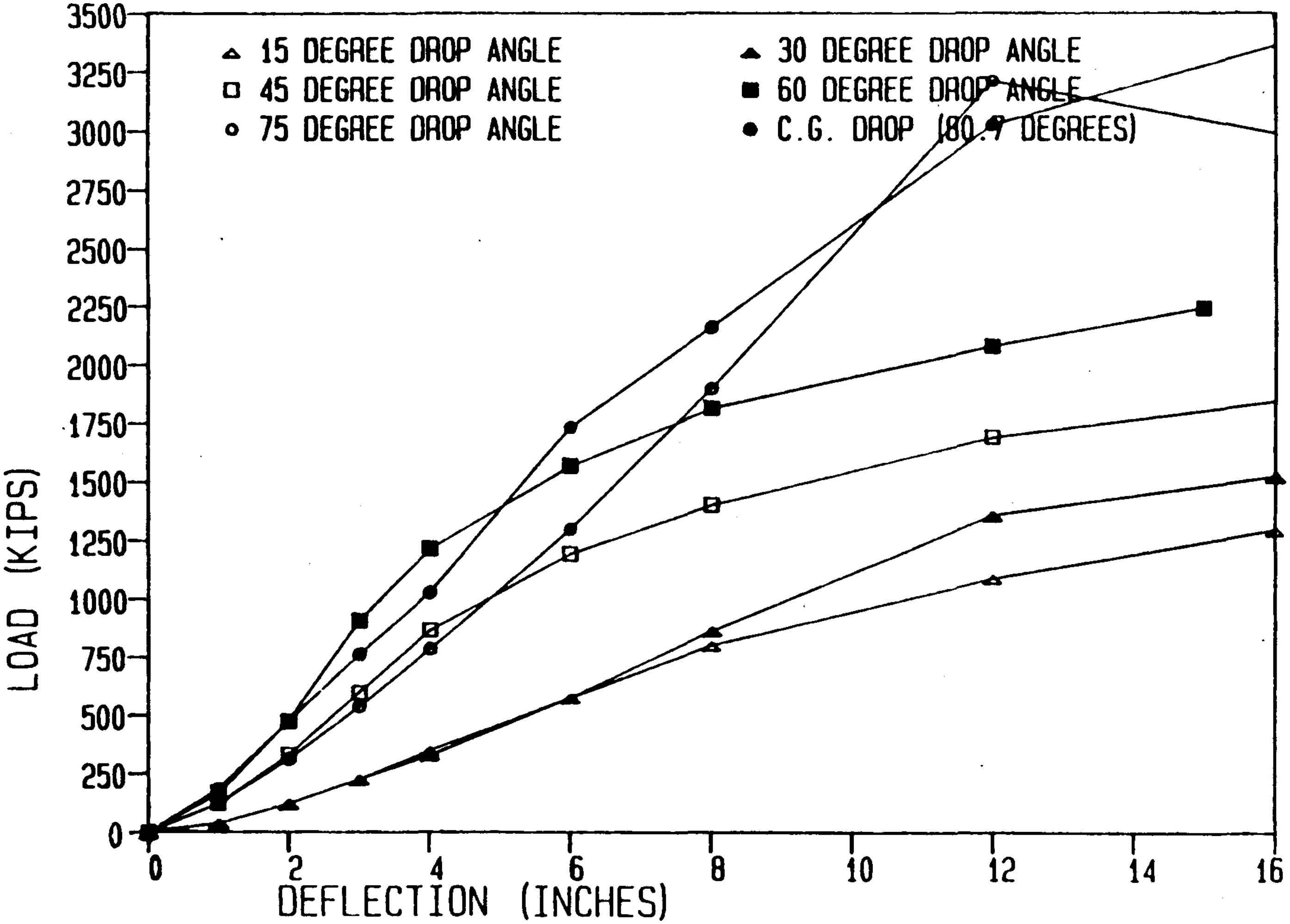


Figure 2.3-3. Nominal Load-Deflection Data

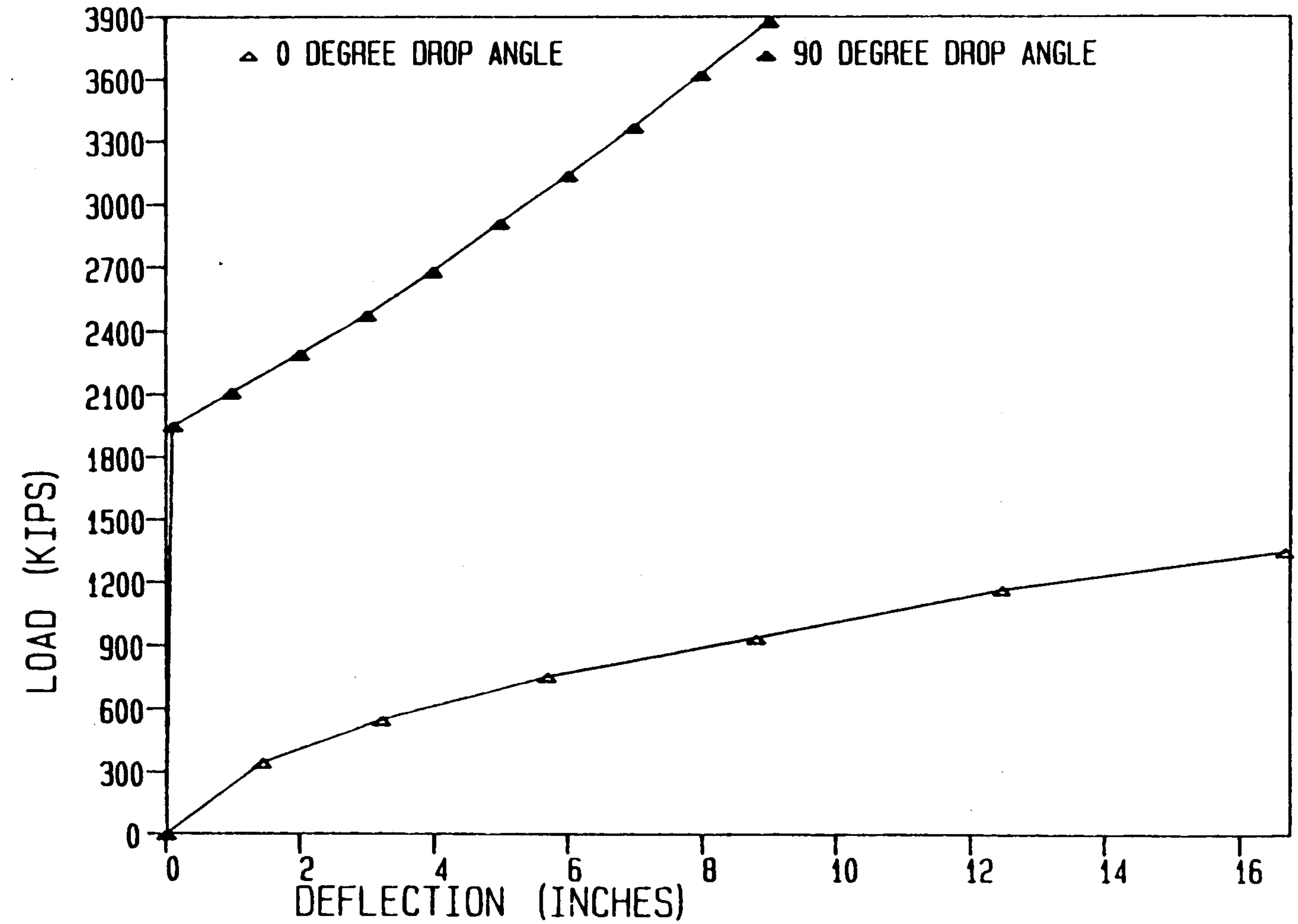


Figure 2.3-3. Nominal Load-Deflection Data (Continued)

Table 2.3-3

Design Allowables for Alloy 718 Bolting Material

Temp. (°F)	S_m (ksi)
100	50.0
200	48.0
300	46.9
400	46.1
500	45.6
600	45.1
700	44.8
800	44.4

Reference 2.1.8, Table I-1.3

2.4.2 Tamper-Proof Feature

The impact limiter is secured to the cask using four bolts. These bolts are recessed in counterbored holes. A tamper indicating wire will be placed across the diameter of one of the holes, effectively blocking access to the bolt head. The integrity of the wire provides evidence that the packaging has not been opened by unauthorized persons.

2.4.3 Positive Closure

The cask closure lid is secured by sixteen, 1.375 - 6 UNC bolts. The cask penetrations are all located in the closure lid and provided with redundant bolted closure protection.

2.4.4 Chemical and Galvanic Reactions

The materials from which the LWT cask is fabricated (i.e., stainless steel, Grade 9 titanium, depleted uranium, Boro-Silicone and Alloy 718) will not cause significant chemical, galvanic or other reactions in air, helium or inert environments. It is further noted that the aluminum honeycomb impact limiters are sealed within stainless steel skins eliminating water interaction with the aluminum honeycomb.

2.5 Lifting and Tie-down Standards For All Packages

Material properties and allowable stresses are based upon a temperature of 200°F for the outer shell of the cask and the allowable structural limits for non-containment structures given in Table 2.1-8 of Section 2.1. These are listed in Table 2.5-1.

2.5.1 Lifting Devices

The LWT cask will be lifted by the trunnions which are described below:

Table 2.5-1 Material Properties and Allowable Structural Limits

Material Property @ 200°F	Type 316 SS[(1)]	SA 479 Type[(1)] S21800	Grade 9 Titanium[(2)]	Alloy 718[(1)]
Modulus of Elasticity E, (10^6 psi)	27.6	27.6	14.5	28.3
Yield Strength, S_y (ksi)	25.8	39.80	61.60	144.0
Ultimate Strength, S_u (ksi)	75.0	93.70	79.20	177.60
Design Stress, S_m(ksi)	20.0	25.90	29.0	48.00
Allowable Stresses (ksi)				
Normal Primary Membrane S.I.	25.8	39.80	61.60	144.00
Normal Primary Membrane + Bending S.I.	30.0	39.80	61.60	144.00
Normal Pure Shear	15.48	23.88	36.96	86.40
Normal Bearing	25.80	39.80	61.60	144.00

(1) Reference 2.1.8

(2) Appendix 2.10.5

2.5.1.1 Description of Trunnions

The cask has six replaceable trunnions. Four of these six trunnions are located 90° apart near the closure end. Two of these four top trunnions are used for upending, general handling and also for securing the cask to the cask support system on the trailer. The other two top trunnions are used when single failure-proof handling systems are required at reactor sites. Two additional replaceable trunnions located near the bottom end of the cask provide a pivot for upending the cask, for securing to the cask support system, and for horizontal lifting of the cask. Each trunnion assembly consists of three components, which are: (1) a replaceable sleeve of SA 479 Type S21800 steel, (2) a trunnion of SA 479 type S21800 steel and (3) a Grade 9 titanium receptacle. The replaceable sleeve is bolted to the trunnion by six, 0.50" 13 UNC - 2A, Alloy 718 bolts. The trunnion is bolted to the receptacle by eight, 0.75" 10 UNC - 2A, Alloy 718 bolts. The receptacles for both the top and bottom trunnion assemblies are welded to the cask outer shell. In the bottom trunnion assembly, a 1.0" thick circular reinforcement pad is welded to the receptacle and the cask outer shell. During transportation, the cask is supported in the horizontal position in a cradle near the top end and a trunnion saddle near the bottom end. The cask includes a support ring between the upper trunnions which rests directly in the top end cradle. The bottom end of the cask is supported by the two bottom trunnions which rest on the rear support. The top and bottom trunnion assemblies are shown in Figures 2.5-1 and 2.5-2, respectively. Detailed information is provided in Drawing 1988E43.

2.5.1.2 Lifting Loads:

Based on Paragraph 71.45 of 10 CFR 71, the design of the combined lifting devices which are a structural part of the cask shall be based on supporting at least three times the weight of the cask without yielding. The loads

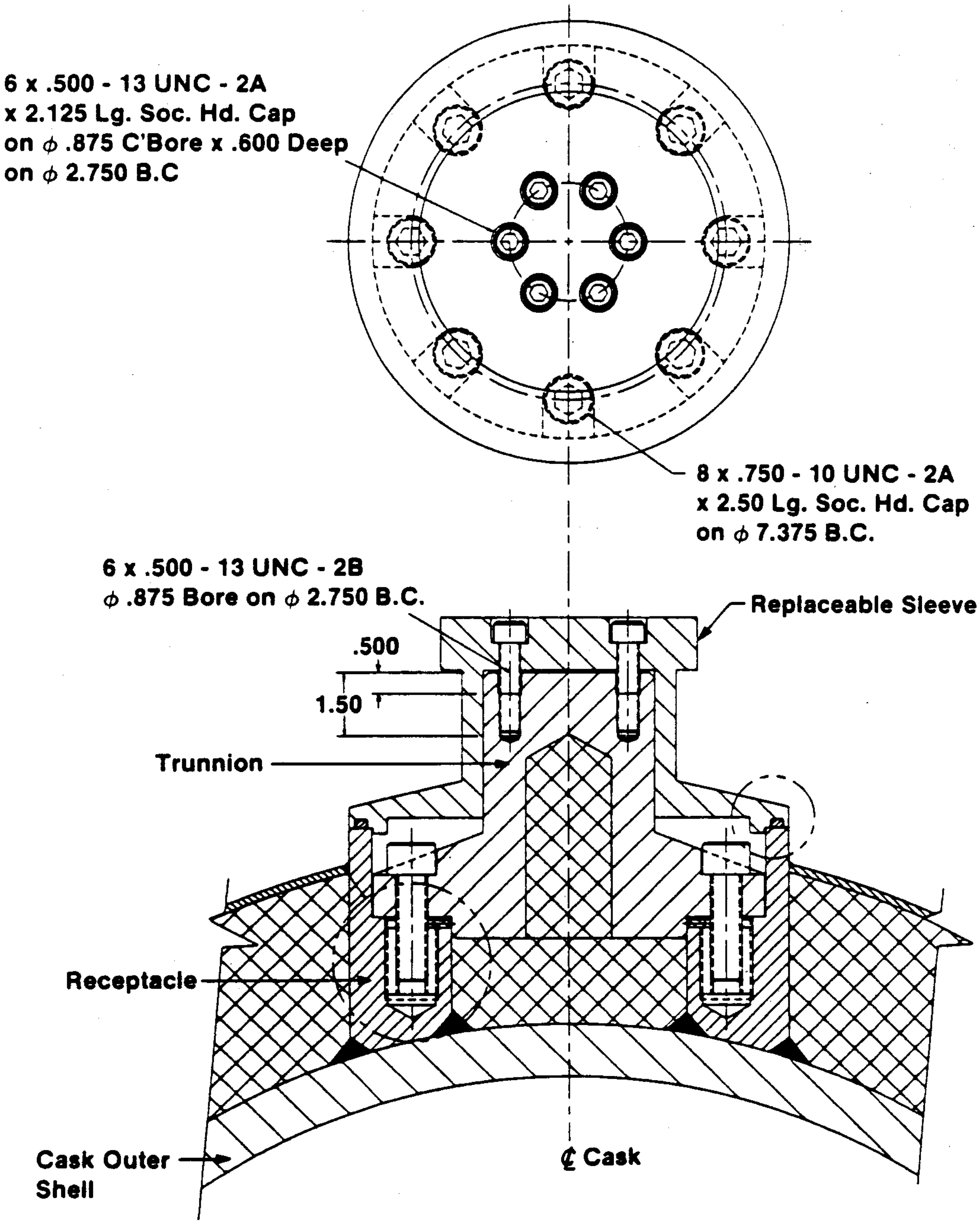


Figure 2.5-1. Top Trunnion Assembly

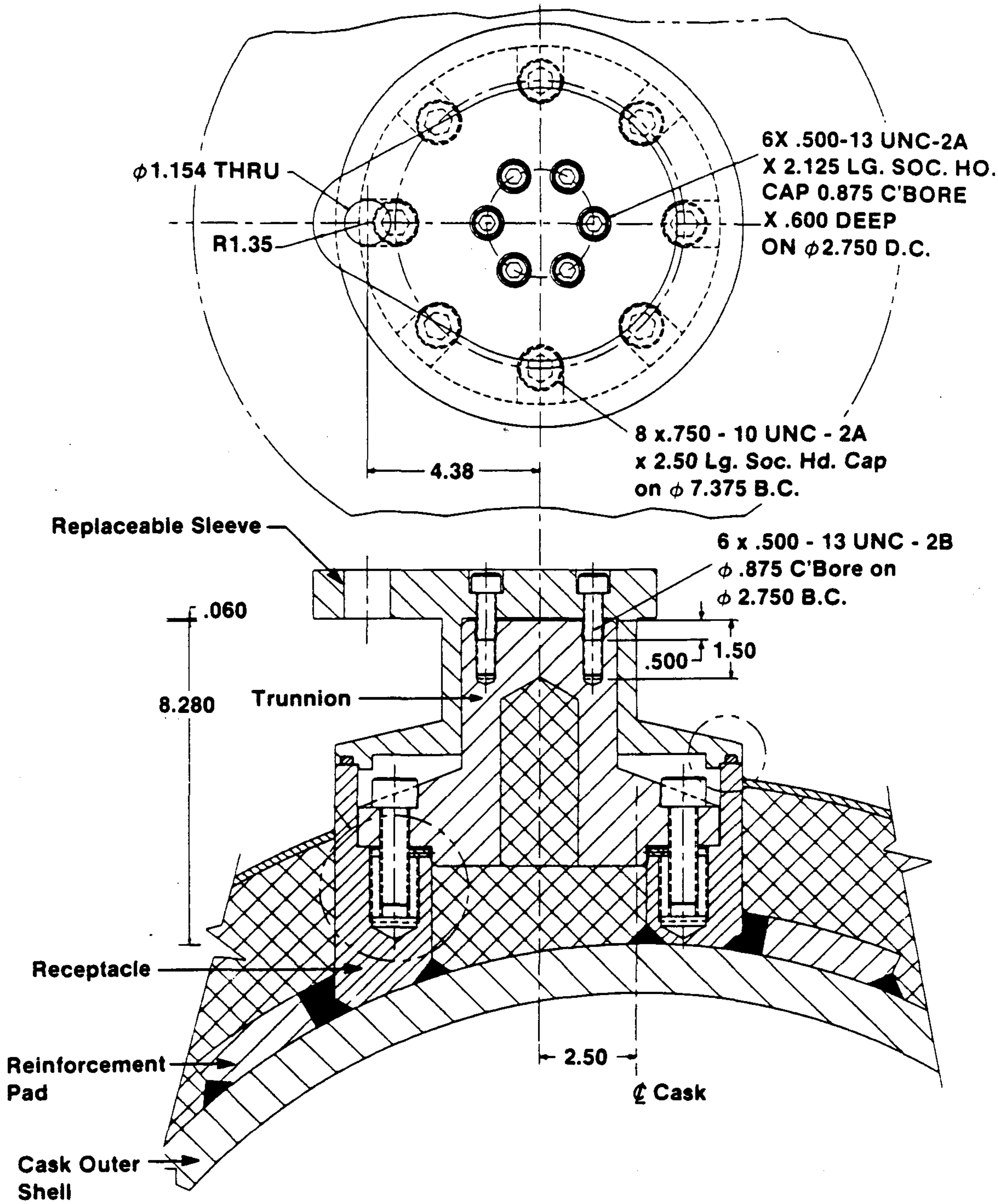


Figure 2.5-2. Bottom Trunnion Assembly

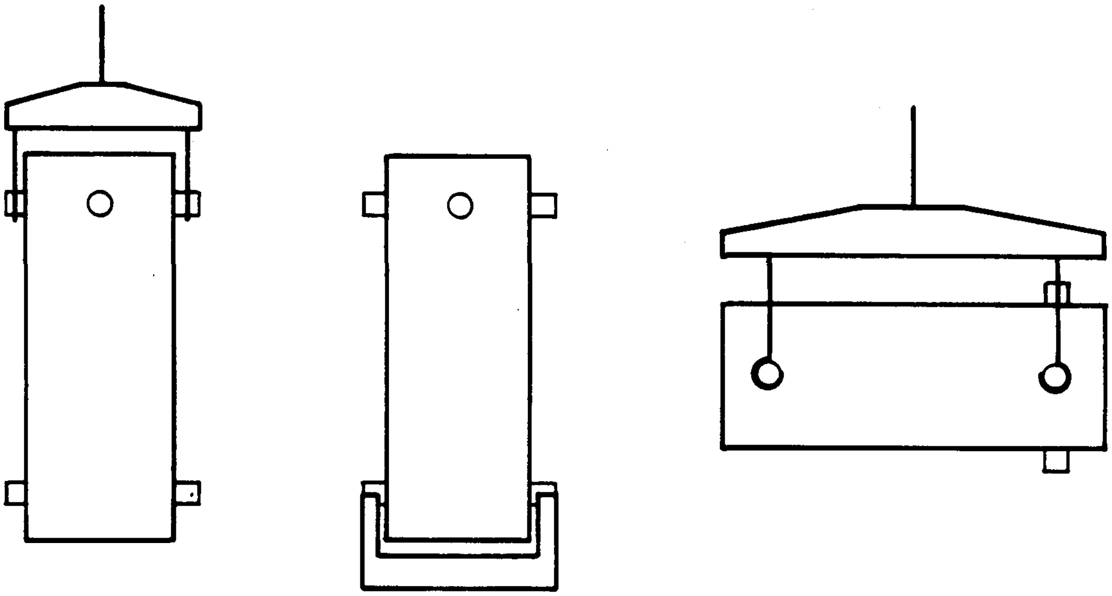
under this category apply to the replaceable sleeve, the six, 0.50" diameter bolts, trunnion, the eight, 0.75" diameter bolts, receptacle, weld and the cask outer shell. The three loading situations are as follows:

1) The cask is upended by lifting it by the two top trunnions while pivoting on the two bottom trunnions. At the beginning of the upending, each of the four trunnions share the load equally. The design load would be (3x54,000)/4; i.e. 40,500 lbs. When the cask is in the upright position and being lifted and supported by the two top trunnions only, each of the two top trunnions has a design load of 3x54,000)/2 or 81,000 lbs. applied in the longitudinal direction of the cask. This is the worst loading condition for the top trunnions under lifting loads (See Figure 2.5-3).

2) Considering the cask in an upright position, sitting in the bottom cradle, the lifting device just keeps the cask in vertical position. In this condition, each of the two bottom trunnions carries a load of 81,000 lbs. in the longitudinal or axial direction of the cask as calculated above (See Figure 2.5-3).

3) During an intermodal transfer operation, the cask will be lifted in the horizontal position by four trunnions (two top trunnions and two bottom trunnions). Each trunnion will carry 3x54,000/4 or 40,500 lbs. in the circumferential or tangential direction of the cask (see Figure 2.5-3).

The lifting loads are summarized in Table 2.5-2.



(a) Cask lifted using two top trunnions

(b) Cask in upright position, sitting in the rear support

(c) Cask in horizontal position, lifted using two top and two bottom trunnions

Figure 2.5-3. Cask Orientations Under Lifting Load Category

768370-28A

Table 2.5-2

Lifting Loads

	Cask Lifted By 2 Trunnions (V_l) (lbs.)	Cask Resting on Rear Support (V_l) (lbs.)	Cask Lifted Horizontally (V_c) (lbs.)
<u>Top Trunnion Assembly</u>			
Replaceable Sleeve	0	0	40,500
Six 0.5" diameter bolts	0	0	40,500
Trunnion	81,000	0	40,500
Eight 0.75" diameter bolts	81,000	0	40,500
Receptacle	81,000	0	40,500
Weld	81,000	0	40,500
Shell	81,000	0	40,500
<u>Bottom Trunnion Assembly</u>			
Replaceable Sleeve	0	0	40,500
Six 0.5" diameter bolts	0	0	40,500
Trunion	0	81,000	40,500
Eight 0.75" diameter bolts	0	81,000	40,500
Receptacle	0	81,000	40,500
Weld	0	81,000	40,500
Reinforcement Pad	0	81,000	40,500
Outer Shell	0.	81,000	40,500

<u>Notes</u>:

V_c = Load in circumferential direction of the cask

V_l = Load in longitudinal direction of the cask

2.5.2 Tie-Down Devices

Two of the four top trunnions and the two bottom trunnions are used for cask tie-down to the support system.

2.5.2.1 Tie-down Loads for Components Integral with Cask

The design of the cask tie-down devices or trunnions which are attached to the cask shall be based on withstanding the specified combined or simultaneous loadings of 10 g longitudinal, 2 g vertical and 5 g lateral without yielding. Further, each tie-down device which is a structural part of the cask shall be designed so that failure of the device under excessive load would not cause failure of the cask. Thus the loads under this category apply to the receptacle, weld and the cask outer shell. Loads will be shared by the trunnions as discussed in the following:

1) The 10 g longitudinal tie-down load will be taken by each of the two bottom trunnions. Thus the load on each bottom trunnion (i.e. the load on receptacle, weld, reinforcement pad and outer shell) was calculated to be 10x54,000/2 or 270,000 lbs. This ignores the frictional force developed between the cask body (i.e., outer shell) and the support cradle at the top end.

2) One-half of the 5 g lateral load will be taken by the front support system near the top end of the cask and the remaining one-half of the 5 g load will be taken by only one of two bottom trunnions. Thus the bottom trunnion (i.e. the receptacle, weld, reinforcement pad and outer shell) was analyzed for a load equal to (1/2)x5x54,000 or 135,000 lbs.

3) The $\pm$ 2 g vertical load when combined with the dead weight of the cask (i.e. 1 g down) results in a net 1g (up) load and a 3 g (down) load. This 1 g (up) load is shared equally by the two top trunnions and two bottom trunnions. Thus the load per trunnion equals 54,000/4 or 13,500 lbs (up). However, for the 3 g (down) load, one-half of the load is taken by the front support system (the cradle) and the

remaining load is taken by the two bottom trunnions. Thus the load per bottom trunnion is (1/2)(3x54,000/2) or 40,500 lbs. (down).

Table 2.5-3 presents the calculated tie-down loads in the longitudinal, vertical and lateral directions.

2.5.2.2 Tie-down Loads for Components Non-integral with Cask

The cask support and tie-down systems, which are not part of the cask, (such as the replaceable sleeve, six 0.5" diameter bolts, trunnions and eight 0.75" diameter bolts), shall be designed for transport loadings specified in proposed ANSI Standard N14.2 (Reference 2.5.1) and for the vibration and shock environment normally incident to transport. For the worst non-accident event in highway transportation, the support and tie-down systems was designed for the following three cases: ± 2.3 g longitudinal + dead weight (down), ± 1.6 g lateral + dead weight (down) and ± 2.0 g vertical + dead weight (down). Further explanation of these load cases is given in the following:

1) ± 2.3 g longitudinal + 1.0 g vertical (down). The longitudinal load 2.3x54,000 or 124,200 lbs. is resisted by the two bottom trunnions. One-half of the dead weight of the cask is taken by the top end support system and the remaining one-half is taken by the two bottom trunnions. Thus in this case, the trunnion and eight 0.75" diameter bolts of the bottom trunnion assembly are subjected to 124,200/2 or 62,100 lbs. load in the longitudinal direction along with 13,500 lbs in the circumferential direction of the cask.

2) ± 1.6 g lateral + 1.0 g vertical (down). One-half of the lateral load is taken by the top end support system and the remaining one-half is taken by only one bottom trunnion. The dead weight is taken by the top end support system and the two bottom trunnions as described above in (1). Therefore, for the replaceable sleeve and six 0.5" diameter bolts, 43,200 lbs load act in the lateral direction whereas the trunnion and eight 0.75" diameter bolts are subjected to 43,200 lbs in the lateral and 13,500 lbs in the vertical direction of the cask.

Table 2.5-3

Tie-down Loads for Integral Components

<u>Design Basis Loads</u>

Longitudinal	10 g	540,000 lbs.
Vertical	± 2g	± 108,000 lbs.
Lateral	5g	270,000 lbs.

<u>Trunnion Loads</u>

	Load in Longitudinal Direction, V_l (lbs.)	Load in Vertical Direction, V_c (lbs.)	Load in Lateral Direction, P (lbs.)
<u>Top Trunnion</u>			
Receptacle	0	13,500 (up)	0
Weld	0	13,500 (up)	0
Outer Shell	0	13,500 (up)	0
<u>Bottom Trunnion</u>			
Receptacle	270,000	40,500 (down)	135,000
Weld	270,000	40,500 (down)	135,000
Reinforcement Pad	270,000	40,500 (down)	135,000
Outer Shell	270,000	40,500 (down)	135,000

<u>Notes</u>: P = Load in the axial direction of the attachment
V_c = Load in the circumferential direction of the cask
V_l = Load in the longitudinal direction of the cask

3) $\pm$ 2.0 g vertical + 1.0 g vertical (down). The net effect, in this case, is 1 g up or 3 g down. The 1 g up load will be shared by the two top and two bottom trunnions equally (i.e. 54,000/4 or 13,500 lbs.). However, one-half of the 3 g down load (3x54,000/2) or 81,000 lbs. will be taken by the top end support system whereas the remaining one-half or 81,000 lbs will be shared by the two bottom trunnions.

The loads on individual components of the top and bottom trunnion assemblies subjected to design basis environmental loads are listed in Table 2.5-4.

All of the components of the top and bottom trunnion assemblies subjected to lifting, tie-down and design basis environmental loads are analyzed using standard structural engineering formulas. However, to determine the stresses in the receptacle to outer shell reinforcement pad as well as the outer shell, computer program CYLNOZ, version NOZC, is used (Reference 2.5.2). This program uses the equations of Bulletin 107, Welding Research Council (Reference 2.5.3).

The results of the analysis are summarized in Table 2.5-5.

Table 2.5-4

Tie-down Loads for Non-integral Trunnion Components

Design Basis Loads

Longitudinal	± 2.3 g + 1.0 g Vertical
Lateral	± 1.6 g + 1.0 g Vertical
Vertical	± 2.0 g + 1.0 g Vertical

Trunnion Loads

	Longitudinal Direction, V_l (lbs.)	Lateral Direction, P, V_c (lbs.)	Vertical Direction, V_c (lbs.)
Top Trunnion			
Replaceable Sleeve	0	0	0
Six 0.5" diameter bolts	0	0	0
Trunnion	0	0	13,500
Eight 0.75" diameter bolts	0	0	13,500
Bottom Trunnion			
Replaceable Sleeve	0	43,200	0
Six 0.5" diameter bolts	0	43,200	0
Trunnion	62,100 & 13,500	43,200 & 13,500	40,500
Eight 0.75" diameter bolts	62,100 & 13,500	43,200 & 13,500	40,500

Notes:

V_l = load in the longitudinal direction of the cask
V_c = load in the circumferential direction of the cask
P = load in the axial direction of the attachment

Table 2.5-5
Summary of Stresses in the Trunnions

Trunnion Assembly	Component/ Location	Load Category	Load (lbs)	Type of Stress (psi)	Calculated Stress (psi)	Allowable Stress (psi)	Margin of Safety
Top and Bottom	Trunnion	Lifting Load	V_1=81,000	Bending	38,812	39,800	+0.025
Bottom	Receptacle to Pad Junction	Tie-down Loads	P=135,000 V_c=40,500 V_1=270,000	Membrane plus Bending	55,190	61,600	+0.116
Bottom	Pad to Shell Junction	Tie-down Loads	P=135,000 V_c=40,500 V_1=270,000	Membrane plus Bending	60,580	61,600	+0.017
Bottom	Receptacle to Shell Weld	Tie-down Loads	P=135,000 V_c=40,500 V_1=270,000	Shear	11,888	31,416[(1)]	+1.643
Bottom	Receptable	Tie-down Loads	P=135,000 V_c=40,500 V_1=270,000	Combined Axial Plus Bending	43,672	61,600	+0.411
Top and Bottom	3/4" Dia. Bolts	Lifting Load	V_1=81,000	Tensile	74,501	129,600[(2)]	+0.740

Table 2.5.5 (Continued)
Summary of Stresses in the Trunnions

Trunnion Assembly	Component/ Location	Load Category	Load (lbs)	Type of Stress (psi)	Calculated Stress (psi)	Allowable Stress (psi)	Margin of Safety
Top	Receptacle to Shell Junction	Lifting Load	V_1=81,000	Membrane plus Bending	31,840	61,600	+0.935
Top	Receptacle to Shell Weld	Lifting Load	V_c=40,500	Membrane plus Bending	23,190	61,600	+1.656
Top	Receptacle to Shell Weld	Lifting Load	V_1=81,000	Shear Plus Bending	12,271	31,416[1]	+0.819
Bottom	Replaceable Sleeve Hole	Lifting Load	V_c=40,500	Shear	20,957	23,880	+0.139
Bottom	Replaceable Sleeve Hole	Lifting Load	V_c=40,500	Tensile	20,957	39,800	+0.899
Bottom	Replaceable Sleeve	Tie-down Load	P=43,200	Shear	2,200	23,880	+9.855

Table 2.5.5 (Continued)
Summary of Stresses in the Trunnions

Trunnion Assembly	Component/ Location	Load Category	Load (lbs)	Type of Stress (psi)	Calculated Stress (psi)	Allowable Stress (psi)	Margin of Safety
Bottom	Replaceable Sleeve	Lifting Load	V_c=40,500	Shear	5,730	23,880	+3.168
Bottom	0.5" Diameter Bolts	Lifting Load	V_c=40,500	Shear	47,569	86,400	+0.816
Bottom	0.5" Diameter Bolts	Tie-down Load	P=43,200	Tensile	50,740	144,000	+1.838
Bottom	Pad/Shell Junction	Tie-down Loads	P=43,200 & V_l=62,100	Membrane Plus Bending	9,756	61,600	+5.314
Bottom	Pad/Shell Junction	Tie-Down Loads	P=43,200 & V_c=13,500	Membrane Plus Bending	12,570	61,600	+3.900

Table 2.5.5 (Continued)
Summary of Stresses in the Trunnions

Trunnion Assembly	Component/ Location	Load Category	Load (lbs)	Type of Stress (psi)	Calculated Stress (psi)	Allowable Stress (psi)	Margin of Safety
Bottom	Pad/Shell Junction	Tie-Down Loads	V_c=40,500	Membrane Plus Bending	12,210	61,600	+4.045

Notes:

(1) Includes a 0.85 weld factor.

(2) Includes a 0.90 bolt factor.

2.6 Normal Conditions of Transport

The LWT cask, when subjected to the Normal Conditions of Transport as specified in 10 CFR Part 71, must meet the performance requirements as specified in Subpart E of 10 CFR Part 71. For this preliminary design phase, the major effort has been to demonstrate the performance of the package during the free drop test condition. Other Normal Conditions and tests have been considered to the extent necessary to insure that the package will meet the applicable design criteria.

The thermal evaluation for the Normal Heat Condition is presented in Section 3.0 of this report. The conditions of Normal Heat result in rather modest temperature differences throughout the cask, and the effect of these temperature differences will have negligible consequences on the cask structural integrity. Simple hand calculations have been carried out to confirm this conclusion. For the final design, more detailed thermal stress analyses will be carried out to show that all criteria are met.

The structural behavior and performance of the package for the free drop condition was determined using the SCANS computer program (Reference 2.6.1). A detailed description of the use and contents of this program is given in Section 2.7.1 and Appendix 2.10.3. The program was used to calculate the dynamic time-history behavior of the package during the free drop condition and the resulting forces, moments and stresses in the package. Several drop orientations were considered to determine the most damaging cases for the various cask components.

The structural response of the 3 PWR and 7 BWR fuel baskets to the free drop is also briefly discussed in this section. Decelerations obtained from the SCANS dynamic analyses were used to evaluate the baskets. The detailed structural evaluation of the fuel baskets is included as Appendix 2.10.4.

For the final design, all Normal Conditions and tests will be considered in detail. However, from these preliminary design evaluations it is expected with a high degree of confidence that the package will meet all performance and design requirements.

2.6.1 Heat

For the Heat Condition, the thermal stress for the inner shell is -1074 psi (compression) and 327 psi for the outer shell. See Section 3.4.5 for these calculations. The mechanical loads during the Heat Condition result from dead weight and pressure. The combination of these loads will not be as severe as the free drop condition at temperature. See Section 2.6.7 for the combination of these loads.

2.6.2 Cold

For the Cold Condition, a -40°F steady state ambient temperature is assumed since there is no internal heat generation. This will result in a uniform temperature throughout the cask of -40°F. The materials of construction for the cask are not adversely affected by the -40°F condition.

An evaluation of the effect of differential shrinkage of the Grade 9 titanium and depleted uranium shielding was performed. Since the coefficient of thermal expansion is larger for the DU, it will want to shrink down radially on the Grade 9 titanium inner shell. In the cask axial direction, a gap will open up in the shielding because of the larger shrinkage in the DU than in the Grade 9 titanium shells.

In the radial direction, the differential shrinkage between the DU and cask shell will be:

$$\Delta = (\alpha_{DU} - \alpha_T)\ \Delta TL$$

$$= (8.23 \times 10^{-6} - 5.34 \times 10^{-6})\ [-40 - (70)]\ (12.41")$$

$$= -0.004"$$

Since, there is a 0.03 inch radial gap between the inner shell and the DU shielding for assembly clearance, the differential shrinkage will not introduce any stresses in the inner Grade 9 titanium shell.

In the axial direction, the differential shrinkage will cause the following gap in the shielding,

$$\Delta = (\alpha_{DU} - \alpha_T)\ \Delta TL$$

$$= (8.23 \times 10^{-6} - 5.34 \times 10^{6})\ [-40 - (70)]\ (180")$$

$$= 0.057"$$

Since there is an assembly clearance of 0.05 inches in the shielding, the total gap for the Cold Condition could become 0.107". It is believed that this size of gap will not increase the radiation dosage on the cask outer surface significantly. This will be confirmed by the final design shielding analysis.

2.6.3 Reduced External Pressure

The effect of having the external pressure reduced to 3.5 psia (Paragraph 71.71(c)(3) of 10 CFR Part 71) is considered negligible for the cask. The Maximum Normal Operating Pressure is 35 psig or 49.7 psia. Thus the pressure difference across the containment boundary is normally 35 psig which would increase to 46.2 psig. The increase in the load on the closure lid would be 5645 pounds which means that each of the 16 bolts would pick up an extra load of 352 pounds which is trivial.

2.6.4 Increased External Pressure

The effect of increased external pressure of 20 psia (5.3 psig external pressure), is considered negligible to the cask due to the thick outer shell and end closures as shown below.

For the outer shell, this external pressure produces a compressive membrane stress of,

$$\sigma_m = \frac{PR_m}{t} = \frac{5.3\ (15.935)}{1.25} = 68 \text{ psi}$$

The critical buckling pressure of a short tube, of length L, ends held circular, is given by (Reference 2.6.2),

$$P_{cr} = 0.807\frac{Et^2}{LR_m}\left[\sqrt[4]{\frac{1}{(1 - \upsilon^2)}\ \frac{t^2}{R_m^2}}\right] \qquad (1)$$

Where: P_{cr} = critical elastic buckling pressure
E = modulus of elasticity of Grade 9 titanium outer shell ($E = 14.5 \times 10^6$ psi at 200°F)
L = cask cavity length of 180 inches
R_m = mean radius of 1.25 inch thick outer shell or 15.935 inches
υ = Poisson's ratio of 0.3

Substituting into equation (1) gives the following critical buckling pressure,

$$P_{cr} = 1827.9 \text{ psi}$$

The allowable buckling stress based on the Section 2.1 structural design criteria becomes,

$$\sigma_{CR} = \frac{1}{3.0}\left[\frac{P_{cr}\ R_m}{t}\right] = 7767 \text{ psi}$$

Hence, there is a large positive margin of safety between the actual stress (68 psi) on the shell caused by the increased external pressure and the allowable buckling stress (7767 psi).

The end closures are thick flat plates that are designed for a normal pressure of 35 psig, which greatly exceeds the increased external pressure of 5.3 psi.

2.6.5 Vibration

The effect of vibrations normally incident to transport have not been considered for preliminary design, but will be considered for final design. However, it is believed that the effect of Normal Condition vibrations will be negligible. This conclusion is based on the comparison of stresses obtained for the cask inner and outer shell for the side drop event discussed in Section 2.6.7, with those estimated for lateral truck and rail vibrations.

In Section 2.6.7, the normal side drop results in a 15.0 g's lateral deceleration on the cask which translates to stresses in the cask as follows:

Component	Membrane + Bending Stress(psi)
Inner Shell	12,762
Outer Shell	16,764

As a conservative worst case, it is assumed that normal vibration 'g' loads will equal the normal vertical loading imposed on tie-downs. Utilizing the specification in 10 CFR Part 71, Paragraph 71.45(b)(1), of 2 g's in the vertical direction, the maximum stress, σ, is found by ratioing to be 2235 psi in the outer shell of the cask. This is well below the endurance limit for Grade 9 titanium at room temperature. From Figure 2.6-1 (taken from Reference 2.3.3) for 10^8 cycles, the allowable alternating stress amplitude is 39,000 psi. The cask outer shell vibratory stress margin of safety is:

$$M.S. = (\sigma_{alt/\sigma}) - 1 = \frac{39,000}{2235} - 1 = +16.45$$

The tiedown trunnions must also resist the 2 g's vibration loading. They are not expected to be highly stressed during this vibratory loading.

For the final design, detailed fatigue analyses will be completed for the cask structural components. Fatigue allowables for Grade 9 titanium will be derived for the intermediate-temperature alpha-beta anneal (1475°F, 30 minutes) and at the cask maximum operating temperature.

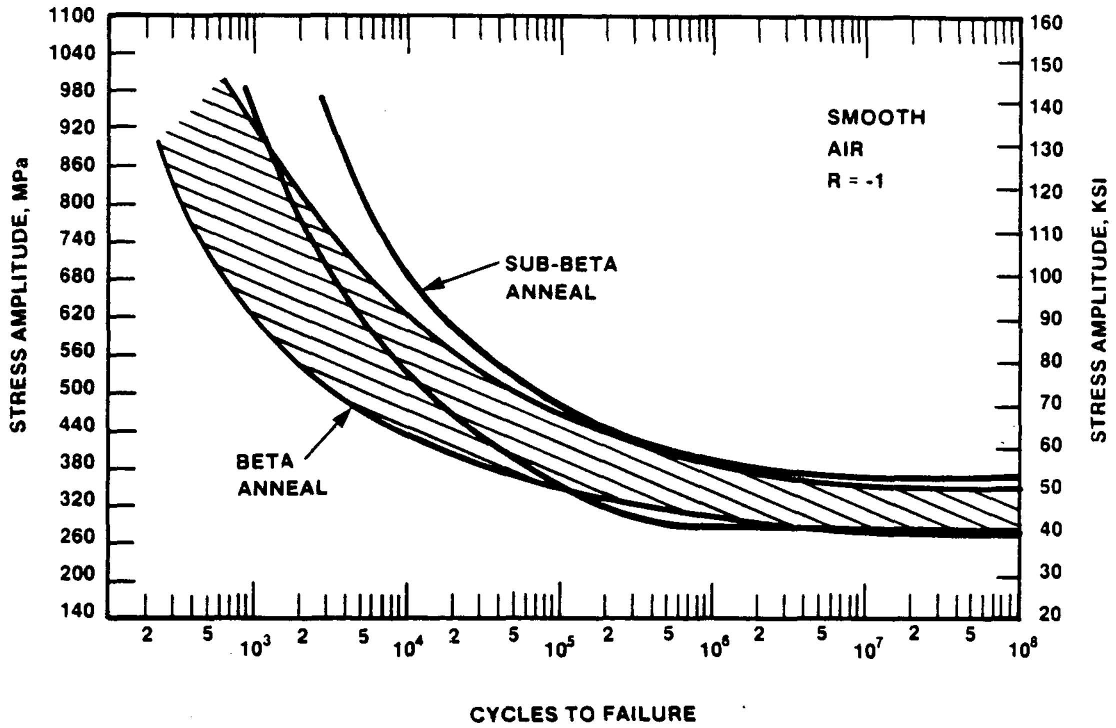


Figure 2.6-1. Fatigue Performance of Grade 9 Plate and GTA Weld Metal.

2.6.6 Water Spray

Due to the materials of construction utilized for the cask, the Water Spray test requirements will have a negligible effect on the package.

2.6.7 Free Drop

The LWT cask weighs about 54,000 pounds. Paragraph 71.71(c)(7) of 10 CFR Part 71 requires that a package in excess of 33,000 pounds be dropped one (1) foot onto a flat, essentially unyielding, horizontal surface, striking the surface in position for which maximum damage is expected. The following subsections address free drops at several angles with respect to the horizontal.

The dynamic behavior of the package for the free drop conditions was determined using the SCANS computer program (Reference 2.6.1). The general comments in Section 2.7.1 concerning SCANS and the detailed description given in Appendix 2.10.3 of the methodology used by SCANS also apply to the one-foot free drop analysis.

The SCANS results provide the maximum decelerations of the cask during the free drop condition for the various cask orientations. SCANS provides forces, moments, and stresses over a cross-section normal to the cask at nodes along the length of the cask. The program also gives moments and stresses in the closure head and bottom head assembly.

For the one-foot free drop, quasi-static and dynamic SCANS analyses were completed for the 0°, 15°, C. G. over corner, and 90° cask orientations. A summary of these results is provided in Table 2.6-1. Other oblique orientations were not run because it was found, as described in Section 2.7.1, that the 15° orientation is the worst case. In all cases, the bottom of the cask is assumed to contact the ground first. Maximum crush of the impact limiter, g-loads, axial force, shear load, bending moment, and stress intensity for the cask are provided in the table for both the primary and secondary impacts.

Table 2.6-1

Summary of SCANS Results for One-Foot Drop

	Parameter	Type of Analysis	0	15	C.G.	90
Primary Impact	Crush (in)	Dynamic	1.5	3.9	2.4	0.3
		quasi-static	1.5	2.6	2.2	0.3
		Dyn/q-static	1.00	1.50	1.09	1.00
	g's	Dynamic	15.0	18.4	12.3	44.8
		quasi-static	14.8	3.3	11.1	44.9
		Dyn/q-static	1.01	5.58	1.11	1.00
	Max. Axial Force (kips)	Dynamic	1.9	65.3	-707.9	-2474.9
		quasi-static	0.0	-59.7	-647.3	-2476.1
		Dyn/q-static	n/a	-1.09	1.09	1.00
	Max. Shear Force (kips)	Dynamic	431.7	-719.7	115.2	0.0
		quasi-static	427.1	222.8	106.4	0.0
		Dyn/q-static	1.01	-3.23	1.08	n/a
	Max. Moment (in-kips)	Dynamic	19736.9	33214.0	-10534.5	0.0
		quasi-static	19343.8	5872.9	-9618.5	0.0
		Dyn/q-static	1.02	5.66	1.10	n/a
	Max. Stress Intensity (ksi)	Dynamic	16.764	28.278	12.928	15.050
		quasi-static	16.427	5.224	11.747	13.692
		Dyn/q-static	1.02	5.41	1.10	1.10
Secondary Impact	Crush (in)	Dynamic	1.5	3.6	n/a	n/a
		quasi-static	1.5	3.9	n/a	n/a
		Dyn/q-static	1.00	0.92	n/a	n/a
	g's	Dynamic	15.0	18.4	n/a	n/a
		quasi-static	14.8	13.0	n/a	n/a
		Dyn/q-static	1.01	1.42	n/a	n/a
	Max. Axial Force (kips)	Dynamic	1.9	69.4	n/a	n/a
		quasi-static	0.0	0.0	n/a	n/a
		Dyn/q-static	n/a	n/a	n/a	n/a
	Max. Shear Force (kips)	Dynamic	431.7	-719.7	n/a	n/a
		quasi-static	427.1	-755.3	n/a	n/a
		Dyn/q-static	1.01	0.95	n/a	n/a
	Max. Moment (in-kips)	Dynamic	19736.9	33214.0	n/a	n/a
		quasi-static	19343.8	23158.9	n/a	n/a
		Dyn/q-static	1.02	1.43	n/a	n/a
	Max. Stress Intensity (ksi)	Dynamic	16.764	28.278	n/a	n/a
		quasi-static	16.427	19.667	n/a	n/a
		Dyn/q-static	1.02	1.44	n/a	n/a

2.6.7.1 Flat End Drop

Analysis of the LWT cask during the one-foot end drop is based on the impact decelerations, forces and stresses obtained from the SCANS analysis for the 90° cask orientation. Table 2.6-1 provides a summary of these results.

The impact analyses were carried out using room temperature values for the modulus of elasticity. However, the calculated stresses will be compared to the allowables at the maximum temperatures in the cylindrical shells and head that result from the 100°F ambient temperature case with maximum spent fuel decay heat and insolation. Maximum temperatures and corresponding material S_m allowables and ultimate tensile strengths are given below:

Component	Temperature °F	Titanium S_m	Allowable (ksi) S_u
Inner Shell	275	27.05	73.8
Outer Shell	240	27.96	76.32
Heads	200	29.0	79.2

The stresses that result from the Maximum Normal Operating Pressure (MNOP) are ignored in the evaluation of the one-foot drop conditions because they are so small.

A comparison of actual stresses and allowable stresses for the major components of the cask for the one-foot end drop is given in Table 2.6-2. The results show that allowables are not exceeded anywhere except for the top closure. This analysis is very conservative, and a more detailed analysis of the head should show that it will meet design allowables.

Table 2.6-2

Stress Results for One-foot Flat End Drop

	SCANS Stress (psi)	Corrected Stress[5] (psi)	Allowable (psi)
Inner Shell			
Axial + Bending[1]	15,050	--	40,575
Shear[2]	15,050	--	16,230
Outer Shell			
Axial + Bending[3]	15,050	--	58,800
Shear[4]	15,050	--	35,280
Bottom End Cap			
Bending[3]	18,039	24,786	61,600
Shear[4]	8,317	8,548	36,960
Top Closure			
Bending[1]	18,039	46,123[6]	43,500
Shear[2]	8,317	7,770	17,400

Notes

(1) Allowable = 1.5 S_m

(2) Allowable = 0.6 S_m

(3) Allowable = 1.0 S_y

(4) Allowable = 0.6 S_y

(5) See discussion in Section 2.7.1.1

(6) Slightly over allowable. Very conservative analysis. More detailed analysis should show positive margin of safety

2.6.7.2 Side Drop Analysis

Cask Analysis

Analysis of the cask during the one-foot side drop is based on the impact decelerations, forces and stresses obtained from the SCANS analysis for the 0° cask orientation. Table 2.6-1 provides a summary of these results. The maximum deceleration of the cask for the side drop is 15.0 g's and the impact limiter is crushed 1.5 inches. Comparing the forces and moments between the quasi-static and dynamic analyses gives a dynamic load factor (DLF) of 1.02. This DLF will be used in the design evaluation of the cask baskets.

This test is assumed to occur at maximum Operating Condition temperatures. A comparison of actual stresses and allowable stresses for the major components of the cask for the one-foot side drop is given in Table 2.6-3. The results show that the allowables are easily met everywhere. The minimum margin of safety for any component is,

$$M.S. = \frac{16,230}{8146} - 1 = +0.99$$

Fuel Basket Behavior

Fuel basket behavior under side drop Hypothetical Accident Conditions is summarized in Section 2.7.1.2. Normal Condition assessments are based upon extrapolations of these values. The structural evaluation for both the 3 PWR and 7 BWR Fuel Baskets during the 30 foot side drop accident is presented in Appendix 2.10.4.

Under Normal Conditions, the maximum side impact acceleration predicted by SCANS is 15.0 g's. To be conservative, the SCANS g-loading of 18.4 g's obtained for the 15° oblique drop will be used for the basket analysis. This maximum g-loading occurs when the cask is essentially horizontal, so the basket probably will experience this load also. The DLF of 1.02 obtained for the normal side drop of 1 foot will be used to scale up the g-loading obtained from SCANS.

Table 2.6-3

Stress Results for One-foot Side Drop

	SCANS Stress (psi)	Corrected Stress (1) (psi)	Allowable (psi)
Inner Shell			
Axial + Bending	12,762	--	40,575
Shear	8,146	--	16,230
Outer Shell			
Axial + Bending	16,764	--	58,800
Shear	8,146	--	35,280
Bottom End Cap			
Bending	Small	--	61,600
Shear	Small	--	36,960
Top Closure			
Bending	Small	--	43,500
Shear	Small	--	17,400

Notes

(1) See discussion in Section 2.7.1.1

The 3 PWR fuel baskets had a maximum adjusted membrane plus bending stress of 100,728 psi at 100 g's for the Hypothetical Accident Condition per Section 2.7.1.2. For the Normal Condition, this stress is:

$$S_{18.4} = [(1.02)(18.4)/100] \times 100,728 = 18,905 \text{ psi}$$

The allowable stress for Type 316N stainless steel at 375°F under Normal Conditions is 34,950 psi (membrane plus bending). The margin of safety (M.S.) for the 3 PWR fuel basket under Normal Conditions is:

$$M.S. = [(34,950/18,905 -1] = + 0.85$$

The 7 BWR fuel basket had a maximum adjusted membrane plus bending stress of 106,064 psi at 100 g's for the Hypothetical Accident Condition per Section 2.7.1.2. For the Normal Condition, this stress is:

$$S_{18.4} = [(1.02)(18.4)/100] \times 106,064 = 19,907 \text{ psi}$$

The allowable stress for Type 316N stainless steel at 450° under Normal Conditions is 33,600 psi (membrane plus bending). It is assumed that the BWR basket will experience higher temperature than the PWR basket or 450°F. The margin of safety for the 7 BWR fuel basket under Normal Conditions is:

$$M.S. = [(33,600/19,907) - 1] = +0.69$$

The maximum thermal stress for the 3 PWR fuel basket was 8717 psi at the mid panel per Appendix 2.10.4. The stress criteria for Normal Conditions are:

$$P_m + P_b + Q \leq 3\ S_m$$

For the 30 foot side drop accident, $(P_m + P_b)$ at the mid panel was 92,358 psi at 100 g's.

During a normal 1 foot drop, the maximum ($P_m + P_b$) stress at the mid panel is:

$$P_m + P_b = [\frac{1.02 \times 18.4}{100}] \times 92,358 = 17334 \text{ psi at normal conditions}$$

$$S_m = 23,300 \text{ psi for 316 stainless steel at 375°F}$$

$$3\ S_m = 69,900 \text{ psi allowable stress at 375°F}$$

$$P_m + P_b + Q = 17,334 + 8717 = 26,051 \text{ psi} < 69,900 \text{ psi}$$

Therefore, the primary membrane plus bending stress plus thermal stress is less than the allowable. The margin of safety for the 3 PWR fuel baskets is:

$$M.S. = [\frac{69,900}{26,051} - 1] = +1.68$$

2.6.7.3 Corner Drop

The cask was evaluated for the one-foot drop where the center of gravity (C.G.) of the cask is over the corner of impact. The orientation of the cask for this condition is at 80.7° from horizontal. The results for this test condition were obtained from a SCANS analysis and the results are summarized in Table 2.6-1. The maximum deceleration of the cask for this condition is 12.3 g's and the impact crush of the impact limiter honeycomb is 2.4 inches.

This condition is assumed to occur at maximum operating condition temperatures and the stresses are calculated using the results from SCANS. A comparison of actual stresses and allowable stresses for the major structural components of the cask is given in Table 2.6-4. The results show that allowables are met everywhere in the cask for this normal drop condition. The minimum margin of safety for any of the structural components is:

$$M.S. = \frac{17,400}{7,770} - 1 = +1.24$$

Table 2.6-4

Stress Results for One-foot C. G. Over Corner Drop

	SCANS Stress (psi)	Corrected Stress(1) (psi)	Allowable (psi)
Inner Shell			
Axial + Bending	10,778	--	40,575
Shear	4,474	--	16,230
Outer Shell			
Axial + Bending	12,928	--	58,800
Shear	4,474	--	35,280
Bottom End Cap			
Bending	1,058	1,454	61,600
Shear	488	1,393	36,960
Top Closure			
Bending	1,058	2,705	43,500
Shear	8,317	7,770	17,400

<u>Notes</u>

(1) See discussion in Section 2.7.1.1

2.6.7.4 Oblique Drops

Analytical predictions of package performance for oblique drop orientations were made with the SCANS computer program. In Section 2.7.1.4, oblique 30-foot drop orientations of 15°, 30°, 45°, 60°, and 75° from the horizontal were considered. The orientation that gave the highest loads and stresses on the cask was the 15° orientation. Therefore, for the one-foot drop condition only the 15° orientation was considered.

Impact decelerations, forces and stresses for the 15° orientation drop were obtained from SCANS analysis. The results from this analysis are summarized in Table 2.6-1. This condition is assumed to occur at maximum Operating Condition temperatures. A comparison of actual stresses and allowable stresses for the major structural components of the cask for the 15° oblique drop is given in Table 2.6-5. The results show that the shear stresses in the inner and outer shell are relatively high, but there is still a positive margin of safety, or

$$M.S. = \frac{16,230}{13,951} - 1 = + 0.16$$

2.6.7.5 Summary of Results

As evidenced by the preceding evaluation, the major structural members of the cask can withstand the primary stresses that result from the one-foot free drop normal test condition. For this preliminary design phase, the cask cylindrical shells, bottom head assembly, closure head, and fuel baskets have been evaluated against the primary stress limits of the cask structural design criteria.

To obtain the primary plus secondary stresses, the maximum drop condition primary stresses will be combined with the thermal stresses given in Section 2.6.1. From the analysis of the various 1 foot drop accidents, the maximum absolute value of the primary membrane plus bending stress ($P_m + P_b$) occurs during the 15° oblique angle drop. The maximum outer shell membrane

Table 2.6-5
Stress Results for One-foot Oblique Drop

	SCANS Stress (psi)	Corrected Stress[1] (psi)	Allowable (psi)
Inner Shell			
Axial + Bending	21,548	--	40,575
Shear	13,951	--	16,230
Outer Shell			
Axial + Bending	28,278	--	58,800
Shear	13,951	--	35,280
Bottom End Cap			
Bending	1,203	1,653	61,600
Shear	348	358	36,960
Top Closure			
Bending	1,203	3,076	43,500
Shear	348	325	17,400

Notes
(1) See discussion in Section 2.7.1.1

plus bending stress is 28,278 psi. The maximum inner shell membrane plus bending stress is 21,548 psi. The allowable stress criterion for combining primary plus secondary stresses for the Normal Condition is:

$P_m + P_b + Q < 3S_m$ for inner shell
$P_m + P_b + Q <$ Large of $3\ S_m$ or $2\ S_y$ for outer shell

For the inner shell at 275°F, S_m is 27,050 psi. For conservatism, it is assumed that the thermal stress (Q) and ($P_m + P_b$) have the same sign. The total stress and allowable for the inner shell is:

$$21{,}548 + 1{,}074 = 22{,}622 < 3S_m$$
$$3S_m = 81{,}150 \text{ psi}$$

$$\text{M.S.} = [\frac{81{,}150}{22{,}622} - 1] = +\ 2.59$$

For the outer shell at 240°F, S_y = 58,800 psi. The total stress and allowable stress for the outer shell is:

$$28{,}278 + 327 = 28{,}605 < 2S_y$$
$$2S_y = 117{,}600 \text{ psi}$$

$$\text{M.S.} = [\frac{117{,}600}{28{,}605} - 1\ ] = +\ 3.11$$

2.6.8 Corner Drop

This requirement or test given in Paragraph 71.71(c)(8) of 10 CFR Part 71 does not apply to the LWT cask, since the package weight is in excess of 100 kg (220 lbs) and the materials of construction do not include wood or fiberboard.

2.6.9 Compression

This requirement or test given in Paragraph 71.71(c)(9) of 10 CFR Part 71 does not apply to the LWT cask, since the package weight is in excess of 5,000 kg (11,000 lbs.).

2.6.10 Penetration

In accordance with Paragraph 71.71(c)(10) of 10 CFR Part 71, the cask must be evaluated for the impact of the hemispherical end of a 13 pound vertical steel cylinder, 1 1/4 inch in diameter, dropped from a height of 40 inches onto the exposed surface of the cask which is expected to be the most vulnerable to puncture. The long axis of the cylinder must be perpendicular to the cask surface at contact. As the cask is either covered by a layer of Boro-Silicone neutron shielding or the impact limiters, the consequence of the steel cylinder impacting the cask will be negligible. In addition, as described in Section 1.2 in the subsection on penetrations, the cask will have no raised local areas or exposed bolt heads that will be vulnerable to the impact of the steel cylinder.

2.7 Hypothetical Accident Conditions

The LWT cask, when subjected to the Hypothetical Accident Conditions as specified in Paragraph 71.73 of 10 CFR Part 71, must meet the performance requirements specified in Subpart E of 10 CFR Part 71. For this preliminary design phase of the cask, the performance and structural integrity of the package was assessed using analysis. The primary accident conditions of interest are the (1) free drop, (2) puncture, and (3) thermal.

The structural behavior of the package for the free drop condition was determined using the SCANS computer program. A detailed description of this program is given in Appendix 2.10.3. Several drop orientations were considered to determine the most damaging for the various cask components.

The effects of the puncture tests were considered near the point of impact and for the overall effect on the package. For the preliminary design, a punch load perpendicular to and at the center of the cask was the only case considered. Oblique orientations and impacts near penetrations, etc. will be considered in the final design phase and during design verification testing of the cask half-scale model.

The effect on the structural integrity of the cask due to any differential thermal expansions or temperature gradients due to the thermal event will be considered in the final design phase. It is believed that the effect of the fire will have negligible consequences on the cask structural integrity based on the preliminary analysis reported in Section 2.7.3.

For the final design, scale model testing will form a significant part of the Hypothetical Accident Condition evaluations. Model testing of the impact limiter will be carried out to confirm its load-deflection and energy absorption behavior. Drop and puncture testing will also be performed on a half scale model of the cask to verify that the design can withstand those accident conditions.

2.7.1 Free Drop

Subpart F of 10 CFR Part 71 requires that a 30 foot free drop be considered for the cask. The drop is to be onto a flat, essentially unyielding, horizontal surface, and the cask is to strike the surface in a position for which maximum damage is expected. The initial temperature for the drop is to be the worst case constant ambient air temperature between -20°F and 100°F. Internal heat generation from the spent fuel and insolation are also required to be considered when it is conservative to do so, in compliance with Regulatory Guide 7.8. (Note: 10 CFR Part 71 does not require consideration of insolation as an initial condition for accident conditions). Regarding initial internal pressure, the Maximum Normal Operating Pressure must be considered unless a lower internal pressure consistent with the ambient temperature assumed to proceed and follow the drop is more unfavorable.

The analysis in this section was carried out using the SCANS computer program (Reference 2.6.1). SCANS provides two approaches to impact analysis to obtain maximum responses: (1) quasi-static, and (2) a dynamic approach which uses lumped parameters and beam finite elements during impacts, and rigid-body kinematics between impacts.

SCANS gives the output described below:

- Primary and secondary impacts
- Maximum rigid body accelerations
- Maximum impact force/moment
- Maximum impact limiter crush
- Maximum stresses
  - o Cask Body
  - o End Caps
  - o Closure Bolts

The dynamic and quasi-static analysis results can be compared to obtain the dynamic amplification factor. For the quasi-static analysis, the cask is treated as a rigid body and the maximum stresses occur in a quasi-static phase.

The following assumptions and limitations are applicable to the SCANS' quasi-static analysis:

- o Assumptions/approximations
  - Cask behaves like a rigid beam
  - Impact occurs at the lowest corner of either end cap
  - The ground is rigid/unyielding
  - Impact occurs only at one end at a time; primary impact at the primary end and at initial impact angle; secondary impact at secondary end and at zero angle
  - All kinetic energy associated with cask rotation goes to secondary impact, the remainder of total impact energy to primary impact
  - Impact energy is equal to impact limiter deformation energy
  - Centrifugal force is omitted

- Limitations
  - Force, moment and stress calculations are applicable for beam-like casks
  - May be unrealistic for small impact angles
  - May need dynamic amplification factor to account for flexibility effect

- Analytical Model
  - Cask body: Rigid beam elements with lumped mass at element end
  - End caps: Lumped mass at cask ends
  - Limiters: Lumped mass at cask ends; reaction force at impact end.

For dynamic analysis, SCANS treats the cask as a lumped mass elastic beam system during impact and as rigid mass between impacts. SCANS' dynamic analysis is subject to the following assumption and limitations:

- Assumptions
  - Cask behaves like a linear elastic beam during impact and like a rigid body between impacts
  - Non-linear, plastic deformation only takes place in the impact limiters
  - Impact occurs at the lowest corner of either end cap
  - The ground is rigid/unyielding

- Limitations
  - Force, moment and stress calculations are applicable only for elastic, beam-like (large aspect ratio) casks

- Analytical Model
  - During impact:

    Cask body: Elastic beam element with lumped mass at each node
    End caps: Lumped mass at cask ends
    Impact limiters: Lumped mass at cask ends; force at impact end
    Contents: Lumped mass uniformly distributed among all nodes
  - Between impacts: Entire cask lumped as a mass at mass center.

SCANS' dynamic analysis describes all three phases of impact phenomenon; primary impact, between impacts, and secondary impact. A representation of this phenomenon is given in Figure 2.7-1. The step-by-step explanation of the analytical procedure is given below:

<u>During Primary Impact</u>

1. Start the solution for the primary impact at t=0, when the cask just touches the ground, establish initial position and kinematic conditions of cask model for primary impact.

2. Using the force-deflection relation of the impact limiter and of the beam elements, find the internal and external forces applied on each lumped mass and establish the equation of motion of the mass.

3. Using the central difference technique, numerically integrate the equation of motion to find the displacement of the mass at the next time step.

4. Repeat Steps 2 and 3 for all mass points.

5. Repeat Steps 2 through 4 for all time steps.

6. Terminate solution when the primary impact is complete.

<u>Between Primary and Secondary Impact</u>

7. Change the cask model to a rigid mass located at the mass center. Find the displacement of the cask at different times until the secondary impact occurs.

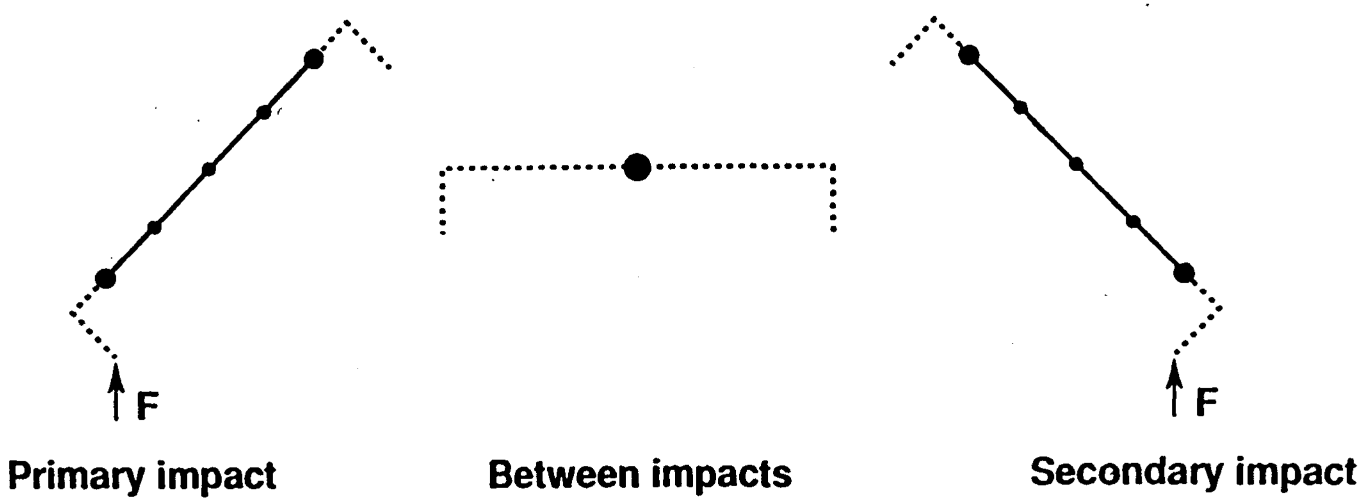


Figure 2.7-1. SCANS Description of the Three Phases of Impact

During Secondary Impact

8. Resume the dynamic solution (Steps 1-6) for the secondary impact until the impact is complete.

An accurate definition of the earlier phases of the impact require a small element size.

The SCANS results provide forces and moments over a cross-section normal to the cask centerline at the nodes along the length of the cask. Bending stresses are calculated assuming a layer-composite beam.

A lumped mass representation of a typical cask is shown in Figure 2.7-2. A rigid link is added to the model at both the top and bottom ends of the cask to represent the thickness and radius of the closures. The impact limiters are represented by non-linear, force-deflection curves applied at impact points.

For the SCANS analysis of the cask, the idealized representation shown in Figure 2.7-3 was used. The total thickness of the closure heads is used to establish the rigid link lengths and the location of the impact points. The weight of the Boro-Silicone neutron shielding on the cylindrical portion of the cask is added on to the contents weight in order to get a better distribution of weight along the length of the model. Thirteen elements were used along the length of the cask. The force-deflection curves used to represent the impact limiters are given in Section 2.3 of this report. Material properties at 70°F were used in the dynamic analysis.

A summary of the SCANS model imput for the LWT cask is given in Table 2.7-1. This table provides the geometry of the cask, impact limiter weights, cask construction and material properties.

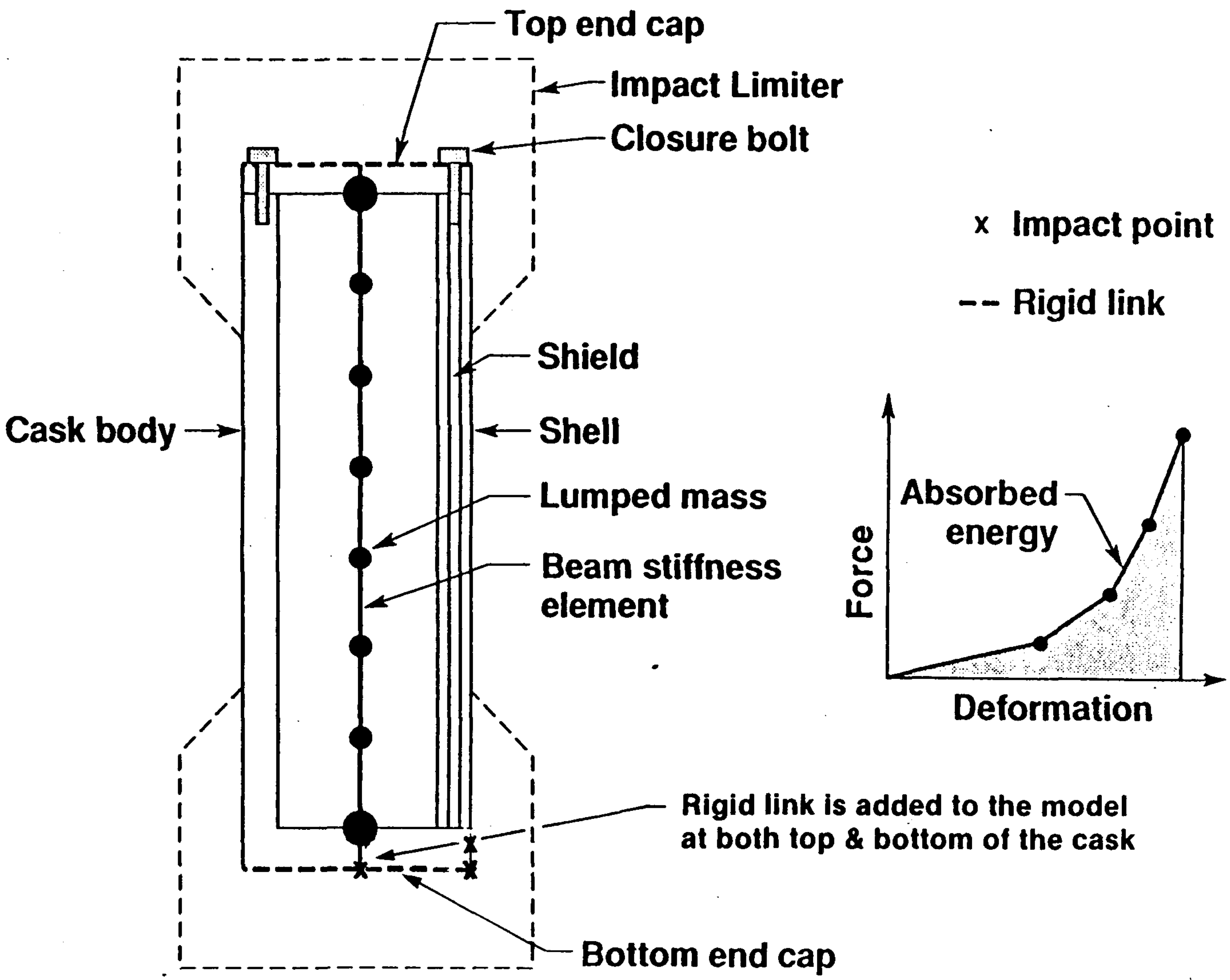


Figure 2.7-2. Lumped Model of a Cask

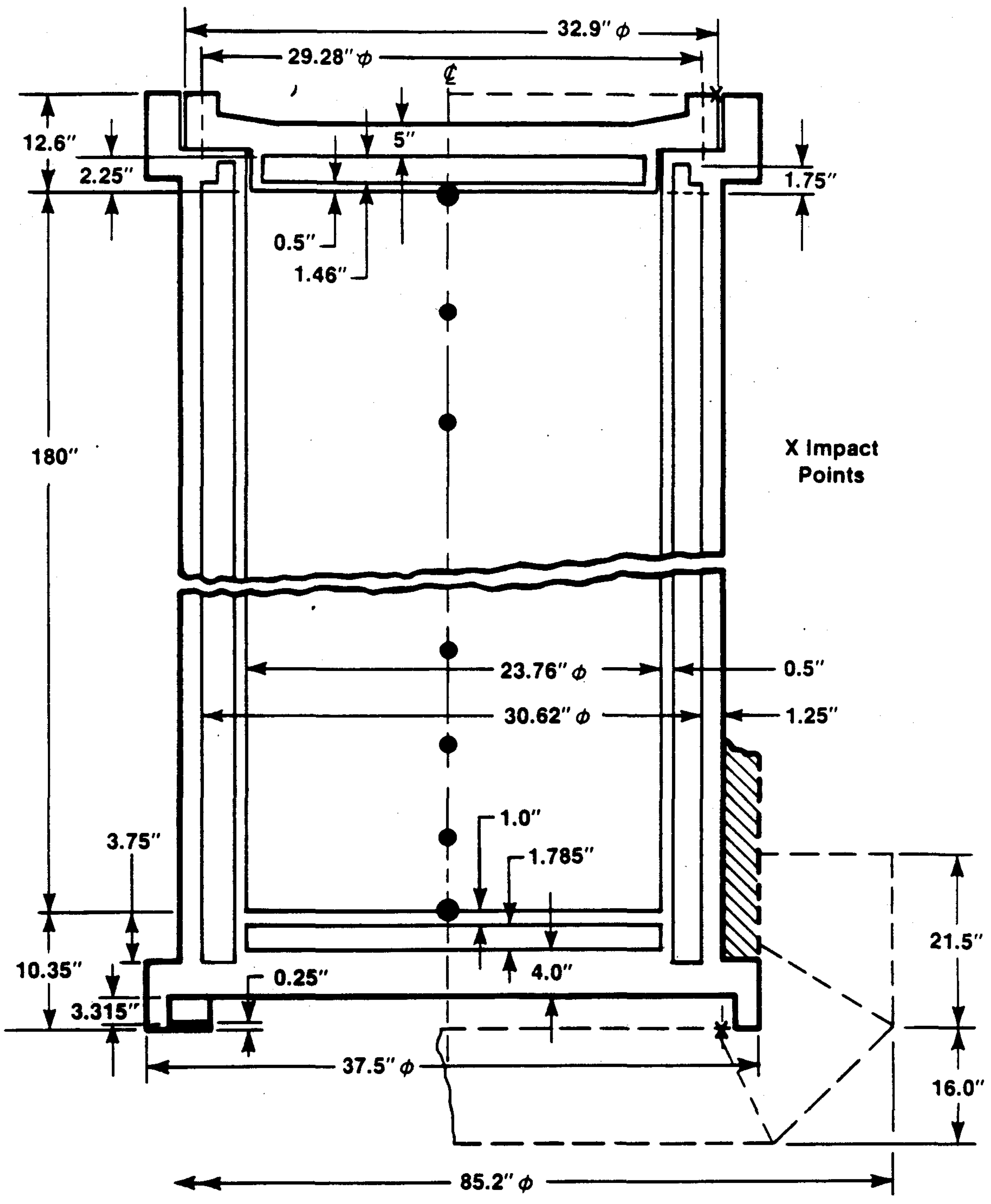


Figure 2.7-3. SCANS Model of the TITAN LWT Cask

Table 2.7-1

SCANS Model Input for the TITAN LWT Cask

CASK GENERAL DIMENSIONS AND SPECIFICATIONS

Cavity inner radius:	11.880 inches
Cavity length:	180.000 inches
Cask body outer radius:	16.560 inches
Cask body length:	202.950 inches

Top impact limiter	is	included in model
Bottom impact limiter	is	included in model
Neutron shield	is not	included in model
Water jacket	is not	included in model

Contents maximum heat generation rate: .00 Btu/minute

Temperature defining stress free condition: 70. degrees F

Initial cavity charge pressure:	14.70 psia
Initial cavity charge temperature:	70.00 degrees F
Maximum normal operating pressure:	50.00 psia

CASK WEIGHTS (By component)

Gross package:	54000. lbs	
Contents/internals:	11076. lbs	
Top impact limiter:	1250. lbs	
Bottom impact limiter:	1250. lbs	
Cask shell / end caps:	40424. lbs	Gross wt - (Contents+Limiters)
Top end cap:	2124. lbs	
Bottom end cap:	1881. lbs	
Shell:	36419. lbs	

Table 2.7-1 (Continued)

SCANS Model Input for the TITAN LWT Cask

CASK SHELL DESCRIPTION

Layer	Material Name	Thickness Inches	Inner Radius Inches	Outer Radius Inches	X-section Area Sq Inches
Inner Shell	TIGR9	.500	11.880	12.380	38.108
Shield	DU	2.930	12.380	15.310	254.883
Outer Shell	TIGR9	1.250	15.310	16.560	125.153
	Total Thickness	4.680		Total Area	418.144

Inner Shell additional thickness at end cap interface: .000 inches
Outer Shell additional thickness at end cap interface: 2.190 inches

Shield height: 186.000 inches

TOP END CAP DESCRIPTION

Layer	Material Name	Thickness Inches
Inner Layer	TIGR9	.500
Shield	DU	1.460
Outer Layer	TIGR9	10.640
	Total thickness	12.600

Shield radius: 11.900 inches

BOTTOM END CAP DESCRIPTION

Layer	Material Name	Thickness Inches
Inner Layer	TIGR9	1.000
Shield	DU	1.785
Outer Layer	TIGR9	7.565
	Total thickness	10.350

Shield radius: 11.900 inches

Table 2.7-1 (Continued)

SCANS Model Input for the TITAN LWT Cask

MATERIAL PROPERTIES

This model uses 3 different materials

TIGR9 (TI GR 9)

Used in: Shell inner layer
Shell outer layer
Top end cap inner layer
Top end cap outer layer
Bottom end cap inner layer
Bottom end cap outer layer

Impact Young's Modulus: 1.500E+07 psi
Impact Poisson's ratio: .3000

Density: .1620 lb/cu.inch

Temp F	Thermal Conductivity BTU/in min F	Specific Heat Capacity BTU/lbm F	Young's Modulus psi	Poisson's Ratio	Coefficient of Thermal Expansion in/in F
-50.	.006100	.1300	1.500E+07	.3000	5.340E-06
68.	.006100	.1300	1.500E+07	.3000	5.340E-06
100.	.006200	.1310	1.475E+07	.3000	5.340E-06
200.	.006500	.1340	1.450E+07	.3000	5.340E-06
400.	.007400	.1400	1.240E+07	.3000	5.370E-06
800.	.009900	.1600	9.500E+06	.3000	5.510E-06
1200.	.012900	.1800	9.500E+06	.3000	5.510E-06
1600.	.012900	.1800	9.500E+06	.3000	5.510E-06

Table 2.7-1 (Continued)

SCANS Model INPUT for the TITAN LWT Cask

DU (Uranium)

Used in: Shell shield layer
Top end cap shield layer
Bottom end cap shield layer

Impact Young's Modulus: 2.775E+04 psi
Impact Poisson's ratio: .2100
Impact Yield Stress : 4.300E+03 psi
Impact Plastic Modulus: 2.400E+03 psi

Density: .6790 lb/cu.inch

Temp F	Thermal Conductivity BTU/in min F	Specific Heat Capacity BTU/lbm F	Young's Modulus psi	Poisson's Ratio	Coefficient of Thermal Expansion in/in F
-50.	.012800	.0280	2.500E+05	.2100	8.230E-06
68.	.012800	.0280	2.500E+05	.2100	8.230E-06
200.	.012800	.0294	2.500E+05	.2100	8.230E-06
300.	.012800	.0305	2.500E+05	.2100	8.500E-06
400.	.012800	.0316	2.500E+05	.2100	8.750E-06
600.	.012800	.0316	2.500E+05	.2100	8.750E-06
800.	.012800	.0316	2.500E+05	.2100	8.750E-06
1200.	.012800	.0316	2.500E+05	.2100	8.750E-06

POLYFOAM (Polyfoam)

Used in: Top impact limiter
Bottom impact limiter

Density: .0116 lb/cu.inch

Temp F	Thermal Conductivity BTU/in min F	Specific Heat Capacity BTU/lbm F
-58.	.000278	.3000
68.	.000278	.3000
1300.	.000278	.3000

Table 2.7-1 (Continued)

SCANS Model INput for the TITAN LWT Cask

IMPACT MODEL DESCRIPTION

Nodal masses and shell stiffness values

Node Number	Position inches	Translational Mass lb-sec**2/in	Rotational Mass lb-sec**2-in	lbs	lb-in**2
1 BOT	0.	12.	3755.		
2	15.	8.	780.	2.456E+09	2.815E+11
3	30.	8.	780.	2.456E+09	2.815E+11
4	45.	8.	780.	2.456E+09	2.815E+11
5	60.	8.	780.	2.456E+09	2.815E+11
6	75.	8.	780.	2.456E+09	2.815E+11
7	90.	8.	780.	2.456E+09	2.815E+11
8	105.	8.	780.	2.456E+09	2.815E+11
9	120.	8.	780.	2.456E+09	2.815E+11
10	135.	8.	780.	2.456E+09	2.815E+11
11	150.	8.	780.	2.456E+09	2.815E+11
12	165.	8.	780.	2.456E+09	2.815E+11
13 TOP	180.	13.	3915.		

Shell areas and inertias for nodes 2 through 12

Layer	Area in**2	Moment of Inertia in**4
Inner Shell	38.11	2805.
Shield	254.88	24702.
Outer Shell	125.15	15914.

For the 30 foot drop, quasi-static and dynamic SCANS analyses were completed for the 0°, 15°, 30°, 45°, 60°, 75°, C.G. over corner, and 90° cask orientations (the cask is horizontal at 0°), respectively. A summary of these analyses results is provided in Table 2.7-2. In all these cases, the bottom of the cask is assumed to contact the ground first. Maximum crush of the impact limiter, g-loads, axial force, shear load, bending moment, and stress intensity for the cask are provided in the table for both the primary and secondary impacts. For the shallow angle drops (15° and 30°), the results for the quasi-static analyses are questionable because of the limitations of the program and will not be used. Also for the shallow angle drops, because both ends of the cask can be in contact with the ground simultaneously, the maximum results reported for primary impact may actually be occurring during the secondary impact.

2.7.1.1 Flat End Drop

Cask Analysis

Analysis of the cask during the end drop is based on the impact decelerations, forces, and stresses obtained from the SCANS analysis for the 90° cask orientation. Table 2.7-2 provides a summary of these results.

SCANS provides stresses in the cask cylindrical shell as depicted in Figure 2.7-4. The cask body is treated as a composite beam, and stresses are calculated for the inner shell, shielding layer and outer shell. The stresses are calculated using the approach and equations given in Figure 2.7-5. Stresses in the shield are negligible because the modulus of elasticity of the depleted uranium is taken at a low value to ensure that the shielding does not contribute to the overall strength of the cask.

The calculation of stresses in the bottom and top closure by SCANS is as depicted in Figure 2.7-6. The bottom end head assembly is treated as a fixed end circular plate while the top closure is modeled as a simply-supported circular plate. The loading on end closures includes the inertia load of the

Table 2.7-2
Summary of SCANS Results for 30 Foot Drops

	Parameter	Type of Analysis	0	15	30	45	60	75	C.G.	90
Primary Impact	Crush (in)	Dynamic	11.2	11.7	10.6	9.0	9.6	11.5	10.9	6.3
		quasi-static	11.3	11.3	12.9	11.6	11.0	11.5	10.8	6.2
		Dyn/q-static	0.99	1.04	0.82	0.78	0.87	1.00	1.01	1.02
	g's	Dynamic	49.5	51.2	26.2	33.2	43.4	69.7	63.5	73.0
		quasi-static	49.7	22.9	31.3	37.5	45.7	70.0	63.2	72.7
		Dyn/q-static	1.00	2.24	0.84	0.89	0.95	1.00	1.00	1.00
	Max. Axial Force (kips)	Dynamic	24.3	-224.3	-669.1	-1238.6	-2014.5	-3674.1	-3443.8	-4415.3
		quasi-static	0.0	-333.5	-872.7	-1468.4	-2184.6	-3702.9	-3421.8	-3979.2
		Dyn/q-static	n/a	0.67	0.77	0.84	0.92	0.99	1.01	1.11
	Max. Shear Force (kips)	Dynamic	1365.7	-1592.8	1309.5	1371.7	1299.3	1035.3	537.1	0.0
		quasi-static	1368.7	1244.6	1511.5	1468.4	1261.3	992.2	562.4	0.0
		Dyn/q-static	1.00	-1.28	0.87	0.93	1.03	1.04	0.96	n/a
	Max. Moment (in-kips)	Dynamic	83411.9	89624.7	30199.2	30849.9	-21727.5	-51007.3	-51730.5	0.0
		quasi-static	61981.6	32808.0	34290.5	26480.1	-23820.3	-51347.6	-50844.5	0.0
		Dyn/q-static	1.35	2.73	0.88	1.17	0.91	0.99	1.02	n/a
	Max. Stress Intensity (ksi)	Dynamic	70.927	76.336	27.833	30.269	29.684	63.703	63.174	26.966
		quasi-static	52.635	29.182	32.578	27.852	32.308	64.080	62.092	22.003
		Dyn/q-static	1.35	2.62	0.85	1.09	0.92	0.99	1.02	1.23
Secondary Impact	Crush (in)	Dynamic	11.2	13.2	13.3	12.5	12.7	n/a	n/a	n/a
		quasi-static	11.2	13.8	12.4	10.4	8.4	7.1	n/a	n/a
		Dyn/q-static	1.00	0.96	1.07	1.20	1.51	n/a	n/a	n/a
	g's	Dynamic	49.5	51.2	26.9	26.1	24.0	n/a	n/a	n/a
		quasi-static	49.7	27.5	25.9	23.1	20.3	18.5	n/a	n/a
		Dyn/q-static	1.00	1.86	1.04	1.13	1.18	n/a	n/a	n/a
	Max. Axial Force (kips)	Dynamic	24.3	151.5	154.5	-170.3	-318.4	n/a	n/a	n/a
		quasi-static	0.0	0.0	0.0	0.0	0.0	n/a	n/a	n/a
		Dyn/q-static	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Max. Shear Force (kips)	Dynamic	1365.7	-1592.8	-1503.4	-1457.9	-1315.7	n/a	n/a	n/a
		quasi-static	1368.7	-1537.0	-1452.3	-1301.0	-1149.4	-1054.7	n/a	n/a
		Dyn/q-static	1.00	1.04	1.04	1.12	1.14	n/a	n/a	n/a
	Max. Moment (in-kips)	Dynamic	83411.9	89624.7	54443.9	51684.2	37817.5	n/a	n/a	n/a
		quasi-static	61981.6	47129.0	44533.2	39892.4	35243.3	32339.1	n/a	n/a
		Dyn/q-static	1.35	1.90	1.22	1.30	1.07	n/a	n/a	n/a
	Max. Stress Intensity (ksi)	Dynamic	70.927	76.336	45.737	43.772	32.422	n/a	n/a	n/a
		quasi-static	52.635	40.022	37.818	33.877	29.929	27.463	n/a	n/a
		Dyn/q-static	1.35	1.91	1.21	1.29	1.08	n/a	n/a	n/a

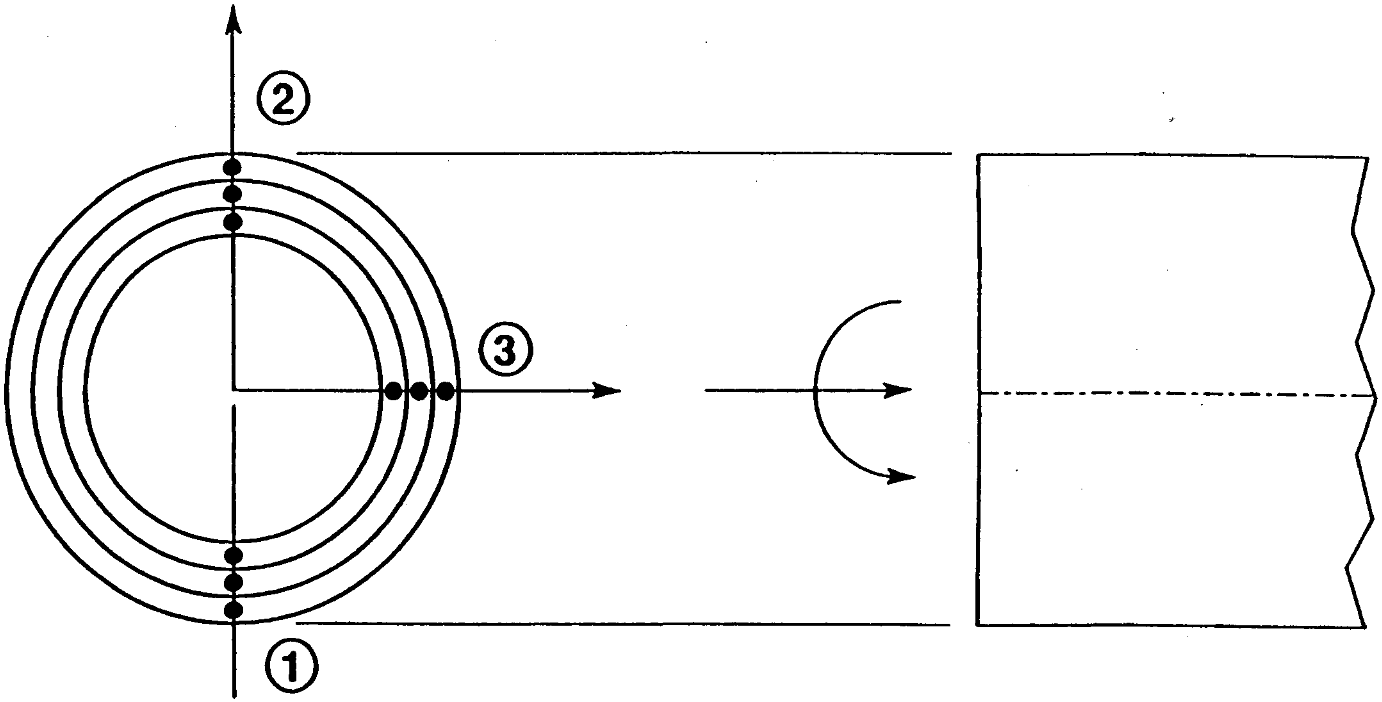
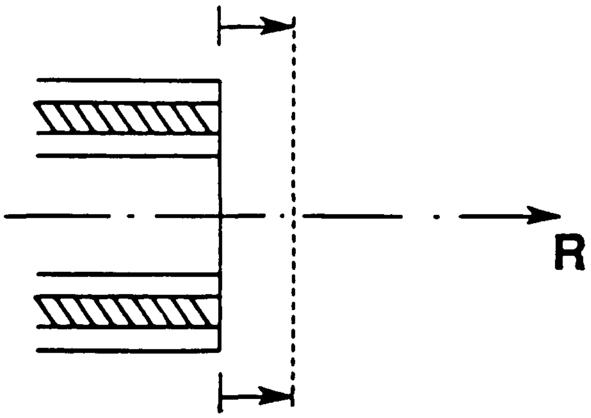


Figure 2.7-4. Stress Calculation Locations for Cask Cylindrical Shell

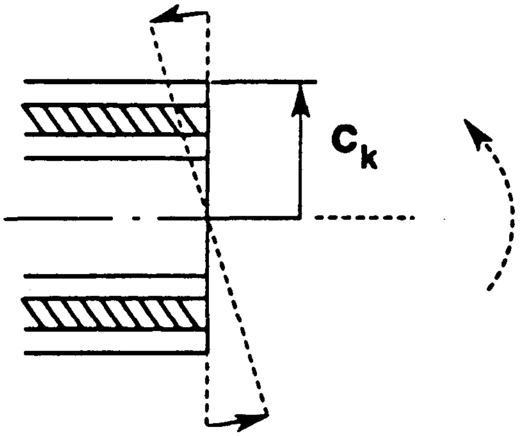
(1) Axial Stress



$$AE = \sum_{k=1,3} A_k E_k$$

$$(\sigma_a)_k = \frac{RE_k}{AE}$$

(2) Bending Stress



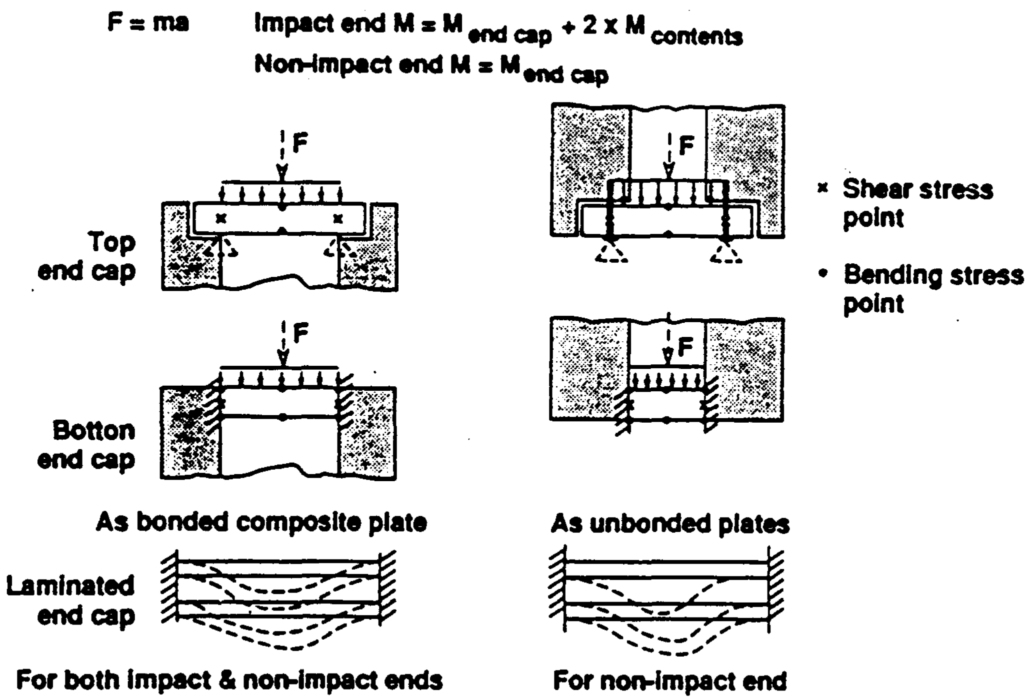
Cross-section remains plane

$$EI = \sum_{k=1,3} E_k I_k$$

$$(\sigma_b)_k = \pm \frac{Mc_k E_k}{EI}$$

$$(\sigma_s)_k = \frac{2VE_i}{AE}$$

Figure 2.7-5. Procedure for Stress Calculations



Notes:

(1) Impact end — always treated as bonded

(2) Non-impact end — worst of bonded and unbonded conditions considered

Figure 2.7-6. Treatment of Stresses in End Caps closure itself and impact load of the contents on the closure. A dynamic load factor of 2 is applied to the g-loading of the contents to account for the sudden impact of contents on the closure. The distributed loading of the impact limiter on the closure head is not considered by SCANS, and will be treated separately by another analysis. For the analysis of the cask, free drops were always considered with the bottom of the cask contacting the unyielding surface first. The loads in the bottom head will be used to estimate bending stresses in the closure head if the closure end was to contact first during the free drops. Secondly, the SCANS calculated stresses in the heads will be corrected to account for the actual head thickness. The SCANS model used increased head thicknesses in order to obtain the correct length of the cask for the impact analysis. Stresses will be estimated by ratioing the squares of the head thicknesses.

The impact analyses were carried out using room temperature values of the modulus of elasticity. However, the calculated stresses will be compared to the allowables at maximum temperatures in the cylindrical shells and heads that result from the 100°F ambient temperature case with maximum spent fuel decay heat and insolation. MNOP stresses are ignored because they are relatively small. Section 3.0 of this report lists these maximum temperatures. The maximum temperatures are given below with the corresponding S_m allowable and ultimate tensile strength for Grade 9 titanium material.

Component	Temperature °F	Grade 9 Titanium Allowable (ksi) S_m	S_u
Inner Shell	275	27.05	73.8
Outer Shell	240	27.96	76.32
Heads	200	29.0	79.2

A comparison of actual stresses and allowable stresses for the major components of the cask for the end drop is given in Table 2.7-3. The results show that allowables are met everywhere except for the top closure. This analysis is very conservative, and a more detailed analysis of the head is reported in the next subsection of this report.

Detailed Head Closure Analysis

When the fully loaded cask drops on its top end, the closure lid must remain in contact with the flange, for both the 1 foot normal condition drop as well as the 30 foot hypothetical accident condition 30' drop. If the closure lid separates from the flange, then the containment will be compromised. To investigate the behavior of the closure lid and the closure lid-to-flange interface, an analysis of the upper end of the cask was performed using the WECAN finite element program (Reference 2.7.1). An axisymmetric WECAN model of the upper end was generated (see Figure 2.7-7) using an interactive graphics program, FIGURES II (Reference 2.7.2). The model used an earlier configuration of the closure head that was not fully recessed. For the final design, the model will be updated to represent the correct design. However, the analysis and results presented here are representative of what is expected for the final design. The closure lid, flange, cask inner and outer shells and closure bolts were modeled using 2-D isoparametric quads and triangles. The equivalent stiffnesses of the bolt hole regions in the closure lid and flange, and of the bolt were accounted for by modeling each item as equivalent rings. The equivalent load carrying area of the bolt hole region was used in conjunction with the geometrical properties of the closure lid and flange to determine the equivalent stiffness of the axisymmetric model. For the equivalent stiffness development, the radial, axial and hoop modulii of the bolt hole region in the closure lid and flange were modified. As superposition of ligament and bolt rings was possible with WECAN, equivalent ligament ring properties and equivalent bolt head ring properties were calculated.

The interface between the closure lid and flange was modeled using WECAN 2-D friction interface elements. To approximate correct boundary conditions and compute appropriate reactions in the model, WECAN 2-D spring elements were used at end of the model of the cask inner and outer shells.

Table 2.7-3

Stress Results for 30 Foot End Drop

	SCANS Stress (psi)	Corrected Stress (psi)	Allowable (psi)
Inner Shell			
Axial + Bending(1)	26,966	--	73,800
Shear(2)	26,966	--	30,996
Outer Shell			
Axial + Bending(3)	26,966	--	76,320
Shear(4)	26,966	--	35,280
Bottom End Cap			
Bending(3)	34,661	47,624	79,200
Shear(4)	15,981	16,425	36,960
Top Closure			
Bending(1)	34,661	88,622(5)	79,200
Shear(2)	15,981	14,929	33,264

Notes:

(1) Allowable = S_u

(2) Allowable = 0.42 S_u

(3) Allowable = S_u

(4) Allowable = 0.6 S_y

(5) Exceeds allowable

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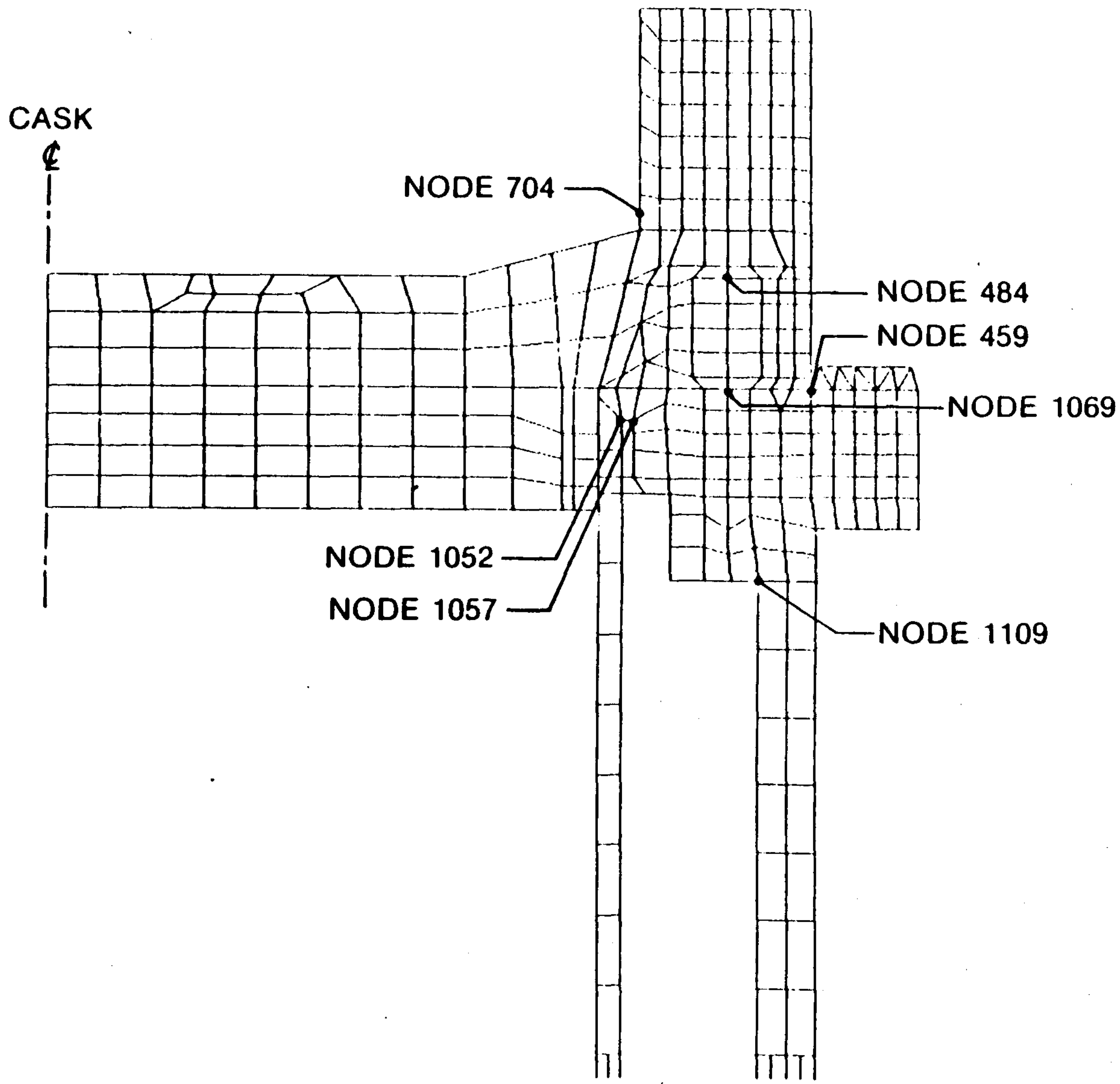


Figure 2.7-7. WECAN Axisymmetric Model of Upper End Identifying Elements

The preload was applied to the bolt ring by effectively cutting the ring near its center and applying a tensile traction to each bolt ring half, equal to the desired preload stress. This was accomplished by making one row of dummy elements at the center of the bolt ring. A negative pressure was applied to the two transverse 'free' surfaces on either side of the row containing the dummy elements.

For the analysis of the Hypothetical Accident load case, the axisymmetric model was subjected to internal, distributed axial loads due to the weight of the fuel basket, fuel assemblies, DU, Boro-Silicone etc. and the 73 g deceleration loading, and an internal pressure of 35 psi (MNOP). The impact limiter reactive force was modeled as an external, distributed axial force on the closure head and cask flange. For the final analysis, the affect of loading through the Boro-Silicone between the impact limiter and closure head will be included in the analysis.

The calculated stresses were compared to allowable stresses for Grade 9 titanium (cask body and closure head) and Alloy 718 (closure bolt). The allowable stresses for the titanium alloy were taken from Appendix 2.10.5 and from ASME B&PV Code Section III, Division I Appendix for the Alloy 718.

The results of the analysis were obtained in the form of deformed geometry plots and stress contour plots; stresses SXX (radial), SYY (cask axial), SZZ (cask circumferential) and SINT (stress intensity). The Design Requirements Document (Reference 2.7.3) specifies allowable stresses for several stress categories. The two stress categories applicable to the analysis performed are: (a) the general primary membrane stress intensity (P_m) and (b) the local primary membrane plus primary bending stress intensity ($P_L + P_b$). The stress intensity (SINT) from the stress contour plot can be directly compared with $P_L + P_b$. Therefore, the stress intensity values (from the stress contour plots and associated post processed stress output data) were carefully determined and compared with ($P_L + P_b$) allowables to evaluate the stresses in the closure lid, closure lid ligament, flange, flange ligament, inner shell, outer shell and preloaded closure bolts.

The deformed geometry plots and stress intensity stress contour plots are shown in Figures 2.5-8 thru 2.5-12.

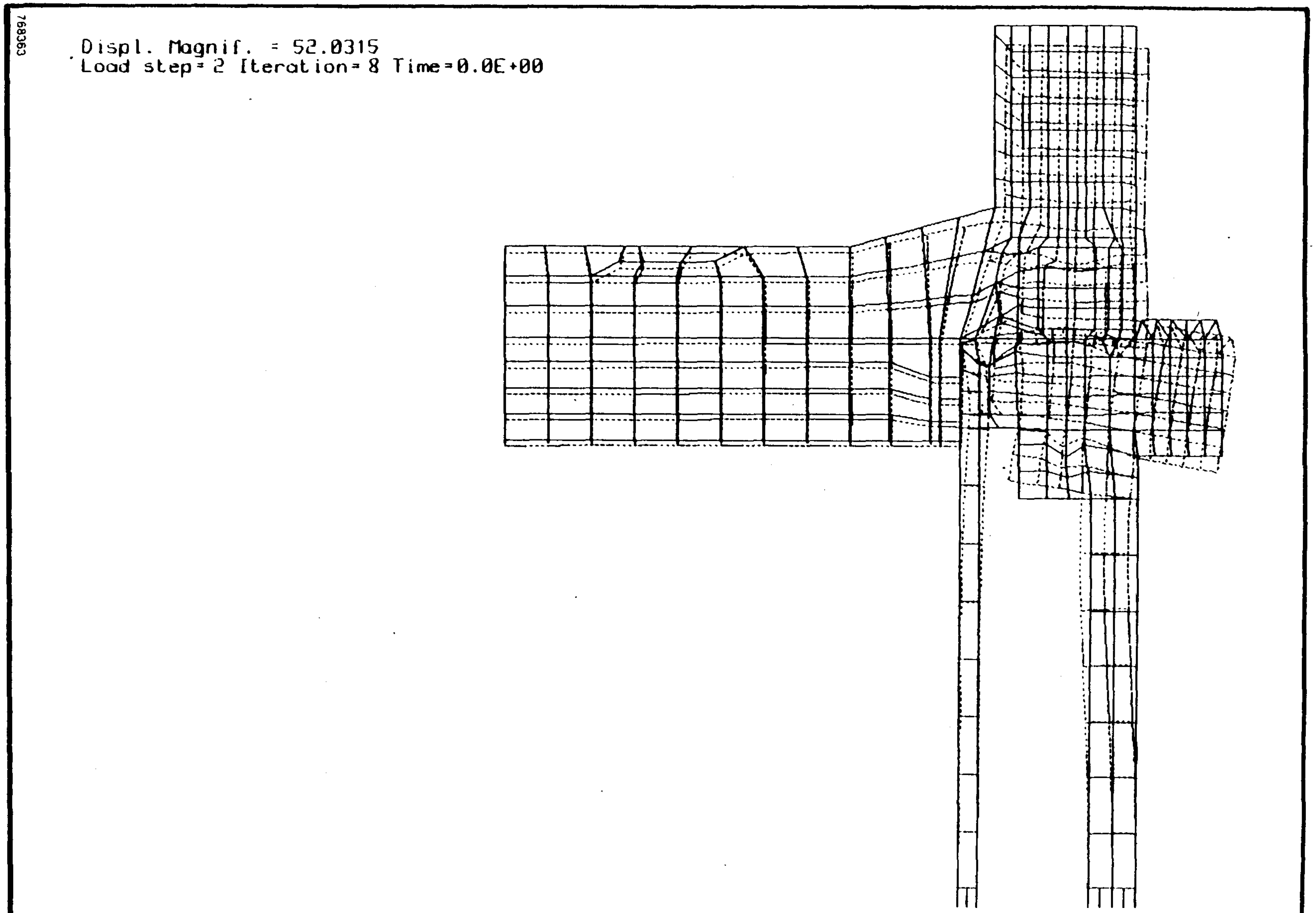


Figure 2.7-8. Deformed Geometry of the Upper End for Hypothetical Accident Load Case

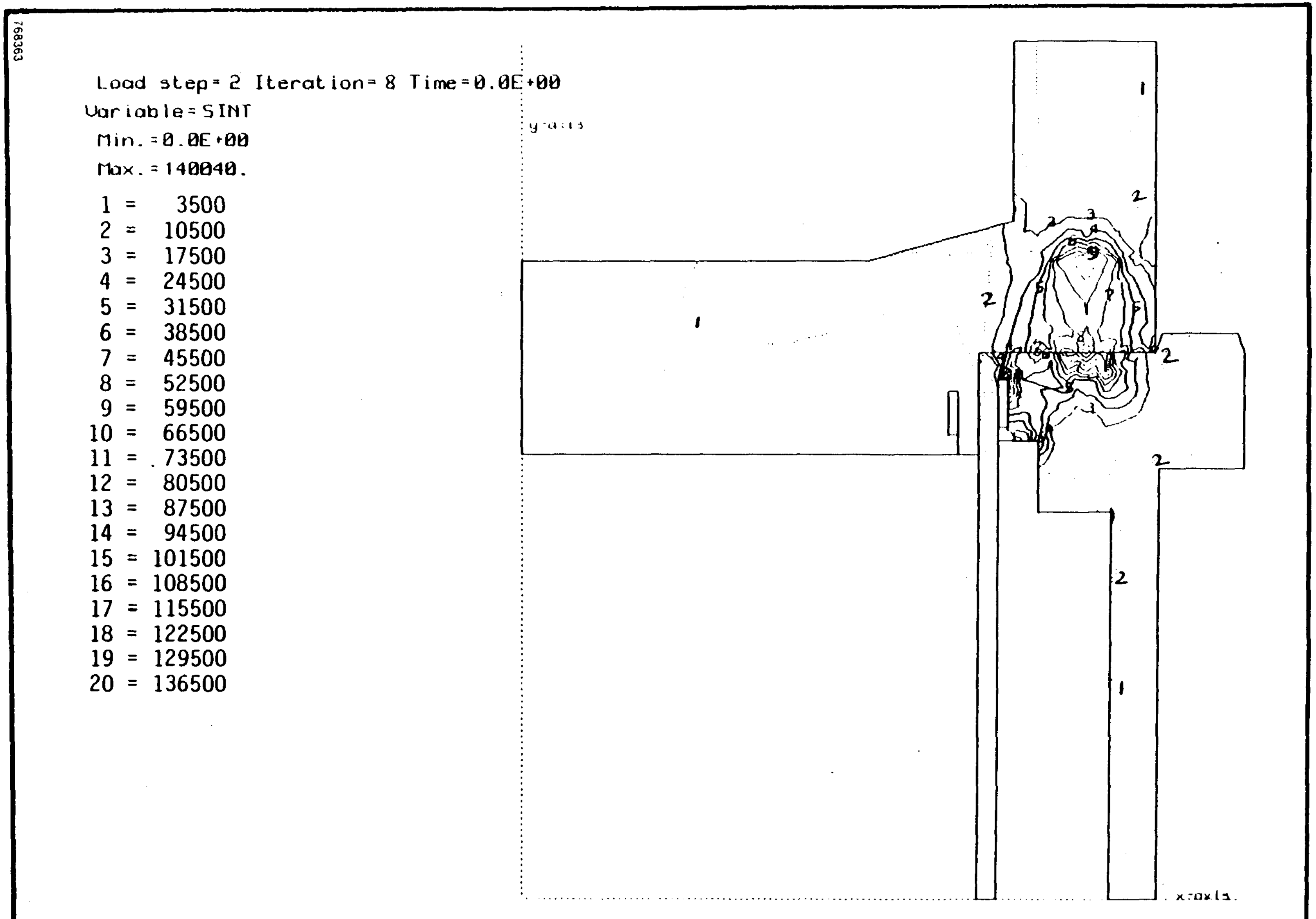


Figure 2.7-9. Stress Contour Plot of Stress Intensity for Hypothethical Accident Load Case

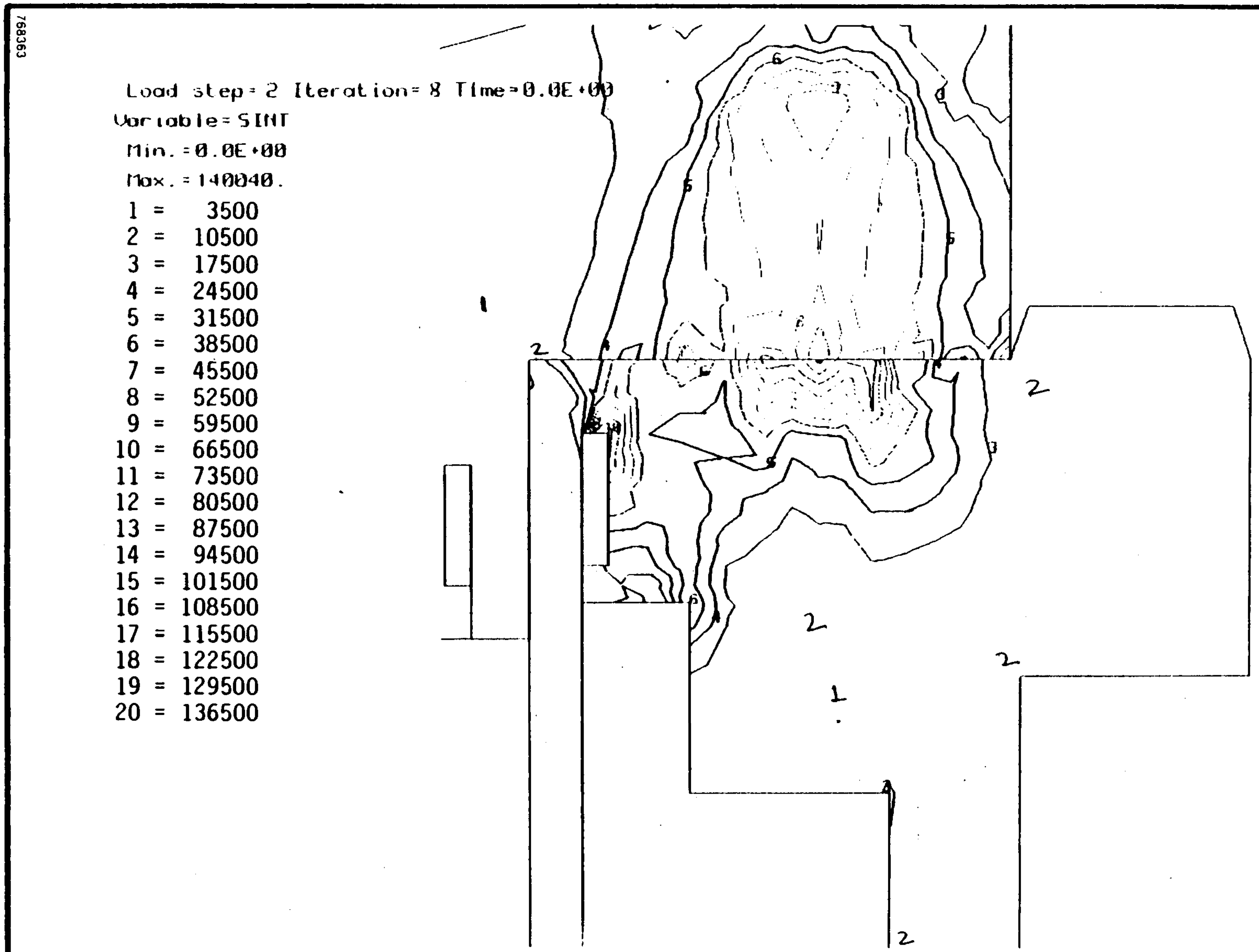


Figure 2.7-10. Enlarged Stress Contour Plot of Stress Intensity for Hypothetical Load Case

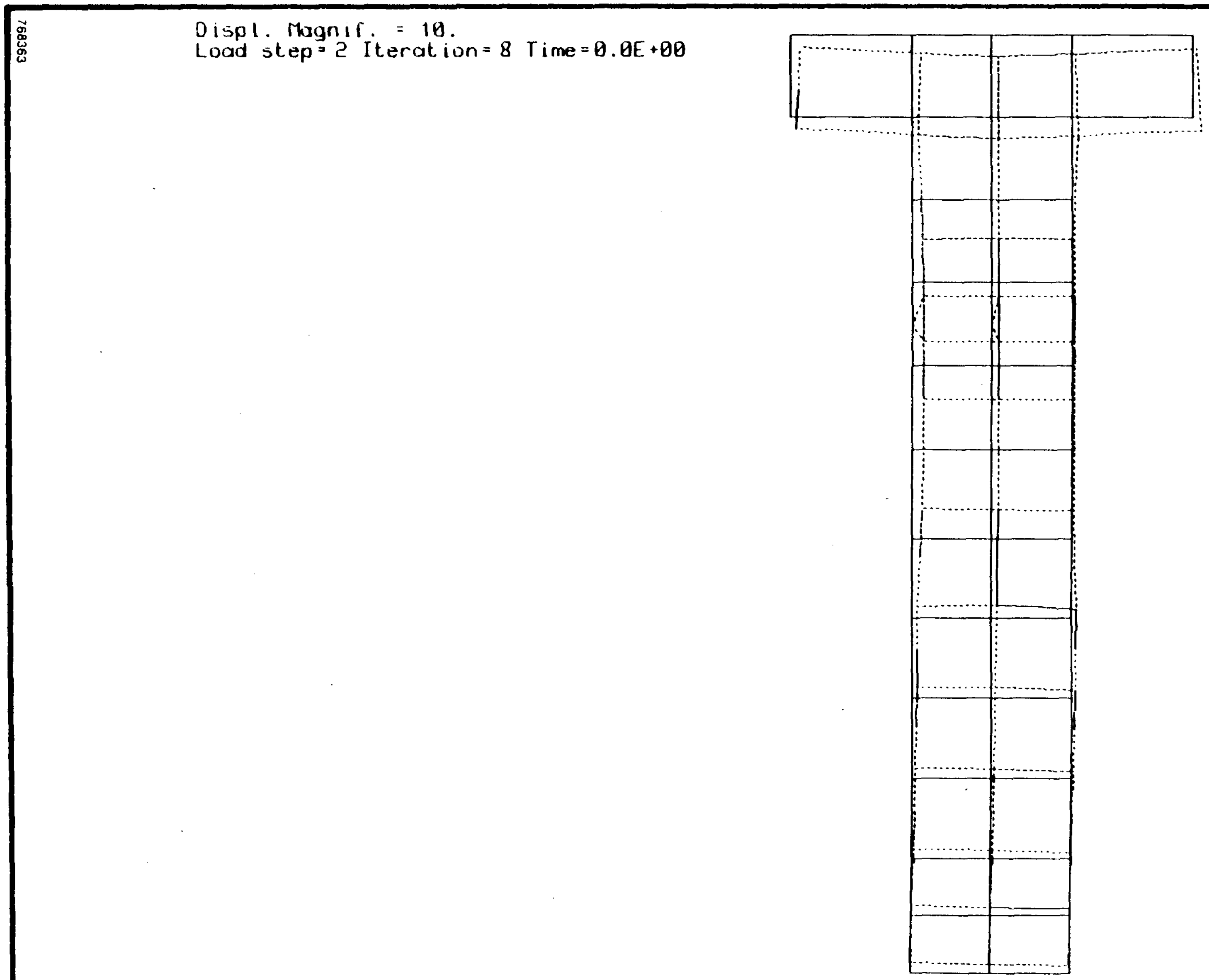


Figure 2.7-11. Deformed Geometry of the Closure Bolt for Hypothetical Accident Load Case

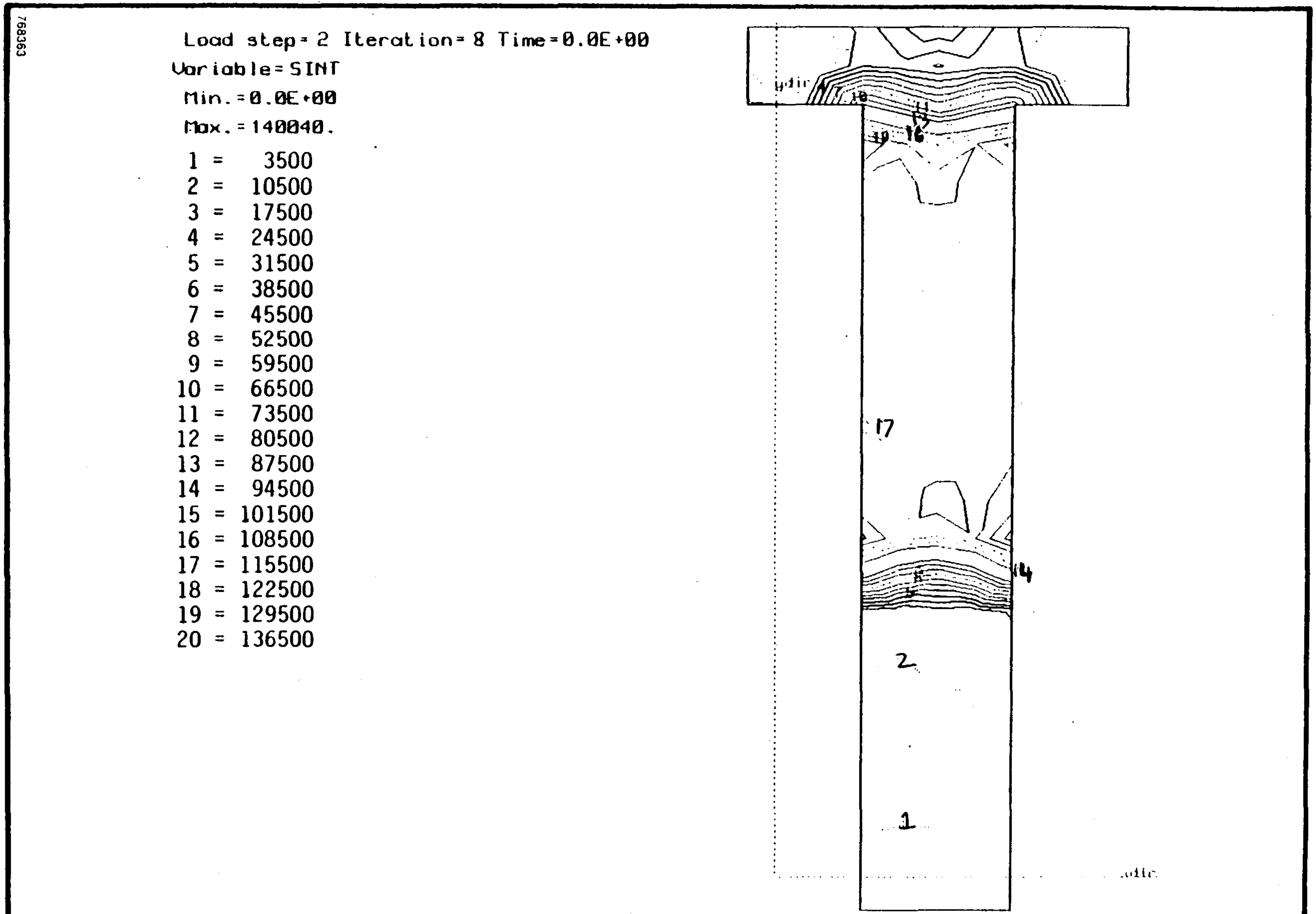


Figure 2.7-12. Stress Contour Plot of Stress Intensity in Closure Bolt of the Upper End for Hypothetical Accident Load Case

The summary of stress results for the Hypothetical Accident load case are presented in Table 2.7-4. Calculated $P_L + P_b$ stresses are below allowables everywhere except for the flange ligament. At this location the margin of safety is -0.04. These analyses are conservative because of the model and loading limitations discussed earlier in this section. It is expected that for the final design, all allowables will be met when the correct final design configuration and loadings are considered. For the final analysis, the cask attachment flange model will include the portion that completely surrounds the outer edge of the closure lid.

2.7.1.2 Side Drop Analysis

Cask Analysis

Analysis of the cask during the side drop is based on the impact decelerations, forces, and stresses obtained from the SCANS analysis for the 0° cask orientation. Table 2.7-2 provides a summary of these results. The maximum deceleration of the cask for the side drop is 49.5 g's, and an impact limiter crush of 11.2 inches results. Comparing the forces and moments between the quasi-static and dynamic analyses gives a dynamic load factor (DLF) of 1.35. This DLF will be used in the design of the cask internal baskets.

This condition is assumed to occur at maximum operating condition temperatures (see Section 2.7.1.1) and the stresses in the cask are calculated using the results from SCANS. The stresses from the MNOP have been ignored in the preliminary drop event evaluations because they are so small. A comparison of actual stresses and allowable stresses for the major components of the cask for the side drop is given in Table 2.7-5. The results show that the allowables are met everywhere except for the shear stress in the inner shell. However, this analysis is very conservative because the use of higher allowables is justified. Since the inner shell, at the place where the high stress occurs, will be at 200°F, the allowable can be increased and the minimum margin of safety for this accident condition becomes;

Table 2.7-4 Hypothetical Accident Load Case

Component/ Area	Location	Calculated Stress (ksi) P_L+P_b	Allowable Stress (ksi) P_L+P_b	Margin of Safety
Closure Lid	@ node 459	47.29	79.20	+0.67
Closure Lid Ligament	@ node 484	66.18	79.20	+0.20
Flange	@ node 1057	70.82	79.20	+0.12
Flange Ligament	@ node 1069	82.46	79.20	-0.04
Inner Shell	@ node 1052	24.10	79.20	+2.29
Outer Shell	@ node 1109	19.03	79.20	+3.16
Bolt (Alloy 718)	@ node 380	140.04	177.60	+0.27

Table 2.7-5

Stress Results for 30 Foot Side Drop

	SCANS Stress (psi)	Corrected Stress (psi)	Allowable (psi)
Inner Shell			
Axial + Bending(1)	54,013	--	73,800
Shear(2)	31,647	--	30,996(5)
Outer Shell			
Axial + Bending(3)	70,741	--	76,320
Shear(4)	31,647	--	35,280
Bottom End Cap			
Bending(3)	Very low	--	79,200
Shear(4)	Very low	--	36,960
Top Closure			
Bending(1)	Very low	--	79,200
Shear(2)	Very low	--	33,264

Notes:

(1) Allowable = S_u

(2) Allowable = 0.42 S_u

(3) Allowable = S_u

(4) Allowable = 0.6 S_y

(5) The inner shell temperatures at the end where this max. stress occurs is 200°F. The allowable can be taken as 33,264 psi.

$$M.S. = \frac{33,264}{31,647} - 1 = +0.05$$

Fuel Basket Behavior Under Side Drop Conditions

The 3 PWR and 7 BWR fuel basket designs for the LWT cask were analyzed using loads which could occur during a 30 foot horizontal free drop (drop angle of 0°). The WECAN finite element computer program, Reference 2.7.1, was used for the analysis. A dynamic deceleration load of 100 g's, acting in several load orientations was used. Details of the finite element analysis are described in Appendix 2.10.4.

Two load cases were performed for the 3 PWR fuel basket. Load case 1 consisted of 100 g's in the negative global Y direction, while load case 2 was run with 100 g's in the negative global X direction (see Figure 2.7-13). The WECAN program calculated the membrane plus bending stresses for each structural component of the 3 PWR fuel basket. These stresses were compared with the allowable stress limits of Reference 2.7.3 for the basket material (Type 316N stainless steel). The maximum temperature for the 3 PWR fuel basket during this accident was determined in Section 3.4.2 as 375°F (heat condition). The maximum allowable stress for membrane plus bending stresses for Type 316N stainless steel at 375°F is 75,650 psi.

The locations of highest membrane plus bending stresses and the stress values are given in Table 2.7-6. The stresses calculated using WECAN were based on 100 g's loadings using basket wall thicknesses from an early design sketch. Since the time the analysis was performed, the impact limiter design was revised and the 3 PWR fuel basket wall thicknesses were changed to those shown in Drawing 1988E43. The results of the WECAN stress analysis were adjusted, according to the revised dynamic decelerations resulting from the use of a honeycomb impact limiter and revised basket wall thicknesses. The stresses were adjusted according to the new wall thicknesses by the following procedure:

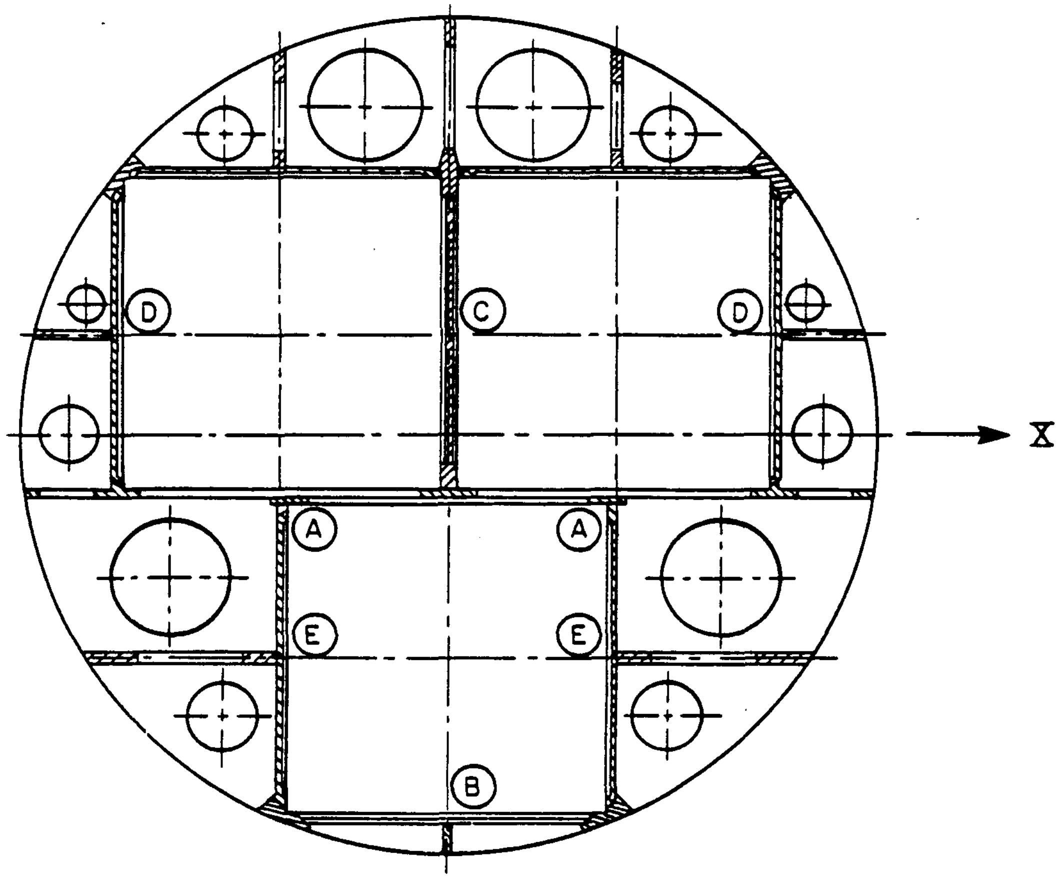
$$S_{new} = S_{old} \times [t_{old}/t_{new}]^2$$

Table 2.7-6

Maximum Stresses for PWR Fuel Baskets During 30 Foot Side Drop Accident

Location Point	Critical Load Case	WECAN Maximum Stress at 100 g's psi	Old Wall Thickness in WECAN inch	New Wall Thickness inch	Adjusted Maximum Stress at 100 g's psi	Adjusted Maximum Stress at 67 g's psi	Margin of Safety
A	1	64,159	0.140	0.204	30,217	20,245	+2.74
B	1	87,933	0.120	0.115	95,746	64,150	+0.18
C(1)	2	61,913	0.250	0.196	100,728	67,488	+0.12
D	2	108,089	0.120	0.128	95,000	63,650	+0.19
E	2	88,108	0.120	0.115	95,936	64,277	+0.18

(1) Critical Location



SCANS results for the side 30 foot side drop showed a 49.5 g deceleration. The dynamic load factor for this drop orientations from the SCANS results is 1.35. Multiplying the g-loading by the DLF gives 67 g's which is used to evaluate the basket. The adjusted stress at 100 g's was then re-adjusted for 67 g's as follows:

$$S_{67} = [67/100] \times S_{100}$$

Table 2.7-6 provides the WECAN results and the adjusted results at each critical location point. The results indicate that all stresses are within their design limits for the side drop accident conditions. The minimum margin of safety is +0.12.

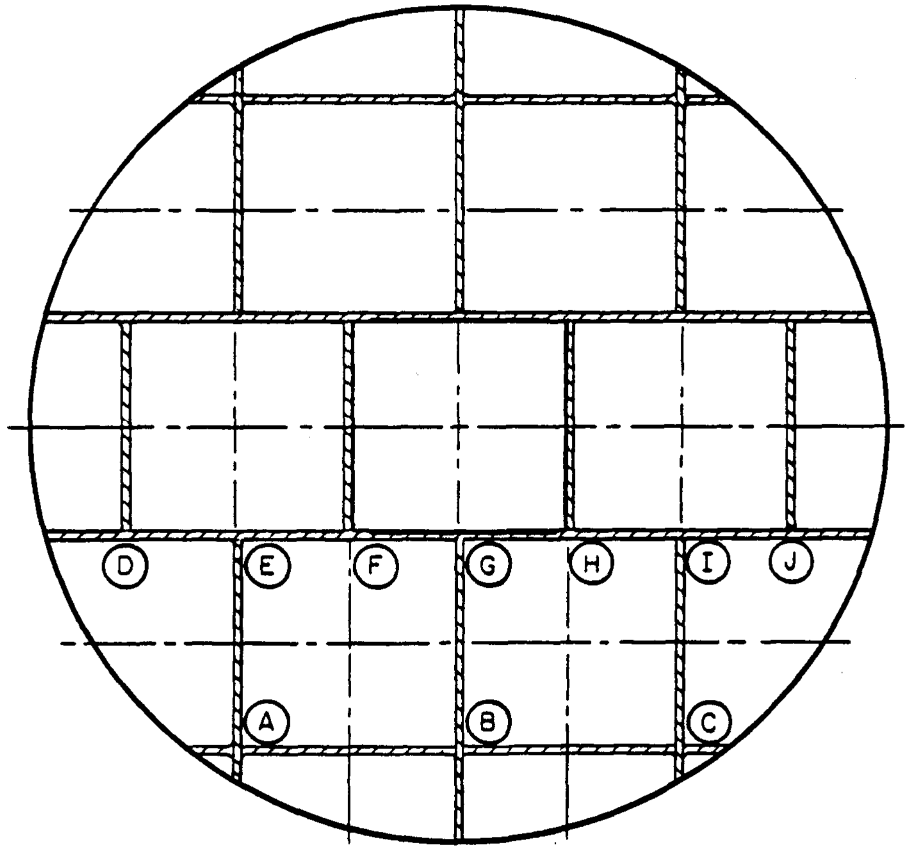
Three load cases were performed for the 7 BWR fuel basket. Load case 1 consisted of 100 g's in the negative global Y direction. Load case 2 was for 100 g's in the positive global X direction. The third load case was for 100 g's at 45° to the global X and Y directions. The WECAN program calculated membrane plus bending stresses for each structural component of the 7 BWR fuel basket. These stresses were compared with the allowable stress limits for Type 316N stainless steel, according to the criteria set forth in Reference 2.7.3. The maximum temperature for the 7 BWR fuel basket has not been determined at this time. Based on the maximum temperature (375°F) for the 3 PWR fuel basket, a very conservative estimate of 450°F for the 7 BWR fuel basket was assumed. The maximum allowable stress for membrane plus bending of Type 316N stainless steel at 450°F is 74,800 psi for accident conditions.

The locations of highest membrane plus bending stress and the stress values are given in Table 2.7-7. The WECAN stresses were calculated at 100 g's using dimensions of basket wall thicknesses per the basket drawings. Because of the design changes in the impact limiter and wall sizes, the same type of adjustments were made for the WECAN analysis of the 7 BWR fuel basket as for the 3 PWR fuel basket.

Table 2.7-7

Maximum Stresses for 7 BWR Fuel Basket During 30 Foot Side Drop Accident

Location Point	Critical Load Case	WECAN Maximum Stress at 100 g's psi	Old Wall Thickness in WECAN inch	New Wall Thickness inch	Adjusted Maximum Stress at 100 g's psi	Adjusted Maximum Stress at 67 g's psi	Margin of Safety
B	1	34,582	0.210	0.190	42,245	28,304	+1.64
C	3	34,666	0.210	0.190	42,348	28,373	+1.64
G	1	45,678	0.320	0.210	106,064	71,063	+0.05
H/F	1	31,045	0.320	0.290	37,800	25,326	+1.95
$I_{(Side)}$	2	53,916	0.130	0.190	25,240	16,911	+3.42
$I_{(Below)}$	2	38,283	0.210	0.190	46,767	31,334	+1.39
J	2	26,378	0.320	0.190	74,823	50,131	+0.49



The results for the adjusted stresses at 67 g's, using current drawing dimensions for wall thicknesses, indicates that all maximum membrane plus bending stresses are within their design limits (74,800 psi). The minimum margin of safety is +0.05.

2.7.1.3 Corner Drop

The cask was evaluated for the 30 foot free drop where the center of gravity (C.G.) of the cask is over the corner of impact. The orientation of the cask for this condition is at 80.7° from horizontal. The results from this accident condition were obtained from a SCANS analysis and are summarized in Table 2.7-2. The maximum deceleration of the cask for this condition is 63.5 g's and the impact limiter crushes to a depth of 10.9 inches.

This condition is assumed to occur at maximum operating condition temperatures (see Section 2.7.1.1) and the stresses are calculated using the results from SCANS. A comparison of actual stresses and allowable stresses for the major components of the cask for the 30 foot C.G.-over-corner drop is given in Table 2.7-8.

The results show that the allowables are met everywhere in the cask for this accident condition. The minimum margin of safety for any of the structural components is;

$$M.S. = \frac{76,320}{63,174} - 1 = +0.21$$

2.7.1.4 Oblique Drops

Cask Analysis

Analytic predictions of package performance for oblique drop orientations were made with the SCANS program. The dynamic analysis program predicts the cask behavior for initial impact (or primary impact) and subsequent behavior during slapdown (or secondary impact). Analyses were carried out for oblique drop orientations of 15°, 30°, 45°, 60° and 75° from the horizontal. The program

Table 2.7-8

Stress Results for 30 Foot C.G. Over Corner Drop

	SCANS Stress (psi)	Corrected Stress (psi)	Allowable (psi)
Inner Shell			
Axial + Bending(1)	52,690	--	73,800
Shear(2)	22,687	--	30,996
Outer Shell			
Axial + Bending(3)	63,174	--	76,320
Shear(4)	22,687	--	35,280
Bottom End Cap			
Bending(3)	5,559	7,638	79,200
Shear(4)	2,563	2,634	36,960
Top Closure			
Bending(1)	5,559	14,213	79,200
Shear(2)	2,563	2,394	33,264

Notes:

(1) Allowable = S_u

(2) Allowable = 0.42 S_u

(3) Allowable = S_u

(4) Allowable = 0.6 S_y

uses the force-deflection curve for the impact limiter corresponding to the drc orientation for the primary or initial phase and uses the 0° force-deflection curve for the slapdown or secondary phase.

Impact decelerations, forces and stresses obtained from the SCANS analysis are summarized in Table 2.7-2. It can be seen from this table that SCANS does not provide credible results for the shallow angle (15° and 30°) quasi-static, oblique drop, test conditions. Hence, the results from these analyses will not be used. The maximum g-loading on the cask is 69.7 g's at the 75° orientation. However, the maximum stresses in the shells occur during the secondary impact shallow angle drops or at the zero degree orientation.

This test condition is assumed to occur at maximum operating condition temperatures (see Section 2.7.1.1) and the stresses are calculated using the results from SCANS. A comparison of actual stresses and allowable stresses for the major components of the cask for the oblique drops is given in Table 2.7-9. The results shows that the allowable shear stresses are slightly exceeded for both the inner and outer cylindrical shell. A more detailed analysis should show that these shear stresses were conservatively calculated. If local shell thickening was accounted for, and the supporting capability of the honeycomb impact limiter skirt was taken into account, the shear stresses in the cylindrical shells should be below the allowable.

Closure Bolts Analysis

The closure bolts must prevent the closure lid from opening during an accidental 30 foot drop with the top end landing on its corner at some oblique angle. This load scenario is considered in the SCANS analysis for every drop angle.

The SCANS model is illustrated in Figure 2.7-13. For conservatism, the impact point is taken as the furthermost location (at the corner) from the cask centerline. This will maximize the turning moment about the imposed impact point which could cause separation of the closure lid. The bolt orientation is assumed to be such that one single outer bolt lies 180° from the point of impact. This assumption will maximize the load in any of the 16, 1-3/8 diamete

Table 2.7-9

Stress Results for 30 Foot Oblique Drops

	SCANS Stress (psi)	Corrected Stress (psi)	Allowable (psi)
Inner Shell			
Axial + Bending(1)	58,163	--	73,800
Shear(2)	38,912	--	30,996
Outer Shell			
Axial + Bending(3)	76,336	--	76,320
Shear(4)	38,912	--	35,280
Bottom End Cap			
Bending(3)	5,460	7,502	79,200
Shear(4)	2,517	2,587	36,960
Top Closure			
Bending(1)	5,460	13,960	79,200
Shear(2)	2,517	2,351	33,264

Notes:

(1) Allowable = S_u

(2) Allowable = 0.42 S_u

(3) Allowable = S_u

(4) Allowable = 0.6 S_y

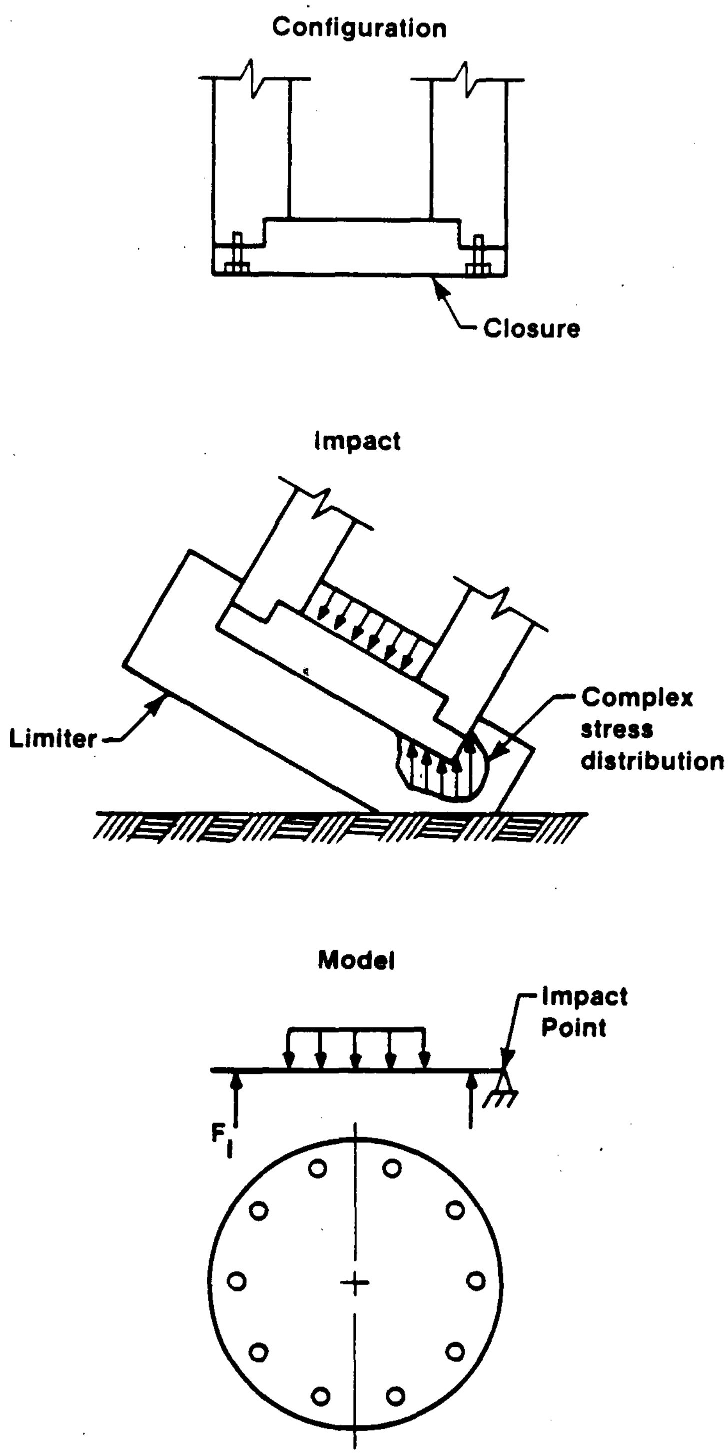


Figure 2.7-13. SCANS Model for Maximum Bolt Load Due to Oblique Drop

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closure bolts. SCANS assumes that the load which the bolts must carry are the weights of the closure lid and the fuel basket containing the fuel assemblies. This load is applied uniformly over the internal closure area and varies with the drop angle. The SCANS output of stress results indicates maximum bolt axial loads are realized for impact angles less than the 80.7° center of gravity over corner angle. The SCANS 75° primary impact angle case was used for the initial assessment.

The results of the SCANS analysis gave a peak bolt load of about 142,000 pounds. However there are two major short comings with the SCANS analysis. First, the flexibility of the bolt (shank portion) is not included in the SCANS model; that is, the bolt length is not used as input and the bolt is modeled as a short stub with no axial flexibility. Secondly, the stress area is based on the nominal bolt diameter size of 1-3/8 inches, which results in a too large of a stress area (1.484 square inches).

Drawing 1988E43 indicates the bolt shank is 3.08 inches long and 1.15 inches in diameter (stress area of 1.039 square inches). A WECAN finite element analysis was performed to include the details of the bolts and their flexibility that the SCANS analysis neglected. The 3-dimensional WECAN model illustrated in Figure 2.7-14 consisted of 16 very stiff beams to represent the top end closure plate (which is a 5 inch thick circular plate). The WECAN model is similar to the SCANS model with respect to the impact point (at the extreme corner) and the bolt orientation (one bolt is located 180° from the impact point. However, the bolts are represented by beams having a length of 3.08 inches (shank length which can expand or contract) and a stress area of 1.039 square inches. The model was verified by determining the axial load at the centerline to produce the same maximum bolt load (142,000 pounds) as SCANS. For this preliminary WECAN analysis the bolt lengths were set at 0.10 inch in the model. A load of about 2,273,000 pounds acting at the cask centerline produced a maximum bolt load of about 142,000 pounds. The next WECAN case run used the same centerline load of 2,273,000 pounds, but made the bolts 3.08 inches long. The results indicate the maximum load is reduced substantially to 35,070 pounds. A third WECAN case run was performed using

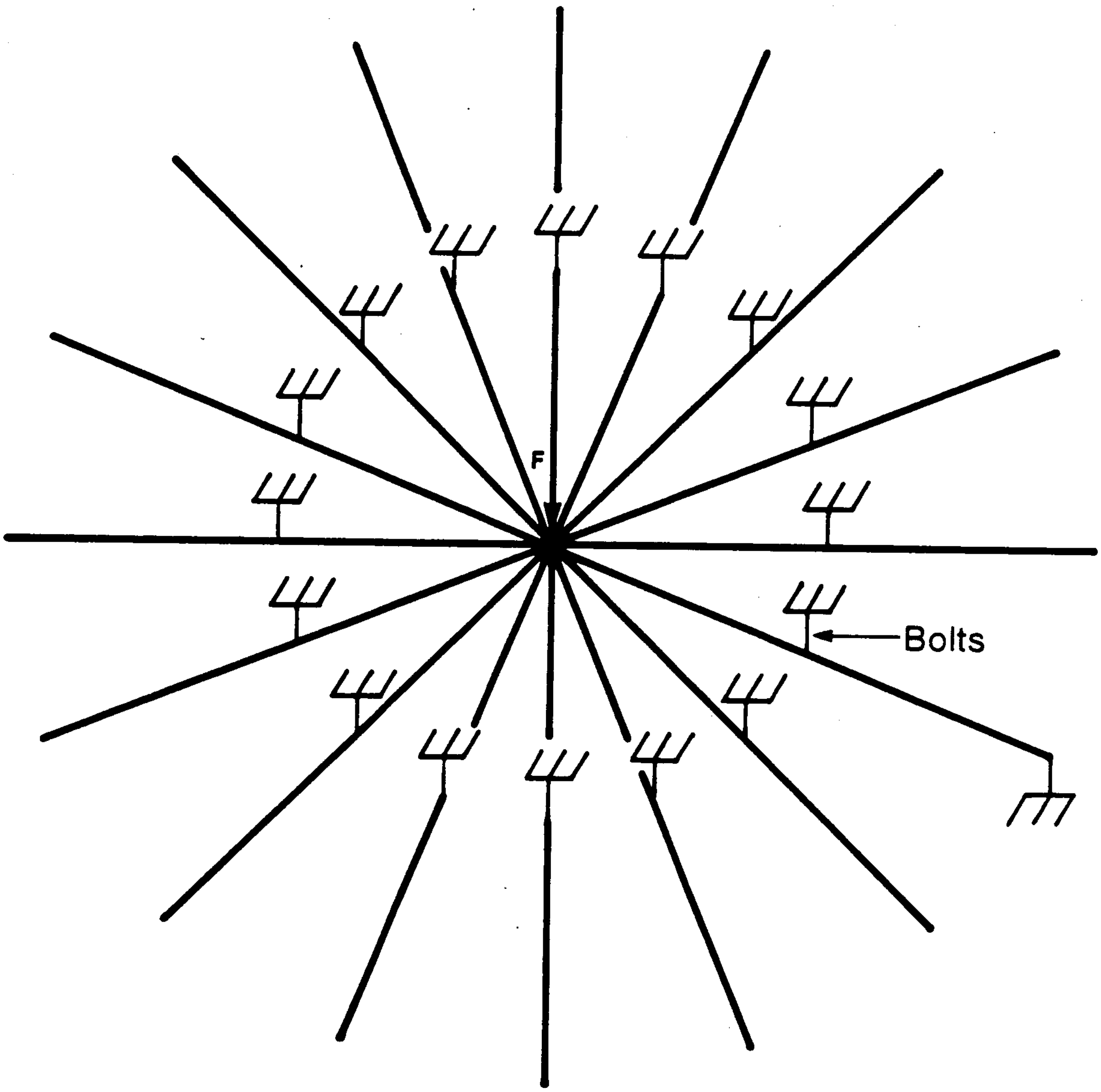

Figure 2.7-14. WECAN Model of Closure Bolts During Oblique Drop

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the most severe total axial load possible. This load was based on the maximum dynamic acceleration of 72 g's, which occurs from a 90 degree drop. This load is 72 x 54000 or 3,888,000 pounds. The maximum bolt load for this case is only about 60,000 pounds.

The criteria for bolt acceptance are based on the allowable stresses in shear (69,120 psi) and membrane (124,320 psi). The shear stress for all 16 bolts is based on the SCANS shear load near the bolts. The total shear load is 809,400 pounds. Dividing 809,400 pounds by the number of bolts (16) and the shear area (1.039 square inches), a shear stress of 48,689 psi is calculated and is less than the allowable shear stress of 69,120 psi at 200°F. The maximum bolt membrane stress is based on the preload of 95,000 pounds. This preload is needed for the difference in thermal expansion of the Alloy 718 bolts and Grade 9 titanium structures during the fire accident. The membrane stress from the 95,000 pound preload is 91,430 psi and is less than the 124,320 psi allowable. The bolt bending stresses from the WECAN case runs were only a few thousand psi so there is a large margin for the allowable bending plus membrane allowable stress of about 177,600 psi.

Inner and Outer Shell Weld Analysis

A WECAN model, similar to the model for determining the maximum bolt loads during oblique drops, was developed to determine the maximum membrane stress in the inner and outer shell wall, in the vicinity of the welds. The inner and outer shells were represented by 16 beams at a radii of 12.38 inches for the inner shell and 16.56 inches for the outer shell, respectively. The angular spacing of each beam was 22.5 degrees. The cross sectional area of each beam was the total shell area divided by 16 (2.38 inches square for the inner shell beams and 7.822 inches square for the outer shell beams). The load used for this case was based on the 90° drop dynamic acceleration of 72 g's. The load was 72 x 54,000 or 3,888,000 pounds. The WECAN model is shown in Figure 2.7-15.

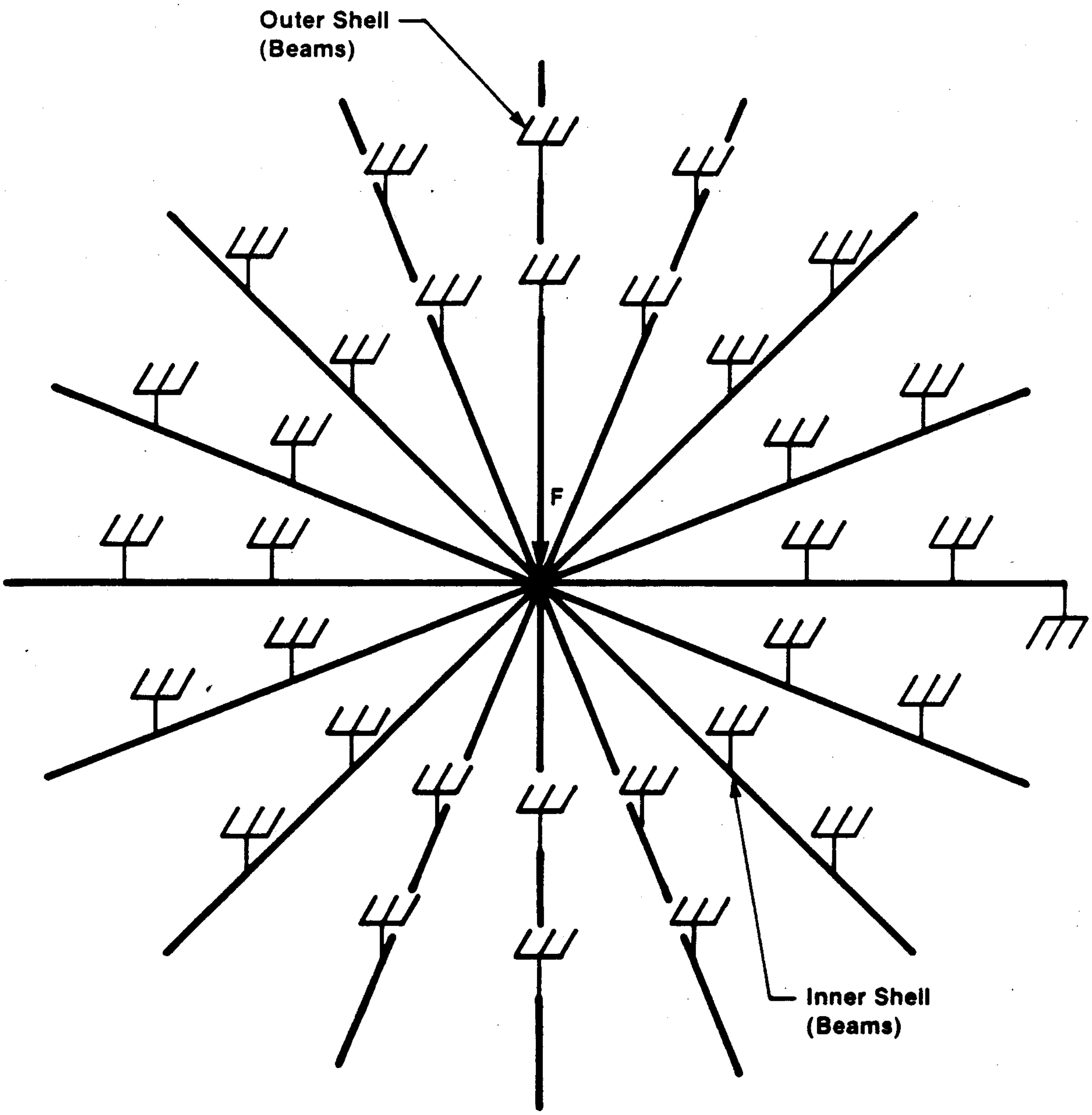

Figure 2.7-15. WECAN 3-D Model for Maximum Inner and Outer Shell Membrane Loads

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The results of the WECAN run indicated the maximum load to average load for the inner shell was 1.12 and 1.21 for the outer shell. The highest average inner and outer shell membrane stresses from the SCANS analysis were from the 75° angle drop with the top end hitting the ground during the primary impact. The inner shell average membrane stress from SCANS was 31,475 psi in the vicinity of the top weld. The local peak membrane stress for the inner shell near the weld is 1.12 x 31,475, or 35,252 psi. The allowable stress, assuming the weld strength is equivalent to the base material at 270°F, is 51,900 psi. Therefore, the inner shell membrane stress at the weld is within the design allowable limits. The outer shell average membrane stress from SCANS is 41,284 psi in the vicinity of the top weld. The local peak membrane stress at that point is 1.21 x 41,284, or 49,954 psi. The allowable stress for Grade 9 titanium at 230°F is 53,928 psi. Therefore, the outer shell weld peak membrane stress is within its design allowable stress limits.

2.7.1.5 Summary of Results

As evidenced by the preceding evaluations, the major structural members of the LWT cask can withstand the loadings that result from the 30-foot free drop. For the preliminary design phase, the cask cylindrical shells, bottom head assembly, closure head, closure head bolts and fuel baskets have been evaluated against the design requirements of Section 2.1 of this report.

Loads on the cask that result from the drops were conservatively calculated using the SCANS computer program which accounts for the flexibility of the cask. Because SCANS performs a dynamic analysis directly, the evaluation of the adequacy of the design has not had to depend on estimates of dynamic load factors (DLF) that would be needed to scale up results of quasi-static analyses based on g-values only.

For the final design phase, more detailed structural and finite element analyses will be completed to assure that stresses meet design allowables. In addition, scale model testing of the cask and impact limiter will be completed to confirm and verify analysis results.

2.7.2 Puncture

Subpart F of 10 CFR 71 requires that a 40 inch free drop of the cask onto the upper end of a solid cylindrical mild steel bar mounted vertically on an essentially unyielding horizontal surface be considered. The bar must be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than 0.25 inches. The cask is to be oriented in a position for which maximum damage is expected and the length of the pin is to be such that maximum damage will occur.

The puncture analysis utilizes some or all of the following data:

h	=	drop height
	=	40 inches
l_o	=	punch length for maximum damage for either a side or end drop
	=	26 inches
r	=	punch edge radius
	=	0.25 inch
d	=	punch diameter
	=	6.0 inches
S_o	=	punch yield strength
	=	36,000 psi for A36 carbon steel
W	=	package weight
	=	54,000 pounds
D_o	=	package outer shell outer diameter
	=	33.120 inches
D_i	=	package inner shell outer diameter
	=	24.76 inches

L = package Length, without limiter
= 202.95 inches

S_u = package outer shell ultimate tensile strength (Section 2.3)
= 77,040 psi, at 230°F for Grade 9 titanium

t_a = actual package outer shell thickness
= 1.25 inches

t = required package outer shell thickness, inches

Maximum Impact Load

The maximum expected dynamic impact load for the cask falling 40 inches on a 6 inch diameter ASTM A36 carbon steel punch was determined from the technique given in Reference 2.7.4. The key assumptions are that:

1. All of the kinetic energy due to the 40 inch drop is absorbed by punch.

2. The effective yield strength (S_o) of the carbon steel punch remains essentially constant during the deformation of the punch bar.

The kinetic energy of the cask when it strikes the pin is:

$$E_o = W \times 40 = 54{,}000 \times 40 = 2{,}160{,}000 \text{ inch-pounds}$$

The impact force on the punch can be calculated by equations 2-14 and 2-10 of Reference 2.7.4 as follows:

P_f = dynamic impact force = $S_o \times A_o \times e^b$, pounds where,

$$b = E_o/(S_o \times A_o \times l_o)$$

A_o = original punch cross section area = $0.7854 \times d^2$
= $28.27\ in^2$

b = 2,160,000/(36,000 x 28.27 x 26) = 0.08163 (dimensionless)

therefore

P_f = 1,104,281 pounds

The dynamic deceleration for the 40 inch drop of a 54,000 pound cask on a 26 inch long, 6 inches diameter punch is:

$DA = P_f/W = 20.45$ g's

Side Puncture

Local Damage Evaluation at Point of Impact:

For impact occuring on the side of the cask, the required cask outer shell thickness (t) to prevent local puncture at the point of impact may be determined using Nelm's Equation (Equation 2.1 of Reference 2.7.5).

Use of Nelm's equation can be justified for the cask because Grade 9 titanium has toughness comparable to that of stainless steel. The development of the Nelm's equation was based upon data for a stainless steel material having a graphite backing. The backing to the outer cask shell is depleted uranium (DU), which is much harder than the soft graphite backing used to develop the Nelm's equation, and has a higher resistance to shear puncture than graphite.

Application of the Nelm's equation to the outer cask shell gives the following required thickness.

$t = (W/S_u)^{0.71}$
$= 0.777$ inches at 230°F

Based on the Nelm's equation, the outer shell thickness margin of safety (M.S.) to resist puncture at the point of impact is:

$$M.S. = [t_a/t - 1] = [1.25/0.777 - 1] = +0.61$$

To further evaluate local damage near the point of impact after a 40 inch side drop on a punch, a finite element analysis was performed using the WECAN program. The point of impact was assumed to occur at the center (lengthwise) of the cask, which is the approximate center-of-gravity of the cask.

The WECAN model was constructed of 20 node, 3-D isoparametric, elastic brick elements to represent the outer and inner titanium shells. These elements were employed to elastically calculate axial, hoop, radial, and shear stresses. The depleted uranium shielding (DU), which is sandwiched between the inner and outer shells, was represented by interface elements. These interface elements permit stiff radial contact between the DU and the inner and outer shells with sliding friction, as well as gap spaces between the shells and the DU. Any structural benefit of the DU to resist shear and bending was neglected. Use of the interface element to represent the DU resulted in non-linear, load-displacements and required several iterations per load case to obtain a converged solution. Other types of elements employed for this analysis consisted of 3-D isoparametric wedge elements as part of the bottom head model, and six 3-D spring elements to describe the punch interaction with the outer shell. The WECAN model consisted of 1166 elements. Due to symmetry, only one-quarter of the cask needed to be modeled. Figure 2.7-16 illustrates the entire 3-D WECAN model, along with the boundary conditions utilized for symmetry. Figure 2.7-17 depicts the local model in the vicinity of the punch.

The results of this analysis indicated that, for a dynamic deceleration load of 20.45 g's, the cask ends will deflect 1.34 inches below the top of the punch. The deflection directly over the punch was a small dent, about 0.054 inches above the punch. These deflections seem reasonable for this preliminary model.

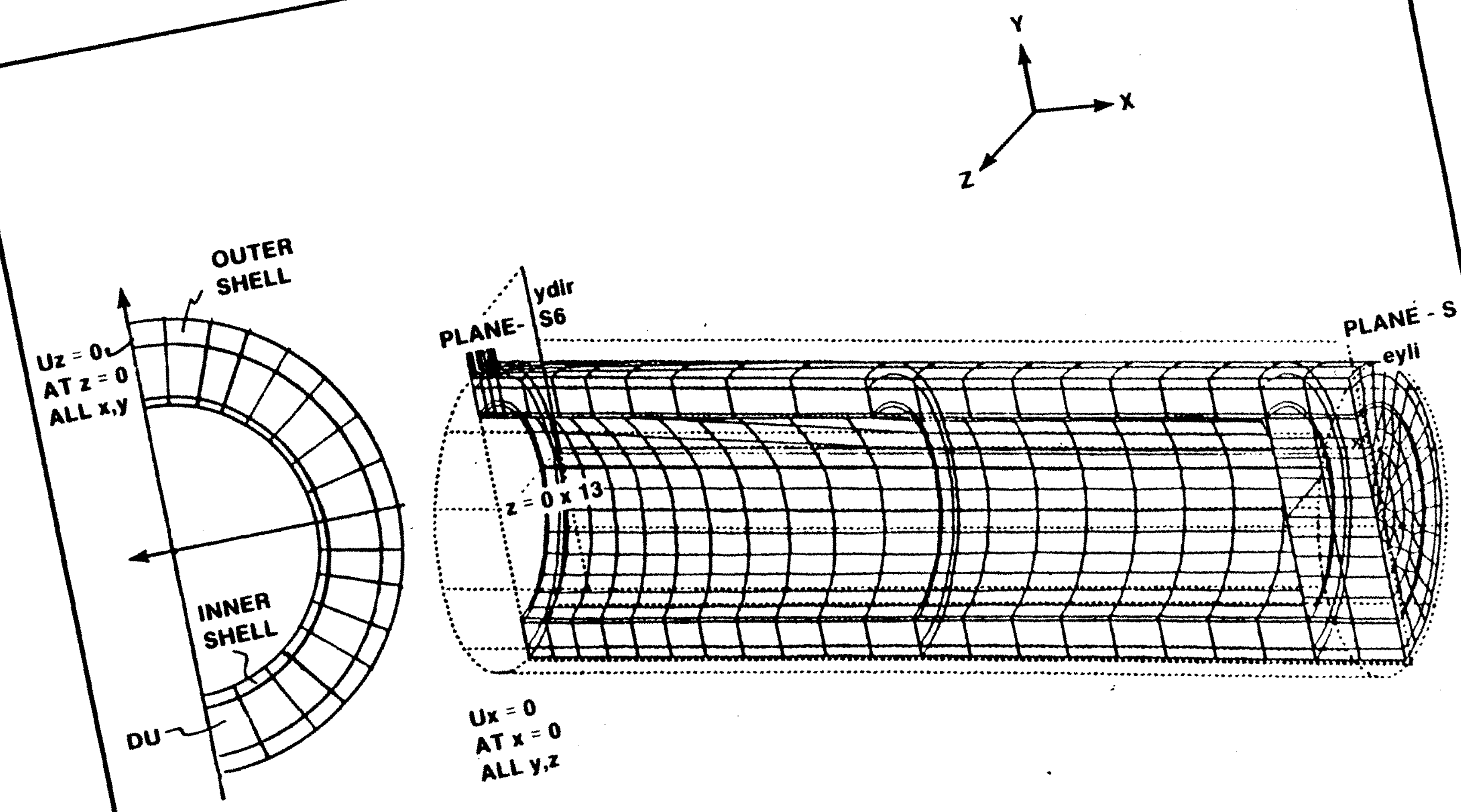

Figure 2.7-16. 3-D WECAN Model for Punch Analysis of Cask Shell

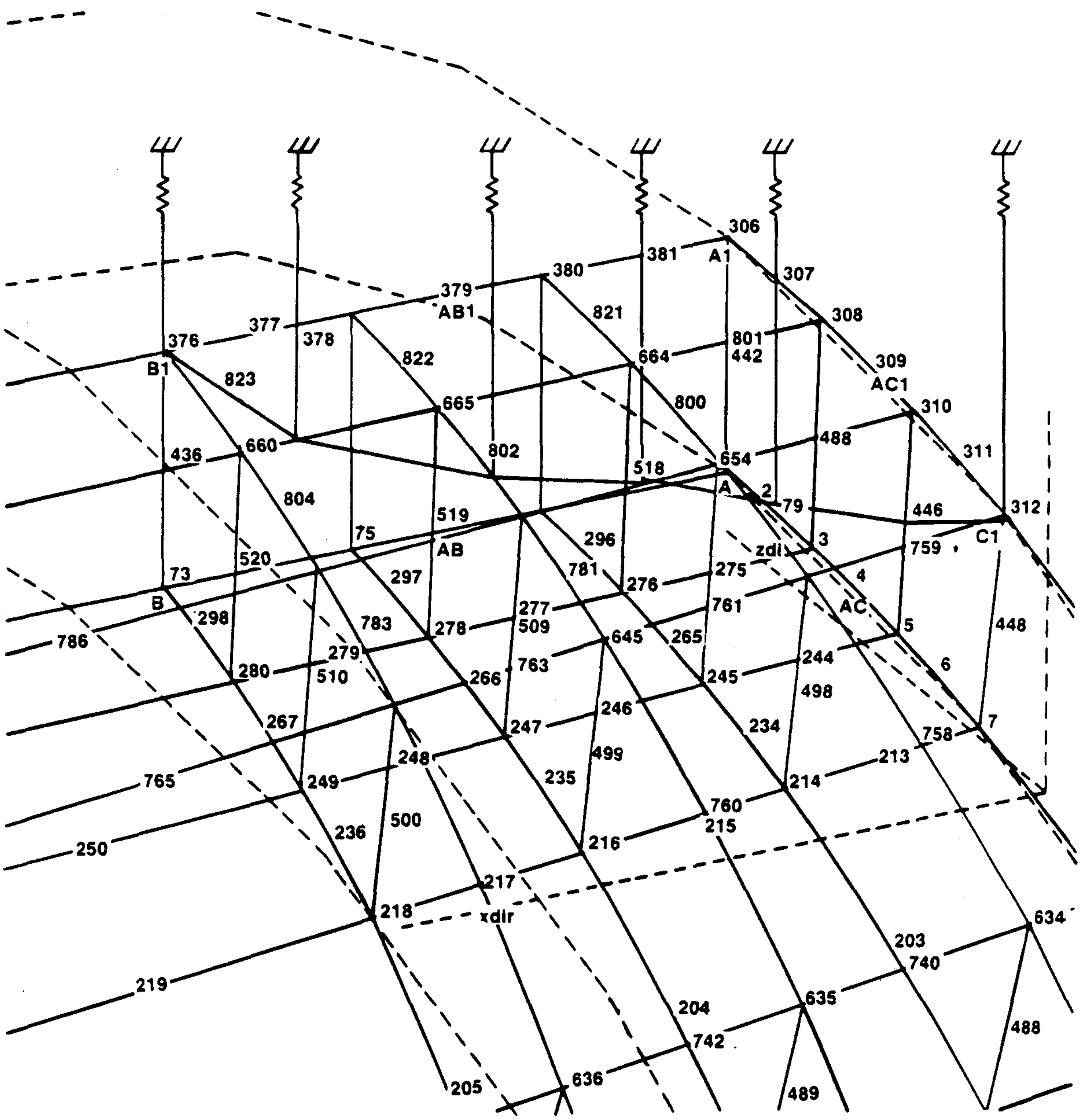

Figure 2.7-17. Local WECAN Model of the Cask Shell at Punch

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The stress results from this analysis indicate that the maximum stresses all occur under the punch at the nodes where the punch loads are applied. These stresses rapidly reduce to modest values at nodes away from the punch. The portion of the model which applied the punch load had six 3-D spring elements and represented one-quarter of the punch outer perimeter. This model was used because it was expected that a dent would occur in the outer shell directly over the punch, which indicates that only the punch outer perimeter will remain in contact with the outer shell surface. The effect of point loads on the shell cause unrealistic stresses. For final design, a finer mesh will be used with distributed loading from the punch. For this preliminary analysis, the stresses at the center of the punch are more representative and will be used for comparison with the design criteria.

Under the Reference 2.7.3 design criteria, surface stresses under the punch are peak stresses. The allowable stress for peak stresses is $2xS_a$ at 10 cycles. From Figure 2.6-1 in Section 2.6, the $2xS_a$ value is greater than 1,400,000 psi. Bending stresses under the point of impact (accident conditions) are considered secondary stresses and are not limited by the design criteria. Stresses at the midplane nodes can be taken as average or membrane stresses. These membrane stresses are very localized under the punch and are highest at the nodes where the loads are applied. The accident condition allowable stress for local membrane stress is S_u or 77,040 psi for Grade 9 titanium at 230°F. Shear stresses at the midplane nodes in the shell under the punch can be considered local shear stresses and the allowable stress can be taken as 0.8 S_Y or 47,600 psi. The stresses from the WECAN output have been compared to the design criteria and any local damage under the punch impact will be limited to a small dent.

Using the stress results for the shell at the center of the punch the maximum surface shell stress is 320,450 psi for the 20.45 g punch loading which is well below the 1,400,000 psi allowable. The local primary membrane stress is 84,032 psi which is slightly higher than the 77,040 psi allowable. However, a simple shear stress calculation for the shell around the perimeter of the punch using the 20.45 g punch load gives a stress of 46,868 psi which is below the allowable of 47,600 psi. Hence, the outer shell should be able to withstand the punch load with only minor damage.

Overall Damage Effect on Package:

The overall effect on the entire package was evaluated using simple beam theory. The beam bending model also assumes the punch is applied at the cask center-of gravity, and is assumed to be at the center. The bending slope under the punch is zero and the bending model can be applied as a cantilever beam model of half the cask (See Figure 2.7-18).

The loads which act on the cask are both distributed (for the region of the inner and outer shells and DU) and concentrated at the end (region of end caps and impact limiters). These loads for 1 g are:

W_h = weight of half the cask = 54,000/2 = 27,000 pounds

$W_h = W_{dist} + W_{end}$ = 27,000 pounds

W_{end} is about 2000 pounds

W_{dist} is 27,000 - 2,000 = 25,000 pounds

W_{dist} is the distributed load in pounds per inch

W_{dist} = 25,000/101.475 = 246.4 pounds per inch

The bending moments due to these two types of loads for a cantilever beam are:

$$M = W_{end} \times L + W_{dist} \times (L/2)^2$$

L = half length of TITAN cask, = 101.475 inches

M = 1,470,000 inch-pounds

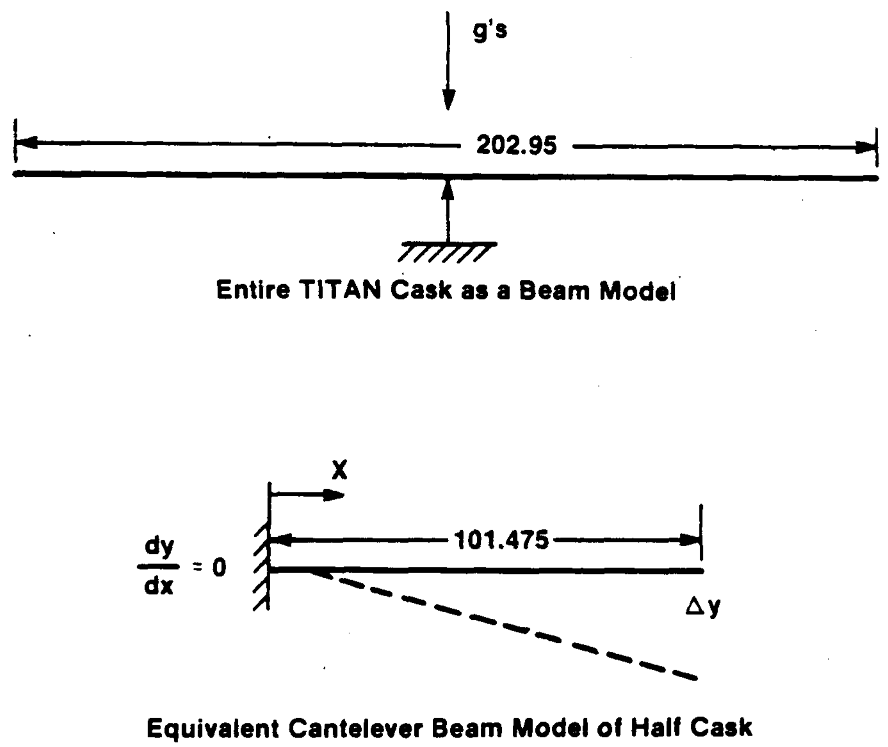


Figure 2.7-18. Beam Model of TITAN LWT Cask for Side Punch Load

768370-44A

The outer shell is evaluated first. The moment of inertia for the outer shell is:

$$I_o = 0.7854[R_o^4 - R_i^4]$$

$$R_o = 16.56 \text{ inches}$$

$$R_i = 15.31 \text{ inches}$$

$$I_o = 15{,}914 \text{ inches}^4$$

The moment of inertia for the inner shell is:

$$I_i = 0.7854[r_o^4 - r_i^4]$$

$$r_o = 12.38 \text{ inches}$$

$$r_i = 11.88 \text{ inches}$$

$$I_i = 2805 \text{ inches}^4$$

The maximum bending stress at 1 g for the outer and inner shells is:

$$S_b = \frac{MC_o}{I_o+I_i}$$

where,

$$C_o = 16.56 \text{ inches for the outer shell}$$

$$S_b = 1302 \text{ psi at 1 g for the outer shell}$$

The inner shell bending stress at 1 g is;

$$S_b = \frac{MC_i}{I_o + I_i}$$

where,

C_i = 12.38 inches

S_b = 973 psi at 1 g for the inner shell

For a dynamic g-loading of 20.45 g's, the outer shell maximum bending stress is 26,626 psi and the inner shell maximum bending stress is 19,900. The allowable stress criteria were utilized from Reference 2.7.3. The outer shell is a non-containment structure at 230°F and has an allowable stress of 77,040 psi. The inner shell is a containment structure at 270°F with an allowable stress of 74,160 psi. The results of this analysis indicate that the inner and outer shell beam bending stresses for 20.45 g's resulting from the punch test are within their allowable stresses.

- Valves and Fittings Considerations:

There are no exposed valves and fittings in the LWT cask design. The quick-disconnect fittings used for the cask penetrations are provided with double-closure protection and will not be seeing any direct impact loads.

Puncture of Cask Heads

The structural integrity of the closure and the bottom head assembly must be maintained if the cask falls 40 inches and lands with its end on a 6 inch diameter punch. For conservatism, the end plates are assumed to be containment boundaries. The stress analysis is performed for only the end plates and not for the 0.25 inch thick cover plate or the Boro-Silicone shielding. Puncture of these items is assumed (so the punch can reach the top or bottom end plate), and no credit is taken for their energy absorption.

The bottom end plate is the more critical area because it is 4 inches thick at the cask centerline, compared to 5 inches for the closure lid. Both plates will be considered as simply-supported or fixed edge circular plates. Therefore, all the analysis was performed for the thinner or more critical bottom end plate.

A small deflection, pseudo-elastic analysis (elastic analysis extended beyond the elastic limit) was performed using the equations of Reference 2.7.5. The stress results are compared with the appropriate design allowables from Reference 2.7.3 for accident conditions. The temperature for both end plates is 200°F per Section 3.4.2.

The model consisted of the 6 inch diameter load acting either at the center line of the cask, or at any radii between the center line and the outer cask diameter (37.5 inches). Solutions were obtained for the circular end plate having both simply supported or fixed edges. This type of engineering analysis bounds the real solution; the higher stresses and deflections are obtained from the simply supported model. The more realistic solution for the end head assembly is expected to be closer to that of the fixed edge solution because the slope of the outer edges of the circular end plates is expected to be small, even with the punch at the cask centerline.

There are no membrane stresses with this small-deflection plate model. All stresses are either bending, shear, or bearing stresses. The design criteria of Reference 2.7.3 for accident conditions limits primary membrane plus bending stresses to S_u. Since there are no membrane stresses, the bending stresses will be limited to this value.

First Load Scenerio; Punch at Cask Center:

Figure 2.7-19 illustrates the simply supported and fixed edge models (Reference 2.7.6, Table 24, Cases 16 and 17). The deflection equations for the maximum center deflections are:

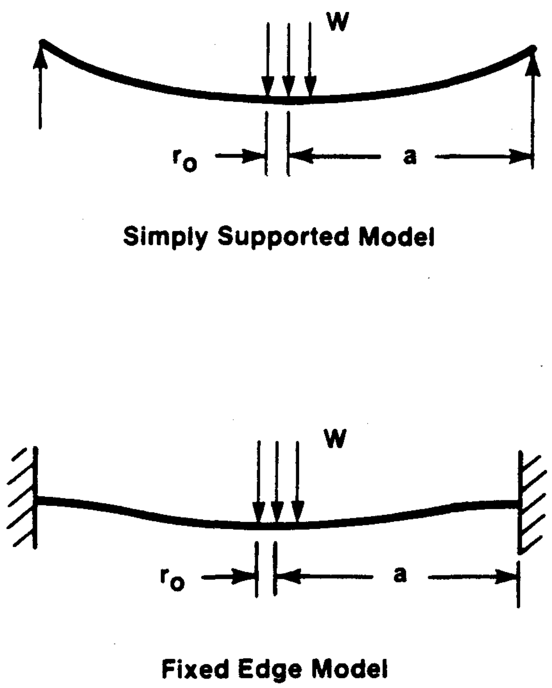


Figure 2.7-19. Circular Plate Models with Punch at Cask Center

768370-31A

For the simply supported, centerload case,

$$y = -\frac{[W \times a^2] \times [3 + \upsilon]}{[16 \times \pi \times D]\,[1 + \upsilon]} \text{ (simply supported model)}$$

where,

$$D = \frac{[E \times t^3]}{[12 \times (1 - \upsilon^2)]} \text{ inch-pounds}$$

$E = 14.5 \times 10^6$ psi

$t = 4$ inches

$a = 11.88$ inches (location of first support, inner shell)

$\upsilon = 0.3$

thus,

$D = 84{,}981{,}700$ inch-pounds, and

$y = 0.00453$ inch per 1 g

For the fixed edge case,

$$y = -\frac{[W \times a^2]}{[16 \times \pi \times D]} \text{ inch (fixed edge model)}$$

$y = 0.00178$ inch per 1 g (fixed edge, center deflection)

The bending moment and stress equations for the punch at the center and stresses at the punch radius for the fixed case are:

At the punch radius,

$$M_r = \frac{[W]}{[4 \times \pi]} \times [(1 + \upsilon)\ln(a/r) - 1 + \{(1 - \upsilon) \times r_o^2\}/\{4 \times r^2\}] \text{ (radial bending moment)}$$

where,

r = radial location where the quantity is being calculated = 3 inches

r_o = 3 inches = punch radius

M_r = 4143 inch-pounds/inch at 1 g

S_r = $[6 \times M_r]/[t^2]$ (radial bending stress)

S_r = 1554 psi at 1 g

$$M_t = \frac{[W]}{[4 \times \pi]} \times [(1+\upsilon)\ln(a/r) - \upsilon + \upsilon \times \{(1-\upsilon) \times r_o^2\}/(4 \times r^2)] \text{ (hoop bending moment)}$$

M_t = 6626 inch-pounds/inch at 1 g

S_t = $[6 \times M_t]/[t_2]$ (hoop bending stress)

S_t = 2484 psi at 1 g

The allowable stress at 200°F for accident conditions is 79,200 psi. The hoop bending stress is the most limiting stress. Based on the allowable stress, the limiting center load for the fixed edge model is 32 g's. The bending stresses from the punch load at the center decreases in the radial direction away from the load.

At the plate centerline the moments and stresses are:

$$M_r = \frac{W}{4\pi}\left[(1+\upsilon)\ln \frac{a}{r_o} \right]$$

M_r = 7660 inch-pounds per inch (radial stress resultant)

$M_t = M_r$

$M_t = 7660$

$S_r = 2872$ psi radial stress at the centerline

$S_t = 2872$ psi hoop stress at the centerline

Based on the allowable stress, the limiting load at the plate centerline is 27.6 g's.

The same type of bending stress analysis was performed for the simply supported model.

At the punch radius,

$$M_r = \frac{W}{16 \times \pi} [4 \times (1 + \upsilon) \ln (a/r) + (1-\upsilon) \times (\frac{a^2-r^2}{a^2}) \times (\frac{r_o^2}{r^2})]$$

= 8392 inch-pounds per inch at 1 g

$S_r = \frac{6 \times 8392}{4^2} = 3147$ psi radial stress at 1 g

$$M_t = \frac{W}{16x\pi} [4 \times (1+\upsilon) \ln (a/r) + (1-\upsilon) \times (4-r_o^2/r^2)]$$

= 9944 inch-pounds per inch at 1 g

$S_t = \frac{6 \times 9944}{4^2} = 3729$ psi hoop stress at 1 g

The allowable deceleration load for this case becomes 79,200/3729 or 21.2 g's.

At the cask centerline, the maximum bending moments and stress using the simply supported model is given as follows,

$$M_r = M_t = \frac{W}{4\pi}\left[(1 + \upsilon) \ln (a/r_o) + 1\right]$$

$$= 11{,}985 \text{ inch-pounds per inch at 1 g}$$

$$S_r = S_t = \frac{6(11{,}985)}{4^2} = 4495 \text{ psi for 1 g}$$

The allowable deceleration load for this case becomes 79,200/4495 or 17.6 g's.

The punch bearing stress considers the pressure of the punch top surface on the flat end plate surface during contact. The stress area is based on the minimum diameter (5.5 inches, due to the 1/4 inch chamfer on the outer perimeter of the top punch). The allowable bearing stress at 200°F is 79,200 psi. The bearing stress is:

$$S_B = W/A_{min}$$

where,

$$A_{min} = \pi/4 \times (5.5)^2$$

$$= 23.76 \text{ square inches}$$

$$S_B = 2273 \text{ psi at 1 g}$$

The allowable deceleration based on bearing stress is equal to 79,200/2273 or 34.85 g's.

In summary, for the first load scenerio (the punch at the center) the tolerable punch load is between 17.6 and 27.6 g's depending on the head assembly edge conditions. The realistic solution is closer to 27.6 g's than 17.6. The maximum deflection at the center is about 0.093 inches at 20.45 g's (0.00453 x 20.45), based on the simply supported solution. The more realistic center deflection is closer to that of the fixed edge model (0.00178 x 20.45), or 0.0364 inches at 20.45 g's. For final design, a more detailed analysis will be performed to eliminate the need for bounding assumptions.

Second Load Scenerio: Punch Halfway From Center to First Support:

The model for the analysis of the punch halfway from the center of the cask to the inner shell on the bottom end plate is illustrated in Figure 2.7-20.

For this load scenario the value of p in Figure 2.7-20 is one half the value of the radius a. The stress solution for the simply supported and fixed edge cases are given (Reference 2.7.6, Table 24, Cases 18 and 19 respectively) as follows.

For the simply supported solution,

$$\max M_r = \max M_t = \frac{W}{4\pi}\left[1 + (1+\upsilon)\ln\left(\frac{a-p}{r_o}\right) - \frac{(1-\upsilon)}{4(a-p)^2}\, r_o^2\right]$$

a_1 = 1.5 (11.88) = 17.82 inches

W = 54000 pounds

r_o = 3 inches

p = a/2 = 11.88/2 = 5.94 inches

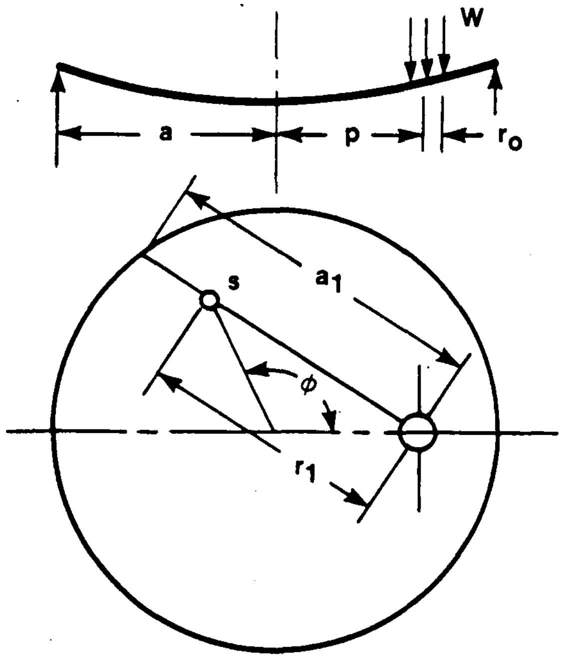
υ = 0.3

max M_r = max M_t = 7921.4 inch-pounds/inch at punch center

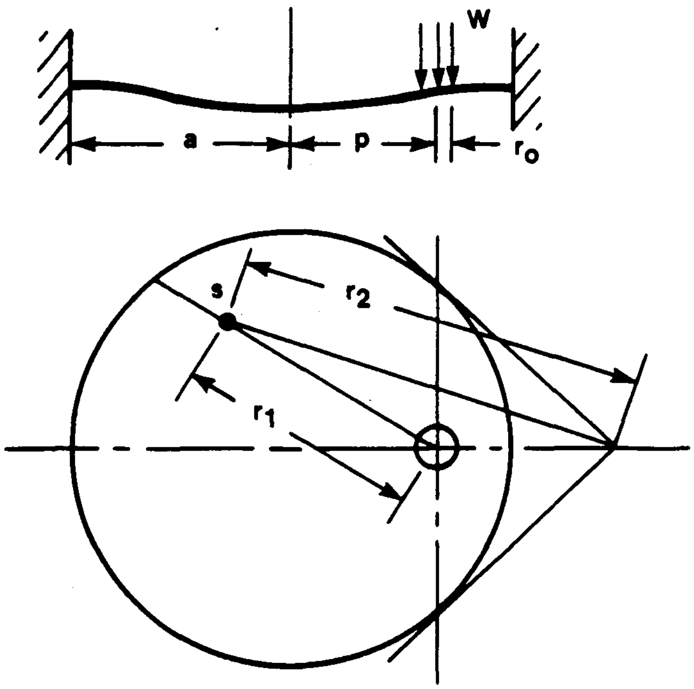
Moments at the punch radius are given by the following:

$$M_r = \frac{\max M_r \times (1+\upsilon)\ln\left(\frac{a_1}{r_o}\right)}{1 + (1+\upsilon)\ln\left(\frac{a_1}{r_o}\right)}$$

$$M_t = \frac{\max M_t \times (1+\upsilon)\ln\left(\frac{a_1}{r_o}\right) + 1 - \upsilon}{1 + (1+\upsilon)\ln\left(\frac{a_1}{r_o}\right)}$$



Simply Supported Model



Fixed Edge Model

Figure 2.7-20. Circular Plate Models for Punch Located at Any Radius

768370-32A

where,

$a_1 = 1.5$
$S = r_1 = 3$ inches
$t = 4$ inches

$M_r = 5532.7$ inch-pounds/inch (radial)
$M_t = 7204.8$ inch-pounds/inch (hoop)

The maximum plate stresses are,

$$(S_r)_{max} = (S_t)_{max} = 6M_{max}/t^2$$

$$S_r = S_t = 2970.5$$

Allowable deceleration = 79,200/2970.5 = 26.7 g's

For the fixed edge case, the maximum moment is at the load point,

$$M_r = \frac{W(1+\upsilon)}{16\pi}[4 \ln (\frac{a-p}{r_o}) + (\frac{r_o}{a-p})^2]$$

$p = a/2 = 5.94$ inches

$M_r = 4171$ inch-pounds/inch

$S_r = 6M_r/t^2$ radial stress

$S_r = 1564$ psi per 1 g

Allowable deceleration = 79200/1564 = 51 g's

The results of this analysis indicates that the maximum tolerable dynamic decelerations are 26.7 g's for the simply supported model and 51 g's for the fixed edge model. Stresses are assumed to be a maximum with the punch located one half the distance between the center of the plate and the outer radius.

Third Load Scenerio; Cask Falls on Punch Over Purge Gas Hole:

This analysis is for the case of the cask falling on the punch and landing on the bottom end plate, just inside the outer shell. Figure 2.7-21 illustrates a schematic of this configuration and also depicts the case of when the punch is directly under the 0.250 inch diameter hole provided for purge gas. Two very conservative assumptions were made so that the analytical model of Reference 2.7.6 can be used. These two assumptions are:

1. The inner shell support is no longer present. The bottom plate edge is only supported at a radius of 15.45 inches, rather than at a radius of 11.88 inches.

2. The bottom plate thickness is uniform at 3 inches rather than 4 inches. This was assumed because the thickness does change from 4 inches to 3 inches at a radial position of 12.38 inches.

The punch shear stress was calculated for this case. The plate thickness used for this calculation was only 2.75 inches, which accounts for the 0.250 inch diameter cavity. The allowable shear stress for a Grade 9 titanium containment structure at 200°F is 33,264 psi. The punch shear stress calculation is as follows:

$$S_s = W/[\pi \times d \times t_p]$$

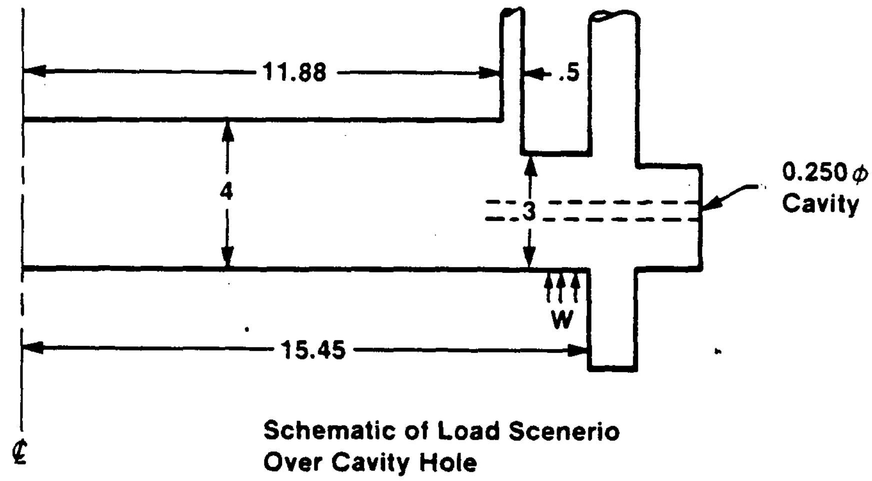
where,

t_p = 2.75 inches minimum plate thickness over the punch

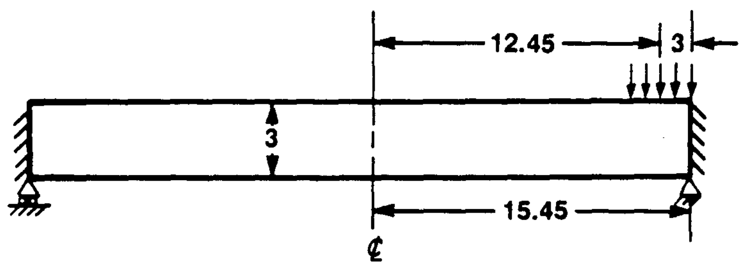
S_s = 1042 psi at 1 g

The tolerable dynamic deceleration due to punch shear is:

D.A. = 33,264/1042 = 32 g's



Schematic of Load Scenerio
Over Cavity Hole



Simplified Model of 3 Inch Thick,
One Outer Support
Fixed Edge or Simply Supported

Figure 2.7-21. Schematic of Load Scenario Three and Simplified Analytical Model

768370-37A

A calculation similar to the other cases was performed to determine the bending stress. The effective plate thickness (including the two 0.250 inch diameter holes) was determined to be 2.997 inches. The results of the bending calculations indicated that the shear stress was the design limiting condition with a tolerable dynamic deceleration of 32 g's. The tolerable dynamic decelerations base on bending stress was 33 g's for the simply supported model and 85 g s for the fixed edge model. The bending stress calculations are as follows:

Simply supported edges,

$$M_r = M_t = \frac{W}{4 x \pi} \left[1 + (1+\upsilon) \ln\left(\frac{a-p}{r_o}\right) - \frac{(1-\upsilon) \times r_o^2}{4x(a-p)^2} \right]$$

M_r = 3545 inch-pounds/inch

$S_r = S_t = 6\ Mr/t^2$

$S_r = S_t$ = 2363 psi at 1 g

Allowable deceleration = 79,200/2363 = 33.5 g's

Fixed edge model,

$$M_r = \frac{W \times (1+\upsilon)}{16 \times \pi} \left[4 \ln\left(\frac{a-p}{r_o}\right) + \left(\frac{r_o^2}{a-p}\right) \right]$$

M_r = 1397 inch-pounds/inch

$S_r = 6\ M_r/t^2$

S_r = 931 psi at 1 g

Allowable Deceleration = 79,200/931 = 85 g's

2.7.3 Thermal

The Hypothetical Fire Accident condition is analyzed in Section 3.5. Maximum temperatures from that analysis are used for structural calculations.

2.7.3.1 Summary of Pressure and Temperatures

The maximum fire accident condition temperatures for the various cask components are presented in Table 3.5-2.

2.7.3.2 Differential Thermal Expansion

Differential thermal expansions due to the fire accident are of little consequence in the LWT cask. All stresses resulting from differential expansions can be classified as secondary, displacement limited stresses. There are no limits on secondary stresses for accident conditions (per Section 2.1.2), because differential expansions do not compromise the integrity of the cask. Throughwall (and through thickness) thermal gradients also result in secondary stresses and again are of little consequence in the cask.

2.7.3.3 Stress Calculations

The concern for accident conditions is with primary, load-controlled stresses. The only load-controlled stresses during and after the fire transient are those resulting from pressure and dead weight, and these are relatively small. Although temperatures associated with the fire transient are higher than those associated with other accident conditions, the cask is design limited by the significantly more severe drop accident events.

The outer shell reaches a maximum temperature of 541.8°F, 42 minutes into the transient (See Table 3.5-1). The inner shell average temperature at 42 minutes into the transient is 225.8°F. The stresses produced on the inner and outer shells as a consequence of this temperature difference are -5,624 psi (compression) for the outer shell and 18,500 psi (tensile) for the inner shell.

The critical elastic buckling stress for a cylinder in axial compression with no constraints on the end (page 428 of Reference 2.7.6) is:

$$\sigma' = 0.3 \times E \times t/r$$

where

E = 12,000,000 psi for outer shell at 541.8°F
t = 1.25 inch for outer shell
r = 15.31 inches for outer shell

Using the above formula, the elastic buckling stress for the outer cylindrical shell is 293,925 psi. Since the outer shell is not a thin cylindrical tube (t/r = 12.25), elastic buckling will not occur. Therefore, the outer shell could only buckle plastically, and a conservative estimate of the plastic buckling stress can be taken as the yield strength of the material at 541.8°F or 43,600 psi. The allowable buckling stress then becomes 43,600/1.5 or 29,070 psi.

The inner shell would be under tension and buckling would not occur. For the outer shell, the margin against buckling is:

M.S. = 29,070/5659 - 1 = + 5.14

2.7.3.4 Comparison with Allowable Stresses

During the final design phase of the Project, thermally induced stresses will be determined for all key areas of the cask. In addition, the rotation of the upper flange due to the moments produced by the differential thermal expansions of the main shells and the temperature gradients within the flange will be evaluated along with deformations of the closure lid. This evaluation will address the potential for any gaps at the lid-to-flange interface which might compromise the containment.

2.7.4 Immersion - Fissile Materials

In accordance with Paragraph 71.73(c)(4) of 10 CFR Part 71, the package must be subjected to an immersion test under a head of water of 3 feet for the case when water in-leakage is not assumed in the criticality analysis. As the criticality evaluation presented in Section 6.0 considers the effect of water inleakage, the test is not applicable.

2.7.5 Immersion - All Packages

In accordance with IAEA Safety Series No. 6, the package must be evaluated for immersion under a head of 200 m (656 feet) of water for a period of not less than one hour. This depth of water is equivalent to an external pressure of 285 psi. This requirement supersedes the requirement in Paragraph 71.73(c)(5) of 10 CFR Part 71 which requires immersion in 50 feet of water.

The external pressure will load the cylindrical portion of the cask in compression, specifically the cylindrical outer shell. In Section 2.6.4, it was shown that the critical buckling pressure for the 1.25 inch thick outer cylindrical shell is 1827.9 psi. Using the 1.5 design factor for buckling during the hypothetical accident conditions, the design allowable buckling pressure becomes 1218.6 psi. Hence, the margin of safety for the outer cylindrical shell against buckling during the immersion accident is:

$$M.S. = \frac{1218.6}{285 \text{ psi}} - 1.0 = +3.3$$

The thick-plate end closures will be loaded in bending during the immersion accident. The bottom end closure plate which has a thickness of 4 inches will be the most severely stressed. If the end closure circular plate is treated as a uniformly loaded, simply-supported plate the maximum stress at the center is given by (Reference 2.7.7).

$$\sigma_{max} = \frac{3\,(3 + \upsilon)\,pa^2}{8t^2} \qquad (1)$$

where υ = Poisson's ratio, 0.3

p = uniform pressure, 285 psi

a = plate radius, 15.935 inches

t = plate thickness, 4 inches

Substituting into equation (1) gives the following bending stress in the plate,

$$\sigma_{max} = \frac{3\ (3+0.3)\ (285)\ (15.935)^2}{8\ (4.0)^2} = 5597 \text{ psi}$$

The design allowable for primary membrane plus bending stress for the accident condition is 3 S_m where

S_m = 29,000 psi at 200°F (for Grade 9 Titanium).

Therefore, there is a large margin of safety against failure of end closures during the immersion accident. This is shown by,

$$M.S. = \frac{(29,000)\ (3)}{5597} - 1 = +14.5$$

For the final design more detailed analysis will be completed at the structural discontinuities between the cask closures and cylindrical shells.

2.7.6 Summary of Damage

From the analyses presented in Sections 2.7.1 through 2.7.5, it has been shown that the accident test sequence will not result in any significant structural damage to the major components (inner and outer shells, bottom head assembly and closure lid) of the cask.

For the 30 foot free drop, the SCANS computer program was used to determine cask decelerations and resulting loads and stresses in the cask. Specifically, the stresses in the major cask structural components were determined and checked against design criteria. It was shown that the design of the outer and inner shell, bottom head assembly, and the closure lid thicknesses are adequate to withstand the loadings from the 30 foot drop. For the 40 inch drop on a 6 inch diameter pin, it was shown that the cask outer shell will not be perforated and the overall response of the cask to this event will produce stresses that are within the design criteria. The cask heads were also shown to be able to withstand the 40 inch drop accident.

In all cases, elastic analysis was used to demonstrate that damage to the cask will be minimal during the accident test sequence, and leak tightness of the cask will not be compromised during these tests.

2.8 SPECIAL FORM

Paragraphs 71.75 and 71.77 of 10 CFR Part 71 concerning the qualification and tests for special form radioactive material does not apply to the LWT cask because it will be certified to transport only spent nuclear fuel.

2.9 FUEL RODS

This section does not apply to the LWT cask. In Section 4.0, Containment, no credit will be taken for the fuel rod cladding for containment of radioactive material under Normal or Accident test conditions.

2.10 Appendix

2.10.1 References

2.1.1 10 CFR Part 71, "Packaging and Transportation of Radioactive Material," May 31, 1988.

2.1.2 International Atomic Energy Agency Safety Series 6, "Regulations for the Safe Transport of Radioactive Materials," 1985.

2.1.3 NRC Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks," Second Proposed Revision 1, September, 1988.

2.1.4 ANSI N14.23-1980, "Design Basis for Resistance to Shock and Vibration of Radioactive Material Packages Greater than One Ton in Truck Transport," May 1980.

2.1.5 SAND-76-0427, "Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks," Magnuson and Wilson, Sandia National Laboratories, June 1977.

2.1.6 Code of Federal Regulations, Volume 49 Part 393, "Parts and Accessories Necessary for Safe Operation," October 1, 1986.

2.1.7 NRC Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," March 1978.

2.1.8 ASME Boiler and Pressure Vessel Code, Section III, Division 1 Appendices, 1989.

2.1.9 ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, "Nuclear Components," 1989.

2.1.10 Manual of Steel Construction, Eighth Edition, American Institute of Steel Construction, Inc., 1980.

2.1.11 Aluminum Construction Manual, "Specification for Aluminum Structures," Section 1, Fourth Edition, April 1982, The Aluminum Association.

2.3.1 Ti-3Al-2.5V Seamless Tube Engineering Guide, Second Edition, Sandvik Special Metals Corp, May 1987.

2.3.2 P. A. Russo and S. R. Seagle, "Properties of Titanium for Industrial Applications with Emphasis on Ti-3Al-2.5V," <u>Industrial Applications of Titanium and Zirconium: Third Conference, ASTM STP 830</u>, R. T. Webster and C. S. Young, Eds., American Society of Testing and Materials, 1984, pp 99-112.

2.3.3 Ivan L. Caplan, "Ti-3Al-2.5V for Seawater Piping Applications," <u>Industrial Applications of Titanium & Zirconium: Fourth Volume, ASTM STP 917</u>, C. S. Young and J. C. Durhan, Eds., American Society for Testing Materials, Philadelphia, 1986, pp 43-54.

2.3.4 "Metallurgical Products," Eldorado Resources Limited, Port Hope Canada.

2.3.5 "Development of Circumferential Honeycomb Impact Limiters for Defense High Level Waste Shipping Cask," A. Zimmer, et. al., Waste Management '88, Tucson, Arizona, March 1988.

2.5.1 ANSI Standard N14.2, (Proposed) "Tie-down for Truck Transport of Radioactive Materials," Draft 5, Revision 2, September 1986.

2.5.2 Computer Program CYLNOZ, Version NOZC, Users Manual prepared by J. G. Dudiak, Westinghouse Nuclear Advanced Technology Division, Pittsburgh, PA, September 11, 1981.

2.5.3 Welding Research Council Bulletin 107, Local Stresses in Spherical and Cylindrical Shells Due to External Loadings, K. R. Wickman, et. al., June 1977 reprint of August 1965 report.

2.6.1 SCANS, "A Microcomputer Based Analysis System for Shipping Cask Design Review," Volume 1 -- User's Manual to Version 1a, NUREG/CR-4554, M. A. Gerhard, et al, Lawrence Livermore National Laboratory, December 1988.

2.6.2 Raymond J. Roark, "Formulas for Stress and Strain," Fourth Edition, McGraw-Hill, 1965.

2.7.1 "WECAN - Westinghouse Electric Computer ANalysis," R&D Report 8-1E7-WESAD-R2, Third Edition, Revision X, Westinghouse R&D Center, Pittsburgh, PA. (Westinghouse Proprietary), June 1, 1988.

2.7.2 "FIGURES II User's Guide, Rev. E," R&D Report 88-1E7-FISAD-R2, Westinghouse R&D Center, Pittsburgh, PA. (Westinghouse Proprietary), August 9, 1988.

2.7.3 "TITAN Legal Weight Truck Cask Design Requirements," NWD-TR-007, Rev. 2, Westinghouse Nuclear Services Division, September 1989.

2.7.4 "Predrop Test Analysis of a Spent-Fuel Cask," EPRI NP-4785, Electric Power Research Institute, October 1986.

2.7.5 "Cask Designers Guide," ORNL-NSIC-68, Oak Ridge National Laboratory, February 1970.

2.7.6 Raymond J. Roark Formulas for Stress and Strain, Fifth Edition, 1975, McGraw-Hill.

2.7.7 S. Timoshenko and S. Woinowsky-Krieger, "Theory of Plates and Shells," McGraw Hill, 1959.

2.10.2 Honeycomb Impact Limiter Load-Deflection Calculations

The total force exerted by a honeycomb impact limiter is equal to the sum of the forces exerted by each honeycomb segment, or

$$F = \sum_{i=1}^{n} \sigma_{n_i} A_i$$

where, F = total force exerted by the impact limiter

σ_{n_i} = stress normal to the plane of crushing in the i^{th} honeycomb segment,

A_i = crush area of the i^{th} honeycomb segment which is a function of crush depth, and

n = number of honeycomb segments that have been partially or fully crushed.

The effective crush stress, σ_n, is a function of the honeycomb crush strength and the angle between the normal to the plane of crushing and cell direction. The corrections are multiplied if angles in two direction are involved, or

$$\sigma n_i = \sigma_{cr} \times \alpha_c \times \beta_c$$

$$\alpha_c = \frac{1}{\sqrt{\cos^2\alpha + 4\sin^2\alpha}}$$ (Circumferential angle correction)

$$\beta_c = \frac{1}{\sqrt{\cos^2\beta + 4\sin^2\beta}}$$ (Drop angle correction)

Where, σ_{cr} = manufacturer's crush strength of honeycomb, in direction of cells

α = angle between the normal to the plane of crushing and cell direction in first direction

β = angle between the normal to the plane of crushing and cell direction in second direction

For the honeycomb impact limiter, load-deflection calculations were completed for the 0° (horizontal), 15°, 30°, 45°, 60°, 75°, 90° and C.G. over corner impact limiter orientations, respectively. The calculations and results are given in Tables 2.10-1 through 2.10-8.

Table 2.10-1

Impact Limiter Honeycomb Segment Crush Areas and Load Calculations for 0° Orientation

DEPTH		2*A1	2*A2	2*A3	2*A4	2*B1	2*B2	2*B3	2*B4	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.452"	AREA	464.04	0.00	0.00	0.00	33.81	0.00	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	339468	0	0	0	26940	0	0	0	366408	329768	403049	458011
3.243"	AREA	431.96	235.77	0.00	0.00	72.18	39.39	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	316000	147386	0	0	57513	26820	0	0	547719	492948	602491	684649
5.707"	AREA	389.57	449.87	0.00	0.00	119.05	137.48	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	284990	281225	0	0	94860	93608	0	0	754683	679214	830151	943353

Table 2.10-1 (Continued)

Impact Limiter Honeycomb Segment Crush Areas and Load Calculations for 0° Orientation

DEPTH		2*A1	2*A2	2*A3	2*A4	2*B1	2*B2	2*B3	2*B4	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
8.803"	AREA	339.27	391.76	240.52	0.00	168.24	194.27	119.27	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	248193	244899	124126	0	134054	132276	67043	0	950591	855532	1045650	1188239
12.477"	AREA	283.71	327.65	447.52	0.00	252.53	245.44	335.23	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	207548	204822	230954	0	201217	167117	188436	0	1200094	1080084	1320103	1500117
16.667"	AREA	225.97	260.89	356.43	255.72	244.42	282.20	385.54	276.61				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	0.975	0.834	0.688	0.588	0.975	0.834	0.688	0.588				
	DROP ANGLE CORR.	1.000	1.000	1.000	1.000	0.584	0.584	0.584	0.584				
	ANGLE CORR.	0.975	0.834	0.688	0.588	0.569	0.486	0.402	0.343				
	CORR. CRUSH STR.	732	625	516	441	797	681	562	481				
	TOTAL CRUSH LOAD	165308	163089	183945	112849	194755	192146	216715	132956	1361764	1225588	1497940	1702205

Table 2.10-2

Impact Limiter Honeycomb Segment Areas and Load Calculations for 15° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	B1	2*B2	2*B3	2*B4	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"	AREA	36.09	9.42	0.00	0.00	12.51	3.56	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	24699	5883	0	0	11899	3090	0	0	45571	41014	50128	56963
2.0"	AREA	76.10	53.96	0.00	0.00	26.03	18.90	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	52081	33698	0	0	24759	16404	0	0	126941	114247	139635	158676
3.0"	AREA	115.16	122.68	0.00	0.00	38.97	43.06	0.00	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	78813	76613	0	0	37067	37373	0	0	229865	206879	252852	287332

Table 2.10-2 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 15° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	B1	2*B2	2*B3	2*B4	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"	AREA	153.34	204.06	7.76	0.00	48.85	71.24	2.98	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	104942	127434	4014	0	46464	61832	2143	0	346829	312146	381512	433536
6.0"	AREA	211.37	315.28	78.26	0.00	72.25	122.28	30.16	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	144656	196890	40485	0	68721	106131	21684	0	578568	520712	636425	723210
8.0"	AREA	194.64	419.76	212.12	0.00	90.77	166.30	81.50	0.00				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	133207	262137	109734	0	86337	144337	58597	0	794348	714914	873783	992936

Table 2.10-2 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 15° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	B1	2*B2	2*B3	2*B4	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"	AREA	163.12	356.02	432.58	89.58	118.55	233.62	199.64	42.30				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	111635	222332	223782	38776	112760	202767	143538	25448	1081037	972934	1189141	1351297
16.0"	AREA	134.19	292.54	384.60	359.30	133.98	273.28	278.14	183.20				
	CRUSH STRENGTH	750	750	750	750	1400	1400	1400	1400				
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	1.000	0.913	0.756	0.633				
	DROP ANGLE CORR.	0.913	0.913	0.913	0.913	0.679	0.679	0.679	0.679				
	ANGLE CORR.	0.913	0.833	0.690	0.577	0.679	0.620	0.514	0.430				
	CORR. CRUSH STR.	684	624	517	433	951	868	719	602				
	TOTAL CRUSH LOAD	91836	182689	198961	155529	127436	237189	199978	110215	1303833	1173450	1434216	1629791

Table 2.10-3

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	C1	2*C2	2*C3	2*C4
1.0"	AREA	19.42	6.40	0.00	0.00	0.00	20.17	6.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	11010	3311	0	0	0	23214	7163	0	0	0	0	0	0	0
2.0"	AREA	40.56	32.40	0.00	0.00	0.00	41.24	34.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	22994	16761	0	0	0	47465	35939	0	0	0	0	0	0	0
3.0"	AREA	61.26	71.84	0.22	0.00	0.00	60.62	76.10	0.28	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	34730	37164	94	0	0	69770	79923	244	0	0	0	0	0	0

Table 2.10-3 (Continued)

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"	44698	40228	49167	55872
2.0"	123159	110843	135475	153949
3.0"	221925	199732	244117	277406

Table 2.10-3 (Continued)

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	C1	2*C2	2*C3	2*C4
4.0"	AREA	81.48	114.68	8.50	0.00	0.00	78.32	119.48	10.06	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	46193	59326	3643	0	0	90142	125482	8752	0	0	0	0	0	0
6.0"	AREA	120.35	197.12	55.74	0.00	0.00	108.83	194.58	67.76	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	68229	101974	23887	0	0	125257	204354	58951	0	0	0	0	0	0
8.0"	AREA	157.18	275.40	137.82	0.66	0.00	132.78	254.34	165.42	1.06	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	89109	142470	59061	237	0	152822	267116	143915	772	0	0	0	0	0

Table 2.10-3 (Continued)

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"	333537	300184	366891	416922
6.0"	582652	524387	640917	728315
8.0"	855501	769951	941051	1069376

Table 2.10-3 (Continued)

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	C1	2*C2	2*C3	2*C4
12.0"	AREA	194.23	404.00	310.54	80.22	0.00	137.89	296.82	333.76	131.82	0.00	12.19	12.84	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	110114	208997	133078	28765	0	158703	311730	290370	95961	0	9467	9099	0	0
16.0"	AREA	159.46	346.74	420.74	267.52	10.18	87.94	196.50	270.62	390.14	34.48	44.42	83.08	60.30	10.16
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.756	0.756	0.756	0.756	0.756	0.822	0.822	0.822	0.822	0.822	0.555	0.555	0.555	0.555
	ANGLE CORR.	0.756	0.690	0.571	0.478	0.419	0.822	0.750	0.621	0.520	0.456	0.555	0.506	0.419	0.351
	CORR. CRUSH STR.	567	517	429	359	314	1151	1050	870	728	638	777	709	587	491
	TOTAL CRUSH LOAD	90402	179375	180303	95927	3201	101214	206371	235438	284010	22013	34496	58873	35397	4990

Table 2.10-3 (Continued)

Impact Limter Honeycomb Segment Areas and Load Calculations for 30° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"				
	1356284	1220655	1491912	1695354
16.0"				
	1532011	1378810	1685212	1915014

Table 2.10-4

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	C1	2*C2	2*C3	2*C4
1.0"	AREA	15.44	6.84	0.00	0.00	0.00	59.29	28.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	7324	2961	0	0	0	80375	35304	0	0	0	0	0	0	0	0
2.0"	AREA	31.85	30.90	0.00	0.00	0.00	113.96	126.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	15109	13376	0	0	0	154486	156704	0	0	0	0	0	0	0	0
3.0"	AREA	47.91	64.26	2.74	0.00	0.00	157.72	249.10	16.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	22727	27816	983	0	0	213808	308138	16498	0	0	0	0	0	0	0

Table 2.10-4 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH	2*C5	2*C6	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	125964	113368	138560	157455
2.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	339674	305707	373642	424593
3.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	589970	530973	648967	737462

Table 2.10-4 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	C1	2*C2	2*C3	2*C4
4.0"	AREA	63.50	97.12	15.62	0.00	0.00	189.87	352.32	89.78	0.00	0.00	0.00	1.04	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	30123	42040	5601	0	0	257392	435821	91999	0	0	0	921	0	0	0
6.0"	AREA	93.37	160.12	68.46	0.00	0.00	163.61	352.56	347.76	0.00	0.00	0.00	17.86	28.12	5.24	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	44292	69311	24548	0	0	221793	436118	356354	0	0	0	15815	22721	3507	0
8.0"	AREA	121.51	219.48	138.16	12.76	0.00	138.10	298.48	375.98	171.62	0.00	0.00	32.79	60.52	41.08	4.76
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	57641	95006	49541	3829	0	187211	369221	385272	147152	0	0	29036	48901	27497	2666

Table 2.10-4 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH	2*C5	2*C6	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	863896	777507	950286	1079870
6.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	1194460	1075014	1313907	1493076
8.0"	0.00	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	0	0	1402972	1262675	1543269	1753715

Table 2.10-4 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	C1	2*C2	2*C3	2*C4
12.0"	AREA	176.60	327.28	265.28	125.50	0.18	92.19	201.10	259.50	393.18	130.56	0.00	53.89	106.46	100.82	82.92
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	83775	141669	95124	37655	47	124975	248761	265913	337124	98176	0	47720	86022	67484	46442
16.865"	AREA	189.26	407.58	396.76	301.98	95.44	45.44	101.92	140.58	229.72	402.58	122.04	63.72	128.34	130.90	134.58
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	1.000	0.913	0.756	0.633
	DROP ANGLE CORR.	0.633	0.633	0.633	0.633	0.633	0.968	0.968	0.968	0.968	0.968	0.968	0.633	0.633	0.633	0.633
	ANGLE CORR.	0.633	0.577	0.478	0.400	0.351	0.968	0.884	0.732	0.612	0.537	0.497	0.633	0.577	0.478	0.400
	CORR. CRUSH STR.	474	433	359	300	263	1356	1237	1025	857	752	696	885	808	669	560
	TOTAL CRUSH LOAD	89780	176428	142270	90607	25114	61599	126075	144054	196969	302725	84887	56424	103701	87618	75375

Table 2.10-4 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 45° Orientation

DEPTH	2*C5	2*C6	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"	25.46	0.00				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	12506	0	1693392	1524053	1862731	2116740
16.865"	136.02	102.24				
	1400	1400				
	0.555	0.513				
	0.633	0.633				
	0.351	0.325				
	491	454				
	66811	46453	1876891	1689202	2064580	2346114

Table 2.10-5

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	C1
1.0"	AREA	0.00	0.00	0.00	0.00	0.00	51.00	56.40	1.34	0.00	0.00	0.00	0.00	0.00	0.00	10.85
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	0	0	0	0	0	70058	70696	1391	0	0	0	0	0	0	11482
2.0"	AREA	0.00	0.00	0.00	0.00	0.00	118.12	165.14	42.14	0.00	0.00	0.00	0.00	0.00	0.00	20.86
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	0	0	0	0	0	162259	207000	43757	0	0	0	0	0	0	22075
3.0"	AREA	0.00	0.00	0.00	0.00	0.00	200.05	297.88	120.82	10.36	0.00	0.00	0.00	0.00	0.00	29.65
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	0	0	0	0	0	274805	373388	125455	9001	0	0	0	0	0	31377

Table 2.10-5 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"	14.34	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	13848	352	0	0	0	0	0	0	0	0	0	0	167827	151044	184610	209784
2.0"	35.96	14.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	34725	11711	0	0	0	0	0	0	0	0	0	0	481528	433375	529680	601909
3.0"	54.96	38.58	5.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	53073	30862	3909	0	0	0	0	0	0	0	0	0	901870	811683	992057	1127337

Table 2.10-5 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	C1
4.0"	AREA	14.58	9.52	0.00	0.00	0.00	196.80	395.86	213.80	49.10	0.00	0.00	0.00	0.00	0.00	37.23
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	6066	3614	0	0	0	270340	496204	222002	42661	0	0	0	0	0	39399
6.0"	AREA	46.29	71.44	13.00	0.00	0.00	166.92	354.36	376.02	171.28	30.94	0.00	0.00	0.00	0.00	48.77
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	19258	27120	4088	0	0	229295	444184	390446	148817	23576	0	0	0	0	51611
8.0"	AREA	75.90	133.40	71.40	1.68	0.00	139.13	296.06	356.22	316.92	113.58	13.62	0.00	0.00	0.00	55.47
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	31576	50642	22453	442	0	191120	371106	369886	275357	86546	9600	0	0	0	58702

Table 2.10-5 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"	71.36	59.52	27.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	68910	47612	18113	0	0	0	0	0	0	0	0	0	1214920	1093428	1336412	1518650
6.0"	96.38	91.64	77.60	30.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	93071	73306	51942	18139	0	0	0	0	0	0	0	0	1574852	1417367	1732338	1968565
8.0"	111.00	110.78	108.46	95.92	28.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	107189	88617	72598	56307	15432	0	0	0	0	0	0	0	1807572	1626815	1988329	2259465

Table 2.10-5 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	C1
12.0"	AREA	128.93	244.38	198.94	102.46	1.84	89.63	192.18	235.92	329.60	324.18	137.06	33.92	0.00	0.00	55.73
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	53638	92772	62561	26961	425	123123	240894	244971	286374	247019	96605	23298	0	0	58977
14.981"	AREA	163.11	315.90	281.14	207.28	62.56	58.03	125.82	158.96	230.16	358.72	257.54	115.00	35.58	0.76	53.17
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	1.000
	DROP ANGLE CORR.	0.555	0.555	0.555	0.555	0.555	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.981	0.756
	ANGLE CORR.	0.555	0.506	0.419	0.351	0.308	0.981	0.895	0.742	0.621	0.544	0.503	0.491	0.503	0.544	0.756
	CORR. CRUSH STR.	416	380	314	263	231	1374	1253	1038	869	762	705	687	705	762	1058
	TOTAL CRUSH LOAD	67858	119923	88411	54543	14437	79715	157713	165058	199975	273338	181523	78987	25078	579	56268

Table 2.10-5 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 60° Orientation

DEPTH	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"	112.04	113.74	116.52	120.32	124.96	130.24	53.24	11.54	5.56	2.94	2.74	0.00				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	108193	90985	77993	70630	67852	68914	28909	6774	3722	2352	2646	0	2086586	1877928	2295245	2608233
14.981"	106.86	108.48	111.14	114.76	119.20	124.24	129.62	100.14	49.70	32.76	26.20	12.21				
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000				
	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756	0.756				
	0.690	0.571	0.478	0.419	0.388	0.378	0.388	0.419	0.478	0.571	0.690	0.756				
	966	800	669	587	543	529	543	587	669	800	966	1058				
	103191	86777	74391	67366	64725	65739	70383	58784	33267	26206	25300	12921	2252456	2027210	2477701	2815570

Table 2.10-6

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
1.0"	AREA	0.00	0.00	0.00	0.00	0.00	13.66	21.64	6.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	16139	23330	6073	0	0	0	0	0	0	0
2.0"	AREA	0.00	0.00	0.00	0.00	0.00	28.82	50.90	27.18	11.90	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	34050	54874	24274	8893	0	0	0	0	0	0
3.0"	AREA	0.00	0.00	0.00	0.00	0.00	45.47	76.42	66.90	34.24	7.12	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	53721	82387	59746	25587	4666	0	0	0	0	0

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
1.0"	0.00	0.00	0.00	18.95	32.36	12.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	24209	37723	11820	0	0	0	0	0	0	0	0	0	0
2.0"	0.00	0.00	0.00	34.18	65.14	53.12	21.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	43665	75935	51296	17405	0	0	0	0	0	0	0	0	0
3.0"	0.00	0.00	0.00	45.34	89.20	83.56	68.18	12.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	57922	103982	80691	55091	9014	0	0	0	0	0	0	0	0

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"	119292	107363	131222	149115
2.0"	310391	279352	341430	387988
3.0"	532806	479525	586087	666008

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
4.0"	AREA	0.00	0.00	0.00	0.00	0.00	66.32	105.54	92.70	60.86	24.58	3.90	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	78354	113781	82787	45479	16109	2364	0	0	0	0
6.0"	AREA	0.00	0.00	0.00	0.00	0.00	102.35	192.76	161.24	119.82	77.76	40.62	10.50	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	120922	207811	143998	89538	50960	24624	6203	0	0	0
8.0"	AREA	0.00	0.00	0.00	0.00	0.00	146.85	278.60	238.70	186.36	133.34	86.68	48.86	19.68	1.44	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	0	0	0	0	0	173497	300354	213175	139262	87385	52546	28863	11930	944	0

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
4.0"	0.00	0.00	0.00	52.43	104.54	103.12	98.62	82.10	17.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	66979	121864	99579	79687	58178	11510	0	0	0	0	0	0	0
6.0"	0.00	0.00	0.00	55.08	110.44	111.24	112.54	114.26	116.32	116.06	25.54	5.48	2.64	1.74	1.30	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	70365	128742	107420	90934	80968	76246	74133	16741	3883	2133	1680	1515	0
8.0"	0.00	0.00	0.00	53.56	107.38	108.16	109.42	111.10	113.10	115.32	117.60	102.36	54.48	35.90	28.72	13.38
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	0	0	0	68423	125175	104446	88413	78729	74135	73661	77085	72535	44021	34667	33479	17093

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"				
	776673	699005	854340	970841
6.0"				
	1298819	1168937	1428701	1623524
8.0"				
	1899819	1709837	2089801	2374773

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
12.0"	AREA	41.68	70.04	27.30	0.00	0.00	153.87	476.72	584.02	342.26	263.34	194.18	138.44	76.14	64.24	41.86
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	16040	24595	7941	0	0	181791	513943	521568	255762	172581	117713	81781	46157	42100	31281
16.037"	AREA	110.83	212.86	184.40	129.24	19.00	87.44	183.46	211.24	265.24	359.30	323.44	170.50	133.90	143.30	112.62
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.513	0.513	0.513	0.513	0.513	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844	0.844
	ANGLE CORR.	0.513	0.468	0.388	0.325	0.285	0.844	0.770	0.638	0.534	0.468	0.433	0.422	0.433	0.468	0.534
	CORR. CRUSH STR.	385	351	291	243	213	1181	1078	893	747	655	606	591	606	655	747
	TOTAL CRUSH LOAD	42650	74746	53640	31457	4056	103307	197785	188651	198207	235469	196072	100719	81171	93912	84158

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
12.0"	26.98	18.48	7.86	50.37	101.50	102.10	103.24	104.92	106.80	108.90	111.04	113.12	114.92	116.34	117.26	58.78
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	24095	19923	9286	64348	118320	98594	83420	74349	70006	69560	72785	80160	92858	112345	136692	75091
16.037"	92.32	80.78	38.54	47.65	95.54	96.24	97.36	98.86	100.64	102.60	104.62	106.56	108.28	109.62	110.48	55.36
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.844	0.844	0.844	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913	0.913
	0.638	0.770	0.844	0.913	0.833	0.690	0.577	0.506	0.468	0.456	0.468	0.506	0.577	0.690	0.833	0.913
	893	1078	1181	1278	1166	966	808	709	655	639	655	709	808	966	1166	1278
	82448	87087	45533	60873	111373	92935	78669	70055	65968	65536	68577	75512	87492	105856	128789	70722

Table 2.10-6 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for 75° Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"				
	3215086	2893577	3536594	4018857
16.037"				
	2983426	2685084	3281769	3729283

Table 2.10-7

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH		2*B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10	2*B11	2*B12	2*C1	2*C2	2*C3
0.1"	AREA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	115.45	115.45	115.45
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	0	0	0	0	0	0	0	0	0	0	0	0	161630	161630	161630
1.0"	AREA	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	16.86	113.91	113.91	113.91
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	16433	16433	16433	16433	16433	16433	16433	16433	16433	16433	16433	16433	159474	159474	159474
2.0"	AREA	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	34.67	112.38	112.38	112.38
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	33792	33792	33792	33792	33792	33792	33792	33792	33792	33792	33792	33792	157332	157332	157332

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
0.1"	115.45	115.45	115.45	115.45	115.45	115.45	115.45	115.45	115.45				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	161630	161630	161630	161630	161630	161630	161630	161630	161630	1939560	1745604	2133516	2424450
1.0"	113.91	113.91	113.91	113.91	113.91	113.91	113.91	113.91	113.91				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	159474	159474	159474	159474	159474	159474	159474	159474	159474	2110885	1899797	2321974	2638607
2.0"	112.38	112.38	112.38	112.38	112.38	112.38	112.38	112.38	112.38				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	157332	157332	157332	157332	157332	157332	157332	157332	157332	2293490	2064141	2522839	2866862

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH		2*B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10	2*B11	2*B12	2*C1	2*C2	2*C3
3.0"	AREA	53.42	53.42	53.42	53.42	53.42	53.42	53.42	53.42	53.42	53.42	53.42	53.42	110.86	110.86	110.86
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	52067	52067	52067	52067	52067	52067	52067	52067	52067	52067	52067	52067	155204	155204	155204
4.0"	AREA	73.11	73.11	73.11	73.11	73.11	73.11	73.11	73.11	73.11	73.11	73.11	73.11	109.35	109.35	109.35
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	71259	71259	71259	71259	71259	71259	71259	71259	71259	71259	71259	71259	153090	153090	153090
5.0"	AREA	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75	93.75	107.85	107.85	107.85
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	91376	91376	91376	91376	91376	91376	91376	91376	91376	91376	91376	91376	150990	150990	150990

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
3.0"	110.86	110.86	110.86	110.86	110.86	110.86	110.86	110.86	110.86				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	155204	155204	155204	155204	155204	155204	155204	155204	155204	2487257	2238531	2735983	3109071
4.0"	109.35	109.35	109.35	109.35	109.35	109.35	109.35	109.35	109.35				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	153090	153090	153090	153090	153090	153090	153090	153090	153090	2692186	2422968	2961405	3365233
5.0"	107.85	107.85	107.85	107.85	107.85	107.85	107.85	107.85	107.85				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	150990	150990	150990	150990	150990	150990	150990	150990	150990	2908395	2617556	3199235	3635494

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH		2*B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10	2*B11	2*B12	2*C1	2*C2	2*C3
6.0"	AREA	115.33	115.33	115.33	115.33	115.33	115.33	115.33	115.33	115.33	115.33	115.33	115.33	106.36	106.36	106.36
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	112410	112410	112410	112410	112410	112410	112410	112410	112410	112410	112410	112410	148904	148904	148904
7.0"	AREA	137.86	137.86	137.86	137.86	137.86	137.86	137.86	137.86	137.86	137.86	137.86	137.86	104.88	104.88	104.88
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	134369	134369	134369	134369	134369	134369	134369	134369	134369	134369	134369	134369	146832	146832	146832
8.0"	AREA	161.33	161.33	161.33	161.33	161.33	161.33	161.33	161.33	161.33	161.33	161.33	161.33	103.41	103.41	103.41
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	157245	157245	157245	157245	157245	157245	157245	157245	157245	157245	157245	157245	144774	144774	144774

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
6.0"	106.36	106.36	106.36	106.36	106.36	106.36	106.36	106.36	106.36				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	148904	148904	148904	148904	148904	148904	148904	148904	148904	3135766	2822190	3449343	3919708
7.0"	104.88	104.88	104.88	104.88	104.88	104.88	104.88	104.88	104.88				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	146832	146832	146832	146832	146832	146832	146832	146832	146832	3374417	3036975	3711858	4218021
8.0"	103.41	103.41	103.41	103.41	103.41	103.41	103.41	103.41	103.41				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	144774	144774	144774	144774	144774	144774	144774	144774	144774	3624229	3261807	3986652	4530287

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH		2*B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10	2*B11	2*B12	2*C1	2*C2	2*C3
9.0"	AREA	185.74	185.74	185.74	185.74	185.74	185.74	185.74	185.74	185.74	185.74	185.74	185.74	101.96	101.96	101.96
	CRUSH STRENGTH	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	DROP ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	ANGLE CORR.	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	0.696	1.000	1.000	1.000
	CORR. CRUSH STR.	975	975	975	975	975	975	975	975	975	975	975	975	1400	1400	1400
	TOTAL CRUSH LOAD	181037	181037	181037	181037	181037	181037	181037	181037	181037	181037	181037	181037	142744	142744	142744

Table 2.10-7 (Continued)

Impact Limiter Honeycomb Segment Areas for Load Calculations for 90° Orientation

DEPTH	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
9.0"	101.96	101.96	101.96	101.96	101.96	101.96	101.96	101.96	101.96				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000				
	1400	1400	1400	1400	1400	1400	1400	1400	1400				
	142744	142744	142744	142744	142744	142744	142744	142744	142744	3885373	3496835	4273910	4856716

Table 2.10-8

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
1.0"	AREA	0.00	0.00	0.00	0.00	0.00	10.85	18.92	11.18	1.74	0.00	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	11904	18942	9272	1208	0	0	0	0	0	0
2.0"	AREA	0.00	0.00	0.00	0.00	0.00	22.61	42.04	33.18	20.38	5.92	0.00	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	24807	42089	27518	14143	3603	0	0	0	0	0
3.0"	AREA	0.00	0.00	0.00	0.00	0.00	35.18	66.74	56.64	42.08	25.44	8.78	0.00	0.00	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	38599	66819	46975	29202	15483	4943	0	0	0	0

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
1.0"	0.00	0.00	0.00	28.46	52.82	37.68	6.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	0	0	0	38370	64981	38400	5509	0	0	0	0	0	0	0	0	0
2.0"	0.00	0.00	0.00	47.04	92.80	88.00	75.04	33.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	0	0	0	63419	114166	89681	63989	25187	0	0	0	0	0	0	0	0
3.0"	0.00	0.00	0.00	55.41	110.86	110.96	110.66	108.28	85.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	0	0	0	74704	136384	113080	94364	80977	59353	0	0	0	0	0	0	0

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
1.0"				
	188586	169727	207444	235732
2.0"				
	468604	421743	515464	585755
3.0"				
	760881	684793	836969	951101

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
4.0"	AREA	0.00	0.00	0.00	0.00	0.00	48.57	91.04	81.62	65.16	46.38	27.62	10.48	0.04	0.00	0.00
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	53290	91147	67692	45219	28227	15549	5749	23	0	0
6.0"	AREA	0.00	0.00	0.00	0.00	0.00	77.77	150.40	136.10	115.50	92.02	68.64	47.34	29.12	16.36	3.30
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	85328	150577	112876	80153	56004	38642	25970	16393	9957	2290
8.0"	AREA	0.00	0.00	0.00	0.00	0.00	110.23	214.14	196.60	171.36	142.64	114.08	88.10	66.00	48.14	34.60
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	120942	214392	163052	118918	86812	64223	48331	37156	29298	24011

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
4.0"	0.00	0.00	0.00	55.44	98.96	99.76	112.36	113.42	114.66	116.02	65.86	15.84	7.64	5.04	4.04	1.88
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	0	0	0	74744	121744	101666	95813	84821	79317	78209	45559	11846	6515	5136	4970	2535
6.0"	0.00	0.00	0.00	53.94	108.04	108.52	109.32	109.70	110.92	112.88	114.24	115.54	116.04	93.08	74.48	34.70
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	0	0	0	72722	132914	110593	93221	82039	76730	76092	79027	86406	98952	94858	91628	46783
8.0"	25.14	19.58	8.88	52.46	117.60	99.32	106.32	107.32	108.50	109.80	111.10	112.36	113.44	114.30	114.84	39.88
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	20850	19603	9743	70727	144675	101217	90663	80259	75056	74016	76855	84028	96734	116484	141280	53766

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
4.0"				
	1019772	917795	1121749	1274715
6.0"				
	1720155	1548139	1892170	2150193
8.0"				
	2163091	1946782	2379400	2703863

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH		A1	2*A2	2*A3	2*A4	2*A5	B1	2*B2	2*B3	2*B4	2*B5	2*B6	2*B7	2*B8	2*B9	2*B10
12.0"	AREA	0.00	0.00	0.00	0.00	0.00	184.88	360.74	335.68	299.68	258.80	218.24	181.46	150.22	125.14	106.16
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	0	0	0	0	0	202847	361165	278399	207968	157507	122861	99547	84568	76161	73671
16.153"	AREA	63.93	160.30	136.50	88.68	11.92	110.15	227.66	251.10	294.10	359.14	345.12	295.02	252.56	218.54	192.86
	CRUSH STRENGTH	750	750	750	750	750	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	CIRCUM ANGL COR.	1.000	0.913	0.756	0.633	0.555	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633
	DROP ANGLE CORR.	0.505	0.505	0.505	0.505	0.505	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784	0.784
	ANGLE CORR.	0.505	0.461	0.382	0.319	0.280	0.784	0.715	0.592	0.496	0.435	0.402	0.392	0.402	0.435	0.496
	CORR. CRUSH STR.	379	346	286	240	210	1097	1001	829	694	609	563	549	563	609	694
	TOTAL CRUSH LOAD	31788	55401	39080	21244	2504	120854	227928	208252	204096	218575	194290	161845	142182	133005	133838

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	2*B11	2*B12	B13	C1	2*C2	2*C3	2*C4	2*C5	2*C6	2*C7	2*C8	2*C9	2*C10	2*C11	2*C12	C13
12.0"	92.96	85.20	41.38	49.56	99.28	99.72	100.44	101.40	102.50	103.72	104.90	106.14	107.18	107.96	108.25	54.24
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	77097	85300	45401	66817	122137	101625	85649	75832	70906	69918	72566	79376	91396	110023	133173	73126
16.153"	175.04	164.56	80.60	46.64	93.42	93.84	94.46	95.40	96.46	97.60	98.78	99.90	100.86	101.62	100.10	51.10
	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400
	0.756	0.913	1.000	1.000	0.913	0.756	0.633	0.555	0.513	0.500	0.513	0.555	0.633	0.756	0.913	1.000
	0.784	0.784	0.784	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963	0.963
	0.592	0.715	0.784	0.963	0.879	0.728	0.609	0.534	0.494	0.482	0.494	0.534	0.609	0.728	0.879	0.963
	829	1001	1097	1348	1230	1019	853	748	692	674	692	748	853	1019	1230	1348
	145171	164754	88433	62880	114928	95633	80549	71345	66727	65792	68332	74710	86007	103561	123146	68893

Table 2.10-8 (Continued)

Impact Limiter Honeycomb Segment Areas and Load Calculations for CG Over Corner Orientation

DEPTH	TOTAL NOMINAL LOAD	90% NOMINAL LOAD	110% NOMINAL LOAD	125% NOMINAL LOAD
12.0"				
	3025036	2722532	3327539	3781295
16.153"				
	3375743	3038169	3713318	4219679

2.10.3 Description of SCANS

This section describes the methodology employed by the SCANS computer program which is used to evaluate the dynamic behavior of end, side and oblique impacts and to predict the associated internal forces and stresses generated within the cask body. SCANS was developed by the Lawrence Livermore National Laboratory (LLNL) to analyze spent fuel shipping casks, and is intended for use by the staff of the U.S. Nuclear Regulatory Commission to perform licensing-related confirmatory analyses. In its current version (Reference 2.10.1), SCANS can handle problems associated with impact, heat transfer, thermal stress, and pressure. For the LWT cask, SCANS will be used to demonstrate compliance of the package with applicable provisions of 10 CFR Part 71 for Normal and Hypothetical accident free drops; as required by Paragraphs 71.71(c)(7) and 71.73(c)(1), respectively.

The impact portion of SCANS is composed of two computer modules, IMPASC (IMPact Analysis of Shipping Containers) and QUASC (QUasi-static Analysis of Shipping Containers). IMPASC is based on the dynamic lumped-parameter method and is an explicit finite element computer code. IMPASC includes one type of element -- the beam element. The mass of the cask is lumped at element ends and the beam element is assumed to have no mass. The cask is modeled as an elastic composite material, but the impact limiter can have nonlinear force-deflection curves. The impact limiter is not explicitly modeled in IMPASC as finite elements, but is in the form of force-deflection curves simulating various possible initial cask impact angles with the horizontal surface.

The other SCANS module, QUASC, is based on a quasi-static method of impact analysis. QUASC treats the cask as slender rigid beams in estimating the maximum impact force and the associated "g" load during impact. By comparing the results of IMPASC and QUASC, the dynamic amplification factor can be determined for the cask during the particular impact event being analyzed. Both IMPASC and QUASC are operational on the IBM PC and compatible computers.

In the case of a laminated cask with shielding laminated between two concentric metal shells, a perfect bonding between the shielding and the metal shells of the cask is assumed in the current version of IMPASC and QUASC.

The material properties used in SCANS are included in a data set within the program. The version of the program received from LLNL contained only carbon and stainless steels for the cask body and lead for shielding. In order to use the program for the LWT cask analysis, Grade 9 titanium and depleted uranium material property data sets were added to the program. Impact analyses use dynamic Young's Modulus, Poisson's Ratio, and material density (used for weight calculations). These properties along with other basic properties included in SCANS for Grade 9 titanium and depleted uranium are given in Tables 2.10-9 and 2.10-10, respectively. To be conservative, the modulus of elasticity of the depleted uranium is reduced to 1/100 of its actual value, so that the strength of the uranium is not included in the overall strength of the cask.

The theoretical basis of the SCANS computer program, taken from Reference 2.10.2, will be described in the following subsections.

2.10.3.1 Conventional Solution For Small Deformation and Small Rigid Body Motion

The conventional equation of motion for small deformation and small rigid body motion can be written as:

$$[M]\{\ddot{X}\} + [K]\{X - X_0\} = \{F\}, \qquad (1)$$

in which [M] is the mass matrix; [K] is the stiffness matrix; {F} is the external force vector; {X} is the position vector; and $\{X_0\}$ is a reference position vector of the nodal points.

In Eq. (1), [M] is a diagonal lumped-mass matrix (Reference 2.10.3). The components of [M] corresponding to translational degrees of freedom are the masses lumped at those nodes, whereas the components corresponding to

TABLE 2.10-9

Grade 9 Titanium Material Property Data Set Included in SCANS

Temp °F	Thermal Cond. (BTU/in. min. °F)	Specific Heat Cap. (BTU/lb °F)	E (psi)	Poisson's Ratio	Coef. of T. E. (in/in°F)
-50	.00611	0.130	15.0E+6	0.3	5.34E-6
68	.00611	0.130	15.0E+6	0.3	5.34E-6
100	.00621	0.131	14.75E+6	0.3	5.34E-6
200	.00653	0.134	14.5E+6	0.3	5.34E-6
400	.00736	0.14	12.4E+6	0.3	5.37E-6
800	.00986	0.16	9.5E+6	0.3	5.51E-6
1200	.01292	0.18	9.5E+6*	0.3	5.51E-6*
1600	.01292*	0.18*	9.5E+6*	0.3	5.51E-6*

* No value available, use previous temperature value.

Impact Young's Modulus: 15.0×10^6 psi

Impact Poisson's Ratio = 0.30

Density: 0.162 lb/in^3

TABLE 2.10-10

Depleted Uranium Property Data Set Included in SCANS

Temp. °F	Thermal Cond.* BTU/in.min. °F	Specific Heat BTU/lb °F	E (**) (psi)	Poisson's Ratio	Coef. of T.E. in/in-°F
-50	.0128	.028	.25E+6	0.21	8.23E-6
68	.0128	.028	.25E+6	0.21	8.23E-6
200	.0128	.0294	.25E+6	0.21	8.23E-6
300	.0128	.03052	.25E+6	0.21	8.50E-6
400	.0128	.0316	.25E+6	0.21	8.75E-6
600	.0128	.0316*	.25E+6	0.21	8.75E-6*
800	.0128	.0316*	.25E+6	0.21	8.75E-6*
1200	.0128	.0316*	.25E+6	0.21	8.75E-6*

Impact Young's Modulus: 24.0×10^6 psi

Impact Poisson's Ratio = 0.21

Impact Yield Stress: 40,000 psi

Impact Plastic Modulus: 2.4×10^6 (Note 1)

Density: 0.679

Melting Temp.: 2065°F

Latent Heat: 19.8 BTU/lb

Notes

Note 1: Taken as 10% of elastic modulus

* No value available, use previous temp. value

** Reduced to ensure that DU strength is ignored rotational degrees of freedom are equal to the product of (mass density) x (contributing length to node) x (moment of inertia of beam cross section around its neutral axis).

A shipping container can be modeled as a series of beam elements, each node of which has two translational degrees of freedom and one rotational degree of freedom (see Figure 2.10-1). The stiffness matrix [K] in Eq. (1) can be obtained by applying the direct stiffness method (Reference 2.10.4) to the element stiffness matrices of contributing elements at the nodal points.

2.10.3.2 Large Rigid Body Rotations

Equation of Motion

In oblique drops of shipping containers, the use of Eq. (1) will produce errors of unacceptable magnitudes, since the equation is not valid for large rigid body motions. To handle large rigid body rotations, Eq. (1) is rewritten as follows:

$$[M]\{\ddot{X}\} = \{F\} - \{P\} \tag{2}$$

where {P} represents the internal force vector on the beam elements, and -{P} can be regarded as the internal force vector on the nodal points. The force vector {P} can be obtained by adding together the appropriate element-level internal force vectors {p} that contribute to a particular node.

Internal Force Vector {P}

A typical element-level internal force vector {p} has six components, three at each end of the beam element (see Figure 2.10-2).

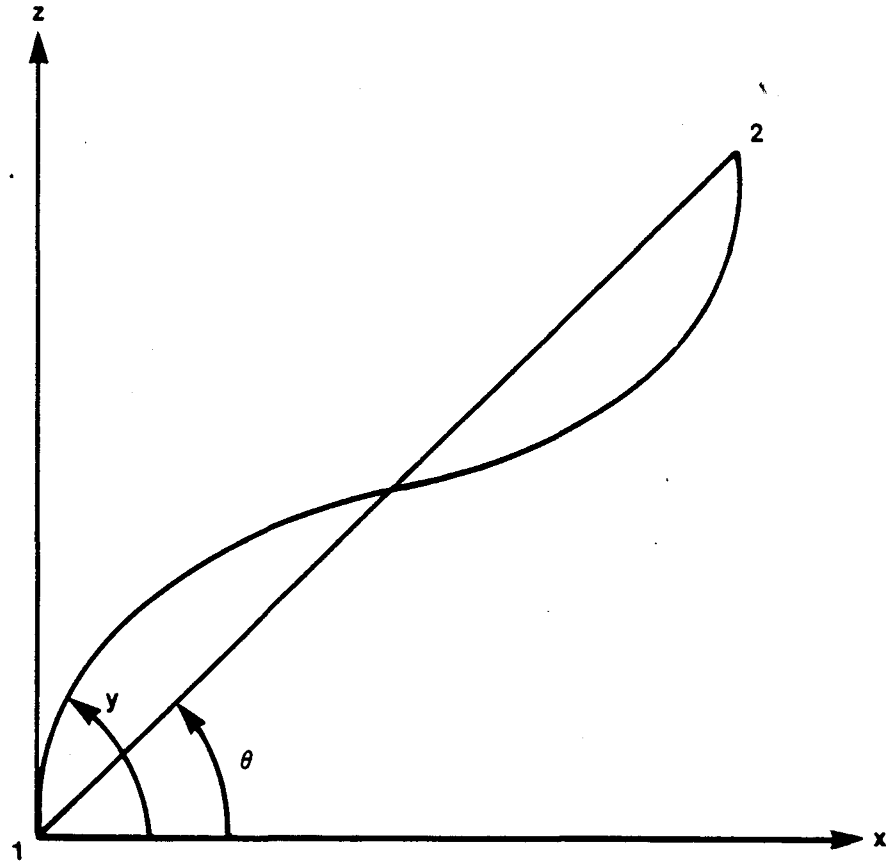


Figure 2.10-1. Beam Element in Global Coordinates

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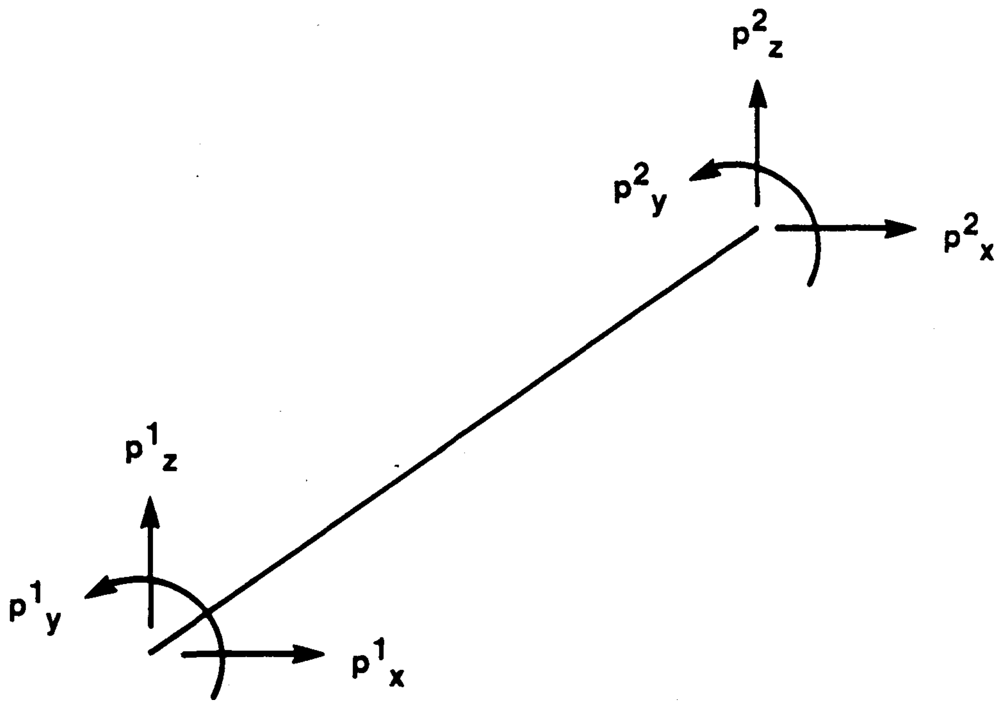


Figure 2.10-2. Beam Element Forces in Global Coordinates

$$\{p\} = \begin{bmatrix} p^1_x \\ p^1_z \\ p^1_y \\ p^2_x \\ p^2_z \\ p^2_y \end{bmatrix} \tag{3}$$

where the superscripts refer to the first or second end of the beam element, and the subscripts refer to the directions in a global coordinate system (see Figures 2.10-1 and -2). These six components of {p} can be expressed in terms of the four components of the generalized forces of the beam element in local coordinates (see Figure 2.10-3):

$$\{p\} = \begin{bmatrix} p^1_x \\ p^1_z \\ p^1_y \\ p^2_x \\ p^2_z \\ p^2_y \end{bmatrix} = \begin{bmatrix} -R\cos\theta - V\sin\theta \\ -R\sin\theta + V\cos\theta \\ M^1 \\ R\cos\theta + V\sin\theta \\ R\sin\theta - V\cos\theta \\ M^2 \end{bmatrix} \tag{4}$$

where R is the axial force; V is the shear force; and M^1 and M^2 are the end moments of the beam element. These generalized forces (R, V, M^1, M^2) can be calculated using the following formulae (Reference 2.10.5):

$$R = AE(L-L_o)/L_o$$

$$\begin{bmatrix} M^1 \\ M^2 \end{bmatrix} = [EI/L(1+\phi)] \begin{bmatrix} 4+\phi & 2-\phi \\ 2-\phi & 4+\phi \end{bmatrix} \begin{bmatrix} \beta^1 \\ \beta^2 \end{bmatrix} \tag{5}$$

$$V = (M^1 + M$$

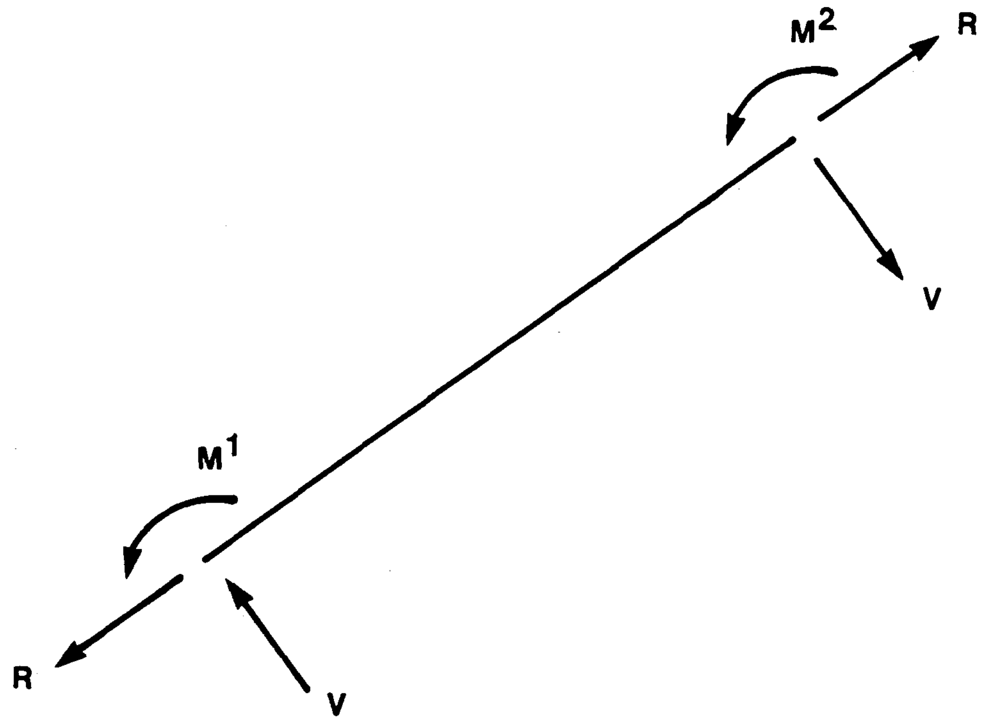


Figure 2.10-3. Beam Element Forces In Local Coordinates

where

A = the cross-sectional area of the beam

E = Young's modulus

I = moment of inertia of the beam cross section

L_o = original length of the beam element

L = current chord length of the beam element

β^1, β^2 = chord deflections at the ends of the beam element

ϕ = $12EI/GA_sL^2 = 24(1+\mu)(EI)/EA_sL^2$

G = shear modulus

μ = Poisson's ratio

A_s = effective shear area of the beam cross section = KA

K = shear coefficient (see Figure 3 of Reference 2.10.6 for formulas of K for different shapes of cross sections.)

Thus, knowing the end positions of the beam element (X,Z,Y,X,Z, and Y), the chord angle can be calculated using the following:

$$\theta = \tan^{-1}[(Z^2 - Z^1)/(X^2 - X^1)], \tag{6}$$

and then the chord deflections (see Figure 2.10-4):

$$\beta^1 = Y^1 - \theta \tag{7}$$

$$\beta^2 = Y^2 - \theta$$

Equation (5) can then be used to calculate R, V, M, and M. Next, {p} can be calculated from Eq. (4) and added up to form the internal force vector {P} in Eq. (2).

<u>External Force Vector</u> {F}

The external force vector {F} comprises the body weights of the shipping container and its contents as well as the impact forces during impact. In IMPASC, it is assumed that the force-deflection curves of the impact limiters are known. (If there is no limiter, one can assume an arbitrarily stiff spring.) The force-deflection curves are assumed to be multi-linear (see Figur 2.10-5). The impact point to which the limiter force is applied is

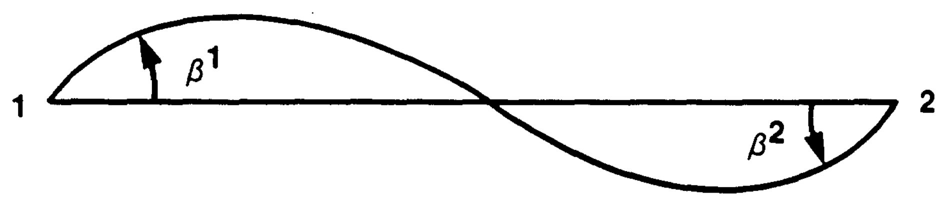


Figure 2.10-4. Definition of Chord Deflections

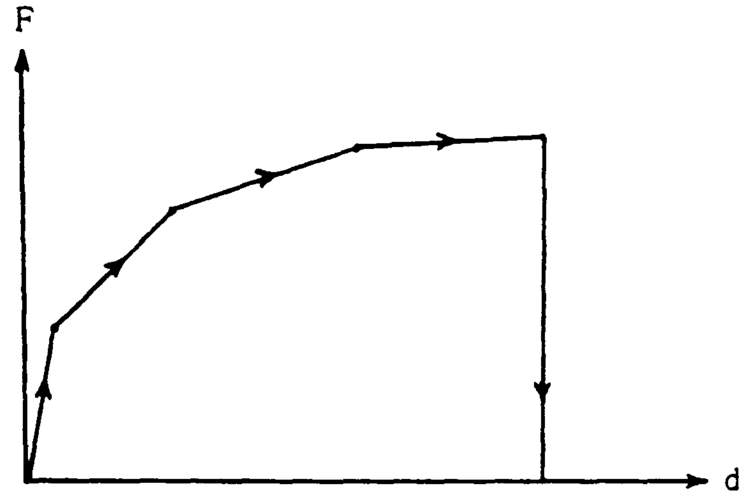


Figure 2.10-5. Multi-linear Force-deflection Curve of Impact Limiters

always assumed to be at the lowest corner of the end cap at the impact end of the cask, except for side and end impacts. In the case of a side impact, there are two impact points, one at each of the two end caps, and it is located at the half-thickness point of each end cap. In an end impact, the impact point is at the center of the circular exterior surface of the impacting end cap.

Explicit Solution of Equation of Motion

IMPASC solves the equation of motion (Eq.(2)) with the method of central difference. Equation (2) can be rewritten as

$$\{\ddot{X}_n\} = [M]^{-1}\{F_n - P_n\}, \tag{8}$$

where the subscript now refers to a point in time. Knowing $\{F_n\}$, $\{P_n\}$, and $\{X_{n-(1/2)}\}$, one can integrate Eq. (8) in the following manner:

$$\{\dot{X}_{n+(1/2)}\} = \{\dot{X}_{n-(1/2)}\} + (\Delta t)\ \{\ddot{X}_n\}, \tag{9}$$

Thus, $\{\dot{X}_{n+(1/2)}\} = \{\dot{X}_{n+(1/2)}\} + (\Delta t)[M]^{-1}\{F_n - P_n\}$,

$$\{X_{n+1}\} = \{X_n\} + (\Delta t)\{\dot{X}_{n+(1/2)}\} \tag{10}$$

Knowing $\{X_{n+1}\}$, one now can calculate $\{F_{n+1}\}$ from the force-deflection curves of the impact limiters, and then use Eqs. (4)--(7) to calculate the internal force vector, $\{P_{n+1}\}$. The whole cycle can then be repeated. This numerical integration requires the use of $\{X_{-(1/2)}\}$ for the first cycle of computation:

$$\{\dot{X}_{-(1/2)}\} = \{\dot{X}_o\} - (1/2)(\Delta t)\{\ddot{X}_o\}$$

$$= \{\dot{X}_o\} - (1/2)(\Delta t)[M]^{-1}\{F_o\} \tag{11}$$

It should be noted that since the l d-mass matrix [M] is diagonal, the inversion $[M]^{-1}$ is trivial. This numerical procedure has the advantage that no actual matrix inversion is required. However, this explicit time integration is stable only if

$$(\Delta t) \leq T_{min}/\pi = 2/\omega_{max}, \tag{12}$$

where T_{min} is the smallest period of the finite element assemblage, and ω_{max} is the maximum frequency in radians per second as explained in Reference 2.10.3. Although Eq. (1) is not used in IMPASC, one relies on it to estimate ω_{max}. Applying the Gerschgorin Theorem (Reference 2.10.6) to Eq. (1) results in:

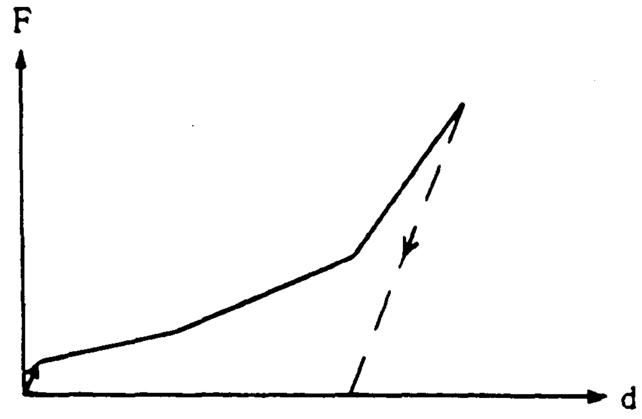
$$\omega^2_{max} \leq \max_i \left[\frac{\sum_j K_{ij}}{M_i} \right] \tag{13}$$

The use of inequalities in Eqs. (12) and (13) will usually dictate the time steps used in these explicit time integrations schemes to be very small. (In the case of shipping containers, they are on the order of microseconds.) In spite of this, one finds this method of numerical integration quite suitable for impact analyses because there are no time-consuming matrix inversions.

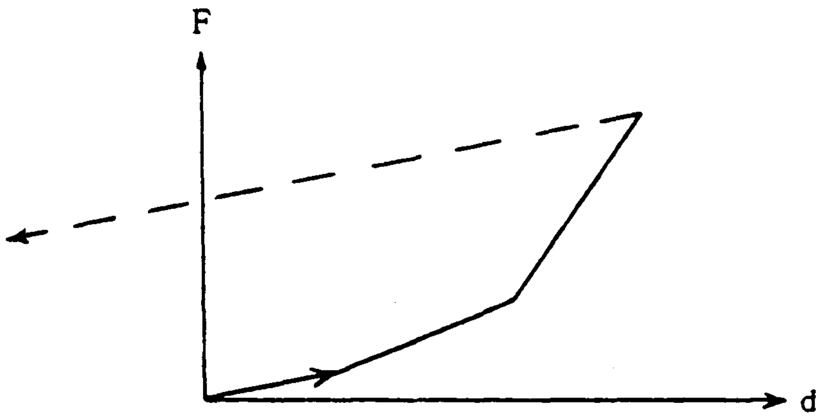
2.10.3.3 Impact Code Development

Limiter Force-Deflection Representation

If there is no user input, IMPASC assumes an unloading stiffness five times greater than the maximum stiffness of the loading curve. This should be adequate for the simulation of an inelastic rebound and help avoid the elastic unloading shown in Figure 2.10-6a. If the unloading stiffness is assumed equal to the initial stiffness, the intractable condition shown in Figure 2.10-6b could occur.



(a) Proper Modeling with Stiff Initial Segment and Stiff Unloading



(b) Improper Modeling with Soft Initial Segment and Unloading Resulting in Erroneous Unloading

Figure 2.10-6. Elastic Unloading Using a Concave Force-Deflection Curve for Impact Limiters

Mass Modeling

In the impact analysis code, the cask is modeled using beam elements where the masses are lumped at the element ends. Masses that need to be included in these calculations are the end cap, element, and impact limiter masses. End cap and impact limiter masses are added at the end nodes only.

The cross-sectional area of the cask shell and the end caps must be calculated so that the necessary volumes can be determined. All cask elements are modeled with the same length. One area is found for a solid cask and three areas are found for a laminated cask. The cross-sectional area for a solid cask is given by

$$A_{cask} = \pi(r_4^2 - r_1^2), \tag{14}$$

where r_1 and r_4 define the inner and outer boundaries of the shell thickness as shown in Figure 2.10-7. The area of a laminated cask shell is

$$A_{cask}(i) = \pi({r_{i+1}}^2 - {r_i}^2), \tag{15}$$

where r is the radius to the material boundaries. The area of a solid end cap is:

$$A_{ec} = \pi(r_4^2), \tag{16}$$

and the area of a laminated end cap accounting for the shield diameter is

$$A_{ec}(1) = A_{ec}(3) = \pi({r_4}^2), \tag{17}$$

$$A_{ec}(2) = \pi(0.5shd),^2 \tag{18}$$

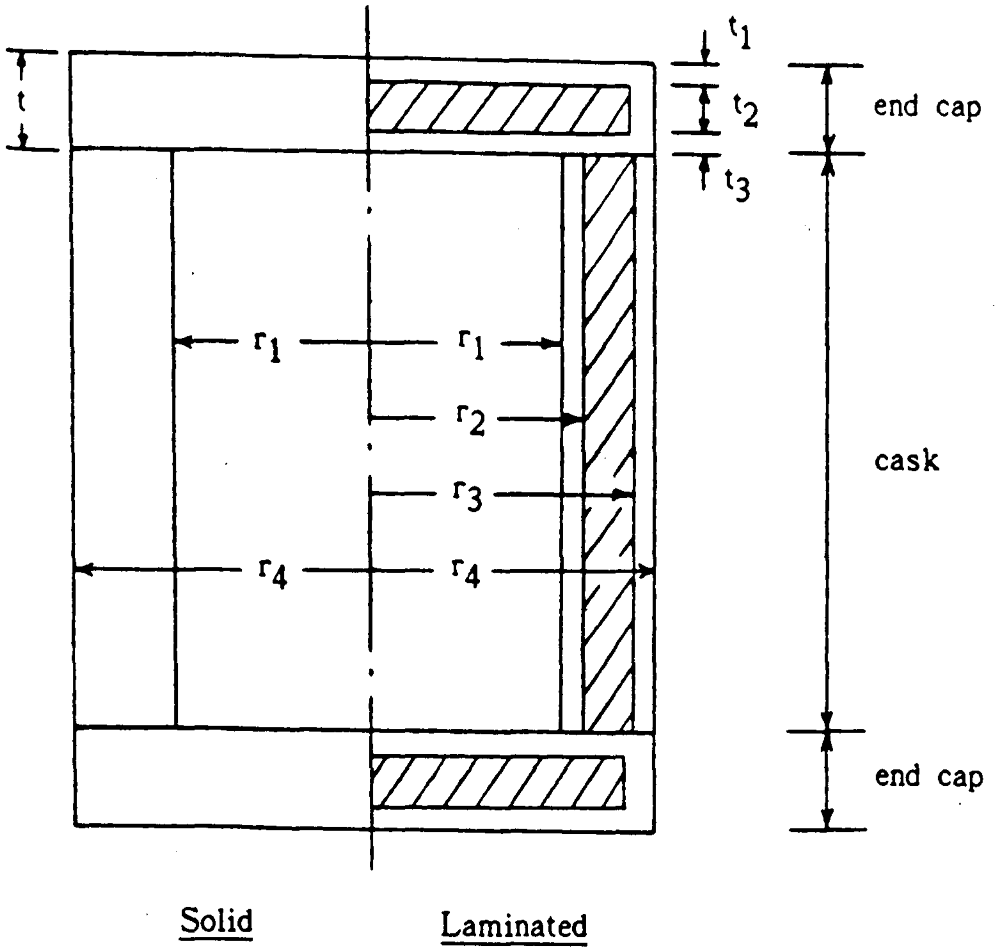


Figure 2.10-7. Configuration of Solid and Laminated Cask Models

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where shd is the shielding diameter. In addition, the small area between r_4 and the outside of the shielding must be determined. This area is given by

$$A_{ec}(extra) = \pi(r_4^{\ 2} - (0.5shd)^2). \tag{19}$$

The volume of any cask shell of length L is then:

solid: $$V_{cask} = A_{cask}L, \tag{20}$$

laminated: $$V_{cask}^{(i)} = A_{cask}^{(i)} \times L \tag{21}$$

and the volume of an end cap is given by

solid: $$V_{ec} = A_{ec} \times t, \tag{22}$$

laminated:
$$\begin{aligned} V_{ec}(1) &= A_{ec}(1)t_1 + A_{ec}(extra)(0.5t_2), \\ V_{ec}(2) &= A_{ec}(2)t_2, \\ V_{ec}(3) &= A_{ec}(3)t_3 + A_{ec}(extra)(0.5t_2). \end{aligned} \tag{23}$$

Translational Mass

The translational masses are determined using the volumes calculated above and the appropriate material densities. The impact limiter mass is added at the end nodes. For the end nodes at the cask top and bottom, the translational mass includes the mass of the impact limiter, the end cap, and half of the adjacent cask element:

solid: $$\begin{aligned} \text{tmass(top/bot end)} = {} & 0.5\rho_{cask}V_{cask\ element} + \rho_{ec}\,V_{ec} \\ & + \text{top/bot limiter mass}, \end{aligned} \tag{24}$$

laminated: $$\begin{aligned} \text{tmass(top/bot end)} = {} & \Sigma[0.5\rho_{cask}(i)V_{cask\ element}(i) + \\ & + \rho_{ec}(i)V_{ec}(i)] \\ & + \text{top/bot limiter mass}, \end{aligned} \tag{25}$$

where i denotes the particular material and ρ is the mass density. The translational mass at each intermediate node is given by

$$\text{solid:} \quad \text{tmass(intermediate)} = \rho_{cask} V_{cask\ elements}, \tag{26}$$

$$\text{laminated:} \quad \text{tmass(intermediate)} = \Sigma[\rho_{cask}(i)V_{cask\ element(i)}] \tag{27}$$

Rotational Mass

The rotational masses are calculated in the same way as the translational masses. For the end nodes at the cask top and bottom, the masses are:

$$\begin{aligned} \text{solid:} \quad \text{rmass(top/bot end)} &= 0.5(\rho_{cask})(I_{cask})L_{cask\ element} \\ &+ \rho_{ec}V_{ec}[0.25r_4^2 \\ &+ 0.33\ (ttot)^2], \\ I_{cask} &= 0.25\pi(r_4^4 - r_1^4). \end{aligned} \tag{28}$$

$$\begin{aligned} \text{laminated:} \quad \text{rmass(top/bot end)} &= \Sigma[0.5\rho_{cask}(i)L_{cask\ element} \\ &+ \rho_{ec}(i)V_{ec}(i)(0.25r_4^2 \\ &+ 0.33\ (ttot)^2)], \\ I_{cask}(i) &= 0.25\pi(r(i+1)^4 - r(i)^4), \end{aligned} \tag{29}$$

where ttot = the total thickness and i denotes the particular material. The rotational mass at each intermediate node is given by

$$\text{solid:} \quad \text{rmass(intermediate)} = (\rho_{cask})(I_{cask})L_{cask\ element}, \tag{30}$$

$$\begin{aligned} \text{laminated:} \quad \text{rmass(intermediate)} &= \Sigma[\rho_{cask}(i))(I_{cask}(i))x \\ &L_{cask\ element}]. \end{aligned} \tag{31}$$

Stress Recovery

Stress Recovery of the Cask Shell

The impact analysis program was developed using the following criteria: (1) to accurately model an actual cask, (2) to minimize the amount of input, and (3) to minimize the number of external calculations.

Since beam elements are used to represent the cask, the results of the analysis are in terms of moments, shears, and axial forces in the elements. These global values must then be converted into stresses in order to evaluate the performance of the material. The method used to recover stresses is dependent on the configuration of the cask as illustrated in Figure 2.10-7. For either type, the primary membrane stress is composed of the axial force at a section divided by the cross-sectional area plus the average bending stress through the section thickness (see Figure 2.10-8). This calculation is straight-forward for a solid cask, with the maximum extreme fiber stress being:

$$\sigma_b = P/A \pm Mc_{avg}/I. \qquad (33)$$

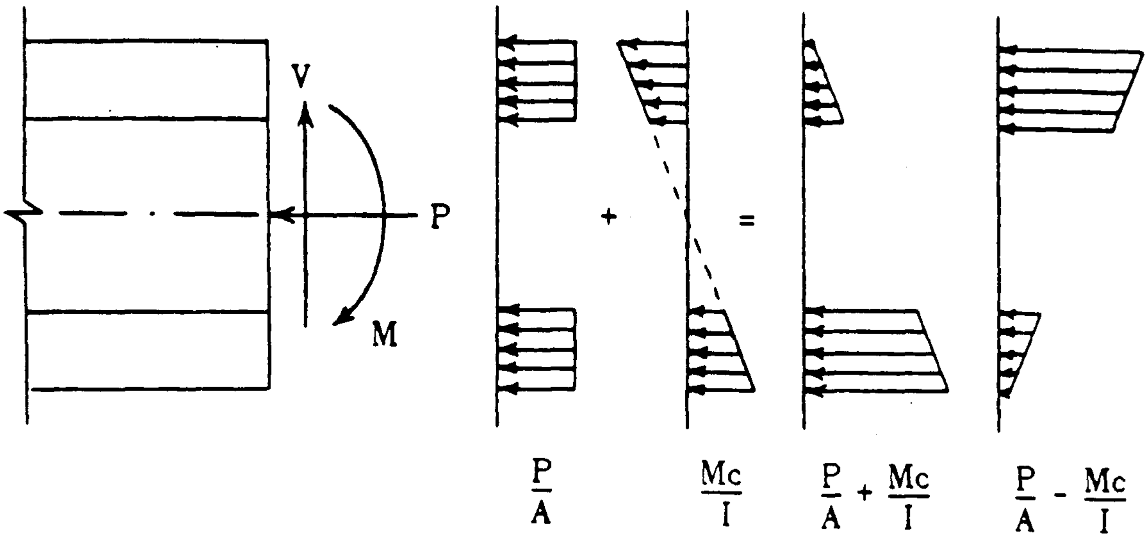
However, for a laminated cask, the portion of the section forces resisted by each material must be weighted by its relative stiffness as determined by its modulus. Using the composite beam properties:

$$AE = A_1E_1 + A_2E_2 + A_3E_3,$$

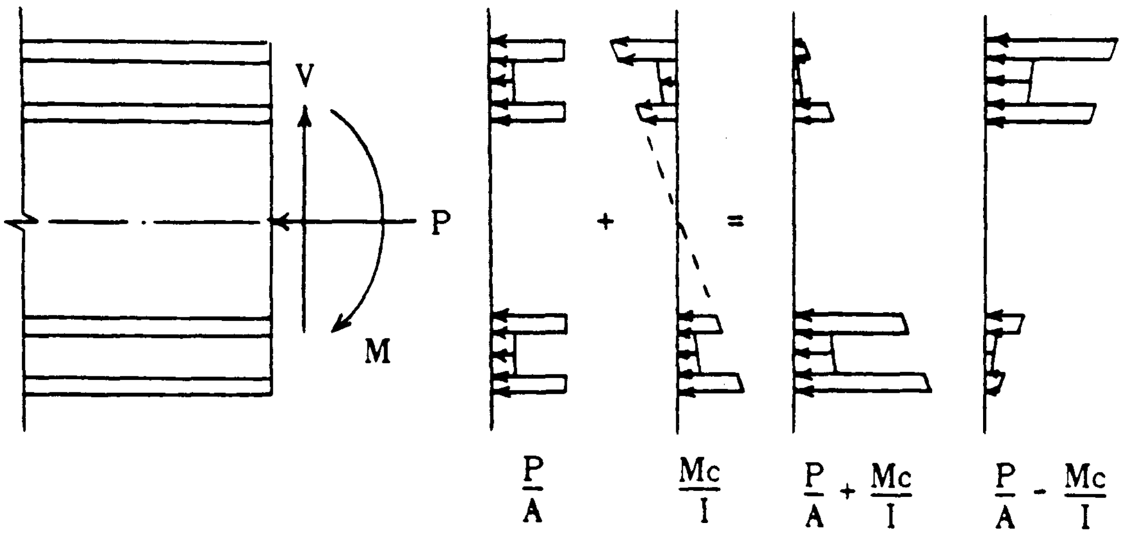
$$EI = E_1I_1 + E_2I_2 + E_3I_3, \qquad (33)$$

to represent the laminated cask, the contribution of each material to the overall force at the section can be found. Assuming plane sections remain plane, the axial contribution for material "i" is given by PE_j/AE, and the bending contribution is given by Mc_iE_j/EI resulting in a maximum extreme fiber stress of:

$$\sigma_b(i) = PE_i/AE \pm Mc_iE_j/EI. \qquad (34)$$



a. Solid Cask



b. Laminated Cask

Figure 2.10-8. Primary Membrane Stresses for Solid and Laminated Casks

Since the thickness of each shell of a laminated cask is small, the variation of the bending stress through the thickness is conservatively ignored.

The maximum shearing stress occurs at the center line of the cask cross-section, where the moment contribution is zero. For a thin cylindrical shell section, the maximum shearing stress is

$$\sigma_V = 2V/A, \tag{35}$$

for a solid cask, and is

$$\sigma_V(i) = 2VE_i/AE, \tag{36}$$

for a laminated cask, again using composite AE (assuming a constant μ for all materials) so that the contribution of each material in resisting the forces can be determined.

2.10.3.4 References for Appendix 2.10.3

2.10.1 SCANS (Shipping Cask Analysis System), NUREG/CR-4554, Volume 1, "Users Manual to Version 1a," M. A. Gerhard, et. al., LLNL, Livermore, CA, 1988.

2.10.2 SCANS (Shipping Cask Analysis System), NUREG/CR-4554, Volume 2, "Theory Manual Impact Analysis," R. C. Chun, et. al., LLNL, Livermore, CA, 1989.

2.10.3 R. W. Clough and J. Pensien, "Dynamics of Structures," McGraw-Hill, 1975.

2.10.4 K. J. Bathe and E. L. Wilson, "Numerical Methods in Finite Element Analysis," Prentice-Hall, 1976.

2.10.5 J. S. Przemieniecki, "Theory of Matrix Structural Analysis," McGraw-Hill, 1968.

2.10.6 G. R. Cowper, "The Shear Coefficient in Timoshenko's Beam Theory," Journal of Applied Mechanics, 1966.

2.10.7 J. Todd, "Survey of Numerical Analysis," McGraw-Hill, 1962.

2.10.4 Fuel Basket Analysis

The purpose of this analysis is to confirm the structural integrity of the PWR and BWR fuel baskets during the 30 foot Hypothetical Accident Condition side drop, as well as the 1 foot normal side drop.

These side drops are assumed to occur during the heated condition because the allowable stresses for the Type 316N stainless steel basket material are reduced at elevated temperatures from those at room temperature.

The analyses of both the PWR and BWR fuel baskets were performed using the WECAN finite element computer program (Reference 2.10.8). The analysis was based on linear-elastic, small deflections and rotations, using properties of 316N stainless steel. The initial WECAN analysis was performed for an assumed load of 100 g's, which was based on a performance objective established during the early stages of the design. This type of analysis is also known as pseudo-elastic because the linear portion of the stress-strain curve is extended beyond the elastic limit to encompass the high loads. Because of the linear nature of this analysis, the resulting stresses at 100 g's of dynamic deceleration can be linearly scaled down to values at lower decelerations as is shown in Section 2.7.1.2 for the 30 foot side drop and in Section 2.6.7.2 for the 1 foot drop.

PWR Fuel Basket Analysis

The PWR fuel basket is a complex plate structure which contains three longitudinal compartments of square cross section. The compartments form an integral plate structure which is stiffened by ten longitudinal plate stiffeners and four longitudinal edge members at the four outside corners of the fuel compartments (Figure 2.10-9). In addition, there are nine radial rib stiffeners, including one at each end, which divides the basket into eight (approximately equal) bays. During a lateral impact, the basket will be loaded by its own mass, plus the mass of a fuel assembly in each compartment. The basket will be supported in the cask by the longitudinal stiffeners and radial ribs. Of the eight bays, the middle six are all of equal length (21.84 in.) and the two end bays are only slightly shorter (21.73 in.). Thus, it was

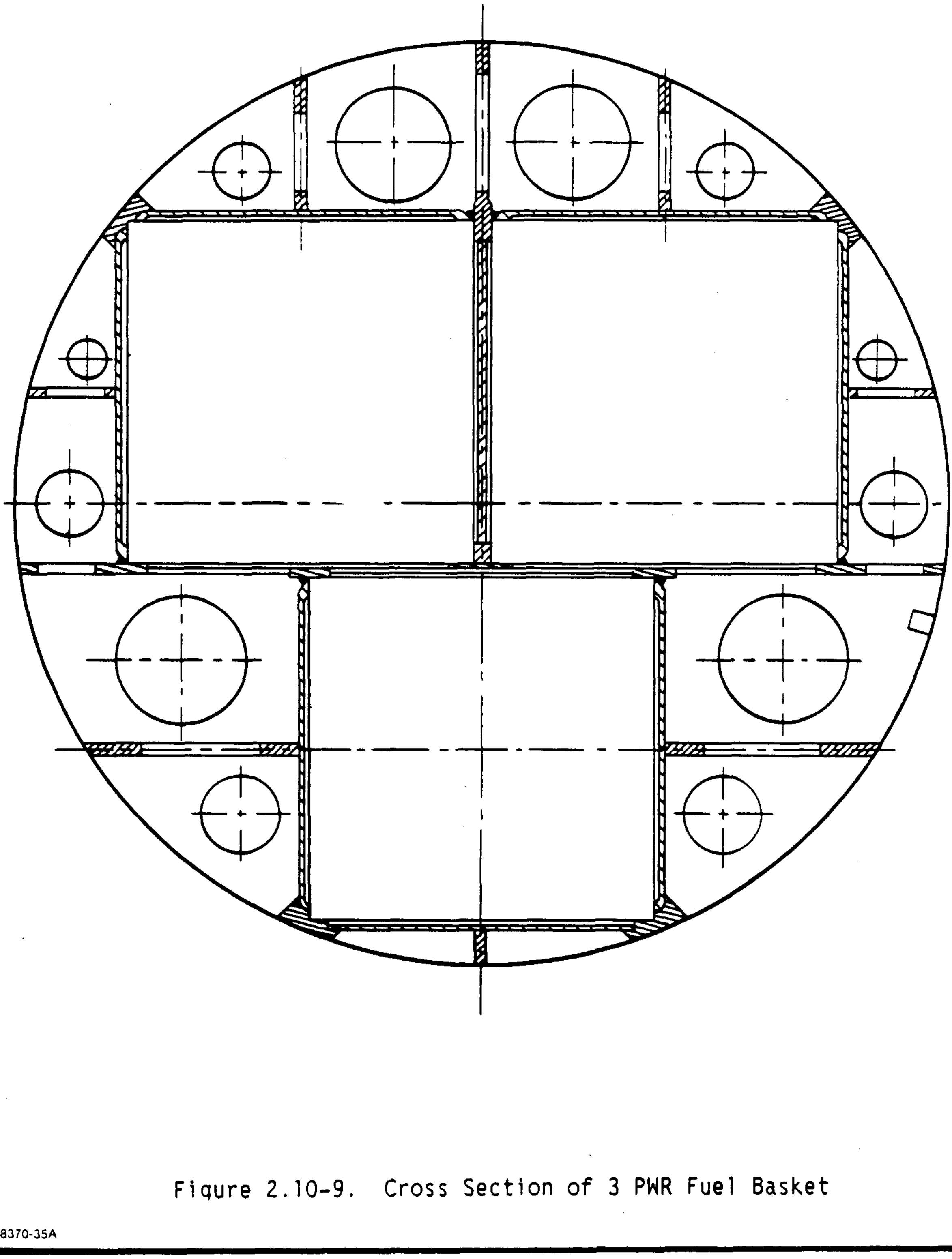


Figure 2.10-9. Cross Section of 3 PWR Fuel Basket

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assumed in the analysis that each bay behaves similarly and as a result, it is necessary only to analyze a single bay or one half of a bay by utilizing symmetry.

Because of the three dimensional nature of the basket structure, it was first considered necessary to develop a finite element model in three dimensions. Utilizing the 3-D model results, a much simpler 2-D beam model was developed by adjusting the boundary conditions to produce the same deflections in the 2-D model as for the 3-D analysis.

The loading case considered was a 100 g lateral acceleration in any given direction. The 3-D finite element model was developed using the WECAN program with mesh generation and post-processing being done by the FIGURES II program (Reference 2.10.9). The 3-D model was sufficiently refined (Figure 2.10-10) to be capable of predicting accurate 3-D stress distributions in the fuel compartments plates with realistic support from the stiffeners.

Two loading directions were chosen, Load Case 1 was loading in the -Y direction and Load Case 2 in the -X direction, each corresponding to 100 g's deceleration. Thicknesses were assumed to be uniform in each compartment panel at the smallest values indicated in Figure 2.10-9. In order to permit economical evaluation of changes in panel thicknesses, the 2-D finite element beam model of the cross-section was used (Figure 2.10-11). This model was validated by a deflection correlation with the 3-D model.

Evaluation of the stresses in the basket due to the 100g loading was performed in accordance with the structural criteria defined for Normal and Accident conditions in Reference 2.10.10. The lateral acceleration due to a 30 foot side drop is classified as an accident condition in accordance with 10 CFR Part 71.

In addition to the Accident Condition, the thermal stresses due to a steady state temperature distribution in the basket during the heated condition were also determined and evaluated as secondary stresses during normal operation.

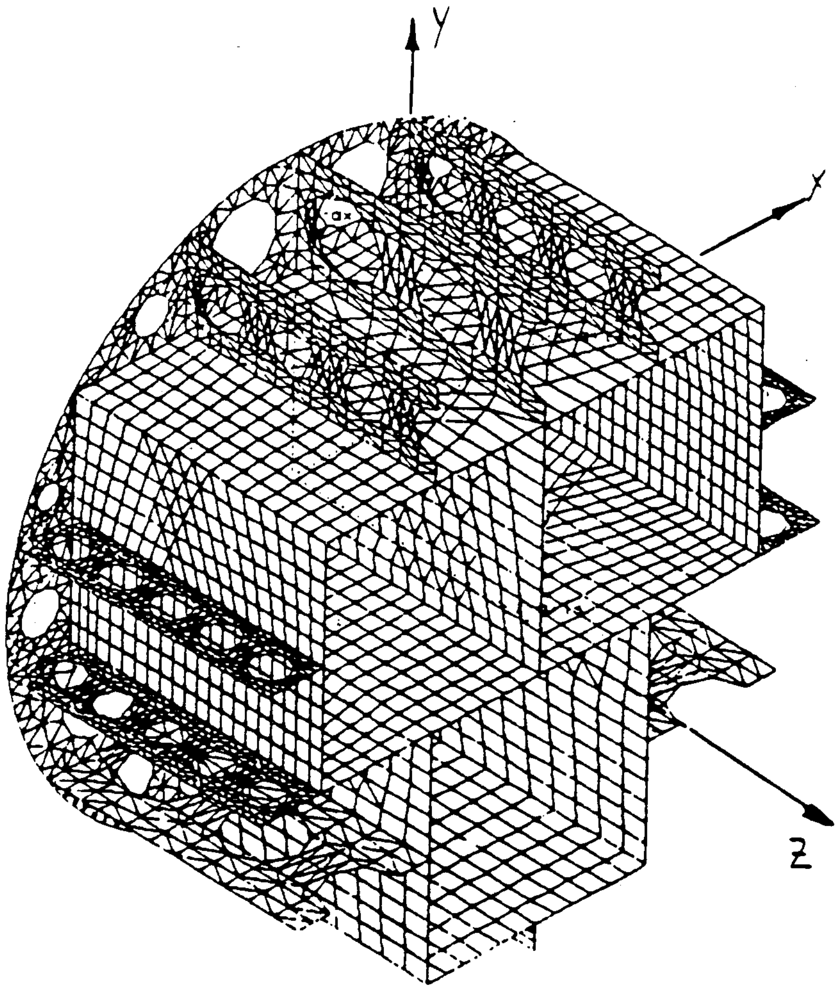

Figure 2.10-10. WECAN Finite Element Model of Half a Bay for the 3 PWR Basket

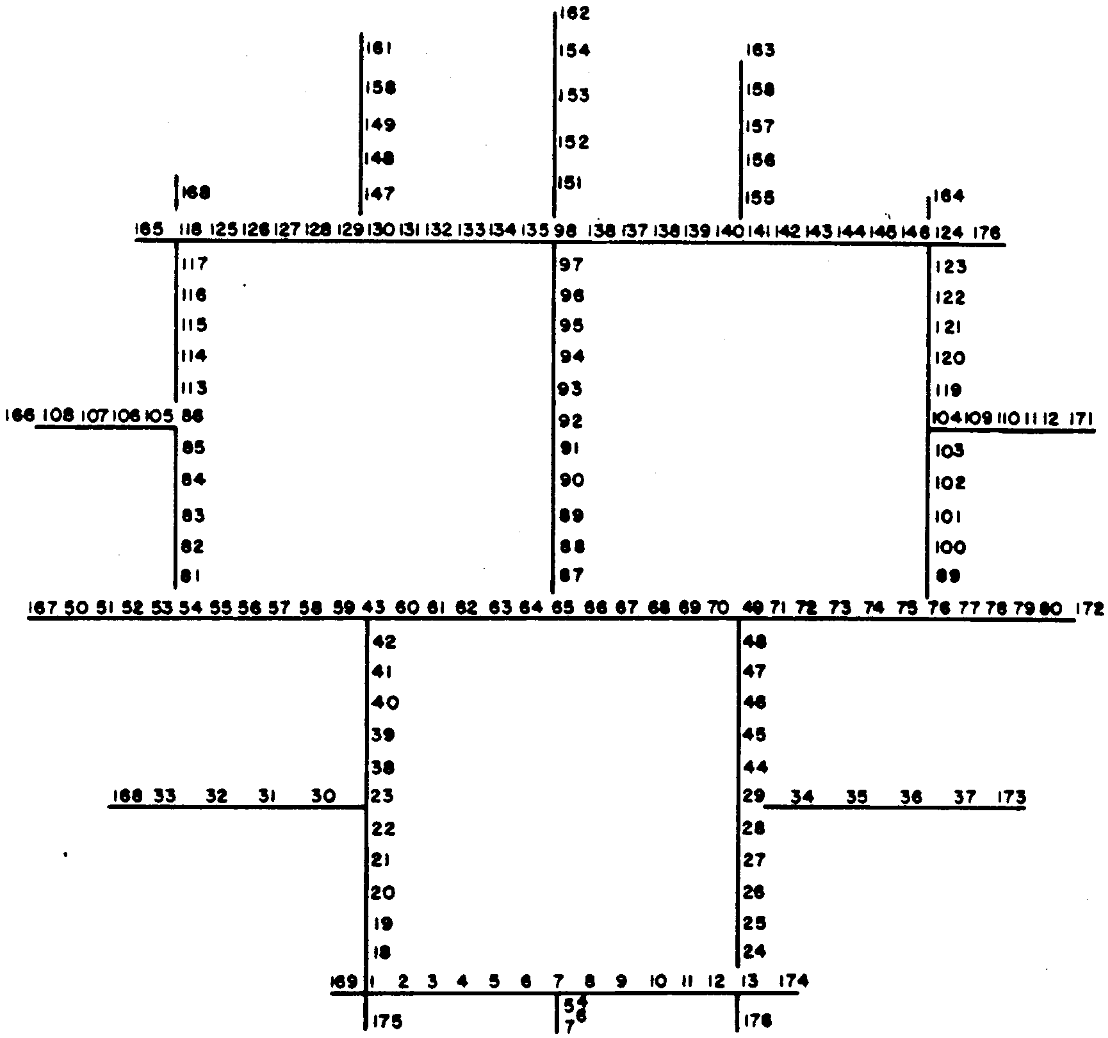

Figure 2.10-11. WECAN 2-D Beam Model of a Mid Bay Cross-Section of the 3-PWR Basket

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Value for stress allowables (S_m, S_u) were obtained for Type 316N SS from the ASME B&PV Code, Section III, Appendix I (Reference 2.10.11).

A. Loading Cases

The Accident Condition loading cases were parallel to the X and Y directions shown in Figure 2.10-12. The structural inertia loads were developed automatically by the WECAN program, given the acceleration magnitude and effective densities of the structural components. The loads due to the fuel assemblies were applied as pressure loadings along specified panels of the fuel compartments. The heaviest fuel assembly which will be transported in the TITAN LWT cask 3-PWR basket is the B&W 15x15 weighing 1515 lb. The inertia loading due to such a fuel assembly at 100 g's was assumed to be uniformly distributed. Figure 2.10-12 shows the loading and support conditions for Load Cases 1 and 2.

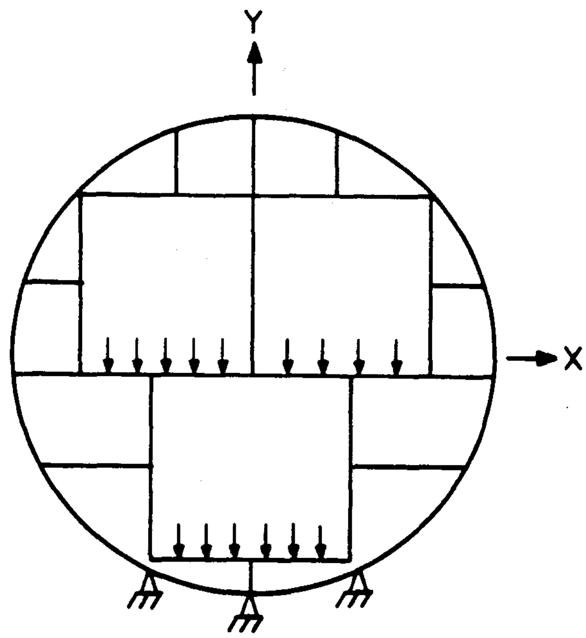
The support conditions were chosen to represent the minimum support likely to occur for the given direction of loading.

For cask orientations other than the two that were analyzed, the fuel assembly load would be shared between two adjacent compartment panels and, in addition, there would probably be more points of support. Load Cases 1 and 2 were therefore selected as being the critical directions.

The thermal loading case was obtained using steady state temperatures (heat condition) developed in Section 3.4.2. These give rise to secondary stresses which were evaluated under criteria for Normal Conditions.

B. Results

The results for the Hypothetical Accident Condition of a 30 foot side drop are illustrated in Table 2.10-11. The required wall thicknesses were determined to give a margin of safety of zero. See Section 2.7.1.2 and 2.6.7.2 for the final stress results for both the Accident and Normal drop conditions.



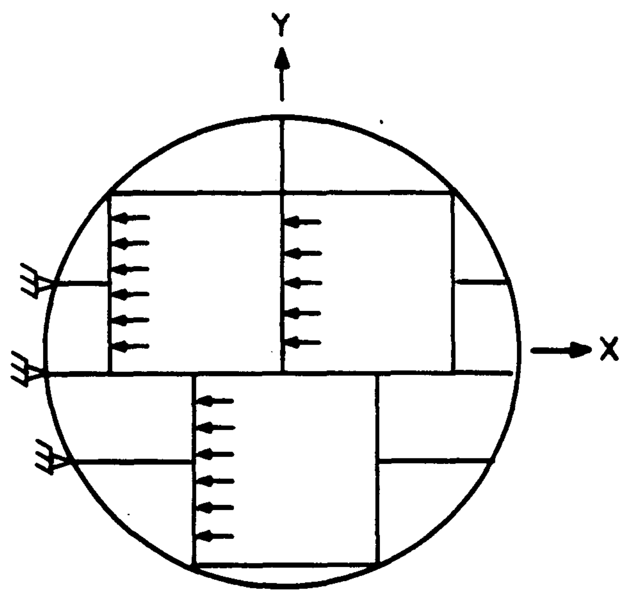


Figure 2.10-12. Accident Condition Loading Cases for the 3-PWR Basket

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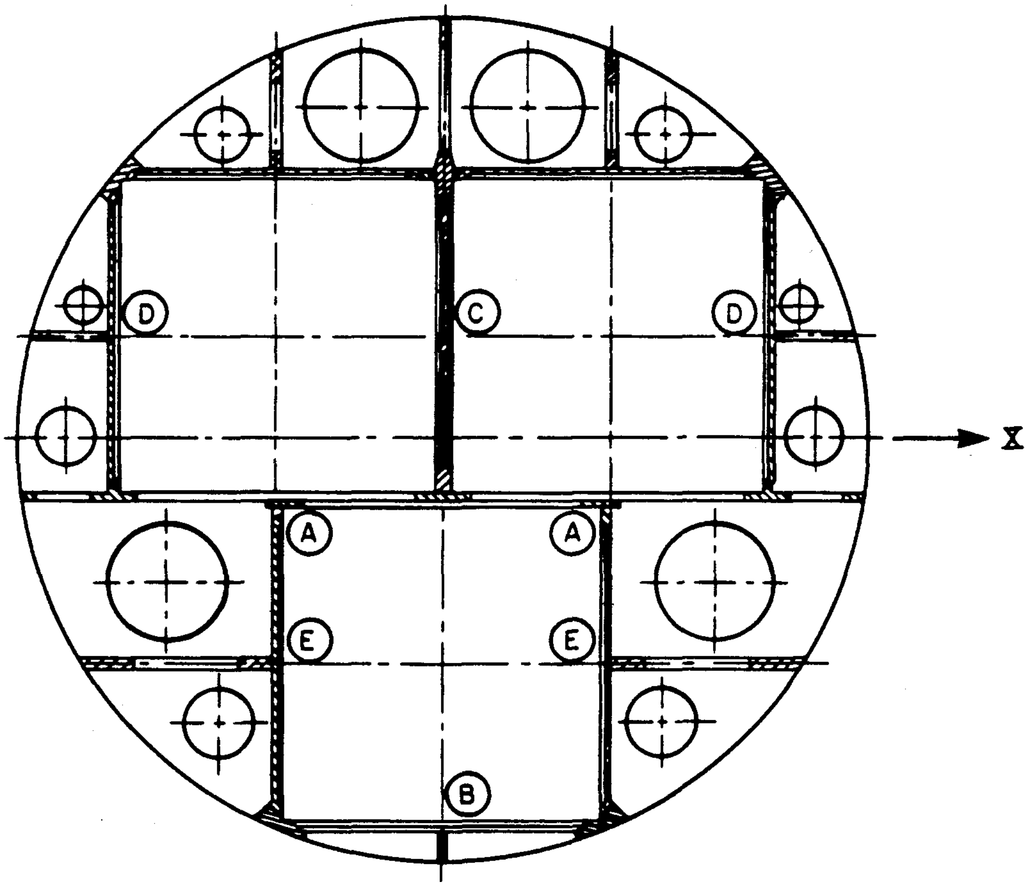
Table 2.10-11

Maximum Stresses for PWR Fuel Basket During 30 Foot Side Drop Accident

Location Point	Critical Load Case	WECAN Maximum Stress at 100g's psi	Wall Thickness in WECAN inch	Margin of Safety M.S.	Required Minimum Wall Thickness
A	1	64,159	0.140	+.18	Adequate
B	1	87,933	0.120	-.14	0.129
C	2	61,913	0.250	+.22	Adequate
D	2	108,089	0.120	-.30	0.143
E	2	88,108	0.120	-.14	0.130

$$M.S. = [\frac{75{,}650}{\text{WECAN Stress}} - 1]$$



The results of the thermal stress analysis indicated the maximum thermal stress was 8717 psi at location F in Figure 2.10-13 (see Sections 3.4.5 and 2.6.7).

BWR Fuel Basket Analysis

A finite element analysis was performed for the preliminary design of the BWR fuel basket. Figure 2.10-13 illustrates the cross sections of the fuel basket, which can support up to 7 BWR fuel assemblies. The analysis was based on a 100 g equivalent static load which the fuel basket must support during an accidental 30 foot side drop. Three drop orientations or cases were considered. The first load case assumed the drop was in the negative Y direction. The second load case was for a drop in the X direction. The third load case represented a side drop at 45 degrees between the X and negative Y directions. These loading cases for the fuel basket are illustrated in Figure 2.10-14.

The WECAN finite element program was used to perform the three side drop cases. The 2D analysis was performed for a 1 inch slice in the axial direction at mid span between two support ribs spaced 21.84 inches apart. This simplified approach was performed for the preliminary design phase using beam elements to represent the cross section of the fuel basket, at the point of maximum deflection. An alternative would be to use shell elements to represent the entire 3-dimensional configuration. Each beam element was 1 inch wide. The model, prepared using the FIGURES II program, is illustrated in Figure 2.10-15 by element number and by node number in Figure 2.10-16.

The properties of the Type 316N stainless steel (SA-240 plate) were taken from Reference 2.10.11. The walls of the cells have thicknesses of 0.210 inch for outer members and 0.320 inch for its inner members for this preliminary design. There are 0.080 inch grooves machined for 5 inch wide Boral plates, which are supported in place by a 0.031 inch liner tube. The WECAN model incorporates the stiffness properties of the wall thicknesses for the 316 N material. It was necessary to include the detail for the thicker wall sections at the joints because the bending moments were maximum at these

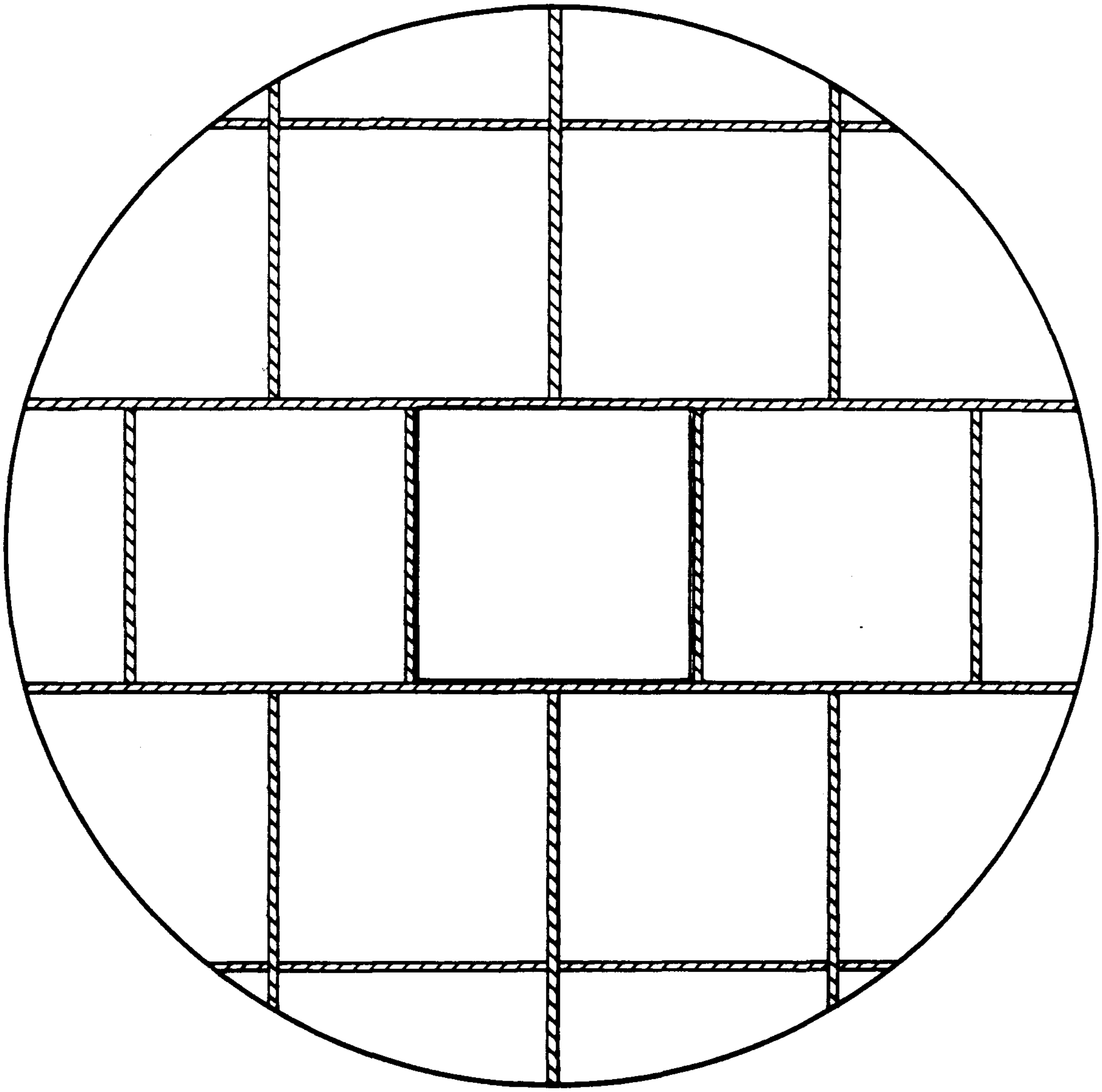


Figure 2.10-13. Cross Section of 7 BWR Fuel Basket

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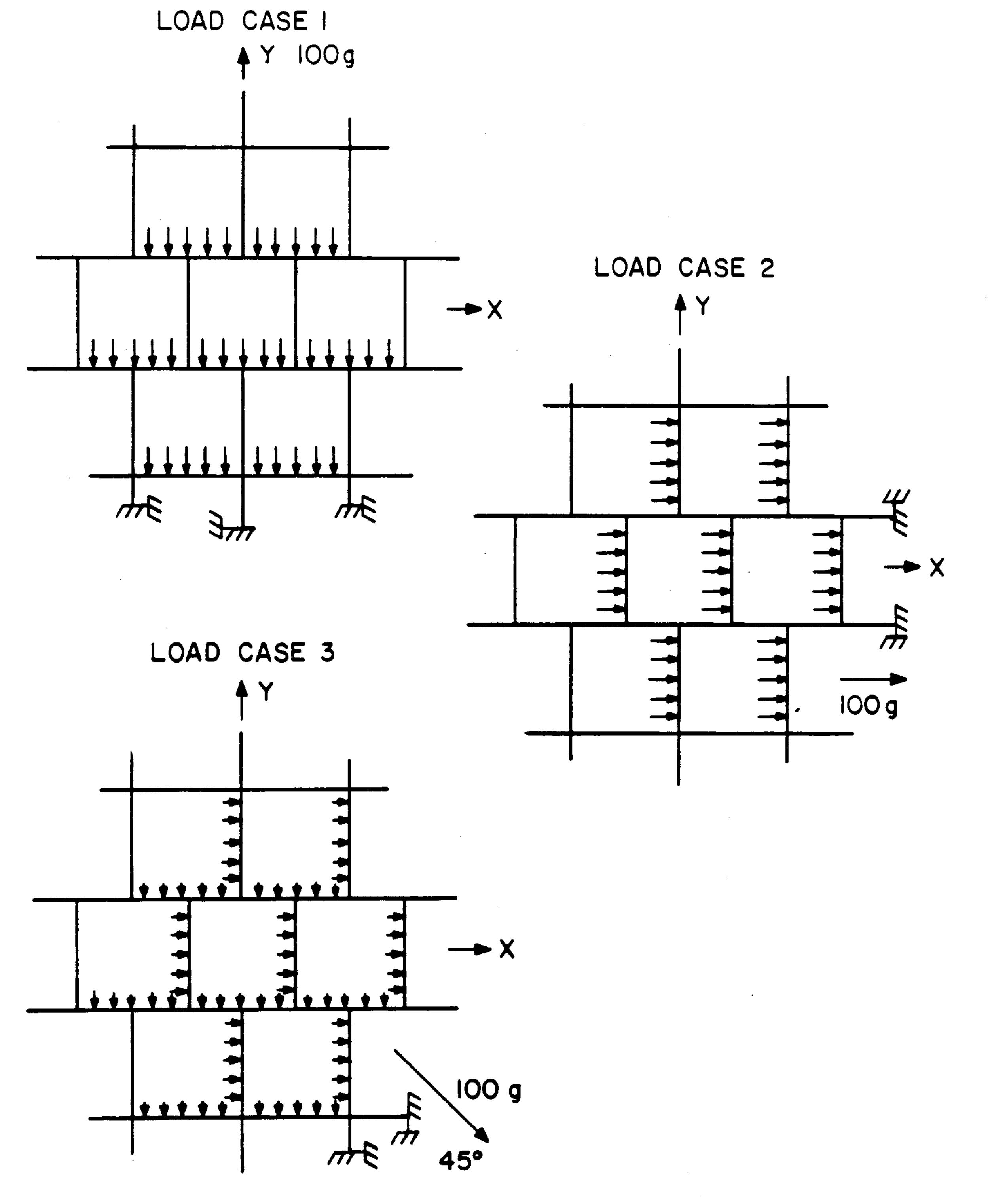

Figure 2.10-14. Accident Condition Loading Cases for the 7 BWR Fuel Basket

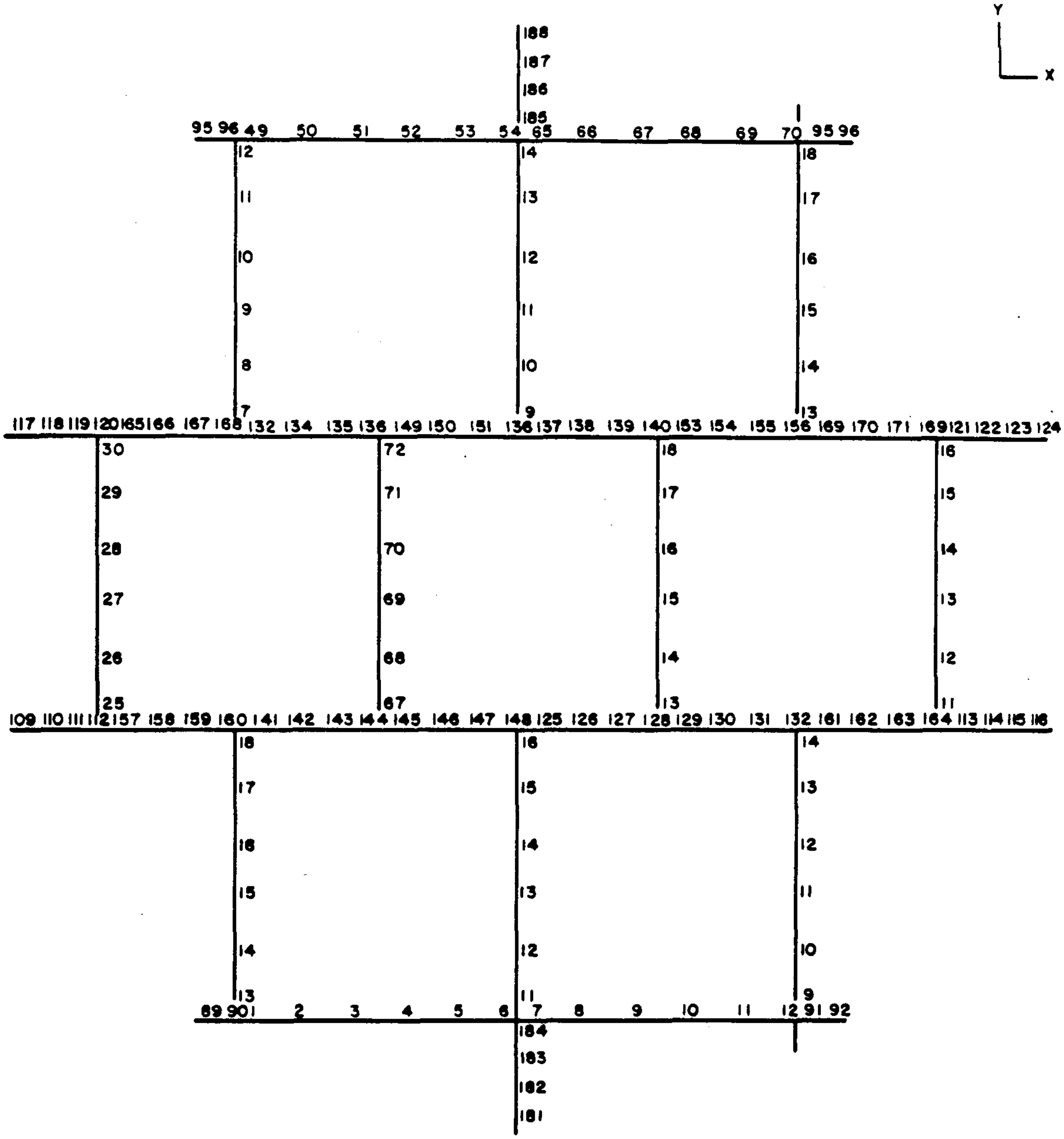

Figure 2.10-15. WECAN Finite Element Model (Element No.)

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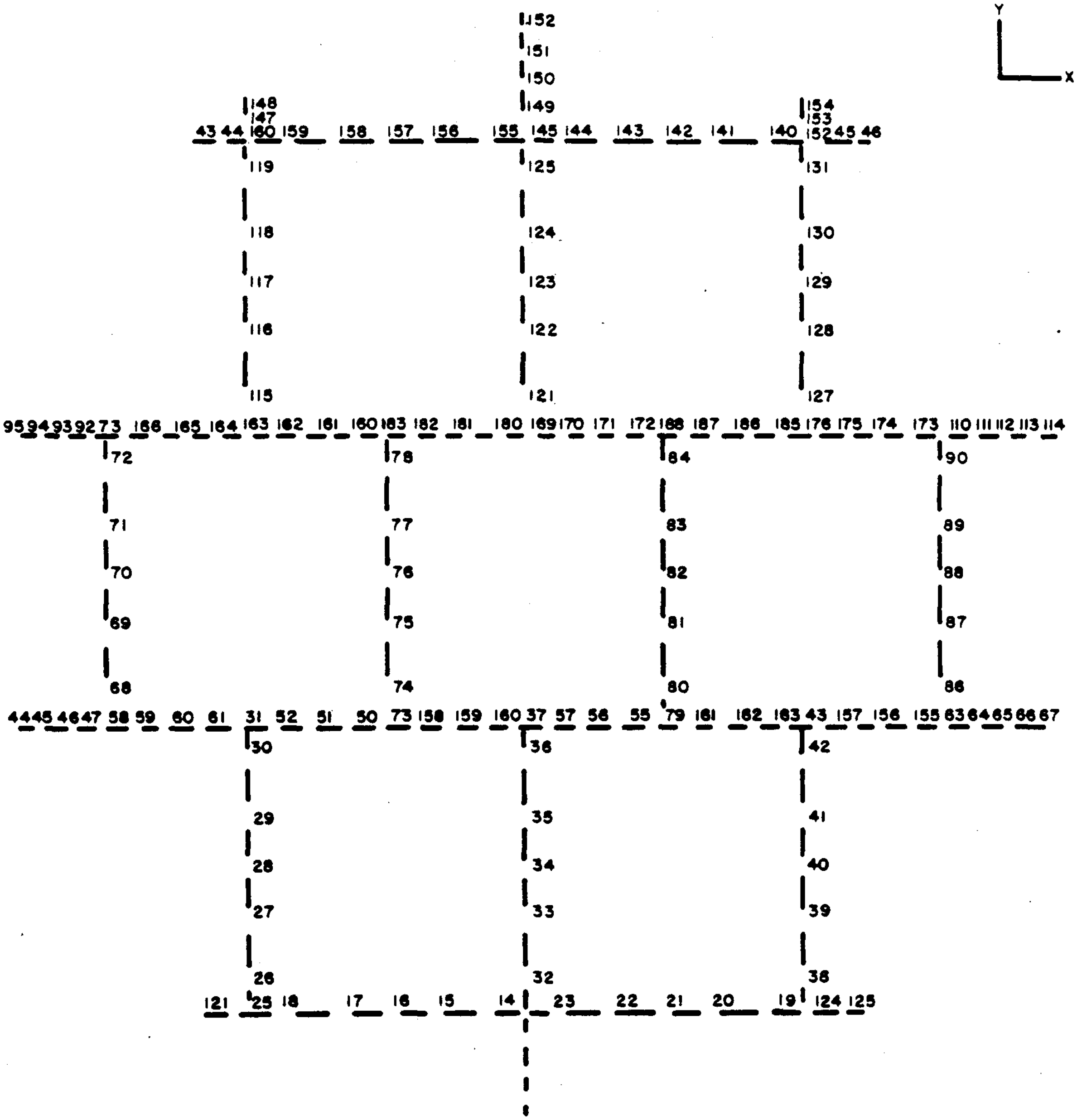

Figure 2.10-16. WECAN Finite Element Model (Node No.)

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locations. The minimum structural wall thickness was 0.130 inch for the outer compartment members having a 0.080 inch groove for the Boral plate. The outer structural members which have holes to reduce weight were compensated by reducing their wall thickness to account for the holes. This was done according to ASME, Section III methods (Reference 2.10.12). Calculations for the distributed load input at 100 g's of the fuel assembly were made for all 3 load cases. The load input was for 1 inch of fuel assembly length at 100 g's in the -Y or X direction. The 45 degree angle drop load was performed by inputing 70.71 g's in the -Y and -X directions. The gravity loads were also used to input the fuel basket dead weight loads, which included the Boral plate and liner tube.

The boundary conditions were adjusted for the BWR fuel basket model similar to that for the PWR basket.

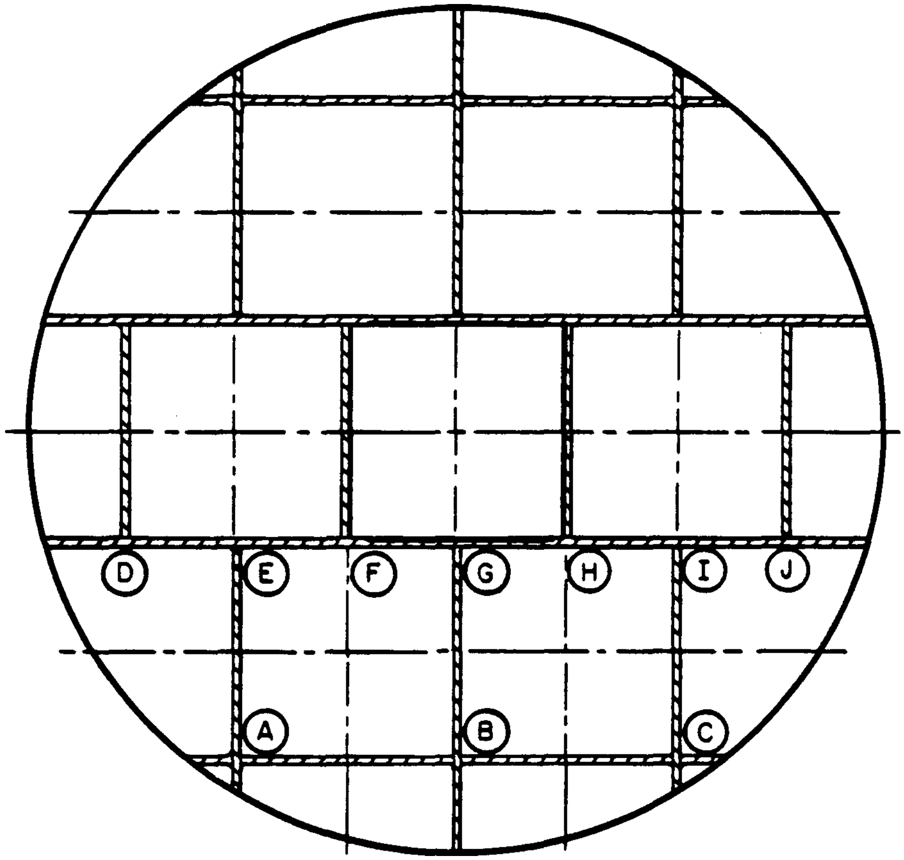
The results for the Hypothetical Accident Condition for the BWR fuel basket are given in Table 2.10-12. All stresses are within design limits. See Section 2.7.1.2 and 2.6.7.2 for the final stress results for both the accident and normal drop conditions, respectively.

Table 2.10-12

Maximum Stresses for 7 BWR Fuel Baskets During 30 Foot Side Drop Accident

Location Point	Critical Load Case	Maximum Stress for 100 g Loading psi	Wall Thickness in Model Inches	Margin of Safety M.S.
B	1	34,582	0.210	+1.16
C	3	34,666	0.210	+1.16
G	1	45,678	0.320	+0.64
H/F	1	31,045	0.320	+1.41
I(Side)	2	53,916	0.130	+0.39
I(Below)	2	38,283	0.210	+0.95
J	2	26,378	0.320	+1.84

$$M.S. = \left[\frac{74,800}{\text{WECAN Stress}} - 1\right]$$



References for Appendix 2.10.4

2.10.8 "WECAN - Westinghouse Electric Computer ANalysis," R&D Report 88-1E7-WESAD-R2, Third Edition, Revision X, Westinghouse R&D Center, Pittsburgh, PA. (Westinghouse Proprietary), June 1, 1988.

2.10.9 "FIGURES II User's Guide, Rev. E," R&D Report 88-1E7-FISAD-R2, Westinghouse R&D Center, Pittsburgh, PA. (Westinghouse Proprietary), August 9, 1988.

2.10.10 "TITAN Legal Weight Truck Cask Design Requirements," NWD-TR-007, Rev. 2, Westinghouse Nuclear Services Division, September 1989.

2.10.11 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Appendix I, 1989 Edition.

2.10.12 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Appendix A, 1989 Edition.

2.10.5 Cases of ASME Boiler and Pressure Vessel Code

The following Section contains the ASME Code Case for (3Al-2.5V) Grade 9 Titanium Alloy.

CASES OF ASME BOILER AND PRESSURE VESSEL CODE

Case N-xxx
Ti-3Al-2.5V Grade 9 Titanium Alloy
Section III, Division 1

Inquiry: Under what rules may Ti-3Al-2.5V Grade 9 titanium alloy sheet and plate, bar and billet, forgings, pipe, tubing, and welding fittings that meet the chemical and minimum mechanical properties requirements given in Tables 1 and 2, and further meet all other applicable requirements of the standard specifications listed in Table 3, be used in Section III, Division 1, Classes 1, 2 and 3 construction?

Reply: It is the opinion of the Committee that Ti-3Al-2.5V Grade 9 titanium alloy product forms as shown in Table 3 may be used in Section III, Division 1, Classes 1, 2 and 3 construction provided the following conditions are met.

(a) The material shall meet the chemical analysis and minimum tensile requirements described in the Inquiry, and otherwise conform to the ASME/ASTM specification for the respective forms.

(b) Allowable stress intensity values, allowable stress values and yield strength values for the material shall be those given in Table 4.

(c) Separate welding procedures and performance qualifications shall be required for this material. The welding procedure qualification and performance qualification shall be conducted as prescribed in Section IX.

(d) All other requirements of Section III, Division 1, for Classes 1, 2 and 3 construction, as applicable, shall be met.

(e) This case number and revision applied shall be identified in the Materials Manufacturer's certification for the sheet and plate, bar and billet, forging, pipe, tubing or welding fitting material.

TABLE 1

CHEMICAL REQUIREMENTS

Composition, %

ELEMENT	(Sheet/ Plate)	(Bar & Billet)	(Forging) (Gr F-9)	(Pipe)	(Tubing)
Nitrogen, max	0.02	0.02	0.02	0.02	0.02
Carbon, max	0.010	0.05	0.05	0.05	0.01
Hydrogen, max	0.015	0.0125[3] 0.010[4]	0.015	0.013	0.013
Iron, max	0.25	0.25	0.25	0.25	0.25
Oxygen, max	0.15	0.12	0.12	0.12	0.12
Aluminum	2.5-3.5	2.5-3.5	2.5-3.5	2.5-3.5	2.5-3.5
Vanadium	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0	2.0-3.0
Residuals[1,2] (each)	0.1	0.1	0.1	0.1	0.1
Residuals[1,2] (total)	0.4	0.4	0.4	0.4	0.4
Titanium	remainder	remainder	remainder	remainder	remainder

Notes:
1 Need not be reported

2 A residual is an element present in a metal or an alloy in small quantities inherent to the manufacturing process but not added intentionally

3 Bars only

4 Billets only

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TABLE 2

MECHANICAL PROPERTY REQUIREMENTS

Tensile strength, min., ksi (MPA)	90 (620)
Yield strength, min., ksi (MPA)	70 (483)
Elongation in 2 in. (50 mm), min., percent	15[(1)]

Note (1): Elongation for continuous rolled and annealed strip product from coils shall be 12% minimum in longitudinal direction and 8% minimum in the transverse direction.

TABLE 3

PRODUCT SPECIFICATIONS

	ASME	ASTM
Strip, Sheet and Plate	SB 265 (1)	B 265 (2)
Bars and Billets	SB 348 (1)	B 348
Forgings	SB 381 (1)	B 381
Seamless and Welded Pipe	SB 337 (1)	B 337
Tubing	SB 338 (1)	B 338
Welding Fittings (3)	SB 363	B 363

Notes: (1) Grade 9 material has not been included in these ASME Specifications.

(2) The inclusion of Grade 9 material in this ASTM specification is in process.

(3) Permissible raw materials are B 337 Grade 9 pipe, B 338 Grade 9 Tubing, B 265 Grade 9 plate, B 348 Grade 9 bar and billet and B 381 Grade F-9 Forgings.

TABLE 4

ALLOWABLE STRESS INTENSITY, ALLOWABLE STRESS AND YIELD STRENGTH VALUES
(S_m, S, and S_y)

For Metal Temperature Not Exceeding °F	Allowable Stress Intensity Values, S_m, ksi	Allowable Stress Values, S, ksi	Minimum Yield Strength Values S_y, ksi
RT	30.0	22.5	70.0
100	30.0	22.5	67.9
150	30.0	22.5	65.1
200	29.0	21.8	61.6
250	27.7	20.8	58.1
300	26.4	19.8	55.3
350	24.8	18.6	52.5
400	23.4	17.6	49.7
450	22.4	16.8	46.9
500	21.1	15.8	44.8
550	20.5	15.3	43.4
600	20.1	15.1	41.3

2.10.6 Cask Support System and Ancillary Equipment Structural Analysis

The purpose of this analysis is to provide a structural evaluation of the TITAN LWT cask support and tiedown structures, the intermodal transfer skid, the personnel barrier, and the special lifting device or lifting yoke. The objective is to show that the structural design limits provided in NWD-TR-007 (Reference 2.10.13) are met for these structures.

The functions of the cask support system are 1) to support and secure the LWT cask on the transporter (semi-trailer), and 2) provide a pivot point for rotating the cask from its horizontal transport position to the vertical for off-loading and vice-versa. The cask support and tiedown system consists of two major components; the front cradle and the rear support and pivot. Design details are provided in Drawings 1988E50, 1988E51 and 1988E52.

The ancillary equipment consists of the following:

- o Lifting Yoke Assembly
- o Personnel Barrier
- o Intermodal Transfer Skid

The lifting yoke assembly is used to handle the cask both at the receiving facility and at those reactor sites where single-failure proof handling systems are not required. The lifting yoke assembly is designed to meet the requirements in ANSI-N14.6, Section 3.2 (Reference 2.10.14) and the recommendations of NUREG-0612, Section 5.1.1 (4) (Reference 2.10.15). Drawing 1988E47 shows the details of the lifting yoke design.

The personnel barrier is designed to protect the cylindrical portion of the cask that is not covered by the impact limiter while sitting on the semi-trailer. The personnel barrier limits access to the cask body and provides protection of the cask body from rain, water spray and dirt while permitting air circulation around the cask. The material of construction is 6061-T6 aluminum to provide a light weight structure with sufficient strength to withstand transportation and handling loads. Design details are provided in Drawing 1988E46.

The intermodal transfer skid provides a means for support and tiedown of the cask for transport using modes other than truck transport, i.e., by rail or by barge. The intermodal transfer skid is designed to be lifted with the cask on it to either a railcar or barge. Design details are provided in Drawing 1988E54. The restraint cradle and upending support features are identical to the support system used for the cask on the semi-trailer, except that the cradle and upending support are welded to a 6061-T6 aluminum base frame.

Conventional stress analysis formulas and methods were used to evaluate load bearing structural members and mechanical components of the cask support and tiedown system and of the ancillary equipment. Axial, axial plus bending, shear, and bearing stress components were calculated and compared to allowables. Acceptability of the designs was evaluated by assuring that positive margins of safety (as calculated below) existed for all structural members and components:

$$M.S. = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1.0$$

2.10.6.1 <u>Support and Tiedown System</u>

The support and tiedown system loads, design limits and analysis results are as follows:

<u>Support and Tiedown System Loads</u>

1. Inertial loads for normal highway travel of $\pm$ 0.5 g's in the longitudinal, vertical and lateral directions were used in the analysis.

2. The following loads were used for the worst non-accident event in highway transportation:

Direction	Inertial Loads
Longitudinal	± 2.3 g's
Lateral	± 1.6 g's
Vertical	± 2.0 g's

Each directional load (combined with the deadweight load) was analyzed independently (not combined). Loads will be shared by the front and rear supports as follows:

a. ± 2.3 g longitudinal + 1.0 g vertical down. The longitudinal load of 2.3 X 54,000 or 124,200 lbs is resisted by the rear support. The vertical (deadweight) load (54,000 lbs) is resisted by both the front and rear supports.

b. ± 1.6 g lateral + 1.0 g vertical (down). The lateral load of 1.6 x 54,000 or 86,400 lbs is resisted by both the front and rear supports. The deadweight load (54,000 lbs) is shared by both the front and rear supports.

c. ± 2.0 g vertical + 1.0 g vertical down. The net effect, in this case, is 1 g up and 3 g down. These loads will be shared by both the front and rear supports.

For the preliminary design only the worst non-accident event was considered.

Design Limits For Support And Tiedown Systems

The design limits used in the analysis of the support system are contained in Table II.3-1 of Reference 2.10.13.

Two primary materials are employed in the design of the support system. These materials and their room temperature yield and ultimate properties are:

Aluminum Alloy 6061-T6, σ_y = 35 ksi, σ_{ult} = 42.0 ksi (Reference 2.10.16)

Stainless Steel Type 304, σ_y = 30 ksi, σ_{ult} = 75.0 ksi (Reference 2.10.17)

The allowable stress for the aluminum and stainless steel alloys are:

Stress Component	Allowable Stresses		
	6061-T6	Welded 6061-T6	304 SS
σ_m	35.0	17.5	30.0
$\sigma_m + \sigma_b$	35.0	17.5	30.0
σ_s	21.0	10.5	18.0
σ_{br}	52.5	26.25	45.0

Analysis Results

Table 2.10-13 presents the results of the stress analysis on the cask support and tie-down system.

2.6.10.2 Intermodal Transfer Skid

This section provides the intermodal transfer skid loads, design limits and results of the structural analyses.

Table 2.10-13

Support and Tiedown System Analysis Results

Front Support	Stress Component	Stress (psi)	Allowable (psi)
Main Support Structure	Axial	3,543	17,500
Cradle Trunnion Clamp	Weld	12,770	18,000
Captive Bolt	Axial	14,431	115,000
Clamp Top Plate	Bending	13,423	30,000
Main Support Structure	Axial + Bending	27,091	35,000
	Shear	5,900	21,000
Bearing Bar	Bending	19,038	35,000
	Shear	9,415	10,500
Tie-down Bolt	Tension	108,536	130,000
	Bearing	38,284	52,500
Rear Upending Support			
Main Support Structure (Lateral Load Case)	Axial + Bending	25,661	35,000
Support Top Plate	Bending	13,376	17,500
	Shear	9,833	10,500
Support Top Plate Weld	Shear	7,660	10,500
Main Support Top Weld	Axial + Bending	16,414	17,500
Main Support Base	Axial + Bending	15,411	17,500
Support Top Plate (Longitudinal Load Case)	Axial + Bending	16,259	17,500
Main Support Base	Axial + Bending	16,010	17,500
Clamp Vertical Load	Axial	8,746	17,500
Rear Support Clamp	Bending	8,511	30,000
Saddle Bearing	Bearing	26,846	45,000
Pivot Pin	Shear	4,623	69,000
	Bending	33,353	115,000

Intermodal Transfer Skid Loads

It is assumed that the worst non-accident loads on the intermodal transfer skid will be the same as those previously described for the truck transportation loads on the support and tiedown system. For final design, rail transportation loads given in Reference 2.10.13 will also be considered. Loads on lifting components, such as the shackles, will have a load factor of three.

Design Limits for Intermodal Transfer Skid

Design limits for the intermodal transfer skid will be in accordance with the AISC Manual for Steel Construction (Reference 2.10.18), except for lifting devices which shall be those given in Table II.3-1 of Reference 2.10.13.

Allowable Stress Limits

Stress Component	Intermodal Skid	Lifting Components
σ_m	$0.6\ S_y$	S_y
$\sigma_m + \sigma_b$	$0.66\ S_y$	Greater of: 1.5S S_y
σ_s	$0.4\ S_y$	Greater of: 0.6S $0.6S_y$
σ_{br}	$0.9\ \sigma_y$	$1.5\ S_y$

The primary structural material is Aluminum Alloy 6061-T6, where $\sigma_y = 35$ ksi and $\sigma_{ult} = 42.0$ ksi at room temperature (Reference 2.10.16). For welded aluminum structures, the allowable stress shall be half of those listed above.

Analysis Results

Table 2.10-14 presents the results of the stress analysis of the lifting components on the intermodal transfer skid. For the preliminary design, it is assumed that the intermodal transfer skid will experience the same worst non-accident event in highway transportation as does the cask support and tie-down system. Therefore, the stress analysis was not repeated for transportation loads. For final design a more detailed analysis will be carried out that includes the effect of rail transportation loads.

2.10.6.3 Personnel Barrier

The following provides a description of the personnel barrier design loads, design limits and the results of the analysis.

Personnel Barrier Design Loads

The personnel barrier structural design is based on withstanding the specified transport loads of 1.5 g's in any direction.

Personnel Barrier Design Limits

The acceptance criteria for the personnel barrier structure are those given in the AISC Manual of Steel Construction, (Reference 2.10.18), and reproduced below:

		Allowable Stresses	
Stress Component	Stress Limit	Alum. 6061-T6 (psi)	Welded Alum. 6061-T6 (psi)
σ_m	$0.6\ S_y$	21,000	10,500
$\sigma_m + \sigma_b$	$0.66\ S_y$	23,100	11,550
σ_s	$0.4\ S_y$	14,000	7,000
σ_{br}	$0.9\ S_y$	31,500	15,750

Table 2.10-14

Intermodal Transfer Skid Analysis Results

Component	Stress Component	Stress (psi)	Allowable (psi)
Rear Support			
Attach. Bracket	Bending	17,298	17,500
	Axial	11,713	17,500
Main Beam	Bending	8,090	17,500
Lifting Eye	Safe Working Load	13,665 lbs	15,200 lbs.
Front Support			
Main Beam	Bending	8,230	17,500

Analysis Results

Table 2.10-15 presents a summary of the results of the stress analysis of the personnel barrier.

2.10.6.4 Lifting Yoke

The lifting yoke design loads, design limits and analysis are as follows:

Lifting Yoke Design Loads

The load-bearing members of the lifting yoke are capable of lifting the combined weight of the cask filled with water, plus the weight of intervening components of the special lifting device. A dynamic hoist load factor of 0.15 was applied to the total unit weight (Reference 2.10.19).

The cask fully loaded with 3 PWR assemblies without the impact limiters weighs 50,754 pounds. The water which fills the void space in the cask cavity, with the closure in place, weighs 2,204 pounds. The lifting yoke weighs 1,321 pounds. The combined weight of the cask, water and lifting yoke is 54,279 pounds. Applying the 0.15 hoist load factor, the total lifting weight becomes 62,420 pounds. Finally, applying a factor of three on the combined weight and hoist load factor, the design lift load becomes 187,260 pounds.

Lifting Yoke Design Limits

The acceptance stress criteria for the load-bearing components of special lifting devices are based on the following criteria given in Table II.3-1 of Reference 2.10.13, or:

$$\sigma_m \leq S = \min S_y/3 \text{ or } S_{ult}/5$$
$$\sigma_m + \sigma_b \leq 1.5S$$
$$\sigma_{br} \leq 1.5\ S_y$$

Table 2.10-15
Personnel Barrier Analysis Results

Component	Stress Component	Stress (psi)	Allowable (psi)
Main Support	Bending	13,165	23,100
	Shear	203	14,000
Longitudinal	Axial	275	21,000
Beams	Buckling	225 lbs.	288.5 lbs.
Lifting Handle	Bending	7,881	10,500

For the materials used in the construction of the yoke, the allowables become:

Stress Component	304 SS	6061-T6
σ_m	10,000	8,400
$\sigma_m + \sigma_b$	15,000	12,600
σ_{br}	45,000	31,500

Analysis Results

Table 2.10-16 presents a summary of the results of the stress analysis of the lifting yoke assembly.

2.10.6.5 Analysis Summary

The structural members and mechanical components of the cask support and tiedown system and of the ancillary equipment have been evaluated for their design basis environment and loads, and these have been compared to design limits and criteria. The structural sizing and design of the TITAN LWT cask support structures, special lifting yoke, personnel barrier, and intermodal transfer skid are adequate and meet design limits.

References For Section 2.10.6

2.10.13 "TITAN Legal Weight Truck Cask Design Requirements," NWD-TR-007, Rev.2, Westinghouse Nuclear Services Division, September 1989.

2.10.14 ANSI N14.6-1978, "Special Lifting Devices for Shipping Containers Weighing 1000 Pounds or More for Nuclear Materials," February 1978.

2.10.15 NUREG-0612 (1980), "Control of Heavy Loads at Nuclear Power Plants: Resolution of Generic Technical Activity A-36", Henry J. George, July 1980.

Table 2.10-16

Lifting Yoke Analysis Results

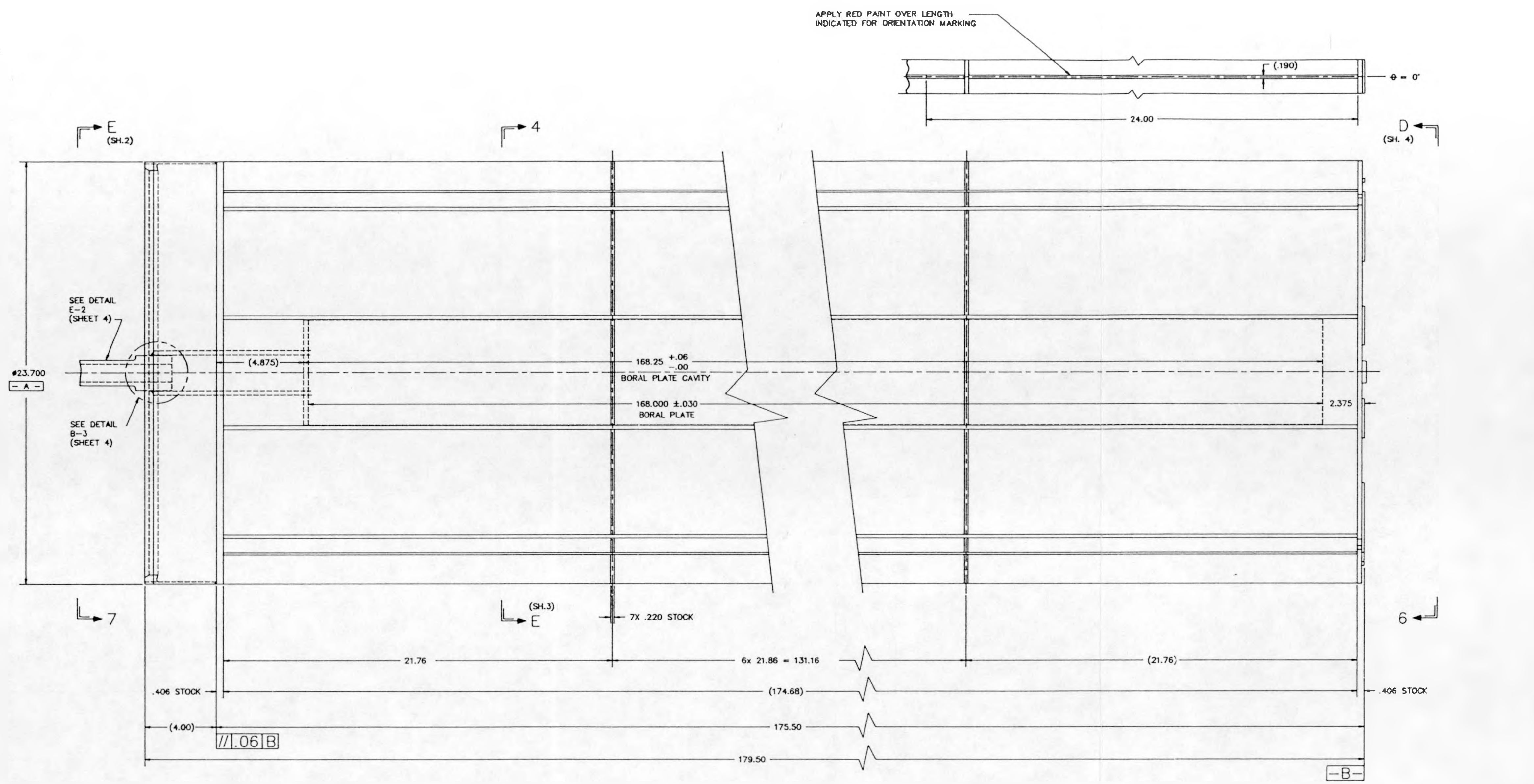
Component	Stress Component	Stress (psi)	Allowable (psi)
Yoke Mast	Weld Shear	16,426	18,000
	Pipe Section	21,235	30,000
Frame Weldment	Bending	23,392	45,000
	Shear Tearout	12,483	18,000
	Bearing	12,483	18,000
Lifting Arm	Weld	16,552	18,000
Bail	Shear	17,023	18,000
	Tension	26,751	30,000
Pivot Pin	Bending	65,473	172,500
	Shear	9,536	115,000

2.10.16 "Engineering Data for Aluminum Structures," Aluminum Construction Manual, Section 3, Aluminum Association, Inc., 1986.

2.10.17 ASME Boiler and Pressure Vessel Code, Section III, Appendices, 1982.

2.10.18 American Institute of Steel Construction (AISC), Manual of Steel Construction, Eighth Edition, 1980.

2.10.19 CMAA Specification #70, "Specification for Electric Overhead Traveling Cranes," revised 1983, Crane Manufacturers Association.



NOTES:

1. ALL MATERIALS ARE ASME SA-240 TYPE 316N EXCEPT AS NOTED.
2. BORAL IS A TRADEMARK OF AAR BROOK & PERKINS.
3. ALL WELDING PROCEDURES AND WELDERS SHALL BE QUALIFIED PER THE ASME B & PV CODE SECTION IX. ALL GROOVE WELDS SHALL BE FULL PENETRATION WELDS EXCEPT AS INDICATED OTHERWISE ON THE DRAWING.
4. ULTRASONIC TEST WELDS IN ACCORDANCE WITH ASME B & PV CODE SECTION V, ARTICLE 5. ACCEPTANCE STANDARDS OF ASME B & PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
5. LIQUID PENETRANT TEST WELDS IN ACCORDANCE WITH ASME B & PV CODE SECTION V, ARTICLE 6. ACCEPTANCE STANDARDS OF ASME B & PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
6. CHROME PLATE PER FEDERAL SPEC QQ-C-320B.

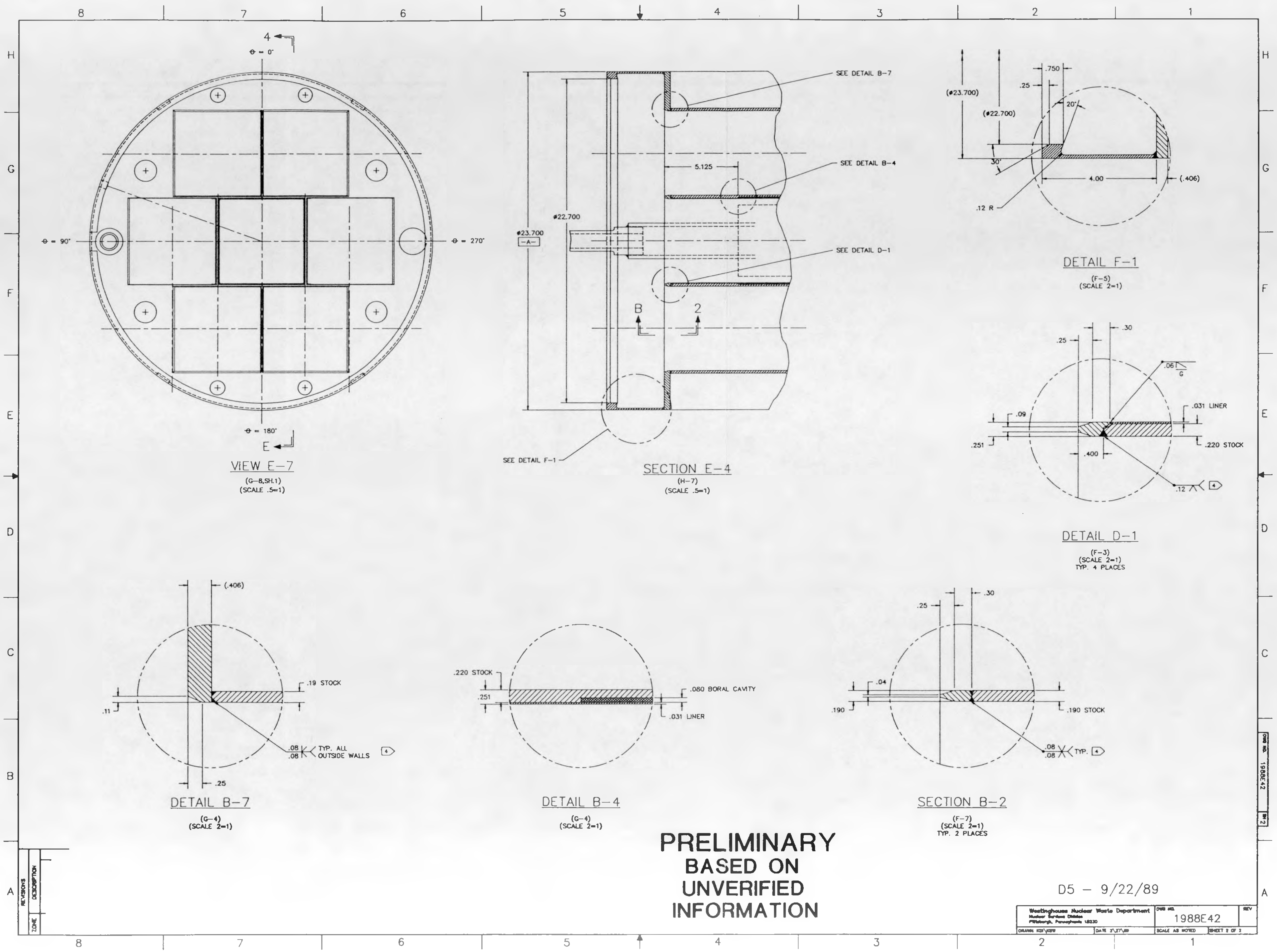
D5 - 9/22/89

PRELIMINARY BASED ON UNVERIFIED INFORMATION

Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230

TITAN LEGAL WEIGHT TRUCK CASK - BWR BASKET - LAYOUT -

DWG NO. 1988E42
SCALE .5=1
SHEET 1 OF 4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(G-8,SH.1)
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SEE DETAIL B-4
SEE DETAIL D-1
SEE DETAIL F-1
DETAIL F-1
(F-5)
(SCALE 2=1)
DETAIL D-1
(F-3)
(SCALE 2=1)
TYP. 4 PLACES
DETAIL B-7
(G-4)
(SCALE 2=1)
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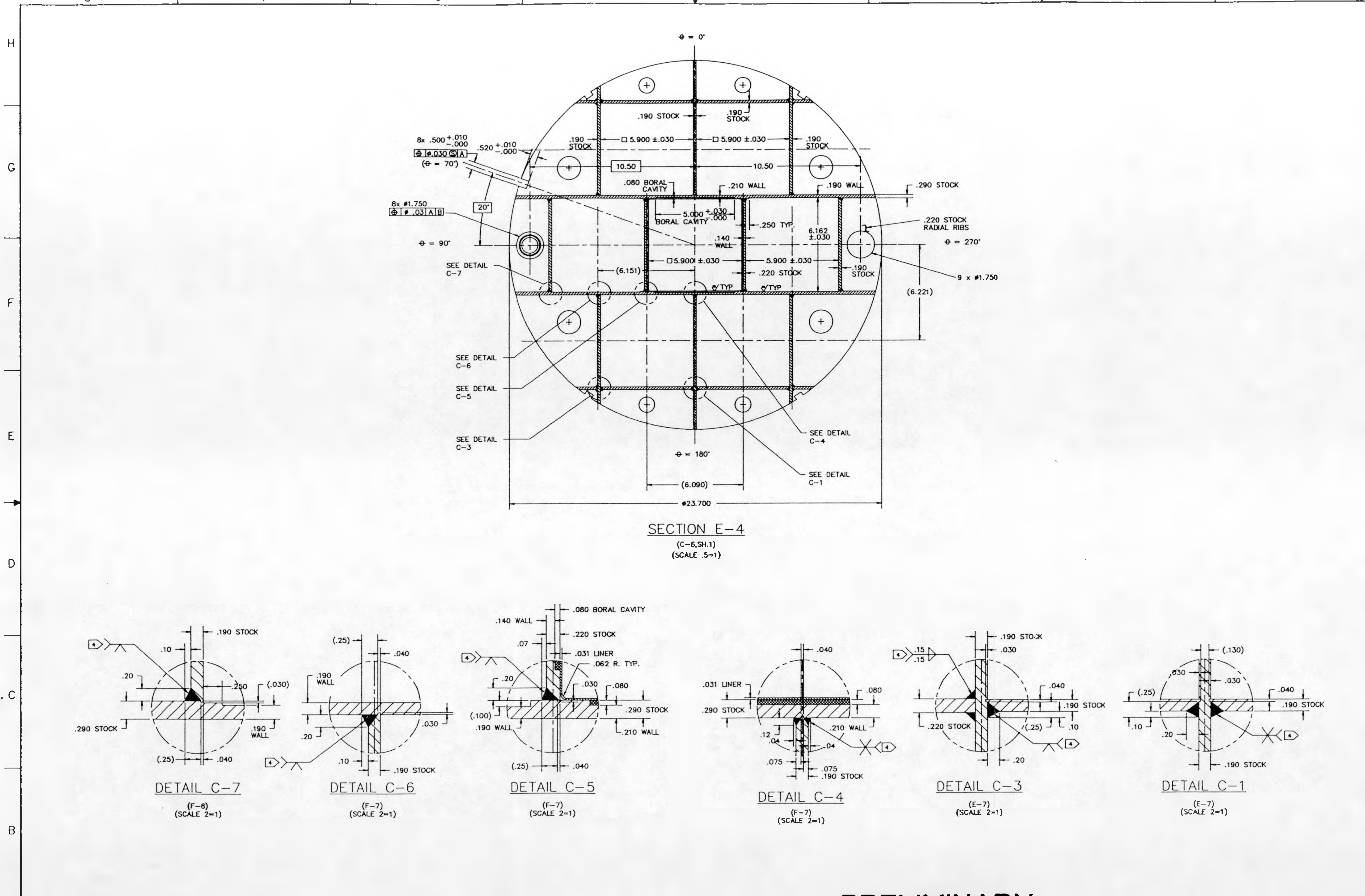
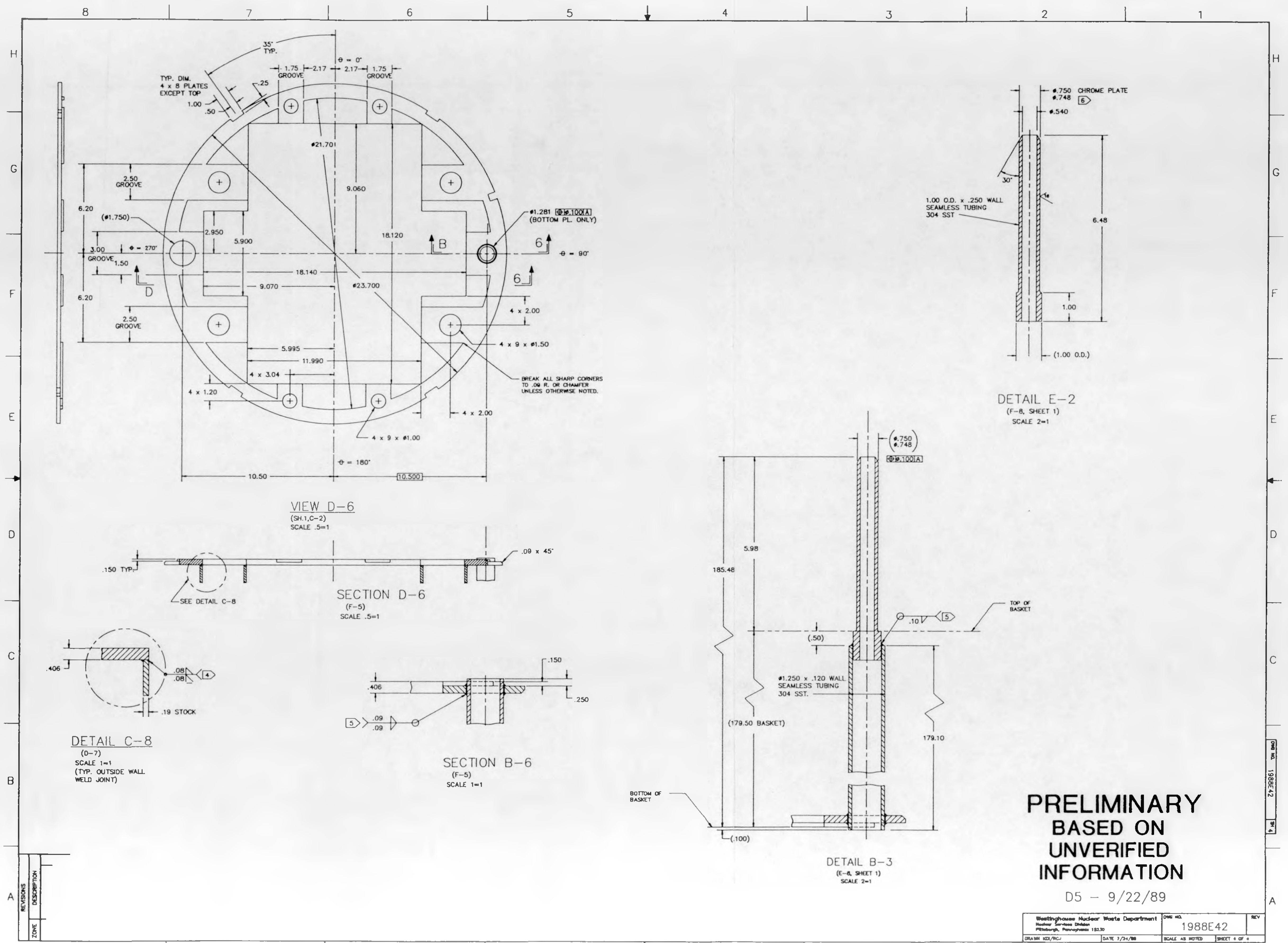
(G-4)
(SCALE 2=1)
SECTION B-2
(F-7)
(SCALE 2=1)
TYP. 2 PLACES
.19 STOCK
TYP. ALL OUTSIDE WALLS
.220 STOCK
.080 BORAL CAVITY
.031 LINER
.190 STOCK
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
D5 – 9/22/89
Westinghouse Nuclear Waste Department
1988E42

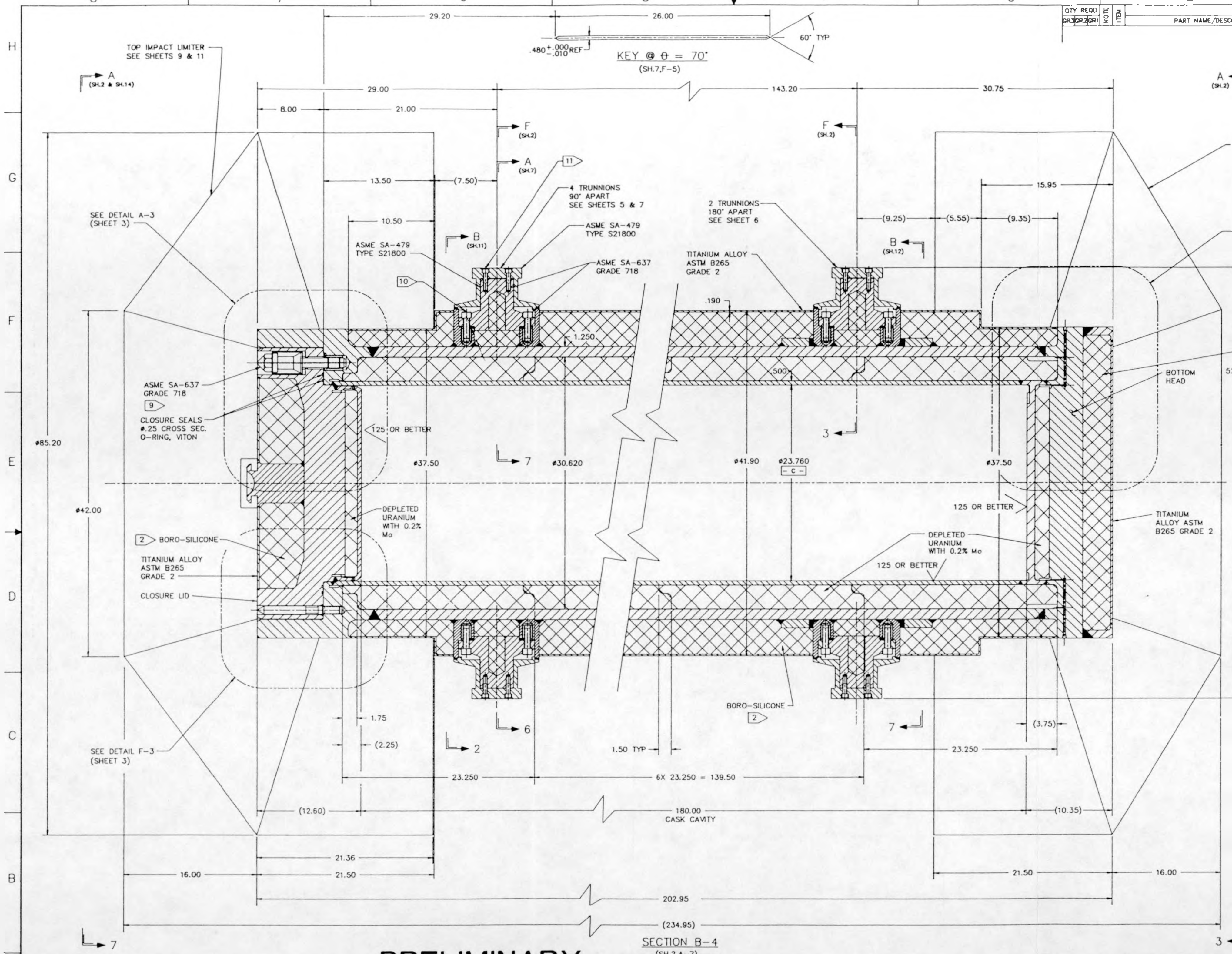


PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

D5 – 9/22/89

Westinghouse Nuclear Waste Department Nuclear Services Division Pittsburgh, Pennsylvania 15230	DWG NO. 1988E42
DRAWN	DATE
SCALE AS NOTED	SHEET 3 OF 4


VIEW D-6
(SH.1,C-2)
SCALE .5=1
SECTION D-6
(F-5)
SCALE .5=1
DETAIL C-8
(D-7)
SCALE 1=1
(TYP. OUTSIDE WALL WELD JOINT)
SECTION B-6
(F-5)
SCALE 1=1
DETAIL E-2
(F-8, SHEET 1)
SCALE 2=1
DETAIL B-3
(E-6, SHEET 1)
SCALE 2=1
TYP. DIM. 4 x 8 PLATES EXCEPT TOP
BREAK ALL SHARP CORNERS TO .09 R. OR CHAMFER UNLESS OTHERWISE NOTED.
ø1.281 (BOTTOM PL. ONLY)
1.00 O.D. x .250 WALL SEAMLESS TUBING 304 SST
ø1.250 x .120 WALL SEAMLESS TUBING 304 SST.
ø.750 CHROME PLATE
TOP OF BASKET
BOTTOM OF BASKET
(179.50 BASKET)
SEE DETAIL C-8
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
D5 – 9/22/89
Westinghouse Nuclear Waste Department
DWG NO. 1988E42



BORO-SILICONE [2>

NOTES:

1. ALL MATERIALS ARE TITANIUM ALLOY ASTM GRADE 9, ASTM B265 STRIP, SHEET AND PLATE, B381 FORGINGS, B348 BARS AND BILLETS, B337 SEAMLESS AND WELDED PIPE, B338 TUBING, AS APPLICABLE EXCEPT AS OTHERWISE NOTED.
2. BORO-SILICONE IS A TRADEMARK OF REACTOR EXPERIMENTS, INC.
3. ALL WELDING PROCEDURES AND WELDERS SHALL BE QUALIFIED PER THE ASME B & PV CODE SECTION IX. ALL GROOVE WELDS SHALL BE FULL PENETRATION WELDS EXCEPT AS INDICATED OTHERWISE ON THE DRAWING.
4. PREFORM ACCEPTANCE TESTING IN ACCORDANCE WITH APPROOVED PROCEEDURES.
5. RADIOGRAPH WELDS IN ACCORDANCE WITH ASME B & PV CODE, SECTION V, ARTICLE 2. ACCEPTANCE STANDARDS OF ASME B & PV CODE, SECTION III, ARTICLE NB-5320 SHALL APPLY.
6. ULTRASONIC TEST WELDS IN ACCORDANCE WITH ASME B & PV CODE SECTION V, ARTICLE 5. ACCEPTANCE STANDARDS OF ASME B & PV SECTION III, ARTICLE NB-5330 SHALL APPLY.
7. LIQUID PENETRANT TEST WELDS IN ACCORD-ANCE WITH ASME B & PV CODE SECTION V, ARTICLE 6. ACCEPTANCE STANDARDS OF ASME B & PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
8. CHROME PLATE PER FEDERAL SPEC QQ-C-320B
9. TORQUE LID BOLTS TO 2,200 ±100 FT. LBS.
10. TORQUE TRUNNION BOLTS TO 540 ±25 FT. LBS.
11. TORQUE TRUNNION SLEEVE BOLTS TO 85 ±5 FT. LBS.
12. TORQUE IMPACT LIMITER BOLTS TO 130 ±7 FT. LBS
13. TORQUE ALIGNMENT PINS TO 400 ±20 FT. LBS.
14. TORQUE PENETRATION LID BOLTS TO 50 ±2 FT. LBS.
15. TORQUE SEAL TEST PORT PLUG TO 100 ±5 FT. LBS.
16. TORQUE SEAL TEST PORT VALVE TO 20 ±1 FT. LBS.
17. O - RING SEAL MATERIAL FOR ALL O - RINGS SHALL BE VITON - PARKER COMPOUND V835-75.

D14 9/22/89
~~D13 8/4/89~~
(ALL SHEETS)

PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

INTERPRET DWG PER ANSI Y14	DFTG KDI/JMB
DIM. IN INCHES BASED ON 68°F	CHKR KDI/XXX
UNLESS OTHERWISE SPECIFIED TOLERANCES	COG. ENG RQJ 9/14/89
2 PL DEC ±.030 / 3 PL DEC ±.010 / ANGLES XXXXXX / 125 AA	COG. MGR
NEXT ASSY	APPD
	APPD
	APPD
	APPD
ENGINEERING RELEASE BY WTSD DATE	DFTG SUPV

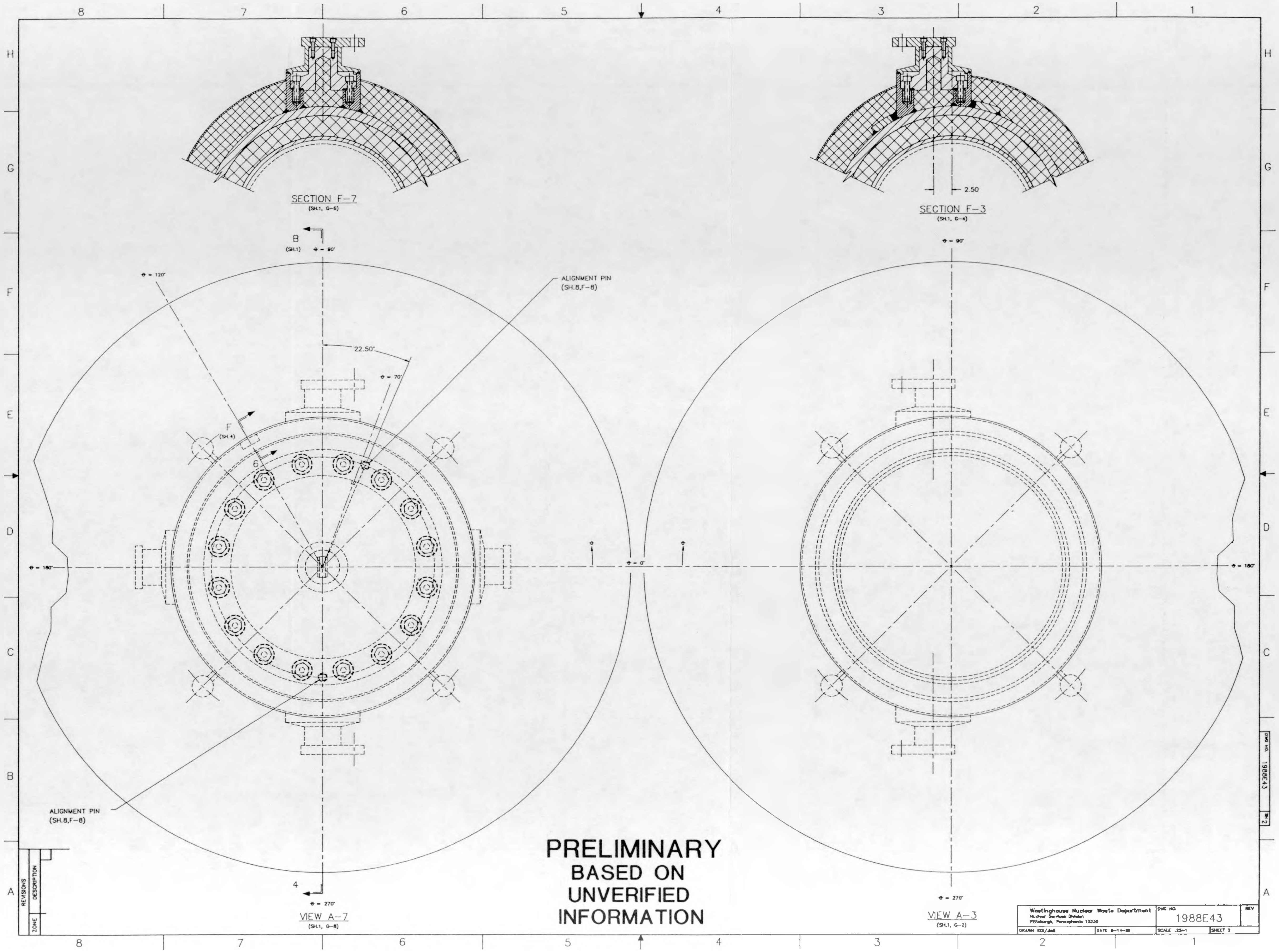
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230

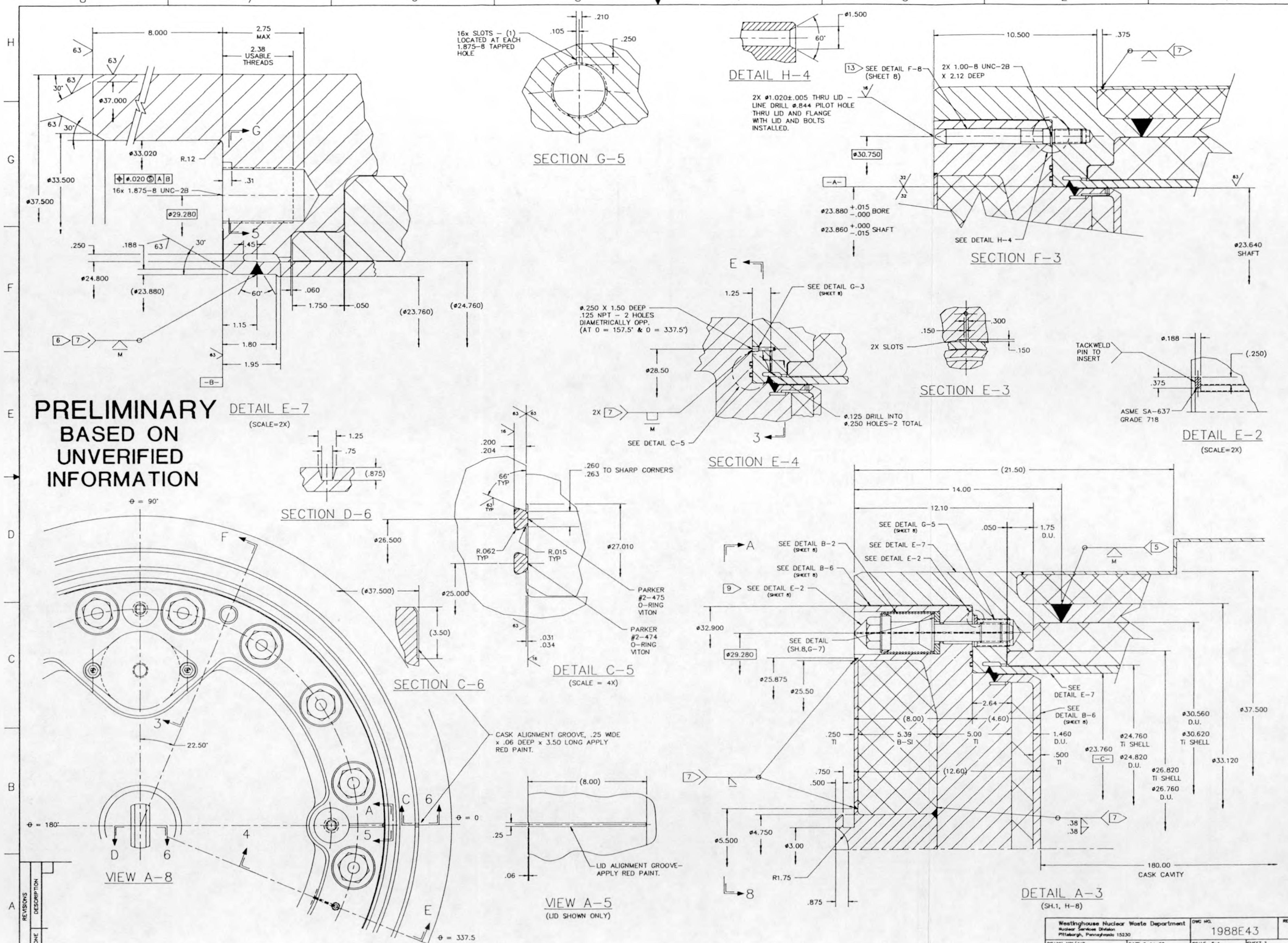
TITAN LEGAL WEIGHT
TRUCK CASK LAYOUT

CODE IDENT NO.	DWG NO.	REV
	1988E43	

G.O. NO. | SCALE .25=1 | SHEET 1 OF 17

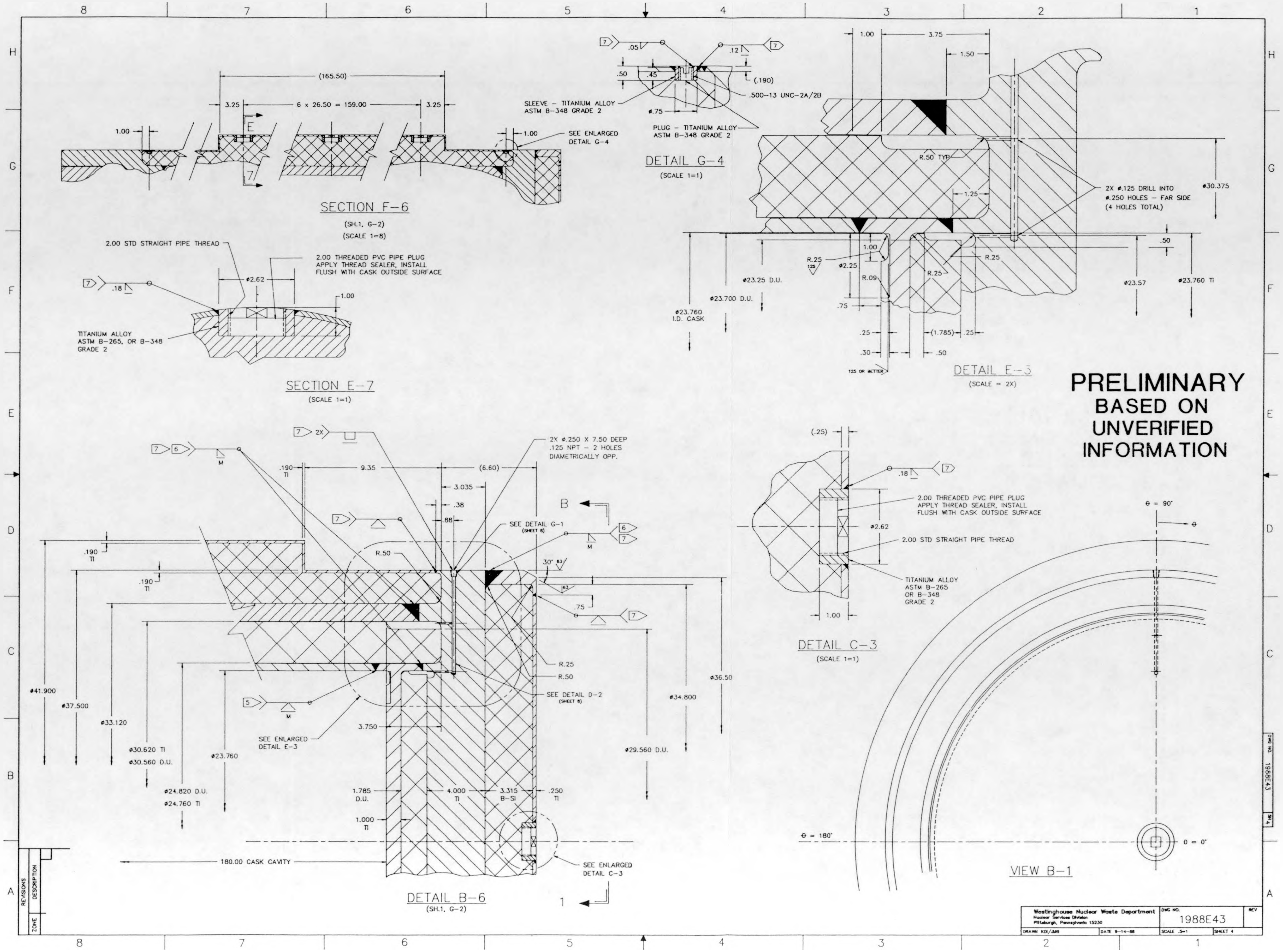
DWG NO. 1988E43 SH 1

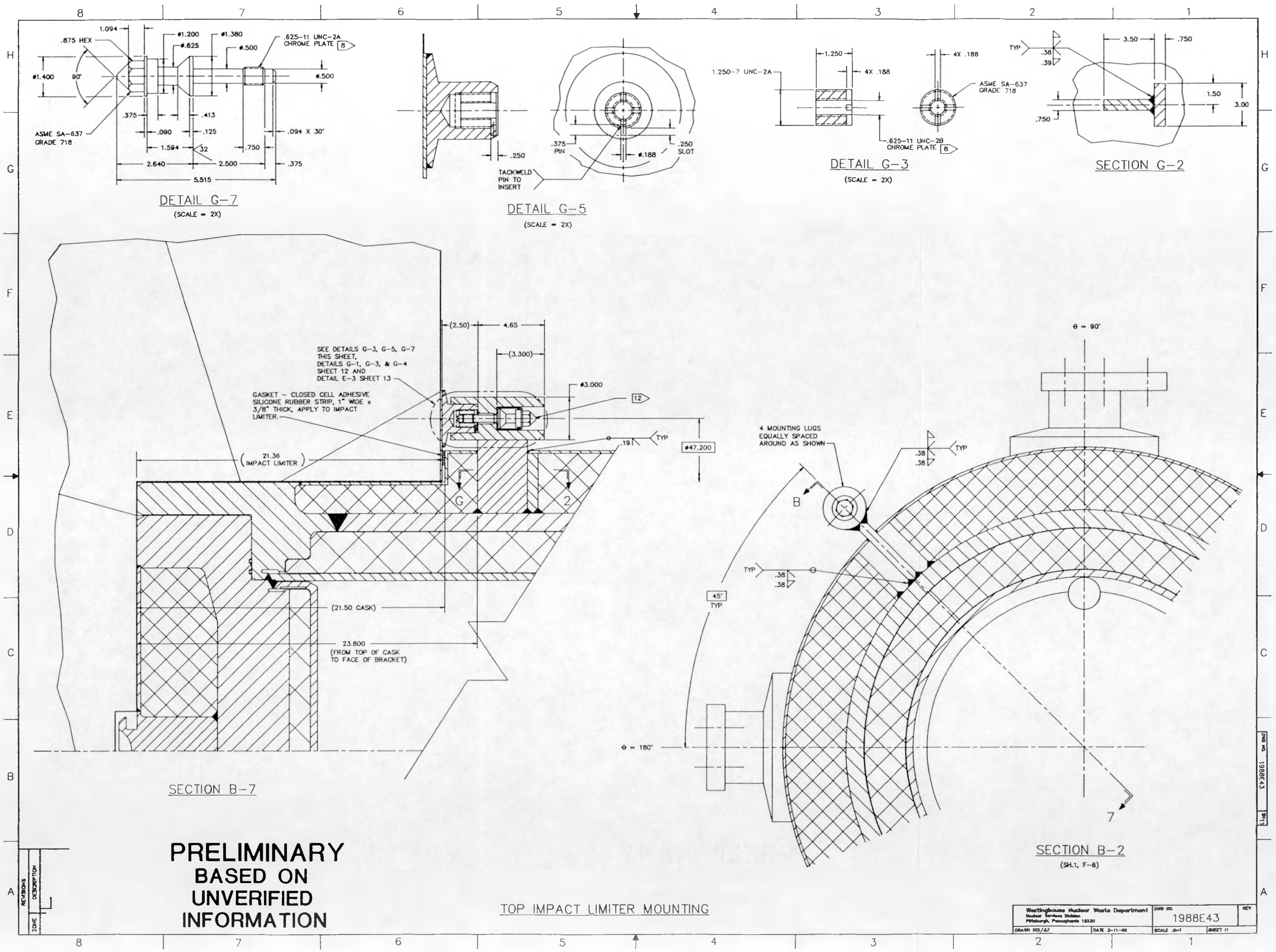

SECTION F-7
(SH.1, G-6)
SECTION F-3
2.50
ALIGNMENT PIN
(SH.8,F-8)
22.50°
VIEW A-7
(SH.1, G-8)
VIEW A-3
(SH.1, G-2)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
DWG NO.
1988E43
SHEET 2

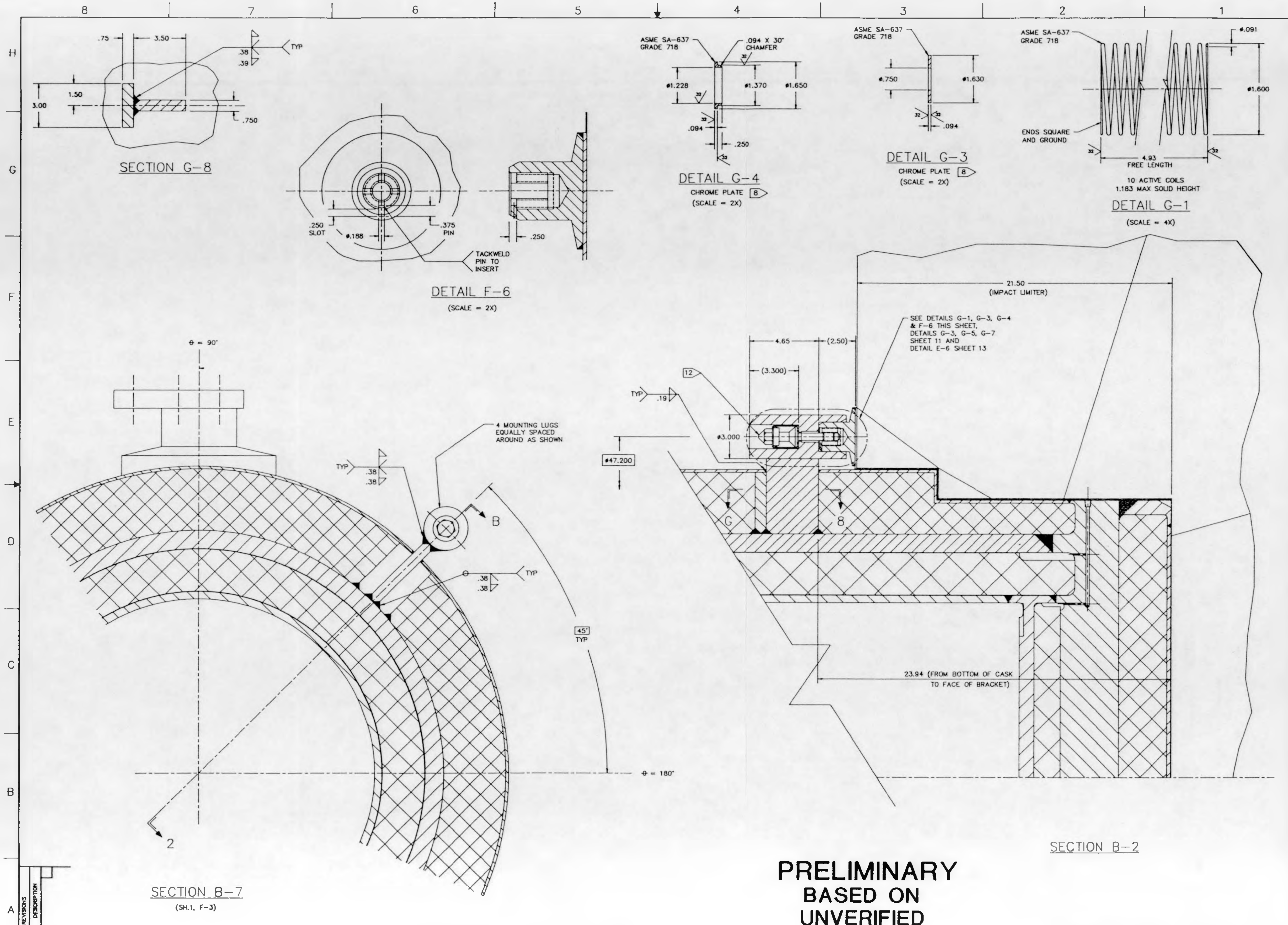


PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

Westinghouse Nuclear Waste Department, Nuclear Services Division, Pittsburgh, Pennsylvania 15230	DWG NO. 1988E43	REV
DRAWN KDI/AHB — DATE 9-14-88	SCALE .5=1	SHEET 3


SECTION F-6
(SH.1, G-2)
(SCALE 1=8)
(165.50)
3.25
6 x 26.50 = 159.00
1.00
SEE ENLARGED DETAIL G-4
DETAIL G-4
(SCALE 1=1)
SLEEVE - TITANIUM ALLOY ASTM B-348 GRADE 2
PLUG - TITANIUM ALLOY ASTM B-348 GRADE 2
.500-13 UNC-2A/2B
(.190)
SECTION E-7
(SCALE 1=1)
2.00 STD STRAIGHT PIPE THREAD
2.00 THREADED PVC PIPE PLUG APPLY THREAD SEALER, INSTALL FLUSH WITH CASK OUTSIDE SURFACE
TITANIUM ALLOY ASTM B-265, OR B-348 GRADE 2
DETAIL E-3
(SCALE = 2X)
2X ø.125 DRILL INTO ø.250 HOLES - FAR SIDE (4 HOLES TOTAL)
ø30.375
ø23.25 D.U.
ø23.700 D.U.
ø23.760 I.D. CASK
ø23.57
ø23.760 TI
R.50 TYP
125 OR BETTER
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
DETAIL B-6
(SH.1, G-2)
2X ø.250 X 7.50 DEEP .125 NPT - 2 HOLES DIAMETRICALLY OPP.
SEE DETAIL G-1 (SHEET 8)
SEE DETAIL D-2 (SHEET 8)
SEE ENLARGED DETAIL E-3
SEE ENLARGED DETAIL C-3
180.00 CASK CAVITY
ø41.900
ø37.500
ø33.120
ø30.620 TI
ø30.560 D.U.
ø24.820 D.U.
ø24.760 TI
ø23.760
ø36.50
ø34.800
ø29.560 D.U.
1.785 D.U.
4.000 TI
3.315 B-SI
.250 TI
1.000 TI
DETAIL C-3
(SCALE 1=1)
2.00 THREADED PVC PIPE PLUG APPLY THREAD SEALER, INSTALL FLUSH WITH CASK OUTSIDE SURFACE
2.00 STD STRAIGHT PIPE THREAD
TITANIUM ALLOY ASTM B-265 OR B-348 GRADE 2
VIEW B-1
θ = 90°
θ = 180°
θ = 0°
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
DWG NO. 1988E43
DATE 9-14-88
SCALE .5=1
SHEET 4

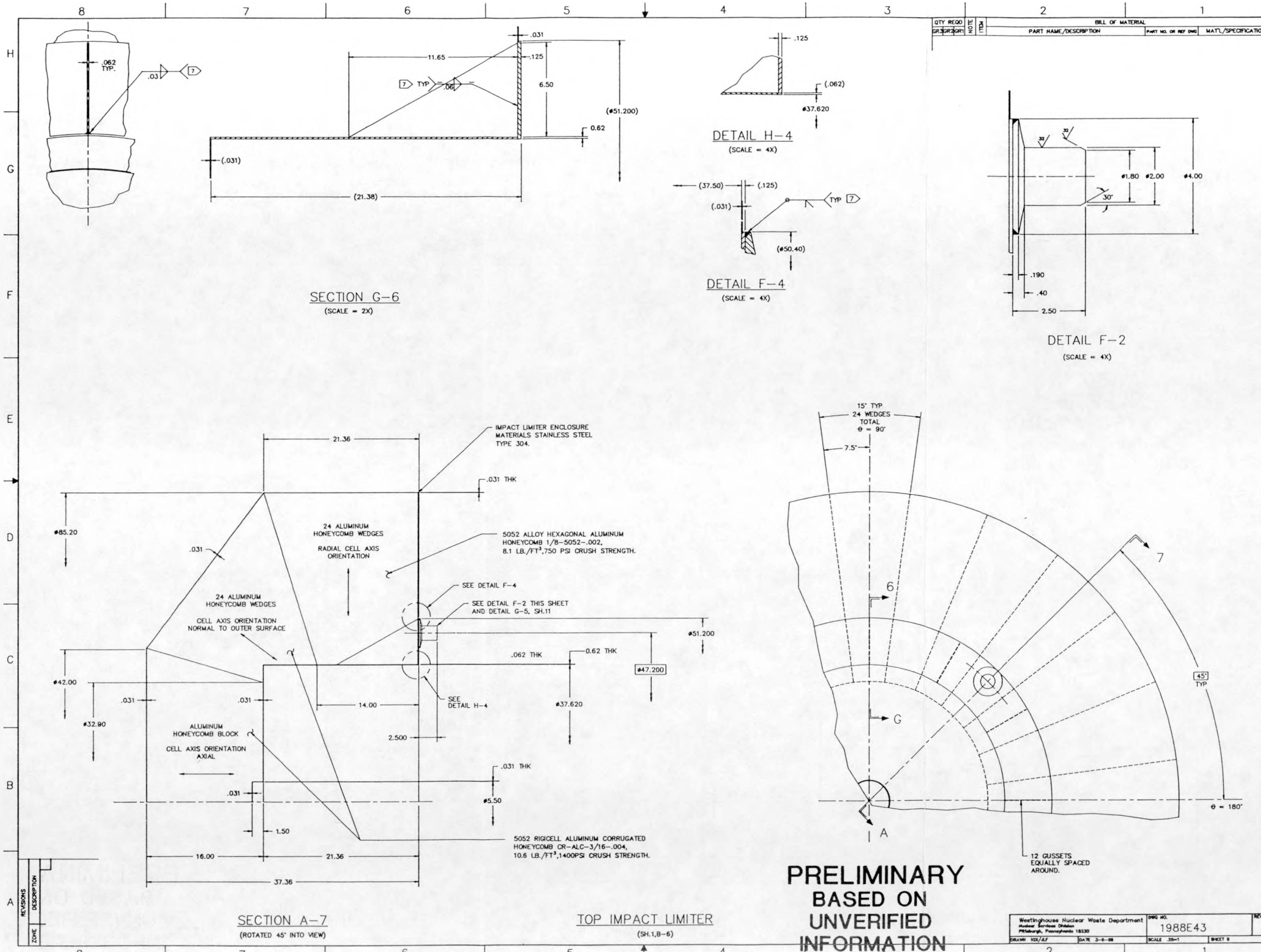

DETAIL G-7
(SCALE = 2X)
.875 HEX
1.094
ø1.200
ø1.380
ø.625
ø.500
.625-11 UNC-2A CHROME PLATE 8
ø1.400
90°
ø.500
.375
.413
ASME SA-637 GRADE 718
.090
.125
.094 X 30°
1.594
32
.750
2.640
2.500
.375
5.515
DETAIL G-5
(SCALE = 2X)
.250
.375 PIN
ø.188
.250 SLOT
TACKWELD PIN TO INSERT
DETAIL G-3
(SCALE = 2X)
1.250-7 UNC-2A
1.250
4X .188
ASME SA-637 GRADE 718
.625-11 UNC-2B CHROME PLATE 8
SECTION G-2
TYP
.38
.39
3.50
.750
1.50
3.00
.750
SECTION B-7
(2.50)
4.65
(3.300)
ø3.000
12
SEE DETAILS G-3, G-5, G-7 THIS SHEET, DETAILS G-1, G-3, & G-4 SHEET 12 AND DETAIL E-3 SHEET 13
GASKET - CLOSED CELL ADHESIVE SILICONE RUBBER STRIP, 1" WIDE x 3/8" THICK, APPLY TO IMPACT LIMITER.
21.36 IMPACT LIMITER
.19
TYP
ø47.200
G
2
(21.50 CASK)
23.800 (FROM TOP OF CASK TO FACE OF BRACKET)
SECTION B-2
(SH.1, F-6)
θ = 90°
θ = 180°
4 MOUNTING LUGS EQUALLY SPACED AROUND AS SHOWN
.38
.38
TYP
B
45° TYP
7
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
TOP IMPACT LIMITER MOUNTING
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania
DWG NO. 1988E43
SCALE
SHEET 11
1988E43

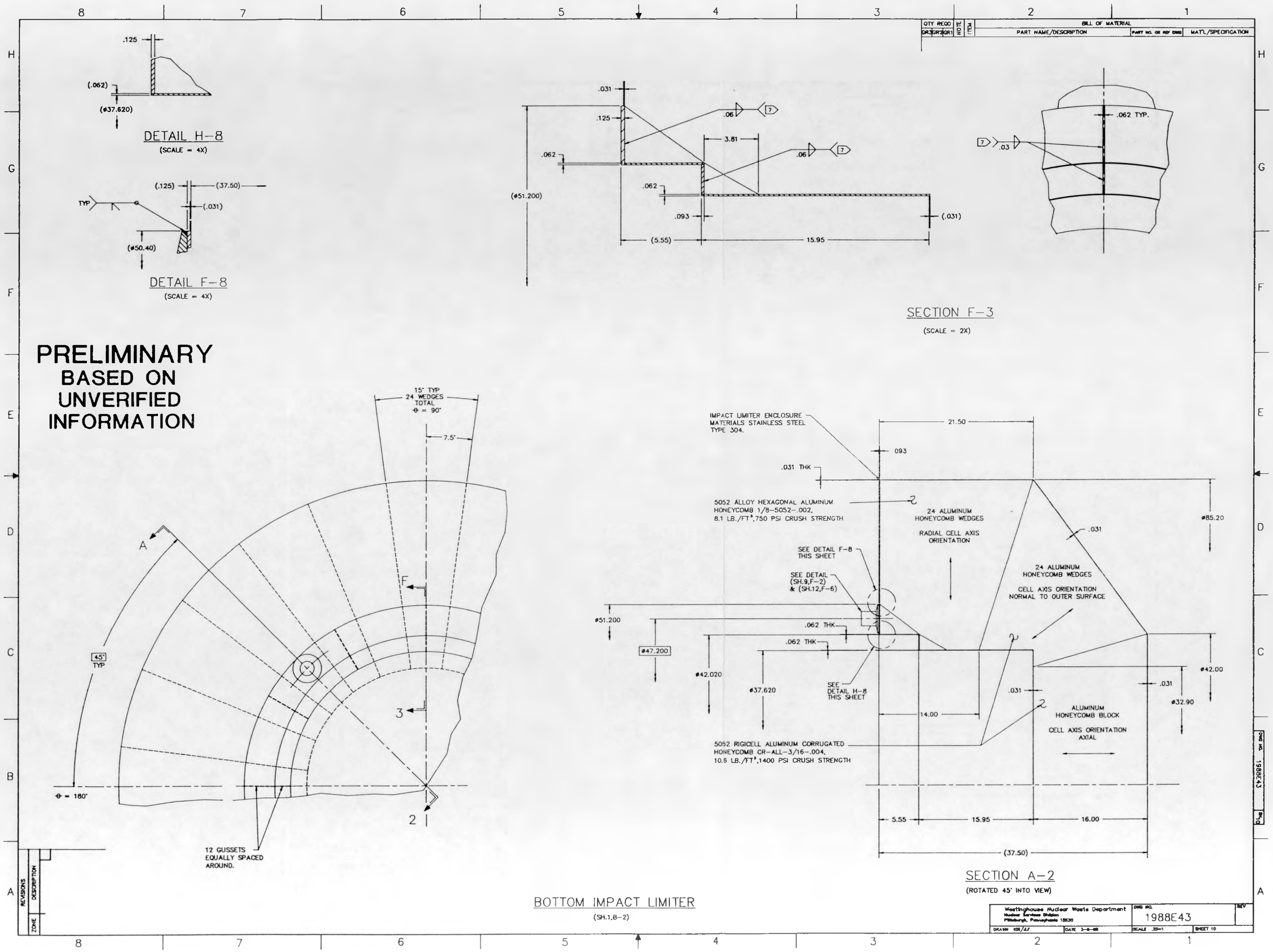


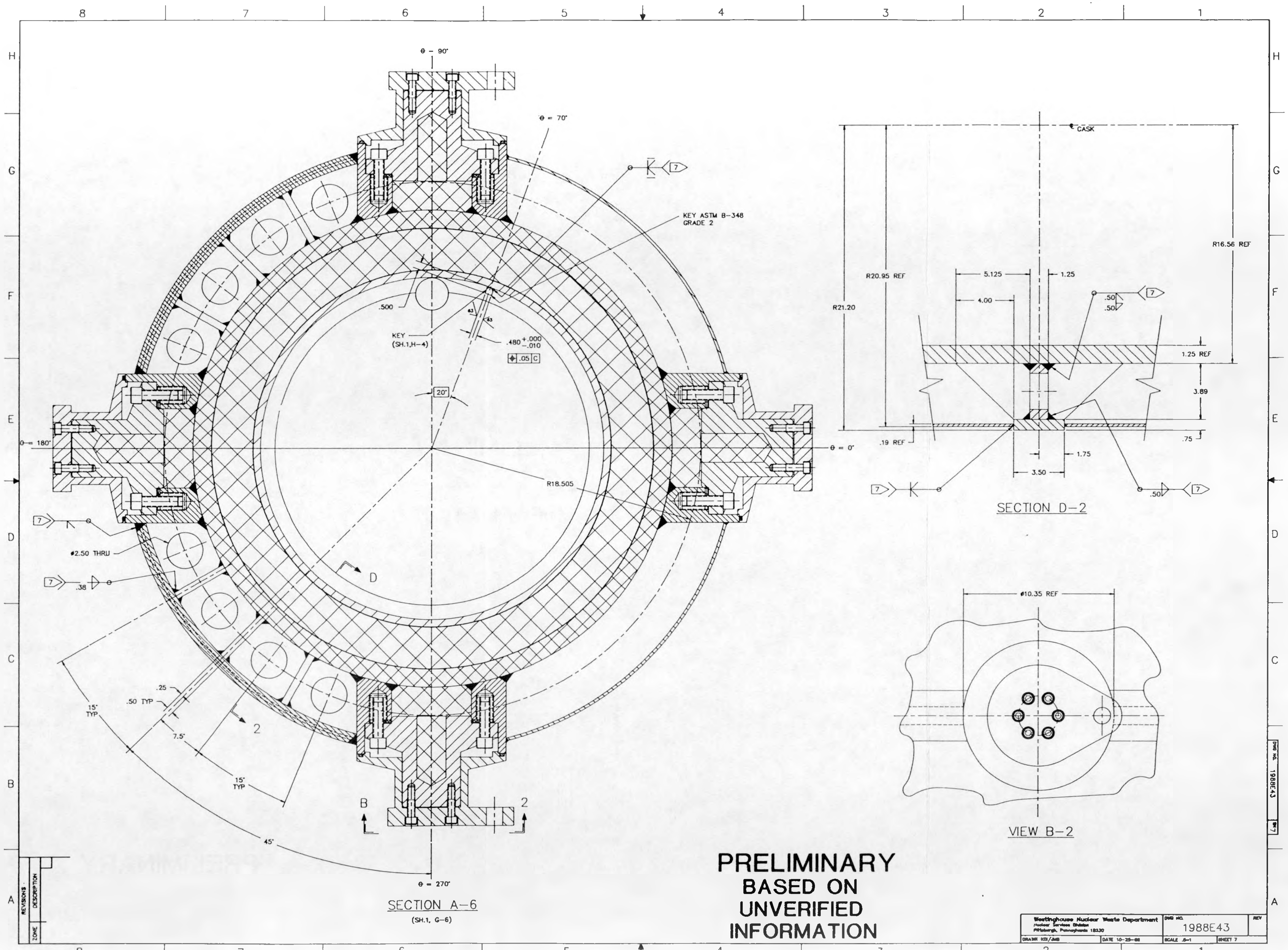
BOTTOM IMPACT LIMITER MOUNTING

PRELIMINARY BASED ON UNVERIFIED INFORMATION

Westinghouse Nuclear Waste Department
DWG NO. 1988E43
DATE 3-13-89
SHEET 12

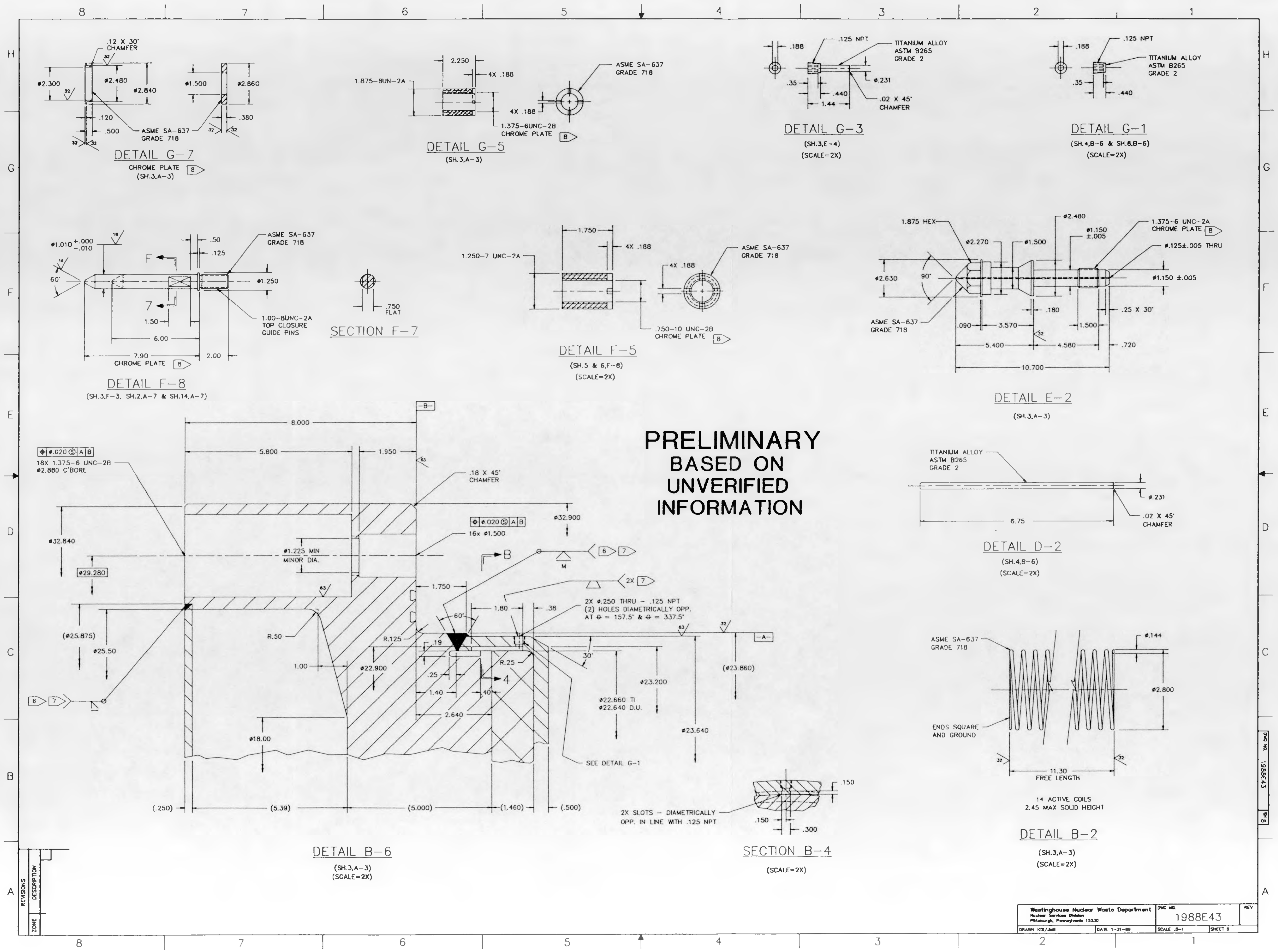

BILL OF MATERIAL
QTY REQD
PART NAME/DESCRIPTION
MAT'L/SPECIFICATION
.062 TYP.
.031
.125
11.65
6.50
(ø51.200)
0.62
(.031)
(21.38)
SECTION G-6
(SCALE = 2X)
(.062)
ø37.620
DETAIL H-4
(SCALE = 4X)
(37.50)
(.125)
(.031)
(ø50.40)
DETAIL F-4
(SCALE = 4X)
ø1.80
ø2.00
ø4.00
30°
.190
.40
2.50
DETAIL F-2
(SCALE = 4X)
IMPACT LIMITER ENCLOSURE MATERIALS STAINLESS STEEL TYPE 304.
21.36
.031 THK
ø85.20
24 ALUMINUM HONEYCOMB WEDGES
RADIAL CELL AXIS ORIENTATION
5052 ALLOY HEXAGONAL ALUMINUM HONEYCOMB 1/8-5052-.002, 8.1 LB./FT³,750 PSI CRUSH STRENGTH.
SEE DETAIL F-4
SEE DETAIL F-2 THIS SHEET AND DETAIL G-5, SH.11
24 ALUMINUM HONEYCOMB WEDGES
CELL AXIS ORIENTATION NORMAL TO OUTER SURFACE
ø51.200
.062 THK
0.62 THK
ø47.200
ø42.00
ø32.90
14.00
SEE DETAIL H-4
ø37.620
2.500
ALUMINUM HONEYCOMB BLOCK
CELL AXIS ORIENTATION AXIAL
.031 THK
ø5.50
1.50
16.00
21.36
37.36
5052 RIGICELL ALUMINUM CORRUGATED HONEYCOMB CR-ALC-3/16-.004, 10.6 LB./FT³,1400PSI CRUSH STRENGTH.
SECTION A-7
(ROTATED 45° INTO VIEW)
TOP IMPACT LIMITER
(SH.1,B-6)
15° TYP
24 WEDGES TOTAL
θ = 90°
7.5°
45° TYP
θ = 180°
12 GUSSETS EQUALLY SPACED AROUND.
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
1988E43

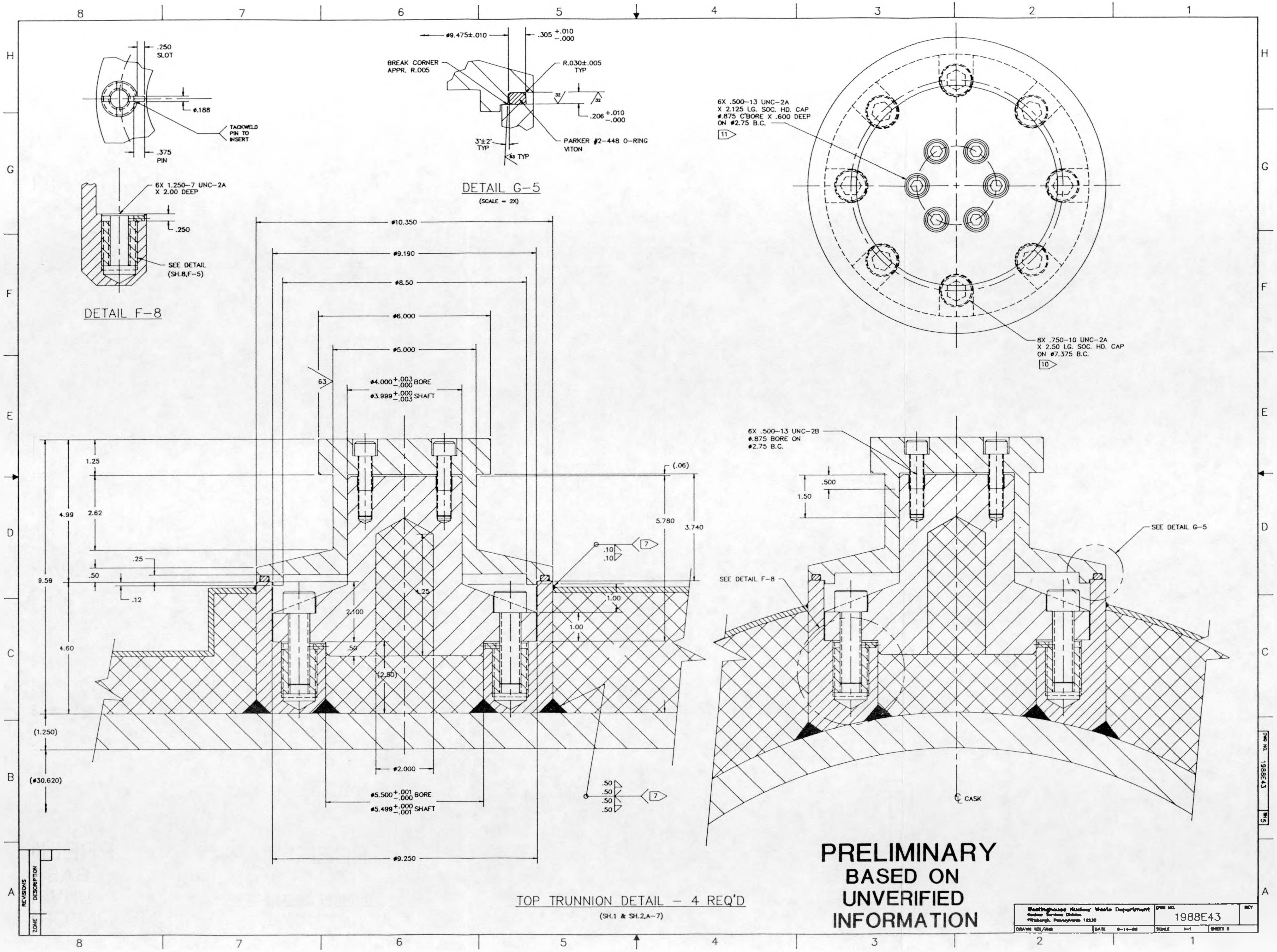

DETAIL H-8
(SCALE = 4X)
DETAIL F-8
(SCALE = 4X)
SECTION F-3
(SCALE = 2X)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
15° TYP
24 WEDGES TOTAL
θ = 90°
θ = 180°
12 GUSSETS EQUALLY SPACED AROUND.
IMPACT LIMITER ENCLOSURE MATERIALS STAINLESS STEEL TYPE 304.
5052 ALLOY HEXAGONAL ALUMINUM HONEYCOMB 1/8-5052-.002, 8.1 LB./FT³,750 PSI CRUSH STRENGTH
24 ALUMINUM HONEYCOMB WEDGES
RADIAL CELL AXIS ORIENTATION
SEE DETAIL F-8 THIS SHEET
SEE DETAIL (SH.9,F-2) & (SH.12,F-6)
24 ALUMINUM HONEYCOMB WEDGES
CELL AXIS ORIENTATION NORMAL TO OUTER SURFACE
SEE DETAIL H-8 THIS SHEET
ALUMINUM HONEYCOMB BLOCK
CELL AXIS ORIENTATION AXIAL
5052 RIGICELL ALUMINUM CORRUGATED HONEYCOMB CR-ALL-3/16-.004, 10.6 LB./FT³,1400 PSI CRUSH STRENGTH
SECTION A-2
(ROTATED 45° INTO VIEW)
BOTTOM IMPACT LIMITER
(SH.1,B-2)
BILL OF MATERIAL
PART NAME/DESCRIPTION
MATL/SPECIFICATION
Westinghouse Nuclear Waste Department
1988E43



**PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION**

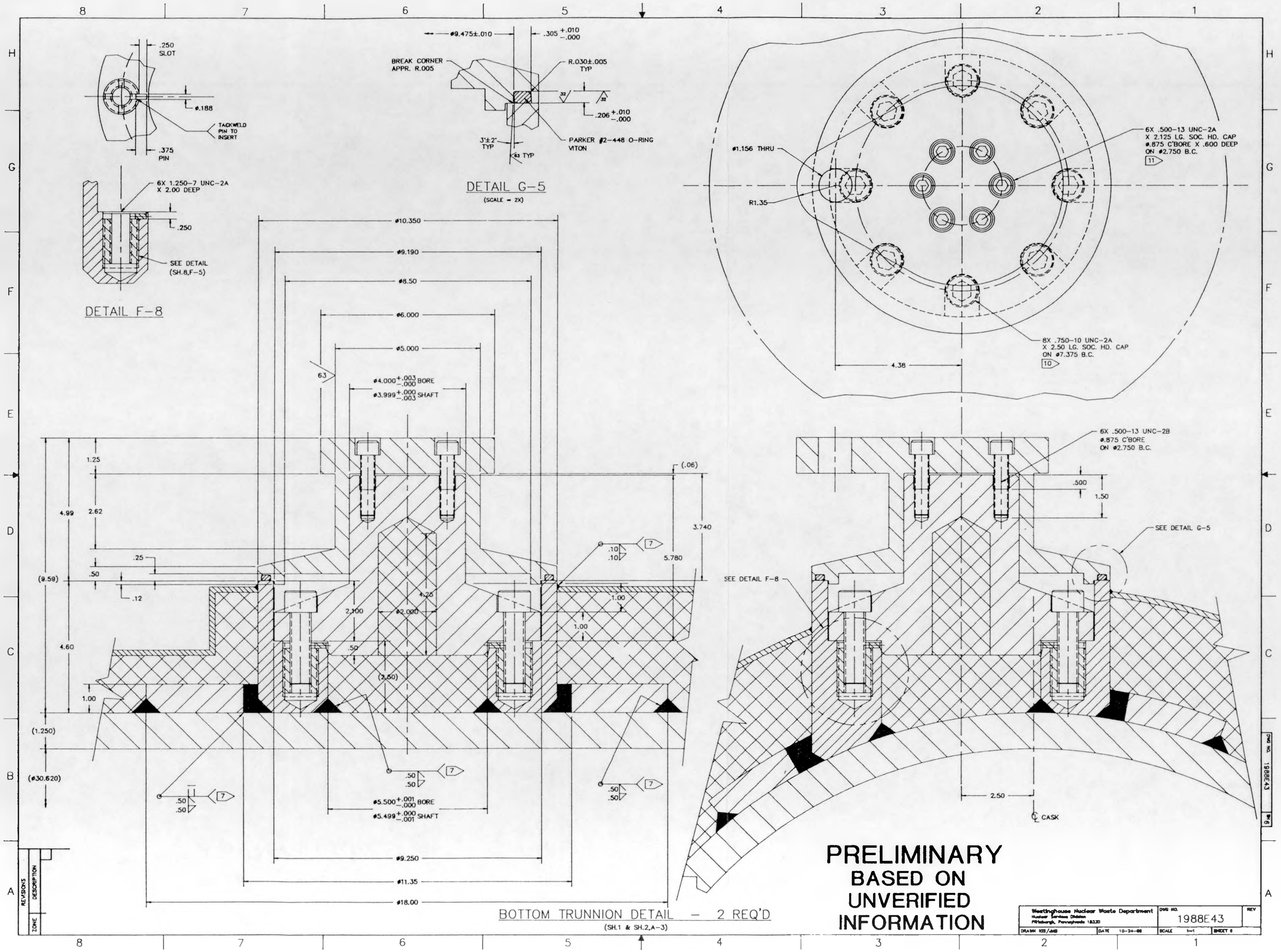
Westinghouse Nuclear Waste Department Nuclear Services Division Pittsburgh, Pennsylvania 15230		DWG NO. 1988E43	REV
DRAWN KOI/JMB	DATE 10-25-88	SCALE .5=1	SHEET 7

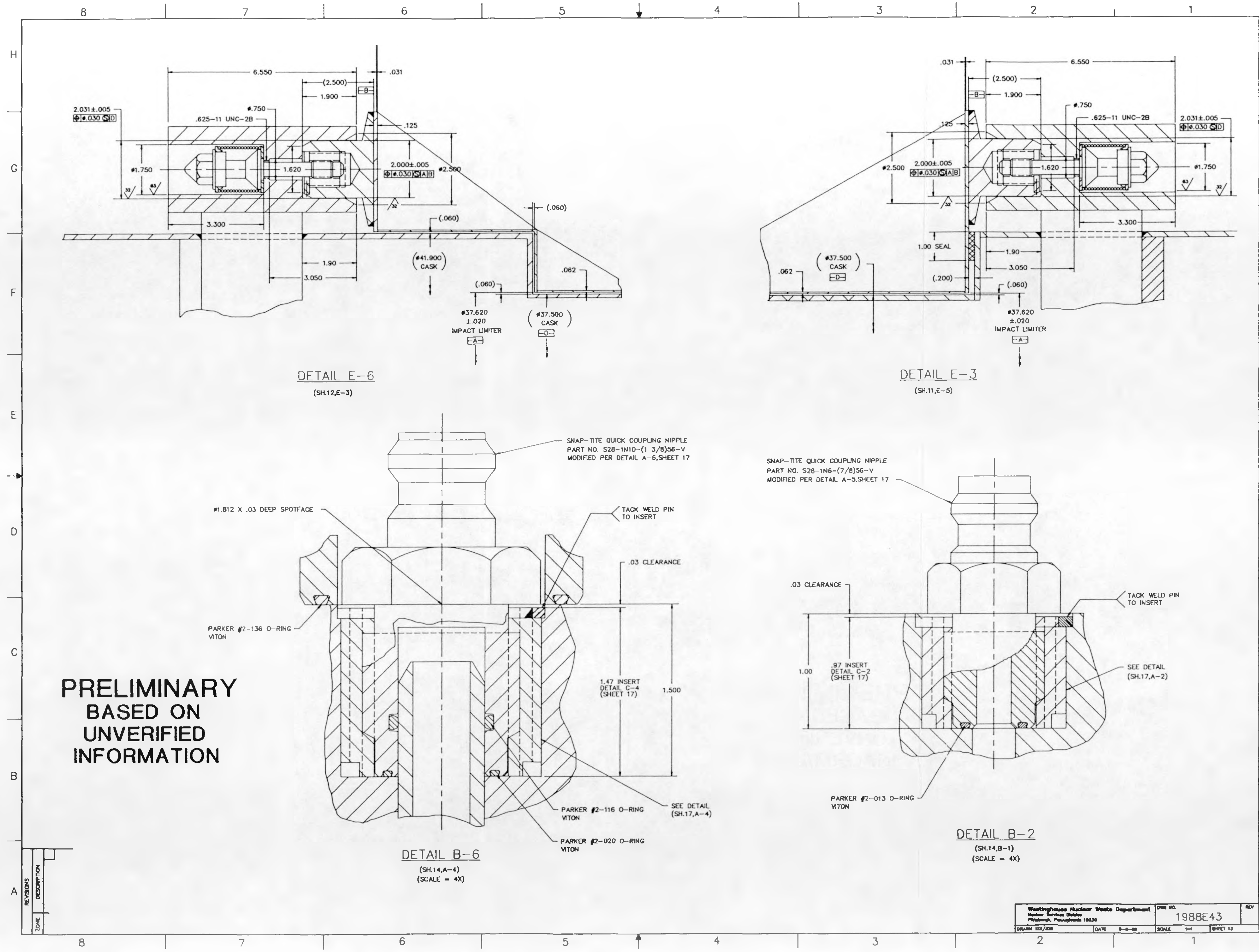

DETAIL G-7
CHROME PLATE
(SH.3,A-3)
ASME SA-637 GRADE 718
DETAIL G-5
(SH.3,A-3)
1.875-8UN-2A
1.375-6UNC-2B CHROME PLATE
DETAIL G-3
(SH.3,E-4)
(SCALE=2X)
TITANIUM ALLOY ASTM B265 GRADE 2
.125 NPT
.02 X 45° CHAMFER
DETAIL G-1
(SH.4,B-6 & SH.8,B-6)
(SCALE=2X)
DETAIL F-8
(SH.3,F-3, SH.2,A-7 & SH.14,A-7)
1.00-8UNC-2A TOP CLOSURE GUIDE PINS
SECTION F-7
.750 FLAT
DETAIL F-5
(SH.5 & 6,F-8)
(SCALE=2X)
1.250-7 UNC-2A
.750-10 UNC-2B CHROME PLATE
DETAIL E-2
(SH.3,A-3)
1.875 HEX
1.375-6 UNC-2A CHROME PLATE
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
DETAIL D-2
(SH.4,B-6)
(SCALE=2X)
18X 1.375-6 UNC-2B ø2.880 C'BORE
.18 X 45° CHAMFER
16x ø1.500
ø1.225 MIN MINOR DIA.
2X ø.250 THRU - .125 NPT (2) HOLES DIAMETRICALLY OPP. AT Θ = 157.5° & Θ = 337.5°
SEE DETAIL G-1
DETAIL B-6
(SH.3,A-3)
(SCALE=2X)
2X SLOTS - DIAMETRICALLY OPP. IN LINE WITH .125 NPT
SECTION B-4
(SCALE=2X)
ENDS SQUARE AND GROUND
11.30 FREE LENGTH
14 ACTIVE COILS
2.45 MAX SOLID HEIGHT
DETAIL B-2
(SH.3,A-3)
(SCALE=2X)
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
DWG NO. 1988E43
SHEET 8

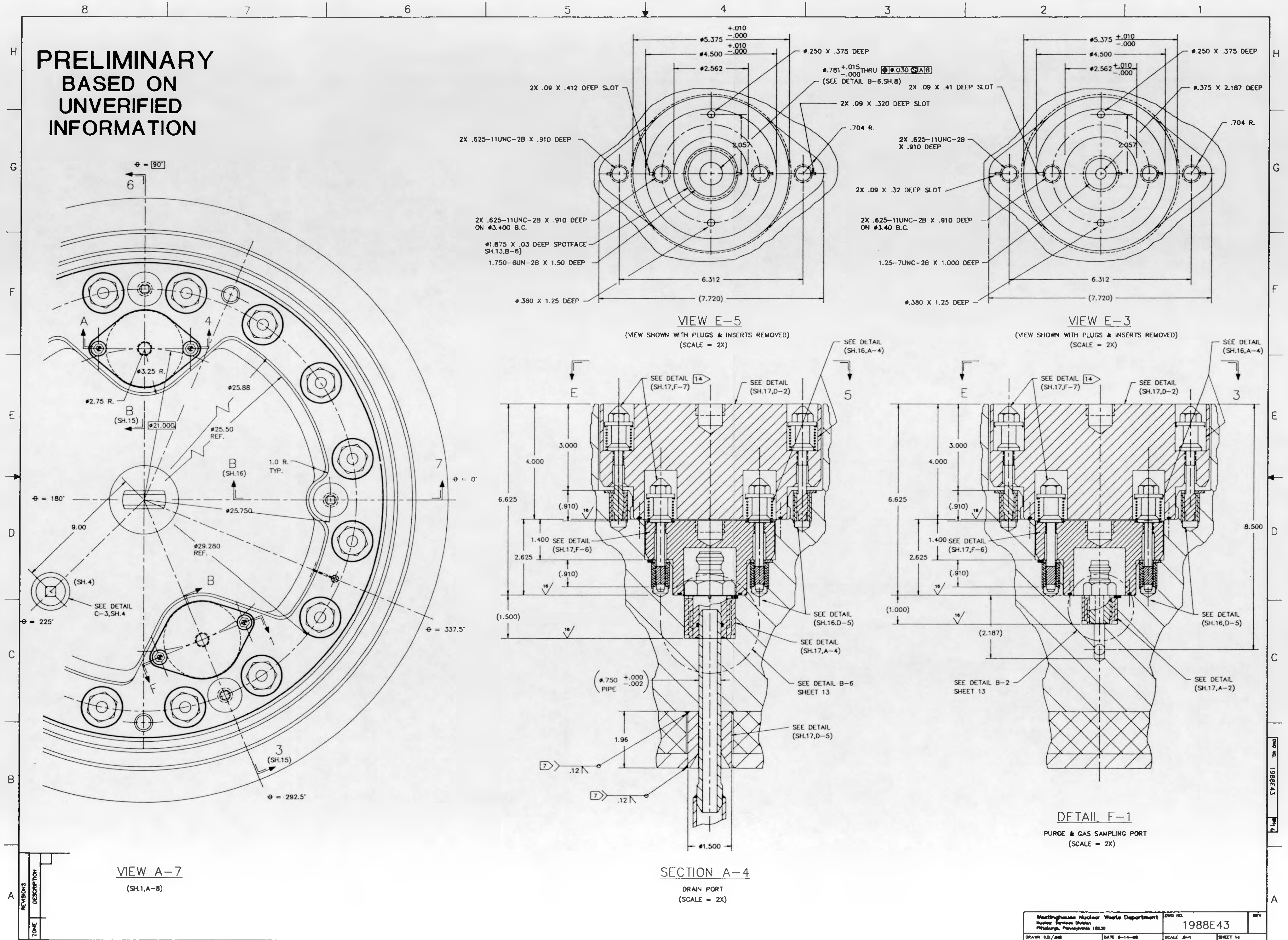


PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

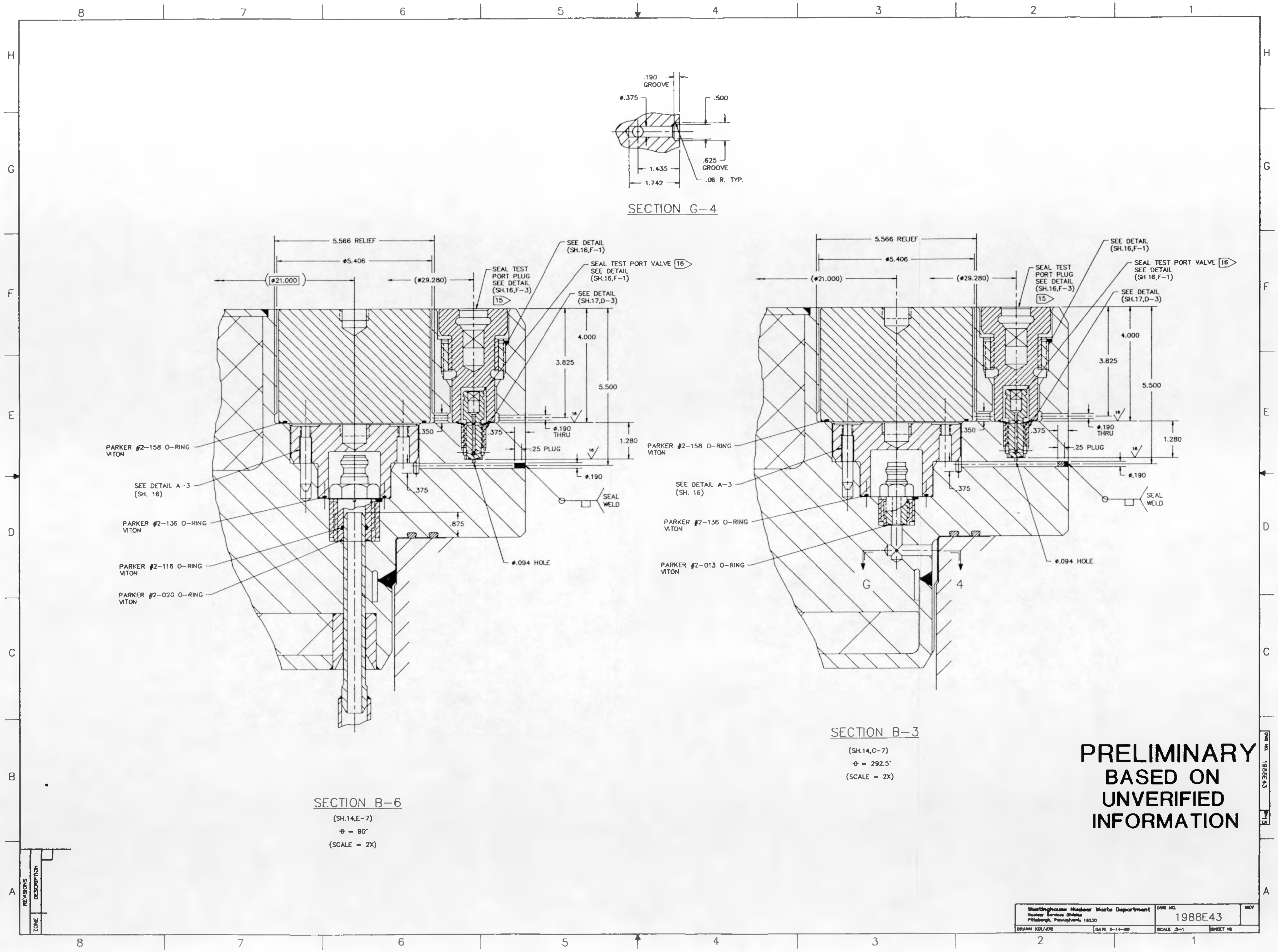
Westinghouse Nuclear Waste Department
DWG NO. 1988E43
SCALE 1=1 SHEET 5

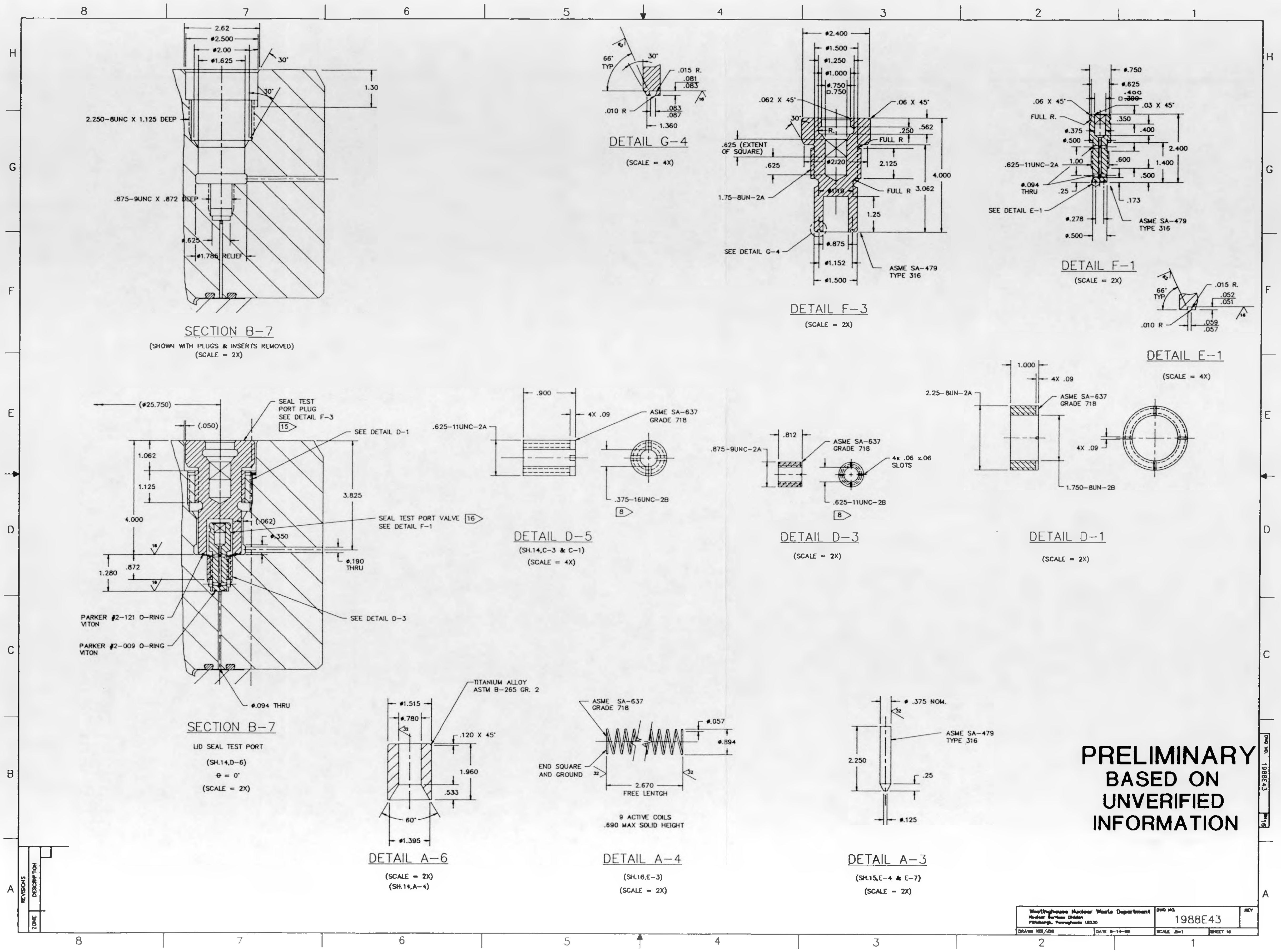

DETAIL F-8
6X 1.250-7 UNC-2A X 2.00 DEEP
SEE DETAIL (SH.8,F-5)
.250 SLOT
TACKWELD PIN TO INSERT
.375 PIN
DETAIL G-5
(SCALE = 2X)
BREAK CORNER APPR. R.005
R.030±.005 TYP
PARKER #2-448 O-RING VITON
ø1.156 THRU
R1.35
6X .500-13 UNC-2A X 2.125 LG. SOC. HD. CAP ø.875 C'BORE X .600 DEEP ON ø2.750 B.C.
6X .750-10 UNC-2A X 2.50 LG. SOC. HD. CAP ON ø7.375 B.C.
6X .500-13 UNC-2B ø.875 C'BORE ON ø2.750 B.C.
SEE DETAIL G-5
SEE DETAIL F-8
℄ CASK
ø4.000 +.003 −.000 BORE
ø3.999 +.000 −.003 SHAFT
ø5.500 +.001 −.000 BORE
ø5.499 +.000 −.001 SHAFT
BOTTOM TRUNNION DETAIL – 2 REQ'D
(SH.1 & SH.2,A-3)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania
1988E43

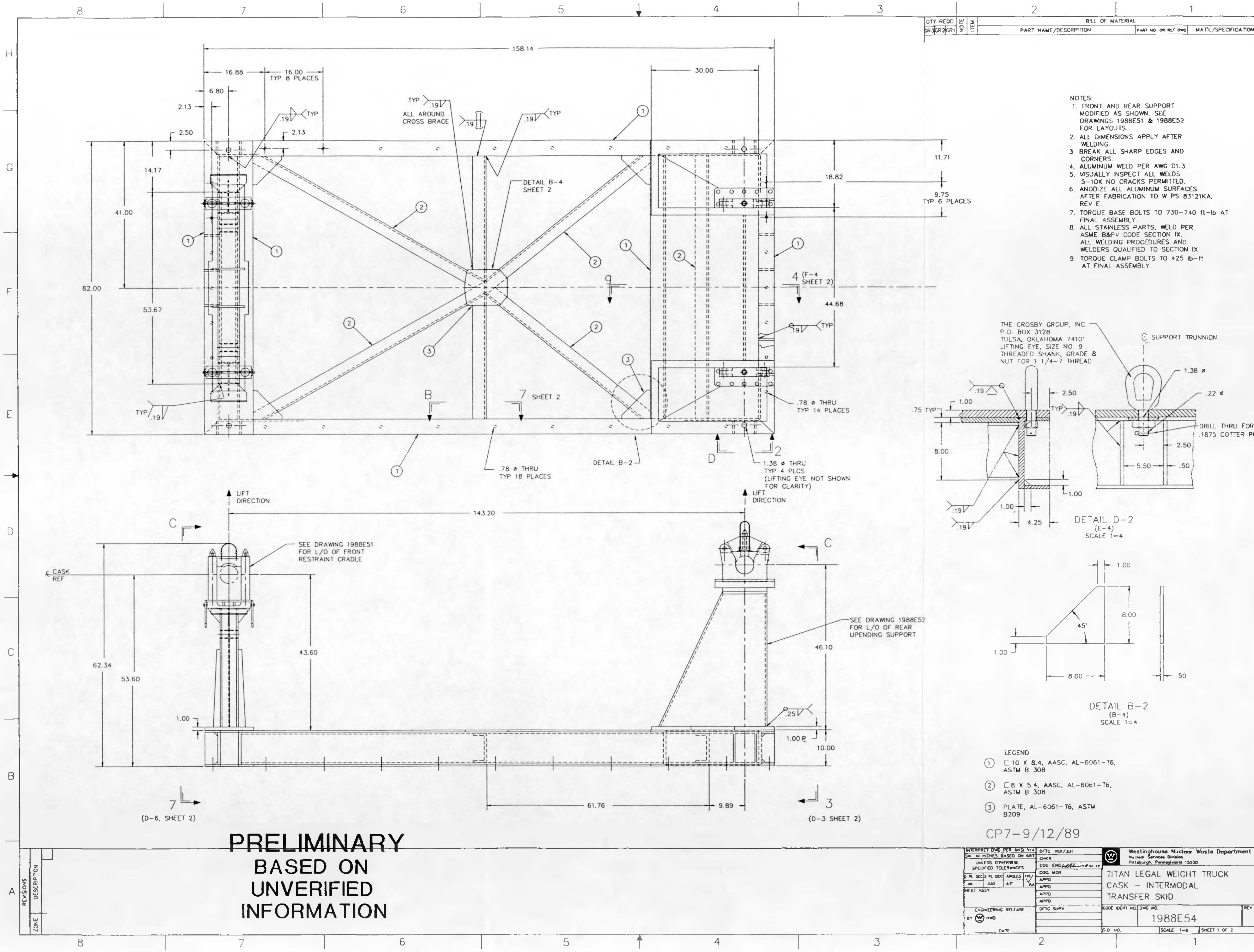

DETAIL E-6
(SH.12,E-3)
DETAIL E-3
(SH.11,E-5)
6.550
(2.500)
1.900
.031
.125
2.031±.005
.625-11 UNC-2B
ø.750
ø1.750
1.620
2.000±.005
ø2.500
3.300
(.060)
1.90
3.050
(ø41.900 CASK)
(ø37.500 CASK)
.062
ø37.620
±.020
IMPACT LIMITER
1.00 SEAL
(.200)
SNAP-TITE QUICK COUPLING NIPPLE
PART NO. S28-1N10-(1 3/8)56-V
MODIFIED PER DETAIL A-6,SHEET 17
ø1.812 X .03 DEEP SPOTFACE
TACK WELD PIN
TO INSERT
.03 CLEARANCE
PARKER #2-136 O-RING
VITON
1.47 INSERT
DETAIL C-4
(SHEET 17)
1.500
PARKER #2-116 O-RING
VITON
PARKER #2-020 O-RING
VITON
SEE DETAIL
(SH.17,A-4)
DETAIL B-6
(SH.14,A-4)
(SCALE = 4X)
SNAP-TITE QUICK COUPLING NIPPLE
PART NO. S28-1N6-(7/8)56-V
MODIFIED PER DETAIL A-5,SHEET 17
.97 INSERT
DETAIL C-2
(SHEET 17)
1.00
SEE DETAIL
(SH.17,A-2)
PARKER #2-013 O-RING
VITON
DETAIL B-2
(SH.14,B-1)
(SCALE = 4X)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
DESCRIPTION
ZONE
Westinghouse Nuclear Waste Department
DWG NO.
1988E43
REV
SCALE 1=1
SHEET 13

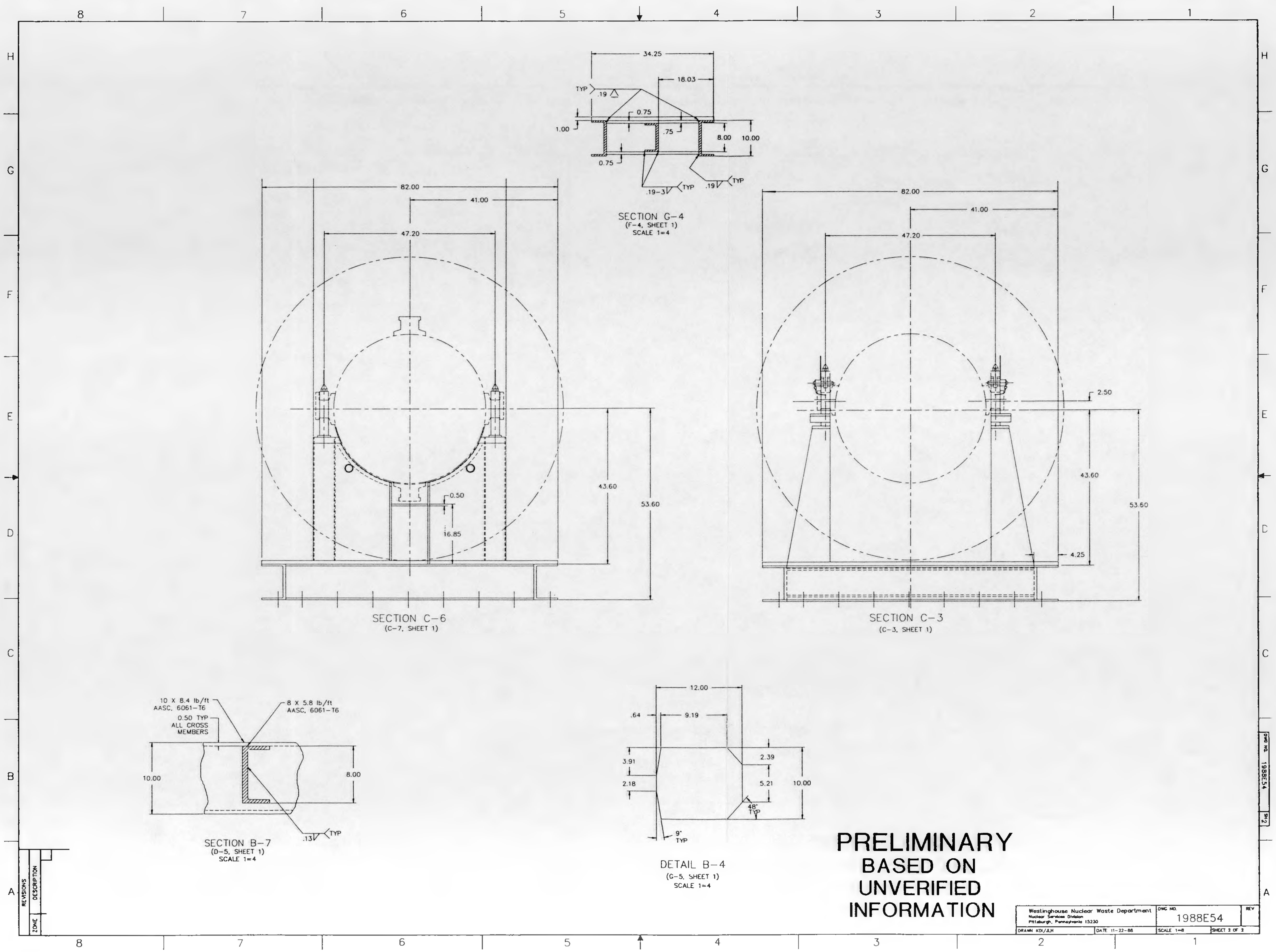


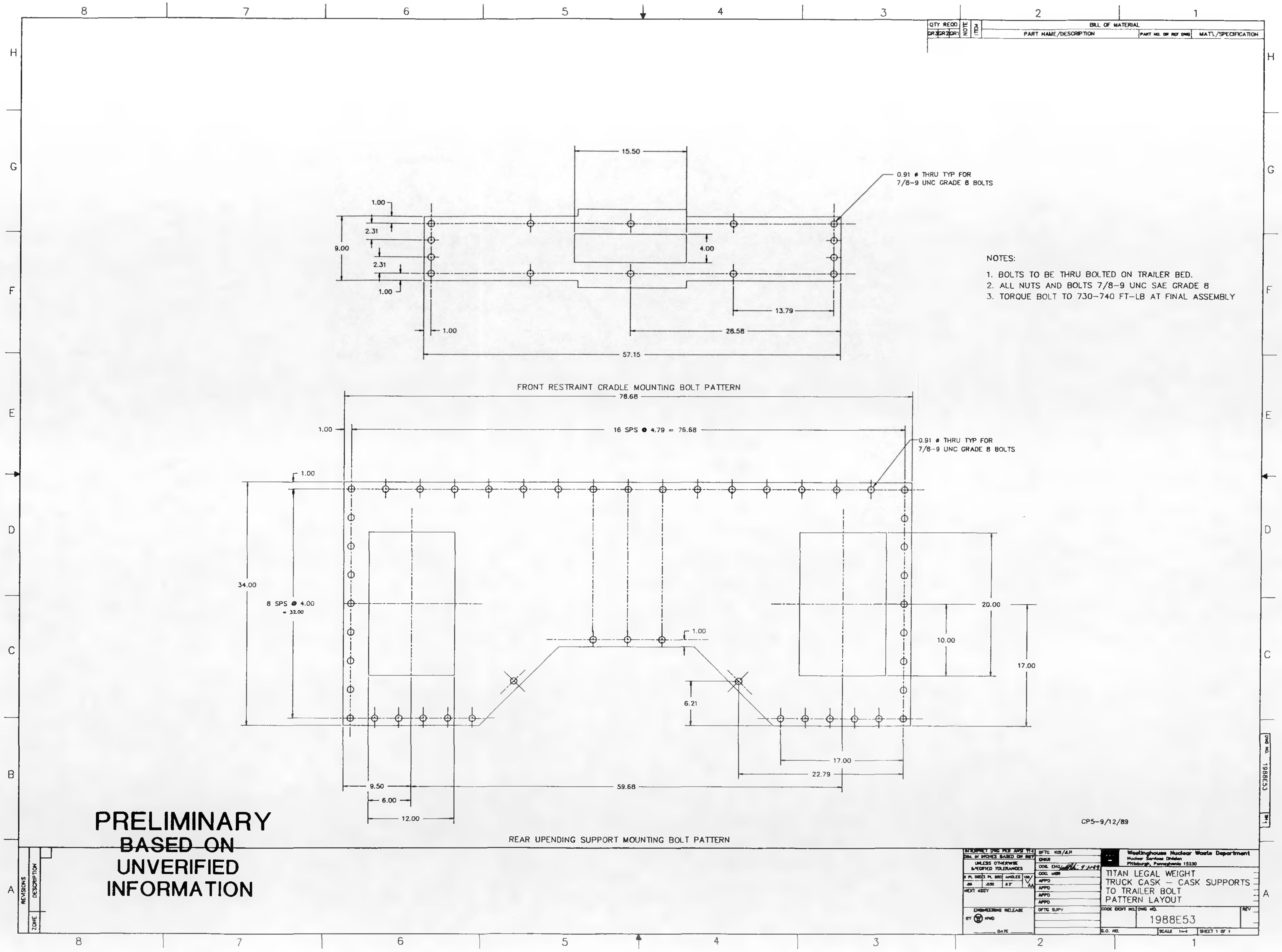
Westinghouse Nuclear Waste Department	DWG NO. 1988E43	REV
DRAWN	DATE 8-14-86	SCALE	SHEET 14


SECTION G-4
SECTION B-6
(SH.14,E-7)
θ = 90°
(SCALE = 2X)
SECTION B-3
(SH.14,C-7)
θ = 292.5°
(SCALE = 2X)
5.566 RELIEF
ø5.406
(ø21.000)
(ø29.280)
SEAL TEST PORT PLUG SEE DETAIL (SH.16,F-3)
SEAL TEST PORT VALVE 16 SEE DETAIL (SH.16,F-1)
SEE DETAIL (SH.16,F-1)
SEE DETAIL (SH.17,D-3)
PARKER #2-158 O-RING VITON
SEE DETAIL A-3 (SH. 16)
PARKER #2-136 O-RING VITON
PARKER #2-116 O-RING VITON
PARKER #2-020 O-RING VITON
PARKER #2-013 O-RING VITON
ø.094 HOLE
SEAL WELD
.25 PLUG
ø.190 THRU
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
1988E43

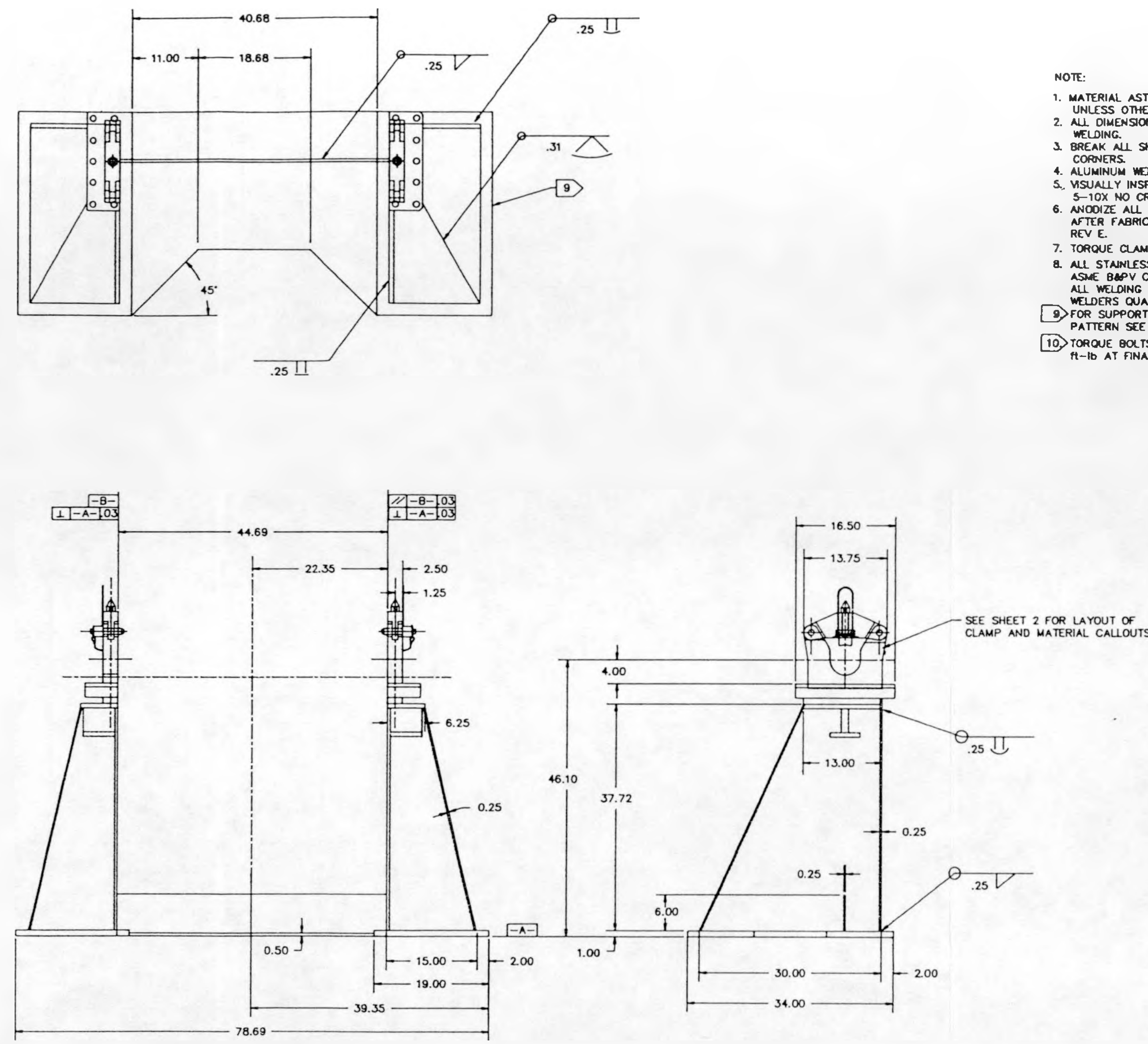

SECTION B-7
(SHOWN WITH PLUGS & INSERTS REMOVED)
(SCALE = 2X)
2.250-8UNC X 1.125 DEEP
.875-9UNC X .872 DEEP
DETAIL G-4
(SCALE = 4X)
DETAIL F-3
(SCALE = 2X)
1.75-8UN-2A
SEE DETAIL G-4
ASME SA-479
TYPE 316
DETAIL F-1
(SCALE = 2X)
.625-11UNC-2A
SEE DETAIL E-1
ASME SA-479
TYPE 316
DETAIL E-1
(SCALE = 4X)
SEAL TEST
PORT PLUG
SEE DETAIL F-3
SEE DETAIL D-1
SEAL TEST PORT VALVE
SEE DETAIL F-1
PARKER #2-121 O-RING
VITON
PARKER #2-009 O-RING
VITON
SEE DETAIL D-3
SECTION B-7
LID SEAL TEST PORT
(SH.14,D-6)
θ = 0°
(SCALE = 2X)
.625-11UNC-2A
ASME SA-637
GRADE 718
.375-16UNC-2B
DETAIL D-5
(SH.14,C-3 & C-1)
(SCALE = 4X)
.875-9UNC-2A
ASME SA-637
GRADE 718
4X .06 x.06
SLOTS
.625-11UNC-2B
DETAIL D-3
(SCALE = 2X)
2.25-8UN-2A
ASME SA-637
GRADE 718
1.750-8UN-2B
DETAIL D-1
(SCALE = 2X)
TITANIUM ALLOY
ASTM B-265 GR. 2
DETAIL A-6
(SCALE = 2X)
(SH.14,A-4)
ASME SA-637
GRADE 718
END SQUARE
AND GROUND
2.670
FREE LENGTH
9 ACTIVE COILS
.690 MAX SOLID HEIGHT
DETAIL A-4
(SH.16,E-3)
(SCALE = 2X)
ASME SA-479
TYPE 316
DETAIL A-3
(SH.15,E-4 & E-7)
(SCALE = 2X)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
1988E43


BILL OF MATERIAL
QTY REQD
NOTE
ITEM
PART NAME/DESCRIPTION
PART NO OR REF DWG
MAT'L/SPECIFICATION
NOTES:
1. FRONT AND REAR SUPPORT MODIFIED AS SHOWN. SEE DRAWINGS 1988E51 & 1988E52 FOR LAYOUTS.
2. ALL DIMENSIONS APPLY AFTER WELDING.
3. BREAK ALL SHARP EDGES AND CORNERS.
4. ALUMINUM WELD PER AWG D1.3
5. VISUALLY INSPECT ALL WELDS 5-10X NO CRACKS PERMITTED.
6. ANODIZE ALL ALUMINUM SURFACES AFTER FABRICATION TO W PS 83121KA, REV E.
7. TORQUE BASE BOLTS TO 730-740 ft-lb AT FINAL ASSEMBLY.
8. ALL STAINLESS PARTS, WELD PER ASME B&PV CODE SECTION IX. ALL WELDING PROCEDURES AND WELDERS QUALIFIED TO SECTION IX
9. TORQUE CLAMP BOLTS TO 425 lb-ft AT FINAL ASSEMBLY.
158.14
16.88
16.00 TYP 8 PLACES
6.80
2.13
2.50
30.00
ALL AROUND CROSS BRACE
DETAIL B-4 SHEET 2
11.71
18.82
9.75 TYP 6 PLACES
41.00
14.17
82.00
53.67
44.68
4 (F-4 SHEET 2)
.78 ø THRU TYP 14 PLACES
7 SHEET 2
.78 ø THRU TYP 18 PLACES
DETAIL B-2
1.38 ø THRU TYP 4 PLCS (LIFTING EYE NOT SHOWN FOR CLARITY)
THE CROSBY GROUP, INC. P.O. BOX 3128 TULSA, OKLAHOMA 74101 LIFTING EYE, SIZE NO. 9 THREADED SHANK, GRADE 8 NUT FOR 1 1/4-7 THREAD
℄ SUPPORT TRUNNION
DRILL THRU FOR .1875 COTTER PIN
DETAIL D-2 (E-4) SCALE 1=4
LIFT DIRECTION
143.20
SEE DRAWING 1988E51 FOR L/O OF FRONT RESTRAINT CRADLE
℄ CASK REF
SEE DRAWING 1988E52 FOR L/O OF REAR UPENDING SUPPORT
62.34
53.60
43.60
46.10
10.00
61.76
9.89
(D-6, SHEET 2)
(D-3 SHEET 2)
DETAIL B-2 (B-4) SCALE 1=4
LEGEND
1 ⊏ 10 X 8.4, AASC, AL-6061-T6, ASTM B 308
2 ⊏ 8 X 5.4, AASC, AL-6061-T6, ASTM B 308
3 PLATE, AL-6061-T6, ASTM B209
CP7-9/12/89
PRELIMINARY BASED ON UNVERIFIED INFORMATION
REVISIONS
ZONE
DESCRIPTION
INTERPRET DWG PER ANSI Y14
DIM IN INCHES BASED ON 68F
UNLESS OTHERWISE SPECIFIED TOLERANCES
2 PL DEC .06
3 PL DEC .030
ANGLES ±2°
NEXT ASSY
ENGINEERING RELEASE BY NWD
DATE
DFTG KDI/JLH
CHKR
COG. ENG
COG. MGR
APPD
DFTG SUPV
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
TITAN LEGAL WEIGHT TRUCK CASK - INTERMODAL TRANSFER SKID
CODE IDENT NO.
DWG NO. 1988E54
REV
G.O. NO.
SCALE 1=8
SHEET 1 OF 2


SECTION G-4
(F-4, SHEET 1)
SCALE 1=4
SECTION C-6
(C-7, SHEET 1)
SECTION C-3
(C-3, SHEET 1)
10 X 8.4 lb/ft
AASC, 6061-T6
0.50 TYP
ALL CROSS
MEMBERS
8 X 5.8 lb/ft
AASC, 6061-T6
SECTION B-7
(D-5, SHEET 1)
SCALE 1=4
DETAIL B-4
(G-5, SHEET 1)
SCALE 1=4
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
DWG NO. 1988E54
SHEET 2 OF 2


BILL OF MATERIAL
QTY REQD
NOTE
ITEM
PART NAME/DESCRIPTION
PART NO. OR REF DWG
MAT'L/SPECIFICATION
15.50
0.91 ø THRU TYP FOR
7/8-9 UNC GRADE 8 BOLTS
1.00
2.31
9.00
4.00
2.31
1.00
13.79
1.00
28.58
57.15
FRONT RESTRAINT CRADLE MOUNTING BOLT PATTERN
NOTES:
1. BOLTS TO BE THRU BOLTED ON TRAILER BED.
2. ALL NUTS AND BOLTS 7/8-9 UNC SAE GRADE 8
3. TORQUE BOLT TO 730-740 FT-LB AT FINAL ASSEMBLY
78.68
1.00
16 SPS @ 4.79 = 76.68
0.91 ø THRU TYP FOR
7/8-9 UNC GRADE 8 BOLTS
1.00
34.00
8 SPS @ 4.00
= 32.00
1.00
20.00
10.00
17.00
6.21
17.00
22.79
9.50
59.68
6.00
12.00
CP5-9/12/89
REAR UPENDING SUPPORT MOUNTING BOLT PATTERN
PRELIMINARY
~~BASED ON~~
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
UNLESS OTHERWISE
SPECIFIED TOLERANCES
NEXT ASSY
ENGINEERING RELEASE
DATE
DFTG KGI/JLH
CHKR
COG. ENG
COG. MGR
APPD
APPD
APPD
APPD
DFTG SUPV
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
TITAN LEGAL WEIGHT
TRUCK CASK – CASK SUPPORTS
TO TRAILER BOLT
PATTERN LAYOUT
CODE IDENT NO.
DWG NO.
1988E53
REV
S.O. NO.
SCALE 1=4
SHEET 1 OF 1

QTY REQD			NOTE	ITEM	BILL OF MATERIAL		
GR3	GR2	GR1			PART NAME/DESCRIPTION	PART NO. OR REF DWG	MAT'L/SPECIFICATION



NOTE:

1. MATERIAL ASTM B209, 6061-T6 UNLESS OTHERWISE SPECIFIED.
2. ALL DIMENSIONS APPLY AFTER WELDING.
3. BREAK ALL SHARP EDGES AND CORNERS.
4. ALUMINUM WELD PER AWS D1.3
5. VISUALLY INSPECT ALL WELDS 5-10X NO CRACKS PERMITTED.
6. ANODIZE ALL ALUMINUM SURFACES AFTER FABRICATION TO W PS 83121KA, REV E.
7. TORQUE CLAMP BOLTS TO 425 ft-lb.
8. ALL STAINLESS PARTS, WELD PER ASME B&PV CODE SECTION IX. ALL WELDING PROCEDURES AND WELDERS QUALIFIED TO SECTION IX.

9. FOR SUPPORT TO TRAILER BOLT PATTERN SEE DRAWING 1988E53.

10. TORQUE BOLTS TO 1000-1010 ft-lb AT FINAL ASSEMBLY

CP7-9/12/89

PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

REVISIONS: ZONE | DESCRIPTION

INTERPRET DWG PER ANSI Y14
DIM. IN INCHES BASED ON 68°F
UNLESS OTHERWISE SPECIFIED TOLERANCES
2 PL DEC .06 | 3 PL DEC .030 | ANGLES ±3° | 125/ AA
NEXT ASSY
ENGINEERING RELEASE BY NWD
DATE

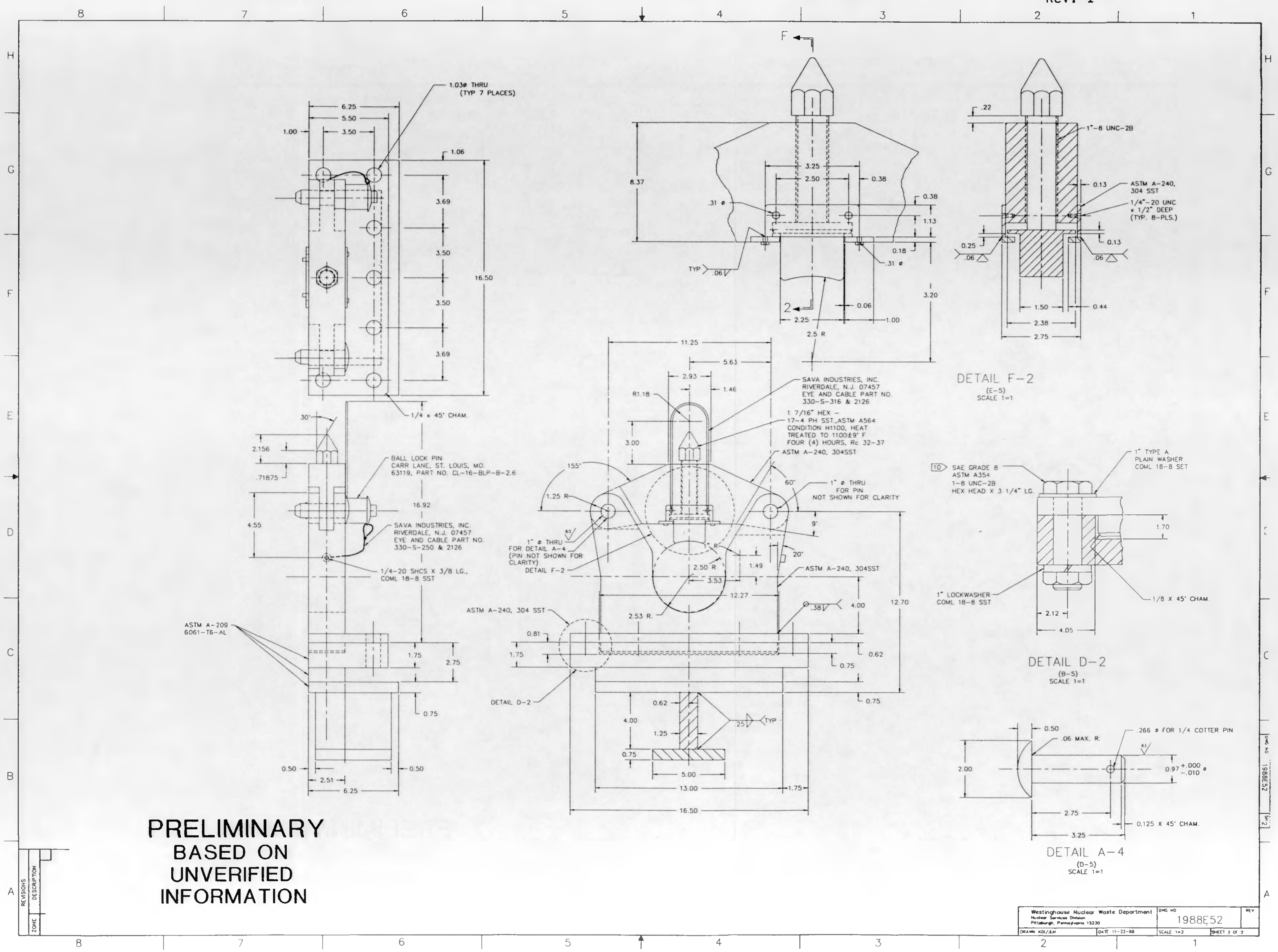
DFTG KDI/JLH
CHKR
COG. ENG
COG. MGR
APPD
APPD
APPD
APPD
DFTG SUPV

Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230

TITAN LEGAL WEIGHT
TRUCK CASK – REAR UPENDING
SUPPORT LAYOUT

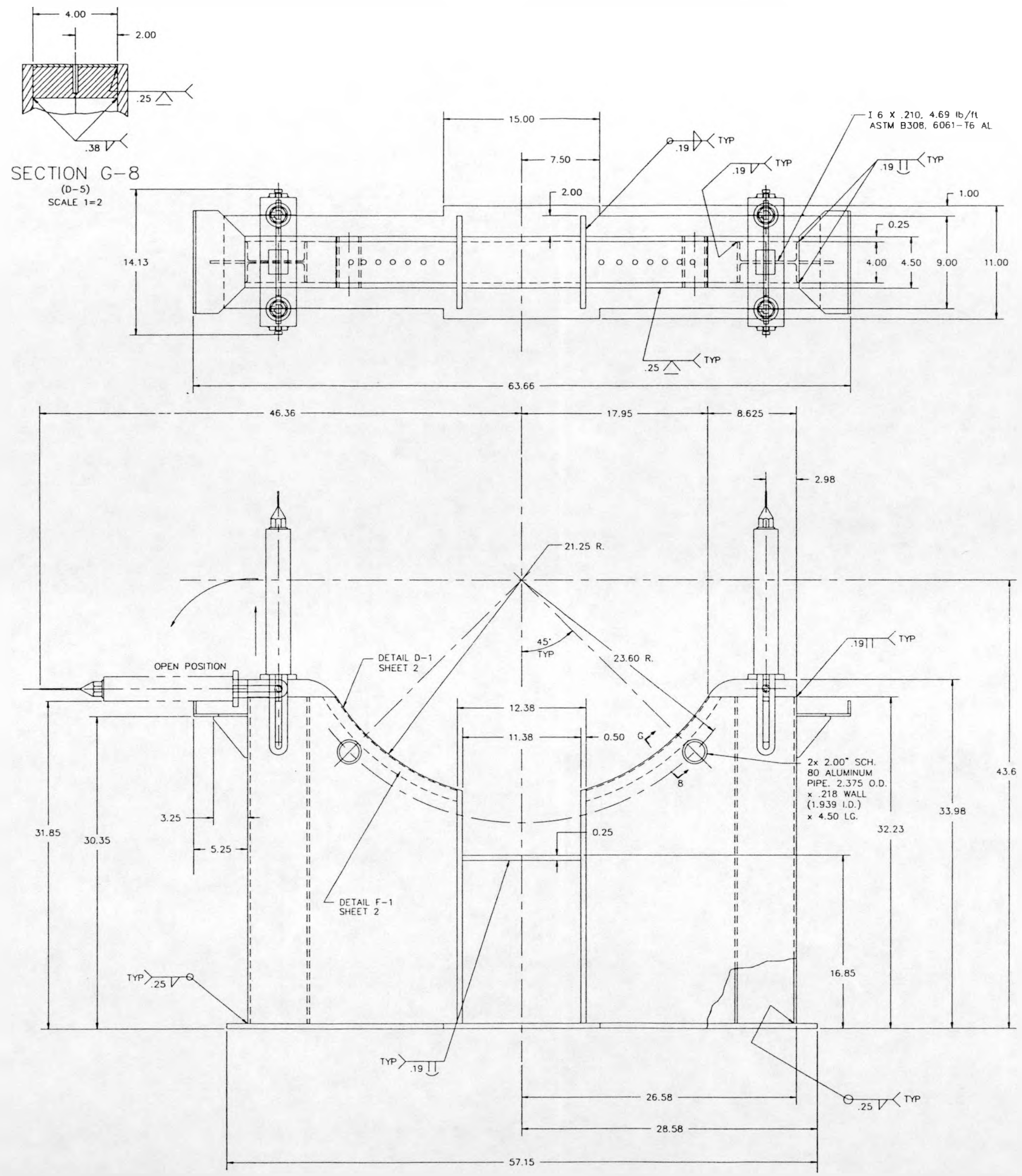
CODE IDENT NO. | DWG NO. 1988E52 | REV
S.O. NO. | SCALE 1=6 | SHEET 1 OF 2

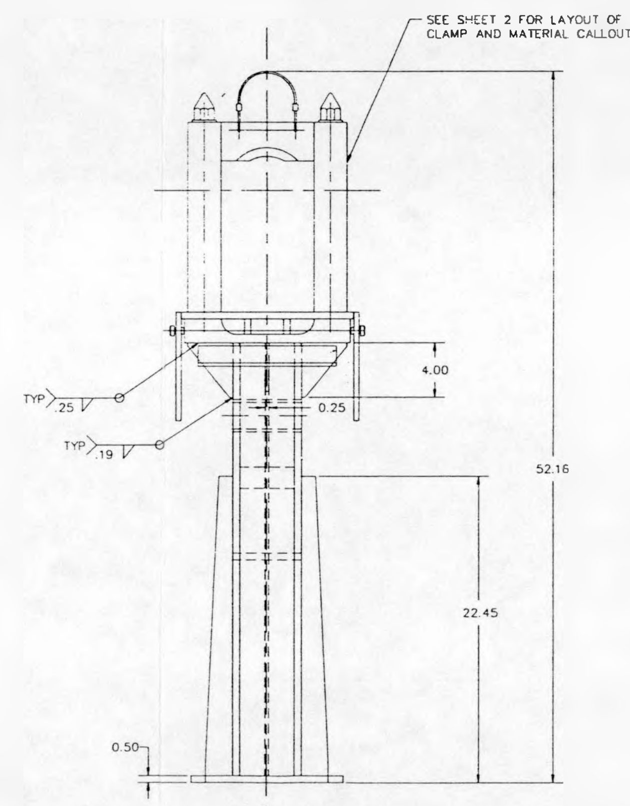
DWG NO. 1988E52 SH 1



**PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION**

QTY REQD GR3	QTY REQD GR2	QTY REQD GR1	NOTE	ITEM	BILL OF MATERIAL PART NAME/DESCRIPTION	PART NO. OR REF DWG	MAT'L/SPECIFICATION





NOTE:

1. MATERIAL ASTM B209, 6061-T6 UNLESS OTHERWISE SPECIFIED.
2. ALL DIMENSIONS APPLY AFTER WELDING.
3. BREAK ALL SHARP EDGES AND CORNERS.
4. ALUMINUM WELD PER AWS D1.3
5. VISUALLY INSPECT ALL WELDS 5-10X NO CRACKS PERMITTED.
6. ANODIZE ALL ALUMINUM SURFACES AFTER FABRICATION TO W PS 83121KA, REV E.
7. TORQUE CLAMP BOLTS TO 425 ft-lb.
8. ALL STAINLESS PARTS, WELD PER ASME B & PV CODE SECTION IX. ALL WELDING PROCEDURES AND WELDERS QUALIFIED TO SECTION IX.
9. FOR SUPPORT TO TRAILER BOLT PATTERN SEE DRAWING 1988E53.

ESTIMATED WEIGHT - 227 lbs

CP7-9/12/89

PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

ZONE | REVISIONS DESCRIPTION

INTERPRET DWG PER ANSI Y14
DIM IN INCHES BASED ON 68°F
UNLESS OTHERWISE SPECIFIED TOLERANCES

2 PL DEC	3 PL DEC	ANGLES	125 √
.06	.030	±2°	AA

NEXT ASSY

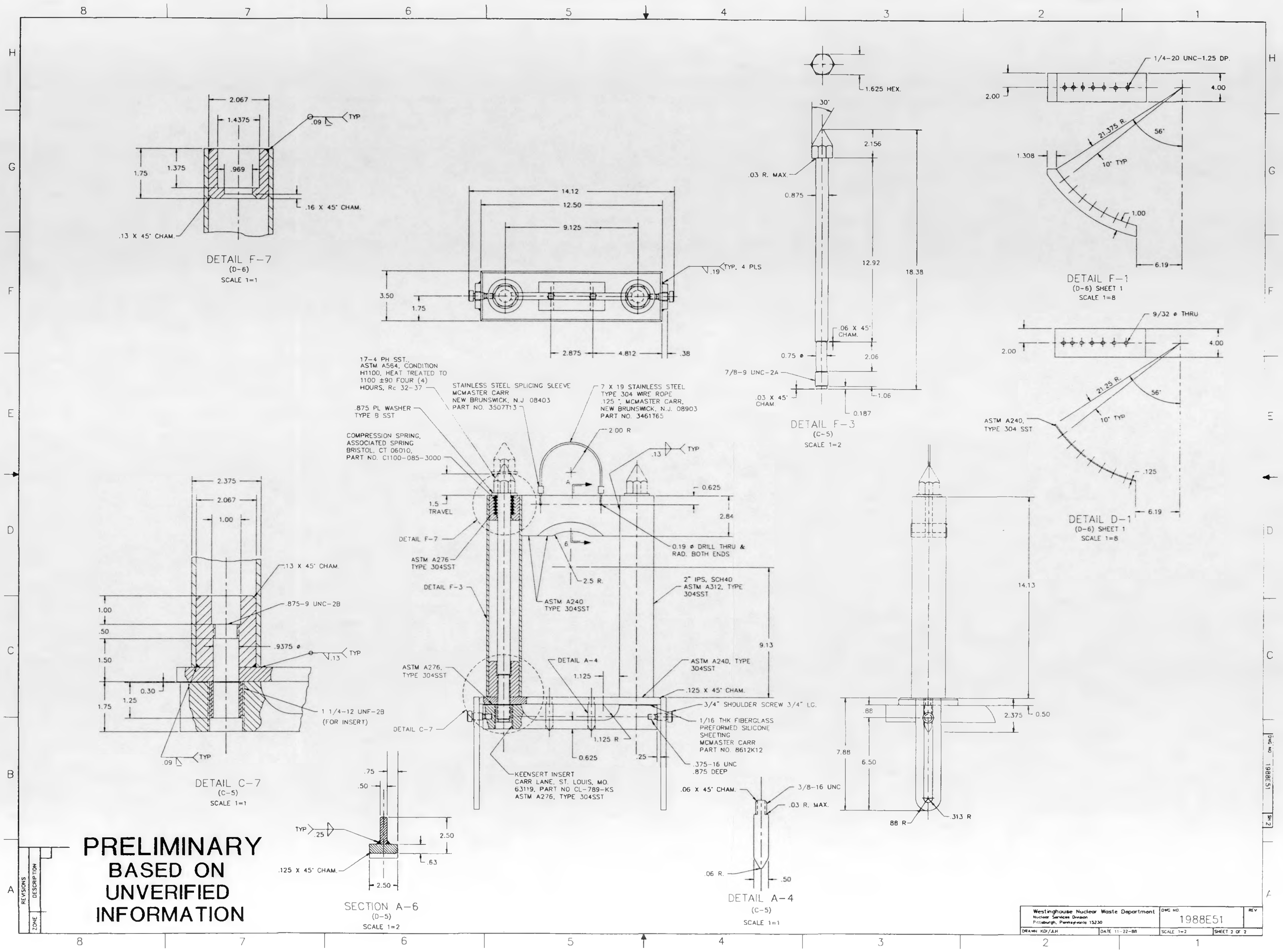
ENGINEERING RELEASE BY NWD
DATE

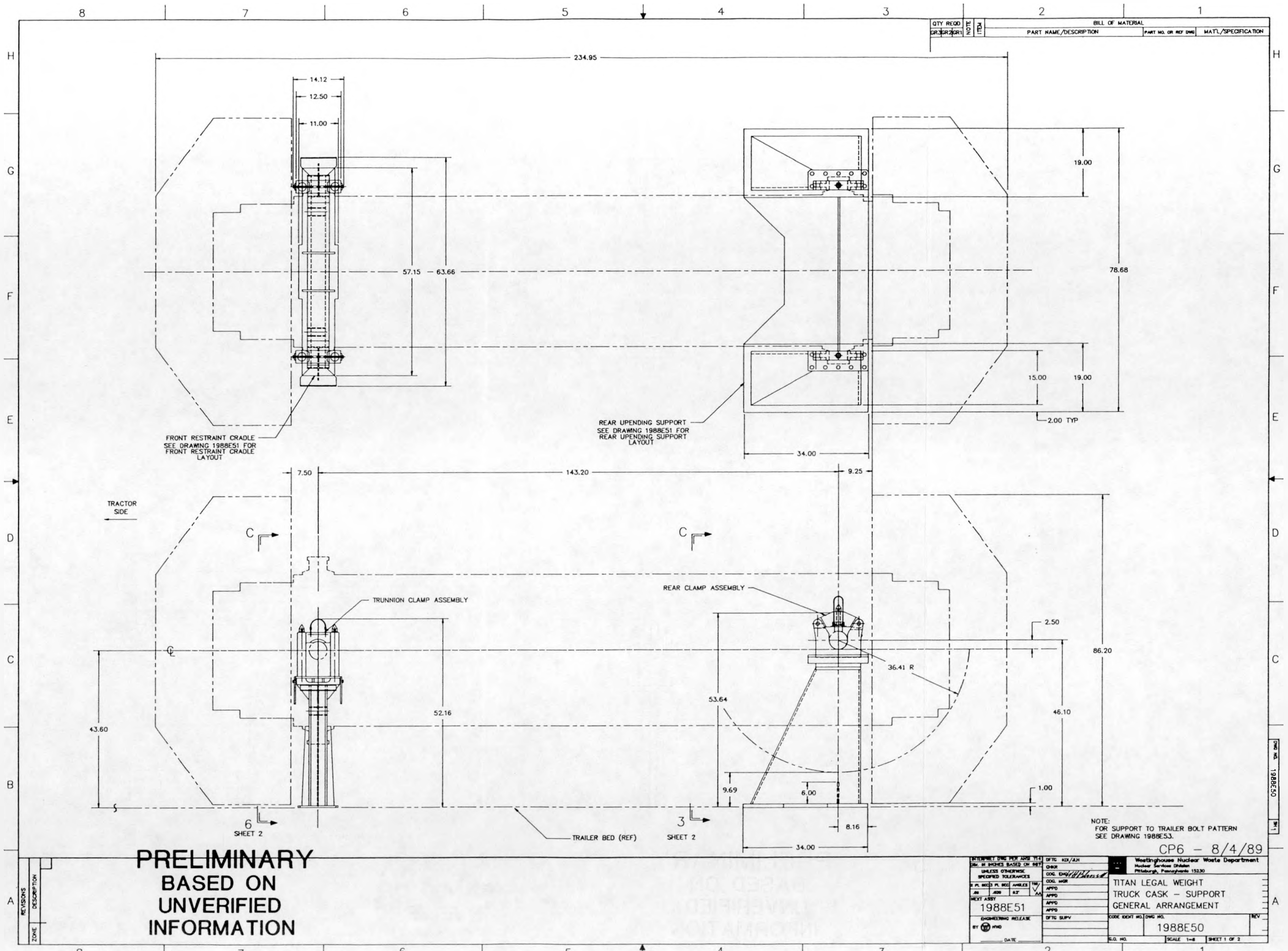
DFTG KDI/JLH
CHKR
COG. ENG
COG. MGR
APPD
APPD
APPD
APPD
DFTG SUPV

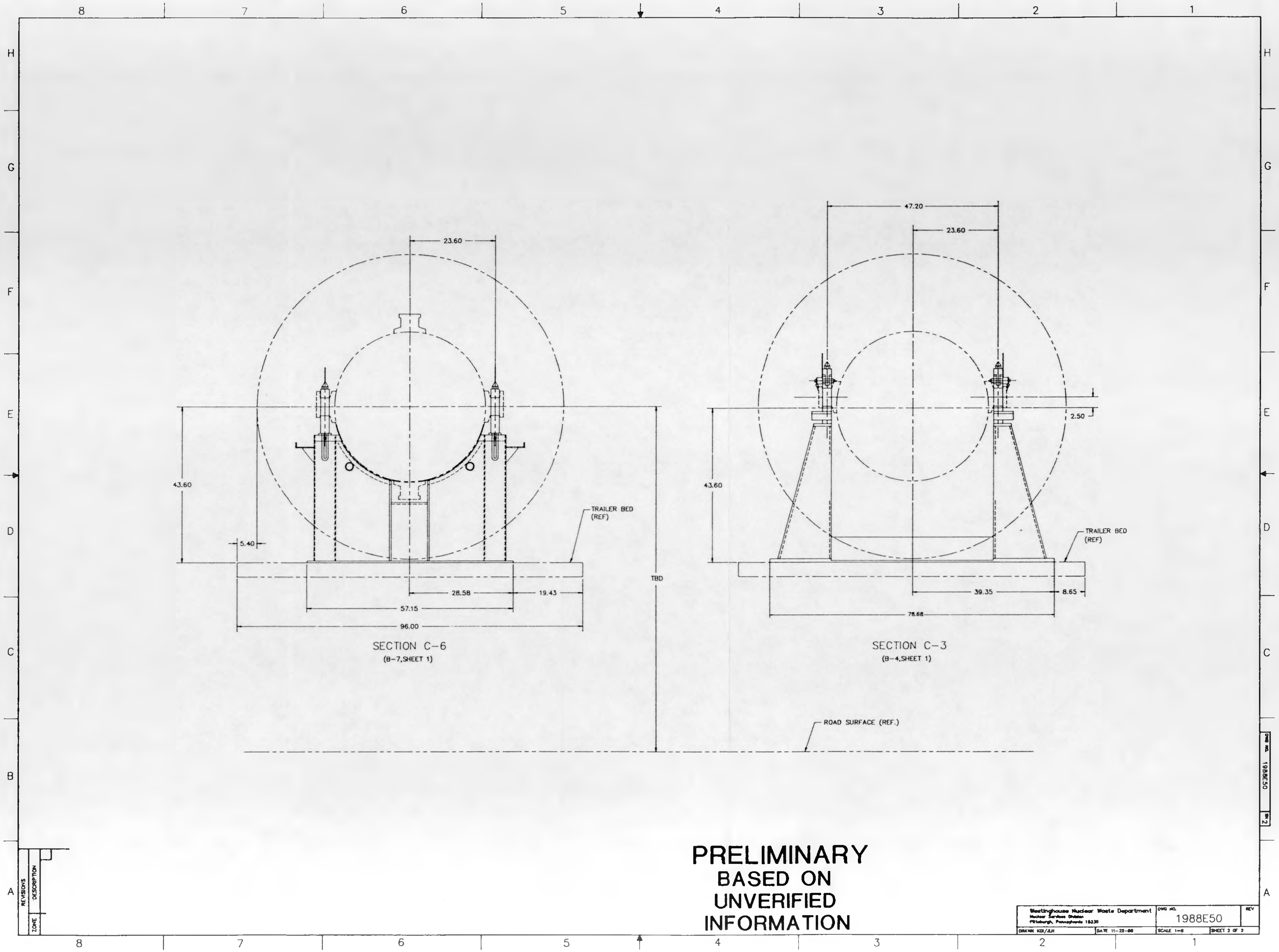
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230

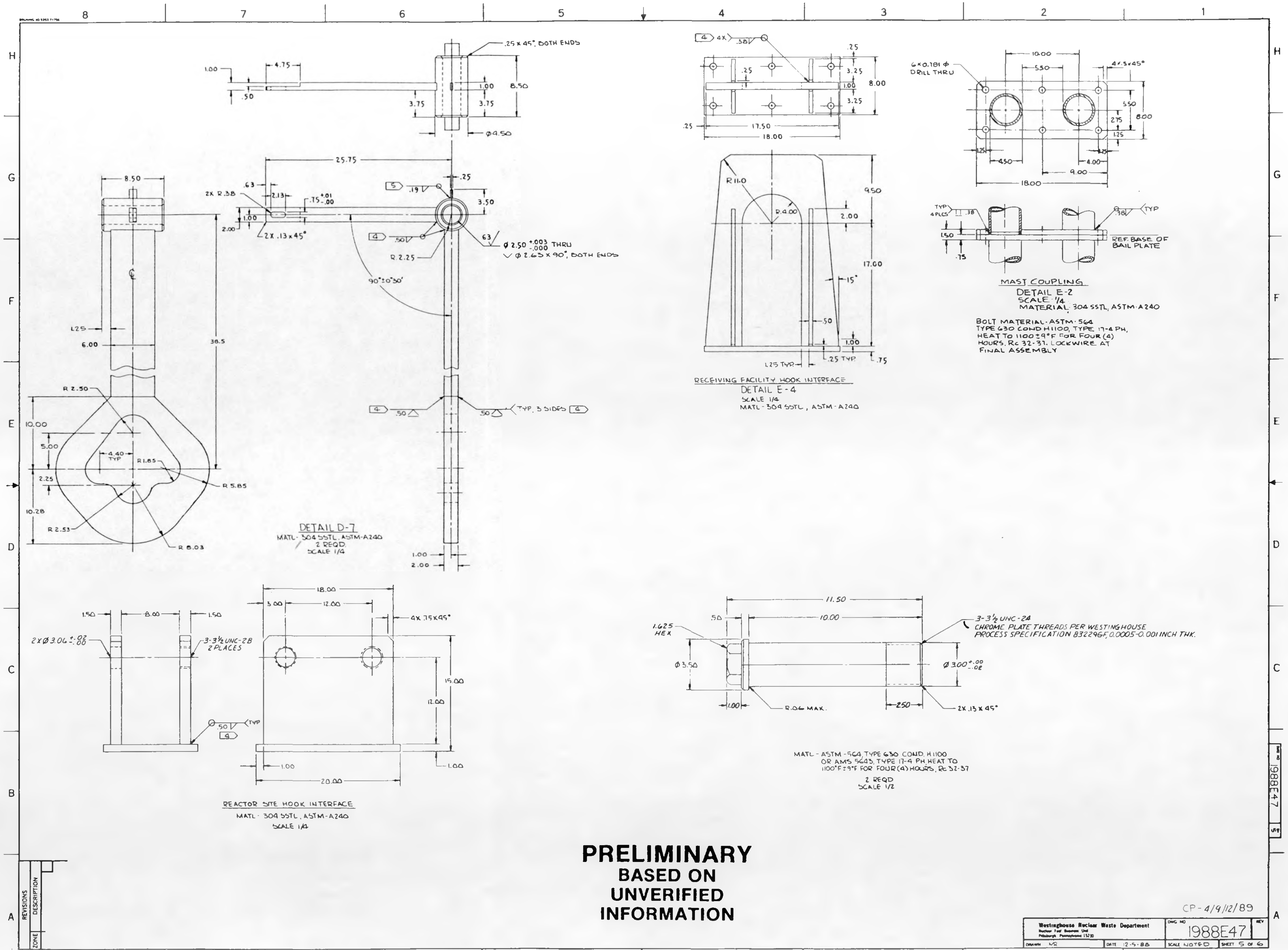
TITAN LEGAL WEIGHT
TRUCK CASK - FRONT
RESTRAINT CRADLE LAYOUT

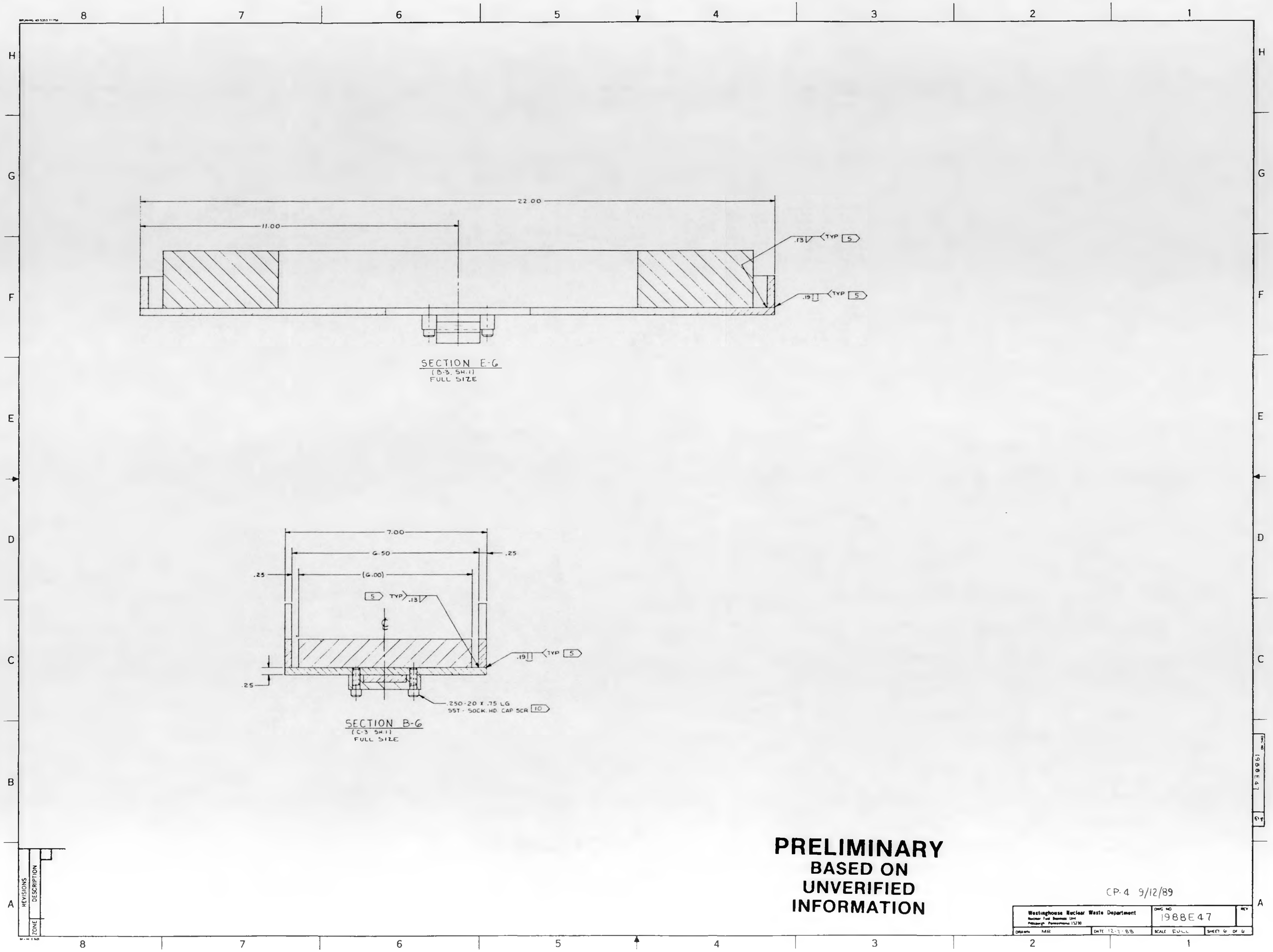
CODE IDENT NO | DWG NO. 1988E51 | REV
G O NO | SCALE 1=4 | SHEET 1 OF 2

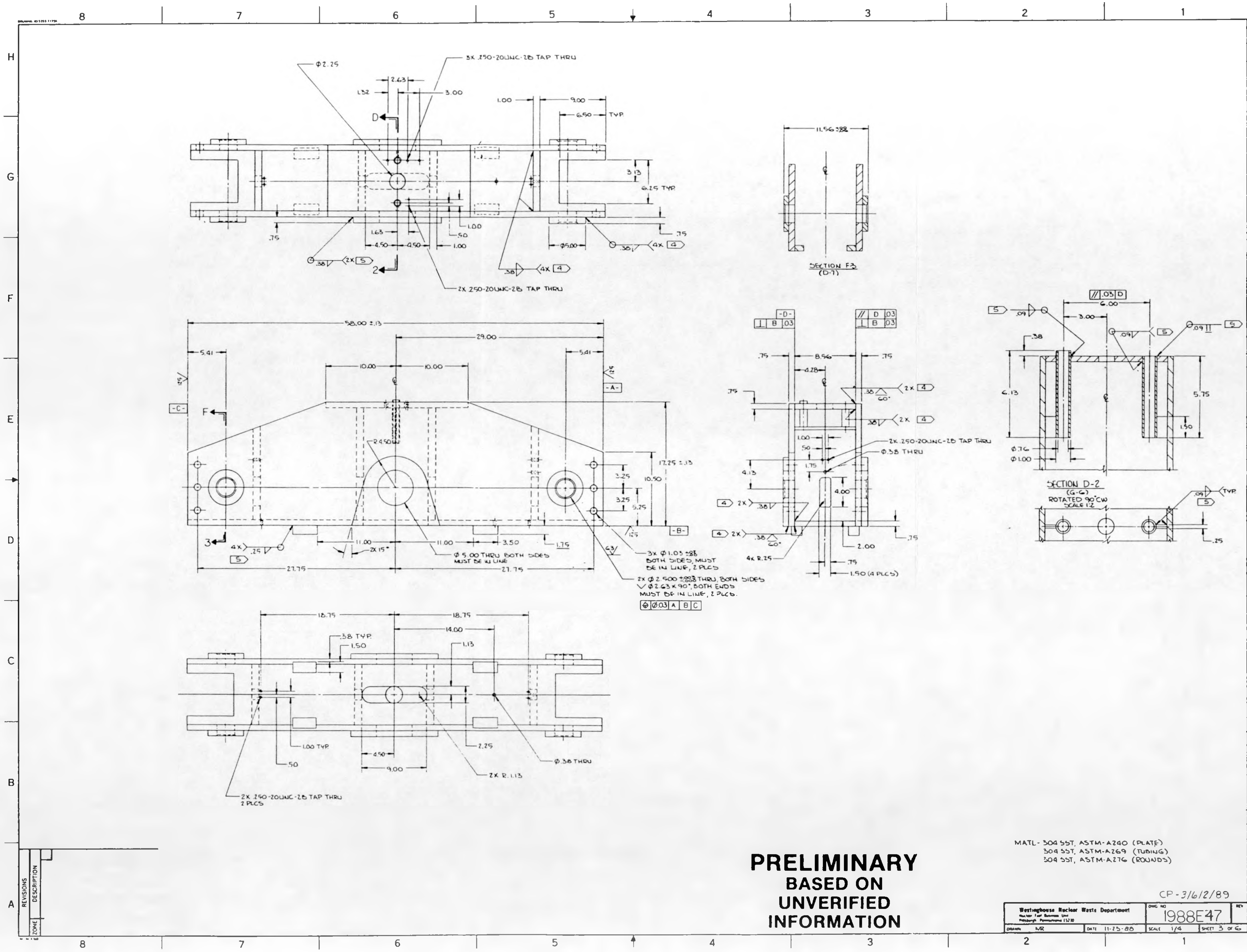

DETAIL F-7
(D-6)
SCALE 1=1
2.067
1.4375
.969
1.75
1.375
.09 TYP
.16 X 45° CHAM.
.13 X 45° CHAM.
14.12
12.50
9.125
3.50
1.75
.19 TYP, 4 PLS
2.875
4.812
.38
1.625 HEX.
30°
2.156
.03 R. MAX
0.875
12.92
18.38
.06 X 45° CHAM.
0.75 ⌀
2.06
7/8-9 UNC-2A
.03 X 45° CHAM.
1.06
0.187
DETAIL F-3
(C-5)
SCALE 1=2
1/4-20 UNC-1.25 DP.
2.00
4.00
21.375 R.
56°
1.308
10° TYP
1.00
6.19
DETAIL F-1
(D-6) SHEET 1
SCALE 1=8
9/32 ⌀ THRU
2.00
4.00
21.25 R.
56°
10° TYP
ASTM A240, TYPE 304 SST
.125
6.19
DETAIL D-1
(D-6) SHEET 1
SCALE 1=8
17-4 PH SST.
ASTM A564, CONDITION H1100, HEAT TREATED TO 1100 ±90 FOUR (4) HOURS, Rc 32-37
.875 PL WASHER TYPE B SST
COMPRESSION SPRING, ASSOCIATED SPRING BRISTOL, CT 06010, PART NO. C1100-085-3000
STAINLESS STEEL SPLICING SLEEVE MCMASTER CARR NEW BRUNSWICK, N.J. 08403 PART NO. 3507T13
7 X 19 STAINLESS STEEL TYPE 304 WIRE ROPE .125 ", MCMASTER CARR, NEW BRUNSWICK, N.J. 08903 PART NO. 3461T65
2.00 R
.13 TYP
0.625
2.84
1.5 TRAVEL
DETAIL F-7
ASTM A276 TYPE 304SST
DETAIL F-3
0.19 ⌀ DRILL THRU & RAD. BOTH ENDS
2.5 R.
ASTM A240 TYPE 304SST
2" IPS, SCH40 ASTM A312, TYPE 304SST
9.13
ASTM A276, TYPE 304SST
DETAIL A-4
1.125
ASTM A240, TYPE 304SST
.125 X 45° CHAM.
3/4" SHOULDER SCREW 3/4" LG.
1/16 THK FIBERGLASS PREFORMED SILICONE SHEETING MCMASTER CARR PART NO. 8612K12
DETAIL C-7
1.125 R
0.625
.25
.375-16 UNC .875 DEEP
KEENSERT INSERT CARR LANE, ST. LOUIS, MO. 63119, PART NO CL-789-KS ASTM A276, TYPE 304SST
14.13
2.375
0.50
.88
7.88
6.50
.88 R
.313 R
2.375
2.067
1.00
.13 X 45° CHAM.
.875-9 UNC-2B
.9375 ⌀
.13 TYP
1.00
.50
1.50
0.30
1.25
1.75
1 1/4-12 UNF-2B (FOR INSERT)
.09 TYP
DETAIL C-7
(C-5)
SCALE 1=1
.75
.50
TYP .25
2.50
.63
.125 X 45° CHAM.
2.50
SECTION A-6
(D-5)
SCALE 1=2
.06 X 45° CHAM.
3/8-16 UNC
.03 R. MAX.
.06 R.
.50
DETAIL A-4
(C-5)
SCALE 1=1
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
DWG NO 1988E51
SCALE 1=2
SHEET 2 OF 2

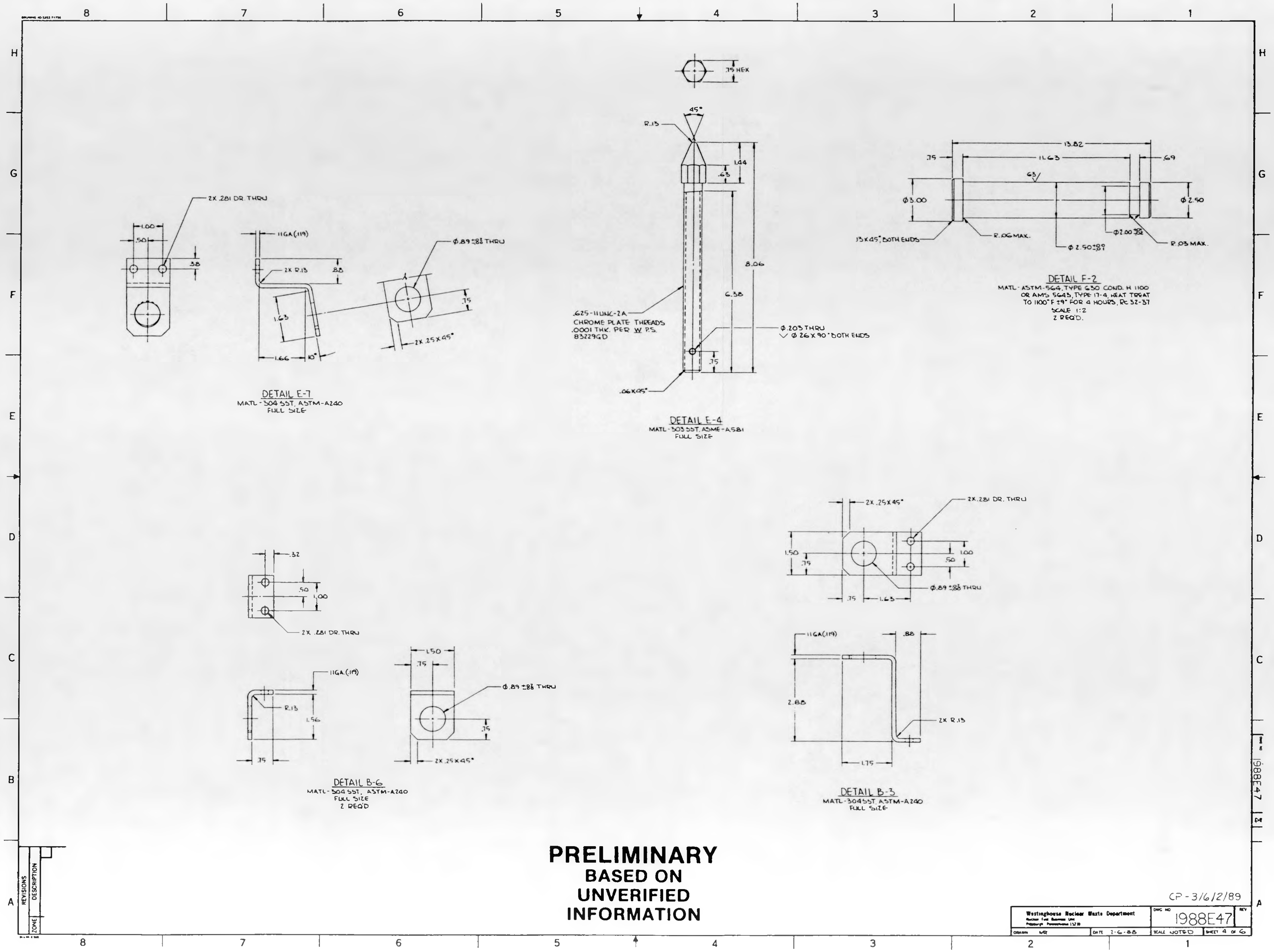

BILL OF MATERIAL
QTY REQD
NOTE
ITEM
PART NAME/DESCRIPTION
PART NO. OR REF DWG
MAT'L/SPECIFICATION
234.95
14.12
12.50
11.00
57.15
63.66
19.00
78.68
15.00
19.00
2.00 TYP
34.00
FRONT RESTRAINT CRADLE
SEE DRAWING 1988E51 FOR
FRONT RESTRAINT CRADLE
LAYOUT
REAR UPENDING SUPPORT
SEE DRAWING 1988E51 FOR
REAR UPENDING SUPPORT
LAYOUT
7.50
143.20
9.25
TRACTOR
SIDE
TRUNNION CLAMP ASSEMBLY
REAR CLAMP ASSEMBLY
2.50
86.20
36.41 R
53.64
46.10
43.60
52.16
9.69
6.00
1.00
8.16
34.00
SHEET 2
TRAILER BED (REF)
SHEET 2
NOTE:
FOR SUPPORT TO TRAILER BOLT PATTERN
SEE DRAWING 1988E53.
CP6 – 8/4/89
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
NEXT ASSY
1988E51
Westinghouse Nuclear Waste Department
TITAN LEGAL WEIGHT
TRUCK CASK – SUPPORT
GENERAL ARRANGEMENT
1988E50
SHEET 1 OF 2

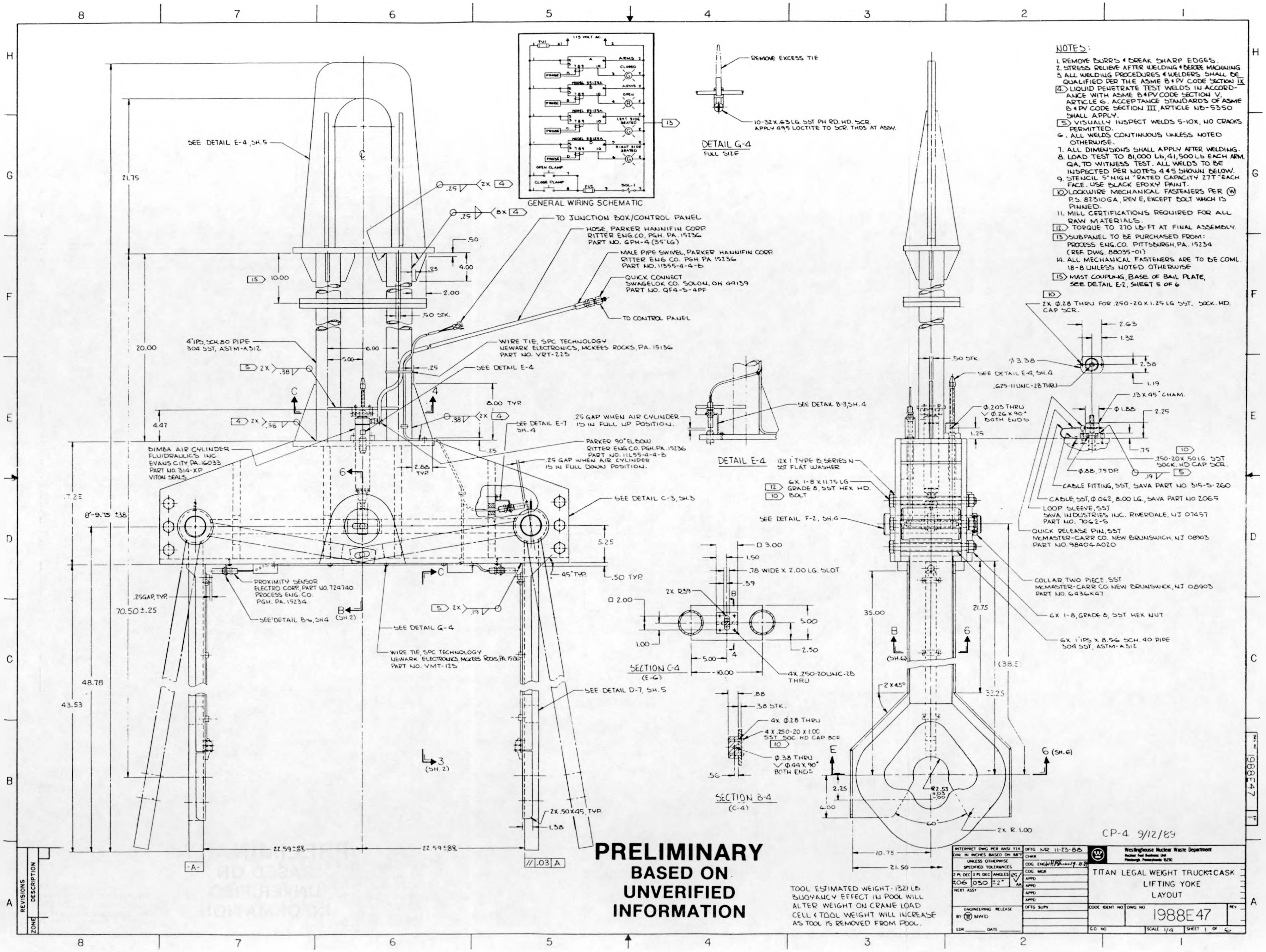

23.60
43.60
5.40
TRAILER BED (REF)
28.58
19.43
57.15
96.00
SECTION C-6
(B-7, SHEET 1)
TBD
47.20
23.60
2.50
43.60
TRAILER BED (REF)
39.35
8.65
78.68
SECTION C-3
(B-4, SHEET 1)
ROAD SURFACE (REF.)
REVISIONS
ZONE
DESCRIPTION
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
DWG NO.
1988E50
REV
DRAWN
SHEET 2 OF 2

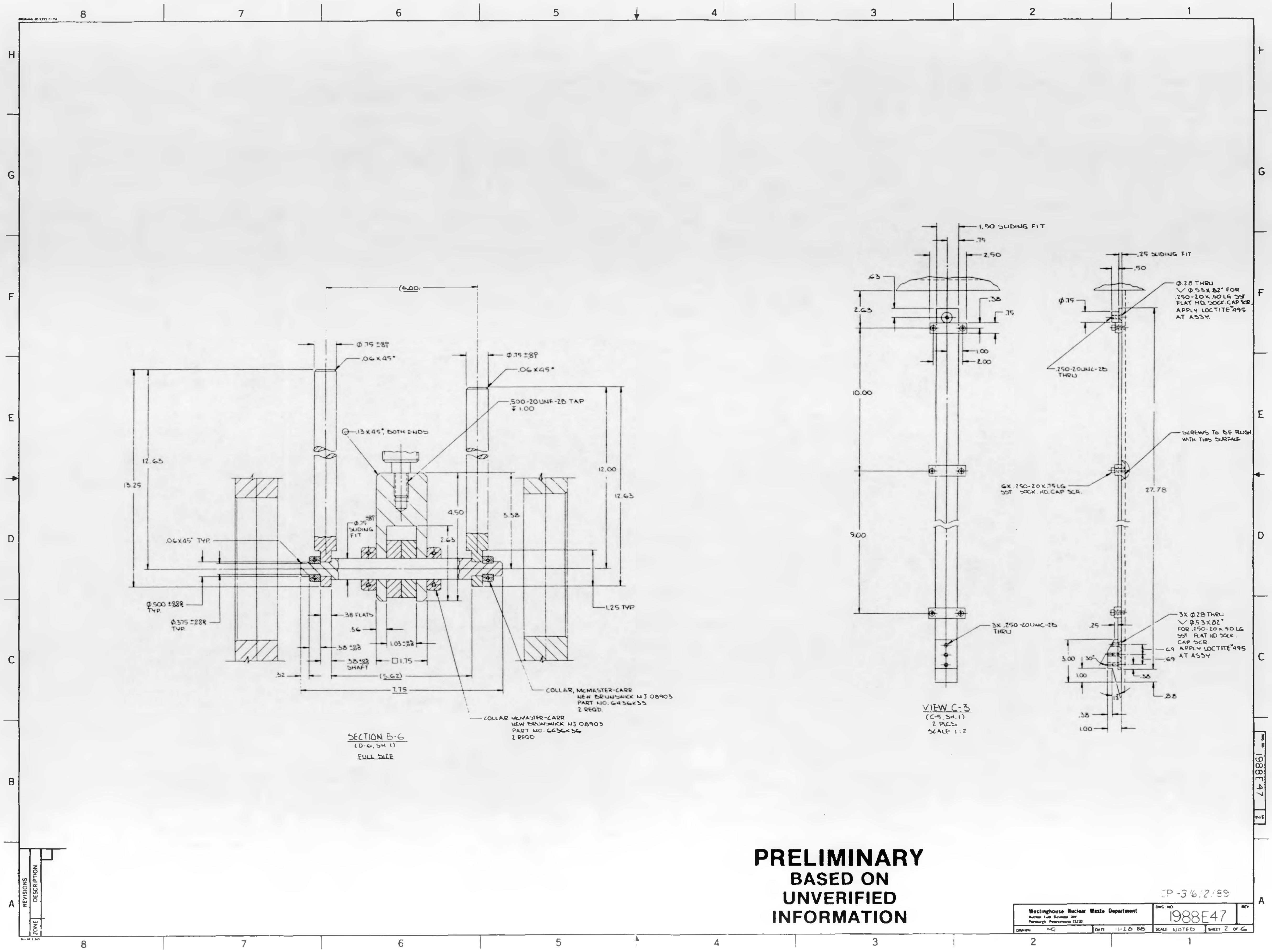

DETAIL D-7
MATL - 304 SSTL, ASTM-A240
2 REQD
SCALE 1/4
REACTOR SITE HOOK INTERFACE
MATL - 304 SSTL, ASTM-A240
SCALE 1/4
RECEIVING FACILITY HOOK INTERFACE
DETAIL E-4
SCALE 1/4
MATL - 304 SSTL, ASTM-A240
MAST COUPLING
DETAIL E-2
SCALE 1/4
MATERIAL 304 SSTL, ASTM-A240
BOLT MATERIAL - ASTM-564
TYPE 630 COND H1100, TYPE 17-4 PH,
HEAT TO 1100±9°F FOR FOUR (4)
HOURS, Rc 32-37. LOCKWIRE AT
FINAL ASSEMBLY
3-3½ UNC-2A
CHROME PLATE THREADS PER WESTINGHOUSE
PROCESS SPECIFICATION 83229GF, 0.0005-0.001 INCH THK.
MATL - ASTM-564, TYPE 630 COND. H1100
OR AMS 5643, TYPE 17-4 PH HEAT TO
1100°F±9°F FOR FOUR (4) HOURS, Rc 32-37
2 REQD
SCALE 1/2
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
CP-4/9/12/89
Westinghouse Nuclear Waste Department
1988E47
DATE 12-5-88
SCALE NOTED
SHEET 5 OF 6


22.00
11.00
.13 TYP 5
.19 TYP 5
SECTION E-6
(B-3, SH.1)
FULL SIZE
7.00
6.50
.25
.25
(6.00)
5 TYP .13
.19 TYP 5
.25
.250-20 X .75 LG
SST - SOCK HD CAP SCR 10
SECTION B-6
(C-3 SH.1)
FULL SIZE
REVISIONS
ZONE
DESCRIPTION
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
CP-4 9/12/89
Westinghouse Nuclear Waste Department
DWG NO
1988E47
REV
DRAWN MR
DATE 12-7-88
SCALE FULL
SHEET 6 OF 6

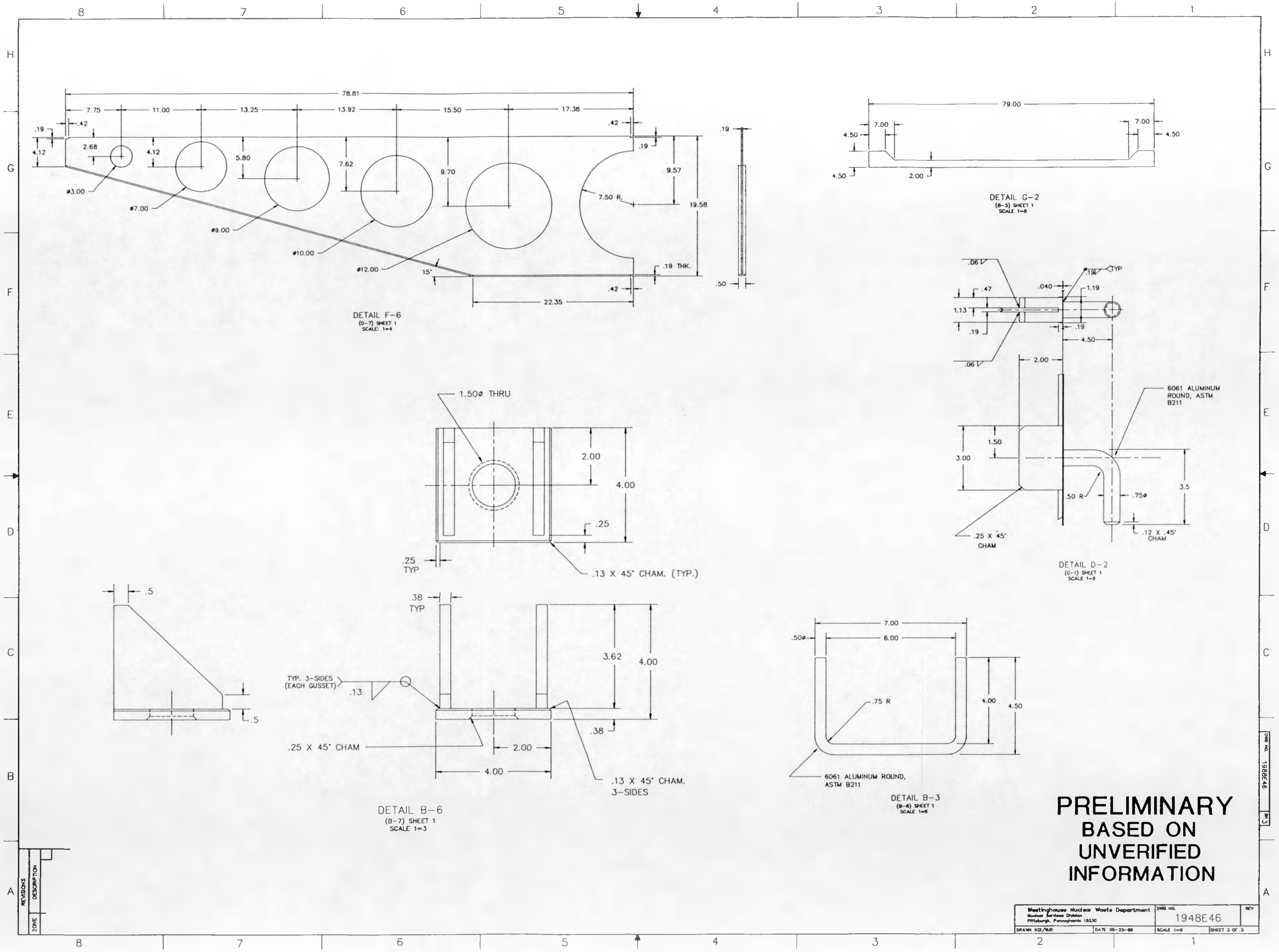

SECTION F-3
(D-7)
SECTION D-2
(G-6)
ROTATED 90° CW
SCALE 1/2
MATL- 304 SST, ASTM-A240 (PLATE)
304 SST, ASTM-A269 (TUBING)
304 SST, ASTM-A276 (ROUNDS)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
CP-3/16/2/89
Westinghouse Nuclear Waste Department
1988E47
DATE 11-25-88
SCALE 1/4
SHEET 3 OF 6

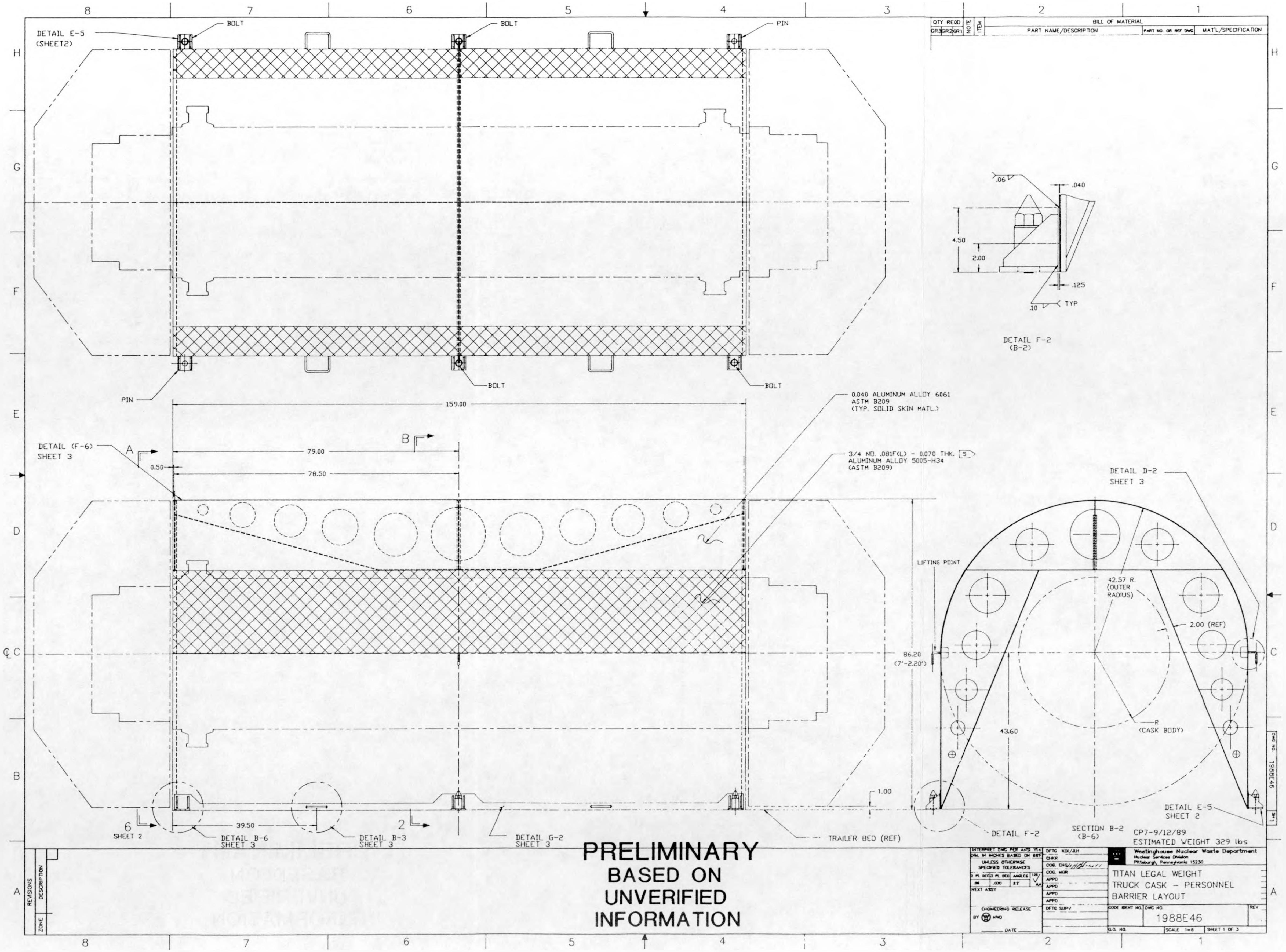

DETAIL E-7
MATL - 304 SST, ASTM-A240
FULL SIZE
2X .281 DR. THRU
11GA (.119)
2X R.13
Ø.89 THRU
2X .25X45°
DETAIL E-4
MATL - 303 SST, ASME-A581
FULL SIZE
.75 HEX
45°
R.13
.625-11UNC-2A
CHROME PLATE THREADS
.0001 THK. PER W.P.S.
83229GD
Ø.203 THRU
Ø.26 X 90° BOTH ENDS
.06X45°
DETAIL F-2
MATL - ASTM-564, TYPE 630 COND. H 1100
OR AMS 5643, TYPE 17-4, HEAT TREAT
TO 1100°F ±9° FOR 4 HOURS, Rc 32-37
SCALE 1:2
2 REQ'D.
Ø3.00
Ø2.50
R.06 MAX.
R.03 MAX.
.13X45° BOTH ENDS
DETAIL B-6
MATL - 304 SST, ASTM-A240
FULL SIZE
2 REQ'D
DETAIL B-3
MATL - 304 SST, ASTM-A240
FULL SIZE
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
CP - 3/6/2/89
Westinghouse Nuclear Waste Department
1988E47
DATE 1-6-88
SCALE NOTED
SHEET 4 OF 6

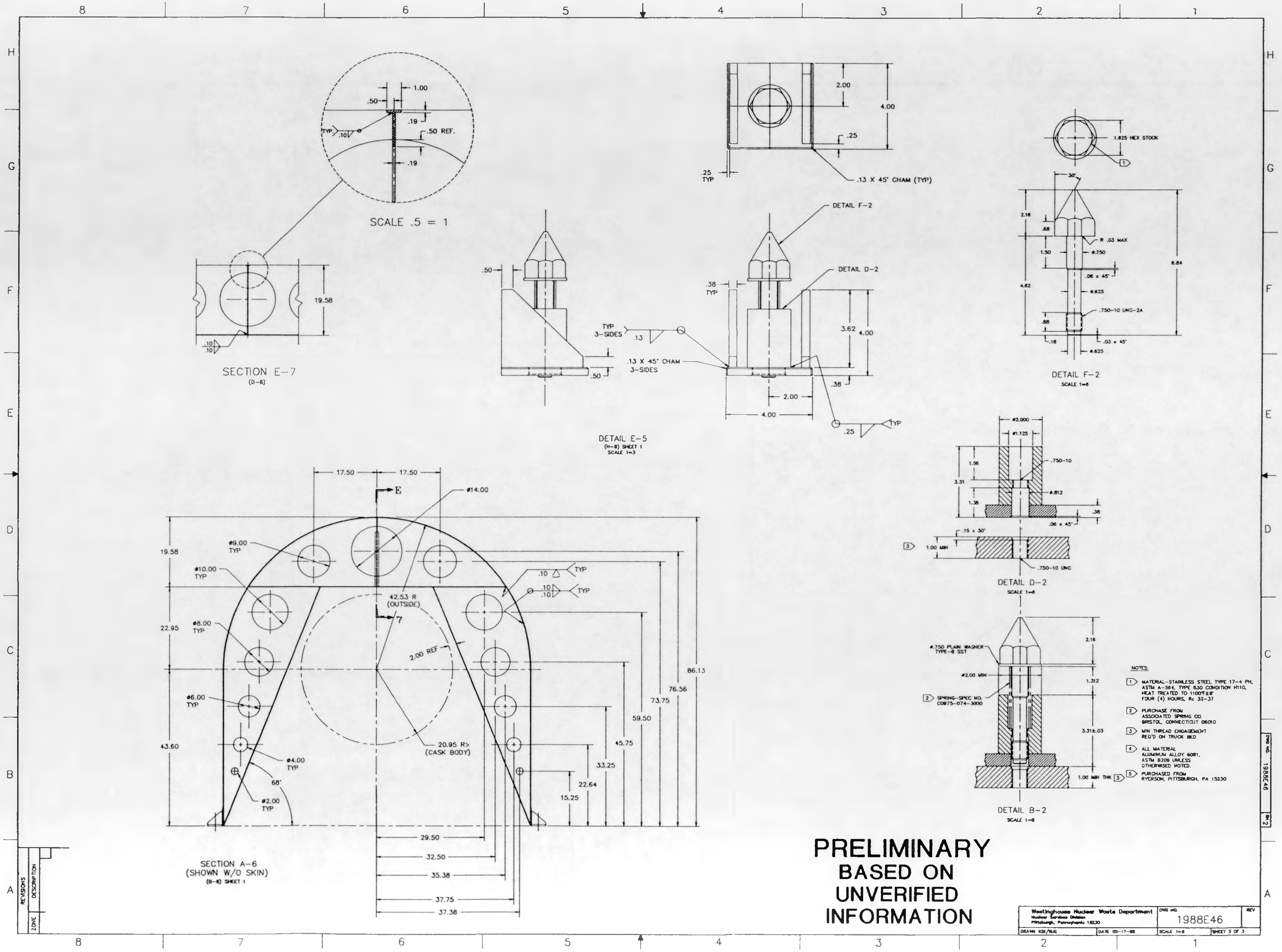

NOTES:
1. REMOVE BURRS & BREAK SHARP EDGES.
2. STRESS RELIEVE AFTER WELDING & BEFORE MACHINING
3. ALL WELDING PROCEDURES & WELDERS SHALL BE QUALIFIED PER THE ASME B&PV CODE SECTION IX
4. LIQUID PENETRATE TEST WELDS IN ACCORDANCE WITH ASME B&PV CODE SECTION V, ARTICLE 6. ACCEPTANCE STANDARDS OF ASME B&PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
5. VISUALLY INSPECT WELDS 5-10X, NO CRACKS PERMITTED.
6. ALL WELDS CONTINUOUS UNLESS NOTED OTHERWISE.
7. ALL DIMENSIONS SHALL APPLY AFTER WELDING.
8. LOAD TEST TO 81,000 LB, 41,500 LB EACH ARM. QA. TO WITNESS TEST. ALL WELDS TO BE INSPECTED PER NOTES 4 & 5 SHOWN BELOW.
9. STENCIL 5" HIGH "RATED CAPACITY 27T" EACH FACE. USE BLACK EPOXY PAINT.
10. LOCKWIRE MECHANICAL FASTENERS PER W P.S. 82310GA, REV E, EXCEPT BOLT WHICH IS PINNED.
11. MILL CERTIFICATIONS REQUIRED FOR ALL RAW MATERIALS.
12. TORQUE TO 270 LB-FT AT FINAL ASSEMBLY.
13. SUBPANEL TO BE PURCHASED FROM: PROCESS ENG. CO. PITTSBURGH, PA. 15234 (REF. DWG. 88035-01)
14. ALL MECHANICAL FASTENERS ARE TO BE COML. 18-8 UNLESS NOTED OTHERWISE
15. MAST COUPLING, BASE OF BAIL PLATE, SEE DETAIL E-2, SHEET 5 OF 6
GENERAL WIRING SCHEMATIC
DETAIL G-4
FULL SIZE
DETAIL E-4
SECTION C-4
SECTION B-4
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
TOOL ESTIMATED WEIGHT: 1321 LB. BUOYANCY EFFECT IN POOL WILL ALTER WEIGHT ON CRANE LOAD CELL & TOOL WEIGHT WILL INCREASE AS TOOL IS REMOVED FROM POOL.
CP-4 9/12/89
Westinghouse Nuclear Waste Department
TITAN LEGAL WEIGHT TRUCK CASK
LIFTING YOKE
LAYOUT
DWG NO 1988E47
SCALE 1/4
SHEET 1 OF 6
DFTG MR 11-23-88

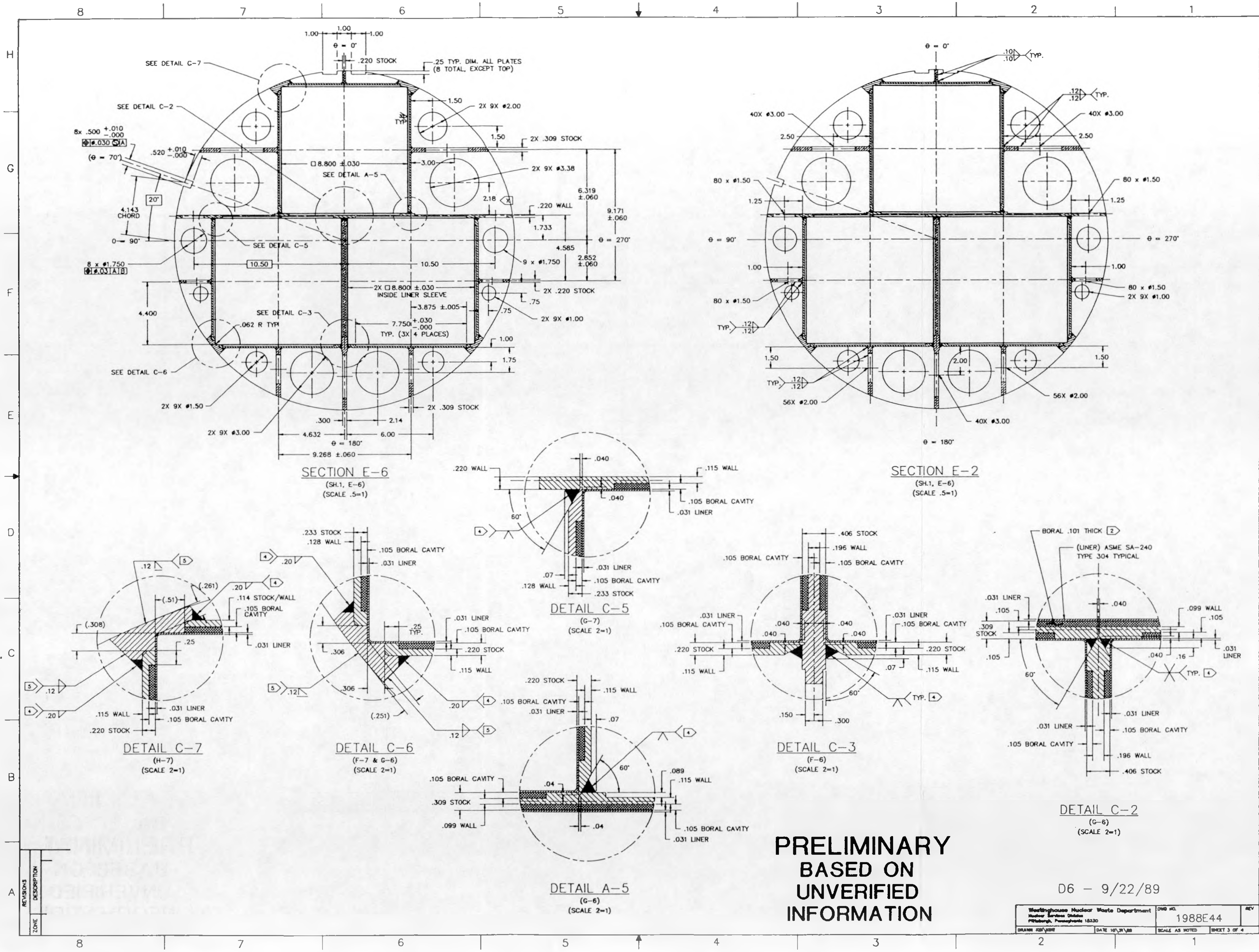


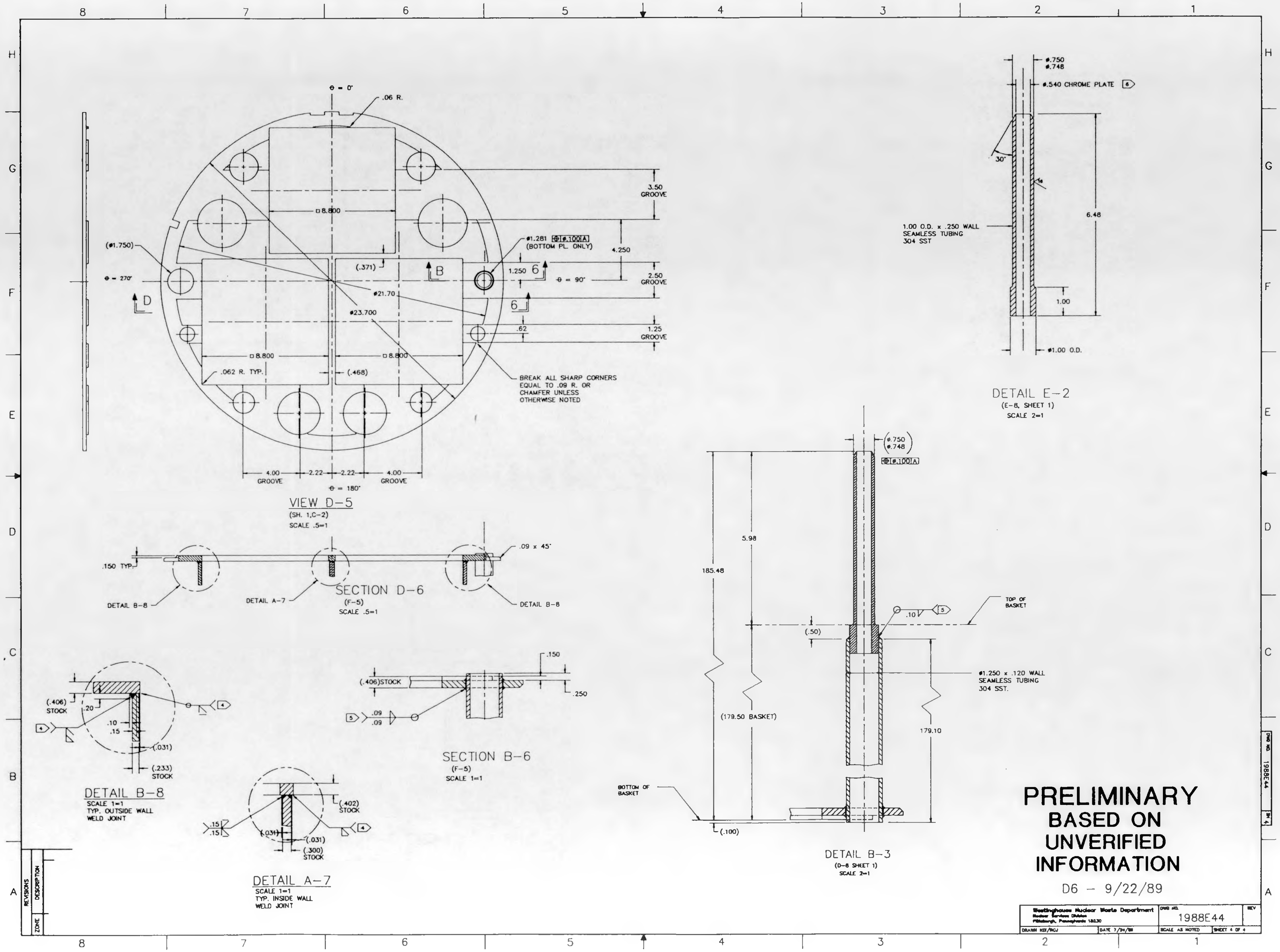
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION

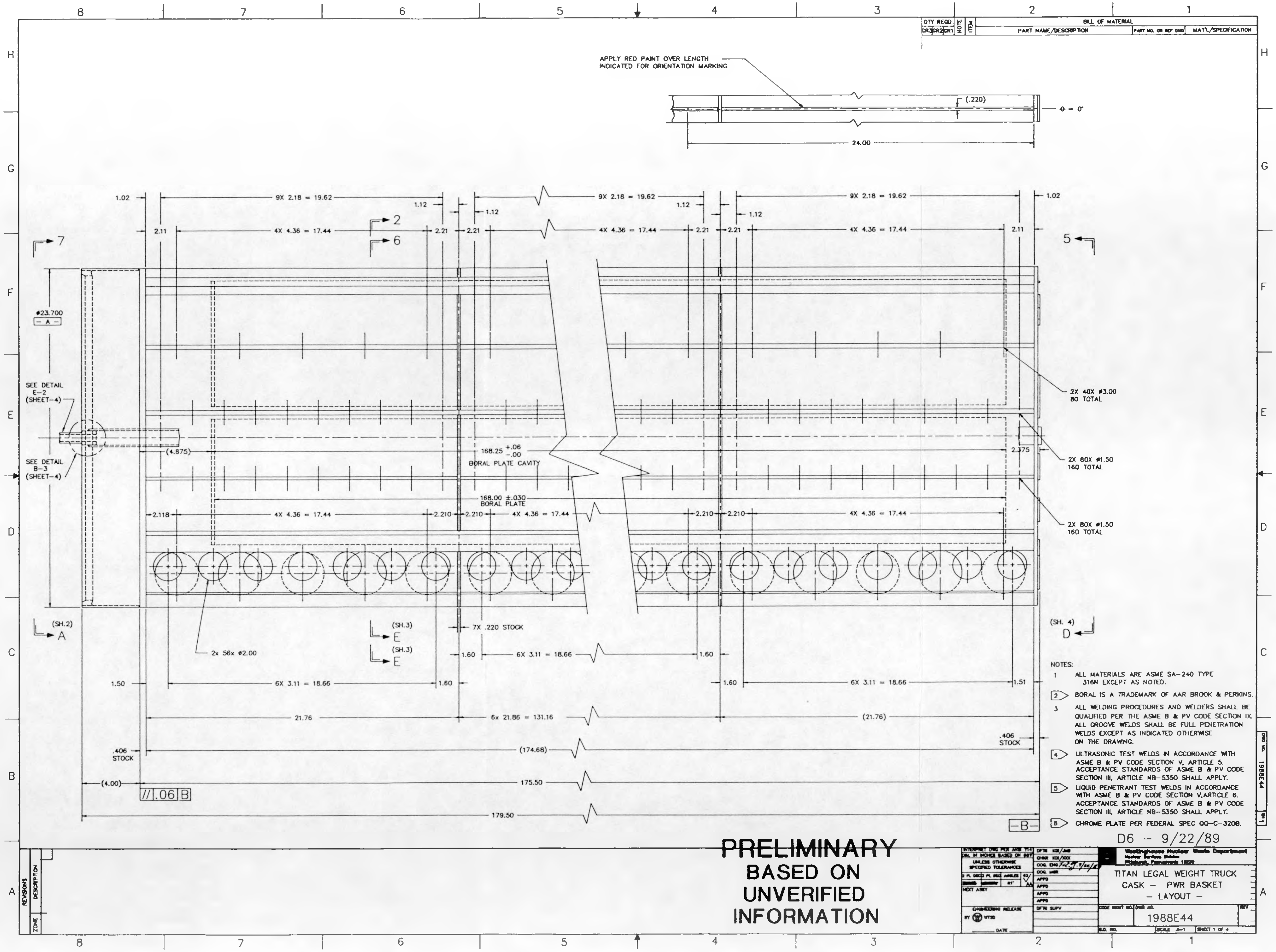

DETAIL F-6
(D-7) SHEET 1
SCALE: 1=4
DETAIL G-2
(B-3) SHEET 1
SCALE 1=8
DETAIL D-2
(C-1) SHEET 1
SCALE 1=8
6061 ALUMINUM ROUND, ASTM B211
1.50ø THRU
.13 X 45° CHAM. (TYP.)
TYP. 3-SIDES (EACH GUSSET)
.25 X 45° CHAM
.13 X 45° CHAM. 3-SIDES
DETAIL B-6
(B-7) SHEET 1
SCALE 1=3
6061 ALUMINUM ROUND, ASTM B211
DETAIL B-3
(B-6) SHEET 1
SCALE 1=8
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
Westinghouse Nuclear Waste Department
Nuclear Services Division
Pittsburgh, Pennsylvania 15230
DWG NO.
1948E46
REV
SHEET 3 OF 3

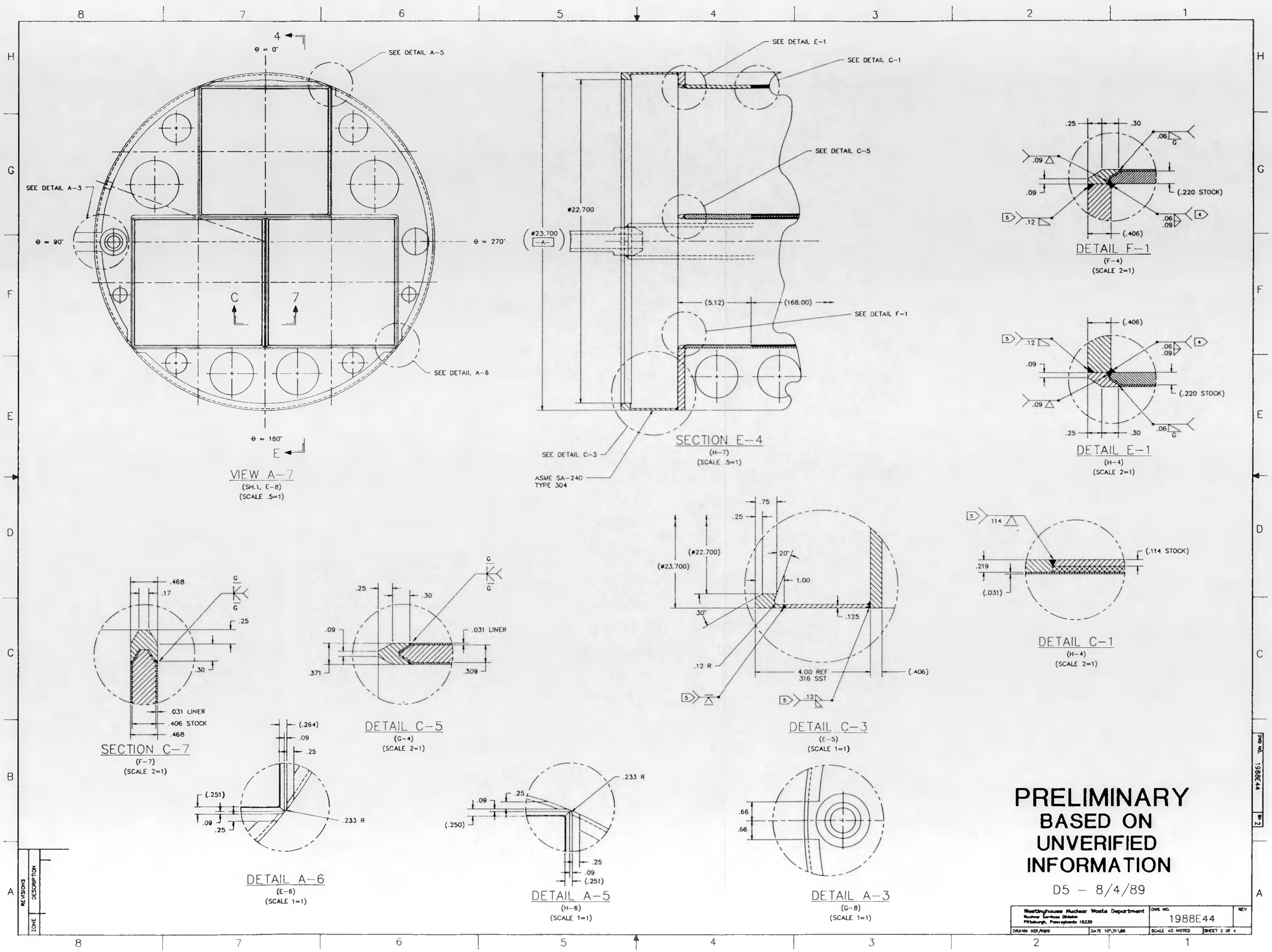

DETAIL E-5 (SHEET2)
BOLT
BOLT
PIN
BOLT
BOLT
PIN
159.00
79.00
78.50
0.50
DETAIL (F-6) SHEET 3
0.040 ALUMINUM ALLOY 6061 ASTM B209 (TYP. SOLID SKIN MATL.)
3/4 NO. .081F(L) - 0.070 THK. ALUMINUM ALLOY 5005-H34 (ASTM B209)
LIFTING POINT
86.20 (7'-2.20")
1.00
39.50
SHEET 2
DETAIL B-6 SHEET 3
DETAIL B-3 SHEET 3
DETAIL G-2 SHEET 3
TRAILER BED (REF)
DETAIL F-2 (B-2)
.040
4.50
2.00
.125
TYP
DETAIL D-2 SHEET 3
42.57 R. (OUTER RADIUS)
2.00 (REF)
43.60
R (CASK BODY)
DETAIL E-5 SHEET 2
DETAIL F-2
SECTION B-2 (B-6)
CP7-9/12/89
ESTIMATED WEIGHT 329 lbs
BILL OF MATERIAL
PART NAME/DESCRIPTION
MATL/SPECIFICATION
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
TITAN LEGAL WEIGHT
TRUCK CASK - PERSONNEL
BARRIER LAYOUT
1988E46
SCALE 1=8
SHEET 1 OF 3

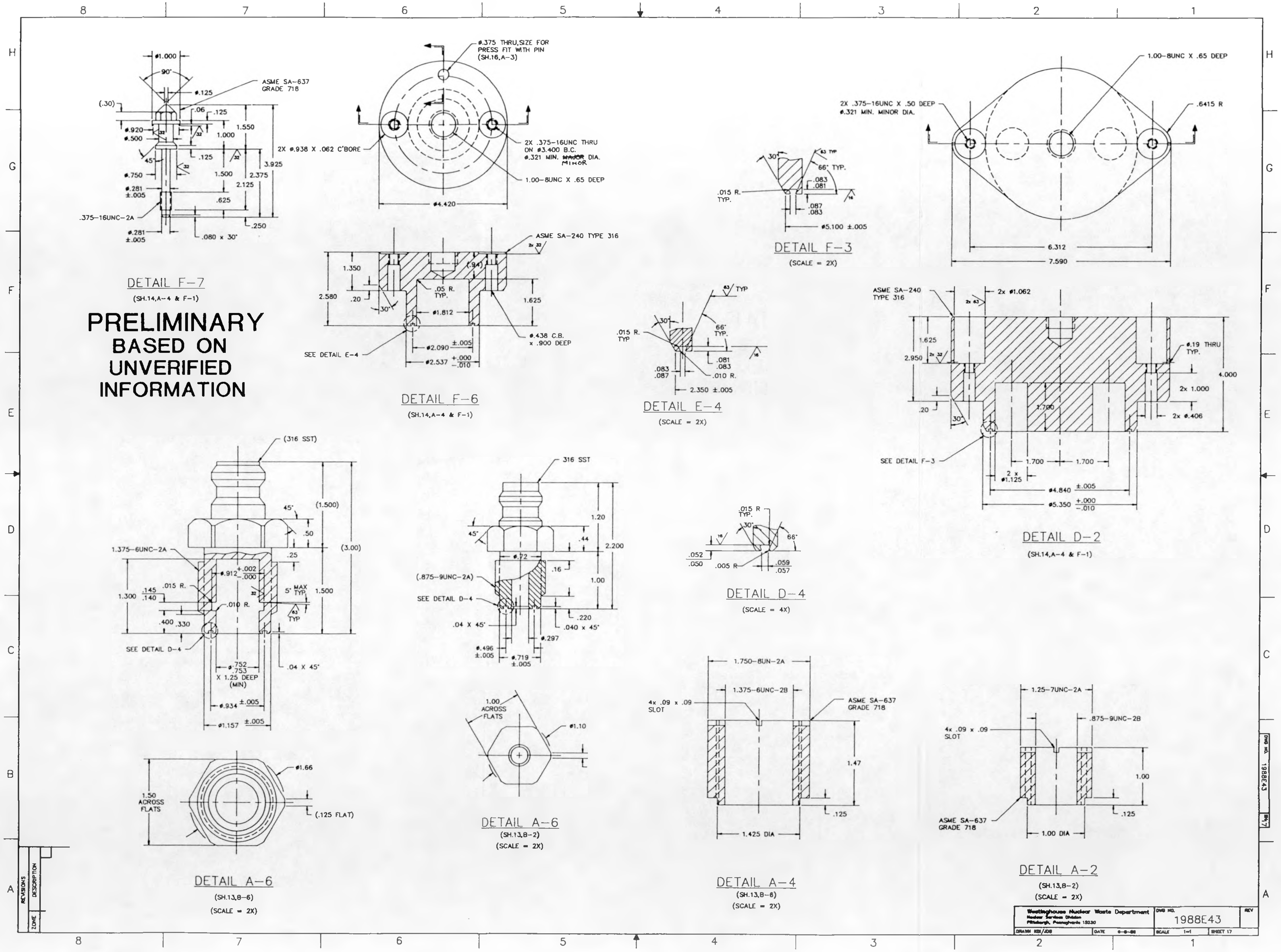

SCALE .5 = 1
SECTION E-7
(D-6)
DETAIL E-5
(H-8) SHEET 1
SCALE 1=3
.13 X 45° CHAM (TYP)
DETAIL F-2
DETAIL D-2
.13 X 45° CHAM
3-SIDES
1.625 HEX STOCK
DETAIL F-2
SCALE 1=6
.750-10 UNC-2A
DETAIL D-2
SCALE 1=6
.750-10 UNC
SECTION A-6
(SHOWN W/O SKIN)
(B-8) SHEET 1
42.53 R
(OUTSIDE)
20.95 R>
(CASK BODY)
2.00 REF
ø.750 PLAIN WASHER
TYPE-B SST
SPRING-SPEC NO.
C0975-074-3000
DETAIL B-2
SCALE 1=6
1.00 MIN THK
NOTES:
1 MATERIAL-STAINLESS STEEL TYPE 17-4 PH, ASTM A-564, TYPE 630 CONDITION H110, HEAT TREATED TO 1100°F±6° FOUR (4) HOURS, Rc 32-37
2 PURCHASE FROM ASSOCIATED SPRING CO. BRISTOL, CONNECTICUT 06010
3 MIN THREAD ENGAGEMENT REQ'D ON TRUCK BED
4 ALL MATERIAL ALUMINUM ALLOY 6061, ASTM B209 UNLESS OTHERWISED NOTED.
5 PURCHASED FROM RYERSON, PITTSBURGH, PA 15230
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
Westinghouse Nuclear Waste Department
DWG NO. 1988E46
DATE 05-17-88
SCALE 1=6
SHEET 2 OF 3
REVISIONS
ZONE
DESCRIPTION


SECTION E-6
(SH.1, E-6)
(SCALE .5=1)
SECTION E-2
(SH.1, E-6)
(SCALE .5=1)
DETAIL C-7
(H-7)
(SCALE 2=1)
DETAIL C-6
(F-7 & G-6)
(SCALE 2=1)
DETAIL C-5
(G-7)
(SCALE 2=1)
DETAIL A-5
(G-6)
(SCALE 2=1)
DETAIL C-3
(F-6)
(SCALE 2=1)
DETAIL C-2
(G-6)
(SCALE 2=1)
BORAL .101 THICK
(LINER) ASME SA-240 TYPE 304 TYPICAL
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
D6 - 9/22/89
Westinghouse Nuclear Waste Department
1988E44
SCALE AS NOTED
SHEET 3 OF 4


VIEW D-5
(SH. 1,C-2)
SCALE .5=1
SECTION D-6
(F-5)
SCALE .5=1
DETAIL B-8
SCALE 1=1
TYP. OUTSIDE WALL WELD JOINT
DETAIL A-7
SCALE 1=1
TYP. INSIDE WALL WELD JOINT
SECTION B-6
(F-5)
SCALE 1=1
DETAIL E-2
(E-8, SHEET 1)
SCALE 2=1
1.00 O.D. x .250 WALL SEAMLESS TUBING 304 SST
DETAIL B-3
(D-8 SHEET 1)
SCALE 2=1
ø1.250 x .120 WALL SEAMLESS TUBING 304 SST.
BREAK ALL SHARP CORNERS EQUAL TO .09 R. OR CHAMFER UNLESS OTHERWISE NOTED
TOP OF BASKET
BOTTOM OF BASKET
(179.50 BASKET)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
D6 – 9/22/89
Westinghouse Nuclear Waste Department
1988E44


BILL OF MATERIAL
QTY REQD
NOTE
ITEM
PART NAME/DESCRIPTION
PART NO. OR REF DWG
MAT'L/SPECIFICATION
APPLY RED PAINT OVER LENGTH INDICATED FOR ORIENTATION MARKING
(.220)
θ = 0°
24.00
9X 2.18 = 19.62
4X 4.36 = 17.44
1.02
1.12
2.11
2.21
168.25 +.06 −.00 BORAL PLATE CAVITY
168.00 ±.030 BORAL PLATE
2.375
2X 40X ⌀3.00 80 TOTAL
2X 80X ⌀1.50 160 TOTAL
2X 80X ⌀1.50 160 TOTAL
⌀23.700
SEE DETAIL E-2 (SHEET-4)
SEE DETAIL B-3 (SHEET-4)
(4.875)
2.118
2.210
2x 56x ⌀2.00
7X .220 STOCK
6X 3.11 = 18.66
1.50
1.60
1.51
21.76
6x 21.86 = 131.16
(21.76)
.406 STOCK
(174.68)
(4.00)
175.50
179.50
//.06 B
NOTES:
1 ALL MATERIALS ARE ASME SA-240 TYPE 316N EXCEPT AS NOTED.
2 BORAL IS A TRADEMARK OF AAR BROOK & PERKINS.
3 ALL WELDING PROCEDURES AND WELDERS SHALL BE QUALIFIED PER THE ASME B & PV CODE SECTION IX. ALL GROOVE WELDS SHALL BE FULL PENETRATION WELDS EXCEPT AS INDICATED OTHERWISE ON THE DRAWING.
4 ULTRASONIC TEST WELDS IN ACCORDANCE WITH ASME B & PV CODE SECTION V, ARTICLE 5. ACCEPTANCE STANDARDS OF ASME B & PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
5 LIQUID PENETRANT TEST WELDS IN ACCORDANCE WITH ASME B & PV CODE SECTION V, ARTICLE 6. ACCEPTANCE STANDARDS OF ASME B & PV CODE SECTION III, ARTICLE NB-5350 SHALL APPLY.
6 CHROME PLATE PER FEDERAL SPEC QQ-C-320B.
D6 – 9/22/89
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
REVISIONS
ZONE
DESCRIPTION
APPD
DFTG SUPV
ENGINEERING RELEASE
DATE
TITAN LEGAL WEIGHT TRUCK
CASK – PWR BASKET
– LAYOUT –
DWG NO.
1988E44
SHEET 1 OF 4


SEE DETAIL A-5
SEE DETAIL A-3
SEE DETAIL A-6
θ = 0°
θ = 90°
θ = 270°
θ = 180°
VIEW A-7
(SH.1, E-8)
(SCALE .5=1)
SEE DETAIL E-1
SEE DETAIL C-1
SEE DETAIL C-5
SEE DETAIL F-1
SEE DETAIL C-3
ASME SA-240 TYPE 304
ø22.700
ø23.700
(5.12)
(168.00)
SECTION E-4
(H-7)
(SCALE .5=1)
DETAIL F-1
(F-4)
(SCALE 2=1)
(.220 STOCK)
(.406)
DETAIL E-1
(H-4)
(SCALE 2=1)
(.114 STOCK)
DETAIL C-1
(H-4)
(SCALE 2=1)
.031 LINER
.406 STOCK
SECTION C-7
(F-7)
(SCALE 2=1)
DETAIL C-5
(G-4)
(SCALE 2=1)
4.00 REF
316 SST
DETAIL C-3
(E-5)
(SCALE 1=1)
.233 R
DETAIL A-6
(E-6)
(SCALE 1=1)
DETAIL A-5
(H-6)
(SCALE 1=1)
DETAIL A-3
(G-8)
(SCALE 1=1)
PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
D5 - 8/4/89
Westinghouse Nuclear Waste Department
1988E44
SCALE AS NOTED


PRELIMINARY
BASED ON
UNVERIFIED
INFORMATION
DETAIL F-7
(SH.14,A-4 & F-1)
ASME SA-637
GRADE 718
.375-16UNC-2A
DETAIL F-6
(SH.14,A-4 & F-1)
ø.375 THRU,SIZE FOR PRESS FIT WITH PIN (SH.16,A-3)
2X ø.938 X .062 C'BORE
2X .375-16UNC THRU ON ø3.400 B.C. ø.321 MIN. MINOR DIA.
1.00-8UNC X .65 DEEP
ø4.420
ASME SA-240 TYPE 316
SEE DETAIL E-4
ø.438 C.B. x .900 DEEP
DETAIL F-3
(SCALE = 2X)
DETAIL E-4
(SCALE = 2X)
2X .375-16UNC X .50 DEEP ø.321 MIN. MINOR DIA.
1.00-8UNC X .65 DEEP
.6415 R
ASME SA-240 TYPE 316
SEE DETAIL F-3
DETAIL D-2
(SH.14,A-4 & F-1)
(316 SST)
1.375-6UNC-2A
SEE DETAIL D-4
316 SST
(.875-9UNC-2A)
SEE DETAIL D-4
DETAIL D-4
(SCALE = 4X)
1.750-8UN-2A
1.375-6UNC-2B
4x .09 x .09 SLOT
ASME SA-637 GRADE 718
1.425 DIA
1.25-7UNC-2A
.875-9UNC-2B
4x .09 x .09 SLOT
ASME SA-637 GRADE 718
1.00 DIA
1.50 ACROSS FLATS
(.125 FLAT)
DETAIL A-6
(SH.13,B-6)
(SCALE = 2X)
1.00 ACROSS FLATS
DETAIL A-6
(SH.13,B-2)
(SCALE = 2X)
DETAIL A-4
(SH.13,B-6)
(SCALE = 2X)
DETAIL A-2
(SH.13,B-2)
(SCALE = 2X)
Westinghouse Nuclear Waste Department
1988E43
SHEET 17