ATG INC.
ALLIED TECHNOLOGY GROUP

71-9208

May 31, 2002

Mr. E. William Brach, Director
Spent Fuel Project Office
Office of Nuclear Material Safety and Safeguards
US Nuclear Regulatory Commission
1 White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

Subject: **Consolidated Application for 10-142B Package, Docket No. 71-9208**

Reference: NRC Request for Consolidated Application for the Model No. 10-142 Package, Dated September 4, 2001

Dear Mr. Brach:

In response to the above referenced request by your office, ATG has prepared a consolidated application for the subject package. This consolidated application incorporates information that is referenced in the current certificate. Attachment 1 to this letter lists all supplements addressed by the consolidated application and method of their incorporation. Please note, in some cases, later supplements may have superceded previous supplements. All these cases have been addressed in Attachment 1.

Attachment 2 to this letter is a revision summary describing all affected pages, the nature of the revision and the basis for the revision. Revision bars have been placed next to all the affected paragraphs in the document, except where minor grammatical or editorial errors were corrected.

As part of this consolidation effort, ATG has combined the proprietary and the nonproprietary versions of the design drawings referenced in condition 5(a)(3) of the certificate, as supplemented in ATG's 6/22/2001 application. Based on the above, design drawing X-103-110-SP, Rev. J and X-103-110-SNP, Rev. D were consolidated into a nonproprietary drawing X-103-110-SNP, Rev. E, which supercedes the aforementioned proprietary drawing. This decision is justified by the age of the original application and its current approval status.

Enclosed please find three (3) copies of the consolidated application for the model 10-142 package, ATG Safety Analysis Report for the 10-142 Shipping Cask, SAR-10-142, Rev. 1, 5/2002, for your files.

Should you need to contact me, I can be reached at (865) 425-1014, or via e-mail at tony.patko@atgcusa.com.

Sincerely,

Anthony L. Patko

Anthony L. Patko
Manager, Engineering and Licensing

Encl.

cc: Nancy Osgood – NRC
Ken Hilton - ATG
10-142B

NMSS01 Public

Mr. E. W. Brach, Director
Spent Fuel Project Office
US NRC

ATTACHMENT 1

Summary of ATG SAR-10-142 Consolidation per NRC C of C No. 9208, Rev. 12, Supplements

Supplement Dated	C of C Rev. No. Change	Subject	Incorporation
May 24, 1991	3 to 4	Quality Assurance Program	Chapter 9 updated, per NRC February 26, 2002 approval letter, to approval number 0870, Rev. 3
		Leak test procedures	Superceded by November 24, 1992 Supplement for C of C Rev. 5
		Fissile material limits	Superceded by May 19, 1993 Supplement for C of C Rev. 6
November 24, 1992	4 to 5	Freon leak test replaced by CO_2 leak test	Chapters 4 and 8 revised, including incorporation of ANSI N14.5-1977 analysis from Supplement
		Cavity seal maintenance	Chapter 8 revised
May 19, 1993	5 to 6	Type and form of material and maximum quantity of material per package	Chapter 1 clarified with respect to LSA limits, fissile material limits, use of secondary containers, transuranic limits, and cask payload weight limit
January 20, 1994	6 to 7	Transuranic limits for resins	Chapter 1 clarified with respect to transuranic limits for resins
		Certificate holder name change from NuPac Services, Inc. to VECTRA Technologies, Inc.	Superceded by current SAR consolidation
May 16, 1996	7 to 8	C of C renewal	No change to SAR required
August 5, 1997	8 to 9	Certificate holder name change from VECTRA Technologies, Inc. and Molten Metal Technology, Inc.	Superceded by current SAR consolidation
December 1, 1998	9 to 10	Certificate holder name change from Molten Metal Technology, Inc. to ATG Nuclear Services L.L.C.	Superceded by current SAR consolidation
August 9 and 11, 1999	10 to 11	Pre-shipment leak test requirements	Chapter 7 revised
March 15, 2001	11 to 12	Use of bolts or studs and nuts on primary and secondary lids	Chapters 1, 2, 4 and 7 revised

Summary of ATG SAR-10-142 Consolidation per NRC C of C No. 9208, Rev. 12, Supplements (Continued)

Supplement Dated	C of C Rev. No. Change	Subject	Incorporation
August 22, 2000	12 to 13 *	As part of the consolidation of Drawings No. X-103-110-SP, Rev. H and X-103-110-SNP, Rev. D; text added to clarify dimensional tolerances and bolt or stud and nut use	Drawing No. X-103-110-SNP, Rev. E, incorporates changes
		Impact limiter lug pin-hole diameter and tolerance revision	Drawing No. X-103-110-SNP, Rev. E, incorporates change and Chapter 2 incorporates associated analysis
June 22, 2001	12 to 13*	Submittal of changes to Drawing No. X-103-110-SP, Rev. H which incorporated August 22, 2000 submittal changes	Updated format and consolidated proprietary (X-103-110-SP, Rev. H) & non-proprietary (X-103-110-SNP, Rev. D cask drawing into X-103-110-SNP, Rev. E.
July 31, 2001	12 to 13*	Radiation protection per 10 CFR 20	Chapter 7 revised
September 4, 2001	12 to 13*	NRC request for consolidated SAR	SAR consolidated, as summarized in this table, based on Supplements cited in Rev. 12 of C of C No. 9208; SAR cask ownership revised to: Allied Technology Group, Inc. (ATG)

* Rev. 13 Pending: Consolidation of C of C, Rev. 12 supplements into SAR

Mr. E. W. Brach, Director
Spent Fuel Project Office
US NRC

ATTACHMENT 2

ATG SAR-10-142, Revision 1 Summary

Pg. No.	Par. No.	Nature of Revision	Basis
General	General	Clarified table/figure page callout, improved figure/table presentation quality, and other minor editorial changes; NOTE: there are no revision bars for these minor improvements	Document format, clarity, and style normalized
General	Header and Footer	Revised Format	Document format, clarity, and style normalized
Title Pg.	N/A	Deleted "Proprietary"	Corporate decision to drop proprietary version of SAR
	N/A	Addressed cask ownership, name, and address	Current C of C supplements consolidation into SAR submittal
Notice Pg.	1	Addressed cask ownership, name, and address	Current C of C supplements consolidation into SAR submittal
iv	2	Replaced Freon with CO_2 based seal integrity leak test and deleted soap bubble leak test	November 24, 1992 Supplement for C of C Rev. 5
1-1	Title, 1	Addressed cask ownership	Current C of C supplements consolidation into SAR submittal
1-2	2	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
1-3	9	Clarified LSA limits; fissile material limits; use of secondary containers; and transuranic limits	May 19, 1993 Supplement for C of C Rev. 6; January 20, 1994 Supplement for C of C Rev. 7
1-4	1	Clarified LSA limits; fissile material limits; use of secondary containers; and transuranic limits	May 19, 1993 Supplement for C of C Rev. 6; January 20, 1994 Supplement for C of C Rev. 7
	2	Clarified cask payload weight limit	May 19, 1993 Supplement for C of C Rev. 6
2-1	6	Updated to consolidated drawing X-103-110-SNP, Rev. E	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
2-8	2	Updated to consolidated drawing X-103-110-SNP, Rev. E	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
2-9	2	Changed symbol typo from A to P for pressure	Text clarification
2-10	4	Addressed cask ownership	Current C of C supplements consolidation into SAR submittal
	5	Changed symbol typo from & to for angle beta	Text clarification
2-13	1	Addressed cask ownership	Current C of C supplements consolidation into SAR submittal
2-20	1	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
2-21	6	Clarified use of bolts or studs	March 15, 2001 Supplement for C of C Rev. 12
2-22	2	Clarified use of bolts or studs	March 15, 2001 Supplement for C of C Rev. 12

ATG SAR-10-142, Revision 1 Summary (Continued)

Pg. No.	Par. No.	Nature of Revision	Basis
2-28	5	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
2-41	3; 5, 6	Corrected exponent typo from (10)6 to $(10)^6$; Updated overpack tearout analysis	Text clarification; August 22, 2000 Supplement for C of C Rev. 13 (pending)
2-43	1	Updated Overpack tearout analysis	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending)
	7	Clarified use of bolts or studs	March 15, 2001 Supplement for C of C Rev. 12
2-45	4	Updated to consolidated drawing X-103-110-SNP, Rev. E	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
2-49	9	Corrected figure callout	Text clarification
2-54	5	Clarified use of bolts or studs	March 15, 2001 Supplement for C of C Rev. 12
2-55	1	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
2-59	1	Updated format and consolidated proprietary (X-103-110-SP, Rev. H) & non-proprietary (X-103-110-SNP, Rev. D cask drawing into X-103-110-SNP, Rev. E.	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
2-60 to 2-64	N/A	Consolidated drawing X-103-110-SNP, Rev. E (5 sheets)	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
2-80	Fig. box	Clarified figure citation	Text clarification
2-104	1	Clarified use of bolts or studs	March 15, 2001 Supplement for C of C Rev. 12
3-5	5	Corrected A_i^y value typo from 13.625 to 13.265	Text clarification
3-6	2	Corrected A_i value typo from 13.625 to 13.265	Text clarification
3-8	1	Corrected V formula bracket typo from {(50.5 to {[(50.5 and parameter typo from (36-a)} to (36-d)}	Text clarification
3-20	1	Corrected typo in second $°F$ temperature value in table column heading from 100 to 130	Text clarification
3-26	1	Added text to describe existing SAR Rev. 0 solar load plus fire analysis tabular data and plot	Text clarification
3-26 to 3-28	N/A	Added table numbers and titles to existing SAR Rev. 0 solar load plus fire analysis tabular data	Text clarification
3-29	N/A	Added figure number and title to existing SAR Rev. 0 solar load plus fire analysis plot	Text clarification

ATG SAR-10-142, Revision 1 Summary (Continued)

Pg. No.	Par. No.	Nature of Revision	Basis
4-2	1	Added subsection title 4.1.1.1 for clarity	Document style normalized
4-3	6	Clarified text	Document style normalized
4-4	1, 2	Clarified text	Document style normalized
	3, 4	Added titled subsection 4.1.1.2 covering CO_2 leak test analysis	November 24, 1992 Supplement for C of C Rev. 5
4-5	All	Continued subsection 4.1.1.2 covering CO_2 leak test analysis	November 24, 1992 Supplement for C of C Rev. 5
4-6	1, 2	Continued subsection 4.1.1.2 covering CO_2 leak test analysis	November 24, 1992 Supplement for C of C Rev. 5
	4, 6, 7	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
4-7	5, 8	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
4-8	4	Updated to consolidated drawing X-103-110-SNP, Rev. E	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
	5	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
7-1	1, 2	Clarified radiation protection compliance	July 31, 2002 Supplement for C of C Rev. 13 (pending)
	5	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
7-2	2	Clarified use of bolts or studs and nuts	March 15, 2001 Supplement for C of C Rev. 12
	3	Clarified pre-shipment leak test requirements	August 9 and 11, 1999 Supplement for C of C Rev. 11
7-4	1	Clarified radiation protection compliance	July 31, 2002 Supplement for C of C Rev. 13 (pending)
8-1	3	Updated to consolidated drawing X-103-110-SNP, Rev. E	August 22, 2000 & June 22, 2001 Supplements for C of C Rev. 13 (pending); Corporate decision to drop proprietary drawing;
	7	Clarified text covering cask seal maintenance	November 24, 1992 Supplement for C of C Rev. 5
8-2	1	Clarified text covering cask seal maintenance	November 24, 1992 Supplement for C of C Rev. 5
	2, 3, 4	Revised text to reflect CO_2 leak testing	November 24, 1992 Supplement for C of C Rev. 5
8-12	Appendix 8.4.2	Replaced freon leak test procedure with CO_2 leak test procedure	November 24, 1992 Supplement for C of C Rev. 5
N/A	Appendix 8.4.3	Removed soap bubble leak test	November 24, 1992 Supplement for C of C Rev. 5
9-1	1	Addressed cask ownership; Revised text to reflect new Quality Assurance Program Approval	December 1, 1998 Supplement C of C Rev. 10; NRC letter dated February 26, 2002
9-2		Replaced NRC approval letter	NRC approval letter dated February 26, 2002
9-3		Replaced Quality Assurance Program Approval sheet	Quality Assurance Program, Approval Number 0870, Rev. 3

SAFETY ANALYSIS REPORT

FOR THE

ATG 10-142 CASK

TO

10 CFR 71 PACKAGING REQUIREMENTS

PREPARED BY:

Allied Technology Group, Inc.

1550 Bear Creek Road

Kingston, TN 37763

(865) 425-1100

NOTICE

TABLE OF CONTENTS

APPLICATION
FOR
NRC CERTIFICATE OF COMPLIANCE
AUTHORIZING
SHIPMENT OF NUCLEAR MATERIAL
IN
ATG MODEL 10-142 PACKAGING

1.0 GENERAL INFORMATION

1.1 Introduction

The model 10-142 packaging has been developed by Allied Technology Group, Inc. (ATG) as a safe means of transporting Type *'B'* and large quantity levels of radioactive materials in all forms other than liquids. Fissile radioactive material is limited to those exempt quantities licensed under 10 CFR 71.10 and IAEA Safety Series No. 6, Section VI. Authorization is sought for shipment by cargo vessel, motor vehicle and rail.

Radioactive material is contained within a heavy gauge cylindrical inner container or 'liner.' The containment vessel itself is a shielded lead and steel cask surrounding the liner. Protection from the normal conditions of transport and hypothetical accident conditions is provided by shock or impact limiters placed peripherally around the top and bottom of the shield.

1.2 Package Description

1.2.1 Packaging

1.2.1.1 General Description

The Model 10-142 packaging is a reusable insulated and shock absorbing shipping package designed to protect radioactive material from normal conditions of transport and hypothetical accident conditions.

1.2.1.2 Materials of Construction Dimensions and Fabricating Methods

General Arrangement drawings of the Model 10-142 packaging are included in Appendix 2.10.1. They show the overall dimensions as well as the materials of fabrication. A general outline of the cask is shown in figure 1-1 and 1-2.

The packaging system consists of a pair of circular shock or impact limiters placed peripherally around the top and bottom of a cylindrical shield. Each impact limiter has an external shell fabricated from ductile low carbon steel which allows them to undergo large deformations without fracturing. All joints are arc welded with full penetration welds to assure structural integrity.

The volume between the inner and outer shell of the overpack is filled with a shock-and-thermal-insulating material consisting of rigid polyurethane foam having a density of approximately twenty pounds per cubic foot. The insulating material is poured into the cavity between the two shells and allowed to expand, completely filling the void. Here it bonds to the shells creating a unitized construction for the packaging. Mechanical properties of these materials are further described in Section 2.3 below.

The upper and lower impact limiters are each pinned to the cask by eight 1-inch diameter ball lock pins located symmetrically around the cask. The lower overpack may be built integral to the cask, thereby obviating pins on the lower overpack.

The shield body consists of an external one inch thick shell and a 1/2-inch thick inner shell of A516 gr 70 carbon steel. Three and one half inches of lead is located between the two for shielding. The outer shell that is not covered by the impact limiters is covered with a 10 gauge stainless steel fire shield that is held away from the body approximately 1/4-inch. Optionally, this area may be covered with Albi-clad intumescent coating. The inner cavity of the cask and lid optionally may be clad with 12 gauge 304 stainless steel. The external surfaces of the cask lid and body under the impact limiters may also be clad with 12 gauge 304 stainless steel, or else painted with high quality epoxy paints.

There are two optional lids. All lids consist of a basic primary lid consisting of two 3 inch thick 516 grade 70 steel plates that are fastened to the body with sixteen 1-1/2 inch bolts or studs and nuts. Within the primary lid there is a 16 inch, or 29 inch centered secondary lid. The 16 inch lid is secured by eight 7/8-inch bolts or studs and nuts and the 29 inch lid is secured by sixteen 1-1/4-inch bolts or studs and nuts.

The tiedowns are a structural part of the cask. The lifting lugs are an integral part of the cask lid.

All cask body welds are designed as full penetration and are made in accordance with weld procedures qualified to ASME, Section IX requirements. This is verified on all longitudinal welds via full radiographic inspection. All circumferential welds joining the inner and outer cask shells are made utilizing groove configurations, that assure full penetration. Integrity of these welds is verified via magnetic particle or liquid penetrant inspection.

1.2.1.3 Containment Vessel

The overpacks are not part of the containment vessel. Their prime function is to reduce the severity of the hypothetical accident conditions such that the transportation cask can serve as the containment vessel. As can be seen from the drawing in Appendix 2.10.1, the containment vessel uses two 3 inch thick steel plates joined together to provide a 6 inch thick steel lid assembly.

A high temperature silicone gasket is employed in the primary and secondary lid interfaces. The secondary lid also uses a redundant neoprene dust seal. To assure seal integrity, an operation and maintenance program is prescribed together with a leakage test on the containment vessel prior to its first use. (Refer to Section 7.0 and 8.0 below)

Dispersible waste products are contained within heavy gauge disposable steel liners.

1.2.1.4 Neutron Absorbers

There are no materials used as neutron absorbers or moderators in the Model 10-142 packaging.

1.2.1.5 Package Weight

Gross weight for the package is approximately 68,100 lbs. This includes an estimated payload weight of 10,000 lbs.

1.2.1.6 Receptacles

There are no internal or external structures supporting or protecting receptacles. A test port is machined into the lid structure to facilitate leak testing.

1.2.1.7 Drain Port

The cask may be provided with a NPT pipe plug and drain system. Its use is for removal of entrapped liquids, i.e., rain, decontamination fluids, etc.

1.2.1.8 Tiedowns

Tiedowns are a structural part of the package. From the attached general arrangement drawing it can be seen that four reinforced tiedown locations are provided. Refer to Section 2.5.2 for a detailed analysis of their structural integrity.

1.2.1.9 Lifting Devices

Lifting devices are a structural part of the package. From the general arrangement drawing it can be seen that three reinforced lugs are provided. Refer to Section 2.5.1 for a detailed analysis of their structural integrity.

1.2.1.10 Pressure Relief System

There are no pressure relief valves.

1.2.1.11 Heat Dissipation

There are no special devices used for the transfer or dissipation of heat. The package maximum design capacity is 400 watts.

1.2.1.12 Coolants

There are no coolants involved.

1.2.1.13 Protrusions

The only inner or outer protrusions from the cask body are the overpack attachment lugs, the tiedown lugs, and the lid lifting lugs. These protrusions are all within the region protected by the overpacks.

1.2.1.14 Shielding

The contents will be limited such that the radiological shielding provided will assure compliance with DOT and IAEA regulatory requirements.

1.2.2 Operational Features

Refer to the General Arrangement drawing of the packaging, in Appendix 2.10.1. There are no complex operational requirements connected with the Model 10-142 packaging and none that have any transport significance.

1.2.3 Contents of Packaging

This application is for transporting the following radioactive materials as defined in U.S.A. and IAEA regulations:

a) Type 'A' quantities in normal or special form;
b) Type 'B' quantities in normal or special form, as defined in 10 CFR 71.4 (q) and IAEA Safety Series No. 6, Section IV for Type B (U) packages;
c) 'Large Quantity' radioactive materials, in normal or special form, as defined in 10 CFR 71.4 (f);
d) Low specific activity (LSA) materials including greater than Type A quantity LSA materials.
e) Fissile material content shall not exceed the limits of 10 CFR 71.53.
f) Dewatered wastes, solid wastes, solidified wastes, and activated component materials are limited to a Type A quantity of transuranic materials. This limitation does not apply to LSA or ion exchange resin materials.

g) The chemical and physical form of the package contents will be in all forms, other than liquids. This will include ion exchange resins in a dewatered state and miscellaneous radioactive solid waste materials such as pipe, wood, metal, scrap, etc. Dewatered wastes, solid wastes, solidified wastes, activated components, ion exchange resins, or LSA materials may be in secondary containers.

The contents of the packaging shall not exceed 400 watts of internal decay heat, and shall be so limited to those quantities of radionuclides which result in acceptable radiation dose rates on the exterior surface of the package (200 mr/hr) and at 2 meters from the package surface (10 mr/hr). The maximum weight of the cask contents, including dunnage and secondary containers, shall not exceed 10,000 pounds.

ATG Safety Analysis Report for the 10-142 Shipping Cask SAR-1 0-142

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1-1 Shielded Cask Model 10-142 Removable Lower Overpack

Rev. 1, 5/2002 1-5 1

ATG Safety Analysis Report for the 10-142 Shipping Cask SAR-1 0-142

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1-2 Shielded Cask Model 10-142 Fixed Lower Overpack

2.0 STRUCTURAL EVALUATION

This Section identifies and describes the principal structural engineering design aspects of the packaging, components and systems important to safety and to compliance with the performance requirements of 10 CFR 71 and I.A.E.A. Safety Series No. 6.

2.1 Structural Design

2.1.1 Discussion

The principal structural members and systems in the Model 10-142 packaging are: (1) the overpacks; (2) the primary containment vessel or transport shield, as described in Section 1.2.1, above; and (3) the disposable steel liner. The overpacks and transport shield are identified on the drawings shown in Appendix 2.10.1. They work together to satisfy the standards set forth in subparts E and F of 10 CFR 71 and applicable sections in I.A.E.A. Safety Series No. 6. A detailed discussion of the structural design and performance of these components is provided below.

2.1.2 Design Criteria

As noted above, the waste products such as dewatered ion exchange resins are contained within a welded heavy gauge disposable steel tank or liner. Resins are pumped into the liner where the carrier water is drawn off leaving only the dewatered resins behind. Liners used for dewatered resins have been pressure tested to 11.2 psig to substantiate their integrity. Liners are placed within the combined transportation shield and overpack.

The shield top and bottom are each constructed of two 3-inch thick steel plates laminated together to provide a full 6 inches of solid steel. Cylindrical side walls have an external skin of one inch steel plate and an internal skin of 1/2-inch steel plate. These two plates encase 3-1/2 inches of lead resulting in a total side wall thickness of 5 inches.

Overpacks or impact limiters provide localized protection to the critical areas of the assembly, one of which is the primary lid to body interface or seal. This area must receive minimum deformation during impact, as well as not exceed a maximum temperature of 500°F. Due to the design of the seal area, direct compression, or crushing of the seal is not possible because the seal is recessed below the top of the 1 inch thick cask outer shell.

2.2 Weights and Center of Gravity

The combined weight of the overpacks, cask and liner (or pay load) will not exceed 68,100 pounds. The overpack and cask weight is approximately 58,100 pounds. The center of gravity for the assembled package is located at the approximate geometric center of gravity. A reference point for locating the center of gravity is shown on Drawing X-103-110-SNP. Table 2.2-1 presents a more detailed weight breakdown for the 10-142 package.

Component	Weight (lb)
Upper Overpack	5,200
Primary plus Secondary Closure Lid	7,200
Main Cask Body (Steel = 16,150 lb lead = 24,350 lb)	40,500
Lower Overpack	5,200
Payload	10,000
Total	68,100

Table 2.2-1 10-142 Component Weights

2.3 Mechanical Properties of Materials

The Model 10-142 packaging uses an outer and inner shell fabricated of various thicknesses of low carbon hot rolled steel. Material properties of the steel are as follows:

		ASTM A-516 Grade 70
F_{tu}	=	70,000 psi
F_{ty}	=	38,000 psi
F_{su}	=	42,000 psi
F_{sy}	=	22,800 psi

Tie-down lugs are fabricated from ASTM A-514 or ASTM A-517 steel. Material properties of these steels are as follows:

F_{tu}	=	115,000 psi (A-517)
		110,000 psi (A-514)
F_{ty}	=	100,000 psi (A-514 or A-517)
F_{su}	=	69,000 psi (A-517)
		66,000 psi (A-514)
F_{sy}	=	60,000 psi (A-514 or A-517)

Rigid polyurethane foam fills the cavity between the steel shells of the overpack. This material will have a density of approximately 20 pcf and be of a self-extinguishing variety.

Figure 2.3-1 represents the stress-strain curve for the NuPac NPI.F6 foam applicable for this package. The curve provides both minimum and maximum compressive properties derived from over 18 years of testing.

Foam Specification NPI.F6 defines the detail foam testing procedure. It specifies that foam samples will be taken during the actual foaming process and tested to verify that they are within the two curves at 10%, 40% and 70% strains. Typically one sample is tested per batch of foam, and one overpack may include as many as 6 or more batches. Occasionally, a data point from the test of one sample may fall outside the range specified. In such a case, several more samples are prepared to verify that 95% of the foam tests do fall within the curves at 10%, 40% and 70% strain.

The foam utilized in the 10-142 has been fully qualified throughout the stress strain spectrum that would be experienced in an accident condition. Its reliable performance up to 80% strain has been fully documented.

The proprietary process for placing the foam is highly developed and monitored under the control of the NuPac NRC approved 10 CFR 71, Subpart H, QA System. The foam qualified up to 80% compression was produced under the full control of this proprietary process. This is the exact foam utilized in production 10-142 overpacks.

Each production pour is sampled in accordance with written procedures and subjected to stress/strain testing. Compliance with the stress/strain curve is verified to 70% strain during the production sampling tests. Many years of accumulated data has shown that stress/strain data within the allowable tolerance band at 70% will proceed within the tolerance band out to 80%. A minimum of one sample from each overpack will be tested to 80% strain to further demonstrate this.

Complete test series are run on each production pour placed in every 10-142 overpack. The data is evaluated, accepted and retained in strict accordance with the NuPac QA system.

Bolt or stud material properties are as follows:

Material	Yield Strength	Ultimate Strength
A354 Grade BD (SAE Grade 8)	130,000 psi	150,000 psi
A540 Grade B24V Class 3	130,000 psi	145,000 psi

The nut material to be used with the stud is specified as ASTM A194, Grade 2H, Heavy Hex. In accordance with ASTM A354 Grade BD (i.e., the strongest specified bolt material), the proof load stress of this specified nut material (175,000 psi) is equivalent to that of the recommended A563, Grade DH, Heavy Hex nut. This equivalency provides sufficient basis for use of the specified A194 nut per ASTM A354-79 Section 1.3.

Lead shielding will possess those properties referenced in ORNL-NSIC-68, Table 2.6, Page 84.

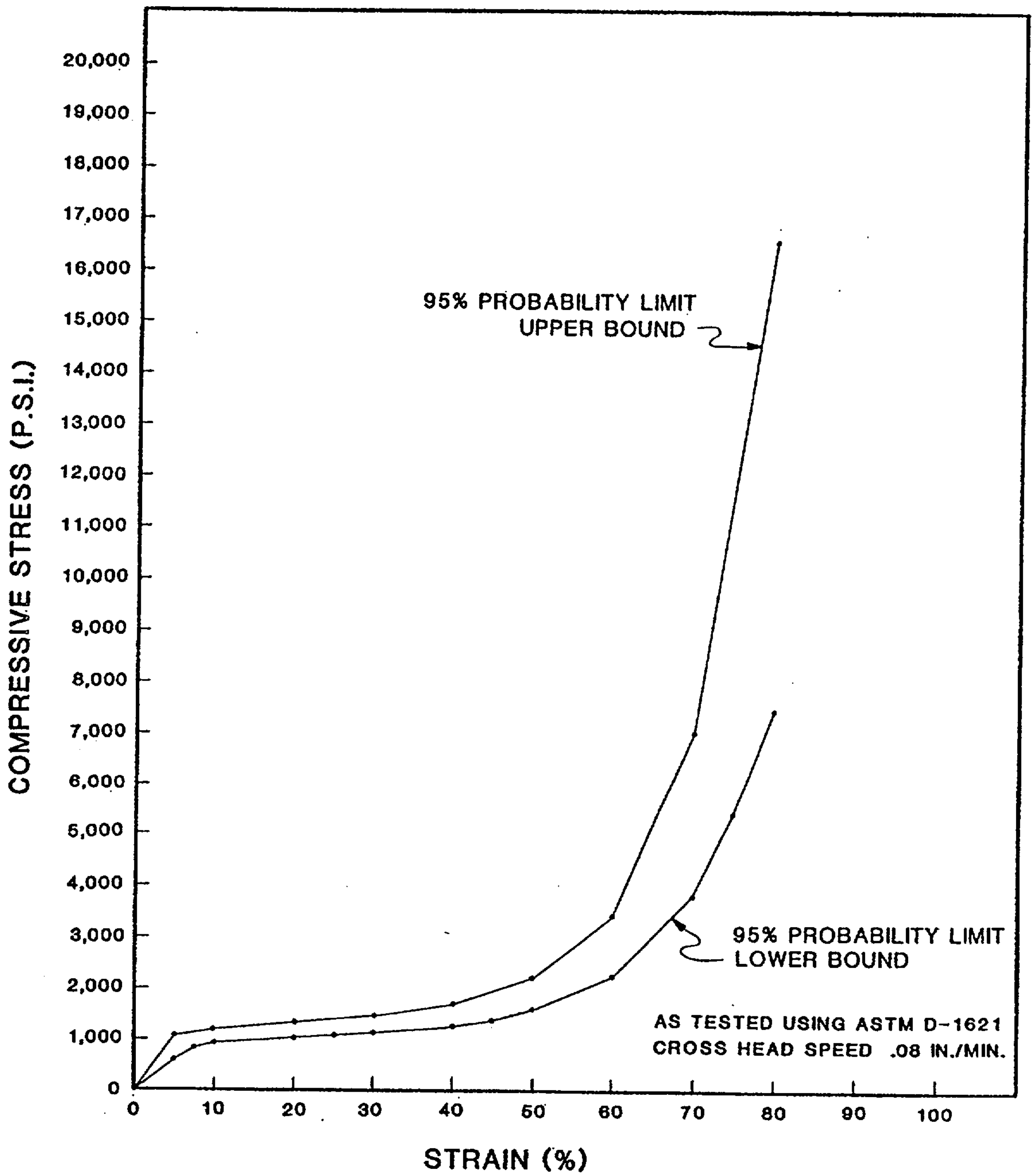


Figure 2.3-1 NPI.F6 Foam Properties Stress vs. Strain

1. PRODUCT NAME
ALBI-CLAD Intumescent Fireproofing Mastics

2. MANUFACTURER
Albi Manufacturing Corporation
Cities Service Company
98 E. Main Street
Rockville, Conn. 06066
Phone: (203) 875-3385

3. PRODUCT DESCRIPTION

Basic Use: ALBI-CLAD mastics are intumescent coatings applied to provide fire protection for structural steel and to extend the inherent fire protection of concrete or masonry.

ALBI-CLAD is used wherever a long-lasting, durable, abrasion resistant fireproofing is required.

Unlike other conventional forms of fireproofing which depend upon water of crystallization or entrapped air, the intumescent coating generates a chemical reaction when exposed to flame or heat in excess of 300°F (148.9°C). This heat activated reaction generates a multi-cellular, carbonaceous foam many times the thickness of the coating. This cellular carbonaceous foam serves as an excellent high temperature insulator protecting the substrate. Simultaneously, this reaction liberates inert gases in the form of nitrogen and carbon dioxide which starves the flame of oxygen driving it further away from the protected surface. The carbonized surface acts as an excellent radiation shield reflecting much of the radiant energy input. Further, this reaction is endothermic providing additional cooling properties to the substrate to which it is applied.

Limitations: Before applying ALBI-CLAD over previously painted or primed surfaces, test for compatibility. If removal of incompatible primers by sand blasting is not practical, apply a suitable barrier coat and build-up to required thickness of ALBI-CLAD in multiple layers. Allow drying of previous coat before applying the succeeding build-up.

When using ALBI-CLAD 89 products, observe Red Label precautions. ALBI-CLAD 89 products contain aromatic solvent mixtures and should be protected from open flame. Fire extinguishing equipment should be available during installation.

Vapors of ALBI-CLAD 89 products may be strong and irritating. Fresh air hoods, masks and blowers should be provided when application is in confined area with inadequate ventilation.

Composition and Materials: ALBI-CLAD mastics are proprietary formulations of resins, binders, pigments and reinforcing inorganic fibers. Contains no asbestos.

ALBI-CLAD is offered in three formulations to effectively suit the end use desired.

ALBI-CLAD 89S (standard): A modified vinyl rich heavy-bodied mastic containing pigments, resins, and aromatic solvents. ALBI-CLAD 89S is a standard all purpose formulation for interior use on surfaces where heavy service abuse is anticipated.

ALBI-CLAD 89X (exterior): A modified vinyl rich heavy-bodied mastic containing pigments, resins and a blend of inorganic fibers using an aromatic solvent system. ALBI-CLAD 89X is recommended for exterior or corrosive exposures and for installations subject to abnormal structural movement.

Where ALBI-CLAD 89X is used for exterior application to steel members, a suitable and compatible rust inhibitive primer is required, such as Albi 487S primer (see below). Further, wherever ALBI-CLAD 89X is used for exterior application, a compatible, fire-inert weather resistant coating such as Albi 144 (see below) must be applied to the exterior surface for maximum durability.

ALBI-CLAD 101 (interior use only): A latex base, water-emulsion system, for interior applications only in areas not subject to high-humidity conditions.

Albi 487S Primer: A recommended phenolic primer for steel exposed to exterior or highly corrosive conditions. To be applied in accordance with manufacturer's directions to steel substrate.

Albi 144: A fire-inert weather-resistant coating, providing long-term protection of the ALBI-CLAD fireproofing, and supplied in a choice of decorative color finishes.

Sizes: ALBI-CLAD is packaged in 55 gal. (208.2 liters) and 30 gal. (113.6 liters) drums or 5 gal. (18.9 liters) pails.

Albi 487S Primer and Albi 144 are packaged in 5 or 1 gallon (3.79 liters) pails.

Textures and Finishes: Spray application of ALBI-CLAD results in a stucco-textured surface. Use a short nap paint roller to smooth down the finish or correct unsightly drippings and surface irregularities.

Colors: ALBI-CLAD comes in a standard light grey finish. On large size orders, special color pigmentation is available at a nominal up-charge.

SPEC DATA

This Spec-Data Sheet conforms to editorial style prescribed by The Construction Specifications Institute. The manufacturer is responsible for technical accuracy.

4. TECHNICAL DATA

Fire Ratings: All ALBI-CLAD formulations provide comparable maximum protection at minimum thickness. ALBI-CLAD has been tested and listed by UL Inc. under Guide #40 U 18.12E. These tests on columns and beams were conducted in accordance with standard ASTM E119 test methods and such reports are available upon request.

ALBI-CLAD has been tested by Factory Mutual as well as other independent laboratories and has demonstrated excellent fire protection performance when subjected to instantaneous flame temperatures of 1800°F (982.2°C).

Research papers, published by the Portland Cement Association, indicates that a 3/16" (5 mm) application of ALBI-CLAD to the undersurface of concrete slabs can extend the composite fire rating by approximately 1 hour. A 7/16" (11 mm) application of ALBI-CLAD can extend the composite fire rating up to 2 hours. These independent tests confirm added fire protection value which could influence critical design of reinforced concrete as well as prestressed concrete construction.

July, 1971
(Supersedes July 1970)

Physical Characteristics: ALBI-CLAD resists impact, abrasion, vibration, flexure and similar physical abuse. It cures to a hard, dense film which will not dust, spall or flake: is resilient enough to permit expansion and contraction of substrate without cracking or delamination.

Withstands weathering (with weather resistant coating) and thermal shock without deleterious effect.

Chemical Resistance: Characteristics typical of other vinyl films. Accelerated weathering and aging tests conducted at UL Inc. indicate that: "after exposure to high-intensity ultra violet light, hydrogen sulphide atmosphere, sulphur dioxide—carbon dioxide, and 9 months exposure to 90% humidity, at temperatures in excess of 160°F (71.1°C), no significant adverse affect was observed."

Specific Gravity: 1.2.

Weight Per Gallon: 10.5 lbs. per gallon (1.25kg/L).

Drying/Curing Time: ALBI-CLAD dries to the touch within 10 to 15 minutes. Curing time to completely disperse occluded solvents—6 to 14 days as determined by thickness of application.

Cleaning and Thinning Solvents: For ALBI-CLAD 89 products use Toluol, Xylol or Albi's 89 solvent mixture. For ALBI-CLAD 101 use water.

5. INSTALLATION

Certified applications may be made by contractors qualified by Albi. Quality control is maintained by requiring factory or on-site training of applicators in proper application techniques as well as fundamentals of fire protection requirements.

Due to simplicity of equipment and application techniques, company personnel can be properly trained to apply it themselves under the supervision of company safety or fire prevention engineering staff.

Preparatory Work: On new work, masking need not be extensive because ALBI-CLAD overspray does not drift or dust beyond the immediate vicinity of the application. On existing work, where ALBI-CLAD will be applied and have possible contact with interior finish, equipment, etc. protection must be provided due to potential attack by aromatic solvents.

Surfaces to receive ALBI-CLAD should be dry and free of mill scale. loose rust, dirt, grease and oil. Priming is required where the substrate may be exposed to high humidity, corrosive fumes or exterior environments. Where primer is required for Albi 89 use Albi 487S or other compatible primers possessing equal protective properties. Where primer is required for interior application of Albi 101, use a suitable PVA primer.

On new or existing work, where substrate is already primed, check the compatibility of ALBI-CLAD by installing a sample area to determine bonding adhesive characteristics.

Method: ALBI-CLAD is applied directly from the shipping container utilizing standard, heavy duty, pneumatic spray equipment. On small or hard to reach areas, ALBI-CLAD can be trowelled or palmed to the thickness specified.

The thickness of the application will depend upon the fire endurance rating specified. Measurement of the application is based upon wet film thickness taken at random with a probe to assure adequate coverage.

Architects or owners approval of an applied sample, large enough to provide a guide to the acceptability of the finished work, should be part of the specifications and contract documents. The completed project must match the thickness and texture of the approved sample.

In exterior or humid locations, a final weather resistant coating is required, such as Albi 144. The coating should not supress the intumescent action of ALBI-CLAD when the composite construction is exposed to fire.

Certification: Where required, certification of installation in accordance with specifications can be obtained. Upon completion of the work, the applicator will submit a certificate attesting to the proper rate of coverage to meet the specified fire endurance rating. To be acceptable, the certification should be signed by the applicator and countersigned by the Albi Manufacturing Corporation.

The responsibility of inspection and verification of correct thickness application lies with the representative of the owner or architect who initiates the request for certification.

Building Codes: Approval has been granted by authorities in areas governed by building codes and acceptance has been obtained by all major insurance rating organizations.

6. AVAILABILITY AND COST

Availability: ALBI-CLAD is a patented proprietary product, manufactured by Cities Service Company and its authorized licensees. ALBI-CLAD is manufactured in the United States, Canada and Europe. Shipment is made from the nearest manufacturing facility to the job-site or through authorized warehouse distribution centers.

Cost: Wherever fire protection, coupled with long-term durability, abrasion resistance and weatherability is required, ALBI-CLAD offers the maximum benefits for the money expended. While more expensive than the low cost spray asbestos and lightweight plaster fireproofing applications, it offers excellent economy when compared with concrete, masonry, gunite and lath and plaster.

Since prices will vary depending upon job conditions, location and fire protection requirements, refer to nearest Albi representative for accurate budget figures.

Due to its excellent wear resistant properties, ALBI-CLAD could provide a feasible solution for in-plant production of prefabricated modular homes or fabricated steel construction.

7. GUARANTEES

Cities Service Albi Products are guaranteed against manufacturing defects in material and workmanship.

Our responsibility under this guarantee shall be entirely fulfilled by furnishing, FOB factory, freight allowed to destination, a quantity of product equal to the quantity of product shown to our satisfaction within one year from date of installation to be so defective; or, at our sole option, this guarantee shall be entirely fulfilled by refund of the invoice value of the quantity of product shown to our satisfaction to be so defective within such guarantee period. *This guarantee is in lieu of all express warranties and, except as stated in this guarantee, the products are sold as is.*

Applicator shall guarantee that its installation of material conforms to manufacturer's recommendations, and shall further guarantee its workmanship connected with the installation for a period of one year from the date of installation.

8. MAINTENANCE

Cracks, nicks or dents caused by human or machine abuse may be repaired easily by hand using a putty knife.

When used in up-grading of existing fire rating requirements, or in plant additions, ALBI-CLAD can be applied directly to existing ALBI-CLAD surfaces, or to new additional structure. Removal of fireproofing to accomodate additional clips, supports, etc. can be achieved by scraping or chipping material away providing for cleaner and less costly alterations than would be experienced with other types of fireproofing such as concrete, lath and plaster, etc.

9. TECHNICAL SERVICES

Albi qualified applicators or factory representatives are available throughout the country. Write or phone collect to the nearest office for prompt assistance. Inquiries will be channeled to our nearest representative or qualified applicator for personal contact.

Albi Branch Offices:

P.O. Box 6148
San Mateo, Calif. 94403
(415) 574-3560

Cities Service Company
60 Wall St.
New York, N.Y. 10005
(212) 943-4023

In Canada:

Cities Service Chemicals Ltd.
118 Production Drive
Scarborough, Ontario
(416) 291-5519

10. THERMAL CONDUCTIVITY

Natural form: K = 2.9
Intumesed form: K = .57

2.4 General Standards for all Packages

This section demonstrates that the general standards for all packages are met.

2.4.1 Minimum Package Size

The package size has been previously described in Section 1.2.1.

2.4.2 Tamperproof Feature

Each package will include an approved tamper indicating device to prevent inadvertent and undetected opening.

2.4.3 Positive Closure

The positive closure system has been previously described in Section 1.2.1.

2.4.4 Chemical and Galvanic Reactions

The materials from which the packaging is fabricated (steel, lead and polyurethane foam) along with the contents of the package (disposable containers) will not cause significant chemical, galvanic, or other reaction in air, nitrogen or water atmosphere.

2.4.5 Load Resistance

The requirement for load resistance is that, when simply supported at its ends, the cask must be able to withstand a uniformly distributed load equal to five times the cask weight. Conservatively, the outer shell alone is assumed to support this load. Accordingly, the stress is

$$S_f = Mc/I$$

where

$$M = (1/8)WL = (5)(1/8)(68{,}100)(130) = (5.53)(10^6)in - lb$$

$$c = D/2 = 76/2 = 38in.$$

$$I = \pi(d_o^4 - d_i^4)/64 = (\pi/64)(76^4 - 74^4) = (16.5)(10^4)in^4$$

and the corresponding stress is

$$S_f = MC/I = [(5.53(10^6)(38)]/[(16.5)(10^4)] = 1274psi$$

which results in a margin of safety of

$$M.S. = (F_{ty}/S_f) - 1 = (38{,}000/1274) - 1 = +Large$$

Therefore, the package can safely react the 'Load Resistance' condition.

2.5 Lifting and Tiedown Standards for All Packages

2.5.1 Lifting Devices

Three lifting locations are provided for the 10-142 package. Total load for 3 lugs is:

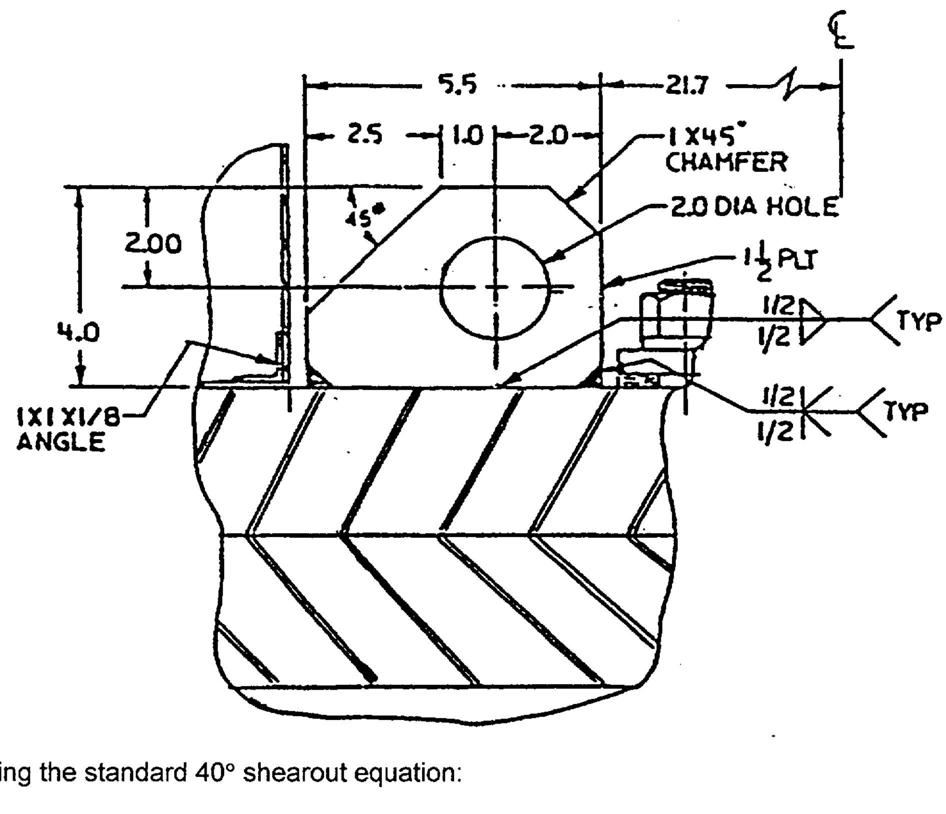
$$P = (PkgWt)(3g's)/No.\ of Lugs$$
$$P = (68{,}100lbs)(3g's)/(3) = 68{,}100lbs/lug$$

From drawing No. X-103-110-SNP and the following sketch, it can be seen that loads from the three lugs are distributed into the six inch thick steel lid. The bulk of the load will be beamed through the lid to the lid bolt or bolts nearest the lug. These lid bolts have a capacity of 182,533 lbs. each, as shown below. Conservatively assuming one bolt may react the entire load carried on one lug:

$$P_y = 130{,}000(1.4041) = 182{,}533lbs$$
$$M.S. = [(182{,}533lbs)/68{,}100lbs] - 1$$
$$M.S. = +1.68$$

The lifting device on the secondary lid is covered by a sheet metal assembly during transit. This prevents inadvertent lifting of the cask assemblies by lugs not designed to withstand the load.

The capacity of each primary lid lifting lug can be determined from the following:



Using the standard 40° shearout equation:

$$P = F_{sy}2t[E.M. - (d/2)\cos 40°]$$
$$= (22{,}800psi)(2)(1.5)[2 - (0.766)]$$
$$= 84{,}405lbs$$

Margin of Safety is:

$$M.S. = (84{,}405/68{,}100) - 1$$
$$M.S. = +0.24$$

The capacity of the lug to cask interface can be calculated as follows:

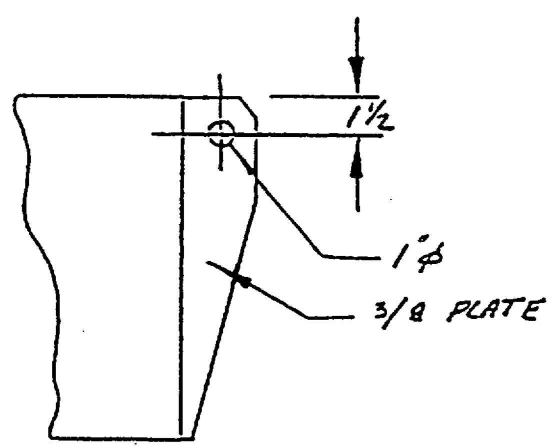
Lug Weld Area (fillet only)

Weld Area
$$A = (5.5)(2)(0.5in)(\sin 45°)$$
$$A = 3.89in^2$$
$$P = F_{sy}A$$
$$= (22{,}800)(3.89)$$
$$= 88{,}692 lbs/lug$$
$$M.S. = (88{,}692/68{,}100) - 1$$
$$= +0.30$$

Therefore, it can be concluded that the lifting points are more than capable of reacting a load equal to three times the package weight. Should the lugs experience a load greater than 84,405 pounds, they will shear out locally. This will have no detrimental effect on the package's ability to meet other requirements of the 10 CFR 71. The lugs will be covered during transport.

Overpack Lifting Lugs

Since the overpack is removable, separate lifting lugs are provided. These will be covered during transit.



Using the standard 40° shear out equation:

$$P = F_{sy}2t[E.M. - d/2\cos 40°]$$
$$= (22{,}800psi)(2)(3/8)[1.5 - 1/2\cos 40°]$$
$$= 19{,}100lbs$$

Margin of Safety:

$$M.S. = \{19{,}100lbs / [(5200lbs)(3g's)/3Lugs]\} - 1$$
$$M.S. = \underline{+2.67}$$

where 5200 lb is the weight of an overpack.

The 3/8-inch thick lugs will easily buckle under end drop impact condition producing no significant effect on the overpack or package. These lugs will be covered during transit.

2.5.2 Tie-down Devices

Four tie-down lugs are provided to resist transportation-induced loads. From 10 CFR 71.45(b) (1), the required load factors are:

$A_x = 10g's$ (longitudinal)

$A_y = 5g's$ (lateral)

$A_z = 2g's$ (vertical)

The four tie-down lugs are located with their lug-eyes at 90° intervals around the package side wall. The lugs are positioned at angles of β=42° (rear lugs) and β=24° (front lugs) with respect to the horizontal, with their end tips just below the lower surface of the upper overpack, as shown in Figure 2.5.2-1. The general arrangement for the ATG 10-142 Cask is shown in Figure 2.5.2-2.

To obtain tie-down loads, the direction cosines of the tie-down cables must be defined. Since the cables will always lie in the plane of the tie-down lug, whose angle β is constant, the cable direction cosines will be entirely dependent on the cable angle θ. Cable angle is defined as the true angle which the tie-down cable makes with respect to the tangent line of the tie-down lug (refer to Figure 2.5.2-1).

The cable angle for both front and rear tie-downs with respect to the direction of travel is 30°, so that the projected cable angle, θ, can be determined as:

$$\theta' = 45° - 30° = 15°$$

The projected lug tangent line length is:

$$T' = z / \tan\beta$$

and, the projected cable length is:

$$T = T' / \cos\theta'$$

from which the dimensional components may be derived:

$$x = T(\cos 30°)$$

$$y = T(\sin 30°)$$

From these components, cable lengths may now be calculated:

$$L = [x^2 + y^2 + z^2]^{.5}$$

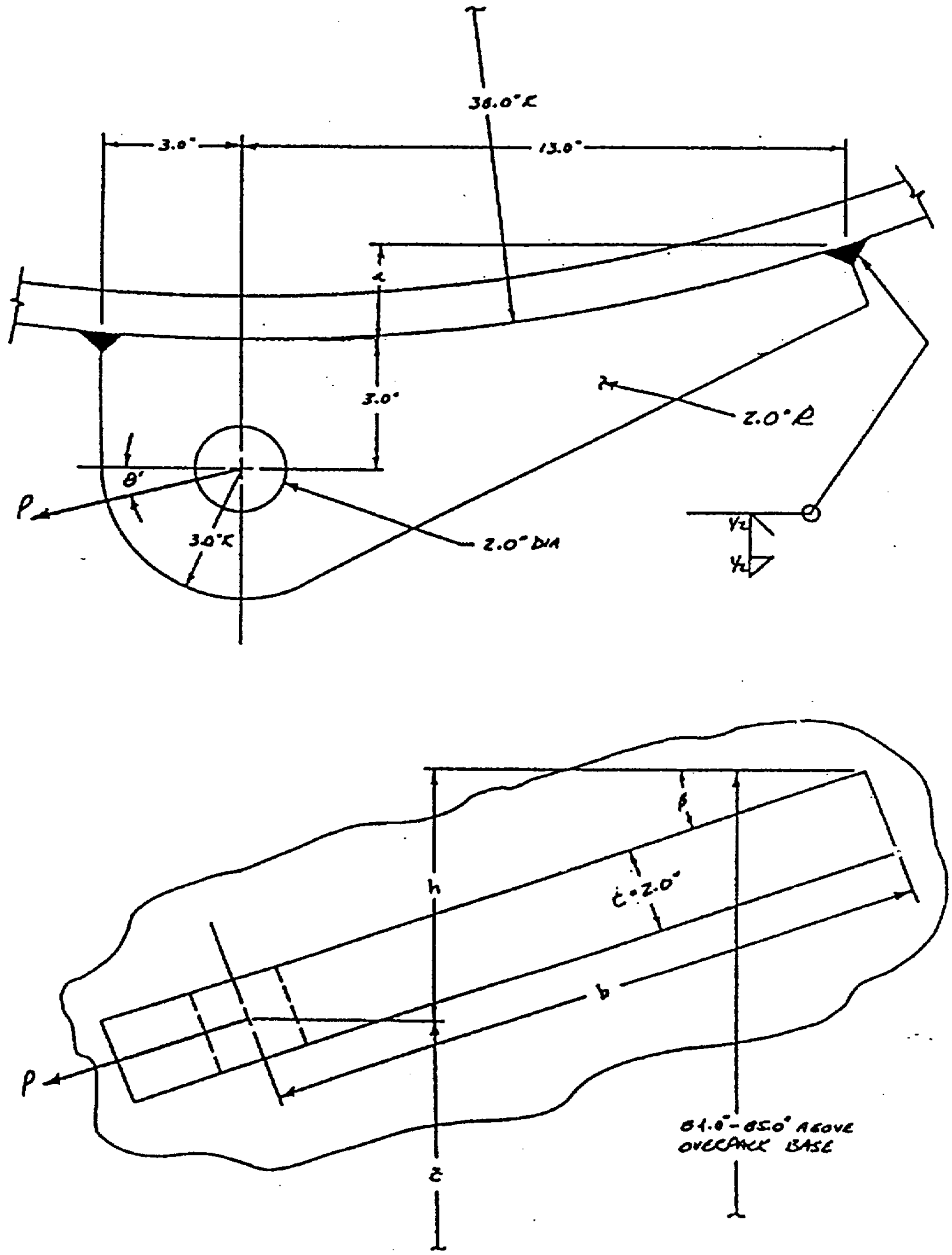


Figure 2.5.2-1 Tie-down Lug Geometry

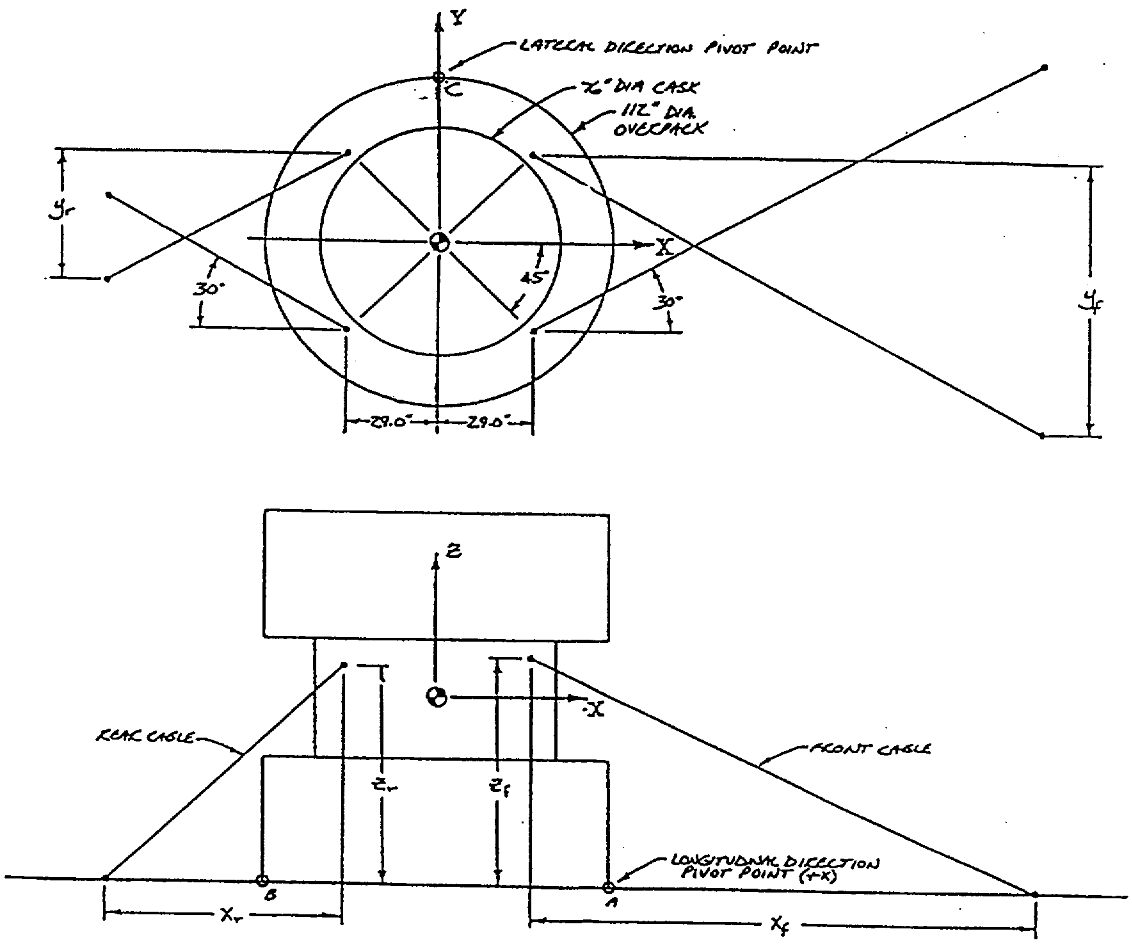


FIGURE 2.5.2-2 Tie-down Cable Arrangement

With reference to Figure 2.5.2-1, the vertical distance from the bottom of the ATG 10-142 Cask to the center of the 2.0 inch diameter hole in the tie-down lugs, z, may be determined by geometry as:

$$a = 38.0 - [(38.0)^2 - (13.0)^2]^{.5}$$
$$= 2.293 in$$

$$b = [(13.0)^2 - (2.293)^2]^{.5}$$
$$= 13.20 in$$

Assuming an average lug height, h, of 84.5 inches, the distance z is:

$$z = 84.5 - t/2(\cos\beta) + b(\sin\beta)$$

Utilizing the above equations, the x, y, z, and L dimensions for both the front and rear lugs may be calculated:

Component	Front Lug	Rear Lug
x	157.15 in	74.01 in
y	90.73 in	42.73 in
z	78.04 in	74.32 in
L	197.53 in	113.25 in

Thus, the corresponding direction cosines are:

Component	Front Lug	Rear Lug
B_x	0.796	0.653
B_y	0.459	0.377
B_z	0.395	0.656

With reference to Figure 2.5.2-2, the loads in the front and rear tie-down cables may be determined by separately applying each of the three component loadings to a cask gross weight of 68,100 pounds.

Apply 10 g's longitudinally:

Load in the +x direction (load rear cables only). Summing moments about point 'A' results in:

$$2(P_{xr}B_{xr}z_r) + 2(P_{xr}B_{zr})(29.0 + 56.0) = (68{,}100)(10g's)(65.0)$$

Solving:

$$P_{xr} = 44{,}265{,}000 / 2[(0.653)(74.32) + (0.656)(85.0)] = 212{,}219 lbs$$

Load in the -x direction (load front cables only). Summing moments about point 'B' results in:

$$2(P_{xf}B_{xf}z_f) + 2(P_{xf}B_{zf})(29.0 + 56.0) = (68{,}100)(10g's)(65.0)$$

Solving:

$$P_{xf} = 44{,}265{,}000 / 2[(0.796)(78.04) + (0.395)(85.0)] = 231{,}282 lbs$$

Apply 5 g's laterally:

Load in the +y direction (load one front and one rear cable). For purposes of this analysis, assume the component load in both the front and rear cables is equal (no twisting). Summing moments about point 'C' results in:

$$P_{yf}[B_{yf}z_f + B_{zf}(56.0-29.0)] + P_{yr}[B_{yr}z_r + B_{zr}(56.0-29.0)] = (68{,}100)(5g's)(65.0)$$

Solving:

$$P_{yf} = P_{yr} = 22{,}132{,}500/\{[(0.459)(78.04)+(0.395)(27.0)]+[(0.377)(74.32)+(0.656)(27.0)]\} = 240{,}007 lbs$$

Apply 2 g's vertically:

Load in the +z direction (load both front and both rear cables). For purposes of this analysis, assume the component load in all cables is equal (no twisting).

$$P_{zf} = (68{,}100)(2g's)/4B_{zf} = 136{,}200/4(0.395) = 86{,}203 lbs$$

$$P_{zr} = (68{,}100)(2g's)/4B_{zr} = 136{,}200/4(0.656) = 51{,}905 lbs$$

Cable Load Summary:

Component	Front Cable	Rear Cable
P_x	231,282 lbs	212,219 lbs
P_y	240,007 lbs	240,007 lbs
P_z	86,203 lbs	51,905 lbs
Total	557,492 lbs	504,131 lbs

Thus, the load in the front cables is highest.

The maximum ultimate load in the tie-down lugs may be determined utilizing Section 4.4 of Structural Methods Manual, Hughes Aircraft Company, February 1966, SSD 60048R. Assuming the lug to be geometrically symmetrical and loaded axially, as shown below, the lug ultimate axial load capacity is:

$$P_u = KDtF_{tu}$$

Where:

$$D = 2.0 in$$

$$t = 2.0 in$$

$$R = 3.0 in$$

$$W = 6.0 in$$

$F_{ty} = 100{,}000 psi$ for ASTM A-514 or A-517 carbon steel

$F_{tu} = 110{,}000 psi$ for ASTM A-514 carbon steel

$= 115{,}000 psi$ for ASTM A-517 carbon steel

Then,

$$W / D = 6.0 / 2.0 = 3.0$$

$$R / D = 3.0 / 2.0 = 1.5$$

Utilizing Figure 2.5.2-3 (Hughes Figure 4.4.1-1), the efficiency factor, K, may be found. When determining K based upon the W/D ratio, use curve 1 for carbon steels. The minimum efficiency factor is K = 1.42. Utilizing the minimum ultimate strength from above, the ultimate axial load is:

$$P_u = (1.42)(2.0)(2.0)(110{,}000) = 642{,}800 lbs$$

The maximum allowable load in the tie-down lugs, based upon the lug yield strength, may be determined as follows:

$$P_y = y(F_{ty} / F_{tu}) P_u$$

Where:

$y = 1.07$ from Figure 2.5.2-3 (Hughes Figure 4.4.1-2)

Then,

$$P_y = 1.07(100{,}000 / 110{,}000)(642{,}800) = 607{,}760 lbs$$

The lug Margin of Safety is:

$$M.S. = (P_y / P) - 1 = (607{,}760 / 557{,}492) - 1 = \underline{+0.09}$$

Figure 2.5.2-3

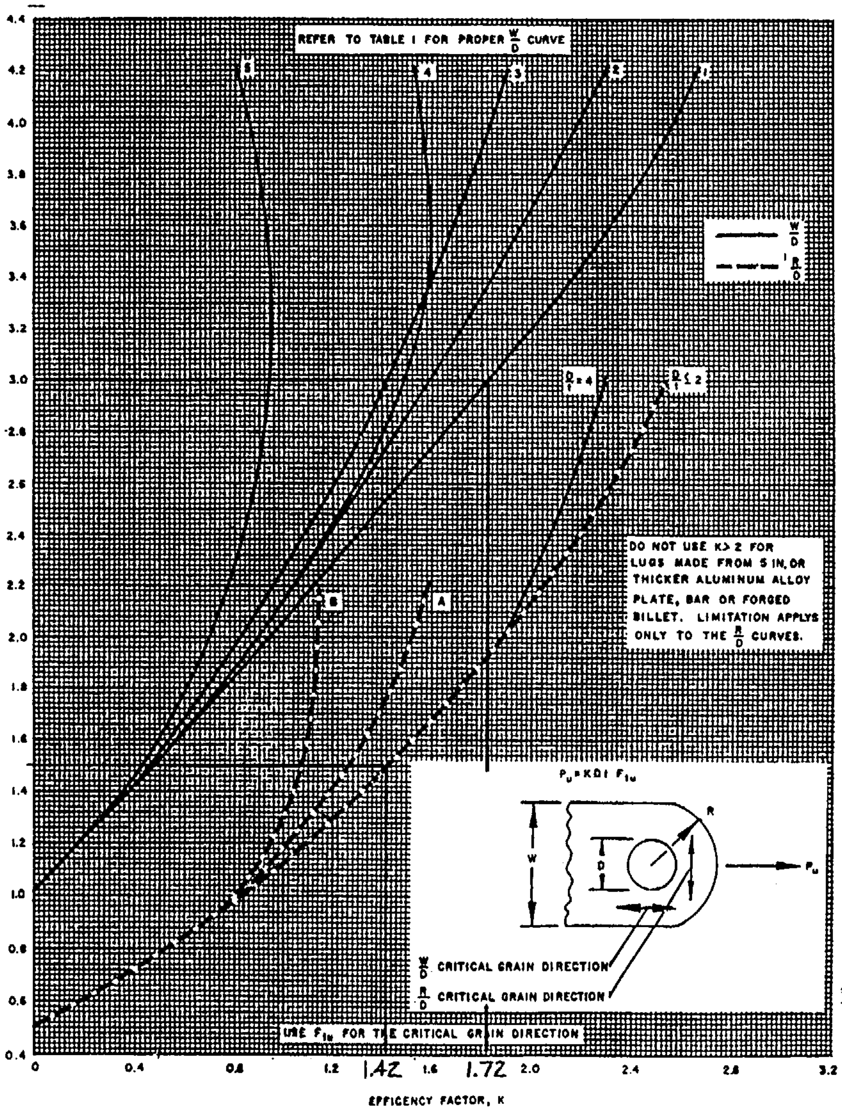


Figure 4.4.1-1. Axially Loaded Lug Design Chart

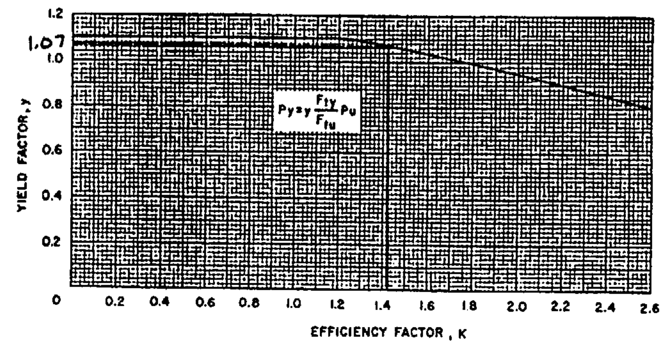


Figure 4.4.1-2. Yield Correction Factor for Axially Loaded Lugs

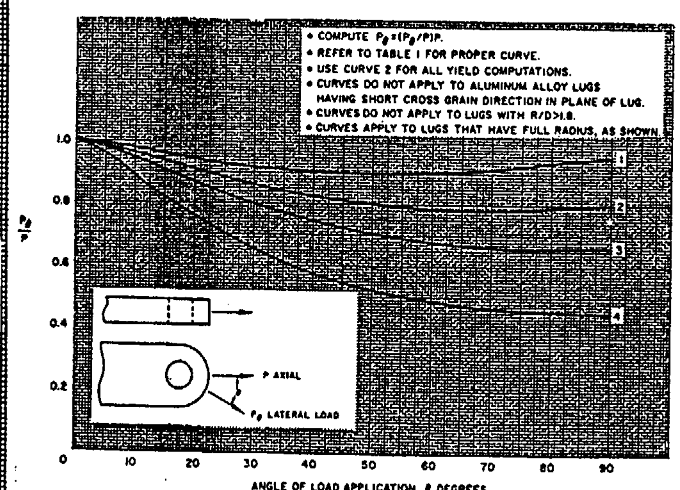
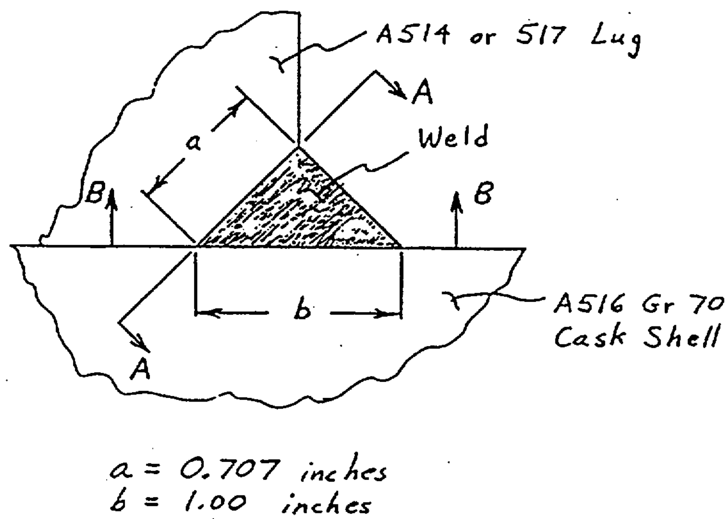


Figure 4.4.1-3. Allowable Laterial-Lug Loads

The maximum lug weld capacity is determined considering direct shear of the lug from the cask body. The weld is a 1/2 inch bevel groove plus a 1/2 inch fillet.



The maximum shear stress in the weld metal or in the lug occurs at section A-A. The shear stress at this interface for applied load P becomes:

$$\tau = P / A = P/[(a)(L)] = 0.0393P$$

where $L = length\ of\ weld = 2(16+2) = 36 inches$

The allowable stress in the weld metal can be taken as the standard AISC allowable times a factor of 1.0/0.6 = 1.67. This factor is applied to account for the fact that the basic AISC tensile allowable is 0.6 F_y whereas the acceptance criteria for tie-downs is based on a tensile allowable of yield, or 1.0 F_Y. With an AISC weld allowable of 0.3 F_{uw} where F_{uw} equals the ultimate strength of the weld metal, the allowable shear stress, F_v, associated with tie-down loads becomes:

$$F_v = 1.67(0.3F_{uw}) = 0.50F_{uw} = 40{,}500 psi$$

where $F_{uw} = 81{,}000 psi$ for the E81 weld rod used for this weld joint.

The allowable load to be applied to a lug, P_a, based on the weld metal strength is therefore:

$$P_a = F_v / 0.0393 = 1.031(10)^6 lbs$$

The allowable shear stress for the A514 or A517 lug itself is 0.6F_Y, or 60,000 psi (F_Y = 100,000 psi). The weld metal strength is therefore more limiting at Section A-A.

The final check is for shear capacity of the A516 Gr. 70 cask body material. For this evaluation, shear at Section B-B must be checked. The shear stress at this interface becomes:

$$\tau = P / A = P /[(b)(L)] = 0.0278P$$

With an allowable shear stress for the A516 Gr. 70 base metal of 0.6 F_Y, or 22,800 psi, the allowable load to be applied to the lug, P_a becomes:

$$P_a = 22{,}800/.0278 = 820{,}800 lbs$$

In summary, the allowable load to be applied to the lug is limited by the A516 Gr. 70 cask outer shell. With an applied load of 557,492 lbs, the Margin of Safety becomes:

$$M.S. = (820{,}800/557{,}492) - 1 = \underline{+0.47}$$

Therefore, it can be concluded that the tiedowns are able to react a load greater than the combined 10, 5 and 2 g tie-down loads. Should the tie-downs experience loads greater than 624,800 lbs, the lug will locally shear out. This will not impair the cask's ability to meet other requirements of 10 CFR 71.

2.6 Normal Conditions of Transport

The Model 10-142 packaging has been designed and constructed and the contents are so limited (as described in Section 1.2.3 above) that the performance requirements specified in 10 CFR 71.35 will be met when the package is subjected to the normal conditions of transport specified in 10 CFR 71. The ability of the Model 10-142 packaging to satisfactorily withstand the normal conditions of transport has been assessed as described below.

2.6.1 Heat

A detailed thermal analysis can be found in Section 3 wherein the package was exposed to direct sunlight and 130°F still air. The steady state analysis conservatively assumed a 24 hour day at maximum solar heat load. The maximum steady state temperature was found to be 160°F. These temperatures will have no detrimental effects on the package.

A second thermal analysis was run using the normal thermal conditions specified in 10 CFR 71 as revised August 1983. These conditions include 100°F ambient air, a significantly higher solar loading, and 400 watts of internal decay heat. The maximum steady state temperature under such conditions was found to be 139.1°F.

2.6.2 Cold

The materials of construction in this package are identical to or better than those approved and used in numerous existing Type 'B' licensed packages. All of the following utilize the same basic materials.

1. DOT 6400 Super Tiger
2. DOT 6272 Poly Panther
3. DOT 6679 Half Super Tiger
4. DOT 6553 Paducah Tiger
5. DOT 6744 Poly Tiger
6. SN-1 Shipping Container N.U.S.
7. Hittman - HN-300 Cask
8. NRC No. 9069 Westinghouse MO-1
9. Ontario Hydro Overpack - CDN U33 U33

Specifically, the Ontario Hydro package has operated continuously at these cold temperatures with no evidence of problems.

Therefore, on the basis of years of actual operating experience it is safe to conclude that cold will not substantially reduce the effectiveness of the package.

The cold weather capability of the 10-142 is enhanced over the above mentioned packages because the material in the shells and lid is A-516, Gr. 70. This material provides improved notch sensitivity and strength. ASTM A-516 Gr. 70 material is made to fine grain practice that greatly enhances its brittle fracture resistance. Per NUREG /CR-1815 this provides sufficient brittle fracture resistance for the inner containment vessel. This vessel is clad with stainless steel, which is backed by the 1/2-inch inner wall of the cask body. The end plates including the lid are laminated plates with the inner 304 stainless steel clad backed by two, 3 inch, 516 Gr. 70 plates at a minimum. This laminated structure insures that the containment will not be breached with a single through the wall fracture.

Foam material has been tested to -40°F. Samples failed in the same manner at -40°F as they did at room temperature, indicating that brittle fracture is not apparent at this temperature range.

2.6.3 Reduced External Pressure

A differential pressure of 11.2 psig will be reacted by the lid and its associated closure bolts or studs and nuts. (Note: All references to bolts herein are equally applicable to studs and nuts.) From Section 2.6.4, it can be seen that the containment vessel can safely react a 25 psig external pressure. It is, therefore, safe to conclude that a positive margin of safety will exist for shells when subjected to the 3.5 psia external pressure.

Loads on the bolts are calculated as follows:

$$P_b = (A\ in^2)(Internal\ pressure,\ psi)/(No.\ of\ Bolts)$$
$$= (3526)(11.2)/16$$
$$= 2468 lbs/bolt$$

where $A = area\ within\ seal\ ID = (\pi/4)(67)2 = 3526 in^2$

Minimum yield strength of each stud or bolt is:

Stress Area (per Machinery Handbook) $= 1.4041 in^2$

$$P_y (perbolt) = 130{,}000(1.4041) = 182{,}533 lbs$$

Margin of Safety:

$$M.S. = (182{,}533/2468) - 1$$
$$= \underline{+Large}$$

It can therefore be concluded that the packaging can safely react an external pressure of 3.5 psia.

2.6.4 Increased External Pressure

An external pressure of 25 psig is reacted by the external shell in hoop compression. The stress can be calculated as follows:

$$f = \Pr/t$$

where $P = 25 psig$
$r = 38 in$
$t = 1.0 in$ (outside shell only)
$f = [(25)(38)]/1.0 = 950 psi$

Margin of Safety:

$$M.S. = (F_{ty}/f) - 1$$
$$= (38{,}000/950) - 1$$
$$= \underline{+Large}$$

The analysis is conservative due to the presence of 3-1/2 inches of lead. The lead assures buckling stability of the shell.

Pressure across each end of the package is carried in plate bending by the two 3-inch thick, laminated steel plates. Assuming a circular plate, uniformly loaded and with edges simply supported, and conservatively using a 3 inch thickness (thickness of one laminate) the stress can be calculated as follows:

$f_r = 6M/t^2 = [3qa^2(3+\mu)]/8t^2$ (per 'Formulas for Stress and Strain' by Roark, Fifth Edition, Table 24, case 10a)

where

$$q = 25psi$$
$$a = 38inches$$
$$t = 3inches$$
$$\mu = 0.3$$

$$f_r = 3(25)(38)^2(3.3)/8(3)^2$$
$$f_r = 4964psi$$

Margin of Safety:

$$M.S. = (38{,}000/4964) - 1$$
$$M.S. = \underline{+Large}$$

It is therefore safe to conclude that the containment vessel can react a 25 psig external pressure without loss of contents.

2.6.5 Vibration

Shock and vibration normally incident to transport are considered to have negligible effects on the Model 10-142 packaging. Bolts and ball lock pins have been used successfully for years on similar Type 'B' packages. The Paducah Tiger, an overpack for 10 ton UF_6 cylinders, uses ball lock pins in securing the lid. (Ref. DOT 6553). More than 30 of these packages are in service and have traveled millions of miles without incident. Ball lock pins are also being used on shielded transportation casks and on an NRC licensed Mixed Oxide Fuel shipping container. (Ref. NRC No. 9069 Westinghouse MO-1). The 10-142 is similar to the model OH-142 which, has had several units in service for some 8 years with no evidence of deterioration due to shock and vibration normally incident to transport.

Therefore, the 10-142 ball lock pins are adequate to secure the overpack when the packaging is subjected to the shock and vibration environment associated with normal transport.

2.6.6 Water Spray

Since the package exterior is constructed of steel, this test is not required.

2.6.7 Free Drop

The 10-142 packaging with its payload is required to survive a 1 foot drop onto an unyielding surface with the package in a worst case orientation. The lids are shown to be adequately restrained by demonstrating that the lid bolt or stud stresses remain well within an acceptance criteria of $2S_m$ (i.e., for bolts or studs, equivalent to (2/3) σ_y). This is in accordance with ASME Section III, paragraph NB-3232.1 dealing with normal condition bolt allowables. Under normal conditions, the overpack deformations will be significantly less than under accident conditions. Therefore, overpack foam strains, potential contact of cask protrusions with the impact surface, and separation of the overpacks from the cask body will be governed by the accident conditions and will be of little concern for normal conditions. Section 2.7.1 addresses accident condition drops from 30 feet.

Employing 'g' loads determined for 1 foot drops using the proprietary drop programs EYDROP, CYDROP, OBLIQUE and SYDROP, it is readily concluded that accident condition 30 foot drops will govern the 10-142 design. These programs are described in detail in Section 2.10.2. Results for an end drop, a cg over struck corner drop, an assortment of oblique drops, and a side drop are presented in Tables 2.6.7-1 through 2.6.7-4. All cases utilize upper bound foam stress-strain characteristics in order to maximize 'g' loads on the primary and secondary cask closures. Table 2.6.7-5 presents a summary of normal condition 'g' loads and compares them with corresponding accident condition 'g' loads. From this table, the maximum ratio of normal to accident condition 'g' loads is 0.404. As this ratio is well less than the ratio of normal to accident condition bolt or stud stress allowables ($0.667\ \sigma_y$ / $0.70\ \sigma_u = 0.854$), accident condition drops will obviously govern the design.

Per the preceding discussions, the 10-142 package will adequately withstand any normal 1 foot drop event.

2.6.8 Corner Drop

This requirement is not applicable since the Model 10-142 packaging is fabricated of steel.

2.6.9 Compression

Not applicable since package exceeds 10,000 pounds.

2.6.10 Penetration

From previous container tests, as well as engineering judgment, it can be concluded that the 13 pound rod would have a negligible effect on the heavy gauge steel shell overpack or cask.

2.6.11 Conclusion

As the result of the above assessment, it is concluded that under normal conditions of transport:

1) There will be no release of radioactive material from the containment vessel.
2) The effectiveness of the packaging will not be substantially reduced.
3) There will be no mixture of gases or vapors in the package which could, through any credible increase in pressure or an explosion, significantly reduce the effectiveness of the package.

EYDROP(END) 10/142 END IMPACT WITH UPPER BOUND 20 PCF FOAM (NORMAL)

PACKAGE WEIGHT = 68100. (LBS)
PACKAGE DIAMETER = 112.00 (IN)
HOLE DIAMETER = 55.00 (IN)
OVERPACK DEPTH = 23.00 (IN)
DROP HEIGHT = 1.00 (FT)

		++++ IMPACT ++++		++++++ ENERGY ++++++		
CRUSH DEPTH (IN)	STRAIN	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)
.13	.005	1389765.	20.4	825713.	86860.	.105
.25	.011	2643263.	38.8	834225.	338925.	.406
.38	.016	3766878.	55.3	842738.	739558.	.878
.50	.022	4766995.	70.0	851250.	1272925.	1.495
.63	.027	5649998.	83.0	859763.	1923987.	2.238
.75	.033	6422273.	94.3	868275.	2678504.	3.085
.88	.038	7090204.	104.1	876788.	3523034.	4.018
1.00	.043	7660176.	112.5	885300.	4444933.	5.021

Table 2.6.7-1 Normal Condition, End Drop, Upper Bound Foam Data

CYDROP(CORNER)　　N U C L E A R　P A C K A G I N G　P R O P R I E T A R Y　　15.38.04　　96/04/11　　PAGE 51

10/142 CORNER IMPACT WITH UPPER BOUND 20 PCF FOAM (NORMAL)

```
PACKAGE WEIGHT             =  68100. (LBS)
PACKAGE EXTERNAL LENGTH    =  130.00 (IN)
PACKAGE EXTERNAL DIAMETER=  112.00 (IN)
PACKAGE EXTERNAL HOLE DIA=   55.00 (IN)
PAYLOAD ENVELOPE LENGTH    =   84.00 (IN)
PAYLOAD ENVELOPE DIAMETER=   76.00 (IN)
OVERPACK LENGTH            =   45.00 (IN)

DROP HEIGHT                =    1.00 (FT)
ORIENTATION ANGLE          =  40.000 (DEGREES WRT TO VERTICAL)

PLATEAU CRUSH STRESS       = 1250.00 (PSI)
   (DEFAULT TAKEN AT 10 PCT STRAIN)

STRESS/STRAIN EVALUATED IN 1/2 CRUSH PLANE ELLIPSE AT:
   NX =    25 POINTS PARALLEL TO SEMI-MINOR ELLIPSE AXIS
   NY =    25 POINTS PARALLEL TO SEMI-MAJOR ELLIPSE AXIS
```

EXPERIMENTAL STRAIN VS. STRESS VALUES

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	1100.00
3	.10	1250.00
4	.20	1360.00
5	.30	1490.00
6	.40	1730.00
7	.50	2220.00
8	.60	3470.00
9	.70	7080.00
10	.80	16500.00

CYDROP(CORNER)　　N U C L E A R　P A C K A G I N G　P R O P R I E T A R Y　　15.38.04　　96/04/11　　PAGE 52

10/142 CORNER IMPACT WITH UPPER BOUND 20 PCF FOAM (NORMAL)

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.13	1.6	0.	93.	.0	825713.	6.	.000	100.00	0.00	0.00	0.00	0.00
.25	4.5	0.	513.	.0	834225.	44.	.000	100.00	0.00	0.00	0.00	0.00
.38	8.2	1.	1324.	.0	842738.	162.	.000	100.00	0.00	0.00	0.00	0.00
.50	12.6	3.	2781.	.0	851250.	422.	.000	100.00	0.00	0.00	0.00	0.00
.63	17.6	4.	4754.	.1	859763.	893.	.001	100.00	0.00	0.00	0.00	0.00
.75	23.1	7.	7338.	.1	868275.	1649.	.002	100.00	0.00	0.00	0.00	0.00
.88	29.1	10.	10555.	.2	876788.	2767.	.003	100.00	0.00	0.00	0.00	0.00
1.00	35.5	14.	14417.	.2	885300.	4328.	.005	100.00	0.00	0.00	0.00	0.00
1.13	42.3	19.	18929.	.3	893813.	6412.	.007	100.00	0.00	0.00	0.00	0.00
1.25	49.5	25.	24091.	.4	902325.	9101.	.010	100.00	0.00	0.00	0.00	0.00
1.38	57.1	32.	29895.	.4	910838.	12475.	.014	100.00	0.00	0.00	0.00	0.00
1.50	65.0	39.	36328.	.5	919350.	16614.	.018	100.00	0.00	0.00	0.00	0.00
1.63	73.2	48.	43374.	.6	927863.	21596.	.023	100.00	0.00	0.00	0.00	0.00
1.75	81.7	58.	51013.	.7	936375.	27495.	.029	100.00	0.00	0.00	0.00	0.00
1.88	90.6	68.	59222.	.9	944887.	34384.	.036	100.00	0.00	0.00	0.00	0.00
2.00	99.7	80.	67978.	1.0	953400.	42334.	.044	100.00	0.00	0.00	0.00	0.00
2.13	109.1	93.	77255.	1.1	961912.	51411.	.053	100.00	0.00	0.00	0.00	0.00
2.25	118.7	107.	87025.	1.3	970425.	61679.	.064	100.00	0.00	0.00	0.00	0.00
2.38	128.6	123.	97264.	1.4	978938.	73197.	.075	100.00	0.00	0.00	0.00	0.00
2.50	138.8	140.	107945.	1.6	987450.	86023.	.087	100.00	0.00	0.00	0.00	0.00
2.63	149.2	158.	119034.	1.7	995963.	100209.	.101	100.00	0.00	0.00	0.00	0.00
2.75	159.9	177.	130515.	1.9	1004475.	115806.	.115	100.00	0.00	0.00	0.00	0.00
2.88	170.7	198.	142356.	2.1	1012988.	132860.	.131	100.00	0.00	0.00	0.00	0.00
3.00	181.8	220.	154532.	2.3	1021500.	151416.	.148	100.00	0.00	0.00	0.00	0.00
3.13	193.1	243.	167035.	2.5	1030013.	171514.	.167	100.00	0.00	0.00	0.00	0.00
3.25	204.6	268.	179861.	2.6	1038525.	193195.	.186	100.00	0.00	0.00	0.00	0.00
3.38	216.4	294.	193035.	2.8	1047038.	216501.	.207	100.00	0.00	0.00	0.00	0.00
3.50	228.3	322.	206532.	3.0	1055550.	241474.	.229	100.00	0.00	0.00	0.00	0.00
3.63	240.4	351.	220362.	3.2	1064063.	268155.	.252	100.00	0.00	0.00	0.00	0.00
3.75	252.7	382.	234527.	3.4	1072575.	296585.	.277	100.00	0.00	0.00	0.00	0.00
3.88	265.2	415.	248996.	3.7	1081088.	326805.	.302	100.00	0.00	0.00	0.00	0.00
4.00	277.9	448.	263804.	3.9	1089600.	358855.	.329	100.00	0.00	0.00	0.00	0.00
4.13	290.7	484.	278950.	4.1	1098113.	392776.	.358	100.00	0.00	0.00	0.00	0.00
4.25	303.8	521.	294348.	4.3	1106625.	428606.	.387	100.00	0.00	0.00	0.00	0.00
4.38	317.0	560.	310077.	4.6	1115138.	466383.	.418	100.00	0.00	0.00	0.00	0.00
4.50	330.4	600.	326088.	4.8	1123650.	506145.	.450	100.00	0.00	0.00	0.00	0.00
4.63	343.9	643.	342396.	5.0	1132163.	547925.	.484	100.00	0.00	0.00	0.00	0.00
4.75	357.6	686.	358998.	5.3	1140675.	591760.	.519	100.00	0.00	0.00	0.00	0.00
4.88	371.5	732.	375886.	5.5	1149188.	637691.	.555	100.00	0.00	0.00	0.00	0.00
5.00	385.5	779.	393041.	5.8	1157700.	685749.	.592	100.00	0.00	0.00	0.00	0.00
5.13	399.7	828.	410458.	6.0	1166213.	735967.	.631	100.00	0.00	0.00	0.00	0.00
5.25	414.0	879.	428109.	6.3	1174725.	788377.	.671	100.00	0.00	0.00	0.00	0.00
5.38	428.5	932.	446059.	6.6	1183238.	843012.	.712	100.00	0.00	0.00	0.00	0.00
5.50	443.1	986.	464281.	6.8	1191750.	899909.	.755	100.00	0.00	0.00	0.00	0.00
5.63	457.8	1043.	482753.	7.1	1200263.	959098.	.799	100.00	0.00	0.00	0.00	0.00
5.75	472.7	1101.	501467.	7.4	1208775.	1020612.	.844	100.00	0.00	0.00	0.00	0.00
5.88	487.8	1161.	520417.	7.6	1217288.	1084480.	.891	100.00	0.00	0.00	0.00	0.00
6.00	502.9	1223.	539618.	7.9	1225800.	1150732.	.939	100.00	0.00	0.00	0.00	0.00
6.13	518.3	1287.	559068.	8.2	1234313.	1219400.	.988	100.00	0.00	0.00	0.00	0.00
6.25	533.7	1352.	582634.	8.4	1242825.	1290756.	1.039	100.00	0.00	0.00	0.00	0.00
6.38	549.3	1420.	603953.	8.9	1251338.	1364918.	1.091	100.00	0.00	0.00	0.00	0.00
6.50	565.0	1490.	624228.	9.2	1259850.	1441679.	1.144	100.00	0.00	0.00	0.00	0.00
6.63	580.8	1561.	646948.	9.5	1268363.	1521127.	1.199	100.00	0.00	0.00	0.00	0.00
6.75	596.7	1635.	670604.	9.9	1276875.	1603487.	1.256	100.00	0.00	0.00	0.00	0.00
6.88	612.8	1710.	692762.	10.2	1285388.	1688710.	1.314	100.00	0.00	0.00	0.00	0.00
7.00	629.0	1788.	714125.	10.5	1293900.	1776640.	1.373	100.00	0.00	0.00	0.00	0.00

Table 2.6.7-2 Normal Condition, Corner Drop, Upper Bound Foam

NUPAC OBLIQUE ANALYSIS-NUPAC 10-142 OBLIQUE IMPACT WITH LOWER BOUND 20 PCF FOAM

```
PACKAGE GEOMETRY-
          LENGTH                      =      84.000
          RADIUS                      =      38.000
          OVERPACK LENGTH             =      45.000
          OVERPACK SIDE THICKNESS     =      18.000
          OVERPACK BOTTOM THICKNESS   =      23.000
PACKAGE MASS PROPERTIES-
          MASS                        =     176.240
          MASS MOMENT OF INERTIA      =  248000.000
          GRAVITATIONAL CONSTANT      =     386.400
SOLUTION CHARACTERISTICS-
          IMPACT VELOCITY (YDOT)      =     -96.300
                          (XDOT)      =       0.000
                          (THETADOT)  =       0.000
          FRICTION COEFFICIENT        =       0.000
          ESTIMATED CRUSH DEPTH       =       7.000
```

THETAO	FMAX	SHEAR	THRUST	MOMENT	DEFLECTION	CLEARANCE
85.0000	858782.	69765.	855963.	868189.	1.38	23.00
80.0000	600567.	98356.	592573.	1223992.	2.03	23.58
75.0000	488451.	119022.	473876.	1481162.	2.76	23.91
70.0000	495688.	159995.	469256.	1991050.	3.78	23.78
65.0000	549168.	221629.	502730.	2758050.	4.85	23.44
60.0000	542484.	261815.	475457.	3258140.	5.50	23.33
55.0000	554920.	312736.	458402.	3891831.	6.00	23.14
50.0000	555125.	357332.	424827.	4446792.	6.33	22.85
45.0000	545806.	391680.	380120.	4874235.	6.37	22.57
40.0000	495124.	386743.	309156.	4812802.	6.05	22.37
35.0000	417495.	349308.	228716.	4346947.	5.47	22.19
30.0000	372501.	328109.	177018.	4083129.	4.64	22.10
25.0000	371251.	340467.	148618.	4236922.	4.08	21.60
20.0000	353067.	334382.	113883.	4161195.	3.55	20.88
15.0000	340486.	330435.	82388.	4112074.	3.25	19.73
10.0000	354473.	349917.	56930.	4354518.	2.54	18.88
5.0000	460490.	459108.	36332.	5713343.	1.86	17.85

++++ OVERPACK SEPARATION MOMENT EVALUATION ++++

NUPAC 10-142 OBLIQUE IMPACT WITH LOWER BOUND 20 PCF FOAM

INITIAL VELOCITY = -96.300

ANGLE	CRUSH DEPTH	FORCE	+++++++ CRUSH ELLIPSE MAJ. DIAG. (A)	WIDTH (C)	XBAR	AREA +++++++	CTR LINE DISTANCE TO C.P. (E)	CORNER (Q)	MOMENTS ABOUT CORNER ADJACENT (MAC)	OPPOSITE (MOC)
85.00	1.31	776130.	56.20	15.48	46.99	822.	44.75	37.86	5345615.	0.
85.00	1.38	858780.	56.18	17.14	46.08	952.	43.88	37.88	5157826.	0.
80.00	2.01	592190.	56.79	12.30	49.45	585.	44.42	37.47	4112208.	0.
80.00	2.03	599860.	56.75	12.71	49.18	613.	44.38	37.50	4079833.	0.
75.00	2.76	488070.	57.74	11.67	50.78	537.	42.45	36.86	2728770.	0.
75.00	2.76	488170.	57.71	11.76	50.69	543.	42.46	36.88	2726662.	0.
70.00	3.78	495370.	59.12	12.45	51.69	584.	39.53	35.99	1750158.	0.
70.00	3.78	495370.	59.12	12.43	51.69	584.	39.53	35.99	1750158.	0.
65.00	4.21	416850.	61.62	11.11	54.99	484.	36.60	34.53	861047.	0.
65.00	4.84	548160.	61.15	13.19	53.27	625.	36.34	34.81	838030.	0.
60.00	3.40	223440.	64.62	7.87	59.92	285.	34.31	32.93	308014.	0.
60.00	5.50	542480.	63.90	13.02	56.13	602.	33.26	33.30	-24815.	0.
55.00	1.87	58746.	68.36	3.98	65.98	101.	31.61	31.13	28115.	0.
55.00	6.00	554920.	67.79	12.98	68.18	577.	29.70	31.39	-937939.	0.
50.00	.20	461.	73.10	.40	72.86	3.	28.04	29.11	-493.	0.
50.00	6.33	555130.	73.18	12.86	65.50	554.	25.70	29.08	-1874313.	0.
45.00	.21	294.	79.28	.41	78.95	3.	23.29	26.87	-1051.	0.
45.00	6.37	545810.	80.41	12.74	72.88	523.	21.45	26.46	-2737950.	0.
40.00	6.05	495120.	89.69	12.41	82.27	477.	17.16	23.73	0.	0.
40.00	6.05	495120.	89.69	12.41	82.27	477.	17.16	23.73	0.	0.
35.00	5.47	417490.	102.25	11.93	95.11	423.	12.65	20.81	0.	0.
35.00	5.47	417490.	102.25	11.93	95.11	423.	12.65	20.81	0.	0.
30.00	4.64	372500.	118.28	11.13	111.62	356.	8.23	17.99	0.	0.
30.00	4.64	372500.	118.28	11.13	111.62	356.	8.23	17.99	0.	0.
25.00	4.08	371250.	140.46	11.15	133.78	328.	3.94	15.15	0.	0.
25.00	4.08	371250.	140.46	11.15	133.78	328.	3.94	15.15	0.	0.
20.00	3.55	353070.	174.45	11.67	167.47	315.	-.33	12.20	0.	-4190944.
20.00	.28	649.	163.73	.88	163.28	7.	-2.21	13.00	0.	-7000.
15.00	3.25	340310.	234.03	13.98	225.66	358.	-4.15	9.09	0.	-1690547.
15.00	.12	193.	216.37	.50	216.07	3.	-7.56	9.84	0.	-439.
10.00	2.54	354180.	353.76	16.24	344.82	365.	-7.74	6.82	0.	611822.
10.00	2.54	354180.	353.76	16.24	344.82	365.	-7.74	6.82	0.	611822.
5.00	1.86	459120.	734.08	24.41	719.45	464.	-9.03	2.90	0.	2812647.
5.00	1.82	444900.	688.60	22.44	675.15	426.	-9.53	3.09	0.	2865339.

MAXIMUM MOMENT ABOUT ADJACENT CORNER = 5345615. ←
MAXIMUM MOMENT ABOUT OPPOSITE CORNER = 2865339.

Table 2.6.7-3 Normal Condition, Oblique Drops, Upper Bound Foam

SYDROP(SIDE) NUCLEAR PACKAGING PROPRIETARY 09.25.20 86/04/10

10/142 SIDE IMPACT WITH UPPER BOUND 20 PCF FOAM (NORMAL)

PACKAGE WEIGHT = 68100. (LBS)
PACKAGE EXTERNAL LENGTH = 90.00 (IN)
PACKAGE EXTERNAL DIAMETER = 112.00 (IN)
PAYLOAD DIAMETER = 76.00 (IN)
DROP HEIGHT = 1.00 (FT)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	1100.00
3	.10	1250.00
4	.20	1360.00
5	.30	1490.00
6	.40	1730.00
7	.50	2220.00
8	.60	3470.00
9	.70	7000.00
10	.80	16500.00

SYDROP(SIDE) NUCLEAR PACKAGING PROPRIETARY 09.25.20 86/04/10 PAGE 2

10/142 SIDE IMPACT WITH UPPER BOUND 20 PCF FOAM (NORMAL)

CRUSH	++ CRUSH PLANE ++		++++ IMPACT ++++		++++++ ENERGY ++++++			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
DEPTH (IN)	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	POTENTIAL (IN-LB)	STRAIN (IN-LB)	RATIO (SE/PE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.10	602.1	40.	76950.	1.1	824010.	3847.	.005	100.00	0.00	0.00	0.00	0.00
.20	851.2	114.	208788.	3.1	830820.	18134.	.022	100.00	0.00	0.00	0.00	0.00
.30	1042.0	209.	367757.	5.4	837630.	46962.	.056	100.00	0.00	0.00	0.00	0.00
.40	1202.6	321.	542568.	8.0	844440.	92478.	.110	100.00	0.00	0.00	0.00	0.00
.50	1344.0	448.	726229.	10.7	851250.	155918.	.183	100.00	0.00	0.00	0.00	0.00
.60	1471.6	589.	913844.	13.4	858060.	237921.	.277	100.00	0.00	0.00	0.00	0.00
.70	1588.8	742.	1101784.	16.2	864870.	338703.	.392	100.00	0.00	0.00	0.00	0.00
.80	1697.7	907.	1287278.	18.9	871680.	458156.	.526	100.00	0.00	0.00	0.00	0.00
.90	1799.9	1082.	1468188.	21.6	878490.	595929.	.678	100.00	0.00	0.00	0.00	0.00
1.00	1896.4	1267.	1642864.	24.1	885300.	751482.	.849	100.00	0.00	0.00	0.00	0.00
1.08	1970.5	1424.	1777970.	26.1	890803.	891001.	1.000	100.00	0.00	0.00	0.00	0.00
1.10	1988.1	1461.	1810049.	26.6	892110.	924127.	1.036	100.00	0.00	0.00	0.00	0.00
1.20	2075.5	1664.	1968814.	28.9	898920.	1113071.	1.238	100.00	0.00	0.00	0.00	0.00
1.30	2159.3	1876.	2118510.	31.1	905730.	1317437.	1.455	100.00	0.00	0.00	0.00	0.00
1.40	2239.8	2096.	2258727.	33.2	912540.	1536299.	1.684	100.00	0.00	0.00	0.00	0.00
1.50	2317.4	2324.	2389269.	35.1	919350.	1768699.	1.924	100.00	0.00	0.00	0.00	0.00
1.60	2392.3	2559.	2510132.	36.9	926160.	2013669.	2.174	100.00	0.00	0.00	0.00	0.00
1.70	2464.8	2802.	2621480.	38.5	932970.	2270249.	2.433	100.00	0.00	0.00	0.00	0.00
1.80	2535.1	3052.	2723634.	40.0	939780.	2537585.	2.700	100.00	0.00	0.00	0.00	0.00
1.90	2603.4	3309.	2826484.	41.5	946590.	2815011.	2.974	100.00	0.00	0.00	0.00	0.00

Table 2.6.7-4 Normal Condition, Side Drop, Upper Bound Foam

Cask Orientation wrt horizontal (degrees)	Normal, 1 foot drop 'g' load	Accident, 30 foot drop 'g' load *	Ratio Normal 'g'/Accident 'g'
90 (end)	58.2	144.0	.404
85	12.61	76.1	.166
80	8.82	58.3	.151
75	7.17	53.4	.134
70	7.28	52.6	.138
65	8.06	53.9	.150
60	7.97	56.2	.142
55	8.15	58.4	.140
50	8.15	57.7	.141
45	8.01	54.0	.148
40	7.27	49.0	.148
35	6.13	44.0	.139
30	5.47	40.0	.137
25	5.45	37.2	.147
20	5.18	35.8	.145
15	5.00	37.4	.134
10	5.21	38.3	.136
5	6.76	42.4	.159
0 (side)	26.1	96.2	.271

* From Sections 2.7.1 and 2.10.3

Table 2.6.7-5 Drop Condition Package 'g' Loads

2.7 Hypothetical Accident Conditions

The Model 10-142 package has been designed and its contents are so limited that the performance requirements specified in 10 CFR 71.36 will be met if the package is subjected to the hypothetical accident conditions specified in 10 CFR 71.

To demonstrate the structural integrity of the package and its ability to withstand the hypothetical accident conditions, a detailed computerized analysis was conducted. It is important to note that the techniques, analysis methods, assumptions, and routines employed follow closely those used for other petitions such as:

1) DOT 6400 Super Tiger
2) DOT 6553 Paducah Tiger
3) DOT 6272 Poly Panther
4) DOT 6679 Half Super Tiger
5) DOT 6744 Poly Tiger
6) AECB - Resin Flask
7) Model MO-1 Packaging - Docket No. 71-9069

These are proven techniques that agree closely with full scale tests as well as other published standards such as ORNL-NSIC-68. In all cases the analysis has been proven to be conservative when compared with full scale testing.

2.7.1 Free Drop

The 10-142 packaging with its payload must survive a 30 foot drop onto an unyielding surface with the package in a worst case orientation. Survivability is proven by demonstrating that:

1) overpacks perform in a manner such that maximum strain in the overpack foam will not exceed 80%,
2) overpack deformations are such that cask protrusions are protected from direct impact with the unyielding surface,
3) overpacks will remain attached to the cask body, and
4) primary and secondary lids remain secured to the cask.

The fourth requirement is met by demonstrating that primary and secondary lid bolts or studs and nuts meet ASME Appendix F allowable limits under worst-case loadings.

The high-density foam contained within the impact limiters is designed to crush on impact thus absorbing and distributing the load. The mechanical properties for the foam used in this package can be found on Figure 2.3-1. These properties are applicable for loading conditions in the direction parallel and perpendicular to the rise direction. High density foams, greater than 18 pcf, exhibit these isotropic properties for two reasons. First, because of their high density, the amount of rise during the formation of the foam is small thus producing a cell structure that is very uniform and not elongated. Secondly, the size of the overpack allows the foam to expand laterally as well as vertically, again resulting in uniform grain structure and its associated isotropic properties. The curves shown in Figure 2.3-1 represent the maximum and minimum statistical compressive properties based on a 95% probability for loading in either direction.

Three drop conditions for the package have been evaluated, i.e. end, oblique (including cg over struck corner), and side. Responses to these three conditions are determined using the proprietary drop programs EYDROP, CYDROP, OBLIQUE, and SYDROP. These programs are fully described in Section 2.10.2. In determining package response, bounding overpack geometries and foam stress-strain characteristics are utilized. Bounding geometries are utilized to conservatively address the issue of foam in unbacked regions of the overpack. Bounding stress-strain curves for the foam are utilized to adequately bound both overpack deformations and 'g' loads. Details are as follows (Note: All references to bolts herein are equally applicable for studs).

2.7.1.1 End Drop impact Analysis

To bound the effects of the end drop, two EYDROP analyses were run. The first utilized the full end area of the overpack (112.0 inch OD, 55.0 inch ID) and the upper bound foam stress-strain relationship. The resulting maximum g load and corresponding deformation are available from Table 2.7.1.1-1 as:

$$g = 144.0g's$$
$$d = 3.21inches$$

The second analysis utilized only the foam area directly backed by the cask body (i.e., 76.0 inch OD, 55.0 inch ID), and the lower bound foam stress- strain relationship. Results for this case are available from Table 2.7.1.1-2 and are as follows:

$$g = 48.75g's$$
$$d = 11.17inches$$

As expected, the first case resulted in the maximum 'g' load on the package and the second case resulted in maximum overpack deformation.

The preceding deformation results clearly indicate that the overpacks perform adequately in the end drop case. The maximum foam strain associated with the 23 inch end thickness of the overpack is 48.6% [(11.17/23)(100)], well within the 80% acceptance criteria. Also, as lid lift lugs only protrude 4 inches from the cask end, no cask body member directly contacts the impact surface in an end drop. Overpack attachments will not see any significant loads as the load path will be directly into the end of the cask.

Retention of the primary and secondary lids is now considered as follows. For the primary lid bolts, the maximum end drop 'g' load can be directly applied to the lid and payload and the resultant bolt force directly determined.

$$F = Wg = 2.477(10)^6 lbs = total\ applied\ load$$

where $W = lid\ weight + payload\ weight = 7{,}200 + 10{,}000 = 17{,}200lbs$

$g = 144.0$

The above determined applied load is offset in an end drop, since the lid is also loaded in the opposite direction by the overpack. As a minimum, this opposing force, P_r will be (considering only the foam directly backing the lid):

$$P_r = \sigma_c(\pi/4)(76^2 - 55^2) = 2.161(10)^6 lbs$$

where $\sigma_c = 1000psi$ is used as the effective crush stress for the foam.

EYDROP(END)

10/142 END IMPACT WITH UPPER BOUND 20 PCF FOAM (ACCIDENT)

PACKAGE HEIGHT = 68100. (LBS)
PACKAGE DIAMETER = 112.00 (IN)
HOLE DIAMETER = 55.00 (IN)
OVERPACK DEPTH = 23.00 (IN)
DROP HEIGHT = 30.00 (FT)

CRUSH DEPTH (IN)	STRAIN	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)
.50	.022	4766995.	70.0	24550050.	1191749.	.049
1.00	.043	7660176.	112.5	24584100.	4298541.	.175
1.50	.065	9088164.	133.5	24618150.	8485626.	.345
2.00	.087	9459578.	138.9	24652200.	13122562.	.532
2.50	.109	9472908.	139.1	24686250.	17855683.	.723
3.00	.130	9726443.	142.8	24720300.	22655521.	.916
3.50	.152	9906426.	145.5	24754350.	27563738.	1.113
4.00	.174	10038051.	147.4	24788400.	32549857.	1.313
4.50	.196	10146510.	149.0	24822450.	37595997.	1.515
5.00	.217	10307012.	151.4	24856500.	42709378.	1.718
5.50	.239	10492980.	154.1	24890550.	47909376.	1.925
6.00	.261	10698458.	157.1	24924600.	53207235.	2.135
6.50	.283	10930357.	160.5	24958650.	58614439.	2.348
7.00	.304	11192887.	164.4	24992700.	64145250.	2.567
7.50	.326	11485926.	168.7	25026750.	69814953.	2.790
8.00	.348	11830734.	173.7	25060800.	75644118.	3.018
8.50	.370	12238063.	179.7	25094850.	81661317.	3.254
9.00	.391	12718667.	186.8	25128900.	87900500.	3.498
9.50	.413	13224188.	194.2	25162950.	94386214.	3.751
10.00	.435	13801755.	202.7	25197000.	101142700.	4.014
10.50	.457	14530328.	213.4	25231050.	108225721.	4.289
11.00	.478	15449077.	226.9	25265100.	115720572.	4.580
11.50	.500	16597175.	243.7	25299150.	123732135.	4.891
12.00	.522	17753139.	260.7	25333200.	132319713.	5.223

Table 2.7.1.1 Accident End Drop, Upper Bound Foam Characteristics, Fully Effective Overpack

EYDROP(END)

10/142 END IMPACT WITH LOWER BOUND 20 PCF FOAM

PACKAGE WEIGHT = 68100. (LBS)
PACKAGE DIAMETER = 76.00 (IN)
HOLE DIAMETER = 55.00 (IN)
OVERPACK DEPTH = 23.00 (IN)
DROP HEIGHT = 30.00 (FT)

CRUSH DEPTH (IN)	STRAIN	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)
.50	.022	609541.	9.0	24550050.	152385.	.006
1.00	.043	1232781.	18.1	24584100.	612966.	.025
1.50	.065	1749219.	25.7	24618150.	1358466.	.055
2.00	.087	2008790.	29.5	24652200.	2297968.	.093
2.50	.109	2095558.	30.8	24686250.	3324055.	.135
3.00	.130	2172896.	31.9	24720300.	4391168.	.178
3.50	.152	2217919.	32.6	24754350.	5488872.	.222
4.00	.174	2243906.	33.0	24788400.	6604328.	.266
4.50	.196	2264137.	33.2	24822450.	7731339.	.311
5.00	.217	2306238.	33.9	24856500.	8873933.	.357
5.50	.239	2353208.	34.6	24890550.	10038794.	.403
6.00	.261	2399992.	35.2	24924600.	11227095.	.450
6.50	.283	2446811.	35.9	24958650.	12438795.	.498
7.00	.304	2491855.	36.6	24992700.	13673462.	.547
7.50	.326	2527042.	37.1	25026750.	14928186.	.596
8.00	.348	2566670.	37.7	25060800.	16201614.	.646
8.50	.370	2617840.	38.4	25094850.	17497742.	.697
9.00	.391	2687656.	39.5	25128900.	18824116.	.749
9.50	.413	2789108.	41.0	25162950.	20193306.	.803
10.00	.435	2919346.	42.9	25197000.	21620420.	.858
10.50	.457	3073087.	45.1	25231050.	23118528.	.916
11.00	.478	3250775.	47.7	25265100.	24699494.	.978
11.50	.500	3457009.	50.8	25299150.	26376439.	1.043
12.00	.522	3668526.	53.9	25333200.	28157823.	1.111
12.50	.543	3917912.	57.5	25367250.	30054432.	1.185
13.00	.565	4221593.	62.0	25401300.	32089308.	1.263
13.50	.587	4595997.	67.5	25435350.	34293706.	1.348
14.00	.609	5051332.	74.2	25469400.	36705538.	1.441
14.50	.630	5602784.	82.3	25503450.	39369067.	1.544
15.00	.652	6280452.	92.2	25537500.	42339876.	1.658
15.50	.674	7105201.	104.3	25571550.	45686290.	1.787
16.00	.696	8097898.	118.9	25605600.	49487064.	1.933
16.50	.717	9270777.	136.1	25639650.	53829233.	2.099
17.00	.739	10662925.	156.6	25673700.	58812658.	2.291
17.50	.761	12306128.	180.7	25707750.	64554921.	2.511
18.00	.783	14229243.	208.9	25741800.	71188764.	2.765

Table 2.7.1.1-2 Accident End Drop, Lower Bound Foam Characteristics, Partially Effective Overpack

The net load per bolt, P, is simply:

$$P = (F/N) + P_p - (P_r/N) = 154{,}800 + 2{,}468 - 135{,}039 = 22{,}229 lbs \; per \; bolt$$

where $N = 16 = number \; of \; primary \; lid \; bolts$
$P_p = bolt \; load \; due \; to \; 11.2 \; psig \; internal \; pressure = 2{,}468 \; lbs \; per \; Section \; 2.6.3$

With a minimum tensile area for the 1-1/2-6UNC - 2A bolts of 1.404 in^2,

$$\sigma = P/A = 22{,}229/1.404 = 15{,}833 psi$$

With an allowable stress of $0.7S_u$ = 101,500 psi, the margin of safety becomes

$$M.S. = (101{,}500/15{,}833) - 1 = \underline{+5.41}$$

Shear out of the primary lid bolts from the 3 inch deep ring will not occur as follows. Note that since the bolt or stud material has a substantially higher strength than the ring, the shear strength of the joint will be based on the weaker ring material (i.e., internal thread shearing). For this case, the shear area can be calculated per ANSI B1.1-1974, Section C.4.1.1 for internal thread shear area:

$$AS_n = \pi n L_e D_s \min[(1/2n) + 0.57735(D_s \min - E_n \max)]$$

where: $n = number \; of \; threads \; per \; inch = 6$
$L_e = length \; of \; engagement = 1.80 in \; minimum$
$D_s \min = minimum \; major \; diameter \; of \; external \; thread$
$= 1.4794 in$
$E_n \max = maximum \; pitch \; diameter \; of \; internal \; thread$
$= 1.4022 in$

Substituting these values yields a shear area of 6.42 in^2. Alternately, the shear area can be computed per Product Engineering, Nov. 27, 1961, pp. 41-47. Per this reference, the shear area per inch engagement for the internal threads of the ring is 3.566 in^2/in. For the specified minimum engagement of 1.80 inches, the shear area is:

$$AS_n = (1.80)(3.566) = 6.42 in^2$$

To determine the minimum engagement required to develop the full strength of the bolt or stud, Section C5.1 of ANSI B1.1-1974 specifies:

$$L_e \min = (S_{st} A_s)/(S_{ns} AS_n / L_e)$$

where: $A_s = Bolt \; Tensile \; stress \; area = 1.404 in^2$
$S_{st} = Unit \; tensile \; strength \; of \; external \; thread \; material$
$= 150{,}000 psi$ (maximum per Section 2.3 herein)
$S_{ns} = Unit \; shear \; strength \; of \; internal \; thread \; material$
$= 42{,}000 psi$ (per Section 2.3 herein)

$$AS_n / L_e = Shear\ area\ per\ unit\ engagement\ length$$
$$= 3.566 in^2 / in$$

Substitution of these values yields a required minimum engagement of 1.41 inches, which is less than the specified minimum engagement of 1.80 inches. Therefore, the strength of the bolt/stud is fully developed.

The shear stress, τ, for the load case under consideration is:

$$\tau = P / A_s = 22{,}229 / 8.024 = 2{,}770 psi$$

With a shear allowable of σ_{sy} = .6(38000) = 22,800 psi, the margin of safety becomes

$$M.S. = (22{,}800 / 2{,}770) - 1 = \underline{+7.23}$$

Note: as the margin of safety for shear out exceeds that for direct bolt tension, the full strength of the bolt is developed.

The secondary lid bolts are similarly considered except that P_r equals zero, since secondary lids are not backed by the impact limiter.

For the 29 inch lid, which weighs approximately 1800 pounds and is secured via 16, 1-1/4 - 7UNC-2A bolts and considering the projected area of the payload as effectively acting on the lid:

$$W = 1800 + (29/66)^2 (10{,}000) = 3731 lbs$$
$$F = Wg = (3731)(144.0) = 537{,}264 lbs$$
$$P = (F / N) + P_p = (537{,}264 / 16) + 495 = 34{,}074 lb per bolt$$
$$P_p = (\pi / 4)(30)^2 (11.2) / 16 = 495 lbs$$
$$\sigma = P / A = 34{,}074 / .969 = 35{,}164 psi$$
$$M.S. = (101{,}500 / 35{,}164) - 1 = \underline{+1.89}$$

For thread shear out of these bolts, minimum engagement is 2.00 inches, thus:

$$A_s = (2.0)(2.9441) = 5.8882 in^2$$
$$\tau = P / A_s = 5{,}787 psi$$
$$M.S. = (22{,}800 / 5{,}787) - 1 = \underline{+2.94}$$

Again, the full bolt strength is developed.

For the 16 inch lid, which weighs approximately 675 pounds and is secured via 8, 7/8 - 9UNC-2A bolts:

$$W = 675 + (16/66)^2(10{,}000) = 1263 lbs$$
$$F = Wg = (1263)(144.0) = 181{,}872 lbs$$
$$P = (F/N) + P_p = (181{,}872/8) + 318 = 23{,}052 lbs per bolt$$
$$P_p = (\pi/4)(17)^2(11.2)/8 = 318 lbs$$
$$\sigma = P/A = 23052/.462 = 49{,}896 psi$$

$$M.S. = (101{,}500/49{,}896) - 1 = \underline{+1.03}$$

For shear out, minimum specified engagement is 1.25 inches, thus:

$$A_S = (1.25)(2.0252) = 2.5315 in^2$$
$$\tau = P/A_S = 9106 psi$$
$$M.S. = (22{,}800/9{,}106) - 1 = \underline{+1.50}$$

The full bolt strength is again developed.

The final item to be addressed is stress in the cask shells and their attachment welds. Considering a bottom end drop, the weight of a single overpack, the primary and secondary lids, and the shells themselves will directly load the shells in compression. This compressive force, F, will be:

$$F = Wg = 3.161(10)^6 lbs$$

where $W = 5{,}200 + 7{,}200 + 16{,}150 - 6{,}600 = 21{,}950 lbs$ per Table 2.2-1 (note: 6,600 lbs= weight of bottom end closure plates)

$$g = 144.0 g's$$

The stress in the shells, σ, is therefore

$$\sigma = F/A = 9{,}294 psi$$

where $A = (\pi/4)(76^2 - 74^2 + 67^2 - 66^2) = 340.08 in^2$

The inner shell is attached to the bottom end plate with a 0.5 inch fillet weld and the outer shell is attached with a 0.5 inch bevel weld combined with a 0.5 inch fillet. The minimum throat area associated with these welds is:

$$A_t = \pi(66)(.707)(.5) + \pi(74)(.707) = 237.68 in^2$$

The resultant shear stress in the welds, τ, is therefore:

$$\tau = F/A_t = 13{,}299 psi$$

These stresses are well below the corresponding tensile and shear yield stresses of the A516 material (38,000 psi and 22,800 psi respectively).

Conclusion: It is therefore safe to conclude that the 10-142 package can safely react the maximum loads for a 30 foot end drop.

2.7.1.2 Oblique Drop and Corner Impact Analysis

The oblique impact orientations (including the cg over struck corner case) are analyzed using the proprietary drop programs CYDROP and OBLIQUE. These programs are described in Section 2.10.2. To adequately bound overpack deformations, as well as package 'g' loads, two basic cases were considered. The first case, used for determining maximum 'g' loads and maximum overpack separation moments, considered an overpack with fully effective foam in unbacked regions and the upper bound foam stress-strain curve. General results for this case are presented in Table 2.7.1.2-1. The detailed results for the cg over struck corner orientation (approximately 50 degrees, from horizontal) are presented in Table 2.7.1.2-2. The second case, used for determining maximum deformation of an overpack, considered an overpack with totally ineffective foam in unbacked regions and the lower bound foam stress- strain curve. General results for this case are presented in Table 2.7.1.2-3. The corresponding detailed results for the cg over struck corner orientation are presented in Table 2.7.1.2-4. Results are discussed in detail in the remainder of this section.

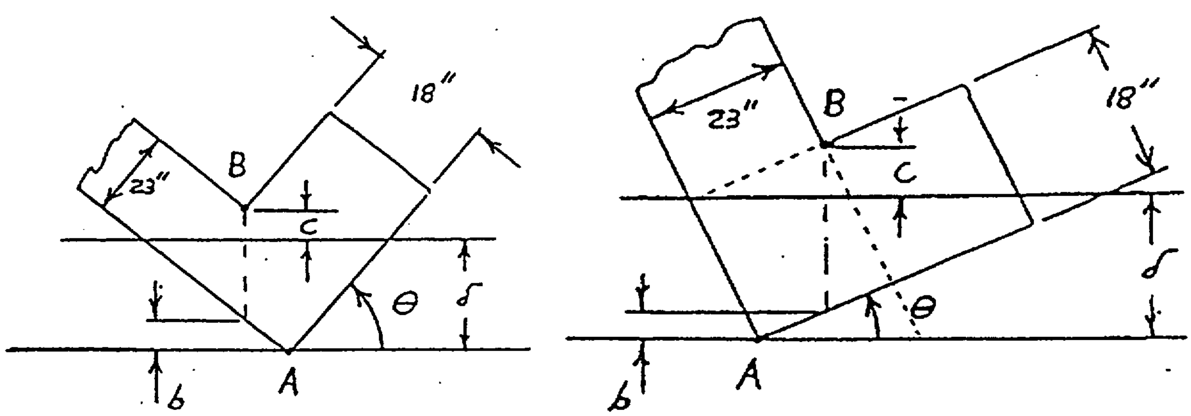
Maximum overpack strain is calculated considering the following geometry (and associated equations) and the deflection and clearance data from Tables 2.7.1.2-1 and 2.7.1.2-3.

Configuration (a), B left of A

$$b = (18\sin\theta - 23\cos\theta)/\tan\theta$$

Configuration (b), B right of A

$$b = (23\cos\theta - 18\sin\theta)\tan\theta$$



For either configuration (a) or (b), the following equations apply:

$$\varepsilon = \frac{(\delta - b)}{(\delta + c - b)} = strain$$

$\delta = deflection$

$c = clearance$

$\theta = orientation \ \ wrt\ horizontal$

Table 2.7.1.2-5 presents the resultant strains for the two oblique drop cases considered herein. As indicated, strains remain within the desired 80% limit. Inspection of Tables 2.7.1.2-2 and 2.7.1.2-4 (the cg over struck corner cases) also indicates that the 80% strain limit is satisfied. Additionally, for the worst case cg over struck corner case, regarding overpack deflections (Table 2.7.1.2-4, partially effective, lower bound foam), less than 4% of the foam in the crush zone is strained beyond 70%. It is further noted that the predicted displacement for the cg over struck corner case of 22.62 inches (interpolated from Table

NUPAC OBLIQUE ANALYSIS-NUPAC 10-142 OBLIQUE IMPACT WITH UPPER BOUND 20 PCF FOAM

PACKAGE GEOMETRY-
LENGTH = 84.000
RADIUS = 38.000
OVERPACK LENGTH = 45.000
OVERPACK SIDE THICKNESS = 18.000
OVERPACK BOTTOM THICKNESS = 23.000
PACKAGE MASS PROPERTIES-
MASS = 176.240
MASS MOMENT OF INERTIA = 248000.000
GRAVITATIONAL CONSTANT = 386.400
SOLUTION CHARACTERISTICS-
IMPACT VELOCITY (YDOT) = -527.450
(XDOT) = 0.000
(THETADOT) = 0.000
FRICTION COEFFICIENT = 0.000
ESTIMATED CRUSH DEPTH = 4.000

THETAO	FMAX	SHEAR	THRUST	MOMENT	DEFLECTION	CLEARANCE
85.0000	5183473.	339147.	5176195.	4220493.	5.63	18.28
80.0000	3968060.	565059.	3934358.	7031843.	7.87	17.24
75.0000	3636692.	798482.	3556961.	9936670.	10.20	16.02
70.0000	3581497.	1071363.	3428365.	13332512.	12.46	14.73
65.0000	3669883.	1402104.	3400569.	17448409.	14.58	13.49
60.0000	3829576.	1802811.	3383482.	22434975.	16.41	12.34
55.0000	3977267.	2249276.	3280154.	27990986.	17.77	11.38
50.0000	3928327.	2582970.	2959733.	32143623.	18.47	10.70
45.0000	3678248.	2716903.	2479504.	33810354.	18.52	10.28
40.0000	3336692.	2697722.	1980210.	33571648.	18.02	10.07
35.0000	2997516.	2582323.	1544921.	32135571.	17.12	10.07
30.0000	2727150.	2466022.	1196070.	30688278.	15.86	10.16
25.0000	2523825.	2363557.	914597.	29413158.	14.39	10.41
20.0000	2418084.	2324622.	692058.	28928626.	12.78	10.77
15.0000	2544006.	2492203.	538445.	31014079.	11.17	11.00
10.0000	2605731.	2584841.	364301.	32166905.	9.17	11.50
5.0000	2887777.	2885019.	179425.	35902456.	8.05	10.94

++++ OVERPACK SEPARATION MOMENT EVALUATION ++++

NUPAC 10-142 OBLIQUE IMPACT WITH UPPER BOUND 20 PCF FOAM

INITIAL VELOCITY = -527.450

ANGLE	CRUSH DEPTH	FORCE	+++++++ CRUSH ELLIPSE MAJ. DIAG. (A)	WIDTH (C)	XBAR	AREA +++++++	CTR LINE DISTANCE TO C.P. (E)	CORNER (Q)	MOMENTS ABOUT CORNER ADJACENT (MAC)	OPPOSITE (MOC)
85.00	1.35	826490.	56.21	15.58	46.95	829.	44.64	37.86	5604882.	0.
85.00	5.63	5183000.	56.08	107.87	.68	9742.	-.38	37.95	0.	0.
80.00	2.39	780460.	56.86	13.98	48.53	705.	43.26	37.42	4553260.	0.
80.00	7.86	3965500.	56.46	62.34	20.82	5623.	17.99	37.69	-78130794.	0.
75.00	3.11	609550.	57.97	12.45	50.55	590.	41.56	36.71	2958041.	0.
75.00	10.19	3634300.	57.22	50.69	27.85	4304.	22.85	37.19	-52116005.	0.
70.00	3.90	561430.	59.59	12.13	52.35	560.	38.95	35.71	1819000.	0.
70.00	12.42	3569200.	58.39	45.73	31.75	3729.	24.22	36.44	-43623241.	0.
65.00	3.83	372130.	61.79	10.01	55.81	415.	36.85	34.44	895366.	0.
65.00	14.54	3656500.	60.30	42.21	35.61	3309.	24.59	35.29	-39111920.	0.
60.00	3.31	228340.	64.66	7.65	60.89	273.	34.34	32.91	326176.	0.
60.00	16.39	3822000.	63.31	39.72	40.00	2990.	24.14	33.61	-36210078.	0.
55.00	1.82	60693.	68.36	3.88	66.04	97.	31.63	31.13	30695.	0.
55.00	17.77	3977300.	67.90	38.10	45.48	2745.	22.94	31.34	-33397280.	0.
50.00	.65	15255.	73.10	1.32	72.31	19.	27.87	29.11	-16469.	0.
50.00	18.47	3928300.	74.33	37.28	52.33	2568.	21.19	28.63	-29211457.	0.
45.00	18.52	3678200.	83.07	37.19	61.09	2443.	19.07	25.62	0.	0.
45.00	18.52	3678200.	83.07	37.19	61.09	2443.	19.07	25.62	0.	0.
40.00	18.02	3336700.	95.16	37.88	72.73	2367.	16.69	22.36	0.	0.
40.00	18.02	3336700.	95.16	37.88	72.73	2367.	16.69	22.36	0.	0.
35.00	17.12	2997500.	110.29	39.13	87.07	2326.	14.45	19.30	0.	0.
35.00	17.12	2997500.	110.29	39.13	87.07	2326.	14.45	19.30	0.	0.
30.00	15.80	2709000.	133.97	41.62	109.25	2332.	12.13	15.88	0.	0.
30.00	15.80	2709000.	133.97	41.62	109.25	2332.	12.13	15.88	0.	0.
25.00	14.32	2502500.	165.40	44.94	138.66	2370.	10.37	12.87	0.	0.
25.00	14.32	2502500.	165.40	44.94	138.66	2370.	10.37	12.87	0.	0.
20.00	12.76	2413600.	208.03	49.23	178.38	2408.	8.93	10.23	0.	0.
20.00	12.76	2413600.	208.03	49.23	178.38	2408.	8.93	10.23	0.	0.
15.00	11.15	2537500.	286.61	58.19	248.89	2415.	6.63	7.42	0.	0.
15.00	11.15	2537500.	286.61	58.19	248.89	2415.	6.63	7.42	0.	0.
10.00	9.16	2603300.	459.93	75.81	405.24	2348.	3.98	4.63	0.	-22414080.
10.00	1.66	185310.	322.59	9.74	316.75	178.	-9.32	6.60	0.	505108.
5.00	8.05	2887800.	1281.55	184.33	1119.26	2451.	1.15	1.66	0.	-8116247.
5.00	1.71	424920.	443.39	19.73	631.56	363.	-10.28	3.31	0.	2964656.

MAXIMUM MOMENT ABOUT ADJACENT CORNER = 5604882.
MAXIMUM MOMENT ABOUT OPPOSITE CORNER = 2964656.

Table 2.7.1.2-1 Accident Oblique Drops, Fully Effective, Upper Bound Foam

```
CYDROP(CORNER)          N U C L E A R   P A C K A G I N G   P R O P R I E T A R Y      15.55.17     86/04/09

                             10/142 CORNER IMPACT WITH UPPER BOUND 20 PCF FOAM

                                PACKAGE WEIGHT            =  68100. (LBS)
                                PACKAGE EXTERNAL LENGTH   =  130.00 (IN)
                                PACKAGE EXTERNAL DIAMETER=  112.00 (IN)
                                PACKAGE EXTERNAL HOLE DIA=   55.00 (IN)
                                PAYLOAD ENVELOPE LENGTH   =   84.00 (IN)
                                PAYLOAD ENVELOPE DIAMETER=   76.00 (IN)
                                OVERPACK LENGTH           =   45.00 (IN)

                                DROP HEIGHT               =   30.00 (FT)
                                ORIENTATION ANGLE         =  40.000 (DEGREES WRT TO VERTICAL)

                                PLATEAU CRUSH STRESS      = 1250.00 (PSI)
                                   (DEFAULT TAKEN AT 10 PCT STRAIN)

                                STRESS/STRAIN EVALUATED IN 1/2 CRUSH PLANE ELLIPSE AT:
                                   NX =    25 POINTS PARALLEL TO SEMI-MINOR ELLIPSE AXIS
                                   NY =    25 POINTS PARALLEL TO SEMI-MAJOR ELLIPSE AXIS
```

EXPERIMENTAL STRAIN VS. STRESS VALUES

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	1100.00
3	.10	1250.00
4	.20	1360.00
5	.30	1490.00
6	.40	1730.00
7	.50	2220.00
8	.60	3470.00
9	.70	7000.00
10	.80	16500.00

CYDROP(CORNER) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 15.55.17 86/04/09 PAGE 32

10/142 CORNER IMPACT WITH UPPER BOUND 20 PCF FOAM

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.32	53.6	35.	27169.	.4	24605756.	17904.	.001	100.00	0.00	0.00	0.00	0.00
2.64	150.1	170.	120051.	1.8	24695512.	114910.	.005	100.00	0.00	0.00	0.00	0.00
3.95	273.2	449.	258315.	3.8	24785267.	364240.	.015	100.00	0.00	0.00	0.00	0.00
5.27	416.5	903.	431246.	6.3	24875023.	818660.	.033	100.00	0.00	0.00	0.00	0.00
6.59	576.3	1557.	640335.	9.4	24964779.	1524832.	.061	100.00	0.00	0.00	0.00	0.00
7.91	749.9	2431.	885790.	13.0	25054535.	2530548.	.101	100.00	0.00	0.00	0.00	0.00
9.23	935.3	3542.	1147538.	16.9	25144291.	3870511.	.154	100.00	0.00	0.00	0.00	0.00
10.54	1130.6	4903.	1436671.	21.1	25234046.	5573505.	.221	100.00	0.00	0.00	0.00	0.00
11.86	1334.5	6528.	1754306.	25.8	25323802.	7676359.	.303	100.00	0.00	0.00	0.00	0.00
13.18	1545.8	8426.	2107331.	30.9	25413558.	10221177.	.402	100.00	0.00	0.00	0.00	0.00
14.50	1763.3	10607.	2489378.	36.6	25503314.	13250409.	.520	100.00	0.00	0.00	0.00	0.00
15.82	1986.0	13077.	2913219.	42.8	25593070.	16810721.	.657	100.00	0.00	0.00	0.00	0.00
17.13	2212.9	15845.	3380972.	49.6	25682825.	20958595.	.816	100.00	0.00	0.00	0.00	0.00
18.45	2443.2	18913.	3933478.	57.8	25772581.	25778816.	1.000	100.00	0.00	0.00	0.00	0.00
19.77	2676.0	22286.	4600531.	67.6	25862337.	31402728.	1.214	100.00	0.00	0.00	0.00	0.00
21.09	2910.6	25968.	5370050.	78.9	25952093.	37973341.	1.463	100.00	0.00	0.00	0.00	0.00
22.41	3146.1	29959.	6423022.	94.3	26041849.	45744976.	1.757	97.29	2.71	0.00	0.00	0.00
23.72	3381.9	34261.	7908726.	116.1	26131604.	55189597.	2.112	95.05	4.95	0.00	0.00	0.00
25.04	3617.2	38874.	9886975.	145.2	26221360.	66916964.	2.552	91.83	6.09	2.08	0.00	0.00
26.36	3851.3	43795.	12468982.	183.1	26311116.	81649540.	3.103	89.42	6.47	4.11	0.00	0.00

Table 2.7.1.2-2 Accident cg Over Corner Drop, Fully Effective, Upper Bound Foam

NUPAC OBLIQUE ANALYSIS-NUPAC 10-142 OBLIQUE IMPACT WITH LOWER BOUND 20 PCF FOAM

PACKAGE GEOMETRY-
- LENGTH = 84.000
- RADIUS = 38.000
- OVERPACK LENGTH = 45.000
- OVERPACK SIDE THICKNESS = 18.000
- OVERPACK BOTTOM THICKNESS = 23.000

PACKAGE MASS PROPERTIES-
- MASS = 176.240
- MASS MOMENT OF INERTIA = 248000.000
- GRAVITATIONAL CONSTANT = 386.400

SOLUTION CHARACTERISTICS-
- IMPACT VELOCITY (YDOT) = -527.450
- (XDOT) = 0.000
- (THETADOT) = 0.000
- FRICTION COEFFICIENT = 0.000
- ESTIMATED CRUSH DEPTH = 4.000

THETA0	FMAX	SHEAR	THRUST	MOMENT	DEFLECTION	CLEARANCE
85.0000	2467436.	197575.	2459513.	2458712.	11.05	13.32
80.0000	3462696.	507717.	3425272.	6318262.	17.83	7.56
75.0000	2852552.	585781.	2792539.	7289714.	19.12	7.06
70.0000	2674933.	759899.	2568213.	9456519.	20.01	7.10
65.0000	2647002.	978206.	2463349.	12173234.	20.59	7.41
60.0000	2802298.	1311100.	2478307.	16315907.	21.48	7.26
55.0000	3081117.	1759865.	2529062.	21900545.	22.23	6.93
50.0000	3125416.	2083025.	2330071.	25922092.	22.63	6.51
45.0000	3148696.	2348620.	2097206.	29227267.	22.62	6.13
40.0000	2917015.	2375492.	1702383.	29561677.	22.43	5.58
35.0000	2788667.	2414669.	1418765.	30049214.	22.00	5.06
30.0000	2640461.	2388021.	1152322.	29717594.	21.31	4.71
25.0000	2536081.	2375578.	914007.	29562746.	20.28	4.55
20.0000	2437334.	2344592.	703278.	29177147.	18.74	4.77
15.0000	2208482.	2167431.	461693.	26972478.	16.41	5.57
10.0000	2000902.	1988486.	267509.	24745609.	14.52	5.82
5.0000	1990509.	1988792.	112175.	24749418.	13.30	5.64

++++ OVERPACK SEPARATION MOMENT EVALUATION ++++

NUPAC 10-142 OBLIQUE IMPACT WITH LOWER BOUND 20 PCF FOAM

INITIAL VELOCITY = -527.450

ANGLE	CRUSH DEPTH	FORCE	+++++++ CRUSH ELLIPSE +++++++ MAJ. DIAG. (A)	WIDTH (C)	XBAR	AREA	CTR LINE DISTANCE TO C.P. (E)	CORNER (Q)	MOMENTS ABOUT CORNER ADJACENT (MAC)	OPPOSITE (MOC)
85.00	2.10	62144.	56.21	24.15	41.93	1559.	39.68	37.86	113343.	0.
85.00	11.05	2467400.	56.18	138.34	0.00	9884.	-1.32	37.88	0.	0.
80.00	3.46	103810.	56.86	20.26	44.85	1206.	39.75	37.42	241619.	0.
80.00	17.83	3462700.	56.61	122.90	0.00	9960.	-1.95	37.59	0.	0.
75.00	4.20	149570.	57.94	16.82	47.98	914.	39.27	36.71	383131.	0.
75.00	19.11	2849800.	57.19	96.25	5.26	9036.	2.21	37.21	0.	0.
70.00	4.62	241170.	59.59	14.38	51.03	718.	37.88	35.71	522811.	0.
70.00	19.98	2666900.	58.28	75.14	15.91	6989.	10.84	36.52	0.	0.
65.00	3.95	219200.	61.79	10.30	55.44	433.	36.72	34.44	500742.	0.
65.00	20.56	2636200.	60.10	60.76	25.15	5360.	16.89	35.41	0.	0.
60.00	3.24	126480.	64.66	7.47	60.19	264.	34.40	32.91	188197.	0.
60.00	21.48	2802300.	63.32	52.04	33.86	4314.	19.87	33.61	-38493159.	0.
55.00	1.66	23963.	68.36	3.53	66.25	84.	31.73	31.13	14363.	0.
55.00	22.23	3081100.	68.22	47.42	40.48	3708.	20.56	31.19	-32760583.	0.
50.00	.81	7443.	73.10	1.44	72.12	26.	27.81	29.11	-9686.	0.
50.00	22.63	3125400.	75.12	45.55	48.36	3384.	19.90	28.33	-26348042.	0.
45.00	22.62	3148700.	84.08	45.53	57.26	3235.	18.66	25.31	0.	0.
45.00	22.62	3148700.	84.08	45.53	57.26	3235.	18.66	25.31	0.	0.
40.00	22.43	2917000.	96.49	47.46	68.48	3243.	17.24	22.05	0.	0.
40.00	22.43	2917000.	96.49	47.46	68.48	3243.	17.24	22.05	0.	0.
35.00	21.98	2779700.	113.02	51.06	82.84	3367.	16.11	18.83	0.	0.
35.00	21.98	2779700.	113.02	51.06	82.84	3367.	16.11	18.83	0.	0.
30.00	21.28	2630000.	133.65	55.92	99.31	3425.	14.54	15.92	0.	0.
30.00	21.28	2630000.	133.65	55.92	99.31	3425.	14.54	15.92	0.	0.
25.00	20.23	2516400.	163.76	62.97	122.48	3400.	11.86	12.99	0.	0.
25.00	20.23	2516400.	163.74	62.97	122.48	3400.	11.86	12.99	0.	0.
20.00	18.69	2422000.	210.99	73.03	159.66	3329.	9.24	10.09	0.	0.
20.00	18.69	2422000.	210.99	73.03	159.66	3329.	9.24	10.09	0.	0.
15.00	16.37	2196100.	303.29	90.19	234.83	3201.	6.40	7.02	0.	0.
15.00	16.37	2196100.	303.29	90.19	234.83	3201.	6.40	7.02	0.	0.
10.00	14.46	1992700.	535.38	139.23	418.13	3151.	3.44	3.97	0.	-14772791.
10.00	2.31	4176.	322.50	13.50	314.41	290.	-7.92	6.60	0.	5535.
5.00	13.30	1990500.	1348.84	320.67	1050.44	3162.	1.06	1.58	0.	-5256215.
5.00	2.60	28526.	642.53	29.92	624.60	677.	-6.27	3.31	0.	84314.

MAXIMUM MOMENT ABOUT ADJACENT CORNER = 522811.

MAXIMUM MOMENT ABOUT OPPOSITE CORNER = 84314.

Table 2.7.1.2-3 Accident Oblique Drops, Partially Effective, Lower Bound Foam

CYDROP(CORNER) N U C L E A R P A C K A G I N G P R O P R I E T A R Y .15.54.37 86/04/09

10/142 CORNER IMPACT WITH LOWER BOUND 20 PCF FOAM

```
PACKAGE WEIGHT              =  68100. (LBS)
PACKAGE EXTERNAL LENGTH     =  130.00 (IN)
PACKAGE EXTERNAL DIAMETER=  112.00 (IN)
PACKAGE EXTERNAL HOLE DIA=   55.00 (IN)
PAYLOAD ENVELOPE LENGTH  =   84.00 (IN)
PAYLOAD ENVELOPE DIAMETER=   76.00 (IN)
OVERPACK LENGTH          =   45.00 (IN)

DROP HEIGHT              =   30.00 (FT)
ORIENTATION ANGLE        =  40.000 (DEGREES WRT TO VERTICAL)

PLATEAU CRUSH STRESS     =     .00 (PSI)
   (DEFAULT TAKEN AT 10 PCT STRAIN)

STRESS/STRAIN EVALUATED IN 1/2 CRUSH PLANE ELLIPSE AT:
   NX =    25 POINTS PARALLEL TO SEMI-MINOR ELLIPSE AXIS
   NY =    25 POINTS PARALLEL TO SEMI-MAJOR ELLIPSE AXIS
```

EXPERIMENTAL STRAIN VS. STRESS VALUES

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1050.00
6	.25	1100.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00

CYDROP(CORNER) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 15.54.57 86/04/09 PAGE 32

10/142 CORNER IMPACT WITH LOWER BOUND 20 PCF FOAM

	++ CRUSH PLANE ++		++++ IMPACT ++++		++++++ ENERGY ++++++			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH (IN)	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
1.32	53.6	35.	12383.	.2	24605756.	8161.	.000	100.00	0.00	0.00	0.00	0.00
2.64	150.1	170.	68059.	1.0	24695512.	61172.	.002	100.00	0.00	0.00	0.00	0.00
3.95	273.2	449.	164153.	2.4	24785267.	214199.	.009	100.00	0.00	0.00	0.00	0.00
5.27	416.5	905.	289880.	4.3	24875023.	513407.	.021	100.00	0.00	0.00	0.00	0.00
6.59	576.3	1557.	438732.	6.4	24964779.	993562.	.040	100.00	0.00	0.00	0.00	0.00
7.91	749.9	2431.	596467.	8.8	25054535.	1675759.	.067	100.00	0.00	0.00	0.00	0.00
9.23	935.3	3542.	756020.	11.1	25144291.	2567047.	.102	100.00	0.00	0.00	0.00	0.00
10.54	1130.6	4903.	922821.	13.6	25234046.	3673404.	.146	100.00	0.00	0.00	0.00	0.00
11.86	1334.5	6528.	1092338.	16.0	25323802.	5001394.	.197	100.00	0.00	0.00	0.00	0.00
13.18	1545.8	8426.	1263509.	18.6	25413558.	6553897.	.258	100.00	0.00	0.00	0.00	0.00
14.50	1763.3	10607.	1447757.	21.3	25503314.	8340621.	.327	100.00	0.00	0.00	0.00	0.00
15.82	1986.0	13077.	1632504.	24.0	25593070.	10370512.	.405	100.00	0.00	0.00	0.00	0.00
17.13	2212.9	15845.	1859683.	27.3	25682825.	12671863.	.493	100.00	0.00	0.00	0.00	0.00
18.45	2443.2	18913.	2085717.	30.6	25772581.	15271882.	.593	100.00	0.00	0.00	0.00	0.00
19.77	2676.0	22286.	2375530.	34.9	25862337.	18211844.	.704	100.00	0.00	0.00	0.00	0.00
21.09	2910.6	25968.	2713148.	39.8	25952093.	21565283.	.831	100.00	0.00	0.00	0.00	0.00
22.41	3146.1	29959.	3054400.	44.9	26041849.	25366096.	.974	97.29	2.71	0.00	0.00	0.00
23.72	3331.9	34261.	3667278.	53.9	26131604.	29795682.	1.140	95.05	4.95	0.00	0.00	0.00
25.04	3617.2	38874.	4428331.	65.0	26221360.	35130687.	1.340	91.83	6.09	2.08	0.00	0.00
26.36	3851.3	43795.	5489377.	80.6	26311116.	41666457.	1.584	89.42	6.47	4.11	0.00	0.00

Table 2.7.1.2-4 Accident cg Over Corner Drop, Partially Effective, Lower Bound Foam

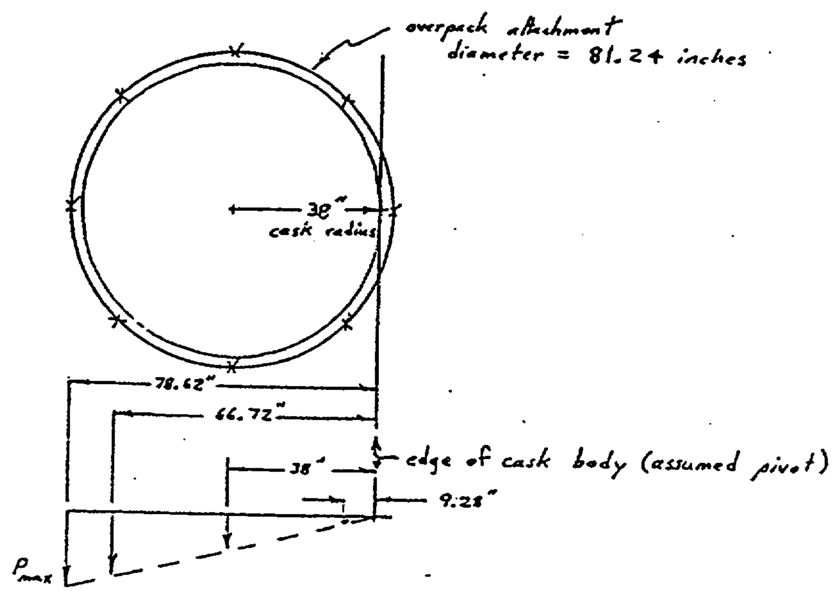
	Maximum Overpack Strain (%)	
Orientation Angle, θ wrt horizontal (degrees)	Case 1 (fully effective, upper bound foam)	Case 2 (partially effective, lower bound foam)
85	18.8	42.0
80	24.0	67.1
75	30.8	69.5
70	38.4	70.2
65	46.0	70.3
60	53.2	72.5
55	59.4	75.3
50	61.8	76.7
45	59.3	75.7
40	56.2	75.7
35	52.6	76.0
30	48.5	76.1
25	44.1	75.6
20	39.9	73.3
15	37.0	67.8
10	33.2	65.6
5	36.1	67.0

Table 2.7.1.2-5 10-142 Maximum Overpack Strains for Accident Oblique Drop Orientations

2.7.1.2-4) is in excellent agreement with the displacement result for the corresponding oblique orientation, i.e., 22.63 inches for an oblique drop orientation of 50° from horizontal per Table 2.7.1.2-3. The specific geometry and deformation associated with the cg over struck corner case is shown in Figure 2.7.1.2-1.

Overpack deformations are such that no cask protrustions (e.g., tiedown lugs or overpack attachment lugs) will come into direct contact with the impact surface. The limiting case regarding cask protrusions is the side drop orientation (see Section 2.7.1.3).

Regarding separation of the overpacks, the maximum overpack separation moment occurs for analysis case 1 and is 5.60(10)^6 in-lb per Table 2.7.1.2-1. This moment is converted to a maximum force, P_{max} at an attachment lug as follows.



From moment equilibrium,

$$M = P_{\max}[78.62 + 2(66.72^2 + 38^2 + 9.28^2)/78.62] = 5.60(10)^6 in.lb$$
$$P_{\max} = 24{,}265 lbs$$

With this applied force, tearout of the overpack attachment is considered using the 40° shearout equation. The allowable load, P_a, is:

$$P_a = \sigma_{sy}(2t)(E.M. - (d/2)\cos 40°) = 55{,}300 lbs$$

where $\sigma_{sy} = .6(38{,}000) = 22{,}800 psi = shear\ yield\ for\ A516\ Gr.\ 70$

$t = 0.75 inches = plate\ thickness$

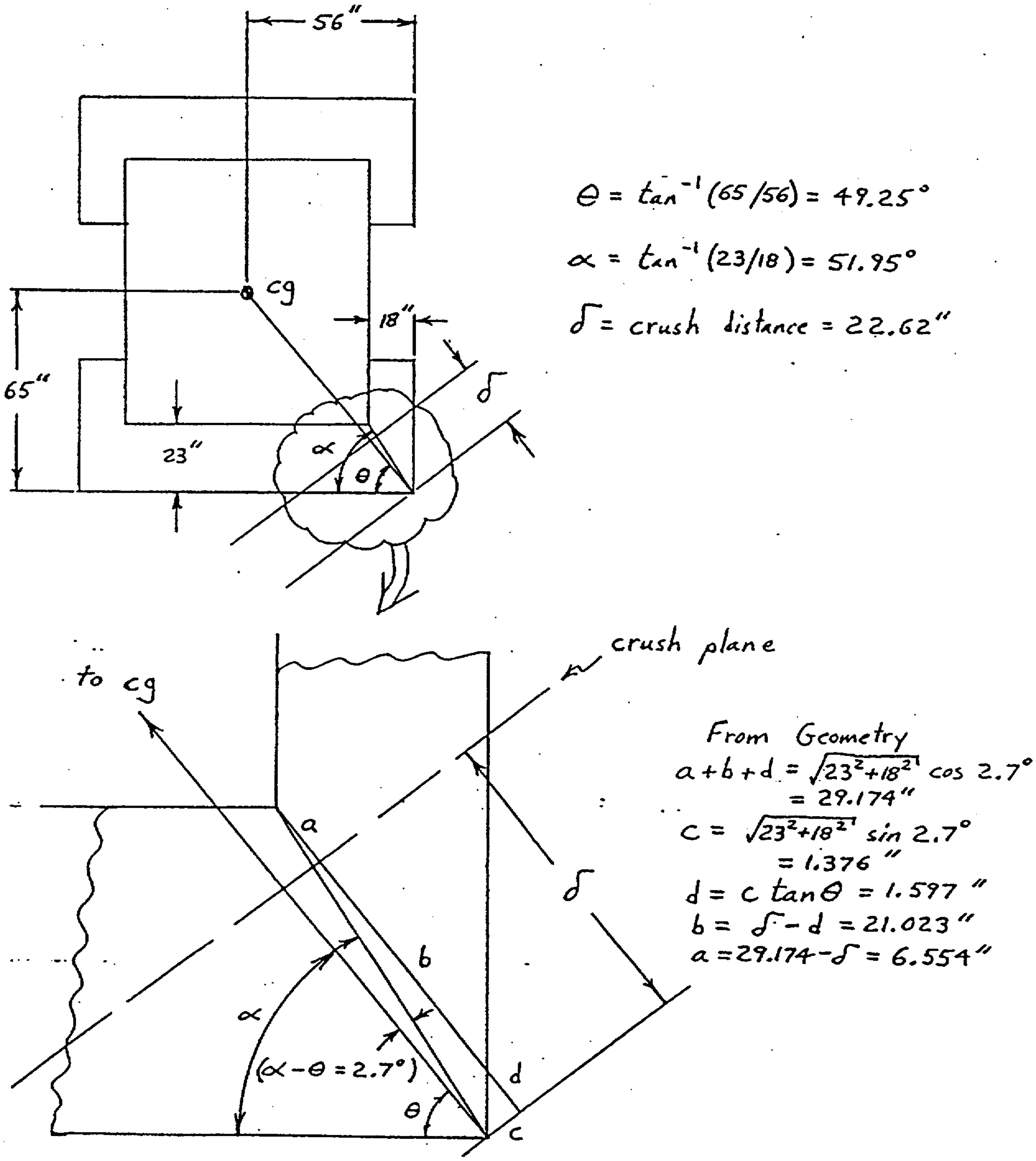
$E.M. = 1.88 inches = edge\ margin$

$d = 1.25 inches = hole\ diameter$

$$M.S. = (47{,}922/24{,}265) - 1 = \underline{+0.98}$$

Bearing stress at the pinhole is

$$\sigma_{br} = P_{\max}/a$$
$$= 24{,}265/(.75)(0.875) = 36{,}989 psi$$



maximum strain = $b/(b+a) = 21.023/27.577$

$= .762$ in/in

maximum strain $= 76.2\ \%$

Figure 2.7.1.2-1 Geometry and Deformation for cg Over Struck Corner (partially effective, lower bound foam) with an allowable bearing stress of σ_y = 38,000psi,

$$M.S. = (38,000/6,989) - 1 = \underline{+0.03}$$

The double shear capacity of the 1 inch ball-lock pins is 147,000 lbs (Carr Lane Model Number CL-16-BLP-S-2BALL). Taking one fifth of this capacity as a rated capacity yields 29,400 pounds, as an allowable load.

$$M.S. = (29,400/24,265) - 1 = \underline{+0.21}$$

The final item to be addressed is retention of the primary and secondary lids. From Section 2.10.3, the worst case combined tensile and shear stress in the primary lid bolts occurs for the 85° (from horizontal) orientation case. For this orientation, the tensile and shear stress are as follows:

$$f_t = 79,888 psi$$
$$f_v = 2,126 psi$$

Per ASME Appendix F, Paragraph F-1335.3, the interaction equation to be satisfied is

$$(f_t / F_{tb})^2 + (f_v / F_{vb})^2 \leq 1$$

where
F_{tb} = *bolt tensile allowable =lesser of* S_y *and* .7 S_u=101,500 *psi*
F_{vb} = *bolt shear allowable =lesser of*.6 S_y *and* .42 S_u=60,900*psi*

The interaction equation therefore yields a value of 0.621 for a resultant margin of safety of

$$M.S. = (1.0/0.621) - 1 = \underline{+0.61}$$

A full summary of interaction equation results for all oblique drop orientations is included in Section 2.10.3.

As demonstrated in Section 2.7.1.1, cask body thread engagement is sufficient to develop the full bolt or stud strength.

The final check to be performed regarding retention of the primary lid is with shear of the welds attaching the 3 inch thick bolting ring at the top of the shell. The ring is attached to the cask inner shell with a combined ½ inch bevel ½ inch fillet weld and to the outer shell with a 1 inch bevel weld. With 16 bolts on a 71.25 inch diameter, the effective length of weld per bolt, L, is:

$$L = \pi(71.25)/16 = 13.99 inches$$

The effective weld area A_w, is therefore:

$$A_w = 13.99(.707 + 1.0) = 23.88 in^2$$

The resultant shear stress is therefore:

$$\tau = P / A_w = 4,679 psi$$

where $P = maximum\ bolt\ tensile\ load = 112{,}163 lbs$ per Section 2.10.3

Conservatively using the base metal shear yield strength of 22,800 psi for the allowable shear stress,

$$M.S. = (22{,}800 / 4{,}697) - 1 = \underline{+3.85}$$

The worst case concerning retention of the secondary lids is the flat end drop case previously considered in Section 2.7.1.1. This is true because thrust loads drop significantly for orientations off vertical (e.g. 144.0 g's for end drop, 76.1 g's for an orientation 85° from horizontal). In addition, shear loads are relatively small for the secondary lids. For example, the shear load on the 1800 pound 29 inch lid for a drop orientation 5° from horizontal is (g's as per Section 2.10.3):

$$F_v = (42.4 g's)(\cos 5°)(1800) = 76{,}030 lbs$$

With 16, $1-1/4-7UNC$ bolts, the shear load per bolt is:

$$P_v = 76{,}030 / 16 = 4752 lbs$$

and the shear stress is:

$$\tau = 4752 / .969 = 4904 psi$$

For these reasons, detailed checks of the secondary lids are not necessary for the oblique drop cases.

2.7.1.3 Side Drop Impact Analysis

The side drop impact orientation is analyzed using the proprietary drop program SYDROP. This program is described in Section 2.10.2. To adequately bound overpack deflection as well as package 'g' loads, two cases were considered. The first case, used for determining maximum 'g' loads, considered an overpack with fully effective foam in unbacked regions (i.e., outboard of the cask ends) and the upper bound foam stress-strain curve. The results obtained for this case are presented in Table 2.7.1.3-1. The second case, used for assessing maximum strain in an overpack and potential contact of a cask tiedown lug with the impact surface, considered an overpack with ineffective foam outboard of the cask ends and the lower bound foam relationship. Results for this case are presented in Table 2.7.1.3-2.

Maximum overpack strain occurs for analysis case 2 where a side thickness, t_s, of 18 inches is considered [(112 -76)/2 = 18.0].

The strain for this case is:

$$\varepsilon = \delta / t_s = 11.47 / 18.0 = .637 in/in$$

This 63.7% strain is well within the desired 80% limit.

Regarding contact of a cask protrusion with the impact surface, tiedown lugs and overpack attachment lugs must be addressed. As the tiedown lugs protrude 6 inches from the cask body and overpack attachment lugs protrude 4.5 inches, the minimum amount of crush required to reach a lug is:

$$c = (112/2) - (38 + 6) = 12.0 inches$$

The maximum crush for the overpack occurs for analysis case 2 (Table 2.7.1.3- 2) and is 11.47 inches. Thus, direct impact of a tiedown lug or overpack attachment lug cannot occur.

In flat side drop orientations, there is no tendency to separate the overpacks from the cask body. Near horizontal impact orientations do, however, tend to separate the overpacks, and these orientations were considered in the oblique drop cases, Section 2.7.1.2.

The final issue to be addressed for the side drop case is shear stress in the primary and secondary lid bolts. From Tables 2.7.1.3-1 and 2.7.1.3-2, the maximum 'g' load identified for side drop is 96.2 g's. This 96.2 'g' load can now be used to determine shear stresses in both the primary and secondary lid bolts. Table 2.7.1.3-3 presents the appropriate shear stress calculations. Table 2.7.1.3-3 also considers the bolt prestress (which exceeds the applied stress due to pressure) and makes the appropriate interaction checks specified in paragraph F-1335.3 of the ASME Code. As shown, positive margins exist for all primary and secondary lid bolts.

It is noted that the maximum permissible primary lid to cask diametral gap is 0.040 inches as noted on drawing X-103-110-SNP, sheet 2. As the lid and interfacing 3 inch deep cask annular ring are match drilled, the 0.125 inch diametral clearance specified between the bolts and the lid holes (1.625 vs. 1.50) assures that the lid will bear against the I.D. of the cask body prior to development of a direct shear load on any lid bolt. The same arguments used above also hold true for the secondary lid and its bolts (i.e., 0.040 inch maximum diametral gap between primary and secondary lids, 0.125 inch diametral clearance between bolts and lid holes, match drilling of lid). Secondary lid bolts are also, therefore, not subjected to a direct shear load from the lid.

The overall bending response of the cask body to the 96.2 'g' side drop load is considered. For this assessment, the cask is treated as a simply supported beam, 84 inches long with a uniformly distributed load, w, as follows:

$$w = (96.2)(68{,}100)/84 = 77{,}991\, lb/in$$

The resultant maximum moment and corresponding stress is determined by conservatively ignoring any strength from the lead or inner shell and assuming that the cask outer shell resists the entire applied loading.

$$M = wL^2/8 = 6.879(10)^7\, in-lb$$

where $L = 84 inches$

$$\sigma = Mc/I = 15{,}776 psi$$

where $c = 38 inches$

$$I = (\pi/64)(76^4 - 74^4) = 1.657(10)^5\, in^4$$

The resultant 15,776 psi stress is well below the yield stress of the A-516 material used for the outer shell (38,000psi).

Conclusion: It is therefore safe to conclude that the 10-142 package can safely react the maximum loads for a 30-foot side drop.

YDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 09.25.21 86/04/10

10/142 SIDE IMPACT WITH UPPER BOUND 20 PCF FOAM (ACCIDENT)

PACKAGE WEIGHT = 68100. (LBS)
PACKAGE EXTERNAL LENGTH = 90.00 (IN)
PACKAGE EXTERNAL DIAMETER = 112.00 (IN)
PAYLOAD DIAMETER = 76.00 (IN)
DROP HEIGHT = 30.00 (FT)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	1100.00
3	.10	1250.00
4	.20	1360.00
5	.30	1490.00
6	.40	1730.00
7	.50	2220.00
8	.60	3470.00
9	.70	7000.00
10	.80	16500.00

SYDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 09.25.21 86/04/10 PAGE 4

10/142 SIDE IMPACT WITH UPPER BOUND 20 PCF FOAM (ACCIDENT)

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ POTENTIAL (IN-LB)	STRAIN (IN-LB)	RATIO (SE/PE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.25	951.4	159.	285732.	4.2	24533025.	35717.	.001	100.00	0.00	0.00	0.00	0.00
.50	1344.0	448.	726229.	10.7	24550050.	162212.	.007	100.00	0.00	0.00	0.00	0.00
.75	1644.2	823.	1194983.	17.5	24567075.	402363.	.016	100.00	0.00	0.00	0.00	0.00
1.00	1896.4	1267.	1642864.	24.1	24584100.	757094.	.031	100.00	0.00	0.00	0.00	0.00
1.25	2117.9	1769.	2044827.	30.0	24601125.	1218055.	.050	100.00	0.00	0.00	0.00	0.00
1.50	2317.4	2324.	2389269.	35.1	24618150.	1772317.	.072	100.00	0.00	0.00	0.00	0.00
1.75	2500.2	2926.	2673680.	39.3	24635175.	2405186.	.098	100.00	0.00	0.00	0.00	0.00
2.00	2669.8	3573.	2929808.	43.0	24652200.	3105622.	.126	100.00	0.00	0.00	0.00	0.00
2.25	2828.6	4260.	3181123.	46.7	24669225.	3869489.	.157	100.00	0.00	0.00	0.00	0.00
2.50	2978.2	4986.	3420196.	50.2	24686250.	4694653.	.190	100.00	0.00	0.00	0.00	0.00
2.75	3120.0	5749.	3647148.	53.6	24703275.	5578071.	.226	100.00	0.00	0.00	0.00	0.00
3.00	3255.0	6546.	3862920.	56.7	24720300.	6516830.	.264	100.00	0.00	0.00	0.00	0.00
3.25	3384.0	7376.	4068755.	59.7	24737325.	7508289.	.304	100.00	0.00	0.00	0.00	0.00
3.50	3507.7	8237.	4266012.	62.6	24754350.	8550135.	.345	100.00	0.00	0.00	0.00	0.00
3.75	3626.6	9129.	4457823.	65.5	24771375.	9640615.	.389	100.00	0.00	0.00	0.00	0.00
4.00	3741.2	10050.	4647620.	68.2	24788400.	10778795.	.435	100.00	0.00	0.00	0.00	0.00
4.25	3851.9	10999.	4834936.	71.0	24805425.	11964115.	.482	100.00	0.00	0.00	0.00	0.00
4.50	3959.0	11976.	5020377.	73.7	24822450.	13196029.	.532	100.00	0.00	0.00	0.00	0.00
4.75	4062.7	12979.	5204551.	76.4	24839475.	14474145.	.583	100.00	0.00	0.00	0.00	0.00
5.00	4163.4	14007.	5388388.	79.1	24856500.	15798262.	.636	100.00	0.00	0.00	0.00	0.00
5.25	4261.2	15060.	5572524.	81.8	24873525.	17168376.	.690	100.00	0.00	0.00	0.00	0.00
5.50	4356.4	16137.	5757583.	84.5	24890550.	18584639.	.747	100.00	0.00	0.00	0.00	0.00
5.75	4449.1	17238.	5943757.	87.3	24907575.	20047307.	.805	100.00	0.00	0.00	0.00	0.00
6.00	4539.4	18362.	6132473.	90.1	24924600.	21556836.	.865	100.00	0.00	0.00	0.00	0.00
6.25	4627.6	19508.	6324632.	92.9	24941625.	23113974.	.927	100.00	0.00	0.00	0.00	0.00
6.50	4713.6	20675.	6521223.	95.8	24958650.	24719706.	.990	100.00	0.00	0.00	0.00	0.00
6.54	4725.9	20849.	6550765.	96.2	24961134.	24961273.	1.000	100.00	0.00	0.00	0.00	0.00
6.75	4797.7	21864.	6723691.	98.7	24975675.	26375320.	1.056	100.00	0.00	0.00	0.00	0.00
7.00	4880.0	23074.	6932772.	101.8	24992700.	28082378.	1.124	100.00	0.00	0.00	0.00	0.00
7.25	4960.4	24304.	7149478.	105.0	25009725.	29842659.	1.193	100.00	0.00	0.00	0.00	0.00
7.50	5039.2	25554.	7369612.	108.2	25026750.	31657546.	1.265	100.00	0.00	0.00	0.00	0.00
7.75	5116.4	26824.	7597479.	111.6	25043775.	33528432.	1.339	100.00	0.00	0.00	0.00	0.00
8.00	5192.0	28112.	7836022.	115.1	25060800.	35457620.	1.415	100.00	0.00	0.00	0.00	0.00

Table 2.7.1.3-1 Accident Side Drop, Fully Effective Overpack, Upper Bound Foam

SYDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 09.25.22 86/04/10

10/142 SIDE IMPACT WITH LOWER BOUND 20 PCF FOAM

PACKAGE WEIGHT = 68100. (LBS)
PACKAGE EXTERNAL LENGTH = 44.00 (IN)
PACKAGE EXTERNAL DIAMETER = 112.00 (IN)
PAYLOAD DIAMETER = 76.00 (IN)
DROP HEIGHT = 30.00 (FT)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	650.00
3	.07	850.00
4	.10	950.00
5	.20	1050.00
6	.25	1100.00
7	.30	1150.00
8	.40	1260.00
9	.45	1400.00
10	.50	1600.00
11	.60	2250.00
12	.70	3850.00
13	.75	5300.00
14	.80	7400.00

SYDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 09.25.22 86/04/10 PAGE 6

10/142 SIDE IMPACT WITH LOWER BOUND 20 PCF FOAM

	++ CRUSH PLANE ++		++++ IMPACT ++++		++++++ ENERGY ++++++			DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA				
CRUSH DEPTH (IN)	AREA (IN2)	VOLUME (IN3)	FORCE (LBS)	ACCEL. (G)	POTENTIAL (IN-LB)	STRAIN (IN-LB)	RATIO (SE/PE)	LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.50	657.1	219.	157389.	2.3	24550050.	39347.	.002	100.00	0.00	0.00	0.00	0.00
1.00	927.1	619.	444241.	6.5	24584100.	189755.	.008	100.00	0.00	0.00	0.00	0.00
1.50	1132.9	1136.	750843.	11.0	24618150.	488526.	.026	100.00	0.00	0.00	0.00	0.00
2.00	1305.3	1747.	992343.	14.6	24652200.	924322.	.037	100.00	0.00	0.00	0.00	0.00
2.50	1456.0	2438.	1199456.	17.6	24686250.	1472272.	.060	100.00	0.00	0.00	0.00	0.00
3.00	1591.3	3200.	1379316.	20.3	24720300.	2114965.	.086	100.00	0.00	0.00	0.00	0.00
3.50	1714.9	4027.	1538505.	22.6	24754350.	2846420.	.115	100.00	0.00	0.00	0.00	0.00
4.00	1829.0	4913.	1689126.	24.8	24788400.	3653328.	.147	100.00	0.00	0.00	0.00	0.00
4.50	1935.5	5855.	1836424.	27.0	24822450.	4534716.	.183	100.00	0.00	0.00	0.00	0.00
5.00	2035.4	6848.	1979796.	29.1	24856500.	5488771.	.221	100.00	0.00	0.00	0.00	0.00
5.50	2129.8	7889.	2119771.	31.1	24890550.	6513663.	.262	100.00	0.00	0.00	0.00	0.00
6.00	2219.3	8977.	2253919.	33.1	24924600.	7607085.	.305	100.00	0.00	0.00	0.00	0.00
6.50	2304.4	10108.	2385745.	35.0	24958650.	8767001.	.351	100.00	0.00	0.00	0.00	0.00
7.00	2385.8	11281.	2520813.	37.0	24992700.	9993641.	.400	100.00	0.00	0.00	0.00	0.00
7.50	2463.6	12493.	2666805.	39.2	25026750.	11290545.	.451	100.00	0.00	0.00	0.00	0.00
8.00	2538.3	13744.	2830274.	41.6	25060800.	12664815.	.505	100.00	0.00	0.00	0.00	0.00
8.50	2610.1	15031.	3012833.	44.2	25094850.	14125592.	.563	100.00	0.00	0.00	0.00	0.00
9.00	2679.3	16353.	3217701.	47.2	25128900.	15683225.	.624	100.00	0.00	0.00	0.00	0.00
9.50	2746.0	17710.	3443133.	50.6	25162950.	17348434.	.689	100.00	0.00	0.00	0.00	0.00
10.00	2810.5	19099.	3696383.	54.3	25197000.	19133313.	.759	100.00	0.00	0.00	0.00	0.00
10.50	2872.8	20520.	3991090.	58.6	25231050.	21055181.	.834	100.00	0.00	0.00	0.00	0.00
11.00	2933.2	21972.	4342110.	63.8	25265100.	23138481.	.916	100.00	0.00	0.00	0.00	0.00
11.47	2988.7	23376.	4743250.	69.7	25297349.	25297537.	1.000	100.00	0.00	0.00	0.00	0.00
11.50	2991.7	23453.	4765128.	70.0	25299150.	25415291.	1.005	100.00	0.00	0.00	0.00	0.00
12.00	3048.4	24963.	5283870.	77.6	25333200.	27927540.	1.102	100.00	0.00	0.00	0.00	0.00
12.50	3103.5	26501.	5923811.	87.0	25367250.	30729460.	1.211	100.00	0.00	0.00	0.00	0.00
13.00	3157.0	28066.	6710539.	98.5	25401300.	33888048.	1.334	84.00	16.00	0.00	0.00	0.00
13.50	3209.0	29658.	7676161.	112.7	25435350.	37484723.	1.474	76.00	24.00	0.00	0.00	0.00
14.00	3259.6	31275.	8858405.	130.1	25469400.	41618364.	1.634	71.00	29.00	0.00	0.00	0.00
14.50	3308.8	32917.	10250216.	150.5	25503450.	46395520.	1.819	67.00	25.00	8.00	0.00	0.00
15.00	3356.7	34583.	11297790.	165.9	25537500.	51782521.	2.028	63.00	19.00	18.00	0.00	0.00

Table 2.7.1.3-2 Accident Side Drop, Partially Effective Overpack, Lower Bound Foam

Table 2.7.1.3-3
Accident Side Drop, Closure Bolt Evaluation

Lid	Weight, W (lb)	Total Force $P = 96.2W$ (lb)	Number of Bolts, N	Force per bolt $P_b = P/N$ (lb)	Area per Bolt, A (in²)	Shear stress $\tau = P_b/A$ (psi)
Primary	7,200*	692,640	16	43,290	1.404	30,833
29 inch Secondary	1,800	173,160	16	10,823	0.969	11,169
16 inch Secondary	675	64,935	8	8,117	0.462	17,569

Lid	Maximum Pretorque, T (in-lb)	Bolt diameter, d (in)	Prestress σ (T/.2d)/A (psi)	Allowable Stresses (psi) Tensile, σ_a (.7S_u)	Allowable Stresses (psi) Shear, τ_a (.42S_u)	Interaction Equation $I = (\sigma/\sigma_a)^2 + (\tau/\tau_a)^2$	Margin of Safety M.S. = (1/I)-1
Primary	3900	1.5	9,259	101,500	60,900	.265	+2.78
29 inch Secondary	2520	1.25	10,402	101,500	60,900	.044	+21.7
16 inch Secondary	2520	.875	31,168	101,500	60,900	.178	+4.63

* Maximum combined weight of primary plus secondary lid

Table 2.7.1.3-3 Accident Side Drop, Closure Bolt Evaluation

2.7.2 Puncture

A 40 inch drop onto a 6 inch diameter pin can occur on three separate regions of the package, i.e., overpack area, ends and side walls between overpack.

Since the overpack is backed by side wall or end type construction any impact in this region would be less severe.

Using ORNL-NSIC-68 for the side wall evaluation, the puncture energy can be calculated:

$$t = (W/S)^{0.71}$$

Where: $S = 70{,}000 psi$ (A-516, Grade 70)
$W = 68{,}100 lbs$

$$t = (68{,}100/70{,}000)^{0.71}$$
$$t = 0.981$$

Margin of Safety:

$$M.S. = (1.00/0.981) - 1 = \underline{+0.02}$$

The ends of the package are constructed from two thicknesses of 3 inch steel plates for a total of 6 inches. From the above, it was shown that the 1 inch (A-516) steel sides backed by 3.5 inches of lead were shown to be adequate. For the sake of completeness, the following analysis is presented to substantiate the adequacy of the end plates.

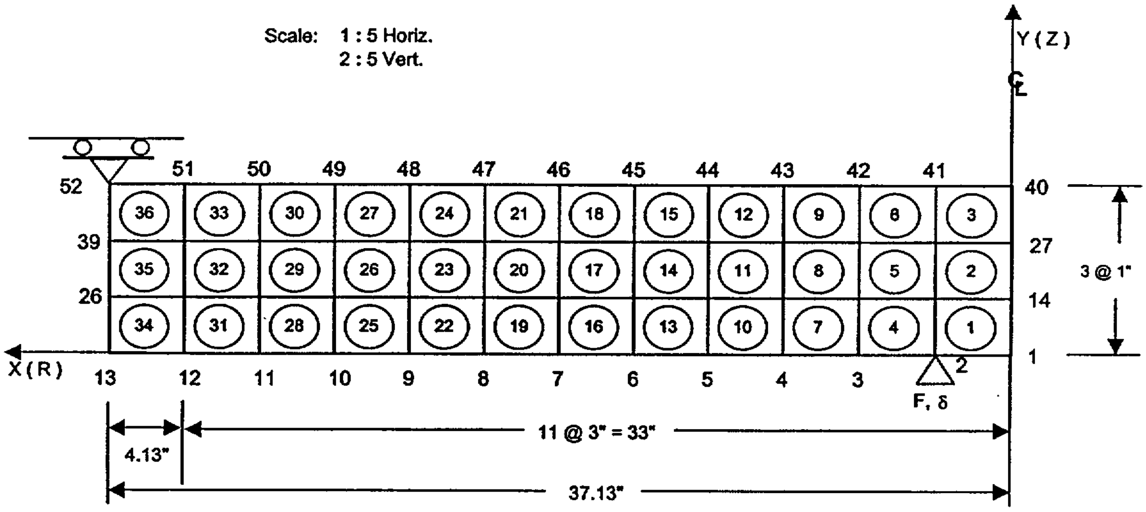
In order to demonstrate adequacy of the cylindrical flask overpack to withstand impact on a 6 inch diameter cylindrical pin, an 'ANSYS' finite element analysis of the circular end plates has been performed. The analysis approach considered both large deflection behavior of the circular plate and bilinear characteristics of the mild steel material.

The mathematical model is shown in Figure 2.7.2-1. This model consists of 52 nodes and 36 iso-parametric quadrilaterals (STIF42) representing an axi-symmetric plate of three inches thickness and 74.5 inches in diameter. The plate model was loaded by applying a series of prescribed displacements to node 2, corresponding to the contact perimeter of the 6 inch diameter puncture pin. At the outer diameter of the plates, node 52, the forces induced by this prescribed displacement were reacted in an axial fashion. No radial constraints were imposed upon the model except at the axis of symmetry.

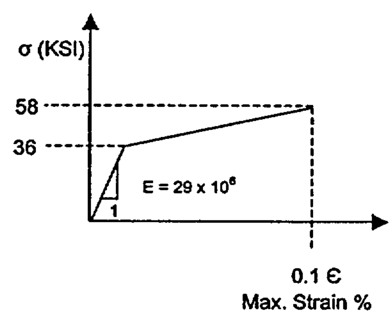
The conventional bilinear properties of mild steel used in this analysis are also shown in Figure 2.7.2-1. Importantly, this analysis assumed a conservative 10% value for strain at rupture.

The structural behavior of the plate at maximum pin penetration is shown in Figure 2.7.2-2. This figure illustrates strains and deformations at an *'ANSYS'* load step (imposed deformation) corresponding to the maximum deformation actually experienced by the plate. Figure 2.7.2-2 illustrates both deformed plate shape and effective strains for each of the 36 finite elements. On an effective strain basis, the roost severely strained element possesses a rupture margin of greater than + 0.66:, thus, no puncture occurs.

Maximum pin penetration (deformation of plate) was determined by plotting the load deformation characteristics of node 2 (the puncture pin diametrical location) as shown in Figure 2.7.2-3. Integrating this load-deformation relation, as shown in Figure 2.7.2-4, produces a description of plate strain energy versus deformation depth.



Bilinear Stress Strain Assumption:



* Rev. 2, UP 186

Figure 2.7.2-1 ANSYS* Flask End Plate Finite Element Model for Pin Impact

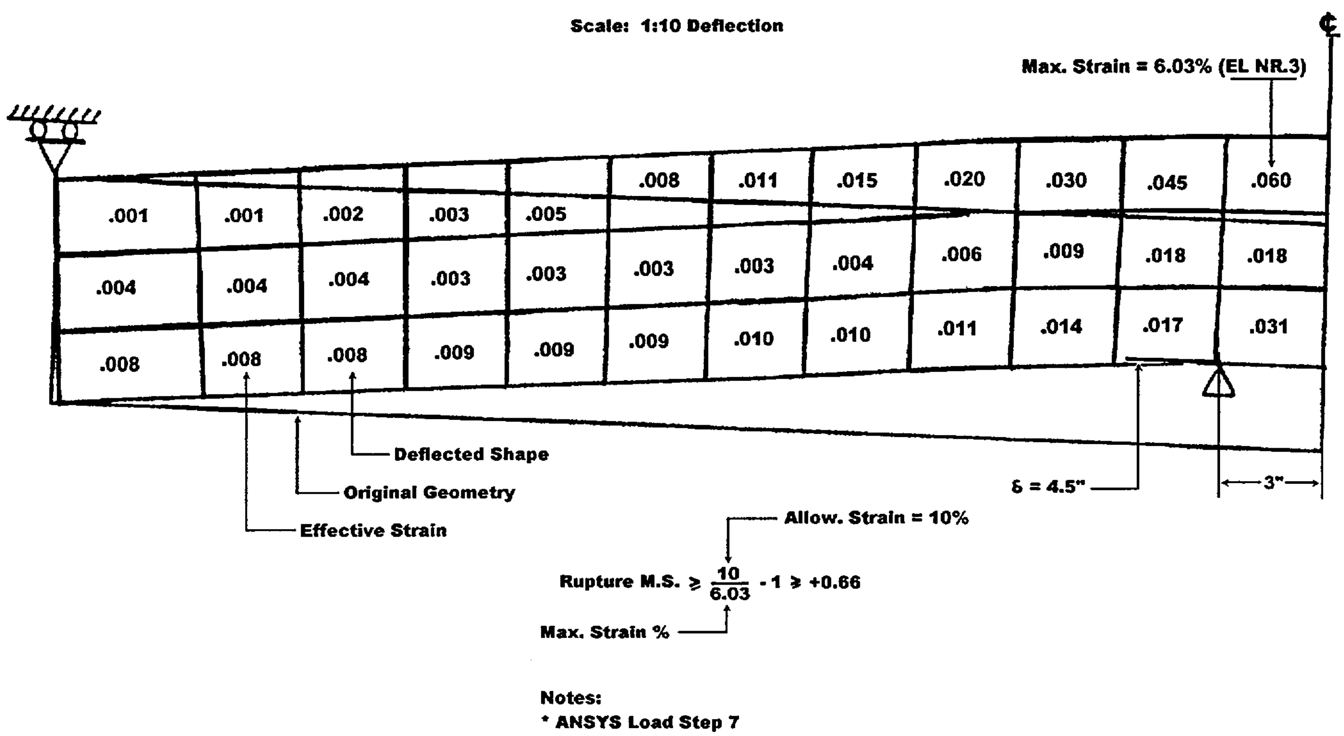


Figure 2.7.2-2 ANSYS Results At a Pin Deflection = 4.5 inches*

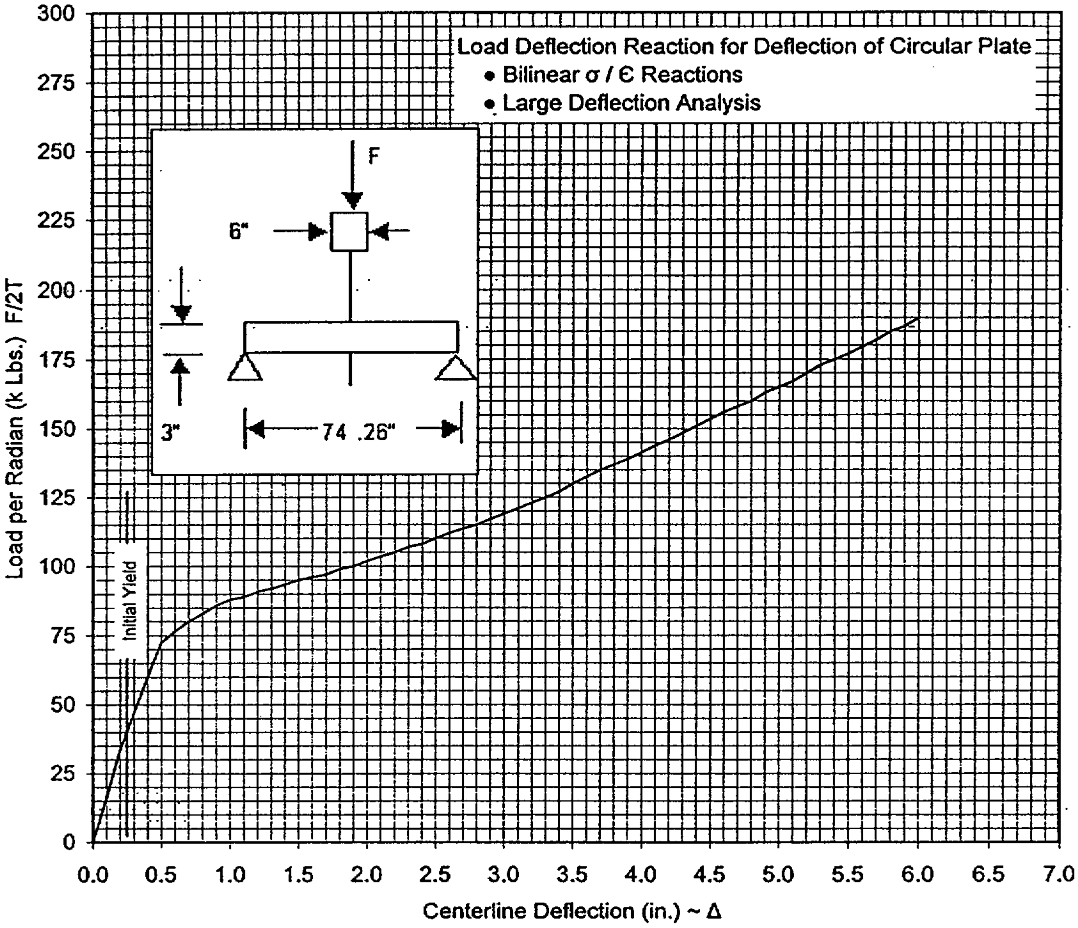

Load Deflection Reaction for Deflection of Circular Plate
• Bilinear σ / ∈ Reactions
• Large Deflection Analysis
F
6"
3"
74 .26"
Initial Yield
Load per Radian (k Lbs.) F/2T
300
275
250
225
200
175
150
125
100
75
50
25
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Centerline Deflection (in.) ~ Δ

Figure 2.7.2-3

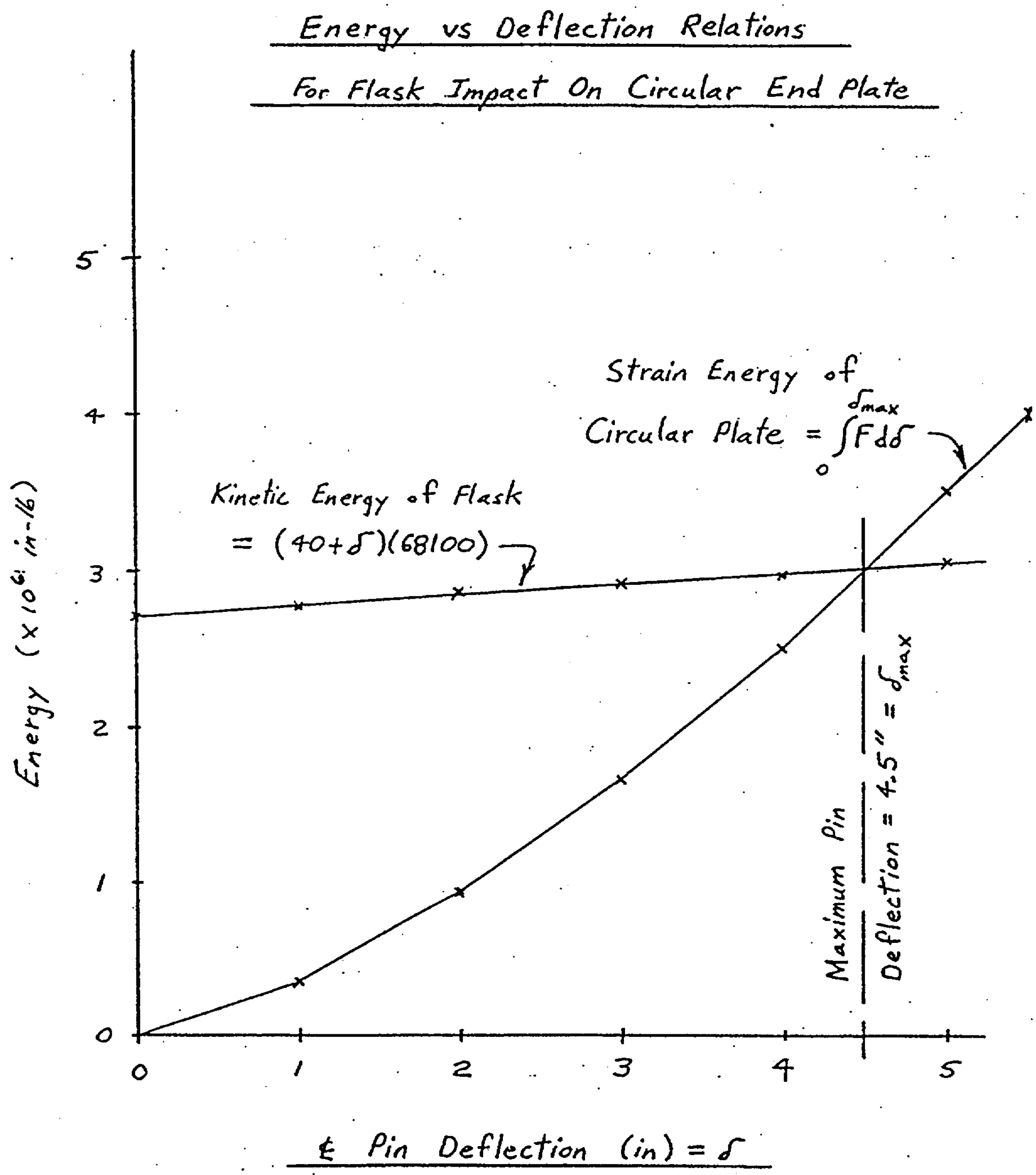

Energy vs Deflection Relations
For Flask Impact On Circular End Plate
Strain Energy of
Circular Plate = ∫₀^δmax F dδ
Kinetic Energy of Flask
= (40+δ)(68100)
Maximum Pin
Deflection = 4.5" = δmax
Energy (x 10⁶ in-lb)
0
1
2
3
4
5
0
1
2
3
4
5
℄ Pin Deflection (in) = δ

Figure 2.7.2-4

The kinetic energy relation of the dropped flask is also plotted on Figure 2.7.2-4. The intersection of these two energy relations defines the deformation depth at which the strain energy (or work done on the plate) equals the available kinetic energy. At this deformation depth, 4.5 inches, the deformation is arrested and can proceed no further.

2.7.3 Pressure Stress Calculations

If the package was assumed to contain water, it would experience an increase in internal pressure as a result of the hypothetical fire condition. From the thermal analysis in Section 3, it can be seen that the inside surface temperature of the package ranged from 187°F node 27 up to 457°F at node 10. Node 27 represents approximately 20% of the cask inside surface area and, as such, provides the condensation surface. These temperatures for the Albi-Clad model are higher than those for the thermal shield model.

Assume that the package was initially loaded at 70°F. Therefore, from the steam tables:

$$P_1 = 14.70psi(1atm) - 0.36psi$$
$$P_1 = 14.34psi$$
$$P_2 = 14.34psi(187° + 460°)/(70° + 460°)$$
$$P_2 = 17.50psi$$

From the tables for 187°F:

$$P_3 = 8.79psi$$
$$P_4 = P_3 + P_2$$
$$P_4 = 26.29psia$$

or a differential internal pressure of:

$$P_L = 26.29 - 14.70$$
$$P_L = 11.59psig$$

This will produce a load on the lid of:

$$F = (\pi d^2/4)P_1$$
$$= [\pi(66)^2/4]11.59psig$$
$$= 39651$$

or $F = 2478 lbs/bolt$

The corresponding bolt or stud stress, σ, is σ=F/A=F/1.404=1765 psi.

The allowable stress is $0.70S_\mu$ = 101,500 psi, thus the margin of safety is:

$M.S. = (101{,}500/1765) - 1 = \underline{+Large}.$

Assuming that the bolts or studs and nuts follow the temperature profile of the uninsulated external surface of the lid, their temperature never exceeds 500°F. The ASME Boiler and Pressure Vessel Code indicates that no significant loss of bolt or stud strength occurs at such temperatures for A354 Gr. BD, or A540 Gr. B24V Class 3 (large margins of safety remain large). By inspection, margins will also remain large for the secondary lid bolts or studs and nuts.

From Section 2.5.2 it was shown that a pressure of 25 psi generated a stress of only 4964 psi for one of the two 3 inch plates. Maximum temperature in this plate was 460°F. The ASME code indicates that the yield strength of the A516 Gr. 70 steel in the lid at 500°F is 30,700 psi. Therefore,

$$M.S. = [30{,}700 psi / 4964 psi] - 1 = +5.18$$

From the above it can be concluded that the package can safely resist the pressures generated from temperature effects.

2.8 Special Form

Since no special form is claimed, this section is not applicable.

2.9 Fuel Rods

Not applicable.

2.10 Appendix

Appendix 2.10 contains the following sections:

2.10.1 General Arrangement Drawings of Model 10-142 Packaging

2.10.2 Description of NuPac Proprietary Drop Programs

2.10.3 Primary Lid Closure Bolt Evaluation For 30 Foot Oblique Drops

APPENDIX 2.10.1

GENERAL ARRANGEMENT DRAWINGS OF MODEL 10-142 PACKAGING

This appendix contains:

Drawing X-103-110-SNP, Revision E, Sheets 1-5 (which constitutes SAR pages 2-60 through 2-64)

X-103-110-SNP SHT. 1

NOTES: UNLESS OTHERWISE SPECIFIED

1. MATERIAL: LOW CARBON HOT ROLLED STEEL:
   PLATE & SHAPES CONFORM TO ASTM-A516, GR 70
   SHEETS CONFORM TO ASTM-A569, A570, A36 OR TYPE
   304 SST PER ASTM-A240

2. MATERIAL: ASTM-A514 OR ASTM-A517 ANY GRADE.

3. FOAM: 1,000 PSI CRUSH STRENGTH RIGID POLYURETHANE PER NUPAC FOAM, SPECIFICATION NPI.F6.

4. LEAD: PER FEDERAL SPECIFICATION QQ-L-171E, GRADE A OR C.

5. REFERENCE DATA: CASK WT: 58,100 LBS
   PAY LOAD: 10,000 LBS
   GROSS WT: 68,100 LBS

6. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME CODE, SECTION IX. (ALL STANLESS STEEL MATERIAL WELDING SHALL BE PERFORMED PER ASME, CODE SECTION IX.) WELD PROCEDURES AND WELDER QUALIFICATIONS SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

7. ALL WELDS SHALL BE INSPECTED VIA NDT METHODS AS FOLLOWS:
   LIFTING LUG AND CIRCUMFERENTIAL CONTINUOUS WELDS: MAGNETIC PARTICLE PER ASME CODE SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 7. LIQUID PENETRANT NDT SHALL BE SUBSTITUTED FOR MAGNETIC PARTICLE ON STAINLESS STEEL WELDS PER ASME CODE SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V ARTICLE 6.
   LONGITUDINAL SHELL WELD: RADIOGRAPHIC PER ASME CODE SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 2, OR ULTRASONIC PER ASME CODE, SECTION III, DIVISION I, SUBSECTION NB, ARTICLE NB-5000, PARA NB 5330 AND SECTION V, ARTICLE 5.

8. CLADDING OPTION: 12 GA TYPE 304 STAINLESS STEEL CLADDING MAY BE INSTALLED ON THE INTERIOR & EXTERIOR SURFACES OF THE CASK BODY & INTERIOR SURFACES OF THE UPPER LID. CLADDING SHALL BE SEAL WELDED ALONG ALL EDGES & SEAMS. THICKER CLADDING MAY BE INSTALLED IN THE LID INTERFACE AREAS AND MACHINED TO OBTAIN SPECIFIED CLEARANCES. WELD METAL MAY ALSO BE DEPOSITED AND MACHINED IN THESE AREAS IN LIEU OF SHEET/PLATE MATERIAL.

9. PAINT ALL EXPOSED CARBON STEEL SURFACES WITH ONE COAT CARBONZINC 11 & ONE COAT PHENOLINE 305, OR ONE PRIMER COAT (3-5 MILS) MOBIL CHEM EPOXY NO. 89 & ONE FINISH COAT (3-5 MILS) MOBIL CHEM EPOXY NO. 89 OR ONE PRIMER COAT (3-5 MILS) TNEMEC 66 SERIES AND ONE FINISH COAT (3-5 MILS) TNEMEC 66 SERIES.

10. COAT ALL EXPOSED EXTERIOR SURFACES OF FLASK BETWEEN UPPER AND LOWER OVERPACKS WITH ONE (1) COAT (MIN 3/16 THICK) "ALBI-CLAD" NO. 89 AS AN OPTION, A 10 GA TYPE 304 STAINLESS STEEL THERMAL SHIELD MAY BE INSTALLED BETWEEN THE OVERPACKS.

11. NOMINAL AIR GAP (MINIMUM .05 IN., MAXIMUM .42 IN.)

12. PACKAGE SHALL BE MARKED & IDENTIFIED IN ACCORDANCE WITH THE REQUIREMENTS OF 10 CFR 71.85(c).

13. PRIMARY & SECONDARY LIDS & DRAIN SHALL BE EQUIPPED WITH TAMPER INDICATING DEVICES IN ACCORDANCE WITH 10 CFR 71.43(b).

15. JOINTS & SEAMS SHOWN ARE THE PREFERRED CONFIGURATION. DUE TO VARYING FABRICATOR CAPABILITIES, SPECIFIC JOINT/SEAM CONFIGURATION SHALL BE CONTROLLED ONLY TO THE EXTENT THAT IT AGREES DIMENSIONALLY WITH THE DESIGN & THAT MATERIALS SHALL BE AS SPECIFIED.

16. TORQUE PRIMARY LID FASTENERS (1-1/2-6UNC) TO 300 ±25 FT-LBS (LUBRICATED).

17. TORQUE SECONDARY LID FASTENERS TO 200 ±10 FT-LBS (LUBRICATED).

18. EITHER OPTION A OR OPTION B USED ON A PARTICULAR PACKAGE BUT NOT BOTH.

19. 29" LID 1-1/4-7UNC ASTM-A354 GR BD OR A540 GR B24V CLASS III THREAD ENGAGEMENT = 2.00 INCHES MINIMUM.

    16" LID 7/8-9UNC, ASTM-A354 GR BD OR A540 GR B24V CLASS III THREAD ENGAGEMENT = 1.25 INCHES MINIMUM.

20. PRIMARY AND SECONDARY LID FASTENERS & INDEX PIN LOCATIONS SHALL BE GUARANTEED BY MATCH DRILLING ASSEMBLIES.

21. THE FABRICATION OF THIS PACKAGE SHALL BE CONTROLLED IN STRICT ACCORDANCE WITH THE NUCLEAR PACKAGING QUALITY ASSURANCE SYSTEM, USNRC APPROVAL NO. 0192.

22. ADDITIONAL PERIODIC SPACERS MAY BE PLACED AT RANDOM LOCATIONS IN ORDER TO GUARANTEE THE MINIMUM AIR GAP.THE CUMULATIVE SPACER AREA SHALL NOT EXCEED 5% OF THE ENTIRE EXPOSED THERMAL SHIELD SURFACE.

23. OVERPACK LUG HOLE $1.125^{+0.125}_{-0.010}$ DIA. THROUGH 3/4" PLATE.

24. UNLESS OTHERWISE SPECIFIED, TOLERANCES SHALL BE

FRACTIONS	1 PL DEC	2 PL DEC	3 PL DEC	ANGLES
±1/8	±0.1	±0.03	±0.010	±1°

REV.	DATE	DESCRIPTION	ENGR	CHKD	OPS	QA	APPD
E	5/31/02	TRANSFERRED TO CADD; ADDED TOLERANCES; CLARIFIED FASTENERS SUPERSEDES X-103-110-SP, REV J	ALP	RWE	KLH	SP	ALP
D	11/2/87	SEE DCN	GLC	RB	DSH	JO	WRB

INTERPRET DWG PER ASME Y14.5M
DIM. IN INCHES BASED ON 68°F
UNLESS OTHERWISE SPECIFIED TOLERANCES

FRACTIONS	2 PL DEC	3 PL DEC	ANGLES	125
24	24	24	24	AA

BREAK ALL SHARP EDGES
FILLET RADII .03 MAX
THIRD ANGLE PROJECTION

ROLE	NAME	DATE
LICENSING	A.L.PATKO	5/31/02
DRAFTER	F.STEINER	4/2/86
ENGINEER	SIGNATURE ON FILE	5/31/02
CHECKER	D.KENT	4/2/86
OPERATIONS	SIGNATURE ON FILE	4/2/86
QA	J.OLIVADOTI	4/2/86
APPROVED	C.TEMUS	4/2/86

ATG NUCLEAR SERVICES

ATG FILE NUMBER: X-103-110-SNP-1

BULK RESIN SHIPPING CASK
MODEL 10-142
BOLT ON LID CONFIGURATION

SIZE: D | DRAWING NUMBER: X-103-110-SNP | REV: E

SCALE: NONE | SHEET 1 OF 5

FIGURE WITHHELD UNDER 10 CFR 2.390

INTERPRET DWG PER ASME Y14.5M	ATG NUCLEAR SERVICES
DIM. IN INCHES BASED ON 68°F	
UNLESS OTHERWISE SPECIFIED TOLERANCES	
FRACTIONS: 24 / 2 PL DEC: 24 / 3 PL DEC: 24 / ANGLES: 24 / 125 AA	ATG FILE NUMBER: X-103-110-SNP-2
BREAK ALL SHARP EDGES	BOLT ON LID CONFIGURATION MODEL 10-142 BULK RESIN SHIPPING CASK
FILLET RADII .03 MAX	
THIRD ANGLE PROJECTION	SIZE: D / DRAWING NUMBER: X-103-110-SNP / REV: E
	SCALE: NONE / SHEET 2 OF 5

FIGURE WITHHELD UNDER 10 CFR 2.390

INTERPRET DWG PER ASME Y14.5M	ATG NUCLEAR SERVICES
DIM. IN INCHES BASED ON 68°F	
UNLESS OTHERWISE SPECIFIED TOLERANCES	
FRACTIONS: 24 · 2 PL DEC: 24 · 3 PL DEC: 24 · ANGLES: 24 · 125 √ AA	ATG FILE NUMBER: X-103-110-SNP-3
BREAK ALL SHARP EDGES	BULK RESIN SHIPPING CASK MODEL 10-142 BOLT ON LID CONFIGURATION
FILLET RADII .03 MAX	
THIRD ANGLE PROJECTION	SIZE: D · DRAWING NUMBER: X-103-110-SNP · REV: E
	SCALE: NONE · SHEET 3 OF 5

FIGURE WITHHELD UNDER 10 CFR 2.390

INTERPRET DWG PER ASME Y14.5M

DIM. IN INCHES BASED ON 68°F

UNLESS OTHERWISE SPECIFIED TOLERANCES

FRACTIONS	2 PL DEC	3 PL DEC	ANGLES	125
24	24	24	24	AA

BREAK ALL SHARP EDGES

FILLET RADII .03 MAX

THIRD ANGLE PROJECTION

ATG NUCLEAR SERVICES

ATG FILE NUMBER: X-103-110-SNP-4

BULK RESIN SHIPPING CASK
MODEL 10-142
BOLT ON LID CONFIGURATION

SIZE: D | DRAWING NUMBER: X-103-110-SNP | REV: E

SCALE: NONE | SHEET 4 OF 5

FIGURE WITHHELD UNDER 10 CFR 2.390

INTERPRET DWG PER ASME Y14.5M	ATG NUCLEAR SERVICES
DIM. IN INCHES BASED ON 68°F	
UNLESS OTHERWISE SPECIFIED TOLERANCES	
FRACTIONS / 2 PL DEC / 3 PL DEC / ANGLES / 125	ATG FILE NUMBER: X-103-110-SNP-5
24 / 24 / 24 / 24	BULK RESIN SHIPPING CASK MODEL 10-142 BOLT ON LID CONFIGURATION
BREAK ALL SHARP EDGES	
FILLET RADII .03 MAX	
THIRD ANGLE PROJECTION	SIZE: D / DRAWING NUMBER: X-103-110-SNP / REV: E
	SCALE: NONE / SHEET 5 OF 5

APPENDIX 2.10.2

DESCRIPTION OF NUPAC

PROPRIETARY DROP PROGRAMS

2.10.2 Description of NuPac Proprietary Drop Programs

This section briefly documents the methodology employed, by the NuPac proprietary computer programs which are used to demonstrate compliance of the package with applicable provisions of 10 CFR 71 for normal and hypothetical accident conditions. The first two subsections deal with the calculation of external and internal forces imposed upon the package, when subjected to drop events. A sample problem is then presented and the NuPac computer code quality assurance program is briefly discussed. These subsections describe techniques and computer programs developed by Nuclear Packaging, Inc. of Federal Way, Washington, as follows:

- 2.10.2.1: Describes derivation of energy absorbing overpack load-deflection relations.
- 2.10.2.2: Describes the methods to evaluate the dynamic behavior of oblique impacts and the associated internal forces generated within the cask body.
- 2.10.2.3: Describes a sample problem, and input and output for each of the four computer codes (EYDROP, SYDROP, CYDROP, and OBLIQUE) discussed in this section.
- 2.10.2.4: Describes the quality assurance program utilized to maintain NuPac computer codes.

2.10.2.1 Overpack Deformation Behavior

The package is protected by foam-filled, energy-absorbing end buffers, called overpacks. For purposes of analysis, the overpacks are assumed to absorb, in plastic deformation of foam, the potential energy of the drop event. That is, the analyses assume that none of the drop potential energy is transferred to kinetic or strain energy of the target (the unyielding surface assumption of 10 CFR 71), nor strain energy in the package body itself.

There are three orientations of the package where the potential energy of a drop is assumed totally absorbed by plastic deformations of the overpacks. At other orientations, where rotational effects are important, the methods outlined in Section 2.10.2.2 are employed. The three orientations where rotational (or pitch) motions play no role in the evaluation of the impact event are:

- End Drop - on the circular end surface of the overpact.
- Side Drop - on the cylindrical side surfaces of the overpacts.
- Corner Drop - with package center of gravity directly above the struck corner of the overpack.

For these three orientations, the prediction of overpack behavior can be approached from straightforward energy balance principles:

$$E = W(h+\delta) = \int_0^{\delta} F_x dx \qquad (1)$$

Where:

W = package weight
h = drop height
δ = maximum overpack deformation
F_x = force imposed upon target and package by the overpack at a deflection equal to x.

The left-hand term represents the potential energy of the drop. The right-hand term represents the strain energy of the deformed overpack.

Each of these three orientations is treated by an individual computer program reflecting the differing geometry characteristics of each event. All three computer programs employ common energy balance techniques to assess maximum overpack deformations, including utilizing a common description of the crushable energy absorbing foam. The foam typically exhibits a stress-strain plateau of nearly constant stress up to a total strain of 40-60%. Above this strain value, pronounced strain hardening effects commence which reflect the collapse or consolidation of the entrapped bubbles within the foam. Accordingly, a tabular definition of foam stress-strain relations is employed in each of the three computer programs. This tabular definition is taken directly from measured properties and accurately reflects the strain hardening behavior of the foam up to strains of about 80%.

The following discussion of these three computer programs proceeds from the geometrically simplest (end drop) to the most complex (corner drop).

2.10.2.1.1 End Drop (EYDROP)

EYDROP performs the calculations outlined in Equations (1), (2), and (3) for a trial range of deformation values, δ. For each trial value of total deformation, the energy balance of Equation (1) is monitored and reported. Solution for total overpack deformation is found by an interpolated balance of Equation (1). EYDROP assumes a constant foam strain across the crush area, neglecting the affects of any unbacked areas. A sample problem input and output for EYDROP may be found in Section 2.10.2.3.1.

The force produced by the overpack is simply:

$$F_x = A\sigma_\varepsilon \qquad (2)$$

Where:

$A = \pi D^2/4$, the end area of the package

D= effective diameter of package

$\sigma_\varepsilon = \xi[\varepsilon]$, the foam crush stress at a strain of ε (3)

$\xi[\varepsilon]$ = the tabular definition of foam stress strain properties

$\varepsilon = x/x_u$

x= deformation

x_u= end thickness of overpack

2.10.2.1.2 Side Drop (SYDROP)

SYDROP differs from the end drop solution only in the fact that both deformation and strain vary from point to point and total force, at a given crush depth, must be found by geometric integration over these points. The details on this geometry are found in Figure 2.10.2.1-1. SYDROP assumes all foam is backed, exhibiting homogeneous properties along the package length. A sample problem input and output for SYDROP may be found in Section 2.10.2.3.2.

For each trial deformation value, the force is found as:

$$F_\delta = 2L \int_0^{X_{max}} \sigma_{\varepsilon x} dx$$

Where:

L = effective length of the overpack

$X_{max} = [r_o^2 - (r_o - \delta)^2]^{0.5}$

$\sigma_{\varepsilon x} = \xi[\varepsilon_x]$, tabular definition of foam stress-strain properties

ε_x = foam strain at location 'x'

Referring to Figure 2.10.2.1-1, the strain at a point 'x' is found by:

$$\varepsilon_x = [\delta - r_o(1 - \cos\theta)]/[r_o(\cos\theta) - r_i(\cos\gamma)]$$

Where:

$$\theta = \sin^{-1}(x/r_o)$$

$$\gamma = \sin^{-1}(x/r_i)$$

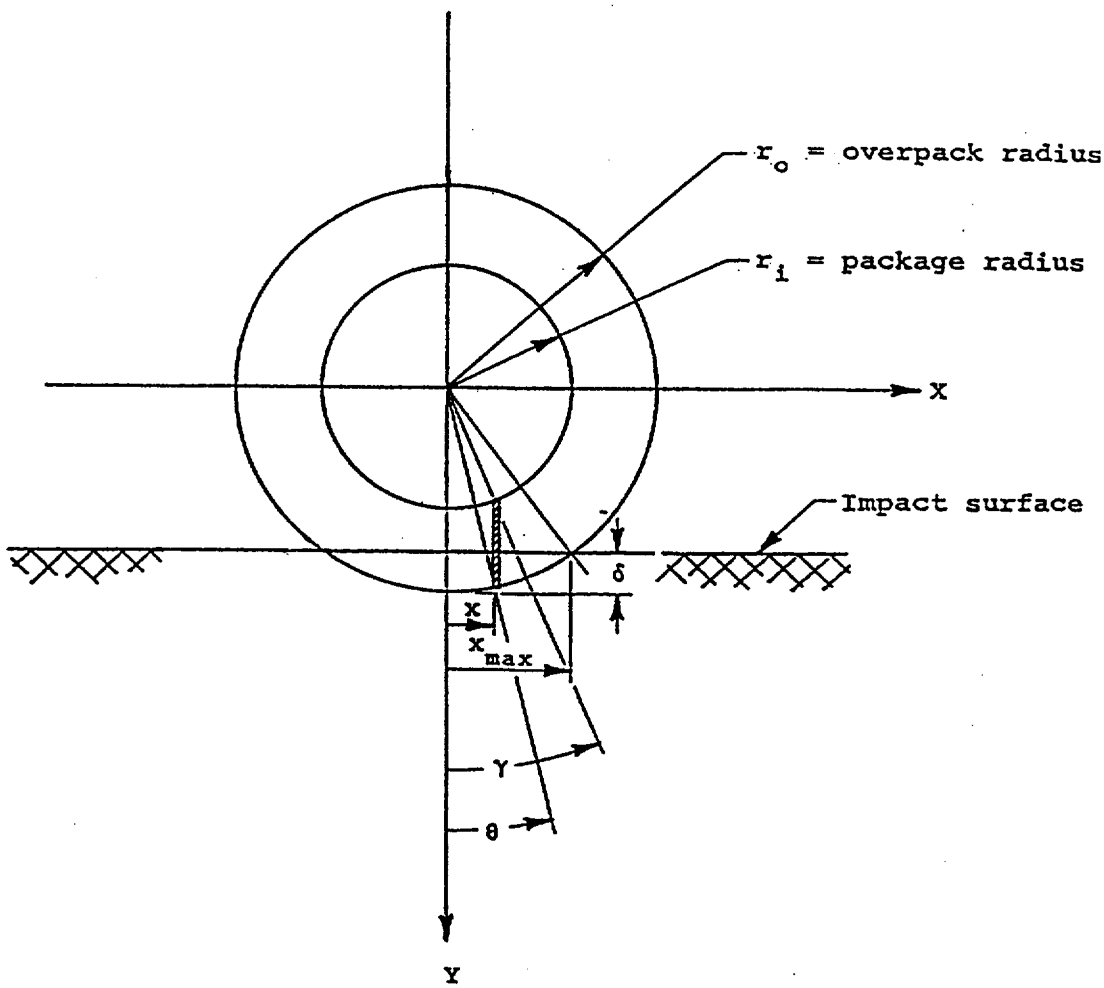


Figure 2.10.2.1-1 Side Impact Geometry (SYDROP)

2.10.2.1.3 Corner Drop (CYDROP)

CYDROP is similar to SYDROP, excepting that a two dimensional geometric integration is required to assess the overpack crush force at each deformation. A sample problem input and output for CYDROP may be found in Section 2.10.2.3.3.

CYDROP treats the corner impact of a cylindrical package upon an unyielding surface. The package itself consists of a cylindrical payload portion surrounded by a larger cylindrical column composed of a crushable media. So long as the deformations of the crushable media are modest, the problem may be approximately solved by assuming a uniform crush stress exists over the elliptical surface of the crush plane (contact surface). CYDROP was developed specifically to address problems of large deformations of this crushable media and to treat geometries where the cylindrical overpack envelope possesses axisymmetric cylindrical voids (e.g., does not completely cover the cylindrical ends of the payload package).

The large deformation behavior of the crushable media is accommodated by determining the actual strain of the crushable media at a point. This strain is used to determine the corresponding stress from an implicit tabular definition of media stress-strain characteristics. The total crush force is found by a double integration over the contact area of the crush plane.

Strain energy absorbed by the crushable media is determined by integrating the crush force and its associated deformation. The package is assumed to be at rest when the computed strain energy value equals the applied drop energy.

The geometric calculations for the contact surface and the associated strains are carried out using a moving (x, y, z) coordinate system in which the x-y plane corresponds to the crush plane, as illustrated in Figure 2.10.2.1-2. The crush plane itself represents a segment of an ellipse. The contact area is this ellipse segment, provided no cylindrical end void exists. When a cylindrical end void exists, the contact area of the crush plane is reduced by the removal of a second elliptical region associated with the projection of this void into the contact plane.

Calculation of strain is somewhat more complex. In principle, the distance from point (x, y) in the crush plane to the payload is found and denoted, Z_{top}. Similarly, the distance to the undeformed external overpack envelope is found and denoted, Z_{bot}. The strain represents deformation divided by original thickness, or:

$$\varepsilon = Z_{bot}/(Z_{bot} + Z_{top})$$

At any point (x, y), the calculation of Z_{top} may follow three branches, according to location. The three possible branches relate to the payload surface intercepted. They are the circular bottom of the payload, the cylindrical surface of the payload, and the unbacked regions, each of which are separately addressed below:

The Circular Bottom of the Payload:

The bottom of the payload cylinder describes an ellipse in the crush plane. If point (x, y) is inside this ellipse, the point is considered backed by the bottom of the payload. An exception to this general statement is noted in the discussion of the unbacked region, below.

The Cylindrical Surface of the Payload:

The cylindrical surface of the payload describes a rectangular region tangent to the payload bottom ellipse at its major axes. If point (x, y) is outside the bottom ellipse yet possesses an x-coordinate less than the radius of the payload bottom, the point is considered backed by the payload cylinder.

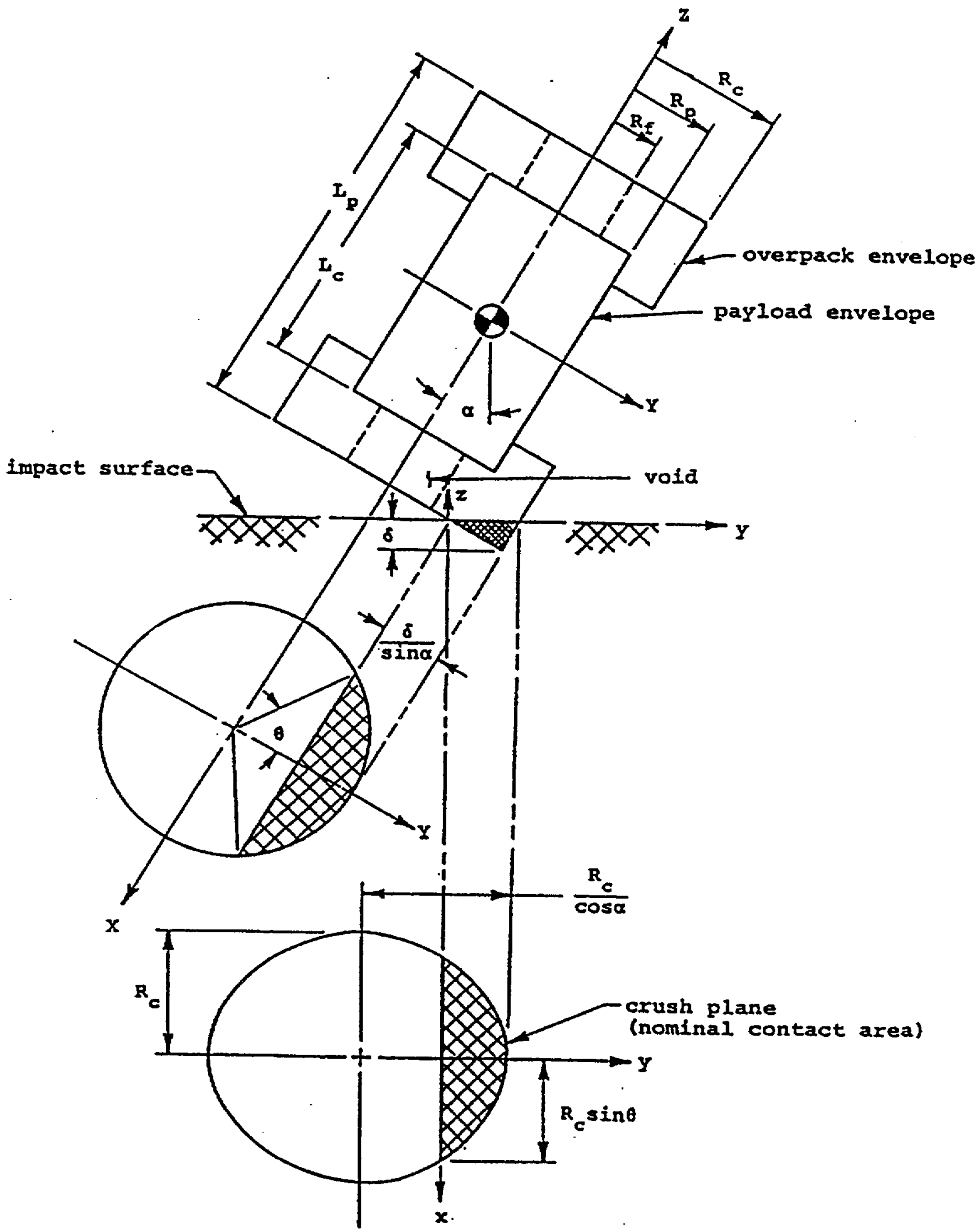


FIGURE 2.10.2.1-2 Corner Impact Geometry (CYDROP)

Unbacked Regions:

Unbacked regions are of two forms – those associated with the cylindrical end void and those near the external surface of the overpack. The unbacked region associated with the end void is a point in the crush plane which lies within the ellipse defined by the void circle lying in the plane of the payload bottom. The unbacked region associated with points near the overpack extremities is defined by those points (x, y) where the x-coordinate exceeds the radius of the payload volume. By default, points which are unbacked employ a nominal crash stress for force integration purposes. As an option, the unbacked regions can be treated as having no energy absorbing capability.

The calculation of Z_{bot}, the distance to the undeformed overpack envelope, may follow two branches. These branches correspond to intercepts with either the cylindrical surface of the overpack or the circular end of the overpack.

The analytics describing the geometry discussed above, consists of the sequential application of a series of geometric transformations of surfaces described in the coordinates of the cylindrical package (X, Y, Z) to the coordinates of the contact plane (x, y, z). The surfaces in package coordinates are:

Overpack Cylinder: $X^2 + Y^2 = R_c^2$

Overpack Bottom Circle: $X^2 + Y^2 = R_c^2$
$Z = -L_c/2$

Payload Cylinder: $X^2 + Y^2 = R_p^2$

Payload Bottom Circle: $X^2 + Y^2 = R_p^2$
$Z = -L_p/2$

Void Circle at Payload: $X^2 + Y^2 = R_f^2$
$Z = -L_p/2$

Void Circle at Overpack Exterior: $X^2 + Y^2 = R_f^2$
$Z = -L_c/2$

CYDROP also performs a sensitivity analysis to determine the amount of unbacked foam at each incremental crush depth. Additionally, this calculation is carried over to the impact force and strain energy. The code automatically prints a warning message if the foam strain exceeds 80% and the ratio of foam strain energy to kinetic energy is less than one (SE/KE<1).

2.10.2.2 Oblique Impact Dynamic Analysis

Impacts at arbitrary orientation angles differ in two major respects from those that occur at angles corresponding to stable or neutral equilibrium (end, side, and center of gravity over struck corner). In the neutral and stable equilibrium conditions, the entire initial kinetic energy of drop is transformed into strain energy associated with plastic deformation of the overpack. At arbitrary orientation angles, only a portion of this kinetic energy is transformed into strain energy at the impacted end. The remainder of this kinetic energy becomes rotational motion of the package. The solution approach must properly reflect the continually changing transformation of initial translational kinetic energy into rotational kinetic energy and plastic deformation of the overpack energy absorber.

The second major difference between neutral equilibrium impacts and arbitrary angle impacts relates to the rather different load-deflection behavior of the overpacks at low angle (<30° from horizontal) orientations. Under neutral equilibrium conditions, a major portion of the crush footprint is backed by the cylindrical body of the package, allowing strain hardening effects to stiffen the overpack load-deflection relation. At low angle orientations (<30° from horizontal), much of the overpack crush footprint is unbacked. Thus, the low angle load-deflection relations are initially quite soft, then abruptly harden as portions of the crush footprint grow into backed regions. As these low angle orientations approach horizontal attitudes, this terminal stiffening phenomena becomes more pronounced.

There are two potential solution paths to problems of this nature – a momentum formulation or a direct solution of the equations of motion. The momentum approach provides an easy and simple means to assess the transformation of translational initial velocities into rotary velocities, hence, total plastic strain energy absorbed by the overpack energy absorber. Unfortunately, this momentum formulation does not produce intermediate values of crush force and crush deformation needed to assess overpack attachment forces, nor does it conveniently provide a means to incorporate the varying load-deflection relationships of the overpack as a function of orientation angle. Thus, a direct solution of the equations of motion was selected.

The three key problem variables, crush force, F, crush depth, δ, and orientation angle, θ, all vary with time, t, for a given initial orientation angle, θ_o. The crush force is assumed to act at the centroid of the elliptical crash footprint. For the model illustrated in Figure 2.10.2.2-1, three independent second order differential equations of motion can be formed:

$$M(\partial^2 X/\partial t^2) = F_x$$

$$M(\partial^2 Y/\partial t^2) = F_y - Mg$$

$$I(\partial^2 \theta/\partial t^2) = \{[\delta(a-c)/c(\sin\theta) + T_B + L/2](\sin\theta)\}F_x + \{\bar{x} - [\delta(a-c)/c(\sin\theta) + T_B + L/2](\cos\theta)\}F_y$$

Where:

M	=	the package mass = ρL
F	=	the crush force
g	=	the gravitational constant = 386.4 in/sec^2
I	=	the rotational mass moment of inertia (as input)
r_o	=	the radius of the body
L	=	the length of the body
T_B	=	overpack bottom thickness
θ	=	the instantaneous orientation angle of the package with respect to the horizon
ρ	=	the mass per unit length

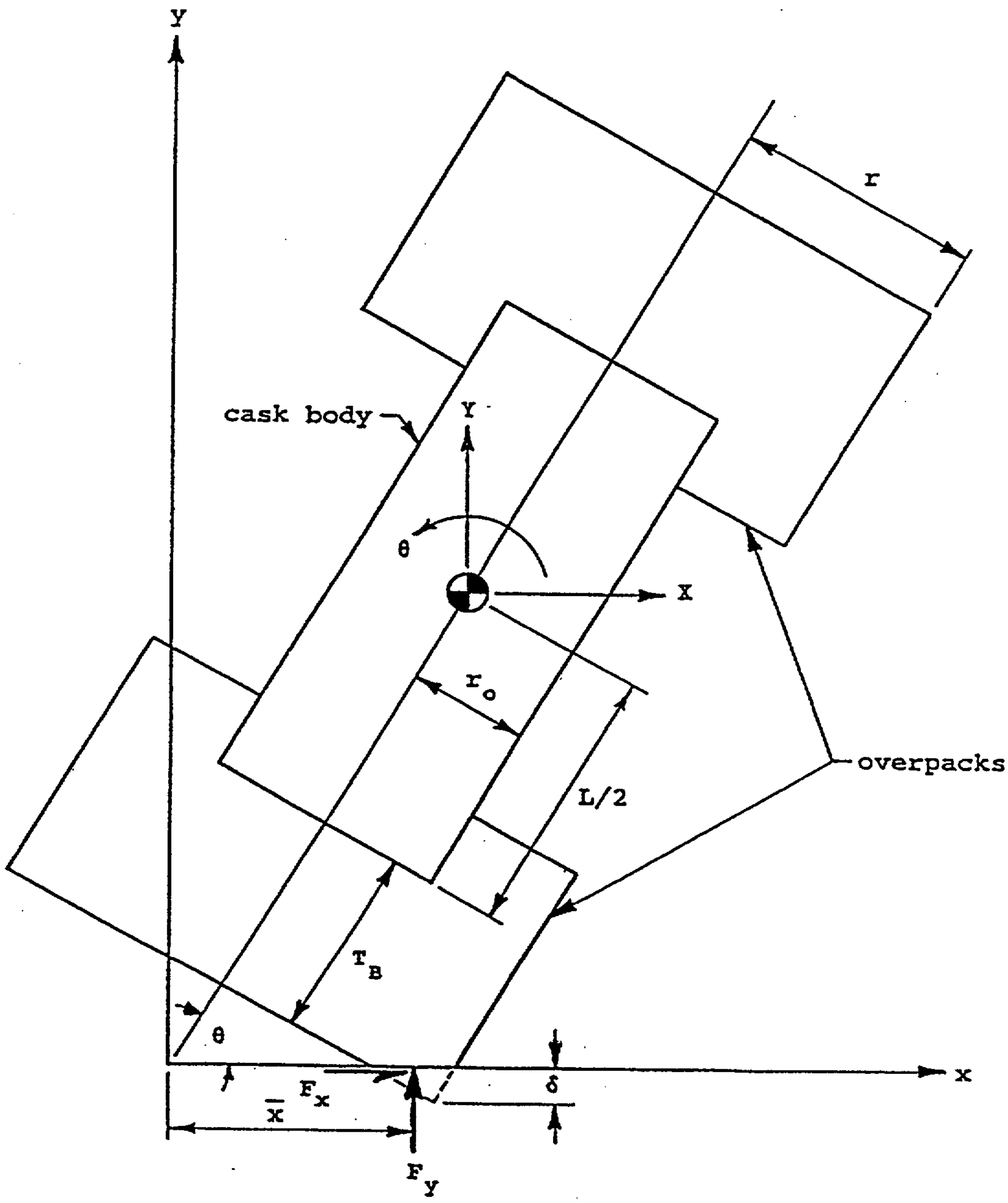


Figure 2.10.2.2-1 Oblique Impact Geometry

$\bar{x}$ = distance to centroid of footprint

a, c = geometric quantities defined in Figure 2.10.2.2-2

These differential equations are integrated subject to initial conditions, associated with the moment of impact when time, t, equals zero, of:

$X = 0$

$Y = 0$

$\theta = \theta_o$

$\partial X/\partial t = \partial X_o/\partial t$

$\partial Y/\partial t = \partial Y_o/\partial t$

$\partial \theta/\partial t = \partial \theta_o/\partial t$

Where:

θ_o = impact angle (varies with time, t)

$\partial Y_o/\partial t = (2gh)^{0.5}$

h = drop height

Each of the above differential equations requires a continuously updated value of the force, F, reflecting both crush depth and package orientation, or:

$$F = \xi(\delta_y, \theta)$$

This continuously updated value of the force, F, is supplied to the integration process by means of a two dimensional Lagrangian interpolation of crush depth, δ_y, and orientation angle, θ. The tabular data used in this interpolation consist of a series of complete force-deflection relations for separate orientation angles developed via the CYDROP computer program, described in Section 2.10.2.1.3. The deflection, δ_y, is expressed in terms of problem variables as:

$$\delta_y = L(\sin\theta - \sin\theta_o)/2 + r_o(\cos\theta - \cos\theta_o) - Y$$

The foregoing analysis process for evaluating impacts at oblique orientations was consolidated in a NuPac developed computer program, OBLIQUE. OBLIQUE integrates the equations of motion for each value of orientation angle versus time, until maximum values are found for crush force, crush deformation, shear, and body bending moment. At each incremental time step (incremental crush deformation), overpack attachment moments are computed, scanned for maximum values and output. By sweeping through a series of initial orientation angles, the maximum values of all internal loads are found. At each specified initial orientation angle, a solution is realized when all internal forces, moments, and deflection have reached a maximum value. Note that these internal forces, moments, and deflections do not necessarily happen at the same instantaneous angle, θ.

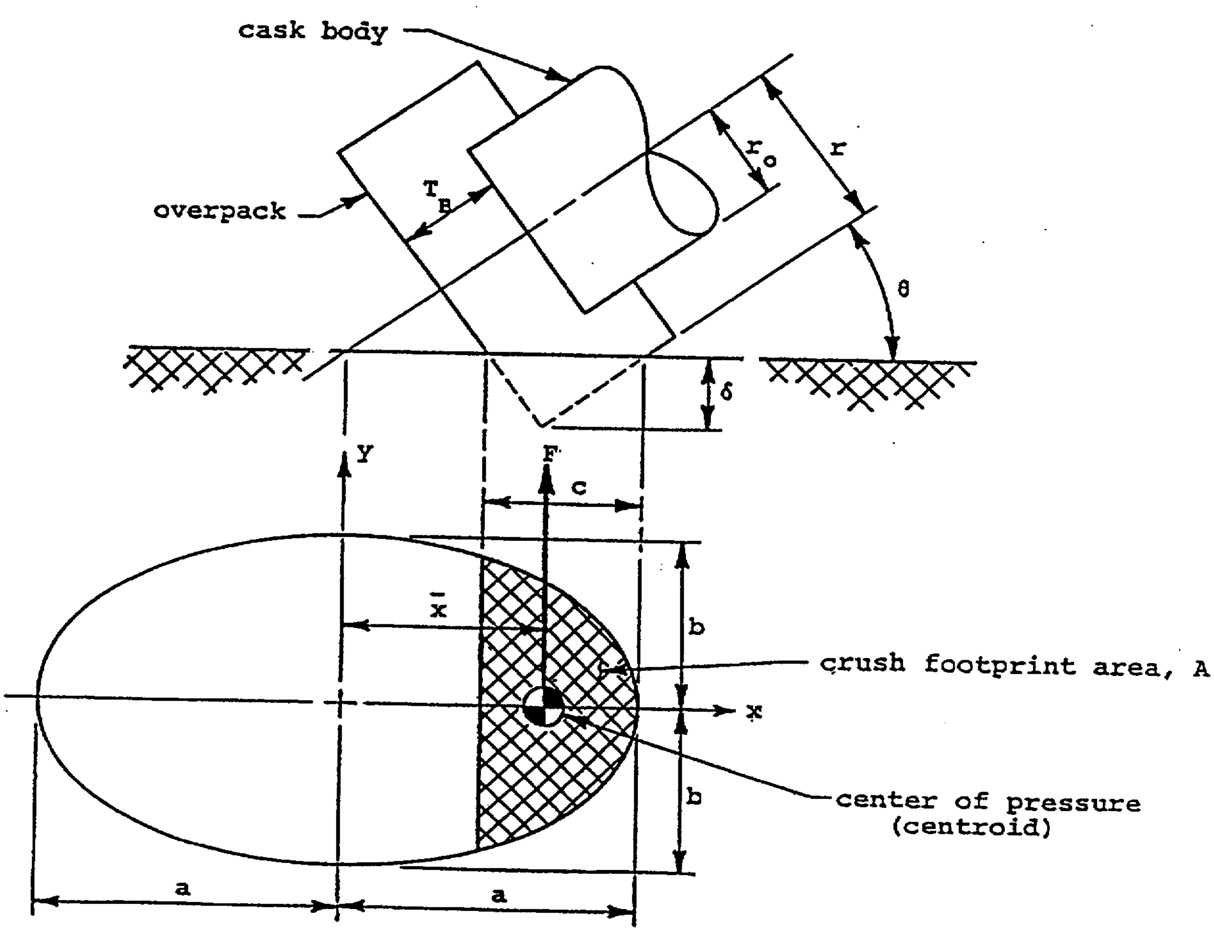


Figure 2.10.2.2-2 Elliptical Footprint Geometry

2.10.2.2.1 Overpack Force Analysis

This section treats both external and internal forces imposed upon the package. Key to the treatment of external force application locations is an understanding of crush footprint geometry.

The crush footprint is a sector of the ellipse, as illustrated in Figure 2.10.2.2-2. The location of the centroid, $\bar{x}$, is calculated relative to the ellipse origin. The geometric properties of the elliptical crush footprint are:

$$a = r/\sin\theta$$

$$b = r$$

$$c = \delta/[(\sin\theta)(\cos\theta)]$$

The area, A, and the centroidal offset, $\bar{x}$, of the crush footprint are derived as:

When c ≤ a:

$$A = 2\int_{(a-c)}^{c} y\,dx$$

Where:

$$y = b(a^2 - x^2)^{0.5}/a$$

Then,

$$A = (2b/a)\int_{(a-c)}^{c} (a^2 - x^2)^{0.5}dx$$

Solving,

$$A = (b/a)\{(\pi a^2/2) - (a-c)(2ac - c^2)^{0.5} - a^2 \sin^{-1}[(a-c)/a]\}$$

The center of pressure, $\bar{x}$, is:

$$A\bar{x} = (2b/a)\int_{(a-c)}^{c} x(a^2 - x^2)^{0.5}dx$$

Then,

$$\bar{x} = \{2b[(2ac - c^2)^{1.5}]/3a\}/A$$

When a < c ≤ 2a:

$$A = \pi ab - A'$$

$$\bar{x} = (A'\bar{x}')/A$$

Where A' and $\bar{x}'$ are as defined for A and $\bar{x}$, except that c' replaces c. The value of c' is:

$$c' = 2a - c$$

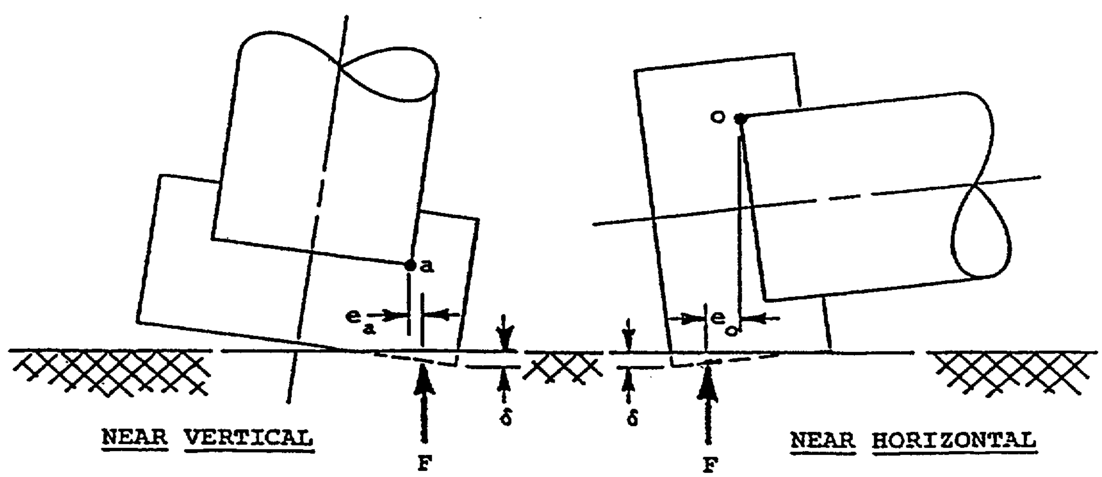
When a > 2a:

$$A = \pi ab$$

$$\bar{x} = 0$$

2.10.2.2.2 Overpack Attachment Forces

For most orientations and crush depths, the overpact crush force is transmitted to the cask body in direct compression, hence, the forces transmitted to the circumferential overpact attachments are near zero. This is not true for near vertical and near horizontal orientations of the package, at very modest crash deformations and crush forces. In these very limited situations, the center of pressure of the crash force can lie beyond the outer extremities of the cask body and exert a resultant moment force upon the overpack attachments. Significantly, these moments exist only for very modest crash deformations and crash forces, regardless of orientation angle. This is because larger crash deformations move the center of pressure toward the cask body. At maximum crash depth and maximum crash force, for all angles of orientation, there are no overpack attachment moments because the overpack interface forces are all direct compression. The near vertical and near horizontal orientations, where attachment moments exist, are illustrated below:



The overpack attachment moment is:

$$M = F(e_a) \text{ or } F(e_o)$$

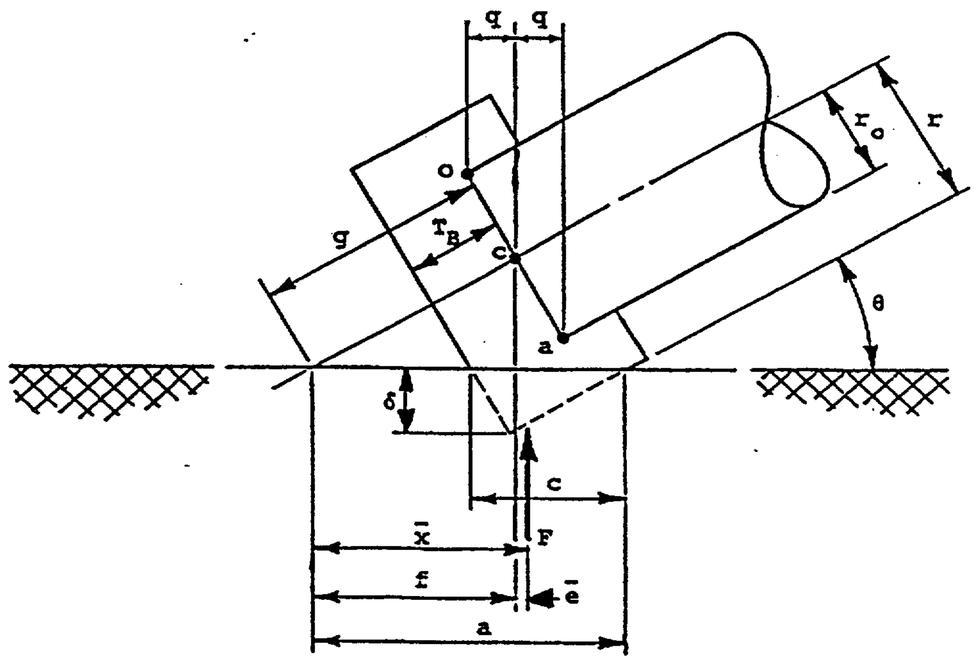
Where:

e_a = moment arm about adjacent corner

e_o = moment arm about opposite corner

The location of the crush force can be approximated as the centroid of the crush footprint area. This approximation is consistently conservative. Specifically, for both near vertical and near horizontal orientations, foam strain-hardening effects tend to move the center of force from the geometric center of the crush footprint toward the cask body. In both instances, this tendency reduces the actual moment arm of the crush force to less than that predicted by the location of the crush footprint centroid. The moment arm, as defined by crush footprint geometry, is derived below. The location of the center of pressure relative to the opposite and adjacent corners of the cask body can be obtained from the geometry as illustrated below:

Where:



$q = r_o(\sin\theta)$

$f = g(\cos\theta)$

$g = T_B + (a-c)(\cos\theta)$

$\bar{e} = \bar{x} - f$

The location of the center of pressure, measured from a normal to the crush plane passed through the intercept of package center line and body base plane (Point c), is:

$\bar{e} = \bar{x} - [T_B + (a-c)(\cos\theta)](\cos\theta)$

The moment arms, e_o and e_a , representing the distance from the center of pressure to the corners of the cask body, are thus given as:

$e_o = -(\bar{e} + q) =$ moment arm about opposite corner

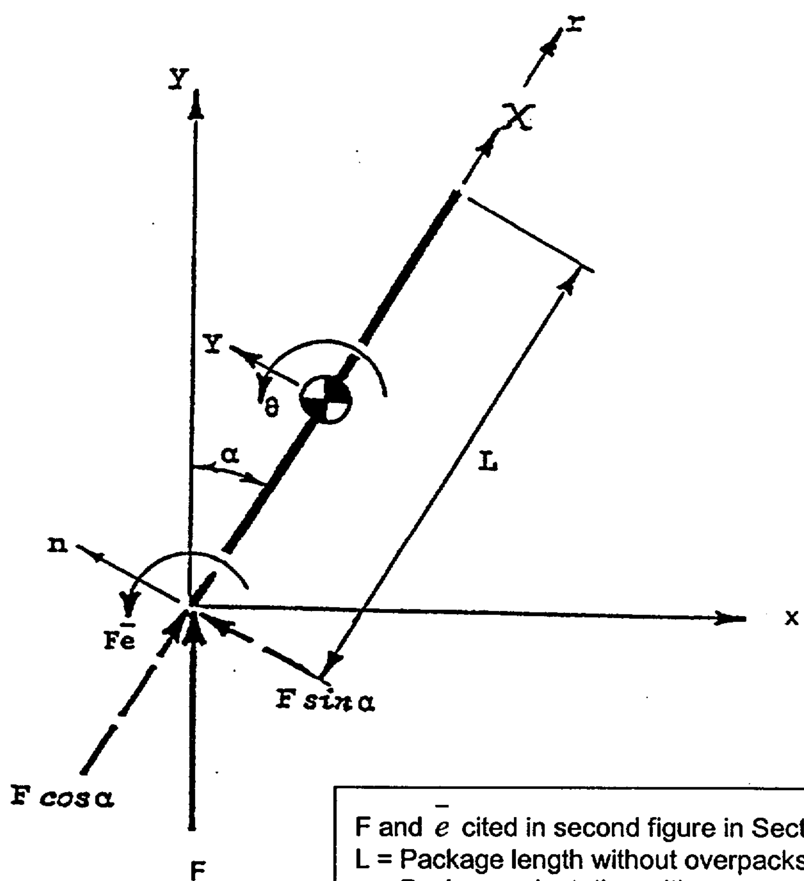
$e_a = (\bar{e} - q) =$ moment arm about adjacent corner

Sign convention for these arms is such that the moment, F(e_o), produces a clockwise (separation) moment about the opposite corner and moment, F(e_a), produces a counter-clockwise (separation) moment about the adjacent corner. In other words, a positive moment must be resisted by overpack attachment bolts whereas a negative moment implies that the center of pressure is totally resisted by compressive interface forces and there are no attachment bolt loads.

In summary, the forces between the overpack and body have been derived in terms of package geometry and three problem variables: orientation angle, crush force, and crush deformation.

2.10.2.2.3 Internal Forces

The package is idealized as a beam impacting on the lower end. The equations of motion are formed and used to define station-wise accelerations. These accelerations, in conjunction with the unit mass of the package, form forces which vary along the length of the package. When integrated, these forces provide a complete definition of internal thrusts, shears, and moments for the package as a function of total impact force and orientation angle.



F and $\bar{e}$ cited in second figure in Section 2.10.2.2.2
L = Package length without overpacks
a = Package orientation with respect to vertical

For a planar rigid body system, the behavior is totally defined by a solution of the three equations of equilibrium written at the center of gravity of the rigid body. In the proceeding figure, local coordinates are defined at the center of gravity, with axes parallel and normal to the beam. The end impact force is resolved into components parallel to these local axes. Summation of forces at the center of gravity leads to three rigid body equations of motion:

Sum of Lateral Forces - $M(\partial^2 Y/\partial t^2) = F(\sin\alpha)$

Sum of Longitudinal Forces - $M(\partial^2 X/\partial t^2) = F(\cos\alpha)$

Sum of Moments - $I(\partial^2 \theta/\partial t^2) = -FL(\sin\alpha)/2 + F\bar{e}$

Where:

$M = \rho L$, the mass of the body

$I = \rho L^3/12$, the mass moment of inertia of the body

$\rho =$ the mass per unit length of the body

$\alpha =$ the orientation angle with respect to vertical

Note that the mass moment of inertia term given above is valid only for infinitely slender beams of mass. A more accurate mass moment approximation is provided by the equation:

$$I = \rho L(3R^2 + L^2)/12$$

Where:

$R =$ the radius of the cylindrical cast.

This increased mass moment of inertia demonstrably decreases the internal moment. Thus, all moments calculated using the slender body approximation are conservative in proportion to the degree with which the cask is not slender. A very squat cask would have an internal moment predicted by OBLIQUE considerably higher than reality.

Substituting for the mass and inertia terms:

$$\partial^2 Y/\partial t^2 = F(\sin\alpha)/\rho L$$

$$\partial^2 X/\partial t^2 = F(\cos\alpha)/\rho L$$

$$\partial^2 \theta/\partial t^2 = -6F(\sin\alpha)/\rho L^2 + 12F\bar{e}/\rho L^3$$

The lateral and longitudinal accelerations at a point 'r' are:

$$\partial^2 S_n/\partial t^2 = \partial^2 Y/\partial t^2 + [r-(L/2)](\partial^2\theta/\partial t^2)$$

$$= [F(\sin\alpha)/\rho L^2]\{L - 6[r-(L/2)]\} + [r-(L/2)](12F\bar{e}/\rho L^3)$$

$$= [2F(\sin\alpha)/\rho L^2](-3r+2L) + [r-(L/2)](12F\bar{e}/\rho L^3)$$

$$\partial^2 S_r / \partial t^2 \qquad = \partial^2 X / \partial t^2 = F(\cos\alpha)/\rho L$$

The lateral inertial force acting on the body at the rth location is:

$$\partial V_r / \partial r = -\rho(\partial^2 S_n / \partial t^2)$$

The corresponding expression for shear is found by integrating this lateral force from the free end to the rth location, or:

$$V_r \qquad = [-2F(\sin\alpha)/L^2] \int_L^r (-3r + 2L) dr - (12F\bar{e}/L^3) \int_L^r [r - (L/2)] dr$$

$$= [-2F(\sin\alpha)/L^2][-3(r^2 - L^2)/2 + 2L(r - L)] - (6F\bar{e}/L^3)(r^2 - Lr)$$

Rearranging,

$$V_r \qquad = [-2F(\sin\alpha)/L^2](-3r^2/2 + 3L^2/2 + 2Lr - 2L^2) - (6F\bar{e}/L^3)(r^2 - Lr)$$

$$= [F(\sin\alpha)/L^2](3r^2 - 4Lr + L^2) - (6F\bar{e}/L^3)(r^2 - Lr)$$

$$= (F/L^2)[(3\sin\alpha - 6\bar{e}/L)r^2 - (4L\sin\alpha - 6\bar{e})r + (L^2 \sin\alpha)]$$

Similarly, the corresponding moment is found by integration of the shear expression:

$$\partial M_r / \partial r = V_r$$

$$M_r \qquad = [F(\sin\alpha)/L^2] \int_L^r (3r^2 - 4Lr + L^2) dr - (6F\bar{e}/L^3) \int_L^r (r^2 - Lr)$$

$$= [F(\sin\alpha)/L^2][(r^3 - L^3) - 2L(r^2 - L^2) + L^2(r - L)] - (6F\bar{e}/L^3)[(r^3 - L^3)/3 - L(r^2 - L^2)/2]$$

Rearranging,

$$M_r \qquad = [F(\sin\alpha)/L^2](r^3 - L^3 - 2Lr^2 + 2L^3 + L^2 r - L^3) - (6F\bar{e}/L^3)(r^3/3 - L^3/3 - Lr^2/2 + L^3/2)$$

$$= [F(\sin\alpha)/L^2](r^3 - 2Lr^2 + L^2 r) - (6F\bar{e}/L^3)(r^3/3 - Lr^2/2 + L^3/6)$$

$$= (F/L^2)[(\sin\alpha - 2\bar{e}/L)r^3 - (2L\sin\alpha - 3\bar{e})r^2 + (L^2 \sin\alpha)r - (\bar{e}L^2)]$$

In order to verify these expressions for shear and moment, they are evaluated at the boundaries, r = 0 and r = L:

At r=0:

$$V_r = [F(\sin\alpha)/L^2](3r^2 - 4Lr + L^2) - (6F\bar{e}/L^3)(r^2 - Lr)$$

$$=[F(\sin\alpha)/L^2](L^2)-0=F(\sin\alpha)$$

$$M_r=[F(\sin\alpha)/L^2](r^3-2Lr^2+L^2r)-(6F\bar{e}/L^3)(r^3/3-Lr^2/2+L^3/6)=-F\bar{e}$$

At $r=L$:

$$V_r=[F(\sin\alpha)/L^2](3r^2-4Lr+L^2)-(6F\bar{e}/L^3)(r^2-Lr)$$

$$=[F(\sin\alpha)/L^2](3L^2-4L^2+L^2)-(6F\bar{e}/L^3)(L^2-L^2)=0$$

$$M_r=[F(\sin\alpha)/L^2](r^3-2Lr^2+L^2r)-(6F\bar{e}/L^3)(r^3/3-Lr^2/2+L^3/6)$$

$$=[F(\sin\alpha)/L^2](L^3-2L^3+L^3)-(6F\bar{e}/L^3)(L^3/3-L^3/2+L^3/6)=0$$

The maximum moment occurs where the shear, V_r, equals zero. For this to occur, the following equation must be solved:

$$(\sin\alpha)(3r^2-4Lr+L^2)-(6\bar{e}/L)(r^2-Lr)=0$$
$$(\sin\alpha)(3r^2-4Lr+L^2)=(6\bar{e}/L)(r^2-Lr)$$

Expanding and rearranging terms yields:

$$(3\sin\alpha-6\bar{e}/L)r^2+(6\bar{e}-4L\sin\alpha)r+L^2\sin\alpha=0$$

This expression can be solved for r by utilizing the binomial expansion:

$$r=\{(4L\sin\alpha-6\bar{e})\pm[(6\bar{e}-4L\sin\alpha)^2-4(3\sin\alpha-6\bar{e}/L)(L^2\sin\alpha)]^{0.5}\}/[2(3\sin\alpha-6\bar{e}/L)]$$

Which reduces to:

$$r=[(4L\sin\alpha-6\bar{e})\pm(6\bar{e}-2L\sin\alpha)]/[2(3\sin\alpha-6\bar{e}/L)]$$

or:

$$r=L,\ (L\sin\alpha)/[3(\sin\alpha-2\bar{e}/L)]$$

The maximum moment is found at $r=(L\sin\alpha)/[3(\sin\alpha-2\bar{e}/L)]$

Note, however, that the absolute value of this maximum moment may be less than the absolute value of the moment at $r=0$, which is:

$$M_{r=o}=-F\bar{e}$$

Therefore, maximum bending stresses may occur at either $r=0$ or $r=(L\sin\alpha)/[3(\sin\alpha-2\bar{e}/L)]$.

The value of the maximum moment may be found by substituting

$$r = (L\sin\alpha)/[3(\sin\alpha - 2\bar{e}/L)]$$

into the moment equation. The resulting expression is:

$$M_{\max} = (F/3L^2)\{(L^5\sin^3\alpha)/[9(L\sin\alpha - 2\bar{e})^2] - (L^4\sin^2\alpha)(2L\sin\alpha - 3\bar{e})/[3(L\sin\alpha - 2\bar{e})^2] + (L^4\sin^2\alpha)/(L\sin\alpha - 2\bar{e}) - 3\bar{e}L^2\}$$

The minimum shear occurs at the location, r, which satisfies the following equation:

$$\partial V_r/\partial r = [F(\sin\alpha)/L^2](6r - 4L) - 6(F\bar{e}/L^3)(2r - L) = 0$$

or

$$(\sin\alpha)(3r - 2L) = (3\bar{e}/L)(2r - L)$$

$$r = (2L\sin\alpha - 3\bar{e})/[3(\sin\alpha - 2\bar{e}/L)]$$

The magnitude of the axial (thrust) force can be found as a function of location as:

$$\partial T/\partial r = -\rho(\partial^2 S_r/\partial t^2)$$

$$T = -\rho(\partial^2 S_r/\partial t^2)\int_L^r dr = -\rho(\partial^2 S_r/\partial t^2)(r - L)$$

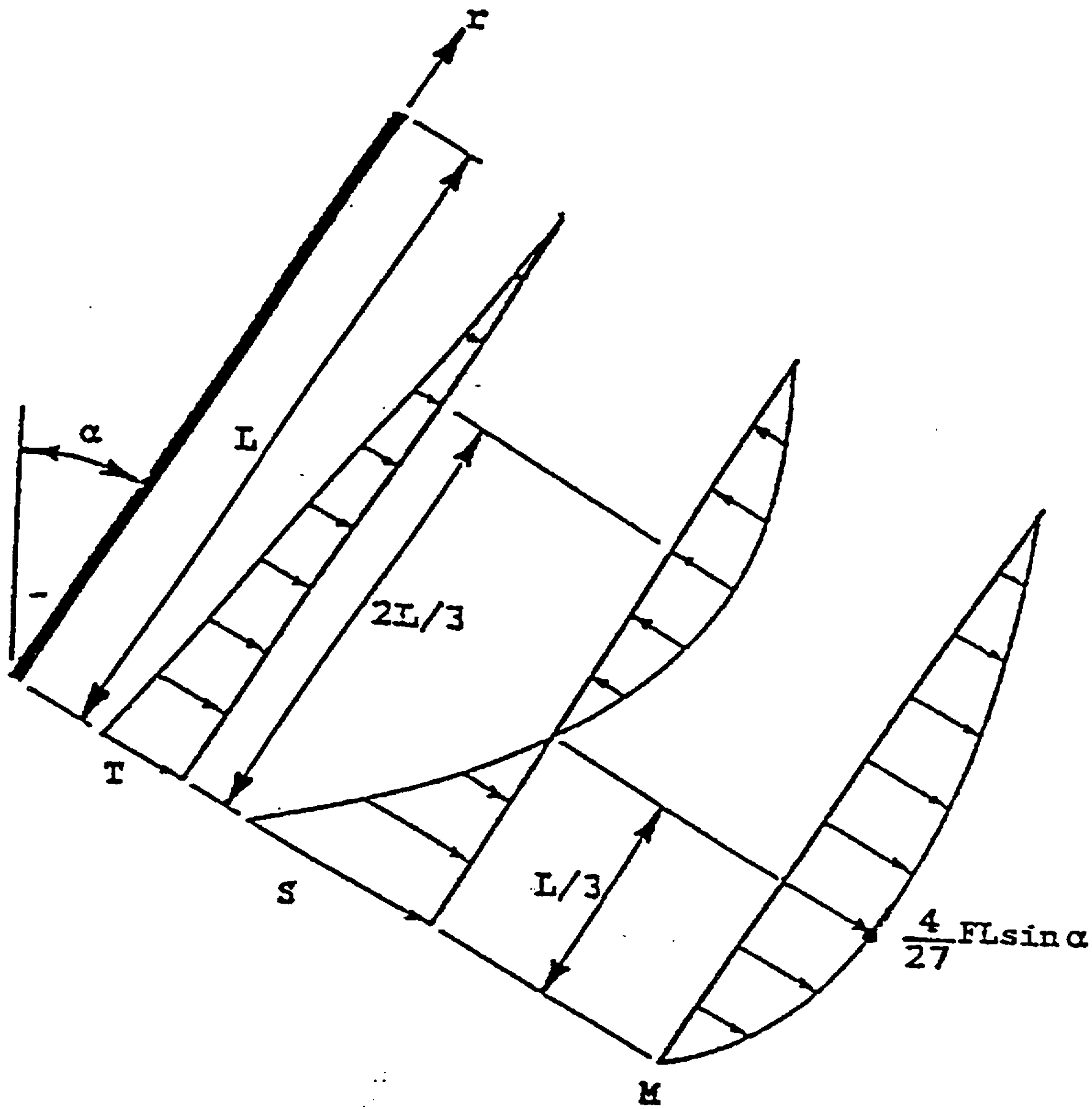
Then

$$T = F(\cos\alpha)[1 - (r/L)]$$

Note that for the special case of $\bar{e} = 0$ or for a pinned-end structure, the above terms can be simplified. The reduced terms are summarized below:

PARAMETER	EQUATION	MAXIMUM	MINIMUM
Thrust	$F(\cos\alpha)[1 - (r/L)]$	$F(\cos\alpha)$ $(r = 0)$	0 $(r = L)$
Shear	$F(\sin\alpha)[3r^2 - 4Lr + L^2]/L^2$	$F(\sin\alpha)$ $(r = 0)$	0 $(r = L/3, L)$
Moment	$F(\sin\alpha)[r^3 - 2Lr^2 + L^2 r]/L^2$	$4FL(\sin\alpha)/27$ $(r = L/3)$	0 $(r = 0, L)$

These forces are graphically illustrated below:



Shears, Thrusts and Moments calculated by current versions of OBLIQUE and presented in Section 2.7.1.2 are based on an $\bar{e}$ value of zero.

2.10.2.3 Sample Program Input and Output

This section contains sample input and output tables for the computer codes EYDROP, SYDROP, CYDROP and OBLIQUE. As a descriptive illustration, assume a package with the geometry described below in Figure 2.10.2.3-1.

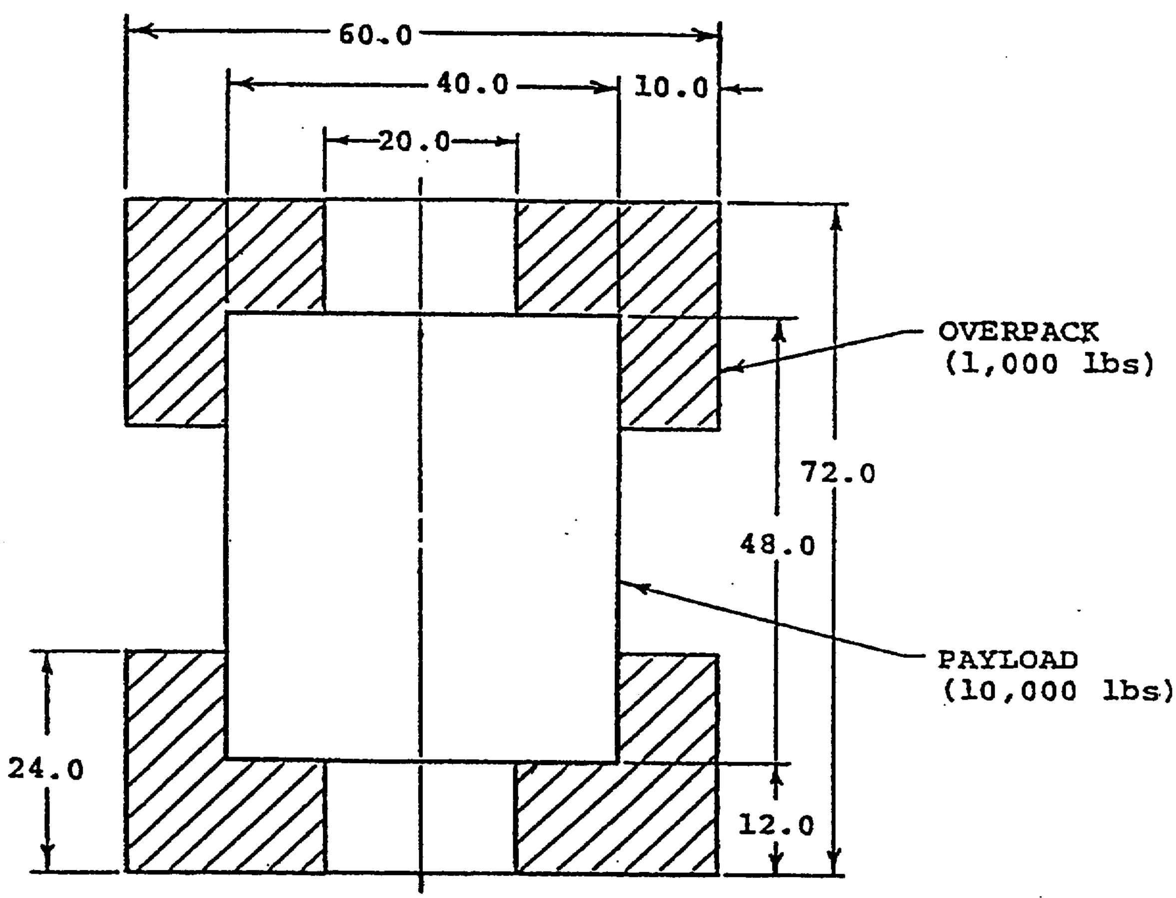


Figure 2.10.2.3-1 Sample Problem Package Geometry

2.10.2.3.1 End Drop Sample Problem

Table 2.10.2.3-1 contains the data input to EYDROP for the above geometry.

```
PROGRAM EYDROP, VERSION 2, DATE 5/11/81

12345678901234567890123456789012345678901234567890123456789012345678901234567890
         V         V         V         V         V         V         V         V
EYDROP (END DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS
   12000.       60.       20.       12.       30.
      .2         3.        .2
  17
     0.00      0.00
     0.05    668.00
     0.10   1337.00
     0.15   1345.00
     0.20   1315.00
     0.25   1347.00
     0.30   1411.00
     0.35   1507.00
     0.40   1673.00
     0.45   1901.00
     0.50   2204.00
     0.55   2623.00
     0.60   3288.00
     0.65   4242.00
     0.70   5908.00
     0.75   9058.00
     0.80  15322.00
```

Table 2.10.2.3-1 EYDROP Input Table

A summary of each card is as follows:

Card 1	Problem Title
Card 2	Package weight, package diameter, overpack hole diameter, overpack end thickness, drop height.
Card 3	Starting crush depth iteration, ending iteration, increment.
Card 4	Number of foam curve data points.
Card 5-N	Foam strain, foam crush stress.

All the required input parameters are straightforward. Table 2.10.2.3-2 contains the sample problem output. Information from this table is essentially self-explanatory. A solution is determined when the kinetic energy of the drop is equal to the strain energy (SE/KE = 1) from crushing the foam overpacks.

```
EYDROP(END)                    EYDROP (END DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

                                    PACKAGE WEIGHT   =  12000. (LBS)
                                    PACKAGE DIAMETER =   60.00 (IN)
                                    HOLE DIAMETER    =   20.00 (IN)
                                    OVERPACK DEPTH   =   12.00 (IN)
                                    DROP HEIGHT      =   30.00 (FT)
```

CRUSH DEPTH (IN)	STRAIN	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)
.20	.017	456640.	38.1	4322400.	45664.	.011
.40	.033	1036803.	86.4	4324800.	195008.	.045
.60	.050	1678867.	139.9	4327200.	466575.	.108
.80	.067	2321210.	193.4	4329600.	866583.	.200
1.00	.083	2902211.	241.9	4332000.	1388925.	.321
1.20	.100	3360248.	280.0	4334400.	2015171.	.465
1.40	.117	3474214.	289.5	4336800.	2698617.	.622
1.60	.133	3461585.	288.5	4339200.	3392197.	.782
1.80	.150	3380354.	281.7	4341600.	4076391.	.939
2.00	.167	3353421.	279.5	4344000.	4749769.	1.093
2.20	.183	3325186.	277.1	4346400.	5417629.	1.246
2.40	.200	3304955.	275.4	4348800.	6080643.	1.398
2.60	.217	3318173.	276.5	4351200.	6742956.	1.550
2.80	.233	3345913.	278.8	4353600.	7409365.	1.702

Table 2.10.2.3-2 EYDROP Output

In this case, a linear interpolation of the SE/KE ratio results in a crash depth of approximately 1.88 inches and an acceleration of almost 281 g's. Equations for EYDROP are discussed in Section 2.10.2.1.1.

2.10.2.3.2 Side Drop Sample Problem

Table 2.10.2.3-3 contains the data input to SYDROP for the sample problem package geometry.

```
PROGRAM SYDROP, VERSION 3, DATE 1/28/85

1234567890123456789012345678901234567890123456789012345678901234567890123456789
         V         V         V         V         V         V         V         V
SYDROP (SIDE DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS
  12000.        48.        60.        40.        30.
 17
     0.00      0.00
     0.05    668.00
     0.10   1337.00
     0.15   1345.00
     0.20   1315.00
     0.25   1347.00
     0.30   1411.00
     0.35   1507.00
     0.40   1673.00
     0.45   1901.00
     0.50   2204.00
     0.55   2623.00
     0.60   3288.00
     0.65   4242.00
     0.70   5908.00
     0.75   9058.00
     0.80  15322.00
  150  .25  6.0  .25
```

Table 2.10.2.3-3 SYDROP Input Table

A summary of each card is as follows:

Card 1	Problem Title
Card 2	Package weight, overpack length, package diameter, payload diameter, drop height.
Card 3	Number of foam curve data points.
Card 4-N	Foam strain, foam crush stress
Card N+I	Number of integration points, starting crush depth iteration, ending iteration, increment.

As with the end drop problem, all required input parameters are straightforward. The chosen number of integration points (150) is based upon previous parametric study for the side drop geometry. Increasing the number will alter the end results by only a fraction of one percent. As with EYDROP, a solution is determined when the kinetic energy of the drop is equal to the strain energy from crushing the foam overpacks. Table 2.10.2.3-4 contains the SYDROP output. Equations for SYDROP are discussed in Section 2.10.2.1.2.

SYDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 10.09.59 05/03/16 PAGE 1

SYDROP (SIDE DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

PACKAGE WEIGHT	=	12000. (LBS)
PACKAGE EXTERNAL LENGTH	=	48.00 (IN)
PACKAGE EXTERNAL DIAMETER	=	60.00 (IN)
PAYLOAD DIAMETER	=	40.00 (IN)
DROP HEIGHT	=	30.00 (FT)

STRAIN VS STRESS TABLE

PT	STRAIN	STRESS
1	0.00	0.00
2	.05	668.00
3	.10	1337.00
4	.15	1345.00
5	.20	1315.00
6	.25	1347.00
7	.30	1411.00
8	.35	1507.00
9	.40	1673.00
10	.45	1901.00
11	.50	2204.00
12	.55	2623.00
13	.60	3288.00
14	.65	4242.00
15	.70	5906.00
16	.75	9058.00
17	.80	15322.00

SYDROP(SIDE) N U C L E A R P A C K A G I N G P R O P R I E T A R Y 10.09.59 05/03/16 PAGE 2

SYDROP (SIDE DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ POTENTIAL (IN-LB)	STRAIN (IN-LB)	RATIO (SE/PE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.25	371.0	62.	82479.	6.9	4323000.	10310.	.002	100.00	0.00	0.00	0.00	0.00
.50	523.6	175.	232410.	19.4	4326000.	49671.	.011	100.00	0.00	0.00	0.00	0.00
.75	639.9	321.	449672.	37.5	4329000.	134931.	.031	100.00	0.00	0.00	0.00	0.00
1.00	737.4	493.	675582.	56.3	4332000.	275588.	.064	100.00	0.00	0.00	0.00	0.00
1.25	822.7	688.	857486.	71.5	4335000.	467222.	.108	100.00	0.00	0.00	0.00	0.00
1.50	899.3	904.	989341.	82.4	4338000.	698075.	.161	100.00	0.00	0.00	0.00	0.00
1.75	969.3	1138.	1096877.	91.4	4341000.	958852.	.221	100.00	0.00	0.00	0.00	0.00
2.00	1034.0	1388.	1191399.	99.3	4344000.	1244887.	.287	100.00	0.00	0.00	0.00	0.00
2.25	1094.3	1654.	1281336.	106.8	4347000.	1553979.	.357	100.00	0.00	0.00	0.00	0.00
2.50	1151.0	1935.	1370454.	114.2	4350000.	1885452.	.433	100.00	0.00	0.00	0.00	0.00
2.75	1204.6	2229.	1459288.	121.6	4353000.	2239170.	.514	100.00	0.00	0.00	0.00	0.00
3.00	1255.4	2537.	1549023.	129.1	4356000.	2615209.	.600	100.00	0.00	0.00	0.00	0.00
3.25	1303.8	2857.	1640286.	136.7	4359000.	3013075.	.691	100.00	0.00	0.00	0.00	0.00
3.50	1350.0	3189.	1735198.	144.6	4362000.	3435808.	.788	100.00	0.00	0.00	0.00	0.00
3.75	1394.3	3532.	1837541.	153.1	4365000.	3882401.	.889	100.00	0.00	0.00	0.00	0.00
4.00	1436.8	3886.	1949171.	162.4	4368000.	4355740.	.997	100.00	0.00	0.00	0.00	0.00
4.01	1437.8	3895.	1952158.	162.7	4368074.	4368082.	1.000	100.00	0.00	0.00	0.00	0.00
4.25	1477.7	4250.	2070772.	172.6	4371000.	4858233.	1.111	100.00	0.00	0.00	0.00	0.00
4.50	1517.1	4624.	2203828.	183.7	4374000.	5392558.	1.233	100.00	0.00	0.00	0.00	0.00
4.75	1555.2	5008.	2349512.	195.8	4377000.	5961725.	1.362	100.00	0.00	0.00	0.00	0.00
5.00	1592.0	5402.	2510461.	209.2	4380000.	6569222.	1.500	100.00	0.00	0.00	0.00	0.00
5.25	1627.6	5804.	2688622.	224.1	4383000.	7219107.	1.647	100.00	0.00	0.00	0.00	0.00
5.50	1662.1	6216.	2890243.	240.9	4386000.	7916465.	1.805	100.00	0.00	0.00	0.00	0.00
5.75	1695.5	6635.	3125496.	260.5	4389000.	8668433.	1.975	100.00	0.00	0.00	0.00	0.00
6.00	1728.0	7063.	3401972.	283.5	4392000.	9484366.	2.159	100.00	0.00	0.00	0.00	0.00

Table 2.10.2.3-4 SYDROP Output

2.10.2.3.3 Corner Drop Sample Problem

Table 2.10.2.3-5 contains the data input to CYDROP for the sample problem package geometry.

```
PROGRAM CYDROP, VERSION 3, DATE 2/07/84
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         V         V         V         V         V         V         V         V
CYDROP (CORNER DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS
    12000.      72.       60.       48.       40.       20.       24.
      30.     39.8
     1100.   17
      0.00     0.00
      0.05   668.00
      0.10  1337.00
      0.15  1345.00
      0.20  1315.00
      0.25  1347.00
      0.30  1411.00
      0.35  1507.00
      0.40  1673.00
      0.45  1901.00
      0.50  2204.00
      0.55  2623.00
      0.60  3288.00
      0.65  4242.00
      0.70  5908.00
      0.75  9058.00
      0.80 15322.00
   25    25.512 15.37 .512
```

Table 2.10.2.3-5 CYDROP Input Table

A summary of each card is as follows

Card 1	Problem Title
Card 2	Package weight, package length, package diameter, payload length, payload diameter, overpack hole diameter, overpack length.
Card 3	Drop height, angle from vertical.
Card 4	Unbacked foam crush stress, number of foam curve data points.
Card 5-N	Foam strain, foam crush stress.
Card N+1	Number of integration points along crush plane semi-minor ellipse axis, number of integration points along crush plane semi-major ellipse axis, starting crush depth iteration, ending iteration, increment.

The angle from vertical to execute a center of gravity over struck corner impact is calculated as:

$$\theta = \tan^{-1}(60.0/72.0) = 39.8°$$

The unbacked foam crush stress is the foam compressive yield strength, about 1,100 psi for the 20 pcf foam. Program default for this entry is to assume the foam crush stress at 10% strain, a value usually close to the plateau compressive strength.

Similar to SYDROP, the number of integration points chosen for CYDROP (25) have been determined from a parametric evaluation. Additional points are unnecessarily time consuming and provide very little change in the end results.

Table 2.10.2.3-6 contains the CYDROP output for the sample problem. CYDROP also calculates the percentage of foam in the crush area less than and greater than 80% foam strain in the backed and unbacked regions. The foam data used in the drop analyses provide accurate empirical relationships to 80% strain. This calculation is carried into the force and strain energy results to provide the program user with information on solution reliability.

Energy equilibrium for the sample problem may be linearly interpolated to a crush depth of about 10.6 inches and an acceleration of 106.5 g's. The distribution of strain energy ratios for this problem indicate the foam stress data interpolated from the input file never exceeded 70% strain.

Linear interpolation of the sensitivity analysis shows approximately 24.5% of the total crush area was unbacked. Additionally, further interpolation shows the unbacked foam accounted for about 17.5% of the total force and 8.7% of the strain energy at SE/KE = 1. Equations for CYDROP are discussed in Section 2.10.2.1.3.

```
CYDROP(CORNER)          N U C L E A R   P A C K A G I N G   P R O P R I E T A R Y      10.11.19    84/02/14      PAGE   1
                              CYDROP (CORNER DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

                                PACKAGE WEIGHT              =  12000. (LBS)
                                PACKAGE EXTERNAL LENGTH  =   72.00 (IN)
                                PACKAGE EXTERNAL DIAMETER=   60.00 (IN)
                                PACKAGE EXTERNAL HOLE DIA=   20.00 (IN)
                                PAYLOAD ENVELOPE LENGTH  =   48.00 (IN)
                                PAYLOAD ENVELOPE DIAMETER=   40.00 (IN)
                                OVERPACK LENGTH           =   24.00 (IN)

                                DROP HEIGHT               =   30.00 (FT)
                                ORIENTATION ANGLE         =   39.800 (DEGREES WRT TO VERTICAL)

                                PLATEAU CRUSH STRESS      = 1100.00 (PSI)
                                   (DEFAULT TAKEN AT 10 PCT STRAIN)

                                STRESS/STRAIN EVALUATED IN 1/2 CRUSH PLANE ELLIPSE AT:
                                   NX =    25 POINTS PARALLEL TO SEMI-MINOR ELLIPSE AXIS
                                   NY =    25 POINTS PARALLEL TO SEMI-MAJOR ELLIPSE AXIS


                                  EXPERIMENTAL STRAIN VS. STRESS VALUES

                                    PT        STRAIN        STRESS
                                     1          0.00          0.00
                                     2           .05        668.00
                                     3           .10       1337.00
                                     4           .15       1345.00
                                     5           .20       1315.00
                                     6           .25       1347.00
                                     7           .30       1411.00
                                     8           .35       1507.00
                                     9           .40       1673.00
                                    10           .45       1901.00
                                    11           .50       2204.00
                                    12           .55       2625.00
                                    13           .60       3288.00
                                    14           .65       4242.00
                                    15           .70       5908.00
                                    16           .75       9058.00
                                    17           .80      15322.00
```

Table 2.10.2.3-6 CYDROP Output

CYDROP(CORNER) NUCLEAR PACKAGING PROPRIETARY 10.11.28 84/02/14 PAGE 2

CYDROP (CORNER DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

CRUSH DEPTH (IN)	++ CRUSH PLANE ++ AREA (IN2)	VOLUME (IN3)	++++ IMPACT ++++ FORCE (LBS)	ACCEL. (G)	++++++ ENERGY ++++++ KINETIC (IN-LB)	STRAIN (IN-LB)	RATIO (SE/KE)	DISTRIBUTION OF STRAIN RATIOS BY PERCENT OF CONTACT AREA LE.70	GT.70 LE.80	GT.80 LE.90	GT.90 LE.95	GT.95
.51	9.6	2.	1386.	.1	4326144.	355.	.000	100.00	0.00	0.00	0.00	0.00
1.02	26.8	12.	8775.	.7	4332288.	2956.	.001	100.00	0.00	0.00	0.00	0.00
1.54	49.0	31.	25334.	2.1	4338432.	11688.	.003	100.00	0.00	0.00	0.00	0.00
2.05	74.9	63.	51131.	4.3	4344576.	31263.	.007	100.00	0.00	0.00	0.00	0.00
2.56	103.9	109.	83257.	6.9	4350720.	65666.	.015	100.00	0.00	0.00	0.00	0.00
3.07	135.6	170.	119934.	10.0	4356864.	117683.	.027	100.00	0.00	0.00	0.00	0.00
3.58	169.6	248.	160452.	13.4	4363008.	189462.	.043	100.00	0.00	0.00	0.00	0.00
4.10	205.7	344.	204557.	17.0	4369152.	282984.	.065	100.00	0.00	0.00	0.00	0.00
4.61	243.6	459.	252250.	21.0	4375296.	399847.	.091	100.00	0.00	0.00	0.00	0.00
5.12	283.1	594.	304305.	25.4	4381440.	542325.	.124	100.00	0.00	0.00	0.00	0.00
5.63	324.1	749.	361485.	30.1	4387584.	712767.	.162	100.00	0.00	0.00	0.00	0.00
6.14	366.4	926.	422256.	35.2	4393728.	913405.	.208	100.00	0.00	0.00	0.00	0.00
6.66	409.8	1125.	490795.	40.9	4399872.	1147146.	.261	100.00	0.00	0.00	0.00	0.00
7.17	454.3	1346.	568073.	47.3	4406016.	1418216.	.322	100.00	0.00	0.00	0.00	0.00
7.68	499.7	1590.	648625.	54.1	4412160.	1729691.	.392	100.00	0.00	0.00	0.00	0.00
8.19	545.9	1858.	736216.	61.4	4418304.	2084210.	.472	100.00	0.00	0.00	0.00	0.00
8.70	592.8	2149.	826311.	68.9	4424448.	2484217.	.561	100.00	0.00	0.00	0.00	0.00
9.22	640.2	2465.	927187.	77.3	4430592.	2933092.	.662	100.00	0.00	0.00	0.00	0.00
9.73	688.2	2805.	1046738.	87.2	4436736.	3438397.	.775	100.00	0.00	0.00	0.00	0.00
10.24	736.6	3170.	1181164.	98.4	4442880.	4008748.	.902	100.00	0.00	0.00	0.00	0.00
10.75	785.3	3560.	1322256.	110.2	4449024.	4649615.	1.045	100.00	0.00	0.00	0.00	0.00
11.26	834.2	3974.	1483465.	123.6	4455168.	5367864.	1.205	99.33	.67	0.00	0.00	0.00
11.78	883.3	4414.	1678477.	139.9	4461312.	6177357.	1.385	98.69	1.31	0.00	0.00	0.00
12.29	932.4	4879.	1920373.	160.0	4467456.	7098714.	1.589	96.31	3.69	0.00	0.00	0.00
12.80	981.5	5369.	2246590.	187.2	4473600.	8165457.	1.825	95.07	4.49	.44	0.00	0.00
13.31	1030.5	5884.	2652834.	221.1	4479744.	9419709.	2.103	92.95	5.75	1.30	0.00	0.00
13.82	1079.4	6424.	3155349.	262.9	4485888.	10906604.	2.431	91.07	6.12	2.82	0.00	0.00
14.34	1128.0	6989.	3762296.	313.5	4492032.	12677521.	2.822	88.97	6.72	4.09	.22	0.00
14.85	1176.2	7579.	4496986.	374.7	4498176.	14791897.	3.288	87.74	6.26	4.70	1.30	0.00
15.36	1224.0	8193.	5345237.	445.4	4504320.	17311506.	3.843	85.88	6.02	6.15	1.07	.87

CYDROP(CORNER) NUCLEAR PACKAGING PROPRIETARY 10.11.27 84/02/14 PAGE 3

CYDROP (CORNER DROP) SAMPLE RUN, 20 PCF FOAM OVERPACKS

SENSITIVITY ANALYSIS OF STRAIN ASSUMPTIONS

CRUSH DEPTH (IN)	++++ CRUSH AREA ++++ TOTAL AREA (IN2)	PCT DISTRIBUTION UN-BACKED	BACKED MAX STRAIN LT .800	BACKED MAX STRAIN GT .800	++++ IMPACT FORCE ++++ TOTAL FORCE (LBS)	PCT DISTRIBUTION UN-BACKED	BACKED MAX STRAIN LT .800	BACKED MAX STRAIN GT .800	++++ STRAIN ENERGY ++++ TOTAL STRAIN ENERGY (IN-LBS)	PCT DISTRIBUTION UN-BACKED	BACKED MAX STRAIN LT .800	BACKED MAX STRAIN GT .800	STRAIN TO KINETIC ENERGY RATIO
.51	10.	0.0	100.0	0.0	1386.	0.0	100.0	0.0	355.	0.0	100.0	0.0	0.000
1.02	27.	0.0	100.0	0.0	8775.	0.0	100.0	0.0	2956.	0.0	100.0	0.0	.001
1.54	49.	0.0	100.0	0.0	25334.	0.0	100.0	0.0	11688.	0.0	100.0	0.0	.003
2.05	76.	0.0	100.0	0.0	51131.	0.0	100.0	0.0	31263.	0.0	100.0	0.0	.007
2.56	105.	0.0	100.0	0.0	83257.	0.0	100.0	0.0	65666.	0.0	100.0	0.0	.015
3.07	138.	0.0	100.0	0.0	119934.	0.0	100.0	0.0	117683.	0.0	100.0	0.0	.027
3.58	173.	0.0	100.0	0.0	160452.	0.0	100.0	0.0	189462.	0.0	100.0	0.0	.043
4.10	211.	0.0	100.0	0.0	204557.	0.0	100.0	0.0	282984.	0.0	100.0	0.0	.065
4.61	250.	0.0	100.0	0.0	252250.	0.0	100.0	0.0	399847.	0.0	100.0	0.0	.091
5.12	292.	.3	99.7	0.0	304305.	.3	99.7	0.0	542325.	0.0	100.0	0.0	.124
5.63	335.	1.0	99.0	0.0	361485.	1.0	99.0	0.0	712767.	.2	99.8	0.0	.162
6.14	380.	1.5	98.5	0.0	422256.	1.5	98.5	0.0	913405.	.4	99.6	0.0	.208
6.66	427.	2.9	97.1	0.0	490795.	2.7	97.3	0.0	1147146.	.8	99.2	0.0	.261
7.17	475.	5.5	94.5	0.0	568073.	5.0	95.0	0.0	1418216.	1.4	98.6	0.0	.322
7.68	524.	7.2	92.8	0.0	648625.	6.4	93.6	0.0	1729691.	2.2	97.8	0.0	.392
8.19	575.	10.6	89.4	0.0	736216.	9.1	90.9	0.0	2084210.	3.1	96.9	0.0	.472
8.70	626.	12.4	87.6	0.0	826311.	10.3	89.7	0.0	2484217.	4.2	95.8	0.0	.561
9.22	679.	14.7	85.3	0.0	927187.	11.9	88.1	0.0	2933092.	5.3	94.7	0.0	.662
9.73	733.	19.0	81.0	0.0	1046738.	14.6	85.4	0.0	3438397.	6.4	93.6	0.0	.775
10.24	788.	22.7	77.3	0.0	1181164.	16.7	83.3	0.0	4008748.	7.8	92.2	0.0	.902
10.75	844.	25.3	74.7	0.0	1322256.	17.8	82.2	0.0	4649615.	9.1	90.9	0.0	1.045
11.26	900.	30.3	69.7	0.0	1483465.	20.2	79.8	0.0	5367864.	10.4	89.6	0.0	1.205
11.78	957.	32.2	67.8	0.0	1678477.	20.2	79.8	0.0	6177357.	11.7	88.3	0.0	1.385
12.29	1015.	36.4	63.6	0.0	1920373.	21.2	78.8	0.0	7098714.	12.9	87.1	0.0	1.589
12.80	1074.	37.0	62.6	.4	2246590.	19.4	77.2	3.3	8165457.	13.8	85.9	.2	1.825
13.31	1151.	38.6	60.1	1.3	2652834.	18.1	71.6	10.3	9419709.	14.3	84.4	1.2	2.103
13.82	1183.	42.0	55.2	2.8	3155349.	17.3	62.0	20.7	10906604.	14.9	81.9	3.2	2.431
14.34	1237.	43.9	51.8	4.3	3762296.	15.9	53.7	30.4	12677521.	15.1	78.5	6.4	2.822
14.85	1289.	44.1	49.9	6.0	4496986.	13.9	46.8	39.3	14791897.	15.1	74.4	10.5	3.288
15.36	1343.	45.4	46.5	8.1	5345237.	12.5	38.5	48.9	17311506.	14.8	69.7	15.4	3.843

Table 2.10.2-3-6 (Continued)

2.10.2.3.4 Oblique Impact Sample Input

Table 2.10.2.3-7 contains the data input to OBLIQUE for the sample problem package geometry. Equations for OBLIQUE are discussed in Section 2.10.2.2.

```
PROGRAM OBLIQUE VERSION 7, DATE 9/15/83

12345678901234567890123456789012345678901234567890123456789012345678901234567890
         V         V         V         V         V         V         V         V
OBLIQUE SAMPLE RUN, 20 PCF FOAM OVERPACKS
       48.       20.       24.       10.       12.
    31.056    12574.     386.4
       .25       12.       .25       10.        0.
        5.       10.       20.       30.       40.       50.
       60.       70.       80.       85.
   -527.45       85.        5.       -5.        0.        3.
```

Table 2.10.2.3-7 OBLIQUE Input Table

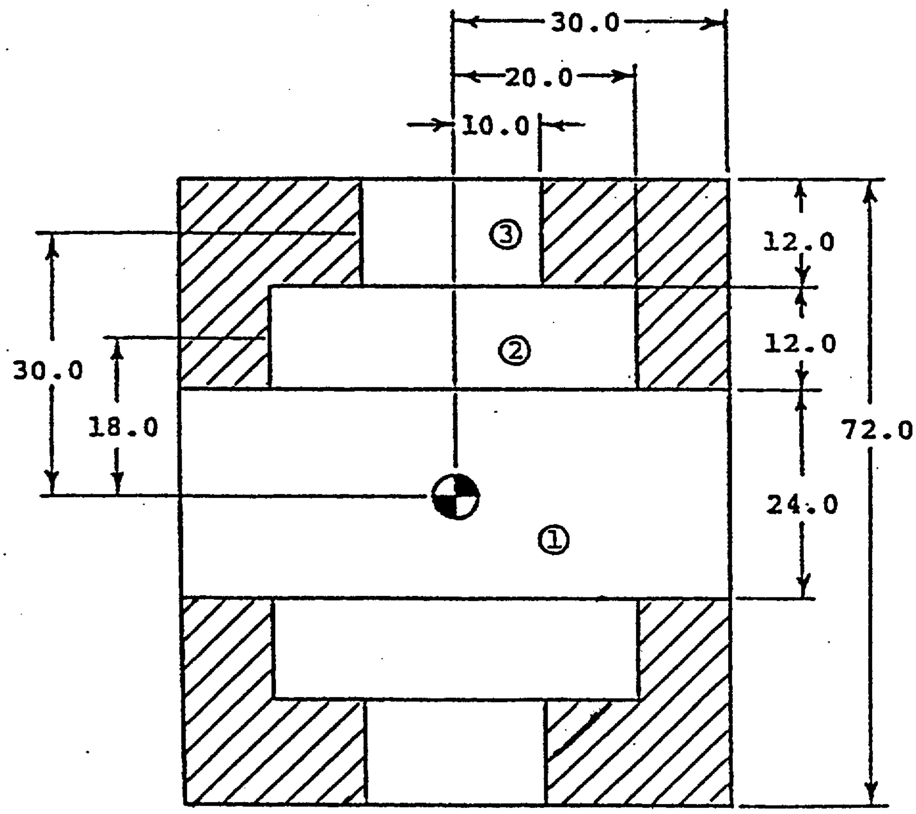
A summary of each card. is as follows:

Card 1	Problem title
Card 2	Payload length, payload radius, overpack length, overpack side thickness, overpack end thickness.
Card 3	Package mass, radial mass moment of inertia about the center of gravity, gravitational acceleration.
Card 4	Starting deflection, ending deflection, deflection increment, number of angles, print control.
Card 5-N	Angles (6 per card, 24 maximum)
Card N+1	Package free-fall velocity, output starting angle, output ending angle, angle increment, friction coefficient, estimated deflection, package translational velocity, package rotational velocity.

The package mass, assuming a gravitation acceleration of 386.4 in/sec^2, is:

$$m = 12{,}000/386.4 = 31.056\,lb - \sec^2/in$$

The radial mass moment of inertia of the system is calculated, knowing the payload and overpack weights, using composite sections:



For the Payload:

$$I_p = m(R^2 + L^2/3)/4$$

Where:

$$m = 10{,}000/386.4 = 25.88\, lb - \sec^2/in$$

$$R = 40.0/2 = 20.0 in$$

$$L = 48.0 in$$

Then,

$$I_p = 25.88[(20.0)^2 + (48.0)^2/3]/4$$

$$= 7{,}557\, lb - in - \sec^2$$

For the overpacks:

$$I_{op} = m[R^2 + (L^2/3)]/4 - m_1[R_1^2 + (L_1^2/3)]/4 - 2m_2[R_2^2 + (L_2^2/3)]/4 - 2m_2 d_2^2 - 2m_3[R_3^2 + (L_2^2/3)]/4 - 2m_3 d_3^2$$

Where:

$m \quad = \overline{m}\pi R^2 L$

$\overline{m} \quad = W_{op}/(386.4)V_{op}$

$W_{op} \quad = 1{,}000 lbs$

$V_{op} \quad = \pi[(30.0)^2 - (20.0)^2]24.0 + \pi[(20.0)^2 - (10.0)^2]12.0 = 49{,}009 in^3$

$\overline{m} \quad = 1{,}000/[(386.4)49{,}009] = 5.28(10)^{-5}\, lb - \sec^2/in^4$

$R \quad = 30.0 in$

$L \quad = 72.0 in$

$m \quad = [5.28(10)^{-5}]\pi(30.0)^2(72.0) = 10.75 lb - \sec^2/in$

$m_1 \quad = \overline{m}\pi R_1^2 L_1$

$R_1 \quad = 30.0 in$

$L_1 \quad = 24.0 in$

$m_1 \quad = [5.28(10)^{-5}]\pi(30.0)^2(24.0) = 3.583 lb - \sec^2/in$

$m_2 \quad = \overline{m} R_2^2 L_2$

$R_2 \quad = 20.0 in$

$L_2 \quad = 12.0 in$

$m_2 \quad = [5.28(10)^{-5}]\pi(20.0)^2(12.0) = 0.7962 lb - \sec^2/in$

$m_3 \quad = \overline{m} R_3^2 L_3$

$R_3 \quad = 10.0 in$

$L_3 \quad = 12.0 in$

$m_3 \quad = [5.28(10)^{-5}]\pi(10.0)^2(12.0) = 0.1991 lb - \sec^2/in$

$d_2 \quad = 18.0 in$

$d_3 \quad = 30.0 in$

Then,

$$I_{op} = 10.75[(30.0)^2 + (72.0)^2/3]/4 - 3.583[(30.0)^2 + (24.0)^2/3]/4 - 2(0.7962)[(20.0)^2 + (12.0)^2/3]/4$$
$$-2(0.7962)(18.0)^2 - 2(0.1991)[(10.0)^2 + (12.0)^2/3]/4 - 2(0.1991)(30.0)^2 = 5{,}017 lb-in-\sec^2$$

Finally,

$$I = 7{,}557 + 5{,}017 = 12{,}574 lb-in-\sec^2$$

The starting deflection, ending deflection, and deflection increment are values set to build a uniform force/deflection table for use by OBLIQUE. Prior to use of OBLIQUE, a tape holding force/deflection data (Table 2.10.2.3-8) over the range of angles from 5° to 85° is created by CYDROP. OBLIQUE, in turn, reads the tape and converts the force/deflection data to a uniform table for each specified angle. Note that the angles specified in OBLIQUE are with respect to horizontal whereas CYDROP references vertical. The magnitude of the ending deflection must be chosen such that it is greater than the maximum deflection expected in OBLIQUE, yet need not exceed the maximum possible deflection in the corner drop evaluation.

The print control determines whether the output will be a tabular summary or a time history table.

Package free-fall velocity is based on the drop height. From the equations of motion:

$$V = -(2gh)^{0.5}$$

Where:

$$g = 386.4 in/\sec^2$$

$$h = 30 ft = 360 in$$

Then,

$$V = -[2(386.4)(360)]^{0.5} = -527.45 in/\sec$$

The output starting angle, ending angle, and angle increment specify the OBLIQUE analysis package angles of impact with respect to the horizon. The sample problem specified solutions at angles of 5° to 85° in 5° increments. The friction coefficient is usually set to zero. Package translational and rotational velocities are parameters specified to study the effects of secondary impacts.

The sample problem output for OBLIQUE is found in Table 2.10.2.3-9. For each specified angle of impact the magnitude of FMAX determined as the maximum value of the vector summation of the thrust and shear forces at some instantaneous package angle during the analysis. Note that the maximum value of the package internal forces, moments, and deflections do not necessarily happen at the same instantaneous angle. When all parameters have achieved a maximum value, the problem terminates for that specified angle of impact. OBLIQUE continues the analysis at each angle of impact.

Additionally, OBLIQUE utilizes the methods delineated in Section 2.10.2.2.2 to determine the maximum overpack separation moments about the opposite and adjacent corners in the overpack. As before, a solution occurs when the maximum value is found for each moment at some instantaneous angle, not necessarily the same instantaneous angle for each moment. A negative moment denotes overpack compression and a positive moment overpack separation.

```
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         V         V         V         V         V         V         V         V
       .55     11.01       .55
    32367.   128991.   205207.   334008.   477903.   583552.   677442.   758737.
   845422.   934841.  1038385.  1135477.  1268206.  1515395.  1751333.  2111306.
  2821622.  3527691.  5437239.  8027229.
       .60     11.93       .60
    18240.    67473.   121760.   173898.   258462.   368714.   504353.   634713.
   743455.   842066.   941411.  1049548.  1178914.  1320453.  1509786.  1859217.
  2337319.  3044434.  4269526.  6258679.
       .67     13.49       .67
    12193.    56671.    91499.   113057.   156188.   229526.   313617.   404088.
   501568.   609987.   733768.   880232.  1023819.  1173033.  1357047.  1585754.
  1992534.  2555789.  3396621.  4655222.
       .73     14.65       .73
     5028.    21986.    51813.   100182.   163505.   232741.   304621.   381703.
   465956.   560855.   668431.   792142.   937642.  1114234.  1326595.  1593802.
  1971609.  2595205.  3524784.  4638336.
       .77     15.39       .77
     3109.    20093.    57039.   108821.   168429.   234305.   311057.   394634.
   486876.   592357.   705257.   841422.   999463.  1197891.  1441110.  1764085.
  2248183.  2989067.  4003001.  5295208.
       .78     15.63       .78
     4255.    26380.    68840.   123526.   187139.   259087.   340108.   434086.
   543328.   667914.   804180.   958380.  1156760.  1371183.  1650632.  2040733.
  2621016.  3413833.  4478667.  5815325.
       .77     15.39       .77
     4057.    26494.    76869.   148989.   234326.   330652.   436820.   555823.
   687002.   828086.   979995.  1150114.  1341620.  1566648.  1844710.  2230726.
  2842792.  3730696.  4961650.  6537525.
       .73     14.69       .73
    18772.    68814.   132583.   236890.   366604.   500474.   640691.   801924.
   979105.  1151239.  1316710.  1487169.  1694789.  1946953.  2263342.  2722947.
  3482689.  4608111.  6214733.  8341342.
       .68     13.55       .68
    52820.   216804.   345960.   547724.   819178.  1093308.  1315683.  1515427.
  1750771.  1988978.  2293295.  2677752.  3097958.  3572765.  4040177.  4728886.
  6012544.  8077597. 10828178. 14261926.
       .64     12.83       .64
   132903.   468917.   829010.  1274790.  1673088.  2085488.  2617955.  3024971.
  3080822.  3176792.  3326468.  3552364.  3876190.  4362971.  5134758.  6525535.
  9073079. 12696963. 17334716. 22804149.
```

Table 2.10.2.3-8 CYDROP Force/Deflection Data

NUPAC OBLIQUE ANALYSIS-OBLIQUE SAMPLE RUN, 20 PCF FOAM OVERPACKS

```
PACKAGE GEOMETRY-
     LENGTH                     =      48.000
     RADIUS                     =      20.000
     OVERPACK LENGTH            =      24.000
     OVERPACK SIDE THICKNESS    =      10.000
     OVERPACK BOTTOM THICKNESS  =      12.000
PACKAGE MASS PROPERTIES-
     MASS                       =      31.056
     MASS MOMENT OF INERTIA     =   12574.000
     GRAVITATIONAL CONSTANT     =     386.400
SOLUTION CHARACTERISTICS-
     IMPACT VELOCITY (YDOT)     =    -527.450
                     (XDOT)     =       0.000
                     (THETADOT)=        0.000
     FRICTION COEFFICIENT       =       0.000
     ESTIMATED CRUSH DEPTH      =       3.000
```

THETA0	FMAX	SHEAR	THRUST	MOMENT	DEFLECTION	CLEARANCE
85.0000	1730212.	114405.	1727493.	813544.	3.30	9.23
80.0000	1330952.	187846.	1319863.	1335795.	4.81	8.36
75.0000	1240256.	266781.	1213409.	1897113.	6.56	7.23
70.0000	1181825.	352957.	1130530.	2509913.	7.43	6.95
65.0000	1166252.	447885.	1078825.	3184961.	8.70	6.20
60.0000	1240948.	592237.	1091295.	4211462.	9.62	5.70
55.0000	1281835.	736041.	1049450.	5234069.	10.29	5.27
50.0000	1270208.	845096.	948282.	6009575.	10.57	5.04
45.0000	1180489.	879539.	789060.	6254501.	10.55	4.91
40.0000	1054731.	854279.	622354.	6074872.	10.24	4.90
35.0000	940457.	811764.	482942.	5772543.	9.73	4.96
30.0000	847985.	766511.	372050.	5450742.	9.06	5.08
25.0000	795586.	745525.	288112.	5301510.	8.26	5.26
20.0000	723357.	693598.	209484.	4932252.	7.32	5.63
15.0000	641400.	628788.	136961.	4471379.	5.92	6.19
10.0000	810749.	805405.	109797.	5727323.	5.81	5.47
5.0000	579215.	577510.	44411.	4106735.	3.28	7.62

Table 2.10.2.3-9 OBLIQUE Output

2.10.2.4 NuPac Computer Code Quality Assurance

NuPac computer analysis programs are maintained in accordance with a formal quality assurance program approved by the Nuclear Regulatory Commission under certificate number 0192 that complies with ANSI N45.2. These provisions are applied to both NuPac authored software and vendor supplied software. Vendors of computer services, such as Boeing Computer Services, have demonstrated that their quality standards are in accordance with the provisions of ANSI N45.2. Documentation of such compliance is maintained in NuPac Quality Assurance files.

The requirements of ANSI N45.2 are interpreted to impose the following stipulations upon computing software:

ANSI N45.2 Section	Requirement
4.3	The supplier shall require the identification and performance of verification/qualification evaluations which demonstrate that computer codes are capable of producing information of sufficient accuracy to satisfy design requirements. All calculations and computer input data shall receive documented, independent, in-house verification.
7.0	The supplier shall establish responsibilities and procedures relating to computer code configuration identification and configuration control. NOTE: Configuration identification is the establishment and use of a unique identifier for a code version. Configuration control includes the documentation and preservation of a code version to assure its retrievability and includes similar preservation of input for computer runs to assure that output results can subsequently be reconstructed.

A valid computer solution requires that each of the following tests be satisfied:

- Does the analytic method accurately represent the modeled physical processes?
- Does the computer code fully and accurately implement the analytic method?
- Does the input problem data accurately reflect the physical properties of the situation being analyzed?
- Can the resultant output data be uniquely identified as resulting from a particular input data set?

NuPac procedures assure that each of the above questions is answered in an affirmative fashion. These procedures include the following configuration control elements.

1. Each safety analysis report or design analysis summary provides a complete description of appropriate analysis methods implemented in NuPac developed software.
2. Version identification for each run of the computer code is maintained by the automatic appearance of current code revisions numbers and dates in both output headers and day file listings.
3. All superseded versions of codes are maintained on file.
4. All input data are automatically echoed on output for verification and checking purposes.

5. All output data, including plots, are labeled with a machine generated name, time and date corresponding to the run which generated the reported engineering results.

Verification of methodology and code accuracy involves one or more of the following steps:

1. End-to-end experiments:

   These experiments simultaneously test the accuracy of both methodology and code implementation of methodology. For example, a full scale series of 30' drop tests conducted in September 1980 on the Chem-Nuclear Systems, Inc. CNSI-13C (II) package demonstrated that the overall predictive error of NuPac impact dynamics software is about 6%. (Reference page 2-91, Section 2.7.1.2 of CNSI-13C (II) S.A.R.)

2. Comparison with Alternative Methods:

   The method of comparison varies with the particular technology involved. Two examples are described below.

   a. Impact Analyses:

      Alternative energy balance and momentum methods are used to checkpoint time history impact dynamics solutions. These end-to-end checks have been performed at three orientations where the dynamic equations of motion become simplified: end, side and center of gravity over struck corner. At other orientations, the impact dynamic solution method has been verified by momentum techniques combined with idealized perfectly plastic energy absorber assumptions.

   b. Thermal Analyses:

      Steady state solutions are checked by independent iteration methods and a careful check of model heat flow balances (equilibrium). Transient analyses are independently checked by Schmidt plot graphical analysis methods.

3. Hand Checks of Code:

   Hand checks have been performed to assure that:

   - Equilibrium is always satisfied. Both thermal and all impact solutions have been so tested.
   - Force or heat transfer between points, or nodes, obey the assumptions of the analysis model.
   - Analytic geometry calculations obey the model assumptions. These features have been checked by both descriptive geometry constructions and mathematical checks of the algorithms.
   - Interpolations of non-linear tabular data are correctly performed.
   - Numerical integrations are properly performed.

APPENDIX 2.10.3

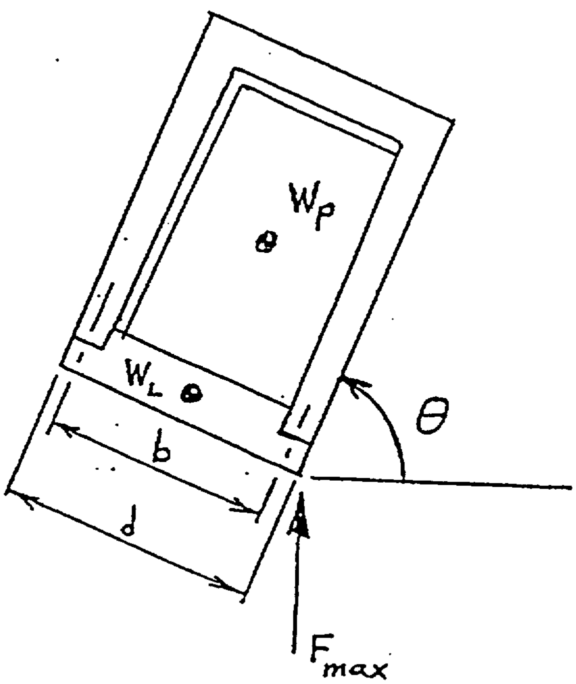
Primary Lid Closure Bolt Evaluation For 30 Foot Oblique Drops

2.10.3 Primary Lid Closure Bolt Evaluation For 30 Foot Oblique Drops

In the following evaluation, all references to bolts are equally applicable to studs.

2.10.3.1 Stress Evaluation

From the OBLIQUE drop program, 'g' loads for all possible oblique cask orientations are available. These g loads are used as follows to determine stresses in the primary lid bolts.



θ	=	Cask orientation wrt horizontal
W	=	Total package weight (with payload)
	=	68,100lbs
W_P	=	Payload Weight
	=	10,000lbs
W_L	=	Lid Weight
	=	7,200lbs
g	=	'g' load on package
F_{max}	=	impact force (from OBLIQUE) = Wg
b	=	Bolt circle diameter
	=	71.25in
d	=	Lid diameter
	=	76.0in

T = Thrust load on lid = $(W_L + W_P)(g)\sin\theta = 17{,}200 g \sin\theta$

V = Shear load on lid = $(W_L)(g)\cos\theta = 7{,}200 g \cos\theta$

Bolt stress is determined as follows using T and V.

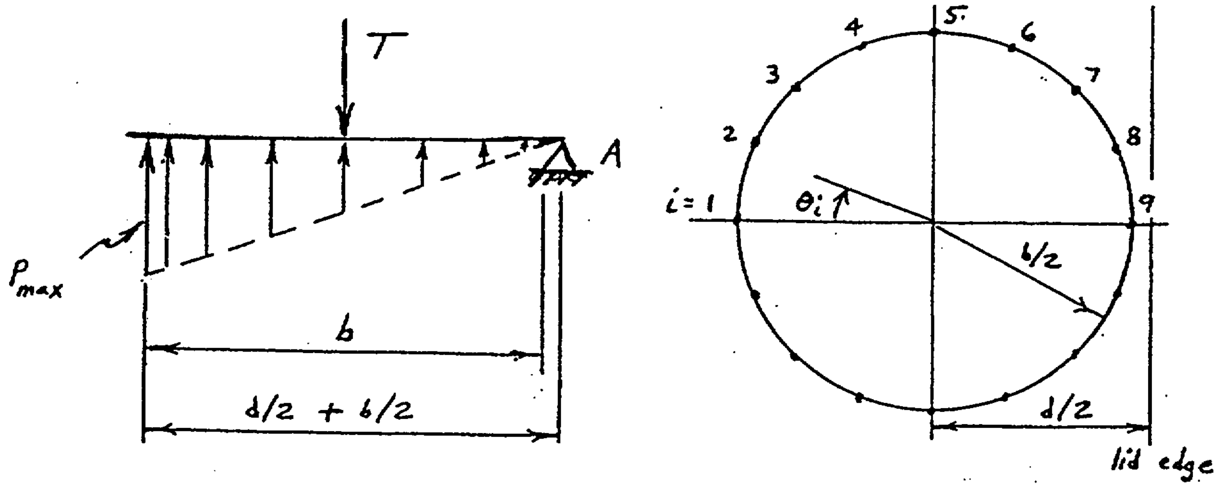
τ = shear stress in bolt = V/NA

where N = total number of bolts = 16

A = minimum tensile area of bolt = 1.404 in^2

(Note: tolerance stackup is such that if the lid slips relative to the cask body, the lid will bear against the cask before it will directly load a bolt in shear.)

σ = tensile stress in the bolt. This stress is conservatively determined assuming no support of the lid from the overpack. It is further assumed that the lid pivots about the impacted edge resulting in the maximum bolt tensile stress on the opposite side of the lid as shown below.



With a 16 bolt configuration, taking moments about point 'A',

$$T(d/2) = P_{max}\{(d/2+b/2)+2\sum_{i=2}^{8}[(d/2)+(b/2)\cos\theta_i]^2 \Big/ [(d/2)+(b/2)] + [(d/2)-(b/2)]^2 / [(d/2)+(b/2)]\}$$

where $\theta_i = 22.5(i-1)$

Thus, $P_{max} = .084125T$

Given an orientation angle, θ, and the corresponding 'g' load, T and P_{max} are directly obtained from the preceding equations and bolt tensile stress becomes:

$\sigma = P_{max}/A$ tensile stress in bolt

τ and σ are therefore readily determined for all drop orientations.

For comparison with the acceptance criteria, the above determined tensile stress, σ, must be increased by the stress due to internal pressure, σ_P.

$\sigma_P = (p)(A_S)/(N)(A) = 1.758 psi$

where p = internal pressure = $11.2 psi$ (Section 2.6.3)

A_S = area within the seal over which pressure acts

$= (\pi/4)(67)^2 = 3526 in^2$

N = number of bolts = 16

A = minimum tensile area of bolt = $1.404 in^2$

Note: if the resultant tensile stress, $\sigma + \sigma_p$ is less than the prestress in the bolt, prestress is used for the bolt tensile stress. Otherwise, prestress is not specifically addressed. Prestress for the primary lid bolts is 9,259 psi per Table 2.7.1.3-3.

2.10.3.2 Acceptance Criteria

Using the previously obtained stresses in the bolts, the interaction check specified in paragraph F-1335.3 of Appendix F of the ASME Boiler and Pressure Vessel Code is utilized to determine acceptance. The equation to be satisfied is as follows:

$$(f_t/F_{tb})^2 + (f_v/F_{vb})^2 \leq 1$$

where f_t = computed tensile stress, psi

= greater of $\sigma + \sigma_p$ and $9{,}259\ psi$ prestress

f_v = computed shear stress, psi

$= \tau$

F_{tb} = allowable tensile stress, psi

= lesser of $0.7S_u$ and S_y

$= 0.7(145{,}000) = 101{,}500\ psi$

F_{vb} = allowable shear stress, psi

= lesser of $0.42S_u$ and $0.6S_y$

$= 0.42(145{,}000) = 60{,}900\ psi$

Table 2.10.3-1 presents a tabular summary of the preceding equations for all accident oblique drop orientations of the 10-142 package. Worst case package 'g' loads and orientation angles are taken from Tables 2.7.1.2-1 and 2.7.1.2-3 of Section 2.7.1.2.

Orientation wrt horizontal (degrees)	Maximum 'g' load (F_{max}/W)	σ (psi)	$\sigma + \sigma_p$ (psi)	$f_t=\sigma+\sigma_p$ or 9,259 (psi)	$f_v = \tau$ (psi)	Interaction Check $(f_t/F_{tb})^2+(f_v/F_{vb})^2$
85	76.1	78130	79888	79888	2126	.621
80	58.3	59171	60929	60929	3245	.363
75	53.4	53158	54916	54916	4430	.298
70	52.6	50940	52698	52698	5766	.279
65	53.9	50344	52102	52102	7301	.278
60	56.2	50160	51918	51918	9006	.284
55	58.4	49302	51060	51060	10736	.284
50	57.7	45553	47311	47311	11887	.255
45	54.0	39352	41110	41110	12238	.204
40	49.0	32460	34218	34218	12031	.153
35	44.0	26009	27767	27767	11552	.111
30	40.0	20612	22370	22370	11103	.082
25	37.2*	16202	17960	17960	10806	.063
20	35.8*	12619	14377	14377	10782	.051
15	37.4	9976	11734	11734	11579	.050
10	38.3	6854	8612	9259	12089	.048
5	42.4	3808	5566	9259	13538	.058

These loads come from Table 2.7.1.2-3. All others are from Table 2.7.1.2-1

Table 2.10.3-1 Primary Closure Bolt Stress Summary for Accident Condition Oblique Drops

3.0 THERMAL EVALUATION

The following thermal evaluation of the package demonstrates its ability to meet the normal transport and hypothetical accident conditions.

3.1 Summary of Pressures and Temperatures

Under steady state conditions, assuming a 24 hour day at maximum solar heat load, the maximum package temperature was found to be 168°F for the Albi-Clad model in a 130°F ambient temperature. The cask was reanalyzed with a thermal shield and the latest conditions required by 10 CFR 71. The maximum temperature under this analysis was 207°F with sun and 118.5°F without solar loads.

When subjected to the hypothetical accident conditions, lead temperatures remained well below the critical melting point. The primary and secondary seal temperature rose to 243°F and 458°F respectively. These are well below the 500°F allowable operating temperature for the silicone rubber seals. It has been shown that internal pressures are easily reacted by the containment vessel. Temperatures predicted for the thermal shield-equipped package were lower than those noted above for the Albi-Clad design. From the above, it can be safely concluded that thermal conditions will have little effect on the containment vessel integrity.

As described below these results are based on a model that represents a cask with 101 inch diameter impact limiters that extend 14 inches beyond the ends of the cask body. This is a conservative model of the actual cask that has 112 inch diameter impact limiters which extend 23 inches beyond the ends of the cask body. The better insulating capacity of the larger impact limiters will tend to reduce the effect of the sun under the steady state normal conditions and the fire during the transient accident event. The actual larger impact limiters will also reduce the effect of the damaged impact limiter analysis shown at the end of Section 3.3.

3.2 Thermal Analysis Model

This analysis treats both normal transport and hypothetical accident conditions. Specifically, conditions evaluated include:

Normal Transport
- Exposed – Maximum Solar Flux
  - 100°F Ambient Air (Design Criteria)
  - 130°F Ambient Air

Hypothetical Accident Condition
- Fire exposure
  - 30 Minute Fire at 1475°F
  - Surface Emissivity = 0.8
  - Initial Conditions – 130°F Ambient Air
  - Cooling – Radiation Free Convection - 70°F Ambient Air

Briefly, the model consists of 68 node lumped parameter idealization. A single node was used to represent the source. For conservatism, the 10-142 shield has been assumed empty; that is, the fraction of heat absorbed by the payload during the hypothetical fire exposure has been neglected. Figure 3.1-1 defines the model and graphically shows the placement of nodes. A detailed explanation is provided in the body of the analysis.

The overpack and cask outer shell is linked to the external environment (ambient air or fire source) by a pair of resistors, one represents radiation effects and one represents convection effects (free). During the 30 minute fire, the convection resistor is switched off. Solar flux is applied by a direct heat input to the outer shell.

Heat transfer through the foam insulation is represented by conduction resistors. To account for the possibility of foam char, the resistors are defined versus temperature such that the foam is replaced by an equivalent air gap at 400°F. Gases generated from decomposition of the foam (temperature 600° F) are vented through four (two in each overpack) 1-1/2 inch diameter holes in the external skin. These vents are closed with a standard ABS plastic pipe plug that melts well before off gassing starts.

The cylindrical steel outer shell of the shield is thermally protected from fire by a 3/16 inch nominal thickness of Albi-Clad 89 intumescent paint which exhibits a 4.1 expansion upon exposure to fire (at 300° F). A comprehensive discussion of the experimental demonstration of this coating's thermal performance is summarized in Union Carbide Report No. K-1661, 'Fissile Material Container and Packaging Development and Testing Program,' April 1, 1966. The experimental thermal response of the container discussed in this reference compares closely with that predicted by the 10-142 shield thermal analysis.

Solution of the transient (fire) case is achieved by a conventional thermal analyzer program, THAN, based on the well known Lockheed Thermal Analyzer.

As an option, the 10-142 may be equipped with a 10 gauge stainless steel thermal shield in place of the Albi-clad 89 intumescent paint. Because the shield is installed slightly away from the surface of the biological shield, heat from the hypothetical fire event must employ the relatively inefficient heat transfer modes of radiation and air conduction to reach the biological shield. This produced similar insulating effects as the Albi-Clad coating.

The cask equipped with the thermal shield has been analyzed using the same thermal model as the Albi-Clad design except for those features specifically modeling the coating's response to the fire event. The August 1983 revision of 10 CFR 71 was used to determine the loads to be applied to the cask equipped with a thermal shield. These loads are given below:

Normal Transport

- 400 watts internal decay heat
- 2950 Btu/12 hour day/ft^2 on upper horizontal flat surfaces
- 100°F ambient air temperature

Hypothetical Accident Condition

- 400 watts internal decay heat
- No solar loads
- 100°F initial ambient air temperature
- 30 minute fire at 1475°F
- 100°F ambient air temperature after fire
- Convection effective before, during, and after fire
- Surface emissivity is 0.8

The analysis for a cask with the thermal shield is presented below, after the analysis for a cask protected with Albi-Clad.

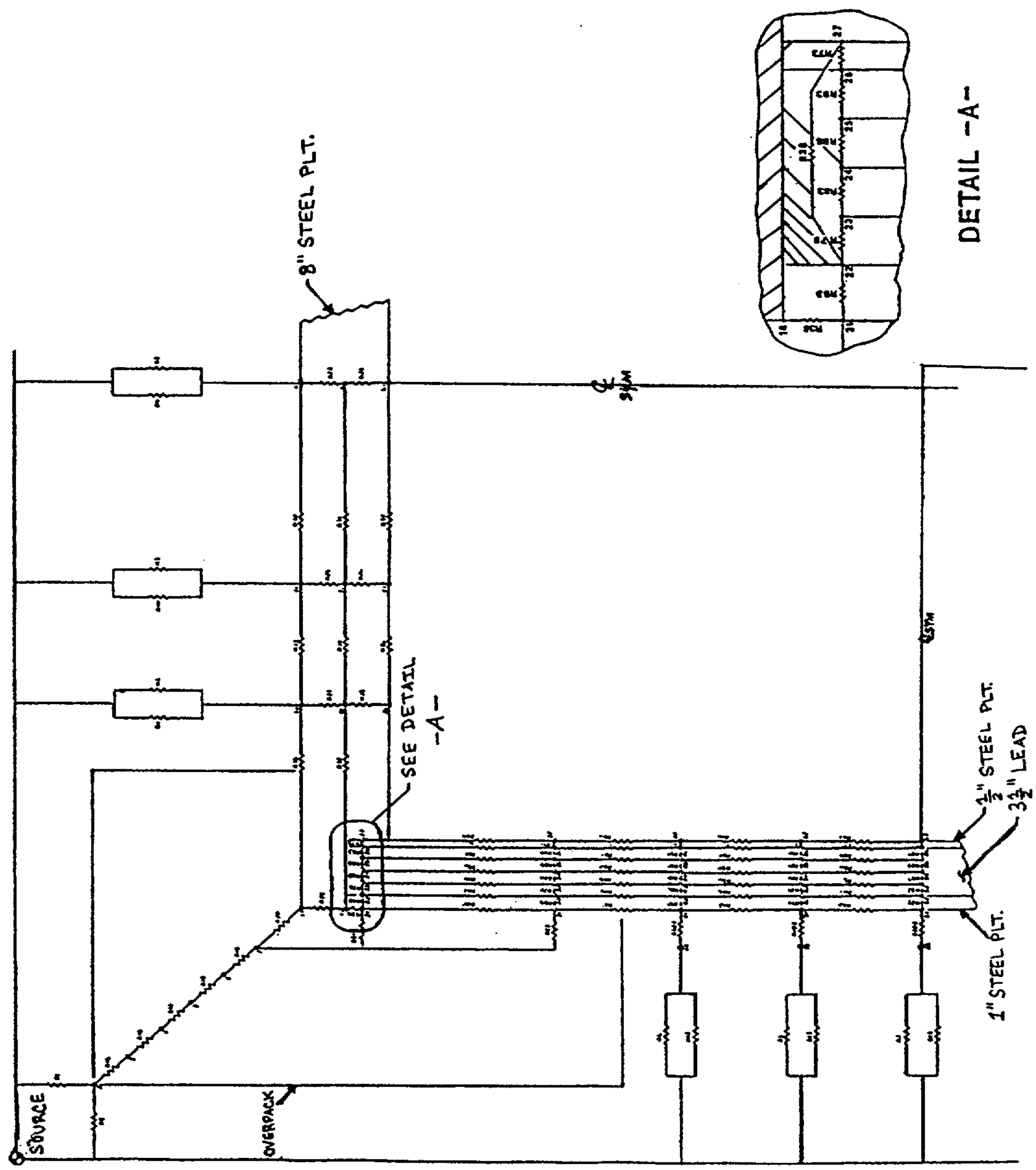
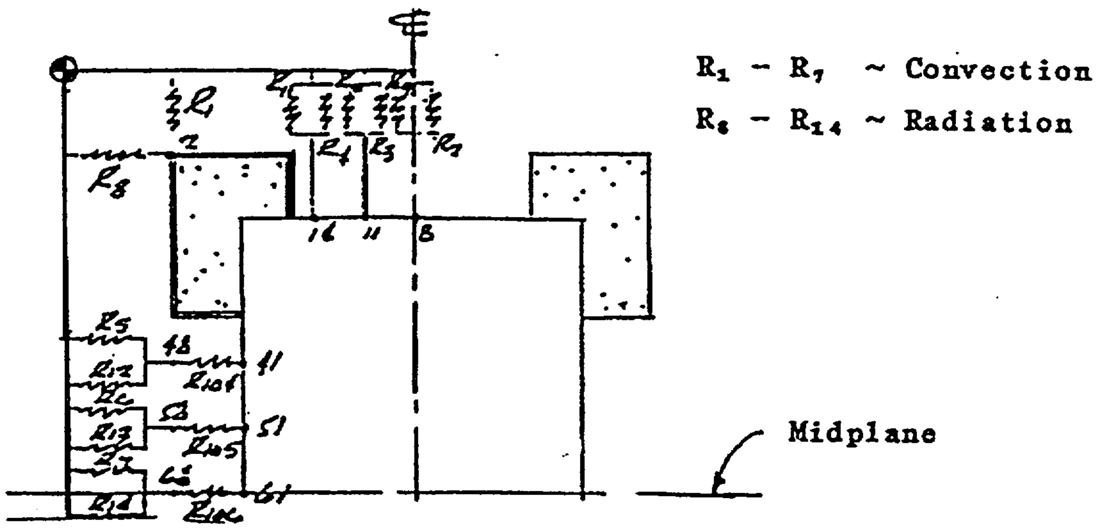


Figure 3.1-1 Model 10-142 Shield Thermal Analysis Model

Thermal - External Heat Transfer

External heat transfer between flash and the prescribed external environment involved both radiant and convective modes. The external environmental node and flash external nodes are illustrated in the sketch below.



Related Nodal Areas

Node NR.	Area Calculation (in^2)		Node Area (Ft^2)
2	$\pi(50.5^2-27.5^2+50.5^2-38^2)+2\pi(50.5)(36)+2\pi(27.5)(14)$	=	159.398
8	$\pi(10^2)$	=	2.182
11	$\pi(19^2-10^2)$	=	5.694
14	$\pi(27.5^2-19^2)$	=	8.623
41	$2\pi(38)(8)$	=	13.265
51	$2\pi(38)(8)$	=	13.265
61	$2\pi(38)(4)$	=	6.632

Convective Heat Transfer

The basic convective mechanism is:

$q = h_i A_i (T_i - T_j)$;

i	= nodal subscript
h_i	= film coefficient for the ith node
A_i	= area of ith node
T_j	= temperature of jth node

The 'THAN' thermal analyzer code only allows specification of a single film coefficient, $\bar{h}$. As a consequence, nodal equivalent areas will be derived as follows:

$A_i^* = h_i A_i / \bar{h}$; A^*_i = equivalent area for the i[th] node

McAdams recommends the following film coefficient expressions:
[L = length in feet]

$h = 0.29(\Delta T/L)^{1/4}$; vertical cylinders

$= 0.27(\Delta T/L)^{1/4}$; horizontal plates – heated plate facing up

$= 0.12(\Delta T/L)^{1/4}$; horizontal plates – heated plate facing down

$= C(\Delta T/L)^{1/4}$; general

For Node 2:

Location	Area (Ft^2)	L (in)	C	A*C*(L/12)$^{-1/4}$
LWR Surface $\pi(50.5^2 - 38^2)/144$	24.135	(50.5-38.0)	0.12	2.867
Exterior Vert. Surface $2\pi(50.5)(36)/144$	79.325	36	0.29	17.479
Top $\pi(50.5^2 - 27.5^2)/144$	39.139	(50.5-27.5)	0.27	8.981
Interior Vert. Surface $2\pi(27.5)(14)/144$	16.799	14	0.29	4.687
	$\sum 159.398$			$\sum 34.015$

$$h_2 = \sum A_i C_i (L_i/12)^{-1/4} / \sum A_i = 0.213397$$

For Nodes 8, 11, 14:

$$h_{8,11,14} = A_8 C_8 (L_8/12)^{-1/4} / A_8 = (0.27)(27.5/12)^{-1/4} = 0.219445$$

For Nodes 41, 51, 61:

$$h_{41,51,61} = C_{41}(L_{41}/12)^{-1/4} = (0.29)(40/12)^{-1/4} = 0.214624$$

Mean Film Coefficient and Nodal Effective Areas

Node NR. (i)	A_i^y	h_i^x	$A_i h_i$	A_i^*
2	159.398	0.213397	34.015	158.900
8	2.182	0.219445	0.479	2.238
11	5.694	0.219445	1.250	5.838
14	8.623	0.219445	1.892	8.838
48	13.265	0.214624	2.847	13.300
58	13.265	0.214624	2.847	13.300
68	6.632	0.214624	1.423	6.647
$\sum$	209.060	1.516	44.753	

$\bar{h} = \sum A_i h_i / A_i = 0.214066$

Radiation Heat Transfer

For external radiation, the applicable expression is:

$$K_{ij} = \sigma A_i \varepsilon_i ; \sigma = 0.1714 \times 10^{-8} ; \varepsilon = 0.8$$

$$K_{ij} / A_i = \sigma \varepsilon_i = 1.371 \times 10^{-9}$$

Resist. NR.	Nodes i	j	A_i	K_{ij} ($x10^{-9}$)
8	1	2	159.398	218.600
9	1	8	2.182	2.992
10	1	11	5.694	7.808
11	1	14	8.623	11.820
12	1	48	13.265	18.190
13	1	58	13.265	18.190
14	1	68	6.632	9.094

Sidewall Conductive Coating (Albi-Clad 89)

Resistors 104, 105, 106 represent an Albi-Clad coating of 3/16-inch thickness which expands at a temperature of 300°F to 4 times the pre-fire thickness. This intumescent material exhibits thermal conductivity of:

Before fire exposure: $K = 2.90\, Btu - in/hr - ft^2 - °F$

After fire exposure: $K = 0.57\, Btu - in/hr - ft^2 - °F$

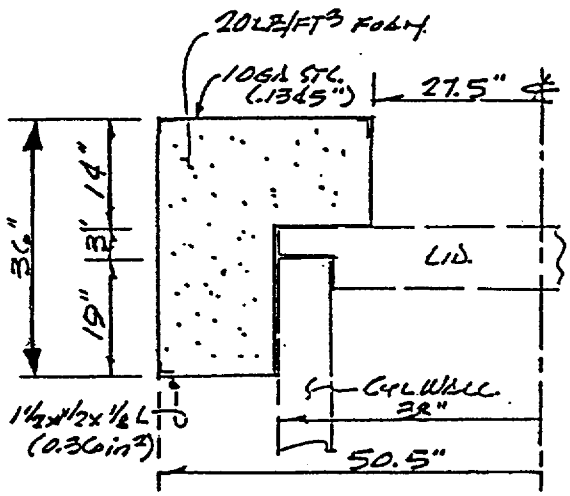
The conductive resistor is thus:

$$R_i = (t/K)(1/A_i); t/K = (3/16)/(2.9) = 6.46552 \times 10^{-2} (T \langle 300°F)$$

$$= \frac{(3/16)(4)}{0.57} = 1.31579 (T \geq 300°F)$$

Resist. NR.	Nodes	(T<300°F) $x10^{-3}$	(T≥300°F) $x10^{-3}$	Area
104	48-41	4.874	99.19	13.265
105	58-51	4.874	99.19	13.265
106	68-61	9.749	198.40	6.632

Cylindrical Corner Protecting Foam 'Donuts'



Carb. Steel Prods.

$K = 25\,Btu-in/hr-ft^2-°F$

$C_p = 0.125\,Btu/lb$

$\rho = 487\,lb/ft^3$

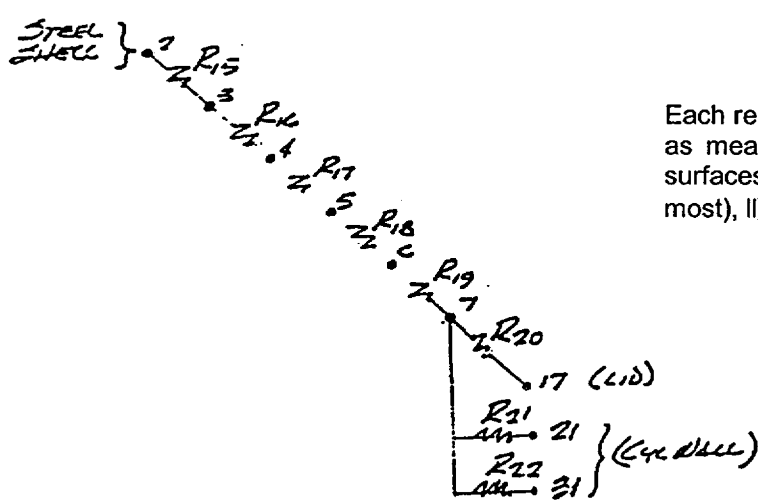
Foam Products

$K = 0.2\,Btu-in/hr-ft^2-°F$

$C_p = 0.3\,Btu/lb$

$\rho = 20\,lb/ft^3$

Analytic Model



Each resistor represents a two inch slab of foam as measured from the outer diameter and top surfaces of the 'donut,' excepting the last (inner-most), $\|\Sigma R_{20}$, R_{21}, R_{22}.

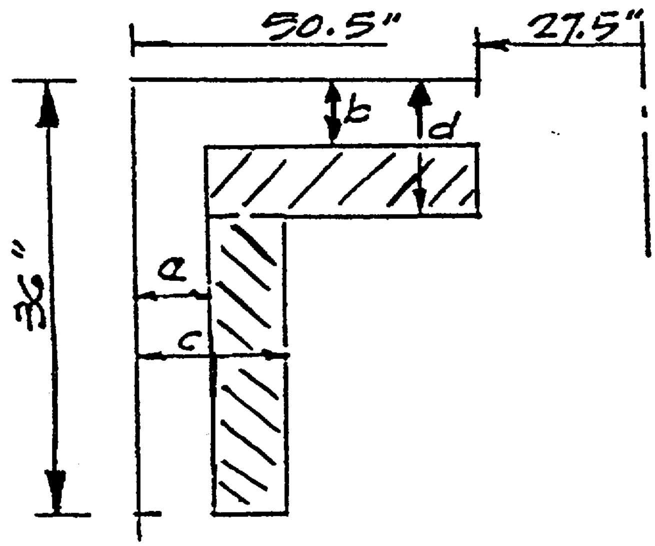
Corner Protector Nodal Capacitances

Node 2 - Steel Shell

$$V = 2\pi[(27.5)+(2)(50.5)](0.36)+(0.1345)\{\pi(50.5^2-27.5^2)+\pi(50.5^2-38^2) + 2\pi[(50.5)(36)+(27.5)(14)]\} = 3377.87 in^2$$

$$C_2 = C_P \rho V = (0.125)(487)(3377.87)/(1728) = 119.00\,Btu/°F$$

Nodes 3, 4, 5, 6, 7, ~ Foam



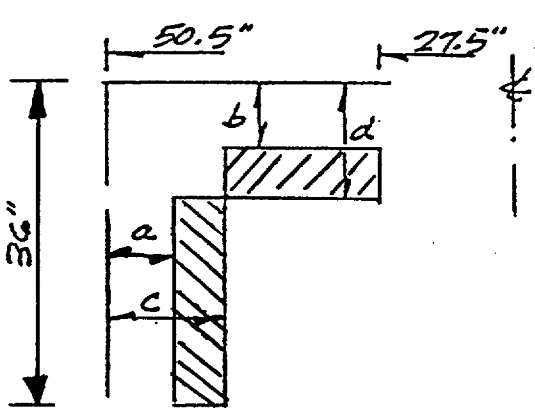
$$C_i = C_P \rho V_i = (0.3)(20)V_i = 6V_i$$

$$V = (\pi/1728)\{[(50.5-a)^2 - 27.5^2](d-b) + [(50.5-a)^2 - (50.5-c)^2](36-d)\}$$

Node NR.	a (in)	b (in)	c (in)	d (in)	C_i (Btu/°F)
3	0	0	3	3	164.54
4	3	3	5	5	95.62
5	5	5	7	7	84.98
6	7	7	9	9	74.85
7	9	9	12.5	14	119.46
					Σ=539.45

Corner Protector Resistances

Resistors R_{15} to R_{19} represent a series heat path through the external 10 inches of foam protector. Resistors R_{20} to R_{22} represent parallel heat paths between the metallic shipping flask walls and this 10 inch point (node 7) within the foam protector. Taken collectively, resistors R_{20} to R_{22}, are in series with resistors R_{15} to R_{19}.



The calculation scheme follows that used for capacitance.

$$R_i = 1/[1/R_{ac} + 1/R_{bd}]$$

$$R_{ac} = \ln(r_o/r_i)/2\pi kL$$

$$= \ln[(50.5-a)/(50.5-c)]/2\pi(0.2/12)[(36-d)/12]$$

$$= 144/2\pi(0.2)\cdot\ln[(50.5-a)/(50.5-c)]/(36-d)$$

$$R_{bd} = t/kA = (d-b)/[(0.2\pi)/144][(50.5-c)^2 - 27.5^2]$$

$$= 144/\pi(0.2)\cdot(d-b)/[(50.5-c)^2 - 27.5^2]$$

Resistor	R_1 a	R_2 b	R_3 c	R_4 d	Resistance Value (10^{-3}°F-hr/Btu)
15	0	0	2	2	92.38
16	2	2	4	4	103.10
17	4	4	6	6	115.90
18	6	6	8	8	131.50
19	8	8	10	10	150.70
*‖Σ(20,21,22)	10	10	12.5	14	265.70

*‖Σ=Parallel Sum ~See following for apportionment

Apportionment of Resistances $R_{20} - R_{22}$

The parallel sum of these resistances is:

$$R\sum\| = 265.7 \times 10^{-3}\,°F - hr/Btu$$

Assuming an area based apportionment rule (contact area with flask):

$$R_{PART}/R_{TOTAL} = (1/A_{PART})/(1/A_{TOTAL});\, therefore R_i = R_t \cdot A_T/A_i$$

Resist. NR.(i)	Area Calculation		Ap (in^2)	R_i (x10^{-3})	Nodes
20	$\pi(38^2 - 27.5^2) + 2\pi(38)(3)$	=	2876.91	684.7	7-17
21	$2\pi(38)(9.5)$	=	2268.23	868.4	7-21
22	$2\pi(38)(9.5)$	=	2268.23	868.4	7-31
	A_T	=	7413.37		

Check: $R\|\sum = 1/[(1/R_{20}) + (1/R_{21}) + (1/R_{22})] = 265.7 \times 10^{-3}$

Foam Char Effects

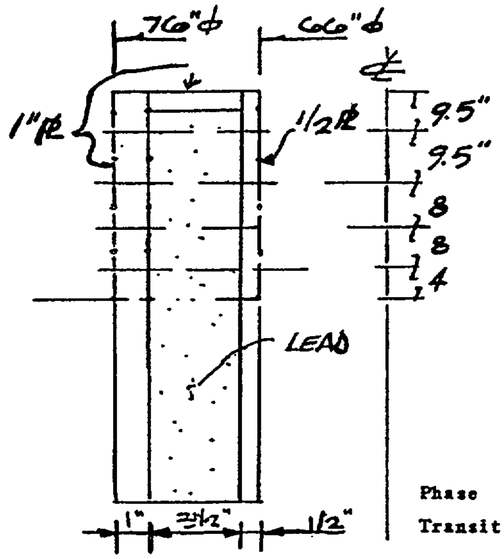
Foam is assumed to char at 400°F and is replaced by an air gap. Define:

$$R_F = R_{AIR}/R_{FOAM} = (k_{FOAM} = 0.2/12)/k_{AIR}$$

-Temperature- °F	°R	k_{AIR}	R_F
70	530		1.0000
401	860	0.0212	0.7862
600	1060	0.0250	0.6667
800	1260	0.0286	0.5828
1000	1460	0.0319	0.5225
1500	1960	0.0400	0.4167
2000	2460	0.0471	0.3539

This temperature variance is assumed for foam resistors R_{15} to R_{22}.

Cylindrical Wall Thermal Model



Carb. Steel (p. 166 Shappert)

$K = 25\,Btu - in/hr - ft^2 - °F$

$C_P = 0.125\,Btu/lb$

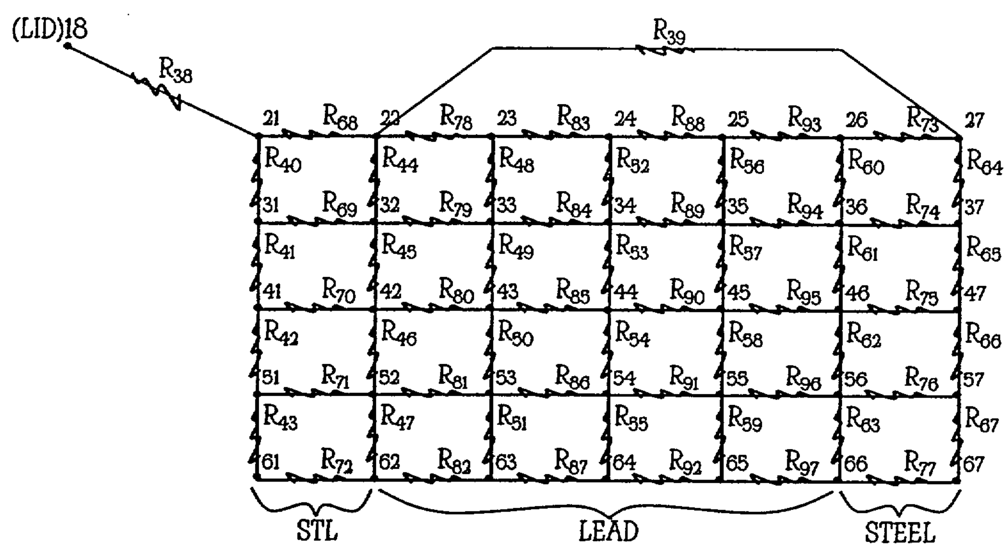
$\rho = 487\,lb/ft^3$

		Lead	
		Solid	Liquid
K	=	18.6	9.3
C_P	=	0.0325	0.038
ρ	=	687	657

Phase Transition — $H_F = 10.55\,Btu/lb$

$T_{MP} = 621°F$

Analytic Model



$$R_{39} = \ln(r_o/r_i)/2\pi kL = \ln(37/33.5)/[2\pi(25)(1/12)] = \underline{7.591\times10^{-3}}$$

Cylindrical Wall Resistors

Vertical (Longitidinal) Resistors:

$$R_{ij} = t_{ij} / kA_{ij}$$

Longitudinal (Radial) Resistors:

$$R_{ij} = \ln(r_o / r_i) / 2\pi k L_{ij}$$

Material	NR. (i)	Radii (in) r_o	r_i	Area (in^2)	t (in^2)	R_i (10^{-3} °F-Hr/Btu) Solid	Liquid
Steel	40,41	38.000	37.500	118.60	9.5	38.45	
Steel	42,43	38.000	37.500	118.60	8.0	32.38	
Steel	44,45	37.500	37.000	117.00	9.5	39.97	
Steel	46,47	37.500	37.000	117.00	8.0	32.81	
Lead	48,49	37.000	36.125	201.00	9.5	30.49	60.98
Lead	50,51	37.000	36.125	201.00	8.0	25.68	51.35
Lead	52,53	36.125	35.250	196.20	9.5	31.24	62.48
Lead	54,55	36.125	35.250	196.20	8.0	26.31	52.61
Lead	56,57	35.250	34.375	191.40	9.5	32.02	64.05
Lead	58,59	35.250	34.375	191.40	8.0	26.97	53.93
Lead	60,61	34.375	33.500	186.60	9.5	32.85	65.70
Lead	62,63	34.375	33.500	186.60	8.0	27.66	55.32
Steel	64,65	33.500	33.000	104.50	9.5	43.65	
Steel	66,67	33.500	33.000	104.50	8.0	36.76	

Vertical Resistors

Material	NR. (i)	Radii (in) r_o	r_i	L(in)	R_i (10^{-6} °F-Hr/Btu) Solid	Liquid
Steel	68,69	38.000	37.000	9.5	214.5	
Steel	70,71	38.000	37.000	8.0	254.7	
Steel	72	38.000	37.000	4.0	509.3	
Steel	73,74	33.500	33.000	9.5	120.9	
Steel	75,76	33.500	33.000	8.0	143.6	
Steel	77	33.500	33.000	4.0	287.2	
Lead	78,79	37.000	36.125	9.5	258.7	517.4
Lead	80,81	37.000	36.125	8.0	307.2	614.4
Lead	82	37.000	36.125	4.0	614.4	1229.0
Lead	83,84	36.125	35.250	9.5	265.0	530.0
Lead	85,86	36.125	35.250	8.0	314.7	629.4
Lead	87	36.125	35.250	4.0	629.4	1259.0
Lead	88,89	35.250	34.375	9.5	271.7	543.4
Lead	90,91	35.250	34.375	8.0	322.6	645.2
Lead	97	35.250	34.375	4.0	645.2	1290.0
Lead	93,94	34.375	33.500	9.5	278.7	557.4
Lead	95,96	34.375	33.500	8.0	330.9	661.9
Lead	97	34.375	33.500	4.0	661.9	1324.0

Note: For lead, $R_{iLIQ}/R_{iSOL} = 2$

Cylindrical Radial Resistors

Node	Material	Area (in)	Thick. (in)	C_i(Btu/°F) Solid	Liquid	Total heat at Phase Change (Btu)
21,31	Steel	118.6	9.5	39.69		
41,51	Steel	118.6	8.0	33.42		
61	Steel	118.6	4.0	16.71		
22,32	Steel	117.0	9.5	39.16		
42,52	Steel	117.0	8.0	32.97		
62	Steel	117.0	4.0	16.49		
23,33	Lead	201.0	9.5	24.67	27.59	8009.1
43,53	Lead	201.0	8.0	20.78	23.23	6744.5
63	Lead	201.0	4.0	10.39	11.62	3372.3
24,34	Lead	196.2	9.5	24.08	26.93	7817.9
44,54	Lead	196.2	8.0	20.28	22.68	6583.5
64	Lead	196.2	4.0	10.14	11.34	3291.7
25,35	Lead	191.4	9.5	23.49	26.27	7626.6
45,55	Lead	191.4	8.0	19.78	22.12	6422.4
65	Lead	191.4	4.0	9.89	11.06	3211.2
26,36	Lead	186.6	9.5	22.91	25.61	7435.3
46,56	Lead	186.6	8.0	19.29	21.57	6261.3
66	Lead	186.6	4.0	9.64	10.78	3130.7
27,37	Steel	104.5	9.5	34.97		
47,57	Steel	104.5	8.0	29.45		
67	Steel	104.5	4.0	14.73		

Note: For lead, $\frac{C_{iLIQ}}{C_{iSOL}} = \frac{(657)(0.038)}{(687)(0.0325)} = 1.1182$

Cylindrical Wall ~ Nodal Capacitance and Phase Change

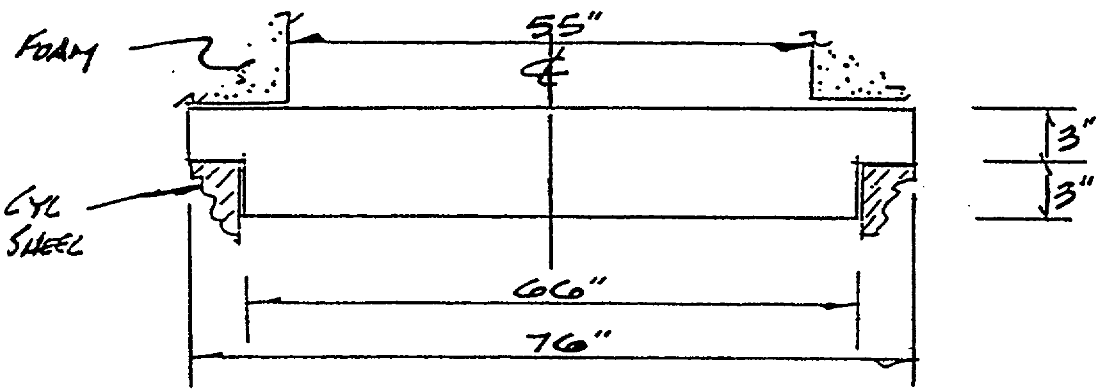
Lid Thermal Model

Material: Carb. Steel $K = 25\,Btu - in/hr - ft^2 - °F$

$C_P = 0.125\,Btu/lb$

$\rho = 487\,lb/ft^3$

Typical Top and Bottom



Analytic Equivalent

Note: Symmetry is assumed about mid-plane. Thus, only the top half of container is analyzed.

Nodal Capacitances:

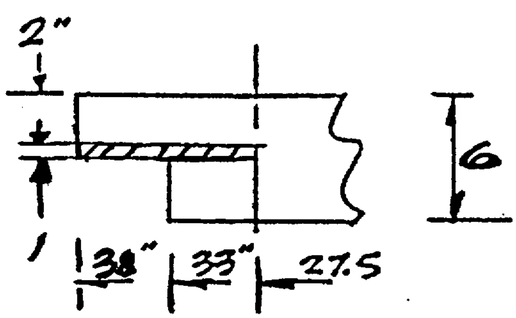
Node	Area (in^2)	Volume (ft^3)	C_i (Btu/°F)
8,9,10	314.2	0.36	22.13
11,12,13	820.0	0.95	57.77
14,15,16	1241.7	1.44	87.49
17	2160.6	2.50	152.23
18	*	3.07	186.60

$A = (\pi/4)(D_o^2 - D_I^2) = \pi(R_o^2 - R_I^2)$

$V = A(2)/1728$

$C_i = \rho V C_P$

* Node 18 Special Geometry: $V = \pi[(33^2 - 27.5^2)(3) + (38^2 - 27.5^2)(1)]/1728 = 3.07\,ft^3$



Conductive Resistors

Two analytic expressions are pertinent:

- For Vertical resistors: $R_{ij} = t_{ij}/kA_{ij}$; t = Ft, A = Ft^2
- For Horizontal Resistors: $R_{ij} = \ln(r_j/r_i)/2\pi kL$; r_j= outer radius, r_i = inner radius

Vertical Resistors:

NR. (i)	A (in^2)	t (in)	R_i (10^{-3} °F-hr/Btu)
23,24	314.2	3	4.583
25,26	820.0	3	1.756
27,28	1241.7	3	1.160
29	2160.6	3	0.667

Horizontal Resistors:

NR.	r_j(in) outer	r_i(in) inner	L (in)	R_i (10^{-3} °F-hr/Btu)
30,31,32	14.50	0.50	2	128.60
33,34,35	23.25	14.50	2	18.04
36,37	32.75	23.25	2	13.09

Resistor 38 couples the lid node 18 to external cylinder shell node 21

$$R_{38} = t/KA; t = (19/4)/12; A = (\pi/4)(76^2 - 74^2)/144$$

$$= (19/4)\cdot(1/12)/[(25)\cdot(\pi/4)(76^2 - 74^2)\cdot(1/144)] = (19)(12)/[(4)(25)\cdot(\pi/4)(76^2 - 74^2)]$$

$$= \underline{9.677\times10^{-3}}$$

Changes to Thermal Model to Account for Presence of Thermal Shield

For this analysis, resistors 104, 105 and 106 are changed to model air conduction and resistors 107, 108 and 109 are added to model in the effects of radiant heat transfer. Nodes 48, 58 and 68 are changed to model the capacitance of the 10 gauge Stainless Steel Thermal Shield.

A payload internal decay heat of 400 watts was assumed to be evenly distributed on the inside surface of the cask.

The thermal conductivity, k, of air varies with temperature as shown in the table below:

Temperature (°F)	k (Btu/hr ft °F)
0	0.0133
32	0.0140
100	0.0154
200	0.0174
300	0.0193
400	0.0212
500	0.0231
600	0.0250
700	0.0268
800	0.0286
1500	0.0400
2500	0.0471

For resistors 104-106, the conduction resistance afforded by the air in the air gap between the shield and the cask wall may be calculated as below:

$R = L/kA$ where L = Length in the direction of heat flow
A = Cross sectional area of flow path

Resistor	L (in)	A (ft^2) (p.1-113)	L/12A=kR (ft^{-1})	Nodes
104	0.25	13.265	0.0016	48-41
105	0.25	13.265	0.0016	58-51
106	0.25	6.632	0.0031	68-61

THAN internally multiples the L/A value with the appropriate value for k.

Radiation heat transfer is given by the following formula:

$$q = k(T_2^4 - T_1^4)$$

where $k = A_1\sigma/\{[(1/\varepsilon_1)-1]+(1/F)+(A_2/A_1)[(1/\varepsilon_2)-1]\}$

For simplicity, for this analysis the radiant areas A_1 and A_2 are taken as equal, and the form or shape factor, F, is assumed to equal unity. Under these assumptions, 'k' may be rewritten as:

$$k = \sigma A/[(1/\varepsilon_1)+(1/\varepsilon_2)-1]$$

where A = Represented Area
σ = Stefan-Boltzman Constant, 0.1714×10^{-8}
ε_1 = Emissivity of Surface 1
ε_2 = Emissivity of Surface 2

The outer surface of the carbon steel outer shell of the 10-142 can be conservatively taken to exhibit an emissivity of 0.9, while the inner surface of the thermal shield, being stainless steel, can be taken as 0.5.

Therefore, the following values of 'k' may be calculated:

Resistor	A	k	Nodes
107	13.265	1.077×10^{-8}	48-41
108	13.265	1.077×10^{-8}	58-51
109	6.632	5.385×10^{-9}	68-61

The specific heat (C_P) of stainless steel is 0.11 Btu/hr-lb-°F. Thus the heat capacity of nodes 48, 58 and 68 may be calculated (density of stainless is taken as 488 lb/ft^3), $C = \rho V C_P$:

Node	Area (Ft^2)	Thickness (in)	C (Btu/°F)
48	13.265	0.135	8.01
58	13.265	0.135	8.01
68	6.632	0.135	4.00

3.3 Determination of Steady State Temperatures

Steady state temperature estimates are used as the initial value (t=0) for the hypothetical fire accident. For this steady state system, heat is input to the flask by solar illumination; heat is removed by a combination of radiation and convection heat transfer modes. Solar illumination data is taken from Schappert's Cask Designers Guide, ORNL-NSIC-68, February 1970.

Two comparative approaches are used to calculate applicable incident solar illumination:

- **Peak Effective Illumination:** Actual solar constant vs time (angle) is assumed to act on the exposed cross section of the flask - assumed as a cylinder,
- **Mean Illumination:** The 24 hour solar constant (10,600 Btu/ft^2-day) is used and assumed to act upon the maximum x-section of the flask.

The total heat imposed upon the system is:

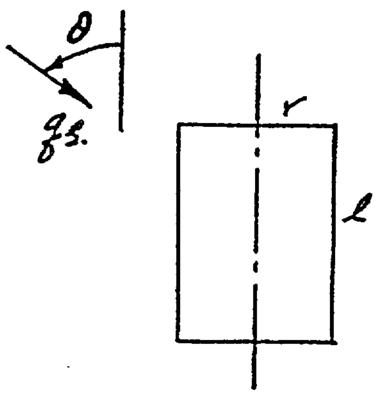
$Q = A_S q_S \alpha$; A_S = cross section exposed to sun
q_S = solar constant (Btu/hr-ft^2)
α = 0.8, absorptivity of surface

The heat imposed on a unit area is:
$q = Q/A_T = (A_S/A_T) q_S \alpha$; A_T = total surface area.

The total (half) area of the flask surface is 180.042 ft^2 (see 'Ext. Heat Transfer')

The maximum cross section of the flask is:
Vertical: $(1/144)[(38)(2)(20) + (50.5)(2)(21) + (2)(50.5 - 27.5)(14)] = 29.76 ft^2$
Horizontal: $(1/144)[(50.5)^2 \pi] = 55.64 ft^2$

Peak Illumination Approach [Ref. Fig. 5.3 (Latitude 42°N), Shappert]



For a right circular cylinder:

$$A_N = \pi r^2 \cos\theta + 2rl\sin\theta$$
$$Q = A_N q_S \alpha$$
$$q = Q/A_T = (A_N/A_T)\cdot q_S\alpha$$

where: $r = 38/12, ft$

$l = (112-28)/12, ft$

$\alpha = 0.8$

$A_T = 2\pi r^2 + 2\pi rl = 202.28 ft$

The objective is to determine a maximum value for the unit solar flux, q:

θ	q_s	q
90	0	0.00
84	100	18.74
78	150	29.61
72	180	36.95
66	210	44.28
60	225	48.18
54	238	51.19
48	250	53.42
42	260	54.58
36	270	55.04
30	275	53.78

$\rightarrow q_{MAX} = 55.1\, Btu/ft^2 - hr$
(total surface area)

Mean Illumination Approach

The 24 hour solar constant = 10,600 Btu/ft^2-day

$$q_s = (10{,}600/24)(0.35) = 154.58\, Btu/ft^2 - hr$$

$$q = (A_S/A_T)q_S\alpha = (55.64/180.42)(154.58)(0.8) = 38.1\, Btu/ft^2 - hr$$

Steady State Temperature (Unit Area)

Let: $f(T_S) = q_{in} - q_{out}$; find T_S such that $f(T_S) \approx 0$

$$f(T_S) = q - k(T_S^4 - T_\infty^4) - \bar{h}(T_S - T_\infty)$$

$$f(T_S) = 1 - (k/q)(T_S^4 - T_\infty^4) - (\bar{h}/q)(T_S - T_\infty) = [1 + (k/q)T_\infty^4 + (\bar{h}/q)T_\infty] - (k/q)T_S^4 - (\bar{h}/q)T_S$$

R_5 R_6 R_7

Where: T_∞ = Sink Temp (°R) = 100 °F/130 °F

$k = 1.371 \times 10^{-9}$

$\bar{h} = 0.213979$

$q = 55.1/38.1$

Flask Steady State Temperatures				Sink Temperatures	
				$T_\infty = 100°F$ (559.69°R)	$T_\infty = 130°F$ (589.69°R)
Mean	q	=	38.1(Btu/ft^2-hr)	130.3°F	156.9°F
Peak	q	=	55.1	142.7°F	168.0°F

The cask equipped with the thermal shield was analyzed per the latest revision of 10 CFR 71 using the same thermal model used in the transient analysis, except that solar loads are included. The solar loads for normal conditions to be applied to the top surface of the package are given in 10 CFR 71 to be

$$800\, gcal/cm^2/12 \text{ hour day} = 2950\, Btu/ft^2/12 \text{ hour day} = 2950/12 = 245.8\, Btu/hr/ft^2$$

It is assumed that the package achieves a steady state condition with the sun perpetually directly overhead. Note that the loads applied in this analysis are considerably higher (by a factor of 4.5) than those used in the previous analysis, and internal decay heat is included as well. Offsetting this extreme increase of severity is the required ambient temperature which in the previous analysis was taken as 130°F. 10 CFR 71 now requires the analysis to assume the ambient temperature is 100°F.

Loads to be imposed on the model can be calculated by multiplying the unit solar load by the horizontal area represented by each node on the upper surface. Since only one half of the cask is modeled for this analysis, the effect of applying the solar loads this way is equivalent to applying the solar loads on both the upper and lower surfaces:

Node	Horizontal Area (Ft^2)	Total Load (Btu/Hr)
2	39.14	9620.6
8	2.18	536.3
11	5.69	1400.0
14	8.62	2119.5

The temperatures predicted by THAN for the loads and assumptions described above are presented in Table 3.3-1 below.

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	138.0797792	3	143.4375047	4	149.4169536
5	156.1387589	6	163.7653111	7	172.5053979	8	207.4315289
9	207.2402001	10	207.1871163	11	203.5959923	12	203.3610179
13	203.3030395	14	201.1097916	15	200.9985060	16	201.2854437
17	195.0757626	18	194.7904999	21	186.0593635	22	185.8991322
23	185.7520368	24	185.6452419	25	185.5786124	26	185.5524231
27	185.5587027	31	180.6898466	32	180.6943570	33	180.7030639
34	180.7165642	35	180.7352055	36	180.7592597	37	180.7717985
41	174.8742055	42	174.9974212	43	175.1269865	44	175.2360235
45	175.3250771	46	175.3943942	47	175.4153549	48	127.1937599
51	172.1150413	52	172.2354112	53	172.3638355	54	172.4733714
55	172.5635675	56	172.6339521	57	172.6551258	58	126.2172005
61	171.1362800	62	171.2630901	63	171.3978613	64	171.5122474
65	171.6059353	66	171.6785459	67	171.7001316	68	127.5764568

Table 3.3-1 Normal Conditions Steady-State Temperatures

A second steady-state analysis was performed on the model assuming no solar loads. This analysis predicts the initial temperatures used for the hypothetical accident thermal event as well as determining compliance with the package surface temperature limits for exclusive use shipments. The results of this analysis appear below as Table 3.3-2.

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	100.1174523	3	101.9975198	4	104.0957550
5	106.4544888	6	109.1307053	7	112.1976698	8	113.8490677
9	114.0090599	10	114.1318048	11	114.8842611	12	115.0542304
13	115.1815199	14	115.4727671	15	115.6393114	16	115.7593587
17	116.5304741	18	116.5885467	21	118.1334486	22	118.1674498
23	118.2017727	24	118.2347268	25	118.2664599	26	118.2970529
27	118.3095157	31	118.4398320	32	118.4450705	33	118.4554336
34	118.4709254	35	118.4913728	36	118.5166975	37	118.5294716
41	118.0835766	42	118.1133275	43	118.1480549	44	118.1823612
45	118.2164454	46	118.2504553	47	118.2648480	48	106.8862372
51	117.9275708	52	117.9574810	53	117.9927127	54	118.0276849
55	118.0624063	56	118.0968875	57	118.1113707	58	106.8289172
61	117.8600704	62	117.8917507	63	117.9287377	64	117.9650597
65	118.0007578	66	118.0358669	67	118.0504672	68	107.2718275

Table 3.3-2 Normal Conditions No Sun - Steady State

A transient analysis using initial temperatures from Table 3.3-2 was performed corresponding to the hypothetical fire event required by 10 CFR 71. Tables 3.3-3 through 3.3-6 give the temperature distributions for various times during the transient. Notably, the temperatures predicted by this analysis are lower than those predicted by the analysis used for the Albi-Clad package, in spite of the 400 watt internal decay heat load included in the thermal shield analysis and omitted from the analysis of the Albi-Clad package.

Figures 3.3-1 and 3.3-2 present plots of nodal temperature vs. time for the same points plotted previously for the Albi-Clad design. Clearly, the thermal shield provides very good protection for the cask during the fire event.

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	1469.8569098	3	195.2162325	4	106.2448564
5	106.4864870	6	109.0921319	7	111.3676345	8	547.2553743
9	419.6289911	10	355.5894289	11	541.2297371	12	414.2553088
13	351.0761989	14	495.7614102	15	377.6664321	16	327.0726306
17	155.4470111	18	150.4889195	21	122.2957738	22	121.8378478
23	121.4932535	24	121.2293532	25	121.0385524	26	120.9159541
27	120.8919258	31	124.4831118	32	124.5033144	33	124.5718970
34	124.5796979	35	124.5481198	36	124.4926016	37	124.4632045
41	157.6094855	42	154.5963602	43	151.7706873	44	149.4878031
45	147.7356599	46	146.5094496	47	146.2142304	48	1447.0851526
51	163.4849911	52	160.4618608	53	157.6479446	54	155.3212223
55	153.4938432	56	152.1782718	57	151.8439854	58	1447.0306850
61	167.1648366	62	163.8012714	63	160.6723889	64	158.0992650
65	156.0871313	66	154.6438621	67	154.2788604	68	1443.7261758

Table 3.3-3 Fire Transient 0.5 hours

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	628.9221698	3	203.7875205	4	107.1957467
5	106.5118266	6	109.0863157	7	111.4402663	8	470.4582184
9	438.3803822	10	405.6021659	11	461.1553878	12	429.6524282
13	397.7814010	14	409.1186443	15	384.3926328	16	365.4050620
17	165.3696607	18	161.6723573	21	124.6078643	22	123.9911193
23	123.5141707	24	123.1434614	25	122.8713224	26	122.6929052
27	122.6561812	31	126.7131636	32	126.7495626	33	126.8455301
34	126.8826973	35	126.8756525	36	126.8358728	37	126.8085266
41	156.3373215	42	155.2302099	43	153.9364846	44	152.7981319
45	151.8721964	46	151.2104747	47	151.0607145	48	527.9228097
51	163.7702777	52	162.6798782	53	161.4239844	54	160.2771333
55	159.3112339	56	158.5901174	57	158.4106367	58	528.1091269
61	167.1581708	62	165.9613313	63	164.5789847	64	163.3225306
65	162.2679553	66	161.4829366	67	161.2884696	68	523.2832920

Table 3.3-4 Fire Transient 0.6 hours

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	321.2572101	3	206.6097900	4	109.1464439
5	106.5900840	6	109.0782138	7	111.6272482	8	429.2446388
9	431.2025983	10	429.7059325	11	412.8140747	12	414.9580081
13	414.1002150	14	356.8142018	15	362.4635903	16	371.4241146
17	180.2577503	18	177.9691577	21	130.0174147	22	129.1960783
23	128.5380216	24	128.0190669	25	127.6336209	26	127.3787105
27	127.3259181	31	130.8062998	32	130.8498053	33	130.9560335
34	131.0182186	35	131.0431243	36	131.0353860	37	131.0194196
41	153.4859279	42	153.2213246	43	152.9036070	44	152.6474986
45	152.4618418	46	152.3549419	47	152.3461046	48	241.8462462
51	162.5744484	52	162.3319584	53	162.0453524	54	161.8051668
55	161.6234231	56	161.5107512	57	161.4960148	58	242.9682178
61	165.6817476	62	165.4304233	63	165.1325251	64	164.8820665
65	164.6916075	66	164.5722813	67	164.5558156	68	239.6474018

Table 3.3-5 Fire Transient 0.8 hours

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	103.1542295	3	158.5424807	4	135.2740667
5	116.6872012	6	113.5271166	7	123.7740815	8	236.0594669
9	238.0283778	10	239.0603285	11	221.0593006	12	222.7679622
13	223.6845184	14	217.1523338	15	218.8506233	16	220.0530252
17	213.3195498	18	212.7073391	21	190.5664977	22	190.1605707
23	189.7829637	24	189.4981124	25	189.3058140	26	189.2068217
27	189.2050538	31	177.9645934	32	177.9798688	33	178.0026504
34	178.0236041	35	178.0445948	36	178.0669296	37	178.0772637
41	167.4302377	42	167.5473153	43	167.6794454	44	167.7881326
45	167.8738046	46	167.9365975	47	167.9534369	48	124.3482388
51	162.1868217	52	162.2975526	53	162.4259723	54	162.5327275
55	162.6172983	56	162.6791357	57	162.6954271	58	122.4666109
61	160.3793327	62	160.4941007	63	160.6267543	64	160.7366234
65	160.8233046	66	160.8863276	67	160.9027308	68	123.2867579

Table 3.3-6 Fire Transient 7.3 hours

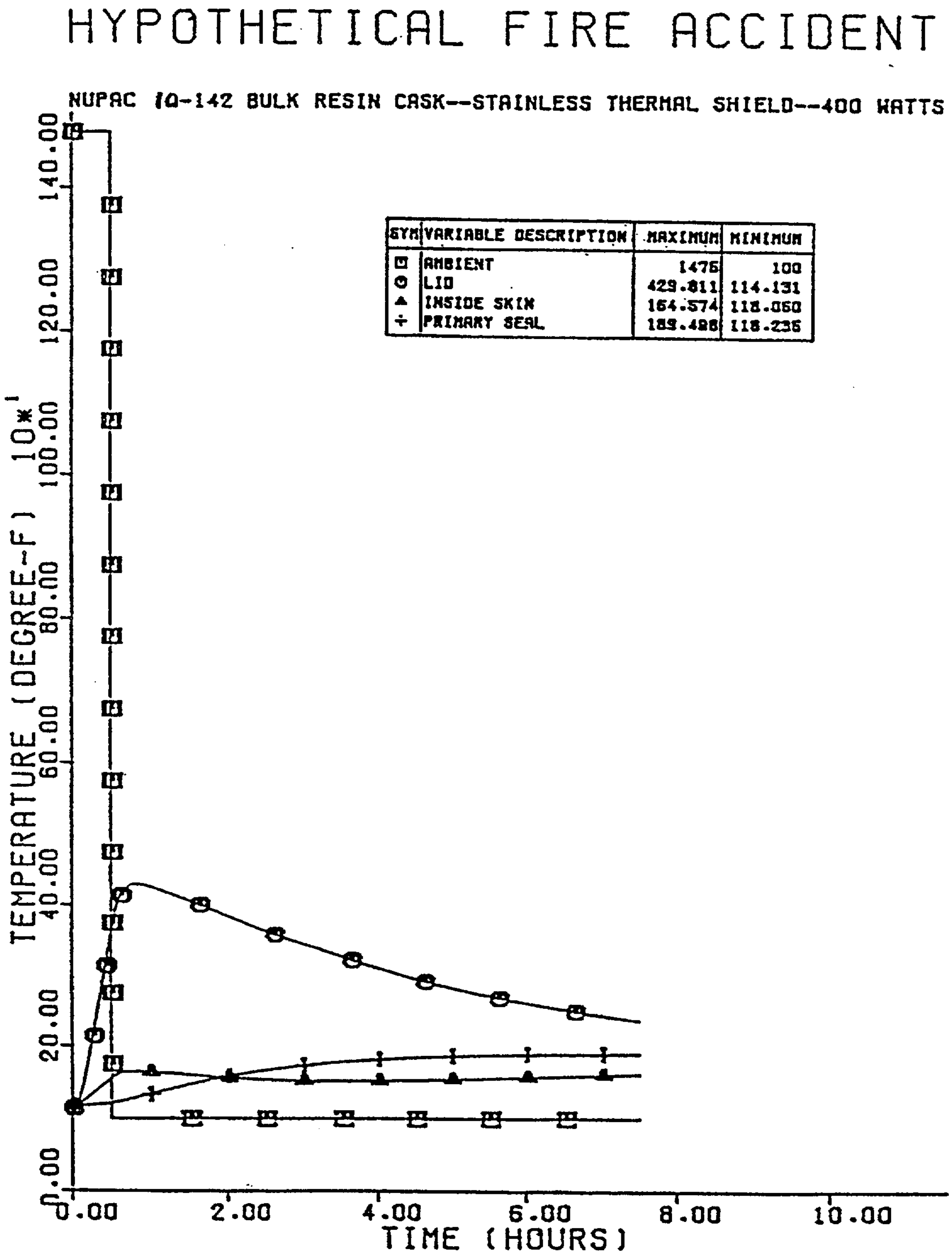

HYPOTHETICAL FIRE ACCIDENT
NUPAC 10-142 BULK RESIN CASK--STAINLESS THERMAL SHIELD--400 WATTS
SYM VARIABLE DESCRIPTION MAXIMUM MINIMUM
AMBIENT 1476 100
LID 429.811 114.131
INSIDE SKIN 164.574 118.060
PRIMARY SEAL 189.486 118.236
TEMPERATURE (DEGREE-F) 10*1
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
2.00
4.00
6.00
8.00
10.00
TIME (HOURS)

Figure 3.3-1

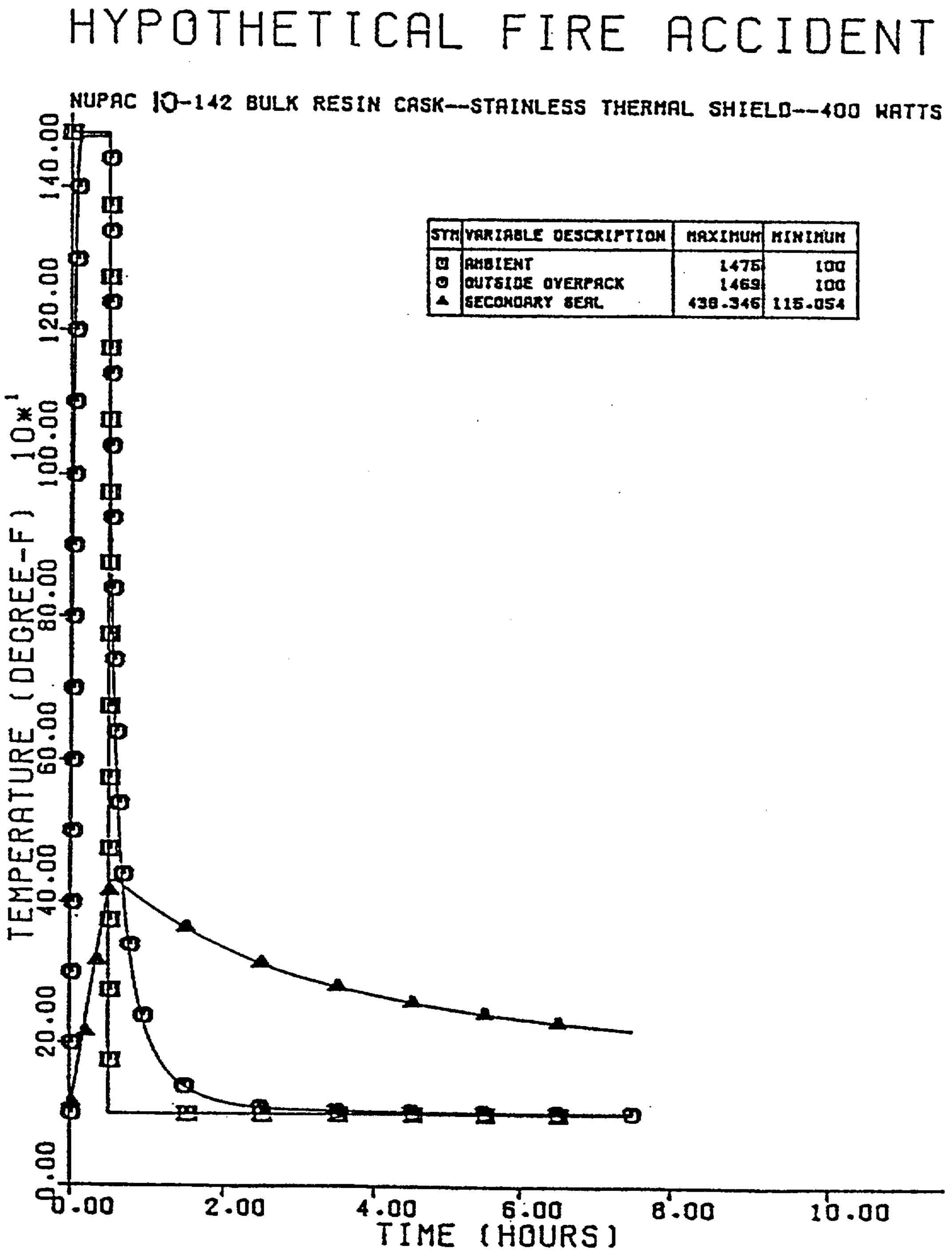

HYPOTHETICAL FIRE ACCIDENT
NUPAC 10-142 BULK RESIN CASK--STAINLESS THERMAL SHIELD--400 WATTS
SYM VARIABLE DESCRIPTION MAXIMUM MINIMUM
AMBIENT 1475 100
OUTSIDE OVERPACK 1469 100
SECONDARY SEAL 438.346 115.054
TEMPERATURE (DEGREE-F) 10*1
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
2.00
4.00
6.00
8.00
10.00
TIME (HOURS)

Figure 3.3-2

A transient analysis, similar to the above treatment, was performed using an initial pre-fire temperature of 168°F for all cask locations. This temperature corresponds to the steady state solar flux peak condition with a 130°F sink. Tables 3.3-7 through 3.3-9 give the temperature distributions for various times during the transient. Figure 3.3-3 presents the plots of temperature vs. time for various cask locations.

TRANSIENT PROBLEM

TIME = .0 SEC.
MINIMUM RC PRODUCT = .0 SEC. ------ FOR NODE 0

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	168.0000000	3	168.0000000	4	168.0000000
5	168.0000000	6	168.0000000	7	168.0000000	8	168.0000000
9	168.0000000	10	168.0000000	11	168.0000000	12	168.0000000
13	168.0000000	14	168.0000000	15	168.0000000	16	168.0000000
17	168.0000000	18	168.0000000	21	168.0000000	22	168.0000000
23	168.0000000	24	168.0000000	25	168.0000000	26	168.0000000
27	168.0000000	31	168.0000000	32	168.0000000	33	168.0000000
34	168.0000000	35	168.0000000	36	168.0000000	37	168.0000000
41	168.0000000	42	168.0000000	43	168.0000000	44	168.0000000
45	168.0000000	46	168.0000000	47	168.0000000	48	168.0000000
51	168.0000000	52	168.0000000	53	168.0000000	54	168.0000000
55	168.0000000	56	168.0000000	57	168.0000000	58	168.0000000
61	168.0000000	62	168.0000000	63	168.0000000	64	168.0000000
65	168.0000000	66	168.0000000	67	168.0000000	68	168.0000000

TRANSIENT PROBLEM

TIME = 5.0000000E-01SEC.
MINIMUM RC PRODUCT = 1.9149394E-03SEC. ------ FOR NODE 66

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	1470.9640978	3	256.5909572	4	170.0400724
5	168.0316068	6	168.0023897	7	168.1644983	8	568.8364753
9	449.9769290	10	390.4093470	11	562.3161792	12	444.0652543
13	385.2934321	14	519.4732961	15	409.6554639	16	362.5795767
17	202.9544061	18	199.4220316	21	176.4347745	22	176.1120725
23	175.9501251	24	175.8015987	25	175.6597193	26	175.5197569
27	175.4602295	31	199.9077475	32	200.0239543	33	200.3234635
34	200.4537965	35	200.4437511	36	200.3137509	37	200.2133597
41	300.9049140	42	296.7816648	43	292.5750631	44	289.1937738
45	286.6430423	46	294.9363728	47	284.5802573	48	1437.9493350
51	307.6668432	52	305.2046903	53	302.8226291	54	300.8307092
55	299.2586296	56	295.1330277	57	297.8555833	58	1452.7005805
61	309.0078509	62	306.6025079	63	304.3367823	64	302.4498242
65	300.9565111	66	299.8720990	67	299.5929301	68	1452.7104636

Table 3.3-7 Fire Transient Initial and 0.5 hours

TRANSIENT PROBLEM

TIME = 5.5000000E-01SEC.
MINIMUM RC PRODUCT = 1.9169394E-03SEC. ------ FOR NODE 66

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	70.0000000	2	855.8521555	3	262.1743557	4	170.4844404
5	168.0427203	6	168.0033715	7	168.2078895	8	523.5399357
9	465.4395743	10	417.6431575	11	515.5792843	12	458.0383151
13	411.0757475	14	469.0752615	15	419.0751732	16	384.3473828
17	208.9940814	18	204.8948086	21	178.3661934	22	177.9844479
23	177.7786021	24	177.5939963	25	177.4231943	26	177.2614687
27	177.1956576	31	202.9957477	32	203.1089902	33	203.3975771
34	203.5270620	35	203.5234075	36	203.4049873	37	203.3111291
41	300.4198190	42	296.7667694	43	293.6173823	44	290.0077381
45	297.7408457	46	296.2311819	47	285.9222500	48	552.0225079
51	306.6046977	52	305.5179672	53	304.0656418	54	302.6804755
55	301.4912389	56	300.6002928	57	300.3818037	58	615.3611569
61	309.4451744	62	308.0331349	63	306.4212790	64	304.9590007
65	303.7324125	66	302.8114166	67	302.5738390	68	838.1418259

TRANSIENT PROBLEM

TIME = 7.0000000E-01SEC.
MINIMUM RC PRODUCT = 1.9169394E-03S. ------ FOR NODE 66

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	70.0000000	2	415.4459931	3	266.1020080	4	171.9665544
5	168.0892275	6	168.0079627	7	168.3664442	8	467.2533093
9	462.7955426	10	454.0306415	11	454.5441635	12	450.3833915
13	442.3429455	14	403.8069498	15	403.8441413	16	406.1052619
17	220.5937790	18	218.3323483	21	184.7584473	22	184.2495929
23	183.9390299	24	183.6662601	25	183.4253506	26	183.2121387
27	183.1327684	31	210.7272292	32	210.8467427	33	211.1199245
34	211.2884347	35	211.3540601	36	211.3182189	37	211.2603737
41	281.6482199	42	292.3420630	43	282.5854524	44	282.7591994
45	282.9177008	46	293.1121853	47	283.2274739	48	258.0311187
51	301.9372970	52	301.9447697	53	301.8100800	54	301.6873611
55	301.5960619	56	301.5550315	57	301.5656480	58	245.1151036
61	307.3054696	62	307.0212058	63	306.6445707	64	306.3170969
65	306.0565069	66	305.9793255	67	305.8456443	68	398.0205612

Table 3.3-8 Fire Transient 0.6 and 0.7 hours

TRANSIENT PROBLEM

TIME = 8.0000000E-01SEC.
MINIMUM PC PRODUCT = 1.9149394E-03SEC. ------ FOR NODE 66

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	70.0000000	2	311.6252311	3	266.1900888	4	172.7809809
5	168.1311010	6	148.0125700	7	168.4924378	8	454.5682266
9	456.1192459	10	457.5325244	11	438.6005394	12	442.2503925
13	442.2141586	14	386.9314498	15	393.6026091	16	402.4455061
17	227.1150674	18	225.2646808	21	189.2001503	22	198.6430159
23	188.2874295	24	187.9779923	25	187.7095430	26	187.4785213
27	187.3959306	31	214.4683085	32	214.5708700	33	214.8005210
34	214.9537796	35	215.0277020	36	215.0194496	37	214.9799345
41	273.4799781	42	274.3303054	43	274.9338568	44	275.4691662
45	275.9430292	46	276.3625686	47	276.5194458	48	250.2776908
51	293.9690694	52	295.1962578	53	296.2507309	54	297.1230129
55	297.8195924	56	298.3542276	57	298.5178493	58	264.3232357
61	305.1939172	62	305.1543194	63	305.0351999	64	304.9720085
65	304.9543027	66	304.9772905	67	305.0039132	68	300.0537208

TRANSIENT PROBLEM

TIME = 3.6500000E+00SEC.
MINIMUM PC PRODUCT = 1.9149394E-03SEC. ------ FOR NODE 66

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	70.0000000	2	70.5988260	3	229.2160719	4	188.6302020
5	171.5050760	6	159.0866131	7	174.3657641	8	208.4461670
9	281.0838535	10	314.1330666	11	192.8350559	12	254.8755156
13	282.9915091	14	190.5253642	15	247.6547437	16	273.2325793
17	270.1196922	18	270.7709836	21	244.3726701	22	243.8801251
23	243.4189933	24	243.0615976	25	242.8081311	26	242.6595441
27	242.6417703	31	230.5401088	32	230.5658966	33	230.5865758
34	230.6472855	35	230.7259316	36	230.8059939	37	230.8360146
41	195.7599682	42	199.8464365	43	203.6611303	44	206.7546894
45	209.1443421	46	210.8404936	47	211.2652098	48	99.4189335
51	191.3866257	52	195.3502703	53	199.0510629	54	202.1129109
55	204.5214317	56	206.2645907	57	206.7150358	58	98.5710833
61	190.9510324	62	194.8818075	63	198.5343402	64	201.5603362
65	203.9459051	66	205.6794138	67	206.1323433	68	98.5994743

Table 3.3-9 Fire Transient 0.8 and 3.7 hours

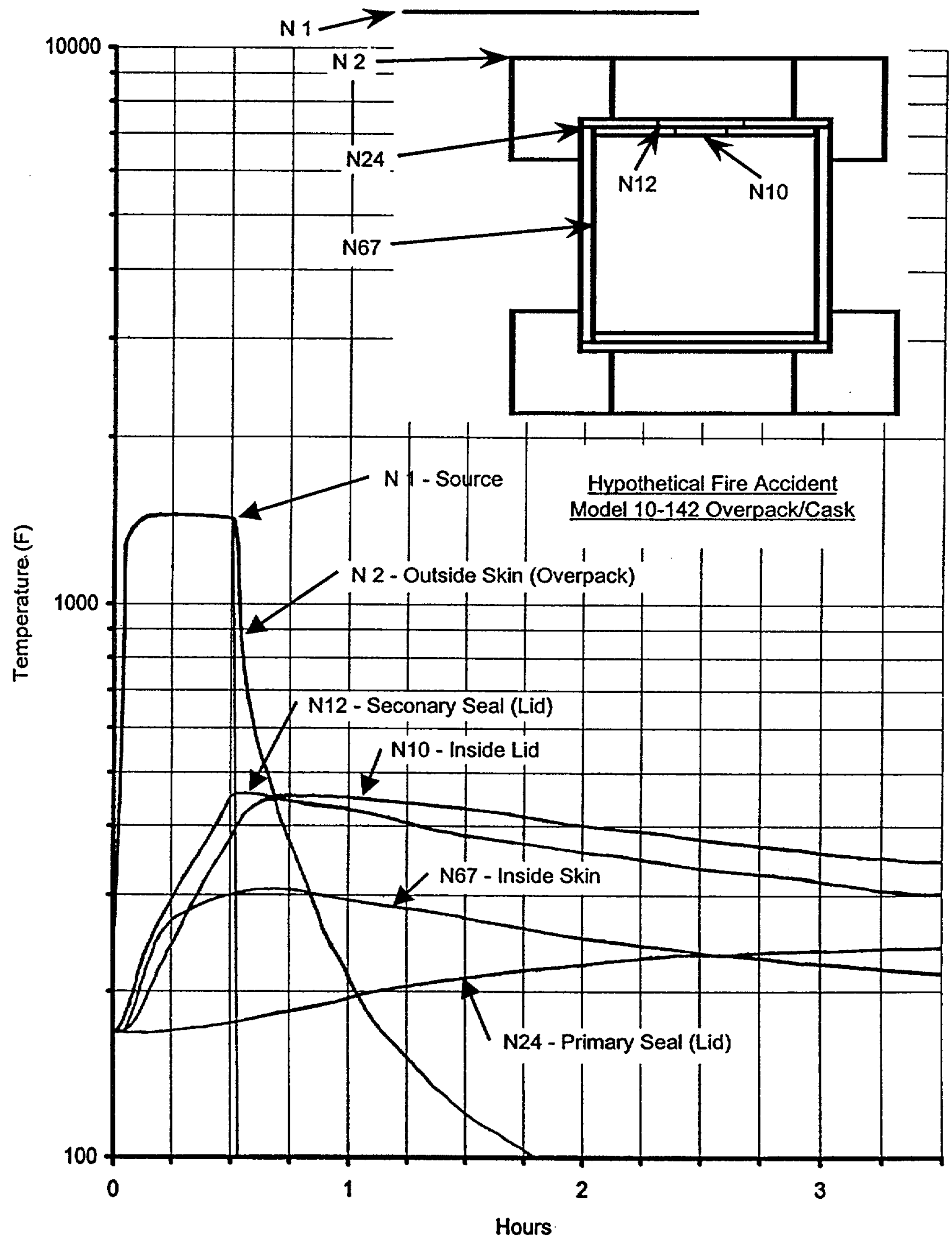


Figure 3.3-3 Hypothetical Fire Accident with Solar Load

In order to evaluate the effect of the reduced insulation associated with a damaged or post-dropped overpack, the following analysis is presented.

An example of the effect a damaged overpack would have on the thermal performance, a typical corner drop damage was evaluated. Under corner impacts, an estimation of the maximum damage sustained is a deformation of 20.5 in. corresponding to a crush volume of 22,684 in. for a 101 in. diameter impact limiter that extends 18 inches beyond the cask.

Original Foam

1. Resistance
   $R_O = 859.28$
2. Volume
   $V_O = (\pi/4)[(101^2 - 55^2)(18) + (101^2 - 76.25^2)(22)] = 177249 in^3$

Damaged Foam Volume

$$V_D = 177249 - 22684 = 154565 in^3$$

Scale Resistance Change

$$R_D/R_O = (t_D/KA)/(t_D/KA)$$

$$V_D = t_D A; t_D = V_D/A$$
$$V_O = t_O A; t_O = V_O/A$$

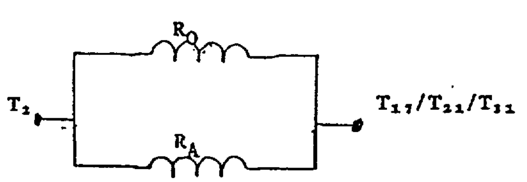
Thus:

$$R_D/R_O = (V_D/KA^2)/(V_O/KA^2) = V_D P/V_O$$

The damaged foam resistance is:

$$R_D = R_O \cdot (V_D/V_O) = (859.28 \times 10^{-3})(154565/177249) = 749.31 \times 10^{-3}$$

This is equivalent to:



$$R_D = 1/[(1/R_O) + (1/R_A)]$$

Where R_A = an additional parallel resistance corresponding to the damage caused by the 30 ft. drop.

$$R_A = R_D R_O/(R_O - R_D) = (749.31)(859.28) \times 10^{-3}/(859.28 - 749.31) = \underline{\underline{5.8549}}$$

The heat that flows across this damage resistor at t = 30 minutes is:

$$q_{2-24} = (T_2 - T_{24})/R_A = (1470.1 - 175.8)/5.8549 = 221.1\,Btu/hr$$

In 30 minutes, the total heat flow is conservatively estimated at:

$$Q_{2-24} = 110.5\,Btu$$

Assuming all this heat goes into the lids:

$$C_{LID} = \sum C_i, i = 8,18 = 841\,Btu/°F$$

The change in lid temperature is thus:

$$\Delta T_D = 110.5/841 = \underline{0.13°F}$$

Thus, the predicted percent increase in seal temperature (Node 24) is:

$$\%\Delta T_{24} = (0.13/175.8) \times 100 = 0.074\%$$

Therefore, it can be concluded that the loss of insulation associated with damaged overpack will have no significant effect on seal or package temperature. The actual larger impact limiters than what is evaluated above would provide a smaller temperature change due to the larger remaining foam volume.

3.4 Water Immersion

Not applicable.

3.5 Summary of Damage

As a result of the above assessment, it is concluded that should the Model 10-142 package be subjected to the hypothetical fire accident conditions, no radioactive material would be released from the package.

4.0 Containment

This chapter identifies the package containment for the normal conditions of transport and the hypothetical accident conditions.

4.1 Containment Boundary

4.1.1 Containment Vessel

The containment vessel claimed for the Model 10-142 package is the shielded transportation cask as described in Section 1.2 and the general arrangement drawing in Appendix 2.10.1.

The 10-142 may be used to carry a liner with a capacity of approximately 120 cubic feet of ion exchange resin. During transport, the liner will contain a maximum of 120 cubic feet of resin originating from the purification system. The size of the resin beads ranges from 0.4 - 0.6 mm in diameter. Type 'B' casks are designed to provide containment of the radioactive material for normal and transportation accident conditions. The design of the 10-142 did not take credit for the liner inside the cask. Thus, there is no containment credit for the liner.

The liner's structural integrity is such that most likely it would retain its contents in case of the hypothetical accident condition. The SAR considers only the cask as containment, which is a conservative position.

It has been demonstrated by calculations that the sealing arrangement is unaffected by accident conditions. For this reason, it is impossible that ion exchange resin, because of the size of the beads, could escape.

Based on analysis of resin samples, it is assumed that the following maximum activities could be present inside the 10-142:

Radionuclide	Activity (Curies)
Arsenic-76	15
Barium-140	30
Cobalt-60	300
Cobalt-58	30
Chromium-51	30
Copper-64	600
Cesium-134 and 137	3000
Iron-59	30
Iodine-131	1500
Iodine (not 131)	1650
Manganese-54	30
Manganese-56	180
Niobium-95	75
Sodium-24	15
Strontium-89	450
Strontium- 90	15
Xenon	1200
Zinc-65	15
Zirconium-95	75

Thus, gaseous radioactivity could be present in the package and is considered to be the critical item in containment calculations.

4.1.1.1 Permissible Leak Rate

Gaseous activity can arise from decay products of radionuclides carried in the ion exchange columns. The only radionuclide that decays to a gaseous radioactive material in the ion exchange resin is iodine which decays to the noble gas xenon. The iodine itself will be in the ionic form, therefore fixed on the ion exchange resin.

There are several isotopes of iodine. However, the only isotopes of relevance to this evaluation are I-131 and I-133. The other isotopes are either in very small quantities compared to I-131 and I-133 or they decay to products that are either stable or would not be in the vapor phase.

From the list of radionuclides shown it can be seen that the maximum anticipated I-131 content will be 1500 Ci. It was conservatively assumed that all other iodine is I-133. For the calculations, it is assumed that when the liner is shipped the above maximum will be jointly present. There would be no xenon present initially as a result of the dedeuteration process. The maximum possible xenon activities have been calculated using the following assumptions:

a) All gaseous fission products originally present in the spent IX resin are removed during the dedeuteration process which takes place on site prior to shipment.

b) Only the formation of xenon, from the decay of radioactive iodine, was considered.

c) Only two isotopes, viz I-131 and I-133, were felt to be of significance in this study. The others were ignored either because they decay to stable isotopes of xenon (eg., I-130, I-132 and I-134) or are expected to be present in negligible amounts (eg., I-135).

d) The xenon isotopes considered were Xe-131^m, Xe-133^m and Xe-133.

e) The processes of build-up and decay of each of these isotopes is such that their concentration in the resin reaches a maximum value several days after dedeuteration. As is shown below, Xe-131^m achieves its maximum value after 13,98 days, Xe-133^m after 1.96 days and Xe-133 after 2.72 days. Although physically impossible, the maximum value of each isotope was assumed to exist concurrently in the resin and this was used in the safety assessment of the overpack.

The maximum activities are calculated to be:

$2.7\ Ci$ of $Xe\text{-}131(m)$ after $13.98\ days$
$48.3\ Ci$ of $Xe\text{-}133(m)$ after $1.96\ days$
$177.0\ Ci$ of $Xe\text{-}133$ after $2.72\ days$

The A_2 value, when considering several radionuclides, must reflect the mixture. The following equation is used to determine an A_2 value taking into account Xe-131 (m), Xe-133 and Xe-133 (m).

$$A_W(mixture) = \frac{\sum Ci}{\sum (Ci/A_2 i)}$$

Where:

Ci = activity of each radionuclide
(Ci/A_2i) = activity of each radionuclide divided by its A_2 value

The maximum activities calculated above for the radionuclides of concern are:

2.7 Ci of Xe-131(m)
48.3 Ci of Xe-133(m)
177.0 Ci of Xe-133

The individual A_2 values are 100 Ci for Xe-131 (m) and 1000 Ci for Xe-133. The A_2 value for Xe-133 (m) is based on a comparison with Xe-133. The effective gamma energy for Xe-133 is 0.0296 MeV.

Thus, A_2 for the mixture is:

$$A_2 = \frac{2.7 + 48.3 + 177}{(2.7/100) + (48.3/1000) + (177/1000)} = 904Ci$$

The permissible leak rate can be determined from ANSI-N14.5 'Leakage Tests on Packages for Shipment of Radioactive Materials.'

a) For normal condition of transport:

$$R_N = A_2 \times 2.78 \times 10^{-10}$$
$$R_N = 904 \times 2.78 \times 10^{-10}$$
$$R_N = 2.51 \times 10^{-7} \, Ci/\sec$$

The free volume within the cask cavity is:

$V_T = 142 ft^3$
$V_R = 120 ft^3$ (Resin Volume)
$V_V = 33\%$ of resin volume is void
$= (0.33)(120) = 40 ft^3$

$$V_{Free} = V_T - V_R + V_V$$
$$= 62 ft^3 or 1.75m^3$$

The specific activity of the medium is:

$$C_N(Xe-131m) = 2.7Ci/1.75m^3 = 1.54 Ci/m^3$$
$$C_N(Xe-133m) = 48.3Ci/1.75m^3 = 27.60 Ci/m^3$$
$$C_N(Xe-133) = 177.0Ci/1.75m^3 = \underline{101.14 Ci/m^3}$$

TOTAL $C_N = 130.28 Ci/m^3$

Therefore, the permissible leak rate for normal transport conditions is:

$$L_N = R_N/C_N$$
$$= 2.51 \times 10^{-7} \, Ci/\sec/130.28 Ci/m^3$$
$$= 1.92 \times 10^{-3} \, cm^3/\sec$$

Rounding yields:

$$L_N = 2\times10^{-3}\ cm^3/\sec$$

and the associated test sensitivity requirement is:

$$s = L/2 = 10^{-3}\ cm^3/\sec \text{ (Normal)}$$

b) For accident conditions:

$$R_A = A_2 \times 1.65\times10^{-9} \sec$$
$$R_A = 904\times1.65\times10^{-9} \sec$$
$$R_A = 1.47\times10^{-6}\ Ci/\sec$$

Therefore, the permissible leak rate is:

$$L_A = 1.49\times10^{-6}\ Ci/\sec/130.28\,Ci/m^3$$
$$L_A = 1.14\times10^{-8}\ m^3/\sec$$
$$L_A = 1.14\times10^{-2}\ cm^3/\sec$$

Rounding yields:

$$L_A = 1\times10^{-2}\ cm^3/\sec$$

and the associated test sensitivity requirement is:

$$S = L/2 = 5\times10^{-3}\ cm^3/\sec\,(Accident)$$

4.1.1.2. Carbon Dioxide Leak Testing

The 10-142 Cask has been designed to permit a leak test at any time necessary for the safe transport of radioactive material. As shown by the above analysis, the normal transport condition permissible leak rate and associated test sensitivity are the limiting criteria. A carbon dioxide (CO_2) and air mixture is the tracer fluid that is used to leak test the cask and seal integrity. The leak testing requirements are specified in Section 8.2.5. The CO_2 minimum usable level (sensitivity) for the leak detector used in the this procedure is 3.00 x 10^{-4} cm^3/sec. The acceptance criterion is no leak in excess of 7 x 10^{-4} cm^3/sec. The procedure for the leak test is given in Appendix 8.4.2.

Carbon dioxide gas is injected into the cask until an internal pressure of 7 psig is achieved. Considering the internal gas to be ideal, its behavior may be defined by Boyle's Law. This law states that the volume and pressure of an ideal gas vary inversely when the temperature is held constant. Stating Boyle's Law in equation form:

$$P_1V_1 = P_2V_2$$

where, P_1 = internal pressure
P_2 = final pressure
V_1 = initial volume

V_2 = final volume

Thus, the ratio of the final volume of air to the initial volume of air in the cask is

$$V_2/V_1 = P_1/P_2$$

where, P_1 = 14.7 psia
= 1.0 atm
P_2 = 14.7 + 7.0
= 21.7 psia
= 1.48 atm

Therefore,

$$V_2/V_1 = 14.7/21.7$$
$$= 0.677$$
$$= 67.7\%$$

Neglecting the small percentage of carbon dioxide in air (0.03%), the composition of the internal gas mixture is considered to be 67.7% air and 32.3% carbon dioxide.

From ANSI N14.5-1977 (AMERICAN NATIONAL STANDARD FOR LEAKAGE TESTS ON PACKAGES FOR SHIPMENT OF RADIOACTIVE MATERIALS; American National Standards Institute, Inc.), the correlation between a measured leakage rate and an equivalent leakage rate for gases at different conditions is given as:

$$L_x = (L_y)(n_y)(P_u^2 - P_d^2)_x / (n_x)(P_u^2 - P_d^2)_y$$

where, L_x = equivalent leakage rate of gas x
L_y = measured leakage rate of gas y
= normal transport permissible leak rate
= $1.92 \times 10^{-3}\ cm^3/\sec$
n = fluid viscosity
P_u = fluid upstream pressure, atm, abs
P_d = fluid downstream pressure, atm, abs

Considering the difference in viscosity between the internal gas mixture and air to be negligible

$$L_x = (1.92 \times 10^{-3})(1.476^2 - 1.000^2)/(1.000^2 - 0.000^2) = 2.26 \times 10^{-3}\ atm - cm^3/\sec$$

Since the internal gas mixture is 32.3% carbon dioxide, the maximum permissible leakage rate for the tracer fluid (CO_2) is

$$L_T = (2.26 \times 10^{-3})(0.323)$$
$$= 7.30 \times 10^{-4}\ atm - cm^3/\sec$$

which is greater than the 7×10^{-4} cm^3/sec test acceptance criterion.

Per ANSI N14.5-1977, the sensitivity of the leakage test shall be considered adequate when it is equal to or less than one-half of the maximum permissible leakage rate for the tracer fluid. Thus:

$$S \le (1/2)(L_T)$$
$$\le (1/2)(7.30 \times 10^{-4})$$
$$\le 3.65 \times 10^{-4}\ atm - cm^3/\sec$$

which is greater than the 3.00×10^{-4} cm^3/sec minimum usable level (sensitivity) for the leak detector with carbon dioxide in the tracer fluid.

As shown above, the leak test acceptance criterion and sensitivity criterion are below the corresponding ANSI N14.5-1977 calculated values. Therefore, the leakage test is considered adequate.

4.1.2 Containment Penetration

There are no penetrations into the containment vessel.

4.1.3 Seals and Welds

Solid silicone seals are placed between the secondary lid to primary lid and primary lid to body interfaces. Additionally, a neoprene dust seal is also installed on the secondary lid. These seals are described in Section 1.2.1.3 above. To ensure proper sealing of these seals, torque values of 300 ± 25 and 200 ± 10 ft-lbs are specified respectively for the primary and secondary bolts or nut onto stud configuration. The resultant seal preloads are sufficient to provide positive sealing of the cask cavity, as demonstrated by the following analyses.

The primary seal is a 1/2-in. thick x 1.25 in. wide, 40 duro hardness solid silicone gasket. In order for the primary lid to make metal-to-metal contact with the cask body, the gasket must be compressed to the 3/8-in. standoff height, or 25% compression (i.e., 0.125/0.50). Using the procedures given by the Handbook of Molded and Extruded Rubber, 3rd Edition (The Goodyear Tire and Rubber Co.), the required compressive force can be determined. For the given geometry, this seal has a compression shape factor of 1.25 (i.e., [one load area]/[total free area] or in our case, the width divided by twice the thickness). For the specified parameters, the required compressive stress to obtain the 25% compression is 325 psi (Fig. 5-11, pg 74 of the referenced Goodyear report), which results in a total required compressive force, F_{req} of:

F_{req} = (Compressive Stress)(Load Area) $= 87{,}425 lbs$

where: Compressive Stress $= 325\ psi$

Load Area $= \pi(71.25 - (1.50 + 1.25))(1.25) = 269 in^2$

This force results in a required bolt or nut on stud load, P_{bolt}, of:

$$P_{bolt} = (F_{req})/(No.of\ bolts)$$
$$= (87{,}425)/16 = 5{,}464 lbs$$

The equivalent bolt (note: all references to bolts herein are equally applicable for nut on stud configuration) torque to develop this force is:

Required Torque $= 0.2(P_{bolt})(d)/12$
$= 0.2(5{,}464)(1.5)/12 = 137 ft-lbs$

where: d = Nominal bolt diameter, in.

An alternate method (Handbook of Molded and Extruded Rubber, 3rd Edition, pg 58 and 82) for determining the required preload to compress the gasket 25% is to calculate the gasket spring rate. By knowing this rate and the required deflection (0.125-in), the total gasket load can be determined. For this gasket, the linear spring rate, K_L is calculated per the following:

$$K_L = (E_C)(A)/h$$

where: E_C = Compression Modulus = 1750 psi at 25% compression
A = load area = 269 in^2
h = seal height = 0.50

Substitution of these values into the above expression yields a linear spring rate of:

$$K_L = 941{,}500\, lb/in$$

The resultant seal force and required bolt load is then:

$$F_{req} = 0.125 K_L = 117{,}688 lbs$$

$$P_{bolt} = (117{,}688)/16 = 7356 lbs$$

The equivalent bolt or nut torque to develop this force is:

Required Torque $= 0.2(7356)(1.50)/12 = 184 ft-lbs$

Since the specified torque of 300 ± 25 ft-lbs exceeds all of these required torque values, the primary lid will make metal-to-metal contact with the non- sealing surface of the cask body.

The secondary lid seal configuration consists of a 1/4-in thick x 1.0 in. wide, 40 duro hardness solid silicone gasket, with a compression shape factor of 2.0. A 1/8-in metal standoff limits the degree of compression to a maximum of 50%. For the specified torque of 200 ± 10 ft-lbs, the resultant deformation can be determined using the linear spring rate method.

Applied Compressive Force $= 12T(n)/(0.2d)$

where: T = Applied bolt or nut torque, ft-lbs
n = No. of bolts or studs and nuts $= 16\ (29\text{-}in\ lid); 8\ (16\text{-}in\ lid)$
d = Nominal bolt or stud diameter, in.
$= 1.25\ in.(29\text{-}in\ lid); 0.875\ in(16\text{-}in\ lid)$

The applied compressive force for the 29-in and 16-in diameter lids are 153,600 lbs and 109,714 lbs respectively. For these applied loads, the gaskets will be compressed approximately 30-35% (0.075-0.0875 in.). The exact degree of compression is obtained by interpolation between these two values.

The linear spring rate and resultant compressive seal force for 30% compression are:

$$K_L = 1.687\times10^6\, lb/in(29-in)$$
$$= 9.788\times10^5\, lb/in(16-in)$$

where: $E_C = 4331 psi$ at 30% compression
$A = 97.4in^2(29-in);56.5in^2(16-in)$
$h = 0.25in$

$$F_{req} = 0.075K_L$$
$$= 126{,}552lbs(29\text{-}in)$$
$$= 73{,}410lbs(16\text{-}in)$$

For 35% compression, E_C is 5775 psi which yields the corresponding numbers:

$$K_L = 2.25\times10^6\, lb/in(29-in)$$
$$= 1.31\times10^6\, lb/in(16-in)$$

$$F_{req} = 0.0875K_L$$
$$= 196{,}870lbs(29-in)$$
$$= 114{,}200lbs(16-in)$$

Based on this analysis and interpolation, the secondary seal will be compressed approximately 32% (0.080 in.) for the 29-in lid and 34.5% (0.086 in.) for the 16-in lid.

All welded joints are arc welded with full NDT inspection per note 7 of Drawing X-103-110-SNP and thus assuring full containment of the cask cavity.

4.1.4 Closure

The closure devices for the primary lid consist of sixteen (16) 1-1/2 - 6 UNC bolts or studs and nuts as described in Section 1.2. Closure for the secondary lid is accomplished with either 16, 1-1/4- 7 UNC bolts or studs and nuts (29 inch lid option) or 8, 7/8- 9 UNC bolts or studs and nuts (16 inch lid option).

4.2 Requirements for Normal Conditions of Transport

The following is an assessment of the package containment under normal conditions of transport as a result of the analysis performed in Chapters 2.0 and 3.0 above. In summary, the containment vessel was not affected by these tests. (Refer to Section 2.6 above) .

4.2.1 Containment of Radioactive Material

There was no release of radioactive material from the containment vessel.

4.2.2 Pressurization of Containment Vessel

Normal conditions of transport will have no affect on pressurizing the containment vessel.

4.2.3 Coolant Contamination

This section is not applicable since there are no coolants involved.

4.2.4 Coolant Loss

Not applicable.

4.3 Containment Requirements for the Hypothetical Accident Conditions

The following is an assessment of the packaging containment under the hypothetical accident conditions as a result of the analysis performed in Chapters 2.0 and 3.0 above. In summary, the containment vessel was not affected by these tests. (Refer to Section 2.7) .

4.3.1 Fission Gas Products

Not applicable since there are no fissionable materials involved.

4.3.2 Release of Contents

The analysis performed in Chapters 2.0 and 3.0 above show that there is no release of radioactive material under the hypothetical accident conditions.

5.0 Shielding Evaluation

5.1 Introduction

The Model 10-142 packaging consists of a lead and steel containment vessel which provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents). Tests and analysis performed under Chapters 2.0 and 3.0 above have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport and hypothetical accident conditions. Prior to each shipment, radiation readings will be taken at the package surface and 2 meters from the package surface based on individual loadings to assure compliance with applicable regulations.

The 10-142 is intended for use with payloads of up to 400 watts (1365 Btu/hr) of internal decay heat. There are many forms of typical 400-watt payloads which will result in dose readings well below 200 mr/hr at the surface and 10 mr/hr at two meters from the cask surface. An example of such a payload is given below, and a simple point-kernal analysis is given to predict exterior dose rates.

5.2 Example Payload

Assume a payload of 400 watts of Cesium-137 concentrated at a point at the center of a concrete shell 6 inches thick at the center of the 10-142. The 0.662 MeV Gamma rays emitted from this source would travel through 6 inches of concrete, 0.5 inches of steel, 3.5 inches of lead, and 1.00 inches of steel to get to the cask surface.

It is generally accepted that 207 curies of Cesium-137 is equivalent to I watt of internal decay heat. Therefore, 400 watts of Cs-137 is equivalent to:

$$(400 watts)(207\, curies/watt) = 82{,}800 curies$$

The number of 0.662 MeV Gamma rays emitted by this source can be found from the definition of a curie (3.7 x 10^{10} disintegration/second) and the fact that Cs-137 generates such a gamma ray in 85% of its disintegrations:

$$(82{,}800 curies)(3.7\times10^{10}\ \text{disint./sec}/Ci)(0.85\, gamma/\text{disint.}) = 2.604\times10^{15}\ gamma/\text{sec}$$

From Blizard, Reactor Handbook, Volume III, Part B Second Edition, the photon (gamma) flux through a multi-layered shield is:

$$\phi_A = SB(\exp(-\Sigma \mu t))/4\pi R^2$$

where ϕ_A = Photon Flux at point in question
S = Photon Generation Rate
B = Dose Build-up Factor
μt = Number of mean free paths through material of mass attenuation coefficient μ and thickness t
R = Distance from source to point in question

The dose buildup factor, B, may be expressed in the Taylor form:

$$B = Ae^{\alpha \Sigma \mu t} + (1-A)e^{-\beta(\Sigma \mu t)}$$

where A, α, β = Experimentally derived factors dependent on material and photon energy.

Reactor Shielding for Nuclear Engineers, by N. M. Schaeffer, states that the outer most shield material greater than two mean free paths thick should be used for determining the coefficients A, α and β.

For a 0.662 MeV photon through concrete, steel and lead, the following table applies (from Blizard):

Shield Material	$\mu(cm^{-1})$	A	α	β
Concrete	0.18060	11.598	0.10202	0.01305
Iron	0.57343	9.452	0.09252	0.01851
Lead	1.16068	1.970	0.03620	0.24635

From this information, the following table may be built:

Layer	Material	Thickness (in/cm)	μt
1	Concrete	6.000/15.24	2.75
2	Steel	0.500/1.27	0.73
3	Lead	3.500/8.89	10.32
4	Steel	1.000/2.54	1.46
	Σ	11.125/27.94	15.26

From the table above, it can be seen that the outer most shield material greater than two mean free paths thickness is the lead.

Therefore B may be determined as below:

$$B = 1.970e^{(0.03620)(15.26)} + (1-1.970)e^{(-0.24635)(15.26)} = 3.400$$

Then, the total flux at the surface of the outer shield is:

$$R = 38.0(2.54) = 96.52cm$$

$$\phi_S = [(2.604\times10^{15})(3.400)e^{-15.26}]/[4\pi(96.84)^2] = 14900\, photons/cm^2 - \text{sec}$$

The flux at 2 meters (200 cm) from the surface is:

$$\phi_{2m} = [(2.604\times10^{15})(3.400)e^{-15.26}]/[4\pi(96.52)^2] = 1890\, photons/cm^2 - \text{sec}$$

These photon fluxes may be converted to an equivalent radiation dose using a conversion factor, found in A Handbook of Radiation Shielding Data, ANS/SD- 76/14, J.C. Courtney, Editor. For a photon at 0.662 MeV, the conversion is 1.460 x 10^{-3} mrem/hr per photon/sec-cm^2

DOSE $= (17838)(1.46\times10^{-3}) = 26.0\, mrem/hr$ at the surface

DOSE $= (1890)(1.46\times10^{-3}) = 2.8\, mrem/hr$ at 2 meters from the surface

Dose margins of safety for this particular payload geometry are as below:

At the surface: $M.S. = (200/26.0) - 1 = +6.69$

At 2 meters: $M.S. = (10/2.8) - 1 = +2.57$

5.3 Discussion

The example payload geometry gives large positive margins of safety on shielding, demonstrating that internal heat loads of 400 watts or more may occur without violating cask external dose rate requirements. This particular geometry was chosen because of the relatively simple calculations required to analyze it. It is both conservative and unrealistic. Many very realistic geometries may occur which involve 400 watts of internal decay heat, but produce external dose rates well below regulatory requirements.

6.0 CRITICALITY EVALUATION

Not applicable for the Model 10-142 packaging

7.0 OPERATING PROCEDURES

General

This section describes the general procedures to be used for loading and unloading the ATG 10-142 shipping package. All standard radiological precautions should be taken. Measures for protection against radiation shall be taken in accordance with 10 CFR 20. Prior to opening, inspections and surveys should be performed. Any damage or abnormalities must be noted and corrected as necessary. Prior to opening the package any dirt, snow etc. should be removed from the opening to minimize the amount of material that possibly could become contaminated.

7.1 Procedures for Loading the Package

The following procedures assume that the cask is in the loading area assembled in its over-the-road configuration. It is assumed that all inspections, surveys and cleanings if necessary have been done within the limitation of 10 CFR 20.

The cask may or may not be on the vehicle used to transport the cask over public roads.

7.1.1

Remove the impact limiter from the cask by removing the covers on the impact limiter lifting lugs, remove the ball lock pins fastening the impact limiter to the cask, and lift the impact limiter off the cask.

7.1.2

After surveying the cask as required, loosen and remove the sixteen (16) 1-1/2 - 6 UNC bolts or nuts off of the studs holding the primary lid on. Remove the secondary lid bolts or nuts off of the studs and uncover the secondary lid lift lug, if the secondary lid is to be removed.

7.1.3

Remove the appropriate lid. Place the lid on a clean surface taking care not to damage the sealing surfaces of the lid.

7.1.4

Inspect all parts for damage or wear corrosion which could affect the use of the package. Clean, repair or replace parts as necessary. The internal cavity of the cask should be treated as potentially contaminated until proven otherwise.

7.1.5

Place the appropriate contents in the cask, verifying before loading that the contents meet the Certificate of Compliance content requirements.

7.1.6

If the contents are loaded through the secondary opening into a liner, verify that the liner is sealed properly before closing the cask.

7.1.7

Insure that the contents are properly shored.

7.1.8

Before closing the cask inspect all sealing surfaces for damage, dirt, etc. that may prevent the cask from sealing. A covering of high quality vacuum grease may be applied to gaskets and sealing surfaces.

7.1.9

Place the lid on the cask and tighten the bolts or nuts onto the studs. The primary lid bolts or nuts on the studs shall be torqued to 300 ± 25 ft-lbs and the secondary lid bolts or nuts on the studs shall be torqued to 200 ± 10 ft-lbs.

For contents that meet the definition of low specific activity material or surface contaminated object in 10 CFR 71.4, and also meet the exemption standard for low specific activity material and surface contaminated objects in 10 CFR 71.10(b)(2), the pre-shipment leak test is not required.

If the shipment is not classified as Low Specific Activity material, and is shipped on an exclusive use vehicle, an assembly verification leak test per section 8.3 shall be performed.

7.1.10

After all lids are properly installed and tested, place the top impact limiter on the cask and attach with the eight ball lock pins.

7.1.11

Replace covers on the lifting devices on both the secondary lid and the impact limiters to prevent their use during shipment.

7.1.12

Survey the loaded cask to assure compliance with 10 CFR 71.47. Inspect for surface contamination per the requirements of 10 CFR 71.87 (i).

7.1.13

Inspect the package for labeling required to meet all applicable regulations.

7.1.14

Install approved tamper-indicating seals.

7.1.15

Secure package to the transport vehicle using the appropriate tie-down devices, if it is not already done. If the cask had been previously secured to the vehicle, re-check all tie-down devices for proper security.

7.1.16

The following checks shall be performed prior to shipment:

7.1.16.1 Exterior nameplates, stencils, placards and other required identification are in place and legible.

7.1.16.2 Ball lock pins, bolts and gaskets are in place and in good operating condition and free of defects.

7.1.16.3 All required documentation is completed and retained/displayed as specified by the regulatory authority and the user.

7.2 Procedures for Unloading the Package

7.2.1

The requirements of 10 CFR 20, Subparts C, D, F, G and H shall be followed.

7.2.2

Move the unopened package to the appropriate unloading area. Insure the cask is level prior to removing the impact limiter and lids.

7.2.3

Perform an external inspection of the unopened package. Report any significant or potentially significant observations to the cask owner.

7.2.4

Remove the tamper-indicating seals. If previously broken, report to shipper.

7.2.5

Perform steps 7.1.1 through 7.1.4 in Section 7.1 above for removing the impact limiter and lid.

7.2.6

Remove the contents of the cask, taking care not to spread any contamination to the exterior of the cask.

7.2.7

After unloading the cask, the interior and exterior shall be visually inspected to assure that it has not been significantly damaged i.e., no cracks, punctures, holes or broken welds.

8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

The Model 10-142 packaging shall be inspected and released for use by responsible operation personnel prior to loading. The following items will be included in such inspection:

8.1.1

After fabrication, the 10-142 package shall be subjected to the leak test as described below in Section 8.1.3 and 8.2.5.

8.1.2

All configuration checks described in section 7.1.16 and those necessary to ensure conformance with Drawing X-103-110-SNP shall be performed.

8.1.3

The cask shall be pressure tested to 1.5 times the normal operating pressure of the cask. This may be taken conservatively as the pressure given for the Hypothetical Accident Condition in Section 2.7.3. In that section, the pressure is given as 11.59 psig, so this test shall be carried out at 17.4 psig.

8.1.4

The integrity of the shield shall be demonstrated by means of a gamma scan performed on the lead-filled cylinder during the fabrication process. See Appendix 8.4.1 for a description of this procedure.

8.2 Maintenance Program

A good sound industrial maintenance program should be followed to assure the integrity of the Model 10-142 packaging. Components such as gaskets, lock pins, nuts, studs and bolts shall be inspected prior to each shipment and repaired or replaced as necessary. A leak test will be performed when seals are replaced or when damaged seals are suspected. The test will be performed in accordance with Section 8.2.5 below.

8.2.2

As a minimum, sealing gaskets and o-rings shall be replaced with new gaskets and o-rings meeting the description in the drawings shown in Section 2.10.1 Appendix every twelve (12) months. The seals must be replaced sooner if inspection shows any defects that would impact seal integrity.

8.2.3

Threaded fasteners should work freely. Clean and lubricate as required and replace if necessary.

8.2.4

Any damaged or lost fasteners will be replaced with the grade and strength fastener as shown on the drawings in Section 2.10.1 Appendix.

8.2.5

Before first use, prior to each shipment (except as specified in Section 7.1.9), and whenever the gaskets are replaced, the leak test described below shall be conducted. Regardless of condition, all gaskets shall be replaced every twelve (12) months.

8.2.5.1

The package should be leak tested, based on ANSI N14.5-1977, utilizing a carbon dioxide (CO_2) detector type test similar to the one presented in Appendix 8.4.2. The CO_2 gas shall be introduced to the fully assembled package through appropriate fittings in the drain port area or test port.

8.2.5.2

The leak test shall be performed at the Primary and Secondary lid seals and at all ports as appropriate for the particular 10-142 cask configuration. The required elements of this leak test are as follows:

1. A CO_2 gas leak detector capable of detecting a leak rate in accordance with item 5 below shall be used. Its calibration, adjustment and use shall be in accordance with the detector manufacturer's requirements.
2. Carbon dioxide shall be used as the pressurizing gas.
3. The package shall be assembled for the test in accordance with Section 7.0. The cask shall be pressurized through the drain or vent port, as applicable.
4. The CO_2 pressurization of the cask shall be 7 psig.
5. The sensitivity of the test shall be $3x10^{-4}$ cc/sec. The acceptance criterion shall be no leak in excess of $7x10^{-4}$ cc/sec.
6. Each seal area shall be tested.
7. If acceptance criterion is not met, a retest shall be conducted following a procedural sequence similar to the one presented in Appendix 8.4.2.

8.3 Assembly Verification Leak Test

8.3.1

Prior to each shipment of Type B quantities material which are not classified as Low Specific Activity, a CO_2 leak test shall be performed as delineated in Section 8.2.5.

8.4 Appendix

8.4.1 Discussion of Gamma Scan Procedure

Lead shielding integrity shall be confirmed via gamma scanning. There are two gamma scan techniques which may be utilized. The main difference is in the method utilized to determine acceptance criteria.

Both Gamma Scan Techniques are exactly the same in all other respects and are conducted as follows:

An Eberline E120 probe or equivalent is used to scan the outer surface of the cask while an Iridium 192 or Cobalt 60 source of sufficient strength is present in the center of the cask. The source is first placed on the bottom of the cask while the surface is scanned around its circumference parallel to the source. The source is then moved up a predetermined distance and the circumference scanned again. This sequence is repeated until the entire cask surface is scanned.

For these tests, the cask surface is gridded (in this case the grid consists of 4 inch squares) and a chart is made to reflect the gridded cask surface. Readings are taken from each grid square by scanning every point in the grid and recording the maximum reading in the corresponding grid on the chart. This data then serves as the raw gamma scan results. All readings are in milliroentgens (Mr).

The readings are evaluated by comparing them to predetermined Mr values for nominal, or as designed, lead thickness and nominal -10% lead thickness.

The two different methods utilized to determine acceptance criteria are discussed below.

The Laboratory Calibration Method (NuPac Procedure GS-001) utilizes test blocks of the cask wall made up of lead and steel sheets. The test blocks simulate nominal or as designed and -10% lead thicknesses. The source is placed behind the test block at a distance equal to the inside radius of the cask. The probe is then placed on the outside of the test block and readings are taken. This sequence is repeated on the nominal and -10% test blocks and the data is recorded.

The resultant values are then averaged. A ratio of the values is also developed. Then the average value is multiplied by the ratio. The value so derived is the maximum acceptable value for the shielding to be inspected.

An optional Laboratory Calibration Method can be utilized in lieu of the lead/steel calibration mockup method. In that case, calculations are run to establish acceptance criteria.

To do this, compiled source power data and attenuation characteristics data for steel, lead and distance through air are utilized to calculate the expected readings at the cask surface. The calculations allow for different source powers and are corrected for nominal and -10% shielding configurations.

The following excerpt from NuPac Gamma Scan Procedure No. GS-001 is provided to illustrate the calculation Method of Laboratory Calibration.

1.1 The nominal and -10% shielding calibration Mr readings may be obtained via calculation as an option. These calculations shall be performed as follows:

1.1.1 Data and transmission charts found in the Tech/Ops Gamma Radiography Radiation Handbook shall be utilized. Copies of the handbook can be obtained from Tech/Ops, Inc. Radiation Products Division 40 North Avenue Burlington, Massachusetts 01803

1.2.2 Attachment A, Table 2, 'Selected Radioisotope Data' from the handbook shall be utilized to obtain source power data. (Copy of Table 2 included as Attachment A).

1.2.3 Attachment B figures of the handbook shall be utilized to determine the attenuation of Gamma Rays in the shielding materials utilized in the cask to be inspected. (Copy of typical figures included as Attachment B).

1.2.4 The following is an example of the calculated calibration method using Cobalt 60.

EXAMPLE

Cask O.D. 48 in. Cask I.D. 36 in. I.D. Wall 0.50 in. O.D. Wall 0.50 in. FE

Lead Shielding = 5.0 in. Less 10% lead shielding = 4.5 in.

Total FE shielding = 1.0 in.
Source Cobalt 60 strength 15 curies x 14.0 = 210 R/hr at 12 in. (using Attachment A).

210 R/hr at 12 in. = 52.5 R/hr at 24 in. This would be the outer surface of the cask

52.5 R/hr at 24 in. x reduction factor for 1.0 in. FE 0.58 = 30.45 R/hr.
30.45 R/hr at 24 in. x reduction factor for 5.0 in. Pb 0.0009 = 27.4 Mr/hr.

30.45 R/hr at 24 in. x reduction factor for 4.5 in. Pb 0.000185 = 56.3 Mr/hr (using Attachment B).

Design thickness reading at cask surface = 27.4 Mr/hr.

Design thickness reading less 10% Pb = 56.3 Mr/hr.

1.2.5 The following is an example of the calculated calibration method using Iridium 192.

EXAMPLE

Cask O.D. 48 in. I.D. Wall 0.25 in. Fe O.D. Wall 0.25 in. FE

Lead shielding = 1.5 in less 10% lead = 1.35 in.

Total FE Shielding 0.50 in.

Source Iridium 192 50 curies x 5.9 = 295 R/hr at 12 in. (using Attachment A).

295 R/hr at 12 in. = 73.75 R/hr at 24 in. This would be the outer surface of the cask.

73.75 R/hr at 24 in. x Reduction Factor for 0.50 in. FE 0.55 = 40.5625 R/hr.

40.5625 R/hr. x Reduction Factor for 1.50 in. Pb 0.0024 = 0.09735 R/hr.

40.5625 R/hr. x Reduction Factor for 1.35 in. Pb 0.004 = 0.16225 R/hr. (using Attachment B).

Design thickness reading at cask surface = 97.35 Mr/hr.

Design thickness reading less 10% of Pb = 162.2 Mr/hr.

The calculation values and methods are based on data developed during approximately 300 actual calibrations utilizing the lead sheet/steel plate sandwich technique described in Rev. 4 of the referenced procedure.

Additional correlation has been provided by the use of established attenuation values obtained from the various figures found in the Tech/Ops Radiation Safety Handbook. This reference source is a recognized standard document utilized throughout the NDE industry. This information, together with NuPac's extensive laboratory data enabled NuPac to develop the current optional calculation method of laboratory calibration for gamma scan.

The calculation method provides a greater degree of accuracy and correlation to the actual gamma scan conditions present in a typical cask than the lead and steel plate setup used in the past. It also reduces operator exposure during the calibration phase. The resultant calibration values for acceptance of the lead shield are, in fact, slightly more conservative and therefore assure a greater margin of safety for the shield.

The resultant improvement in the calibration of gamma scan acceptance criteria provides greatly improved accuracy and repeatability.

To illustrate this accuracy, correlation and conservativeness, the calibration data for a typical OH-142 gamma scan (Certificate of Compliance 9032) was rerun using the calculation method of Laboratory Calibration. The original calibration technique for this cask had been the lead and steel setup method.

The correlation between the two Laboratory Calibration methods is essentially identical. The variance in the acceptance criteria between the two methods is from 0.3 Mr in the nominal to 0.1 Mr in the -10% values. This equals no more than 2% variance between the Pb/FE and calculation methods of Laboratory Calibration. The difference in percentage (DIFF, %) between the nominal and -10% values for the two calibrations is also very close with the Pb/FE at 64% and the Calc at 63%. The calibration results follow:

SUMMARY OF GAMMA SCAN ACCEPTANCE VALUES - OH-142

Source Type	Source Strength	Calib. Type[1]	Nominal Value[2]	-10% Value[3]	Diff[4]
Co 60	11 curies	Pb/FE	21.5 Mr	33.5 Mr	64%
Co 60	11 curies	Calc	21.2 Mr	33.4 Mr	63%

[1]Pb/FE = Laboratory Calibration using lead and steel sheets to simulate the cask wall. Calc = Laboratory calibration using the calculation method.

[2]Nominal Values is the calibrated acceptance value expected if the lead and steel thickness meet the design requirements.

[3]The -10% value is the calibrated gamma reading expected if the lead thickness is 10% less than that required by the design. The steel thickness is assumed to be at the nominal. This reading will be larger than the nominal reading. No reading above this value during actual gamma scan inspection is acceptable.

[4]DIFF (%) refers to the percentage of difference between the Nominal and - 10% values. A variance of approximately 5 to 6% between the nominal and -10% values of separate calibrations is normal. This is attributable to differences in lead density (cast vs. rolled sheet), accuracy of meters and related equipment, as rolled steel thickness variables, etc.

The Field Calibration Method (NuPac Procedure GS-002) utilizes a specially fabricated test lid which incorporates a holder for various lead and steel sheet thicknesses. This fixture is installed onto the cask to be scanned. The test lid is then set up to simulate the nominal lead thickness, the source is placed below the test lid in the cask at a distance equal to the inside radius of the cask. Readings are then taken. The test lid is then set up to recreate the -10% lead thickness configuration, and readings are again taken.

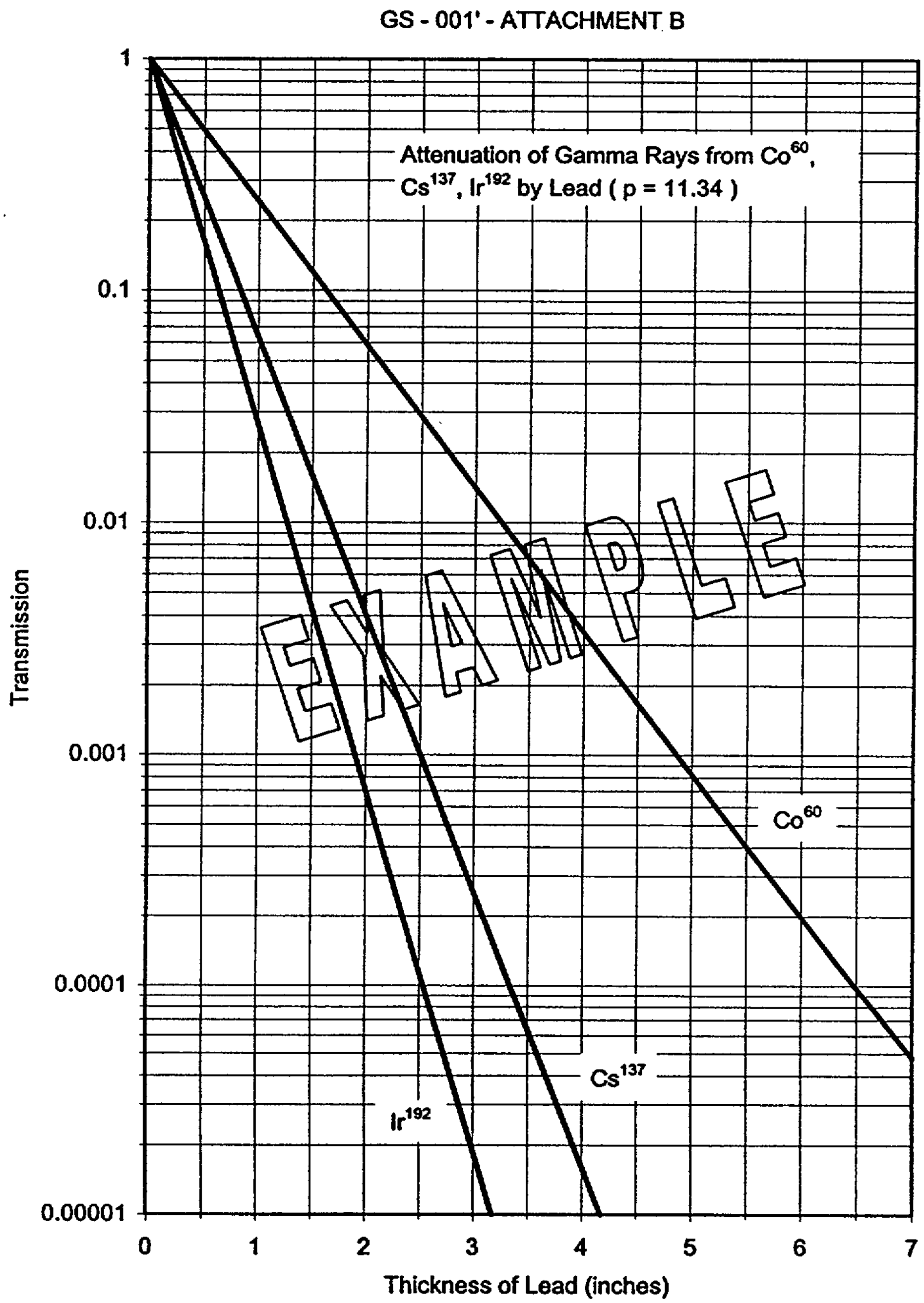
Other readings are then taken in 1/8-inch lead thickness increments between and beyond the two base readings until four to eight readings are obtained. The data is then plotted on a chart of readings versus lead thickness. The value for nominal lead -10% is then utilized as the maximum acceptable reading during the actual gamma scan.

GS – 001 – Attachment A

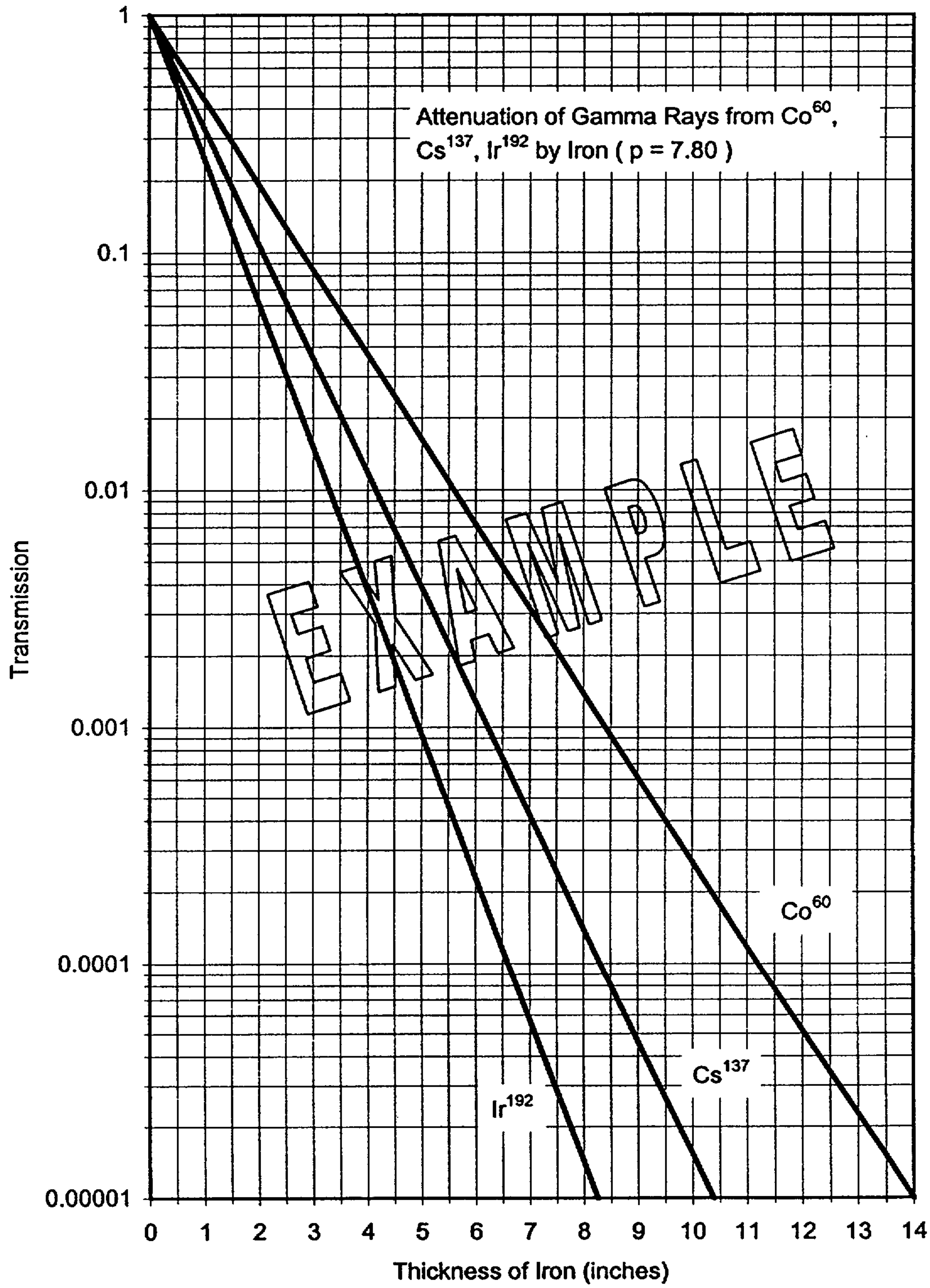
Radioisotope	*Halflife*	*Principal Photon Energies (keV)*	*Specific Gamma Ray Constant R/hr per curie at 1 foot*	*at 1 meter*
Casium^{137}	30y	662	3.4	0.32
Cobalt^{60}	5.3y	1173, 1332	14.0	1.30
Iridium^{192}	74d	311, 468, 603	5.9	0.55*
Thulium^{170}	134d	84, Yb x-rays	0.015	0.0014
Ytterbium^{169}	32d	63, 110, 131 177, 198, 308 Tm x-rays	1.35	0.125

*American National Standards Institute Standard N432 has proposed a value of 0.45R-mi/hr-Ci for the specific gamma ray constant for Iridium 192.

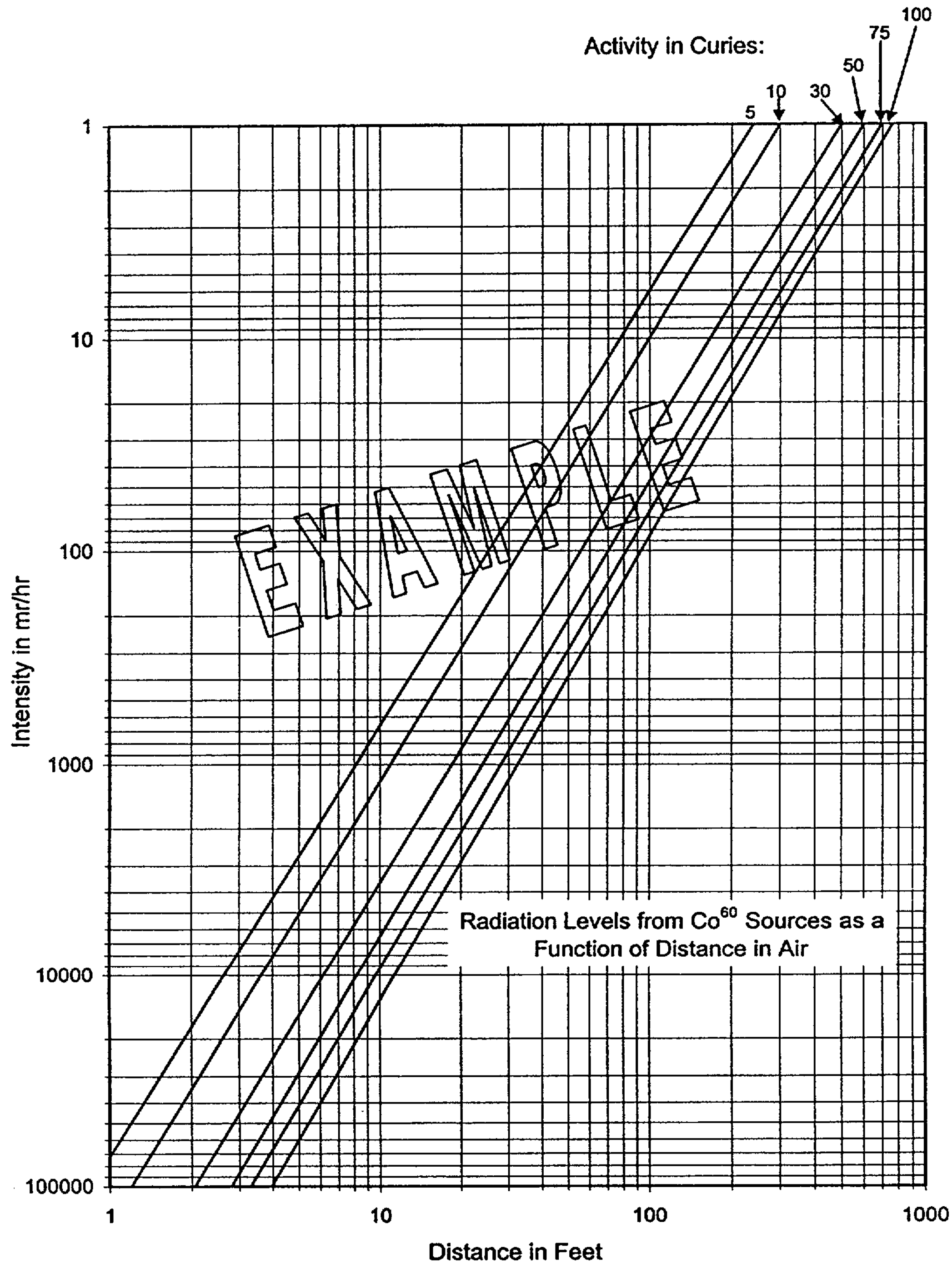
Table 2 Selected Radioisotope Data



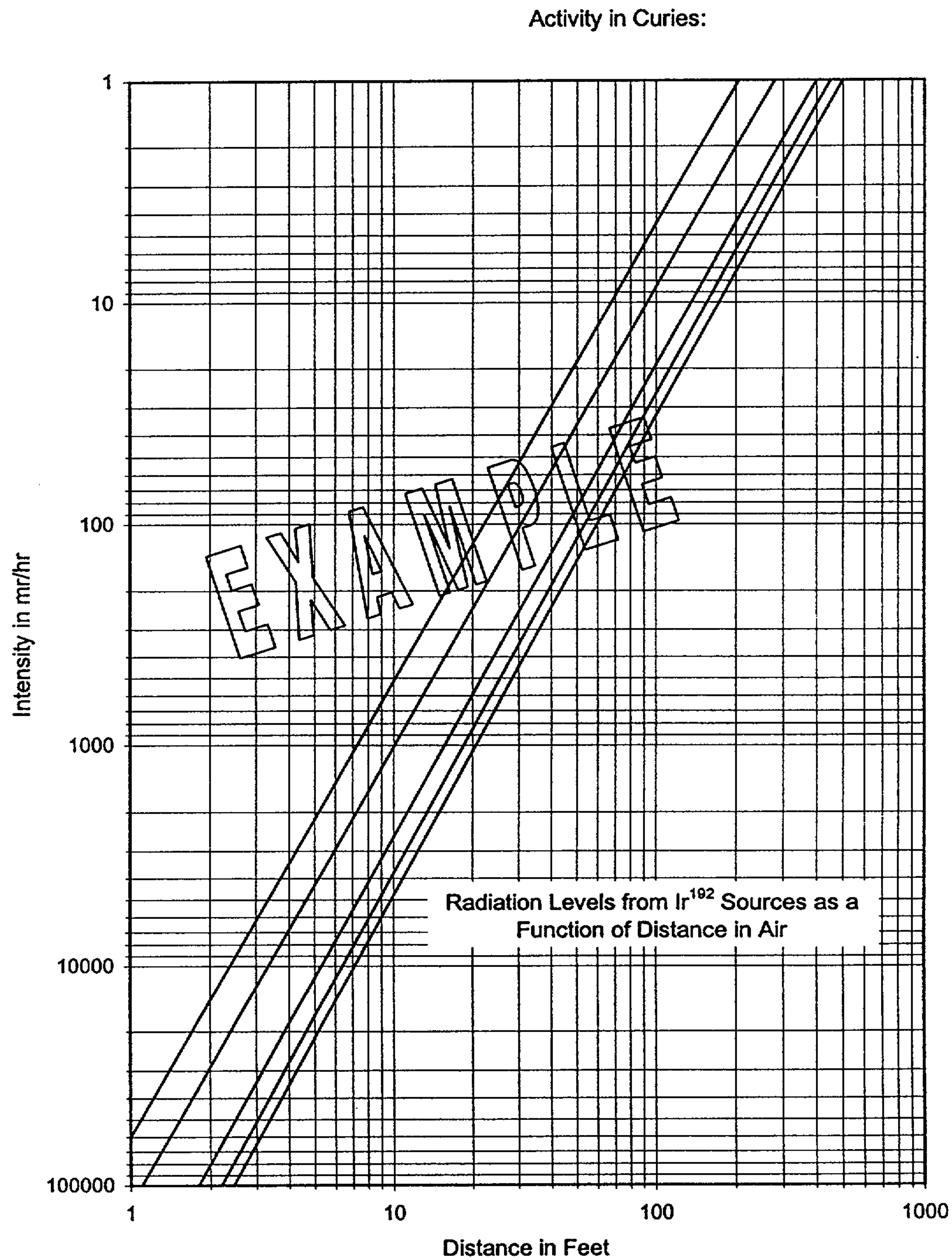
Graph: Attenuation of Gamma Rays by Lead



Graph: Attenuation of Gamma Rays by Iron



Graph: Radiation Levels from Cobalt 60 Sources as a Function of Distance in Air



Graph: Radiation Levels from Iridium 192 Sources as a Function of Distance in Air

8.4.2 Carbon Dioxide Leak Test Procedure

This appendix presents the carbon dioxide seal integrity leak test: LT-006-WS (5 pages).

PACIFIC NUCLEAR

PROCEDURE FOR

SEAL INTEGRITY LEAK TEST

OF THE

10-142 TYPE B SHIPPING CONTAINER

LT-006-WS

Revision: 0 Effective Date: 3/4/93

Essential Related Pacific Nuclear Documents

The following related Pacific Nuclear Document(s) contain operations or information essential to performance of instructions herein and must be issued in conjunction with this document:

1. NONE for service inspect.
2. LT-28-Required for initial fabrication only
3.
4.
5.
6.

G. Wes Caughman Prepared By	2-9-93 Date
[signature] Engineering	2-9-93 Date
[signature] Customer Service	2-9-93 Date
Joe B Jackson Quality Assurance	2-10-93 Date
G. Wes Caughman Other- Licensing	2-10-93 Date
Pam C. Atchley Document Control	3/04/93 Date

Plant Services Group Brookside Office Park No. 1 Harbison Way, Suite 209 Columbia, SC 29212 (803) 781-0426 Fax (803) 781-9316

Table of Contents

1.0 PURPOSE AND SCOPE

1.1 This procedure provides methods and requirements for the verification of seal integrity on the 10-142 Type B Shipping Container. This procedure supersedes Pacific Nuclear Procedure LT-29-NS, Rev. 6.

1.2 The tests in this procedure are to be performed prior to first use as part of the cask acceptance inspection with the test described in Reference 2.8. Thereafter, a seal integrity test shall be performed as part of in-service and/or annual maintenance testing, and prior to shipment of Type B quantities of materials which are not classified as Low Specific Activity (LSA). A complete cask seal integrity test is only required during the annual gasket replacement maintenance program and when assembly verification is required for shipment of greater than LSA quantities of materials. Interim individual gasket replacement (i.e., non-annual gasket replacement) only requires that the replaced gasket sealing interface be leak tested.

1.3 The tests shall be performed as required by 10 CFR 71.87 (c) and the specific sections of USNRC Certificate of Compliance No. for this cask.

1.4 Leak detector testing shall be performed in accordance with Section 6.0.

2.0 REFERENCES

2.1 ANSI N14.5, Leakage Tests on Packages for Shipment of Radioactive Materials.

2.2 RDT Standard, F5-1T, Cleaning and Cleanliness Requirements for Nuclear Components.

2.3 Code of Federal Regulations No. 10, Part 71.

2.4 QPNS-10-1, "QA Inspection Planning".

2.5 QPNS-10-2, "Inspection and Verification".

2.6 QPNS-15-1, "Nonconformance Reporting".

2.7 10-142 Operation and Maintenance Manual, OM-101-NS.

2.8 Procedure LT-28, 10-142 Structural Pressure Test.

2.9 EPD-B4/EPD-B4IS Multi Purpose Gas Leak Detector Instruction Manual.

2.10 QPNS-17-1, "Quality Records".

3.0 DEFINITIONS

"Not Applicable"

4.0 RESPONSIBILITIES

"Not Applicable"

5.0 PRECAUTIONS/PREREQUISITES

5.1 The cask assembly shall have been inspected and tested in accordance with Reference 2.8, pressure test procedure and written inspection instructions prepared and completed in accordance with References 2.4 and 2.5. These acceptance activities shall have been performed prior to first use.

5.2 Prior to each seal integrity test, the cleanliness of the internal and external surfaces shall be in accordance with Reference 2.2 sections as directed by Quality planning per Reference 2.4.

5.3 The seal integrity test described in this procedure shall be performed prior to first use. It shall then be performed after each seal replacement, during the annual maintenance activity, or when greater than Type A quantities of materials not classified as LSA are shipped.

5.4 The following test equipment shall be required for the seal integrity test. Equipment for leak detector testing is specified in Section 6.0.

5.4.1 LEAK DETECTOR: EPD Technology Corporation Multi Purpose Leak Detector Model EPD-B4 or equivalent.

5.4.2 TRACER GAS SOURCE: Carbon Dioxide shall be utilized to provide the tracer gas and pressurization for the seal integrity test.

The Carbon Dioxide container shall be pressurized with appropriate shut off valves and fittings to interface with the cask vent or drain port.

5.4.3 GAUGE: A gauge capable of indicating pressure up to 15 psig to a minimum accuracy of +/- 2.0% of the full scale shall be utilized.

5.5 Cask seal integrity shall be tested with the cask fully assembled in the shipping configuration without the upper and/or lower overpack as applicable. The primary and secondary lids shall be installed per the applicable requirements of Reference 2.7.

6.0 PROCEDURE

6.1 Verify that all cask configuration, cleanliness and test equipment requirements of this procedure have been met.

6.2 The Pacific Nuclear NDT Level III/QA Manager or designee shall insure sensitivity of the leak tester to detect a leak rate of 3.0×10^{-4} cc/sec of Carbon Dioxide.

6.2.1 The leak detector shall be calibrated at 1 year intervals to insure no damage to the equipment has occurred, and that probe tips and batteries are in good working condition. The appearance of the battery symbol on the LCD indicates low battery power.

NOTE: In no case shall batteries be used for more that 6 months. Replacement shall be annotated on the tool usage log.

6.3 Install the appropriate fittings and gauge on the cask vent or drain port for injecting the Carbon Dioxide into the cask containment cavity.

NOTE: Assure that the gauge is placed to indicate containment cavity pressure.

6.4 Pressurize the cask containment cavity with Carbon Dioxide through the provided pressurization port to 7 psig.

6.5 After the Carbon Dioxide has been injected per Step 6.4, close off the injection valve so that the gas cannot escape from the cask containment cavity.

6.6 Hold the probe of the leak detector with the nozzle removed 1/16 to 1/8 inches from the applicable interface areas of the primary lid to cask body, primary lid to secondary lid, the seal welded drain plug (if so equipped), or the non-welded drain plug (if not used in the test).

NOTE: When shipping Type B quantities of material which are not classified as low specific activity, the applicable interface areas which need to be checked are the primary lid to cask body, primary lid to secondary lid, and the non-welded drain plug (if not used in test and if so equipped).

6.7 Move the probe along the area being inspected at a rate not exceeding 2 1/2 feet/minute (1/2 inch/second). Probe all areas described in Step 6.6.

6.8 If the probe passes over a leak, there will be an audible signal from the detector.

7.0 ACCEPTANCE CRITERIA

7.1 Any detectable leak greater than or equal to 7×10^{-4} cc/sec is unacceptable. The detector will emit a rhythmic audible signal. Any detectable leakage will cause an increase in the frequency of these signals. Increase in these signals is an indication of a leak. However, the leak rate must be verified to determine if a detectable leak is rejectable.

7.2 If a rejectable leak is observed, seal condition, fastener torque, and seal interfaces shall be checked and the test rerun.

7.3 If the test is failed three (3) consecutive times, a Nonconformance Report (NCR) shall be prepared and dispositioned in accordance with Reference 2.6 before proceeding further.

8.0 RECORDS

Records generated by this procedure shall become Quality records, and shall be maintained in accordance with Reference 2.10.

9.0 QUALITY ASSURANCE

ATG's quality assurance program used for the design, fabrication, assembly, testing, use and maintenance of the 10-142 cask is designed and administered to meet the applicable criteria of 10 CFR 71, Subpart H. A description of the program has been submitted to the NRC by ATG and has received Quality Assurance Approval number 0870.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 26, 2002

Mr. Scott Poole
Manager, Quality Assurance/Document Control
ATG Nuclear Services
1550 Bear Creek Road
Kingston, TN 37763

SUBJECT: QUALITY ASSURANCE PROGRAM APPROVAL FOR RADIOACTIVE MATERIAL PACKAGES NO. 0870, REVISION NO. 3

Dear Mr. Poole:

Enclosed is the Quality Assurance (QA) Program Approval for Radioactive Material Packages No. 0870, Revision No. 3. This revision is issued to correct the latest QA Program Application Date in Block No. 5 from February 15, 2002, to January 15, 2002. This Approval satisfies the requirements of 10 CFR 71.12(b) and 71.101(c) for a QA Program approved by the Nuclear Regulatory Commission (NRC).

This Approval will remain in effect until the expiration date, indicated in Block No. 3. Termination of your materials license does not cause this Approval to be automatically terminated. If you wish to renew, amend, or terminate this Approval, please request it in writing.

Please note that any substantive changes to the identity of ATG Nuclear Services (ATG), and any changes to the organization and activities described in the ATG QA Program must be reported to the NRC in the form of a request for an amendment to the ATG QA Program.

This letter also serves as a reminder that if you are using or planning to use an NRC-approved packaging, you must be registered for use of that packaging with NRC. Registration for use of NRC-approved packagings should be made pursuant to 10 CFR 71.12(c)(3).

Sincerely,

Michael Tokar

Michael Tokar, Chief
Transportation and Storage Safety
and Inspection Section
Spent Fuel Project Office
Office of Nuclear Material Safety
and Safeguards

Docket No.: 71-0870

Enclosure: QA Program Approval No. 0870, Revision No. 3

NRC FORM 311
(5-2000)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

QUALITY ASSURANCE PROGRAM APPROVAL
FOR RADIOACTIVE MATERIAL PACKAGES

1. APPROVAL NUMBER: 0870
REVISION NUMBER: 3

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, as amended, and Title 10, Code of Federal Regulations, Chapter 1, Part 71, and in reliance on statements and representations heretofore made in Item 5 by the organization named in Item 2, the Quality Assurance Program identified in Item 5 is hereby approved. This approval is issued to satisfy the requirements of Section 71.101 of 10 CFR Part 71. This approval is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

2. NAME: ATG Nuclear Services
STREET ADDRESS: 1550 Bear Creek Road
CITY: Kingston STATE: TN ZIP CODE: 37763

3. EXPIRATION DATE: February 28, 2007

4. DOCKET NUMBER: 71-0870

5. QUALITY ASSURANCE PROGRAM APPLICATION DATE(S)
February 4, 1999, and January 15, 2002

6. CONDITIONS

1. Activities conducted regarding transportation packagings are to be executed under applicable criteria of 10 CFR Part 71, Subpart H. Authorized activities include: design, procurement, fabrication, assembly, testing, modification, maintenance, repair, and use of transportation packagings.

2. Records shall be maintained in accordance with the provisions of 10 CFR Part 71. Specifically:

   a. Records of each shipment of licensed material shall be maintained for 3 years after that shipment [10 CFR 71.91(a)].

   b. Records providing evidence of packaging quality shall be maintained for 3 years after the life of the packaging [10 CFR 71.91(c)].

   c. Records describing activities affecting packaging quality shall be maintained for 3 years after this Quality Assurance Program Approval is terminated [10 CFR 71.135].

3. Planned and periodic audits of all aspects of the Quality Assurance Program shall be conducted in accordance with written procedures or checklists, by appropriately trained personnel not having direct responsibility in the areas being audited, in accordance with 10 CFR 71.137.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

SIGNATURE: Michael Tokar
DATE: 02/26/02

MICHAEL TOKAR, CHIEF
TRANSPORTATION AND STORAGE SAFETY AND INSPECTION SECTION
SPENT FUEL PROJECT OFFICE
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS

NRC FORM 311 (5-2000) PRINTED ON RECYCLED PAPER