# SAFETY ANALYSIS REPORT FOR MODEL UX-30 PACKAGE
## ("-96" Upgrade)

REVISION 0

May 2005

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# 1.0 GENERAL INFORMATION

## 1.1 Introduction

Addendum 2-2004 to ANSI N14.1-2001, which specifies the standard 30C cylinder, was issued after the analyses and testing using 30C as described in this SAR was completed. The cylinder on which the analyses and testing was conducted was named, at the time, the "CBC Watertight™" cylinder. Since the CBC Watertight™ cylinder is identical in every respect to the cylinder that became the standard 30C cylinder in Addendum 2-2004 to ANSI N14.1-2001, references in this SAR are to the "30C," instead of to the "CBC Watertight™" cylinder.

### 1.1.1 Purpose of Application

The analyses performed and testing reviewed in this SAR demonstrates that the UX-30 meets the requirements for use under 10CFR71.17, "General License, NRC Approved Package," as a Type AF package. The UX-30 packaging has been developed to provide a safe and reliable container for transporting standard 30-inch cylinders of enriched uranium hexafluoride ($UF_6$). $UF_6$ enriched to 5% is routinely transported from enrichment facilities such as Oak Ridge and Paducah to fuel fabricators and research facilities around the world.

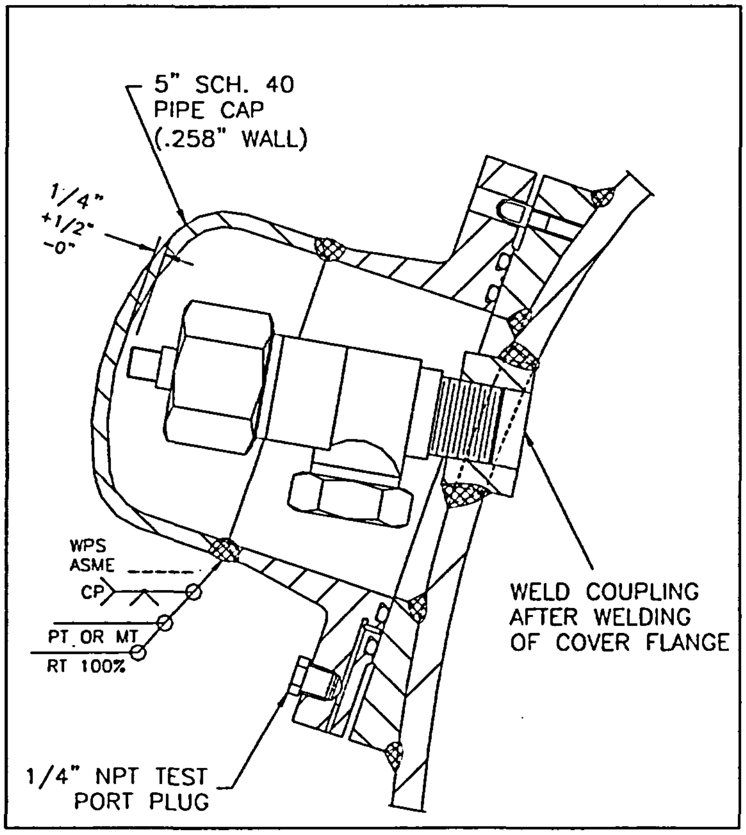
### 1.1.2 Summary Information

The packaging consists of two elements: 1) A standard 30-inch cylinder (or equivalent), and 2) a UX-30 overpack. The UX-30 has been designed as a replacement for the 21PF-1B overpack developed over fifteen years ago. Because the existing 21PF-1B overpack is fabricated from light gauge carbon steel and open cell foam, rust and moisture absorption has dictated frequent maintenance and replacement. Considerable effort has gone into the design of the UX-30 overpack to eliminate operational and maintenance problems associated with the older design. The UX-30 has been designed to meet the requirements of 10 CFR 71.

In an effort to simplify the original review and evaluation process, in 1984 a full scale UX-30 prototype with a loaded 30 inch cylinder was subjected to a series of 5 sequential drop tests, well in excess of impact qualification requirements in 10 CFR 71. Three drops were from 30 feet and two were 40-inch drops onto a 6-inch diameter steel post. Throughout the full series of tests the cylinder was so well protected that it experienced no deformations whatsoever. Subsequent leak tests also demonstrated that the cylinder retained its full integrity.

A second series of tests were performed to support the review and evaluation process for upgrade of the UX-30 certification. These tests again demonstrated compliance with 10 CFR 71 requirements. The test sequence performed, which also utilized a full scale UX-30 with a loaded 30-inch cylinder, included 5 drop tests followed by a fire test and an immersion test. The drop tests included two 30-foot drops and two 40-inch drops onto a 6-inch diameter steel post. The results of this series of tests also demonstrated the excellent protection provided to the 30 inch cylinder by the UX-30 overpack. No deformations of the 30 inch cylinder were caused by the testing; also, the fire test temperatures for the 30B cylinder surface were well within $UF_6$ and 30-inch cylinder safe operational limits. The immersion test confirmed that 30-inch cylinder tested did not allow water in leakage. Post-test leak testing demonstrated that the UX-30 provided the necessary protection for the 30B cylinder.

Another series of testing was performed on the UX-30 with the 30C Cylinder instead of the standard 30-B cylinder previously used in testing. The 30C Cylinder is identical in dimensions and configuration to the standard 30-B cylinder specified by ANSI N14.1, except it is fitted with a Valve Protective Cover (VPC) that bolts over and protects the cylinder valve during transport.



Valve Protective Cover

The purpose of this series of tests was to demonstrate the following:

1. That the 30C is at least equivalent to the standard 30-B cylinder in meeting the transport regulations of 10CFR71. This was demonstrated by successfully completing a series of drop tests of a UX-30 package and a loaded 30C cylinder. Drops onto the corner of package were conducted from 4' and 30', followed by a drop from 40" onto a steel post.
2. That the VPC on the 30C Cylinder assures protection of the cylinder valve during the normal conditions of transport and hypothetical accident conditions of 10CFR71. The drop testing resulted in no damage to the cylinder, and none to the cylinder valve even though the 40" pin drop was conducted with the UX-30 being dropped directly onto its end in the region of the VPC. The inside wall of the UX-30 was deformed sufficiently to strike the VPC, but the VPC was undamaged and protected the cylinder valve. This was evidenced by the VPC successfully passing its post-test acceptance leak test of $1 \times 10^{-5}$ std-cm$^3$/sec, and by there being no damage to the cylinder valve upon examination after the VPC was removed.
3. That the VPC assures protection against leakage of water into the cylinder during the normal conditions of transport and hypothetical accident conditions of 10CFR71. As discussed above, the VPC protects the cylinder valve from damage and thus becoming a path for leakage of water into the cylinder. In addition, testing was conducted that showed a hole with a diameter that leaks $1 \times 10^{-5}$ std-cm$^3$/sec, the maximum permitted leak rate of the VPC, excludes water leakage when pressurized with water exceeding the equivalent pressure of 15 meters feet of water specified in 10CFR71.73(c)(5).
4. In addition to the features of the standard 30B cylinder that protect against water in-leakage, the VPC on the 30C Cylinder provides an additional level assurance. Because of this additional assurance demonstrated by the testing, as well as the periodic and pre-shipment leak testing performed on the VPC and cylinder, the 30C Cylinder qualifies for having the "special design features" of 10CFR71.55(c) that ensure against water leakage into the cylinder.

The testing conducted demonstrated that the VPC on the 30C cylinder provides an additional level of protection for the cylinder valve over the standard 30-B cylinder, and protects against leakage of water into the cylinder. This Safety Analysis Report will demonstrate that the additional level of protection provided by the Valve Protective Cover allows authorization of a criticality safety index of 0.0 (zero) for the 30C cylinder.

The following report will substantiate the ability of the UX-30 package to meet or exceed all the requirements of 10 CFR 71 .

Authorization is sought for shipment by cargo vessel, motor vehicle, and rail as a Fissile Material package with a criticality safety index of :

| | |
|---|---|
| Standard 30B cylinder | 5.0 |
| Standard 30C cylinder | 0.0 |

## 1.2 Package Description

### 1.2.1 Packaging

The UX-30 is designed to protect a standard ANSI N14.1 30B cylinder (or its equivalent), hereafter referred to as the cylinder. From Figure 1.2-1 it can be seen that the UX-30 is a horizontal right circular cylinder, 96 inches long by 43.5 inches in diameter. A horizontal parting plane allows the top half of the overpack to be removed, providing easy access to the cylinder.

All exposed surfaces of the UX-30 are fabricated from ASTM A240 304 stainless steel. The space between the inner and outer overpack shells is filled with an energy-absorbing and insulating closed-cell polyurethane foam material. This foam was developed by Nuclear Packaging, Inc. several years ago and has been successfully demonstrated for use with several existing licensed packages, the most recent of which include:

1. T-3 Spent Fuel Container, Certificate of Compliance No. 9132.

2. N-55, Certificate of Compliance No. 9070.
3. OH-142, Certificate of Compliance No. 9073.

The material, designated by Duratek Specification No. ES-M-170, is a rigid closed-cell polyurethane foam with well-documented mechanical and thermal capabilities. Six inches of this foam completely encases the $UF_6$ cylinder (See Appendix 8.3.1 for the polyurethane foam material specification, ES-M-170).

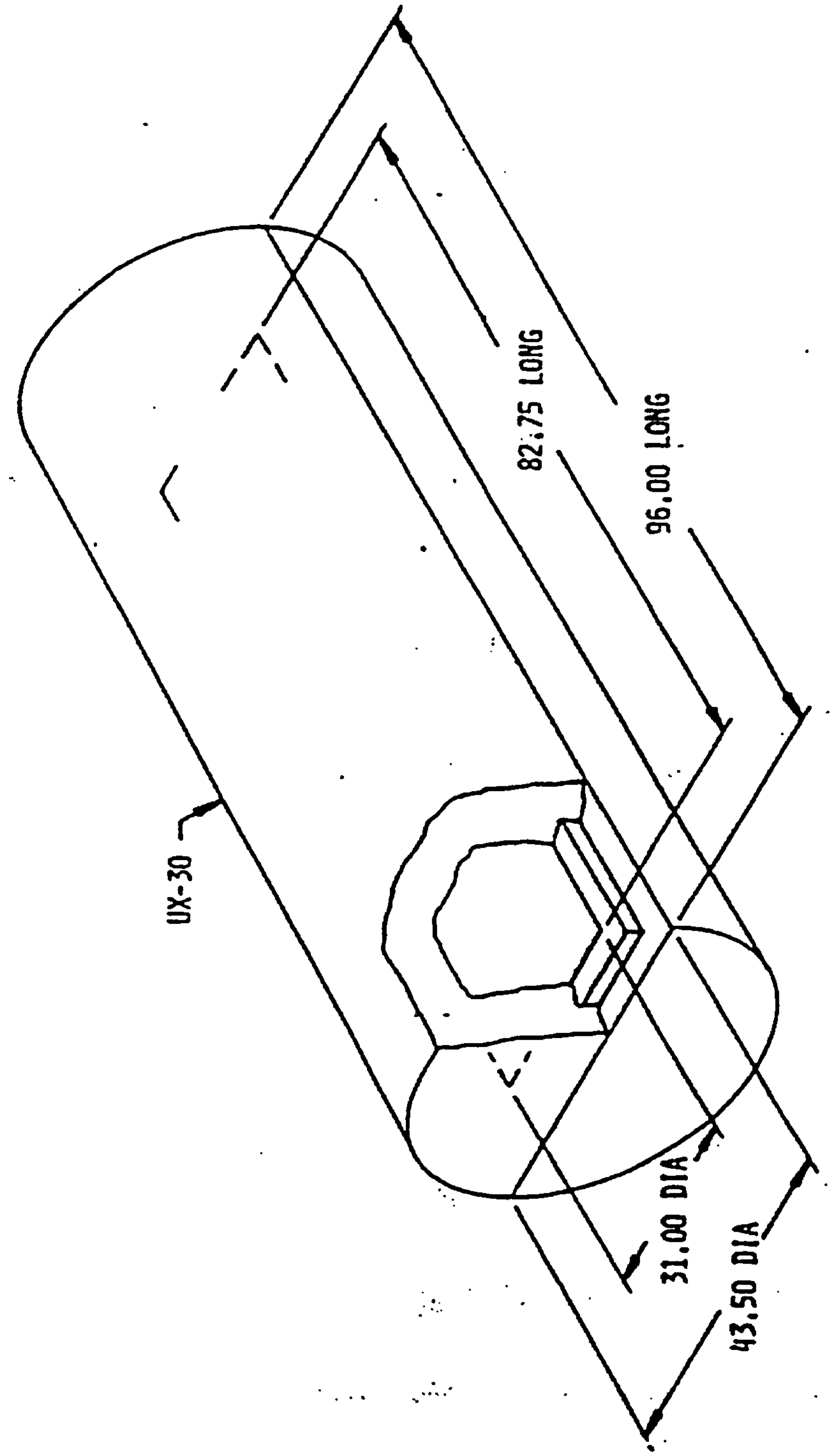


FIGURE 1.2-1
UX-30 Package Dimensions

The design of the UX-30 parallels in many ways the highly successful Paducah Tiger. The Paducah Tiger, Certificate of Compliance No. 6553, was developed by Nuclear Packaging, Inc. personnel for transport of the larger 48-inch cylinders of enriched $UF_6$. Dozens of these packages are in daily service totaling millions of miles of safe and efficient transport. Since they are almost exclusively transported by rail, the general handling environment is severe. Many of the design features that have made the Paducah Tiger so successful have been employed in the UX-30 design, such as:

- Indexing pins with cross-locking 'ball lock' pins assure rapid high strength package assembly.
- A 'step-down' closure design forces foreign material to travel against gravity and then through a seal to reach the overpack interior.
- Nested placement of the lid half of the overpack assures its protection during all handling operations.

The cylinder used in this safety analysis is defined by ANSI N14.1., American National Standard for Packaging of Uranium Hexafluoride for Transport. Any equivalent 30-inch cylinder currently used to transport $UF_6$ may also be used. See Figure 1.2-2. Typical filling and handling procedures for these cylinders are described in detail in USEC-651, Uranium Hexafluoride: Handling Procedures and Container Criteria. Essentially, liquefied $UF_6$ is introduced through a valve into the cylinder, filling the cylinder approximately 3/4 full. The $UF_6$ is allowed to cool, changing phase and volume as it cools, until the $UF_6$ occupies less than two-thirds of the available volume within the cylinder, and has completely solidified.

This Safety Analysis Report also includes provision for transport of the 30C cylinder in the UX-30. This cylinder is equivalent to the standard 30B cylinder specified in ANSI N14.-1, but also includes a Valve Protective Cover to preclude water intrusion (see Figure 1.2-3).

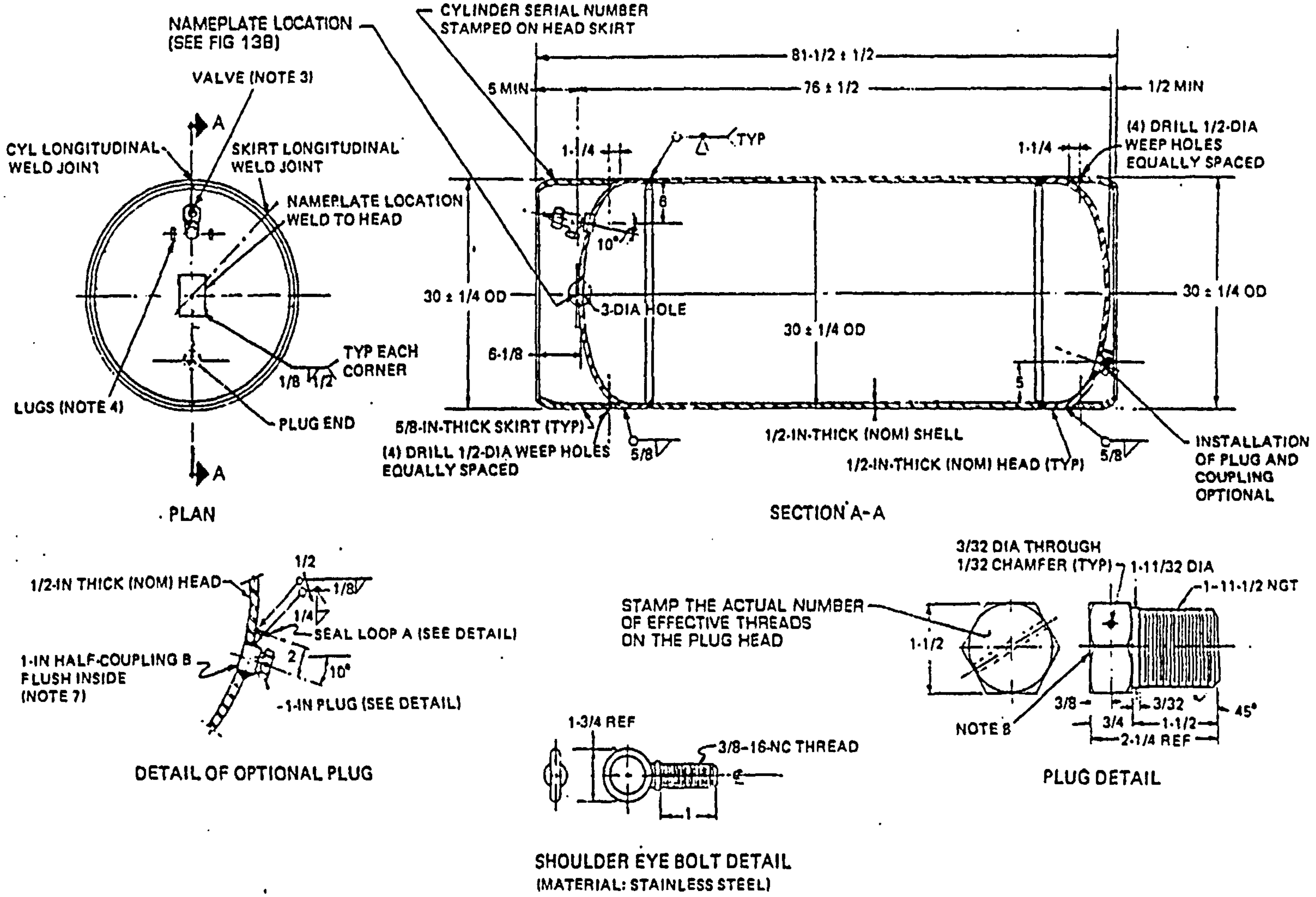


FIGURE 1.2-2
UF$_6$ Cylinder ANSI NI4.1-30B

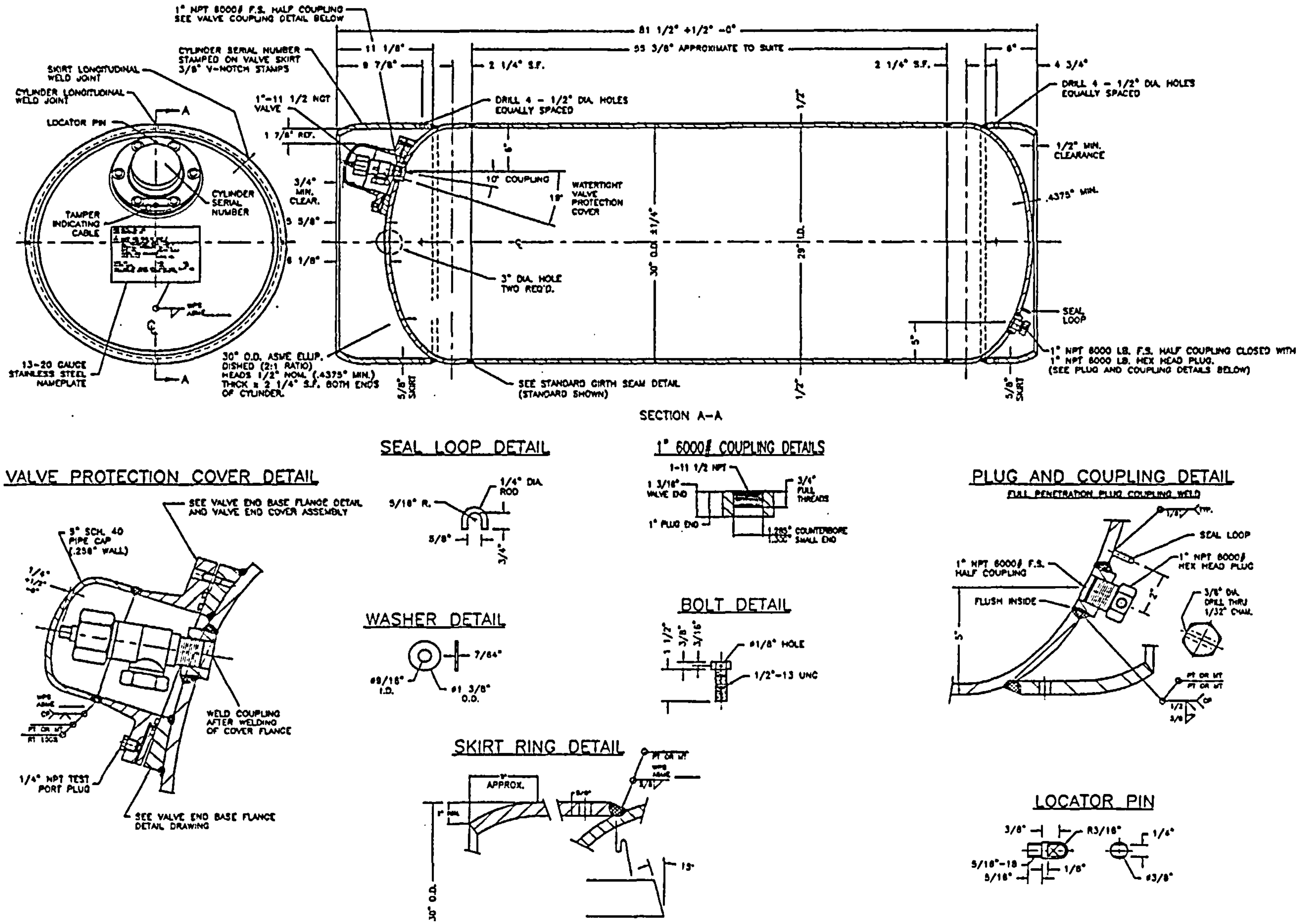


Figure 1.2 – 3
ANSI N14.1 30C Cylinder

### 1.2.1.1 Gross Weights

The package weights are summarized to account for variance in manufacture.

| Package | Weights |
|---|---|
| $UF_6$ max | 5,020 lbs. |
| $UF_6$ Cylinder & UX-30 | 3,250 lbs. |
| Total max gross weight | 8,270 lbs. |

### 1.2.1.2 Materials of Construction

The UX-30 is fabricated from ASTM A240 Type 304, stainless steel, ASTM A36 carbon steel (internal reinforcing), and closed-cell polyurethane foam.

### 1.2.1.3 Neutron Absorbers and Moderators

There are no neutron absorbers or moderators used in the UX-30 packaging.

### 1.2.1.4 Receptacles, Valves and Sampling Parts

There are no receptacles, valves, or sampling ports in the UX-30 overpack. The $UF_6$ cylinder is equipped with a 1-inch fill valve and a 1-inch plug.

### 1.2.1.5 Heat Dissipation Systems

The UX-30 overpack is entirely passively cooled. There are no coolants in the package design.

### 1.2.1.6 Protrusions

There are no inner protrusions on the UX-30 overpack. Light gauge lifting lugs extend from the overpack on each end or on the sides near the closure interface.

### 1.2.1.7 Shielding

There is no shielding required for the intended payload of the UX-30.

### 1.2.1.8 Pressure Relief Systems

There are no pressure relief systems in the UX-30.

### 1.2.2 Containment Boundary

The UX-30 package relies on the 30-inch cylinder to provide containment for the $UF_6$ payload.

### 1.2.3 Contents of Packaging

The maximum quantity of material per package and fissile class of the UX-30 with the 30B cylinder shall be in accordance with the limits of: DOT specification 21PF-1B (49 CFR 173.417, Table 3), as shown in Table 1.2-1. The maximum quantity of material for the 30C cylinder is the same as the 30B cylinder. The criticality safety index for the 30C cylinder is derived in Chapter 6.

Table 1.2-1
UX-30 Material Quantities

| Inner Cylinder Designation | Maximum Weight of $UF_6$ Contents | Maximum Enrichment (W%) | Criticality Safety Index |
|---|---|---|---|
| 30B* | 5,020 | 5.0 | 5.0 |
| 30C* | 5,020 | 5.0 | 0.0 |

* Designations per ANSI N14.1, ANSI N14.1 – 2000, "American National Standard for Nuclear Material – Uranium Hexafluoride – Packaging for Transport

### 1.2.4 Operational Features

The UX-30 is designed to replace the 21PF-1B standard DOT overpack and would be operated in much the same way. Positive closure on the UX-30 however is provided by 10 ball-lock pins, providing for quicker and easier loading and unloading operations. The closed-cell polyurethane foam combined with sealed stainless steel inner and outer shells on the UX-30 prevents much of the maintenance currently required for the 21PF-1, since water cannot penetrate either feature.

## 1.3 General Requirements for All Packages

Minimum Packaging Size

The UX-30 packaging overall dimensions are all much larger than the minimum 10 cm specified in CFR 71.43(a). The minimum size is 43.5 inches.

### Tamperproof Feature

The UX-30 package is installed with a tamper-indicating seal to discourage any unauthorized opening. A tamper-indicating seal is also installed on the cylinder valve of the standard 30B cylinder, and on the VPC for the 30C Cylinder.

### Positive Closure

Positive closure is effected by 10 ball-lock pins through the guide pins. Inadvertent opening is prevented by the design of the ball-lock pins, which require that the release button be pushed while the pin is pulled. A tamper-indicating seal is installed to indicate any unauthorized opening.

## 1.4 Appendix

### 1.4.1 UX-30 General Arrangement Drawings

Security-Related Information Figure Withheld Under 10 CFR 2.390.

DIMENSIONS ARE IN INCHES AND DEGREES
UNLESS NOTED OTHERWISE
DIMENSIONING AND TOLERANCING
IN ACCORDANCE WITH
Y14.5M-1982

FRACTIONS ±1/8
DECIMALS .X±.2 .XX±.06 .XXX±.030
ANGLES ±1°

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UX-30 OVERPACK

B C-110-B-57922-0002 3

Security-Related Information Figure Withheld Under 10 CFR 2.390.

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# 2.0 STRUCTURAL EVALUATION

## 2.1 Description of Structural Design

### 2.1.1 Descriptive Information Including Weights and Center of Gravity

The UX-30 packaging is designed to be used in conjunction with either of two cylinders to provide for the safe transport of $UF_6$:

(1) the standard 30B cylinder described in ANSI N14.1, or its equivalent, or

(2) the 30C Cylinder as described in Addendum 2-2004 to ANSI N14.1. The 30C Cylinder is identical in dimensions and configuration to the standard 30B cylinder, except that the 30C Cylinder is equipped with a Valve Protective Cover (VPC). The following Table 2.1.1-1 below highlights the differences between the standard 30B cylinder and the 30C Cylinder.

Table 2.1.1-1

Comparisons of Standard 30B Cylinder and 30C Cylinder Properties

| | Standard 30B Cylinder | 30C Cylinder |
|---|---|---|
| Meets ANSI N14.1 Specifications | Yes | Yes |
| Base Metal | SA-516, Gr. 55, 60, 65, or 70 | Same |
| VPC | No | Yes |
| Redundant Seal | No | Yes, including VPC O-Rings |
| 100% Weld X-ray and QC | Spot X-ray only. | Yes; 100% X-ray plus liquid penetrant (pt) or magnetic particle (mt) examination of all butt-weld joints; all other joints examined by pt or mt except for nameplate and seal loop fillet welds. |

The packaging is functionally divided into two parts: the impact-absorbing UX-30 overpack and the containment vessel represented by the cylinder. Shielding is not required for the intended payload.

Closure of the cylinder is effected by a valve in one end of the cylinder. On the standard 30-B cylinder the valve is protected by a valve cover that is used during cylinder handling operations only and that must be removed prior to transport to preclude unacceptable interaction with the valve during a hypothetical accident scenario. As discussed above, the cylinder valve is protected on the 30C Cylinder by a VPC which is not removed prior to transport. Additionally, the ends of the UX-30 are reinforced to prevent intrusion during any of the hypothetical accident events.

The UX-30 employs six inches of medium-density, rigid closed cell polyurethane foam as an energy absorber. The energy absorption characteristics of this material are well known, having been incorporated in the design of many licensed Type A(F) quantity packages. Appendix 8.3.1 provides the material specification for the polyurethane foam (Duratek Specification ES-M-170). The foam is completely sealed in a stainless steel shell to provide for durability and corrosion-resistance, resulting in long package life with minimum maintenance. The package is equipped with a shear plate on the bottom surface to transfer longitudinal transport loads into a specially-designed interface saddle not structurally part of the UX-30.

Weights of various components of the UX-30 packaging are presented in Table 2.1.1-2, below:

TABLE 2.1.1-2

Component Weights

| Component | Typical | Maximum Weights for Analysis |
|---|---|---|
| Lid of UX-30 | 824 lbs. | 888 lbs. |
| Base of UX-30 | 707 lbs. | 762 lbs. |
| $UF_6$ Cylinder | 1,400 lbs. | 1,600 lbs. |
| $UF_6$ Payload | 5,020 lbs. | 5,020 lbs. |
| Total | 7,951 lbs. | 8,270 lbs. |

The center of gravity is located longitudinally near the approximate geometric center of the package biased slightly away from the cylinder valve end. The center of gravity is biased slightly below the horizontal geometric center to a degree dependent on how much $UF_6$ is shipped. Importantly, the exact location of the center of gravity is not critical to any of the following tests and analyses.

### 2.1.2 Identification of Codes and Standards for Package Design

The UX-30 overpack in conjunction with the $UF_6$ cylinder has been designed to meet all the applicable structural requirements of 10 CFR 71. Material properties for the packaging are given in Table 2.2-1.

The UX-30 overpack assures that the cylinder, which provides containment for the $UF_6$ contents, is not damaged during normal and hypothetical accident conditions specified in 10CFR71. Compliance with these requirements has been demonstrated by full-scale prototype testing of the UX-30 with both the standard 30B cylinder and the 30C Cylinder.

*Standard 30B Cylinder.* Drop tests and fire testing of the UX-30 were performed to verify protection of the cylinder. The cylinder was visually inspected before and after the series of drop tests to verify that no damage occurred. As an additional check, the cylinder was leak tested before and after the test series with no discernible leaks.

*30C Cylinder.* Drop tests were performed with the 30C Cylinder to verify that the it is equivalent to the standard 30-B cylinder in meeting the transport regulations of 10CFR71, and that it assures protection of the cylinder valve normal and accident conditions of transport. The drop testing resulted in no damage to the cylinder, and none to the cylinder valve, as was evidenced inspections to the cylinder valve and by leak testing of the VPC.

The 30C Cylinder is designed and fabricated to meet or exceed many of requirements of the ASME B&PV Code, Section III, Subsection NC. Specifications for the 30C Cylinder are included in

Addendum 2-2004 to ANSI N14.1. The thickness of the shell and head on the 30C cylinder meet the requirements based on formulas of Section III. Also, 100% radiographic examination of all butt welds is performed on the 30C Cylinder, as required by Section III, and which is more stringent than required for the standard 30B cylinder (see Table 2.1.1-1 above). A comparison of the specifications for the 30C Cylinder and ASME Code, Section III, Subsection NC is given in Table 2.1.2-1 below.

Structural evaluation of other conditions utilized yield and ultimate material properties as presented in the ASME Boiler and Pressure Vessel Code, Section III, Class I. For normal conditions of transport, yield strength was used as a maximum stress, while ultimate strength is used as the limiting strength for hypothetical accident conditions. Shear allowables are calculated where needed using the standard octahedral shear stress theory which predicts shear failure at stresses greater than the tensile failure stress divided by 1.73 (see Juvinall, Stress, Strain and Strength, McGraw Hill, page 86).

The $UF_6$ containment vessel, being fabricated from ASTM A516, Grade 55, ferritic steel, has been evaluated with respect to NUREG/CR-1815, 'Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick.' Brittle fracture of the UX-30 overpack is not of concern because the overpack does not provide containment itself and because it is primarily constructed of stainless steel and foam.

### Table 2.1.2-1
### Comparison of 30C $UF_6$ Cylinder to ASME Code, Section III, Subsection NC, Design and Construction Requirements

| Consideration | Requirements of ASME Code, Section III, Subsection NC | Requirements for 30C $UF_6$ Cylinder | Comment |
|---|---|---|---|
| Base Metal | Not specified; in the discussions below SA-516 – 70 is used for comparison purposes. | Watertight Cylinder specifications require SA 516 – 55, 60, 65, or 70. | Same |
| Impact Testing of Base Metal and Weld Materials | None required (because base metal thickness is less than 5/8") | Impact testing of base metal and weld metal is specified. | 30C $UF_6$ Cylinder specifications are more stringent. |
| Calculation Basis | NC-3300 Rules | Section VIII, Division 1 | |
| Shell Calculations: | | | |
| Joint Efficiency | N/A for Section III because 100% RT and E=1.0 is assumed. | E = 1.0 because 100% RT of joint is specified. | Same |
| Allowable Stress | 20,000 psi (from Section II) | 20,000 for Gr 70 (derived from Section II) | Both based on Section II |
| Shell Thickness (t) Formula | t = PR/(S-0.6P) | t = PR/(SE-0.6P) | Equivalent because E=1.0 for 30C Cylinder |
| Required Shell Thickness (t) | t = 0.1494 based on:<br>P = design pressure = 200 psig<br>R = cylinder inside radius<br>= 15" - t | t = 0.1494 based on:<br>P = design pressure = 200 psig<br>R = cylinder inside radius<br>= 15" - t<br>E = 1.0 | Same |
| Maximum Allowable Longitudinal Stress | t = PR/(2S+0.4P) | t = PR/(2SE+0.4P) | Equivalent because E=1.0 for 30C Cylinder |
| Maximum Allowable External Pressure | 306 psi in Sec. II chart. | 306 psi in Sec. II chart. | Same |
| Head Calculations: | | | |
| Joint Efficiency | N/A for Section III because 100% RT and E=1.0 is assumed. | E = 1.0 because 100% RT of joint is specified. | Same |
| Head Thickness (t) Formula (2:1 Elliptical Head) | t = PD/(2S – 0.2P) | t = PD/(2SE – 0.2P) | Equivalent because E=1.0 for 30C Cylinder |

| Consideration | Requirements of ASME Code, Section III, Subsection NC | Requirements for 30C $UF_6$ Cylinder | Comment |
|---|---|---|---|
| Required Head Thickness | t = 0.1487 based on:<br>P = design pressure = 200 psig<br>D = cylinder inside diameter<br>= 30" - 2t | t = 0.1487 based on:<br>P = design pressure = 200 psig<br>D = cylinder inside diameter<br>= 30" - 2t<br>E = 1.0 | Same |
| Maximum Allowable External Pressure | 244 psi in Sec. II chart. | 244 psi in Sec. II chart. | Same |
| Nozzles | Exempt from Calculations | Exempt from Calculations | Same |
| Weld Procedures | Must conform to the requirements of ASME Code Section IX. Impact testing of weld specimens is not required by Section III because the weld thickness is less than 5/8" | Must conform to the requirements of ASME Code Section IX. 30C Cylinder specifications require impact testing of weld specimens. | 30C Cylinder specifications are more stringent. |
| Weld Metal Testing | Required for each heat and lot. | None required. | Section III is more stringent. |
| Post-Weld Heat Treatment | None required. | None required. | Same |
| NDE of Butt Welds. | 100% RT is required. | 100% RT is required. | Same |
| NDE of Nozzle Welds | RT required if full penetration.<br>MT or PT required if partial penetration or fillet weld. | MT or PT required of all welds. | Section III is more stringent. |
| Hydrostatic Test | Required at 1.25 times design pressure. | Required at 1.3 times design pressure. Hydrostatic test pressure is required to be marked on the Code plate. | 30C Cylinder specifications are more stringent. |

## 2.2 Materials

### 2.2.1 Material Properties and Specifications

The mechanical properties of the materials used in the UX-30 are presented in Table 2.2-1.

TABLE 2.2-1

Mechanical Properties of Materials

| Material | Yield Stress (psi) | Ultimate Stress (psi) | Reference |
|---|---|---|---|
| ASTM A516, Grade 55 | 30,000 | 55,000 | ASTM A516 |
| ASTM A-240, 304 Stainless (UX-30 Shells) | 30,000 | 75,000 | ASME B + PV Code Section III |
| ASTM A36 (UX-30 End Reinforcement) | 36,000 | 58,000 | ASTM A36 |
| NPI.F12 Foam | 400 | Not Applicable | Specification (Duratek Specification No ES-M-170) (See App. 8.3.1) |

### 2.2.2 Prevention of Chemical, Galvanic, or Other Reactions

The materials which make up the UX-30 overpack (carbon and stainless steels as well as polyurethane foam) will not cause significant chemical, galvanic, or other reaction in air, nitrogen or water environments. The chemical make-up of the polyurethane foam contains no unreacted components which could cause corrosion of the stainless steel shell. It is possible, however, for chlorine or other materials to be present as a low level contaminant (parts per million). This contaminant, however, would be chemically or mechanically bound up in the molecular structure and would not be readily leachable so as to allow reaction with the shell material.

### 2.2.3 Effects of Radiation on Materials

The radiation field from the contents of the UX-30 is so low that it will have no effect on the UX-30 materials.

## 2.3 Fabrication and Examination

### 2.3.1 Fabrication

The UX-30 is fabricated in accordance with the drawing in Appendix 1.4. The foam used in the UX-30 is fabricated in accordance with the Duratek specification in Appendix 8.3.1.

The 30B and 30C cylinders are fabricated in accordance with the following standards:

30B Cylinders shall be designed and manufactured per ANSI N14.1, "Uranium Hexafluoride – Packaging for Transport".

30B Cylinders may also be designed and manufactured per ANSI N14.1 – 1995, "Uranium Hexafluoride – Packaging for Transport" and ISO 7195:1993(F), "Packaging of Uranium Hexafluoride ($UF_6$) for Transport".

30C Cylinders shall be designed and manufactured in accordance with Addendum 2-2004 to ANSI N14.1-2001.

### 2.3.2 Examination

Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1, or with ANSI N14.1 – 1995 and ISO 7195:1993(F).

Acceptance tests for the 30C cylinder shall be in accordance with Addendum 2-2004 to ANSI N14.1-2001.

Welds on the UX-30 shall be inspected in accordance the requirements of AWS D1.1.

## 2.4 Lifting and Tiedown Standards for All Packages

### 2.4.1 Lifting Devices

The lid of the UX-30 is equipped with lifting features designed to lift the lid only. The features will be rendered inoperative during transit.

The UX-30 upper section is designed to be lifted using steel lifting lugs attached to the lid. There are no lifting devices that are structurally part of the UX-30 used to lift the entire loaded package. Such an operation should be done via a sling or lifting cradle placed underneath the package.
Lid lift lugs may be one of two designs. The first design employs a two-point lift with lugs located on each end of the lid. Alternatively, the lid may be lifted by four clips mounted on the sides of the lid near the parting plane. The end lugs are analyzed first:

The upper section (the lid) of the UX-30 weighs approximately 815 pounds. The lugs are set at 45° to allow a single point lift. See Figure 2.4-1.

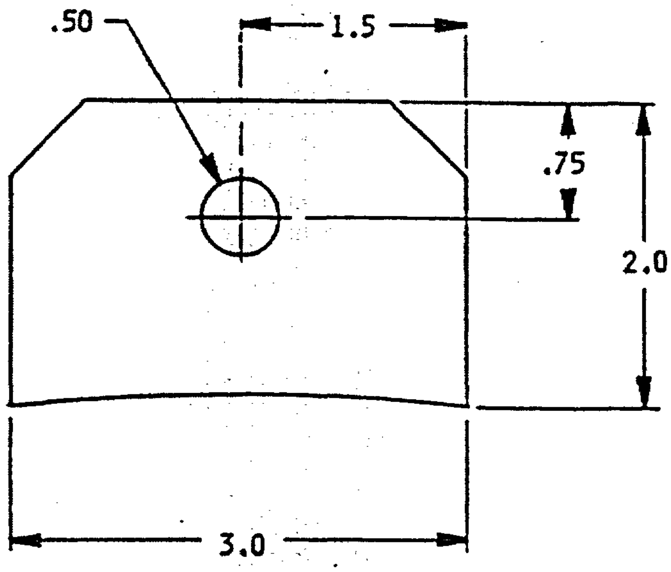


FIGURE 2.4-1

UX-30 Lid Lifting Lug

The load in each lug developed from lifting the lid can be calculated as follows:

$$(888 \text{ lbs.})/(2 \sin 45^{o}) = 628 \text{ lbs.}$$

The 0.5-inch hole is designed to be used with a standard 3/8-inch shackle (0.44-inch pin diameter). The lug is fabricated from 10-gauge ASTM A240 Type 304, stainless steel.

From Figure 2.4-1, the shear and tensile net areas for the lug may be calculated:

$A_s$ = shear area for $40^{o}$ shear-out, $\text{in}^2$
= $2t(EM - [(0.5)(d)(\cos 40^{o})]$

Where:

t = lug thickness (0.135 in)

EM = edge margin (0.75 in)

d = hole diameter (0.50 in)

Then,

$A_s$ = 2(0.135)[0.75 - (0.5)(0.50)(cos 40°)] = 0.151 $in^2$

And,

$A_t$ = tensile net area, $in^2$
= (W - d)t

Where:

W = lug width (3.0 in)

d = hole diameter (0.50 in)

t = lug thickness (0.135 in)

Then,

$A_t$ = (3.0 - 0.5)(0.135) = 0.338 $in^2$

Since the shear area is less than half the net tensile area, shear considerations will control.

$\tau$ = P/$A_s$ where t = shear stress

$\tau$ = 628/0.151 where P = lug total load (628 lbs.)

$\tau$ = 4,159 psi

The tensile yield stress of the ASTM A240 Type 304 stainless is 30,000 psi minimum. This tension allowable may be converted to a shear allowable by dividing by 1.73:

30,000/1.73 = 17,341 psi

10 CFR 71 requires lifting devices to be capable of lifting three times the design load without exceeding yield. The margin of safety is then:

$$\text{M.S.} \quad = \quad \{17{,}341/[3(4159)]\} - 1.0 = \underline{+0.39}$$

The lug has been designed to fail under excessive load in a manner that will not impair the ability of the UX-30 to meet any other design criteria.

The ultimate shear strength of the lug itself may be calculated as follows using the ultimate shear strength of ASTM A240, Type 304 stainless steel:

$$75{,}000/1.73 = 43{,}300 \text{ psi}$$

Then,

$$P_{ult} \quad = \quad (43{,}300)A_s = (43{,}300)(0.151) = 6{,}538 \text{ lbs.}$$

The base of the lug is welded to 12-gauge stainless. The minimum strength of the 3-inch groove weld to the 12-gauge sheet is then:

$$(75{,}000)(0.105)(3.0) = 23{,}625 \text{ lbs.}$$

Since the strength of the lug attachment weld is larger than the shear-out strength by a factor of 23,625/6,538 = 3.61, the lug will fail before the outer skin of the UX-30 is affected.

The alternate lid lift design employs four clips mounted on the side of the pack-age near the closure interface. These lift points interface with a 0.5-inch diameter pin through a lifting frame built for this purpose. The lifting frame may be part of a shipping saddle arrangement and includes provisions such that the loads in the clips will always be directed straight vertically. The load per clip is then:

$$(888)(0.25) = 222 \text{ lbs./clip}$$

The clip is loaded via a 0.5-inch diameter pin, which fits under the lip of the clip shown in Figure 2.4-2. The figure shows the location of the clip relative to a typical saddle/lift frame design. A design requirement of this equipment is that it is impossible to install the lid lifting pin while the frame is secured for transit.

The following analysis is based on worst case tolerance stack up, with tolerances as shown on the drawings in Appendix 1.4.1. The point of vertical load application can be taken as 0.25-inches inside (toward the base of the clip) of the inside surface of the clip lip. The distance from the point of load application to the beginning of the 3.25-inch wide portion may vary from 0.375-inches to 0.500-inches. The distance from the load point to the base of the clip may vary from 0.69 to 0.81.

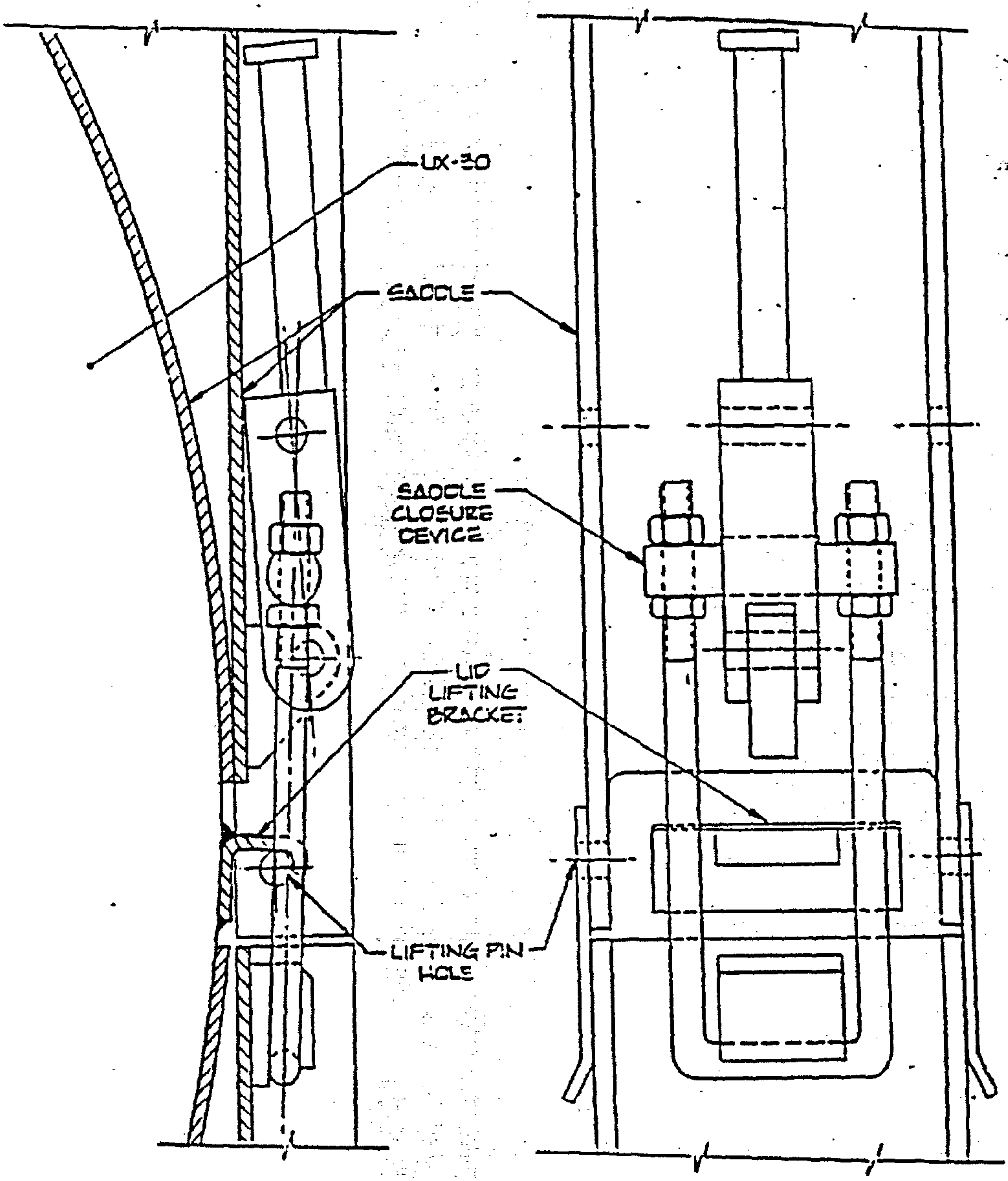


FIGURE 2.4-2

UX-30 Lid Lifting and Tiedown Assembly

The clip is 2-inches wide at its free end and extends 0.5-inches from the point of load application back to where the clip begins to expand to 3.25-inches wide. The maximum moment applied to the 2-inch wide section is then:

$$(222)(0.5) = 111 \text{ in-lbs.}$$

The section modulus for this section is given by:

$$Z = (bh^2)/6 = (2.0)(0.1875)^2/6 = 0.01166 \text{ in}^3$$

Since 10 CFR 71 requires lifting features to be capable of resisting three times the actual load without exceeding yield, the design stress on the clip may be calculated as below:

$$[3(111]/(0.01166) = 28{,}565 \text{ psi}$$

So the margin of safety is:

$$\text{M.S.} = (30{,}000/28{,}565) - 1.0 = \underline{+0.05}$$

At the base of the clip, the moment is:

$$(222)(0.81)=180 \text{ in-lbs.}$$

The section modulus at the base of the clip is:

$$Z = (bh^2)/6 = [(3.25)(0.187)^2]/6 = 0.018938 \text{ in}^3$$

And,

$$\sigma = [3(180)]/(0.018938) = 28{,}512 \text{ psi}$$

$$\text{M.S.} = (30{,}000/28{,}512) - 1.0 = \underline{+0.05}$$

The clip to lid weld is a 0.1-inch fillet weld. The moment of inertia of the weld may be calculated by standard methods:

$$I = 2\{(0.1)(0.707)[1.25 + 2(0.1)(0.707)]^3/12\}$$
$$+ \quad 2(3.25)(0.1)(0.707)[(0.5)(1.25) + (0.1)(0.707)]^2$$

$$I = 0.222 \text{ in}^4$$

And,

$$c = (0.5)(1.25) + (0.1)(0.707) = 0.696 \text{ in}$$

Then,

$$Z = I/c = 0.222/0.696 = 0.319 \text{ in}^3$$

$$\sigma = 3(222)(0.81 + 0.19)/(0.319) = 2{,}088 \text{ psi}$$

$$\text{M.S.} = (30{,}000)/[(1.73)(2{,}088)] - 1.0 = \underline{+7.3}$$

It is clear from an inspection of the margins of safety that the clips will bend up out of the way before the clip to lid weld will fail:

In bending, the clip will yield at a load equal to the actual factored load times the factor of safety (the margin of safety plus unity):

Bending yield: (3)(222)(1.15) = 766 lbs.
Weld yield: (3)(222)(9.00) = 5,994 lbs.

Thus, the clip will yield and bend out of the way prior to possible skin failure.

### 2.4.2 Tiedown Devices

The UX-30 is designed to be used in conjunction with a shipping cradle not structurally part of the package. The cradle is so designed that all tiedown loads except those directed along the longitudinal axis will be reacted by direct compression. In the longitudinal direction, a shear plate is provided to react longitudinal loads into the package skin through shear. Figure 2.4-3 shows an example of such a cradle.

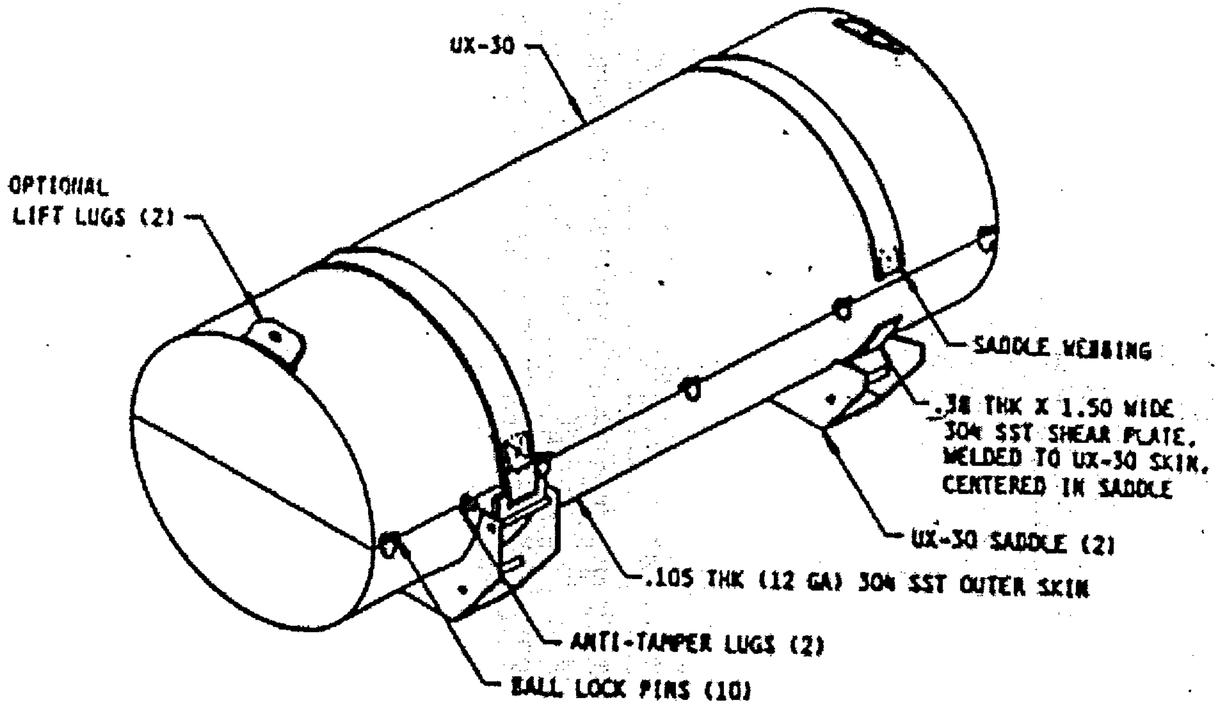


Figure 2.4-3
Tiedown Shear Plate

When the four lid lifting clips are used instead of the top lugs, the configuration would look similar to Figure 2.4-4. In this configuration, the top portion of the saddle doubles as a spreader bar lifting fixture to insure that the loads in the clips are directed vertically. Also, the same fixture secured for transit prevents operation of the clips for lifting.

The only tiedown device structurally part of the packaging is the shear plate on the bottom surface of the UX-30. The plate is designed to react the full 10g longitudinal load required by 10 CFR 71. Tiedown in other directions is effected by devices not structurally part of the package.

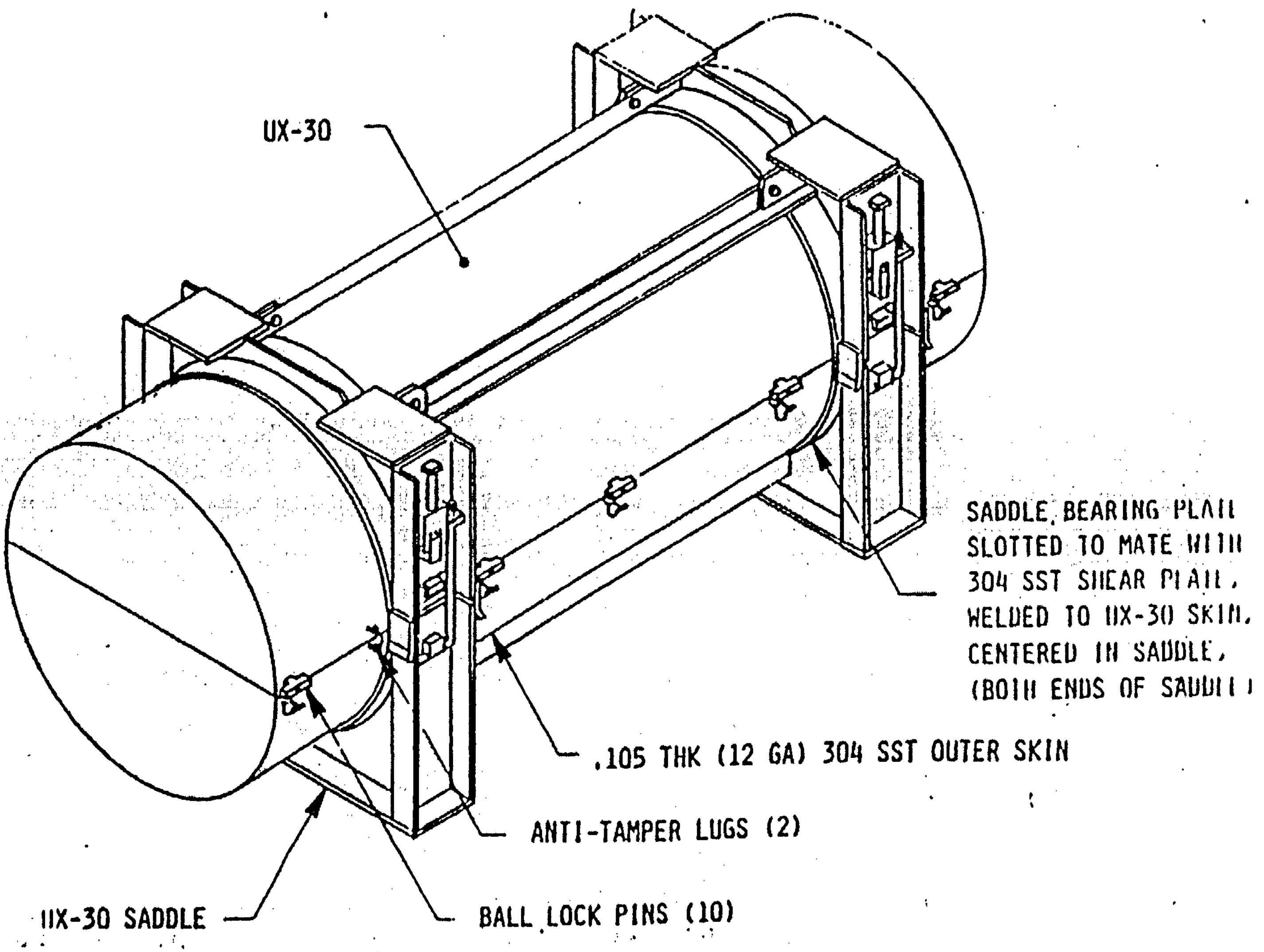


FIGURE 2.4-4
UX-30 Shipping Cradle

Figure 2.4-5 shows the 24-inch long shear plate in cross-section, from the General Arrangement Drawings, Appendix 1.4.1.

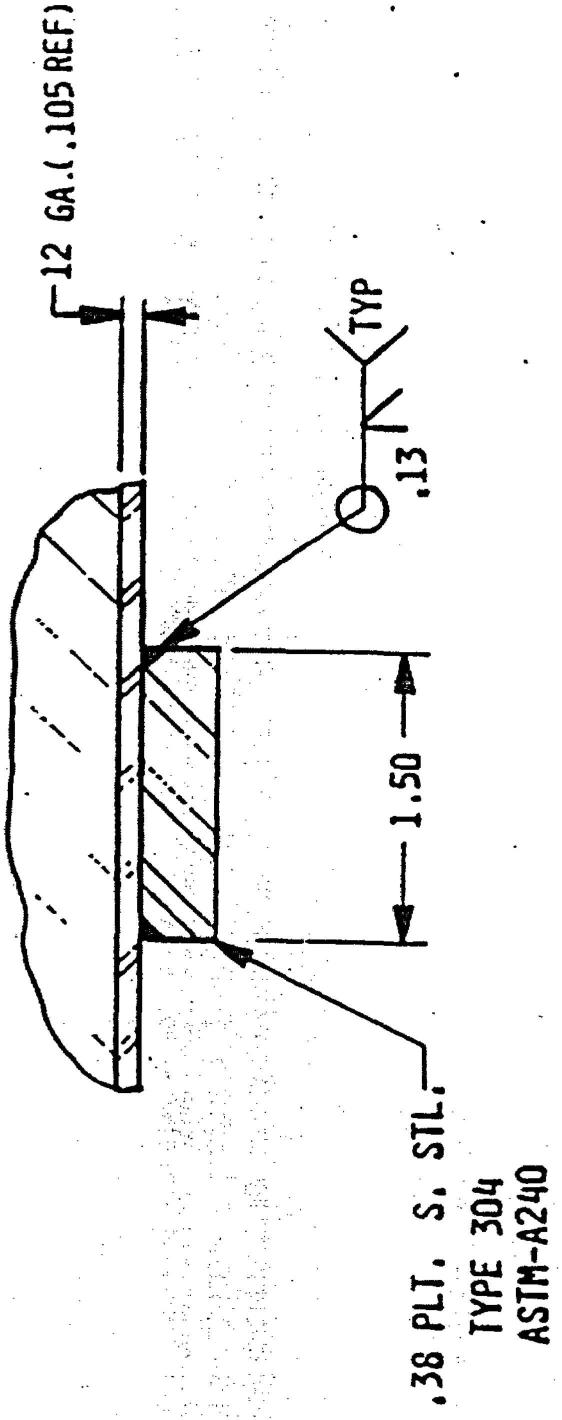


FIGURE 2.4-5

UX-30 Shipping Cradle with Lid Lifting Clips

The plate is welded around its perimeter with a 0.13-inch bevel weld, providing the following shear area:

$$[2(22.7 - 0.125) \text{ inches} + 2(1.5 - 0.125) \text{ inches}](0.125 \text{ inches}) = 5.99 \text{ in}^2$$

The total load on the shear plate can be determined:

$$(10 \text{ g's})(8{,}270 \text{ lbs.}) = 82{,}700 \text{ lbs.}$$

The shear stress in the welds is then

$$\tau = 82{,}700/5.99 = 13{,}810 \text{ psi}$$

The shear allowable can be calculated from the tensile yield stress:

$$\tau_{all} = 30{,}000/1.73 = 17{,}341 \text{ psi}$$

The attachment weld margin of safety is then:

$$\text{M.S.} = (17{,}341/13{,}810) - 1.0 = \underline{+0.26}$$

There is, therefore, adequate strength in the shear plate to react the entire longitudinal load required by 10 CFR 71.

The following discussion confirms, per the requirements of 10 CFR 71.45(b)(3) that in an overload condition the weld will fail before the UX-30 shell base material fails by demonstrating that the margin of safety for the base material is larger than that for the weld (using the maximum allowable weld size per the drawings presented in Section 1.3.1, 1/8" + 1/8"):

M.S. (max. weld) = [[M.S (above) + 1]x .707 x (.125 + .125)/(.125)] - 1 = .41

M.S. (shell base metal) = 30,000 / (82,700 / (2 x.105 x 22.7)) - 1.0 = .73

The UX-30 shipping cradle and saddle configurations used are designed to preclude adverse impact on the UX-30 during an accident scenario. The presence of these components during a hypothetical accident would result in a distributed loading over the surface of the UX-30 which ensures that the damage from such an accident with the cradle or saddle attached would be enveloped by the UX-30 drop testing performed without these attachments.

## 2.5 General Considerations

### 2.5.1 Evaluation by Testing

Evaluation of the UX-30 is performed exclusively by testing. Numerous drops for both Normal and Hypothetical Accident Conditions have been performed, with both the 30B and 30C cylinders. The UX-30 has passed all of these tests. The following is a summary of the testing performed, and where detailed discussions of these tests are located.

*With Standard 30B Cylinder*

A full-scale prototype of the UX-30 package was built and subjected to a series of impact tests corresponding to the drop and puncture events described in 10 CFR 71. A thermal test and analysis of the damaged package's ability to withstand the effects of a fire was also performed, as well as a test and assessment of the effects of immersing the package in water. The results of the tests and analyses indicate that the UX-30 effectively protects the $UF_6$ cylinder (containment vessel) from any damage whatsoever. Impact testing of the UX-30 with the 30B cylinder is described in Sections 2.6.7, 2.7, and Appendices 2.10.1. 2.10.2, and 2.10.4.

*With 30C Cylinder*

After normal condition drop testing was performed on the 30C Cylinder, the 30-ft hypothetical accident condition drop event proscribed by 10CFR71 was completed. The results demonstrated that the VPC is capable of maintaining a water-tight seal around the cylinder valve during normal and hypothetical accident conditions for transport. The cylinder valve did not contact any other component of the packaging during or following the test sequence, and the VPC O-rings remained leak-free prior to and following the test sequence. Additionally, the total effective volume of the packaging was maintained to within 95% of the original, the effective spacing of the fissile contents remained unchanged, and the packaging remained closed, effectively excluding the entry of a 10 cm (4 in) cube. There was no loss or dispersal of the simulated contents, no changes to the packaging that would result in a significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. Thus, the design satisfies the regulatory requirements for licensing of the packaging. Impact testing of the UX-30 with the 30C cylinder is described in 2.6.7, 2.7, and Appendix 2.10.5.

### 2.5.2 Evaluation by Analysis

Evaluation of the UX-30 has been performed by testing.

### 2.5.3 Pressure

The containment system for the UX-30 is the 30B or 30C cylinders. These are pressure tested in accordance with the requirements of ANSI N14.1, which includes a hydrostatic test at 400 psig. This exceeds 150% of the MNOP for the 30B or 30C cylinders.

## 2.6 Structural Evaluation Under Normal Conditions of Transport

### 2.6.1 Heat

The maximum temperature distribution in the UX-30 for normal conditions of transport is presented in Section 3.4. Importantly the maximum temperature experienced by the $UF_6$ cylinder (less than 200°F) is well below the design limit on the cylinder as set by ANSI N14.1 (250 °F).

The UX-30, being constructed from stainless steel and closed-cell polyurethane foam, will be unaffected by the temperature distribution predicted for it under normal conditions. Polyurethane foams enclosed in light gauge steel have been used extensively on Type A and B packages with no reported difficulties due to temperatures in this range.

### 2.6.2 Cold

A steady-state ambient temperature of -40°F will have no adverse effect on the UX-30. The ductility of the austenitic stainless steel skin is unaffected by temperatures in this range.

The $UF_6$ cylinder is fabricated from ferritic ASTM A516, Grade 55, steel. The draft Regulatory Guide 'Fracture Toughness Criteria for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of Four Inches' invokes the use of NUREG/CR-1815 for evaluating resistance to brittle fracture at low temperatures, and designates the criteria for classifying payloads for various levels of safety against brittle fracture. Table 1 of that document, reproduced below as Table 2.6-1 indicates that the payload of a Category II package is less than $3000A_2$, $3000A_1$ or 30,000 curies. Since there is less than one curie of uranium in the designated payload, and 10CFR71 does not limit quantities of uranium enriched to less than 20% by either $A_1$ or $A_2$ values, the UX-30 is considered a Category III package.

TABLE 2.6-1

Categories and Associated Radioactivity

Limits for Shipping Containers

| CATEGORY I | CATEGORY II | CATEGORY III |
|---|---|---|
| Applies if quantity per package is: | Applies if quantity per package is: | Applies if quantity per package is: |
| greater than or equal to $3(10)^4$, $3(10)^3A_2$, or $3(10)^3A_1$ ci. | less than $3(10)^4$ and $3(10)^3A_2$ or $3(10)^3A_1$ ci, but greater than or equal to $30A_2$ or $30A_1$ ci. | less than $30A_2$ and $30A_1$ ci.<br>Also applies if contents are: (1) low specific activity materials, or, (2) objects with fixed contamination (not readily dispersible) and the total quantity per package is less than $3(10)^4$ ci, $3(10)^3A_2$ ci, and $3(10)^3A_1$ ci. |

Fracture toughness requirements for Category III packages may be met, according to NUREG/CR-1815, by using steel made to 'Fine Grain Practice' or better. ASTM A516 steels are made to fine grain practice. Therefore, the $UF_6$ cylinder can be considered safe from brittle fracture failure considerations.

At very low temperatures, the internal pressure of the cylinder will be very close to zero absolute. Structurally, this is equivalent to an external pressure of one atmosphere, or 14.7 psia.

The hoop stress in the cylinder is given by the following formula:

$$s = Pr/t$$

Where,

s = hoop stress, psi

P = pressure, 14.7 psi

r = cylinder radius, 14.75 in

t = shell thickness, 0.5 in

Then,

$$s = (14.7)(14.75)/0.5$$
$$= 433.6 \text{ psi}$$

The yield stress of the ASTM A516, Grade 55, cylinder is 30,000 psi, so the margin of safety is:

$$M.S. = (30{,}000/433.6) - 1 = \underline{+\text{Large}}$$

### 2.6.3 Reduced External Pressure

The reduced external pressure condition of 3.5 psia is equivalent to pressure difference between the inside and outside of the $UF_6$ cylinder of:

$$9.0 \text{ psia} - 3.5 \text{ psia} = 5.5 \text{ psia internal pressure}$$

Such a pressure is significantly less than the design internal pressure of the cylinder.

### 2.6.4 Increased External Pressure

The increased external pressure of 20 psia would result in a hoop stress at low temperatures (when internal pressure is near zero) of the following:

$$\begin{aligned} s &= Pr/t \\ &= (20\text{ psia} - 0\text{ psia})(14.75\text{ inches})/(0.5\text{ inches}) \\ &= 590\text{ psi} \end{aligned}$$

$$\text{M.S.} = (30{,}000/590) - 1 = \underline{+\text{Large}}$$

### 2.6.5 Vibration

Shock and vibration normally incident to transport are considered to have negligible effects on the UX-30 packaging.

### 2.6.6 Water Spray

A water spray simulating exposure to rainfall of approximately two inches per hour for one hour will have a negligible effect on the UX-30 for the following reasons. First, the overpack shell is seal-welded along all seams and joints completely preventing water intrusion to the foam filled cavity. Second, should a break in the skin form for any reason, the closed-cell polyurethane foam has been demonstrated to absorb a maximum water volume of less than 5% of the foam volume. Therefore, a minimal amount of water would be absorbed by the foam even without the protection of the steel skin. Finally, the interior of the UX-30 is protected from water intrusion through the closure joint by a neoprene weather seal. Any water that should penetrate past this seal could easily be removed between shipments, and should not be considered a problem under normal conditions.

### 2.6.7 Free Drop

*With Standard 30B Cylinder*

Examination of damage from the 30-foot drop tests, reported in Section 2.7, indicates that a four-foot drop in any orientation subsequent to a one-foot drop into each quarter of each end as required for Fissile packages will result in no loss of package integrity.

*With 30C Cylinder*

A drop test of the UX-30 package was performed with a 30C Cylinder. The package was dropped from an elevation of 48", at an attitude of 27.5 degrees, onto the package corner nearest the valve. The package was permanently deformed 3.5" longitudinally and 8" radially at the impact site. The slapdown that followed the initial impact caused the handling brackets to be pushed into the overpack approximately 0.5". All welds remained intact, the package remained closed, and the package outer skin was not breached. Following this test, the hypothetical accident condition drop test (paragraph 2.7.1) and the puncture drop test (paragraph 2.7.2) were performed. Details on this testing is described in Appendix 2.10.5.

### 2.6.8 Corner Drop

This test does not apply, since the UX-30 is not constructed from wood or fiberboard and is not less than 220 pounds.

### 2.6.9 Compression

The UX-30 is designed to sustain a compressive load equal to 5 times the weight of the package, or the equivalent of 1.85 psi multiplied by the projected area of the package, whichever is greater, uniformly applied to the top and bottom of the package in the position the package is normally transported.

The vertically projected area of the UX-30:

$$(43.5 \text{ in})(96 \text{ in}) = 4{,}176 \text{ in}^2$$

Five times the weight of the package is:

$$5(8{,}270 \text{ lbs.}) = 41{,}350 \text{ lbs.}$$

This is equivalent to the pressure of:

$$41{,}350/4{,}176 = 9.9 \text{ psi}$$

This pressure is significantly less than the compressive strength of the foam (400 psi):

$$\text{M.S.} \quad = \quad (400/9.9) - 1.0 = \underline{+\text{Large}}$$

### 2.6.10 Penetration

The 13 pound rod described in 10 CFR 71 has a negligible effect on the foam backed 12 gauge steel shell which covers the UX-30.

## 2.7 Structural Evaluation Under Hypothetical Accident Conditions

### 2.7.1 Free Drop Events

*With Standard 30B Cylinder*

Initially to support Type A(F) qualification a single UX-30 prototype was drop-tested in six separate orientations to demonstrate its effectiveness in protecting the $UF_6$ cylinder. The cylinder sustained no deformation and was shown to be leak tight after being subjected to four 30-foot drops and two 40-inch puncture tests. Additional testing was performed to support certification of the package. This testing also utilized a single UX-30 prototype which was drop tested in five separate orientations. The cylinder sustained no deformation and was shown to be leak tight after being subjected to two 30-foot drops and three 40-inch puncture tests followed by an open pool fire test. The test procedure, drop target, and overall approach are very similar or identical to those used on the following licensed packages:

1. DOT 6553 Paducah Tiger
2. Model N-55, Certificate of Compliance No. 9070
3. CNS 1-13C (II) Shipping Cask, Certificate of Compliance No. 9152

The test pads used were designed to simulate an unyielding surface. The test pads have not exhibited any discernible deformation from any of the drop tests conducted on it.

The prototype used for the first set of impact tests was constructed with two differing end structural designs. Both end configurations were tested for 30-foot impacts and provided identical protection to the $UF_6$ cylinder. A full comparison of the prototype structural features to the production configuration is presented in Section 2.7.1.5. The prototype used for the qualification impact tests was fabricated to the requirements of the drawings provided in Appendix 1.4.

The test units were loaded with standard 30B $UF_6$ cylinders filled with 5,023 lbs. of steel punchings (5,261 lbs. of steel punchings and steel shot were used in the second tests) to simulate the maximum payload of 5,020 lbs. of solid $UF_6$. The cylinder was carefully inspected before and after the tests with no perceived damage to the cylinder observed whatsoever. Additionally, a leak test showed no leakage developed from the impact testing.

The particular drop orientations tested were chosen to: 1) impart the highest possible loads on the containment vessel, or, 2) cause the greatest impairment of the UX-30's thermal insulation.

The tests were sequenced such that information gleaned from the early tests could be used in determining the exact orientations and sequencing of the later tests. The drop tests are summarized in Table 2.7-1. Appendix 2.10.1 provides a summary of the testing associated with the initial Type A(F) UX-30 Qualification. Appendix 2.10.2 provides photographs associated with the three testing sequences performed. Appendix 2.10.4 provides a summary of the drop testing performed.

*With 30C Cylinder*

In order to verify the performance of the 30C Cylinder under the normal and hypothetical accident condition drop events proscribed by 10CFR71, a series of drop tests were completed using a full-scale 30C Cylinder prototype in a PSP. The results demonstrated that the VPC is capable of maintaining a water-tight seal around the cylinder valve during normal and hypothetical accident conditions. The series of drop tests performed, as shown in Figures 1*a* to 1*c* in Appendix 2.10.5, encompassed both normal and hypothetical accident conditions as required by 10CFR71, with the exception of the water spray test, the penetration rod drop test, and the fire test. The test series was conducted to demonstrate:

- The cylinder valve does not contact any other component of the packaging during and following the test sequence, and
- The VPC O-rings remain leak-free prior to and following the test sequence.

A full-scale representative prototypes of the UX-30 and 30C Cylinder were used for the test series. The 30C Cylinder was loaded with 5329 lb of lead shot, 309 lb more than the maximum allowable payload weight. Prior to the test, the UX-30 and cylinder were visually inspected for damage, including dents, creases, weld flaws, and corrosion. The VPC O-rings were tested prior to the drop tests. The measured leakage rate was 3.4 x$10^{-6}$ atm-cc/sec.

The drop test was conducted on a 8' x 24' x 4'-6" deep reinforced concrete slab embedded in the ground. The test pad weighs approximately 129,600 lb and consists of 3,000 psi concrete reinforced with ASTM A-615 Gr. 60 rebar. The upper surface of the pad is covered by a 1-1/4" thick A36 carbon steel plate.

Following the normal condition drop test described in paragraph 2.6.7, the package was moved into position for the hypothetical accident condition free drop. No repairs or modifications were made to the package. The package was dropped from an elevation of 30', at an attitude of 27 degrees, onto the package corner nearest the valve (same impact site as the normal condition drop). The accumulated permanent deformation extended 11" longitudinally and 18" radially. A secondary impact occurred at the opposite end and corner from the initial impact, deforming the package approximately 1.75". All welds remained intact, the package remained closed, and the package outer skin was not breached.

Following the damage measurements, the VPC O-ring seal was leakage tested, and the measured rate was 5.9x$10^{-6}$ atm-cc/sec. Following the post-drop leakage testing, the VPC was removed and inspected. Glazing material applied on the interior of the VPC showed no impressions, indicating that the valve did not contact the VPC at any time during the testing. After removal of the VPC, the cylinder valve was visually inspected for traces of the glazing compound. None was found; therefore, it was further concluded that the valve did not contact the VPC during the testing. The cylinder valve was attached to a pressure gauge, and the post-test cylinder pressure was measured to be approximately 140 psig. Thus, the internal pressure of the cylinder was maintained throughout the test.

A detailed report on the normal and hypothetical accident condition testing performed with the UX-30 and 30C Cylinder is provided in Appendix 2.10.5. This report includes pre- and post-test photographs of the UX-30 and cylinder.

### 2.7.1.1 End Impact (With Standard 30-B Cylinder)

End impact was not considered a possible worst case and was not tested. The design of the UX-30 is such that the two most probable failure modes under end impact are more likely under other impact orientations. The cylinder skirt protecting the valve will not cripple under end impact if it does not cripple under the center of gravity, over struck corner impact. The valve will not be damaged by the end impact (where loads are evenly distributed over the end of the package) if it is not damaged by impact on a 6-inch diameter post at a point directly under the valve. Thus the package is stronger in resisting direct end impacts than any other type of impact involving the end of the cylinder.

### 2.7.1.2 Side Drop (With Standard 30-B Cylinder)

Impact directly onto the cylindrical side of the UX-30 was tested in drop numbers A3 and A6 of the initial test program. Drop number A3 was performed to determine the maximum deformation the side wall would experience in a full side impact. This information was used in the thermal analysis to model the effect of the damaged overpack on the thermal response of the package. Drop numbers A6 and B2 were performed onto the closure interface to show that the ball-lock pins were adequately sized to hold the two overpack halves together.

The prototype UX-30 experienced a 1.5-inch deformation from drop number A3 and 1.25-inches from drop number A6 (See Appendix 2.10.1). Drop number B5 resulted in a 3-inch deep puncture deformation. Photographs of drop number A3 are presented as photos 5 and 6 of Appendix 2.10.2, drop number A6 is presented in photos 13 through 15drop number B5 is presented in photos 26 through 28.

TABLE 2.7-1
Drop Test Summary (with Standard 30-B Cylinder)

| Drop Number | Orientation | Performance Aspect Tested |
|---|---|---|
| A1 & B1 | Corner Drop (on End #1 for A1) | Ability to protect valve and cylinder skirt on cylinder. |
| A2 & B4 | Puncture at closure plane | Closure resistance to to penetration, skin resistance to tearing. |
| A3 | Side Impact away from closure | Maximum side deflection for use with thermal analysis. |
| A4 | Corner Drop on End #2 | Ability to protect valve and valve protection ring on cylinder. |
| A5 & B3 | Puncture directly over valve) (End #2 for A5) | Ability to prevent puncture intrusion and subsequent damage to the valve |
| A6 & B2 | Side Impact onto closure plane (30° from horizontal for B2) | Adequacy of closure design. |
| B5 | Puncture away from closure | Maximum side deflection for use with thermal analysis and skin resistance to tearing |

Test Numbers AX are associated with original package certification testing. Test Numbers BX are associated with second package certification testing.

End impact is not considered a possible worst case orientation for the UX-30.

The following general observations were made during the original tests. The UX-30 did experience minor skin tearing on each end near the ball-lock pins from drop number A6. Additionally, the two alignment pins, one on each end of this package on the impacted side showed evidence of shear failure at their base weld. All 5 ball-lock pins were driven flush into the side of the package and could not be removed after the drop. Significantly, the overpack remained tightly closed after the impact, thereby retaining the full effectiveness of the overpack to shield the cylinder from the effects of the hypothetical fire event. The slight tears in the skin were not longer than approximately 2-inches, exposing less foam than the vent plugs provided for gasses to escape during the fire event. Similarly, the optional lid lifting brackets, not included in the prototype, would not be expected to cause any excessive tearing of the skin, if any at all. Most likely the brackets will flatten without any tearing whatsoever. There was no discernible damage to the cylinder from either side impact

The following general observations were made during the second tests. Some tearing of the UX-30 skin was observed as a result of drop number B1 near the vent port on the opposite side of the package (lid vent). Tearing was also observed near the parting plane on the valve side of the package as a result of drop number B2. Drops number B2 and B4 resulted in opening of the parting plane 1-inch maximum on the impact side of the package. This gap was oriented towards the flame in the fire test to appropriately assess its impact on thermal performance of the package. The overpack remained tightly closed after the impacts. The slight tears in the skin were not longer than approximately 2-inches, exposing less foam than the vent plugs provided for gasses to escape during the fire event. There was no discernible damage to the cylinder from these impacts.

### 2.7.1.3 Corner Drop (With Standard 30-B Cylinder)

Drop numbers A1 and A4 of the test program were from 30-feet, impacting on the cylindrical edge of the package such that the center of gravity was directly over the impact point. Two drops were performed to test two different structural designs. Interestingly enough, both designs provided identical protection from the effects of the 30-foot corner drop. The design of the end impacted in test A4 provides the basis for the UX-30 end design, being much more weight and cost efficient than the design employed in the end tested during drop A1.

The principal damage from either drop may be represented as shown in Figure 2.7-1. Photographs of the two corner impacts are presented in Appendix 2.10.2 as photo 2 and photo 7. Photo 8 shows a close-up of the damage from drop A4. Photo 12 shows that the inside surface of the UX-30 was scored superficially from the force of the cylinder end ring impacting that surface. The cylinder, however was completely undamaged from either corner drop.

The results of the second corner drops were consistent with those observed in the original testing. The damage from the original testing is also well represented by Figure 2.7-1. Photographs of the damage resulting from drop B1 is provided in Appendix 2.10.2 as photographs 16 through 18.

### 2.7.1.4 Oblique Impact (With Standard 30-B Cylinder)

The regular shape of the UX-30 dictates that the side (horizontal and 30° from horizontal) and center of gravity. over struck corner impacts would develop the most severe loads to the $UF_6$ containment vessel. Therefore, no additional oblique drop tests were performed.

### 2.7.1.5 Summary of Results

*With Standard 30-B Cylinder*

There was no discernible damage to the containment vessel from any of the drop tests. Further, no leaks were detected in the vessel when tested subsequent to the series of tests. No damage was sustained by the package from any of the drop tests which would compromise the package's ability to meet the requirements of 10 CFR 71.

The test program indicated that some weight-saving design modifications could be made without changing the package's ability to resist the impact load or provide thermal insulation. First, the inner stainless steel shell of the overpack is needed primarily to seal and protect the closed-cell polyurethane foam from water and wear, but provides no significant impact protection itself. Thus the 12-gauge sheet used for the inner shell of the prototype was changed to 14-gage for this application.

Additionally, a 12-inch long cylindrical skirt 1/4-inches thick was built around the outside of the inner shell ends on the prototype. These skirts were intended to provide additional mechanical protection to the cylinder end rings had the corner impact deformation 'bottomed out' against the overpack cavity. Since corner impact did not produce such deformation, the skirts are not required.

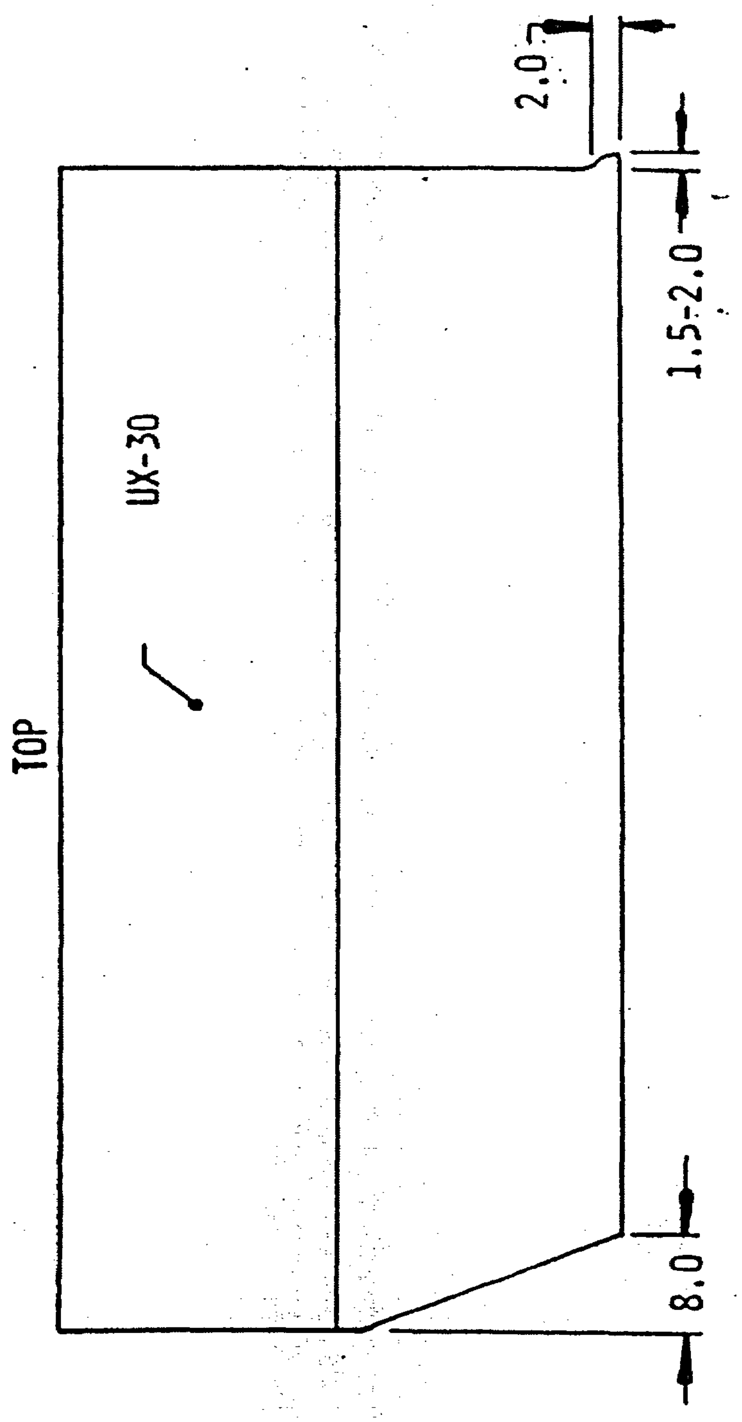


FIGURE 2.7-1
UX-30 Corner Drop Damage (With Standard 30B Cylinder)

The end tested in the first drop (A1) employed a 1/2-inch steel inner shell end plate as well as several short pipe sections welded perpendicular to the end plate to absorb energy. These pipe sections, as well as the 1/2-inch steel end plate, were unaffected by the test, since the impact deformation did not progress far enough.

The end tested in the fourth drop employed (A4) a 1/4-inch steel end plate with no short pipe energy absorbing features. The deformation observed from this test was identical to those from the first test, as one would expect. The structural features which would differentiate the impact performance of the two ends were not mobilized during the tests. As a result, the UX-30 end design is similar to the design tested in drop A4.

The weight savings realized by these design changes actually increases the package's ability to resist the impact loads. The loaded prototype weighed approximately 8,550 lbs. (in the original testing, the second test package weighed 8136 lbs.), yet the nominally loaded UX-30 package weighs only 7,951 lbs. Thus, the drop test program demonstrated the overpack system to be effective for a package weight [(8,550 - 7,951)(100)]/7,951 = 7.5% greater than the nominal UX-30 gross weight. It is recognized that there may be variance in the actual weights of the UX-30's and the 30B cylinders used to contain the uranium hexafluoride. This variance can be due to the allowed tolerances in material thicknesses and densities as specified. Allowing for these tolerances, the maximum gross weight of the package could range upward to 8,270 lbs. The maximum gross weight of 8,270 lbs. is less than the test package weight of 8,550 lbs. A full description of weight differences is presented in Appendix 2.10.3.

Tests showed no significant damage or deformation to the internal cavity of the tested UX-30 or the cylinder that was within the package. Any UX-30 at its maximum gross weight would perform as well or better than the tested package at the higher gross weight. The fact that the cylinder could be slightly heavier than the cylinder that was dropped would have little effect on the package performance. The lighter cylinder was not damaged during previous tests. The approximate 3% weight increase of the cylinder would not be expected to change results. The heavier cylinder would tend to increase the effects of an inside-out impact to the package. However, the proprietary end-configuration, using 1/4-inch plate, distributes any internal applied load to the end foam. It applies the load in such a manner that the force distribution is identical to that which was seen by the heavier tested package (i.e., higher gross weight). The tested package used a heavier internal structure, which would apply approximately the same loading to the end plate (load applied at a diameter of 30.75) as would a heavier cylinder (load applied at a diameter of 29.625). The heavier cylinder, containing the same weight or less of payload, would typically be made of thicker material, and would be less susceptible to damage.

In conclusion, the UX-30 affords excellent protection to the $UF_6$ containment vessel under loads from 30-foot drop impacts, thus assuring conformance to the drop requirements of 10 CFR 71.

*With 30C Cylinder*

The full-scale prototype testing of the 30C Cylinder demonstrated that the VPC is capable of maintaining a water-tight seal around the cylinder valve during normal and hypothetical accident condition testing. The cylinder valve did not contact any other component of the packaging during or following the test sequence, and the VPC O-rings remained leak-free prior to and following the test sequence. Additionally, the total effective volume of the packaging was greater than 95% of the original, the effective spacing of the fissile contents remained unchanged, and the packaging remained closed, effectively excluding the entry of a 10 cm (4 in) cube. There was no loss or dispersal of the simulated contents, no changes to the packaging that would result in a significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. Additionally, the damage sustained to the UX-30 is consistent with previous drop tests for the same model. Therefore, the fire test results for the previous tests remain applicable for the 30C cylinder design, and the maximum packaging temperature is below the design limits for the UX-30.

### 2.7.2 Crush

Not applicable; the UX-30 package weighs more than 1100 lbs.

### 2.7.3 Puncture

*With Standard 30B Cylinder*

Drop tests A2, A5, B3, B4 and B5 were 40-inch drops onto a 6-inch diameter mild steel post that was welded to the pad. Drop number A2, shown in photos 3, 4, and 11 of Appendix 2.10.2, impacted the cylindrical side of the package, immediately adjacent to the closure interface. The 'hard spot' provided by the closure would maximize local outer shell puncture strains. Drop A5, shown in photos 9 and 10 of Appendix 2.10.2, was an end impact such that the post would be driven directly into the $UF_6$ cylinder valve. This orientation maximizes the potential for damaging the valve and breaking containment.

Damage from drop test A2 was limited to a dent 2.75-inches deep in the package outer skin, and the alignment pin and ball-lock pin adjacent to the impact point were deformed. Even so, there was no failure of any sheet metal or fasteners, and the ball-lock pin could be removed without undue force. The interior of the overpack remained undeformed.

Damage from drop test A5 included a dent 2.0-inches deep in the package end, and a slight inward bow of the 1/4-inch thick inner end plate. This inward bow reached a maximum deflection of 1/4-inches. The clearance between the cylinder and the overpack end is at least 1/2-inch per ANSI N14.1, so there was a 1/4-inch margin remaining after impact. There was no evidence from either careful visual inspection or leak testing that the $UF_6$ cylinder was damaged in any way.

The results of the new puncture tests were consistent with those observed during earlier the original tests. Appendix 2.10.2 photographs 23 through 28 document the damage observed in these tests.

The puncture tests performed on the prototype demonstrate that the UX-30 meets the puncture requirements of 10 CFR 71.

*With 30C Cylinder*

Following the hypothetical accident condition Free Drop described in paragraph 2.7.1.5 above, the package was moved into position for the hypothetical accident condition Puncture Drop. No repairs or modifications were made to the package. A 6"OD x 18" mild steel puncture pin was bolted in place on the drop pad.

The package was dropped from an elevation of 58" (40" above the 18" tall puncture pin), at an attitude of 27 degrees, onto the site directly above and slightly off-center of the VPC. The puncture pin indented the package outer skin a maximum of 1.5", perforating the outer skin over approximately 5" of the pin circumference.

In addition to the primary pin impact, a secondary impact mark appeared. The secondary pin imprint was triangular, rather than circular; thus, it appears that the package bounced after the primary impact and landed a second time on the puncture pin at a skewed angle. There did not appear to be additional damage to the off-end of the package due to the final slapdown. All welds remained intact, and, with the exception of the puncture pin tear, the package outer skin was not breached. The packaging remained closed. A single closure pin was wedged in place.

Following completion of the drop sequence, the UX-30 was opened. The wedged closure pin had to be cut to allow the package to be opened. It appeared that the interior wall of the UX-30 at the impact locations had deformed both elastically and plastically. A significant amount of clearance (approximately 1") was visible between the VPC and UX-30 wall; however, it was clear that they had made contact during impact, since the glazing material was missing from the top of the VPC and traces of it were on the UX-30 wall. Additionally, the VPC left a small, dished impression in the buckled UX-30 interior wall at the impact site, approximately 0.125" deep. No damage was visible on the VPC. The UX-30 interior wall was bowed inward across the entire end of the cover approximately 0.625". The location of the puncture pin impression was measured, as was the impression left by the VPC. A comparison of these two impression locations shows that the puncture impact occurred as planned, slightly off-center from the VPC. The cylinder was measured and the results were recorded on Figure 3 of Appendix 2.10.5.

### 2.7.4 Thermal

The effect of the hypothetical accident fire event is examined in Section 3.5 for the UX-30 as damaged by the free drop and puncture events described above. The results of the UX-30) fire test scenario and associated thermal analysis models, used to correct for deviations between test conditions and initial conditions required for the hypothetical accident, are discussed in detail in Appendix 3.6.3. The structural implications of this event are examined here.

#### 2.7.4.1 Summary of Pressures and Temperatures

A summary of the maximum temperatures and the most severe gradient experienced by the package during the hypothetical fire events are given in Table 2.7-2.

TABLE 2.7-2

Fire Event Temperatures and Thermal Gradients

| Location | Maximum Temperature (°F) | Worst Gradient (°F) |
|---|---|---|
| Top Surface of UX-30 | 1,466 | 1,474 |
| Side Surface of UX-30 | 1,474 | 1466 |
| Top Inside Surface of UX-30 | 132 | 132 |
| Inside Surface at Closure Interface | 701 | |
| Top of $UF_6$ Cylinder | 121 | 181 |
| Side of $UF_6$ Cylinder | 181 | 121 |
| $UF_6$ Solid Mass | 180 | 100 |

The maximum pressure within the $UF_6$ cylinder corresponds to the vapor pressure of $UF_6$ at its maximum bulk temperature, 117 °F. This pressure is given in Section 3.5 as approximately 9 psia. The thermal testing indicated that $UF_6$ temperatures may be higher than the original estimate as a result of a larger separation gap observed during the drop testing. The maximum 30B cylinder temperature observed and expected for worst case hypothetical accident conditions (see Appendix 3.6.4) was less than 200 °F. Conservatively assuming that the entire $UF_6$ volume is at 200 °F (this is a very conservative assumption), the corresponding $UF_6$ vapor pressure will be less than 55 psia. The 30B cylinder is designed to operate in this pressure range during cylinder fill and emptying operations. The design service pressure of the cylinder is 200 psig. The cylinder is also hydrotested to a pressure of 400 psig. Therefore, the cylinder design will withstand pressures due to the hypothetical fire scenario even using the extremely conservative assumption that all $UF_6$ is at the maximum temperature observed.

### 2.7.4.2 Differential Thermal Expansion

From the temperatures described above for the maximum thermal gradient, it can be seen that the outer shell of the UX-30 will expand relative to the inner shell. If the stainless steel outer shell is assumed to be 1,466 °F in all locations, and the inner shell is assumed to be 100 °F everywhere (this envelopes gradients obtained from initial thermal analyses as well as those resulting from the thermal testing), the relative thermal expansion of the outer skin may be calculated:

$$AC = a(T_o - T_i)\pi D$$

Where:

$AC$ = Change in circumference of outer shell, inches

$T_o$ = Temperature of outer shell, °F

$T_i$ = Temperature of inner shell, °F

$D$ = Outside diameter, inches

a = Coefficient of thermal expansion, in/in/°F

The thermal expansion coefficient, S, is given in the ASME Boiler and Pressure Vessel Code as $9.82(10)^{-6}$ in/in/°F. The change in circumference of the outer shell is then:

$$\begin{aligned} AC &= [9.82(10)^{-6}](1{,}466 - 100)\pi(43.5) \\ &= 1.83 \text{ inches} \end{aligned}$$

Thus, the overpack outer shell could expand 1.83 inches circumferentially, or $1.83/\pi = 0.58$ inches in diameter.

Importantly, there are no significant gradients in the $UF_6$ cylinder.

### 2.7.4.3 Stress Calculations

Stress in the outer stainless steel shell from the thermal strains imposed by the hypothetical fire event are kept at a minimum by the design of the UX-30. If the outer shell is treated as a semi-circular cylindrical sheet (43.50 + 0.58 =) 44.08-inches in diameter (22.04-inch radius) restrained at the closure interface to a 21.75-inch radius, the stress may be calculated as below (See Figure 2.7-2):

The stress under these conditions may be calculated by taking the stress from a cantilevered beam analysis assuming a beam length equivalent to a quarter arc:

$$L = (0.25)\,\pi\,(44.08) = 34.62 \text{ inches}$$

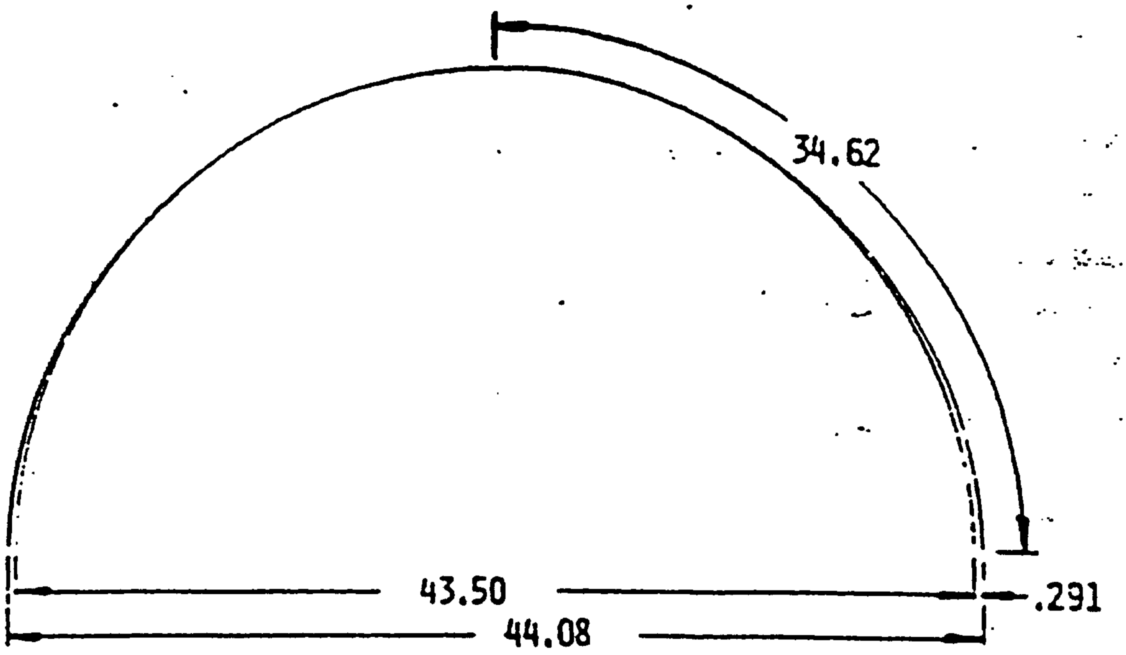


FIGURE 2.7-2

The deflection of such a beam can be related to the force required to develop it by the following relationship from Roark, page 96:

$$d = PL^3/3EI$$

Where:

d = deflection, 0.583/2 = 0.291 in

L = length = 34.62 in

P = restraining force

E = Young's Modulus for steel = $29(10)^6$ psi

I = moment of inertia of beam, $in^4$

The moment of inertia per inch of width for the 12 gauge sheet is:

$$I = bh^3/12$$

Where:

$b = 1.0$ in

$h = 0.135$ in

Then,

$I = 2.05(10)^{-4}$ in$^4$/in

Solving for P:

$$0.291 = P(34.62)^3/3[29(10)^6][2.05(10)^{-4}]$$

$P = 0.125$ lbs./in

And,

$$\begin{aligned} M &= PL \\ &= (0.125)(34.62) \\ &= 4.3 \text{ in-lbs./in} \end{aligned}$$

The bending stress is then:

$$s = Mc/I$$

Where:

$s$ = bending stress, psi

$M$ = bending moment, in-lbs./in

$c$ = distance to extreme fiber, in.

$I$ = moment of inertia, in$^4$/in

Then,

$$s = (4.3)(0.135/2)/[2.05(10)^{-4}]$$
$$= 1{,}416 \text{ psi}$$

Since the yield stress of ASTM A240, Type 304, stainless is 30,000 psi, the margin of safety is as shown below:

$$\text{M.S.} = (30{,}000/1{,}416) - 1 = \underline{+\text{Large}}$$

Deformation observed from the fire testing of the UX-30 were associated with the bulging of the end plates of the cylinder. This was caused by the internal forces generated by the expansion of the foam. The vent ports provided in these end plates precluded rupture of the end plates during the fire test. Several locations were identified from which the expanding foam was extruded to the exterior of the package. These locations were at the vent ports and areas of significant damage from the drop tests (e.g., tears in the outer skin of the package near the vent ports and parting plane). This damage did not, however, impact the integrity of the 30B cylinder as evidenced by visual observations and leak testing.

### 2.7.5 Water Immersion - Fissile Material

10 CFR 71 requires two separate immersion tests to be applied to the UX-30. First, because the packaging will be used to transport fissile material, the package is required to be immersed under 3 feet of water for not less than 8 hours following being subjected to the drop, puncture, and thermal events, to assess the affect of any leaks on payload criticality.

Because the cylinder remains essentially undamaged, no leakage would occur during the indicated test. An immersion test was performed subsequent to the drop and fire testing performed for the qualification (see discussion in Appendix 3.6.3). No leakage of water resulted from this test.

Extensive tests were performed on cylinders to determine their criticality characteristics when immersed in water. The tests are reported by A. J. Mallett and C. E. Newlon in Protective Shipping

Packages for 30-inch Diameter $UF_6$ Cylinders, K-1686. The tests show that for an array of 7 cylinders closely packed and immersed in water, no significant multiplication of neutrons occurs.

### 2.7.6 Water Immersion - All Packages

The second immersion test required by 10 CFR 71 is to be applied to an undamaged package and involves submerging the package for eight hours under 50 feet of water, or 21 psig. Since the internal pressure of the cylinder could be as low as zero absolute, the total pressure experienced by the cylinder under this condition is:

$$21.0 + 14.7 = 35.7 \text{ psia}$$

This pressure results in a hoop stress in the cylinders of:

$$s = Pr/t$$

Where:

P = pressure, psi

r = cylinder radius, in.

t = shell thickness, in.

Then,

$$\begin{aligned} s &= (35.7)(21.75)/(0.5) \\ &= 1{,}553 \text{ psi} \end{aligned}$$

The margin of safety in the ASTM A516, Grade 55, cylinder wall is then:

$$\text{M.S.} = 30{,}000/1{,}553) - 1 = \underline{+\text{Large}}$$

### 2.7.7 Summary of Damage

*Standard 30B and 30C Cylinder*

It has been demonstrated that the accident sequence given in Paragraph 71.73 of 10 CFR 71 will not damage the $UF_6$ cylinder containment boundary in any way. In fact, damage is so limited that the cylinder, protected throughout the events by the UX-30, would not sustain any damage which would prevent its subsequent use for the transport of $UF_6$. The UX-30 provides complete protection to meet the accident requirements of 10 CFR 71.

*30C Cylinder*

Testing of the UX-30 with the 30C Cylinder has been demonstrated that the VPC provides additional protection for the cylinder valve. The cylinder valve did not contact any other component of the packaging during or following the test sequence, and the VPC O-rings remained leak-free prior to and following the test sequence.

## 2.8 Not Used

## 2.9 Not Used

## 2.10 Appendix

# APPENDIX 2.10.1

## Drop Test Damage Records

File: L: 30509

## Drop Test Damage Record

## DROP TEST DATA SHEET AND CHECK LIST

Package Nlac UX-30 S/N 540-10 Drop# 1 Drop Type CG over corner, 30 ft - Armour Ind.

Applicable Test Procedure – Date 5/31/83 Time 11:30 A.M.

Report Written By J. Olivadoti Date 5/31/83

| N/A | | ITEM | CRITERIA | NOTES ② |
|---|---|---|---|---|
| ☐ | ☐ | 1. Package weight noted? | 30 B Payload<br>30B 6420 ± 1% | Cylinder weights = 13<br>Loaded = 6405 lb |
| ☐ | ☐ | 2. Weather Noted? | Hard Rain or High Wind upset ② | Overcast with light<br>10 wind 5/31/83 |
| ☐ | ☐ | 3. Leak Test Performed? | Soap Bubble per LT-04 ② | OK 7 psi to 9 psi<br>No leaks - 5/19/8 |
| ☐ | ☐ | 4. Photos Taken of Package Interior and Exterior | | |
| ☐ | ☐ | 5. Photos Taken of Payload Configuration? | | ✓ ② |
| ☐ | ☐ | 6. Photos Taken of Drop Configuration? | | ✓ ② |
| ☐ | ☐ | 7. Drop Angle/Ht. Recorded? | CG over struck corner CG ≯B between over corner and 3° beyond corner toward horz. [illegible] ∠. | 30 feet - 25° ∠.<br>over corner ②<br>5/31/83 |
| ☐ | ☒ | 8. Instrumentation Activated? | | |
| ☐ | ☐ | 9. Video/Motion Picture Equipment Activated? | | ✓ ② |
| ☐ | ☐ | 10. Area Cleared? | | ✓ ② |
| ☐ | ☐ | 11. Premature Drop/Rigging Damage? | | None ② |
| ☐ | ☐ | 12. Photos Taken of Damaged Area? | | ✓ ② |
| **AFTER DROP:** | | | | |
| ☐ | ☐ | 13. Instrumentation/Video Equipment Shut Down? | | ✓ ② |
| ☐ | ☐ | 14. Photos Taken of In Situ Damage? | | ✓ ② |
| ☐ | ☐ | 15. Damage Recorded (See Reverse)? | | See over ② 5/3 |
| ☐ | ☒ | 16. Package Opened? | | N/A |
| ☐ | ☒ | 17. Interior Photos Taken? | | |
| ☐ | ☒ | 18. Leak Test Performed? | | |

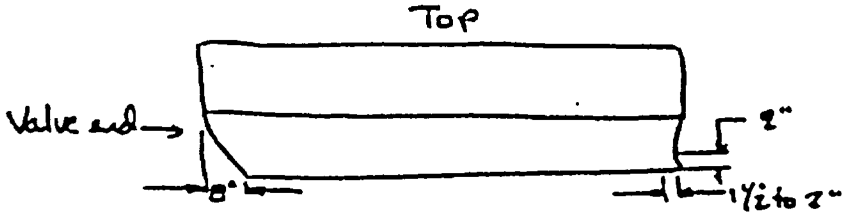
## DROP TEST DAMAGE RECORD

Package UX-30

Drop No. 1

**Exterior Damage**

1. Draw sketch of damaged zone. Show pertinent measurements.



② 5/31/83

2. Describe condition of closure devices and closure interface

All can be removed except one on each end that was hard to remove prior to test. ② 5/31/83

3. Describe damage to or failure of skin

O.P. deformed as shown in #1 above. No weld damage or cracking in weld or parent material. ② 5/31/83

**Interior Damage**

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.

Not Opened

2. Record any other damage, data or interpretations of data from this drop.

N/A

NOTE: Add sheets for data as required. Identify with Drop Test number from Sheet 1.

File: L: 30509

## DROP TEST DATA SHEET AND CHECK LIST

Package UX-30 PO# 540-10 Drop# 2 Drop Type 40" post (6" Dia) on S near seam

Applicable Test Procedure — Date 5/31/83 Time 12:00

Report Written By J. Olivadoti Date 5/31/83

| | N/A | ITEM | CRITERIA | NOTES |
|---|---|---|---|---|
| | X | 1. Package weight noted? | Same as #1 | ok 5/31/83 |
| | | 2. Weather Notes? | Same as #1 | ok 5/31/83 ② |
| | X | 3. Leak Test Performed? | | |
| | X | 4. Photos Taken of Package Interior and Exterior | exterior only | ok 5/31/83 ② |
| | X | 5. Photos Taken of Payload Configuration? | — | |
| | | 6. Photos Taken of Drop Configuration? | | ok 5/31/83 ② |
| | | 7. Drop Angle/Ht. Recorded? | Horiz. within 2°<br>impact within 2" of ℄ | 1° within level - impact on ℄. 40" height 5/31 |
| | X | 8. Instrumentation Activated? | | |
| | | 9. Video/Motion Picture Equipment Activated? | | ok |
| | | 10. Area Cleared? | | ok ② |
| | | 11. Premature Drop/Rigging Damage? | | None ② |
| | | 12. Photos Taken of Damaged Area? | | ok ② 5/31/8 |

**AFTER DROP:**

| | | | | |
|---|---|---|---|---|
| | | 13. Instrumentation/Video Equipment Shut Down? | | ok ② |
| | | 14. Photos Taken of in Situ Damage? | | ok ② |
| | | 15. Damage Recorded (See Reverse)? | | See over ② 5/31/ |
| | X | 16. Package Opened? | | |
| | X | 17. Interior Photos Taken? | | |
| | X | 18. Leak Test Performed? | | |

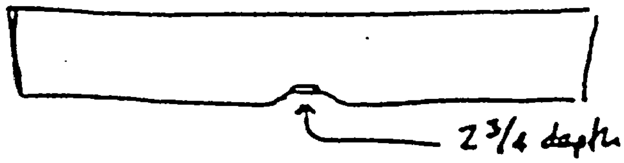
## TEST DAMAGE RECORD

Package UX-30

Drop No. 2

**Exterior Damage**

1. Draw sketch of damaged zone. Show pertinent measurements.



2 3/4 depth x 6" dia in bottom tapered out. ② 5/31/83

2. Describe condition of closure devices and closure interface

Intact - can still be removed ② 5/31/83

3. Describe damage to or failure of skin

Deformed as shown - No skin failure welds ok ② 5/31/83

**Interior Damage**

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.

N/A

2. Record any other damage, data or interpretations of data from this drop.

None

NOTE: Add sheets for data as required. Identify with Drop Test number from Sheet 1.

File: L: 30309

DROP TEST DATA SHEET AND CHECK LIST

Package UX-30 TOS 540-10 Drop# 3 Drop Type 30' on side away from

Applicable Test Procedure — Date 5/31/83 Time 12:30 P.M.

Report Written By J. Olivadoti Date 5/31/83

| | N/A | ITEM | CRITERIA | NOTES |
|---|---|---|---|---|
| ☐ | ☒ | 1. Package weight noted? | Same as #1 | Same ② 5/31 |
| ☐ | ☐ | 2. Weather Notes? | Same as #1 | Same ② |
| ☐ | ☒ | 3. Leak Test Performed? | | |
| ☐ | ☒ | 4. Photos Taken of Package Interior and Exterior | Exterior only | ok ② |
| ☐ | ☐ | 5. Photos Taken of Payload Configuration? | | |
| ☐ | ☐ | 6. Photos Taken of Drop Configuration? | | |
| ☐ | ☐ | 7. Drop Angle/Ht. Recorded? | Horiz. within 2° | 1° ok - Package Upside down. ② 30 feet |
| ☐ | ☒ | 8. Instrumentation Activated? | | |
| ☐ | ☐ | 9. Video Motion Picture Equipment Activated? | | ok ② |
| ☐ | ☐ | 10. Area Cleared? | | ok ② |
| ☐ | ☐ | 11. Premature Drop/Rigging Damage? | | None ② |
| ☐ | ☐ | 12. Photos Taken of Damaged Area? | | ok ② 5/31 |

AFTER DROP:

| | | | | |
|---|---|---|---|---|
| ☐ | ☐ | 13. Instrumentation/Video Equipment Shut Down? | | ok ② |
| ☐ | ☐ | 14. Photos Taken of in Situ Damage? | | ok ② |
| ☐ | ☐ | 15. Damage Recorded (See Reverse)? | | ok ② 5/31 |
| ☐ | ☒ | 16. Package Opened? | | |
| ☐ | ☒ | 17. Interior Photos Taken? | | |
| ☐ | ☒ | 18. Leak Test Performed? | | |

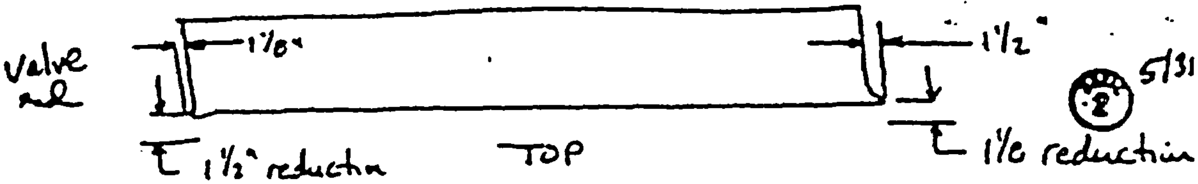
## DROP TEST DAMAGE RECORD

Package UX-30

Drop No. 3

**Exterior Damage**

1. Draw sketch of damaged zone. Show pertinent measurements.



② 5/31/83

2. Describe condition of closure devices and closure interface

1 pin backed out - All can be operated. ② 5/31/83

3. Describe damage to or failure of skin

Deformed as shown - No cracks or weld failures - ② 5/31

**Interior Damage**

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.

N/A

2. Record any other damage, data or interpretations of data from this drop.

None

NOTE: Add sheets for data as required. Identify with Drop Test number from Sheet 1.

File: L: 30509

### DROP TEST DATA SHEET AND CHECK LIST

Package UX-30 S/N 540-10 Drop# 4 Drop Type 30 ft - CG. over corner armour and.

Applicable Test Procedure ____________ Date ________ Time ______

Report Written By ______________________ Date ____________

| N/A | | ITEM | CRITERIA | NOTES |
|---|---|---|---|---|
| | X | 1. Package weight noted? | Same as #1 | OK (same) 2 5/. |
| | | 2. Weather Notes? | Same as #1 | OK (same) 2 |
| | X | 3. Leak Test Performed? | | |
| | X | 4. Photos Taken of Package Interior and Exterior | Exterior | OK 2 |
| | | 5. Photos Taken of Payload Configuration? | | ~~ok~~ N/A 2 |
| | | 6. Photos Taken of Drop Configuration? | | OK 2 |
| | | 7. Drop Angle/Ht. Recorded? | | 25° L - OK 2 |
| | | 8. Instrumentation Activated? | | 3 Cut<br>OK 2 |
| | | 9. Video/Motion Picture Equipment Activated? | | OK 2 |
| | | 10. Area Cleared? | | OK 2 |
| | | 11. Premature Drop/Rigging Damage? | | None 2 |
| | | 12. Photos Taken of Damaged Area? | | OK 2 5/31/85 |
| AFTER DROP: | | | | |
| | | 13. Instrumentation/Video Equipment Shut Down? | | OK 2 |
| | | 14. Photos Taken of In Situ Damage? | | OK 2 |
| | | 15. Damage Recorded (See Reverse)? | | See over 5/31/85 |
| | X | 16. Package Opened? | | |
| | X | 17. Interior Photos Taken? | | |
| | X | 18. Leak Test Performed? | | |

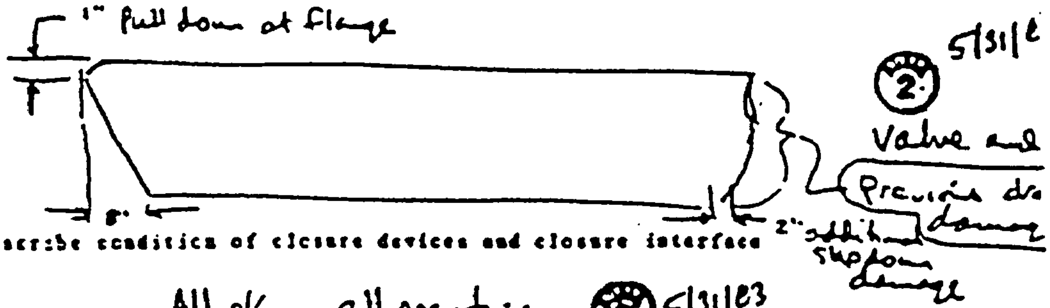
## DROP TEST DAMAGE RECORD

Package UX-30

Drop No. 4

**Exterior Damage**

1. Draw sketch of damaged zone. Show pertinent measurements.



2. Describe condition of closure devices and closure interface

All ok - all operative 2 5/31/03

3. Describe damage to or failure of skin

Deformed - No cracks or weld failure. 2 5/31/03

**Interior Damage**

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.

N/A

2. Record any other damage, data or interpretations of data from this drop.

None

NOTE: Add sheets for data as required. Identify with Drop Test number from Sheet 1.

File: L: 30309

DROP TEST DATA SHEET AND CHECK LIST

Package UX-30 S/N 540-10 Drop# 5 Drop Type 40" drop —lightly prot [illegible] anti: 6" pin

Applicable Test Procedure — Date 3/31/83 Time 1:00 PM

Report Written By J. Olivadoti Date 5/31/83

| N/A | ITEM | CRITERIA | NOTES |
|---|---|---|---|
| X | 1. Package weight noted? | Same as #1 | OK ② 5/31 |
|  | 2. Weather Notes? | Same as #1 | OK ② |
| X | 3. Leak Test Performed? |  |  |
| X | 4. Photos Taken of Package Interior and Exterior | Exterior only | OK ② |
| X | 5. Photos Taken of Payload Configuration? |  |  |
|  | 6. Photos Taken of Drop Configuration? |  | OK ② |
|  | 7. Drop Angle/Ht. Recorded? | Vert within 5° impact and near on seam near pkg ℄ - Lighter [illegible] 40" | 2° to vert. at 40" ② |
| X | 8. Instrumentation Activated? |  |  |
|  | 9. Video/Motion Picture Equipment Activated? |  | OK ② |
|  | 10. Area Cleared? |  | OK ② |
|  | 11. Premature Drop/Rigging Damage? |  | None ② |
|  | 12. Photos Taken of Damaged Area? |  | OK ② 5/31 |
| **AFTER DROP:** |  |  |  |
|  | 13. Instrumentation/Video Equipment Shut Down? |  | OK ② |
|  | 14. Photos Taken of In Situ Damage? |  | OK ② |
|  | 15. Damage Recorded (See Reverse)? |  | See over ② |
|  | 16. Package Opened? | If no further testing req'd. by eng. perform 16, 17 & 18 | No further drops performed. |
|  | 17. Interior Photos Taken? |  | Photos taken. |
|  | 18. Leak Test Performed? | Same as original leak test per LT-[illegible] | Leak test OK. No leaks at 10 ps ② 5/31/8 |

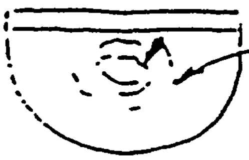
## DROP TEST DAMAGE RECORD

Package UX-30

Drop No. 5

**Exterior Damage**

1. Draw sketch of damaged zone. Show pertinent measurements.



double hit (bounce) 6" dia x 2" deep

Taper out to parent surface.

5/31/83

2. Describe condition of closure devices ~~and closure interface~~

All operative 5/31/83

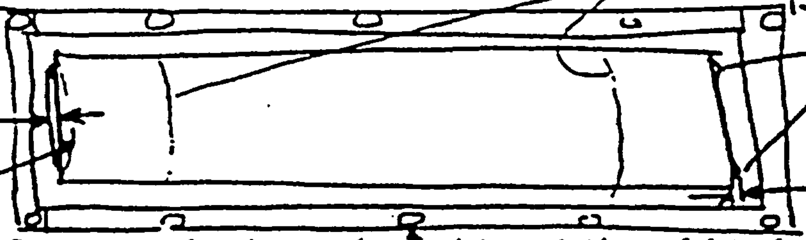
3. Describe damage to or failure of skin 5/31/83

Deformation - No cracks.

① Upon disassembly - cracks noted at corners of bottom step - in weld. Photos taken - 3 out of 4 corners - Not severe.

**Interior Damage**

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.



Seam of UF6 cylinder in bottom of O.P. from test #

Lip of UF6 embossed i ends of O.P

1/16 to 1/8 - values

1/8 to 1/4 light end

2. Record any other damage, data or interpretations of data from this drop.

1/4" bow out at light end from pin drop - Test # 5

Pin Bent above pin drop - ~~Test~~ # 2 5/31/8

NOTE: Add sheets for data as required. Identify with Drop Test number from Sheet 1.

File: L: 30509

DROP TEST DATA SHEET AND CHECK LIST

Package UX-30 WO# 680-10 Drop# 6 Drop Type SIDE AUTO CLOSURE

Applicable Test Procedure NRC REQUEST Date 8/10/04 Time 1:00 pm

Report Written By Stephen Bostick Date 8/10/04

| N/A | | ITEM | CRITERIA | NOTES |
|---|---|---|---|---|
| | ✓ | 1. Package weight noted? | SAME AS BEFORE | NO CHANGE |
| ✓ | | 2. Weather Noted? | | SUNNY & WARM |
| | ✓ | 3. Leak Test Performed? | LEAK TEST NOT PERFORMED NRC CONCERN IS FOR CLOSURE OF OVERPACK | |
| | ✓ | 4. Photos Taken of Package Interior and Exterior | Photos TAKEN AFTER PREVIOUS DROPS | |
| | ✓ | 5. Photos Taken of Payload Configuration? | SEE # 4 ABOVE | |
| ✓ | | 6. Photos Taken of Drop Configuration? | DROP SHOULD BE HORIZONTAL AUTO CLOSURE | |
| ✓ | | 7. Drop Angle/Ht. Recorded? | 30ft | |
| | ✓ | 8. Instrumentation Activated? | | |
| ✓ | | 9. Video/Motion Picture Equipment Activated? | DROP TO BE VIDEOTAPED | |
| ✓ | | 10. Area Cleared? | | |
| | ✓ | 11. Premature Drop/Rigging Damage? | | NO PREMATURE DROPS OCCURRED |
| | ✓ | 12. Photos Taken of Damaged Area? | | |

**AFTER DROP:**

| | | | | |
|---|---|---|---|---|
| ✓ | | 13. Instrumentation/Video Equipment Shut Down? | | |
| ✓ | | 14. Photos Taken of in Situ Damage? | | |
| ✓ | | 15. Damage Recorded (See Reverse)? | | |
| ✓ | | 16. Package Opened? | | |
| ✓ | | 17. Interior Photos Taken? | | |
| | ✓ | 18. Leak Test Performed? | NO VISUAL DAMAGE AT ALL TO 30B CYLINDER | 30B UNDAMAGED |

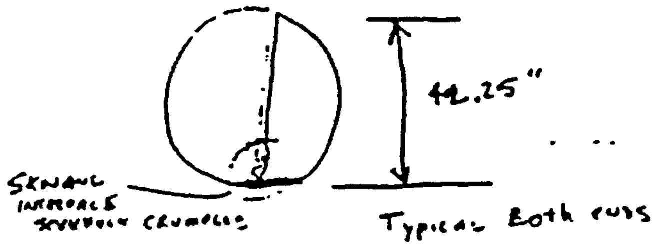
## DROP TEST DAMAGE RECORD

**Package** UX-30

**Drop No.** 6 . (PACKAGE WAS DROP 5 TIMES PREVIOUSLY, 5/03)

### Exterior Damage

1. Draw sketch of damaged zone. Show pertinent measurements.



2. Describe condition of closure devices and closure interface

ALL 5 IMPACTED BALL-LOCK PINS were driven flush into the side of the package. The closure plane did not separate at all.

3. Describe damage to or failure of skin

MINOR SKIN TEARS WERE APPARENT NEAR THE END CLOSURE DEVICES. TEARS WERE NOT LONGER THAN 2 INCHES LONG AND OPENED NOT MORE THAN 3/8".

### Interior Damage

1. Draw sketch of any damage, either to the interior of overpack or to payload. Show measurements.

WELDS ON 30B EMBOSSED A DENT IN THE INTERIOR SURFACE

30B WAS NOT DAMAGED AT ALL FROM THIS IMPACT.

2. Record any other damage, data or interpretations of data from this drop.

WELDS AROUND ALIGNMENT PINS (ONE PIN ON EACH END OF THE IMPACTED SIDE) MAY HAVE FAILED IN SHEAR ON IMPACT. THIS CANNOT BE VERIFIED SINCE THE UX-30 HAD TO BE PRIED OPEN FROM THE UNIMPACTED SIDE, AN OPERATION WHICH SEVERELY LOADED THESE PINS. THERE WAS NO APPARENT SEPARATION

**NOTE:** Add sheets for data as required. Identify with Drop Test number from Sheet 1.

# APPENDIX 2.10.2

## Drop Test Photographs

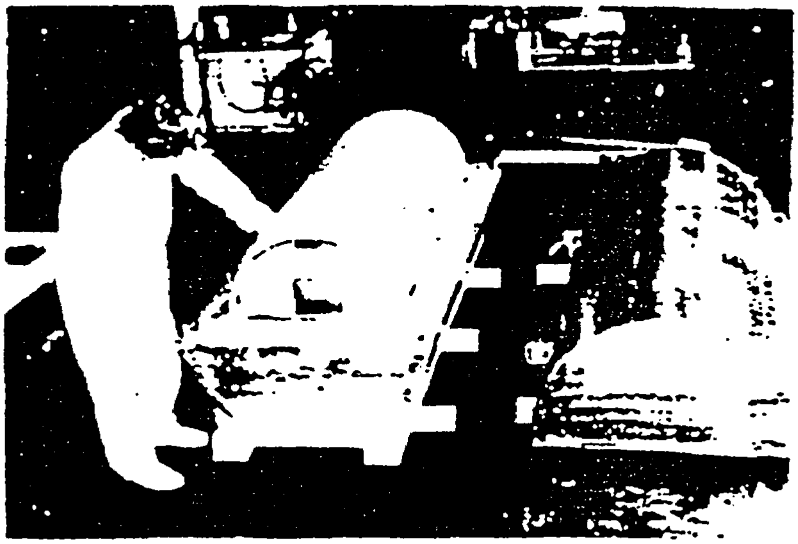


PHOTO #1

Loading UX-30 prior to Drop Test

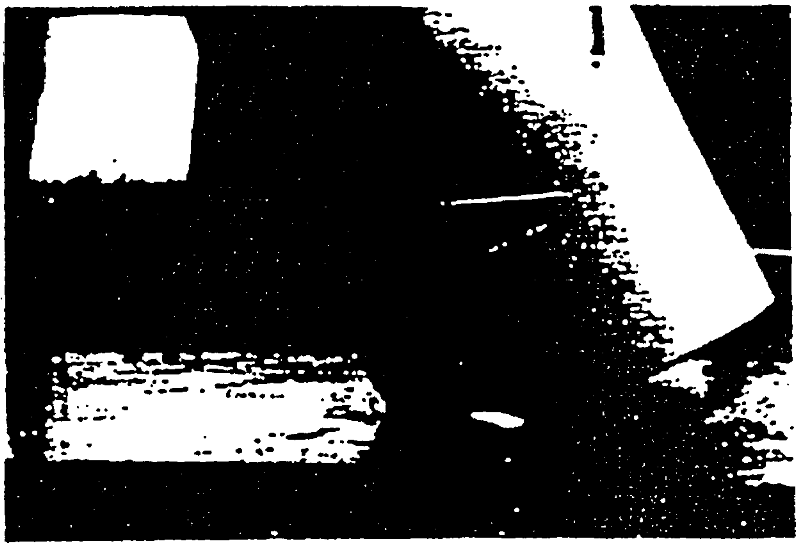


PHOTO #2

Drop #1 impact, with c.g. over struck corner

PHOTO #3 Just prior to 40 in. drop onto 6 in. diameter post (side impact)

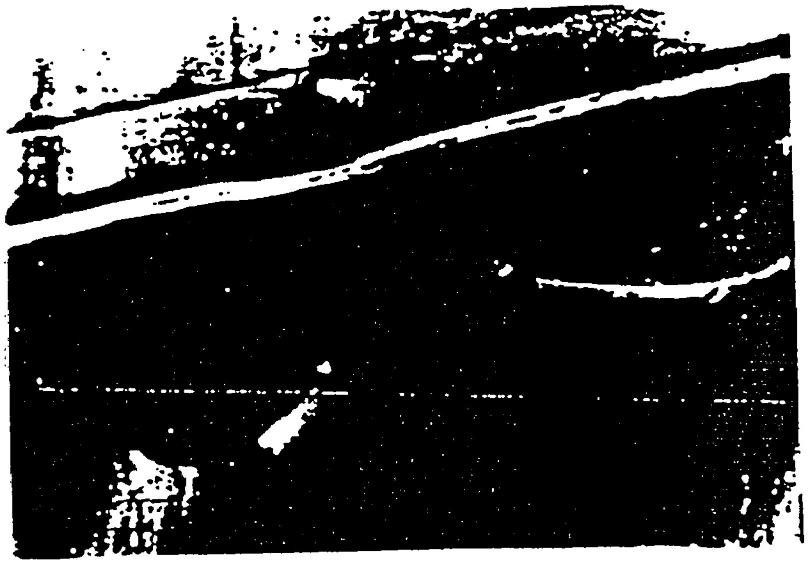


PHOTO #4 Damage from Drop #2

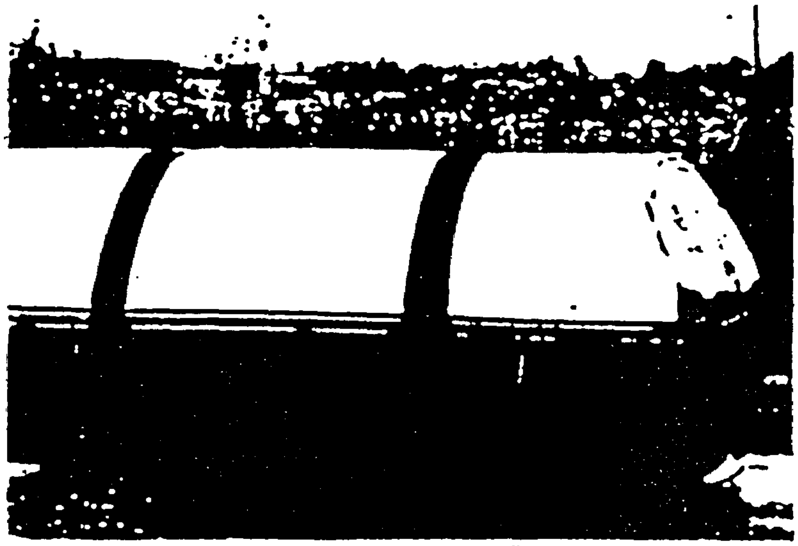


PHOTO #5

Flat side impact (Drop #3
Note slight bounce

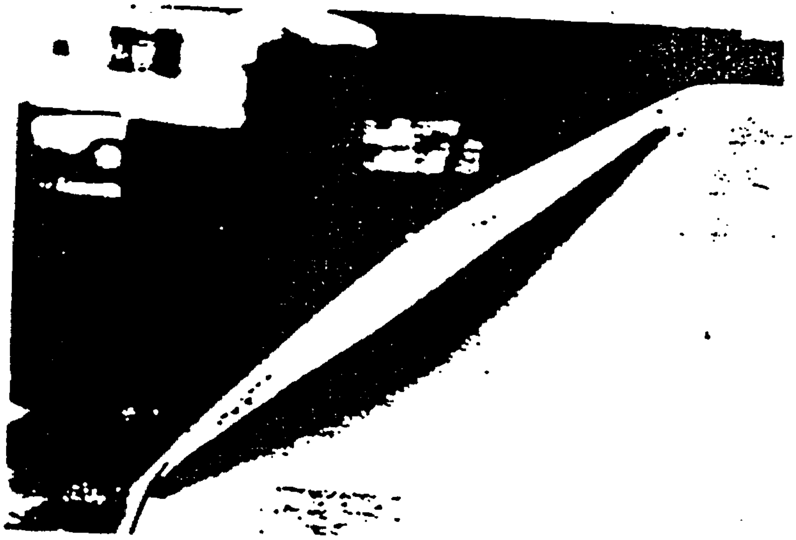


PHOTO #6

Damage from side impact

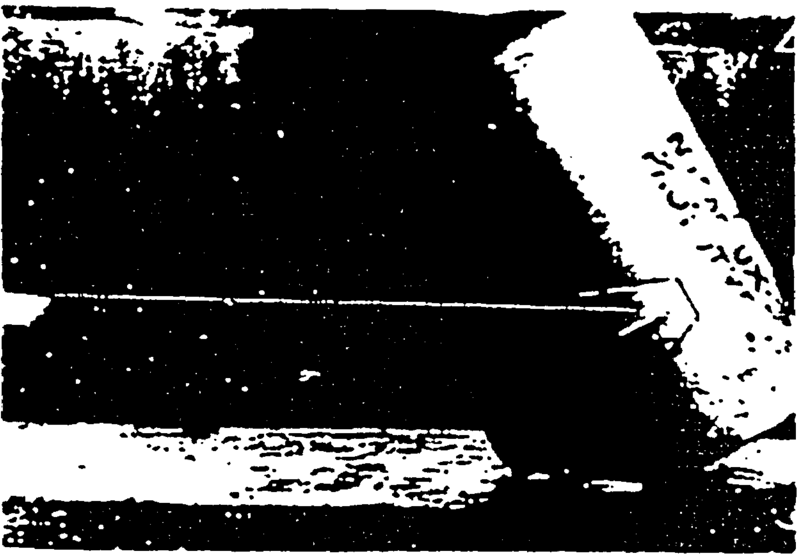


PHOTO #7

Drop #4 impact,
with c.g. over struck corner
(Alternately reinforced end)

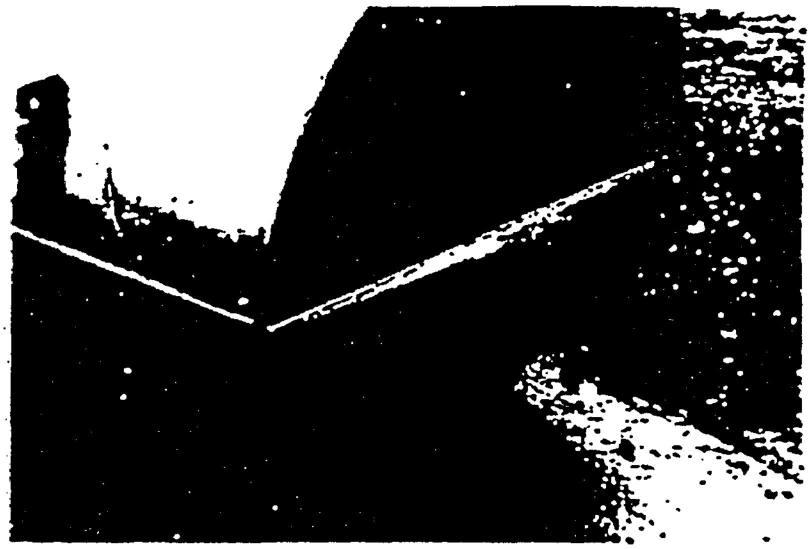


PHOTO #8

Damage from Drop #4

Just prior to 40 in. drop onto 6 in. diameter post (end impact)

PHOTO #9

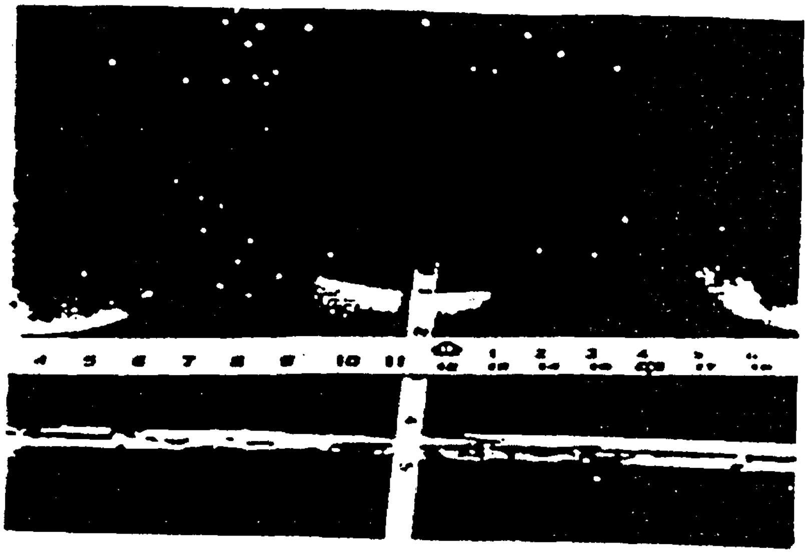


PHOTO #10

Damage from end impact post [illegible]

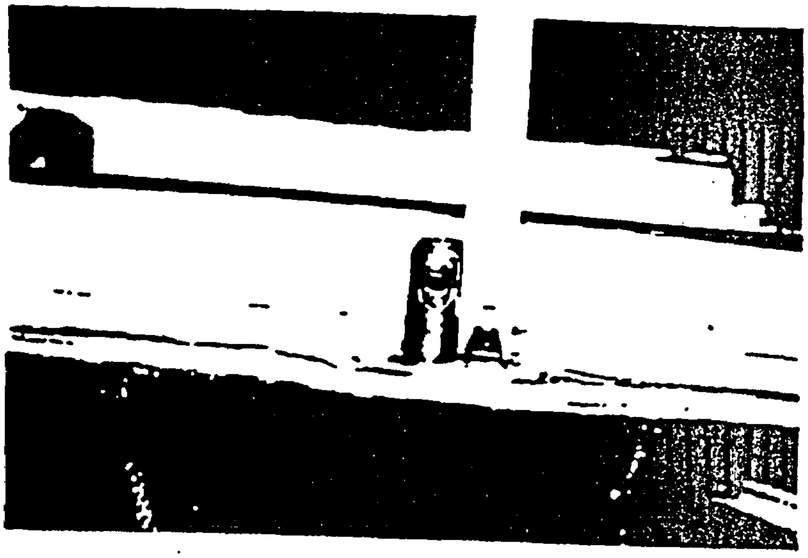


PHOTO #11

Side 40 in. drop

damaged alignment pin

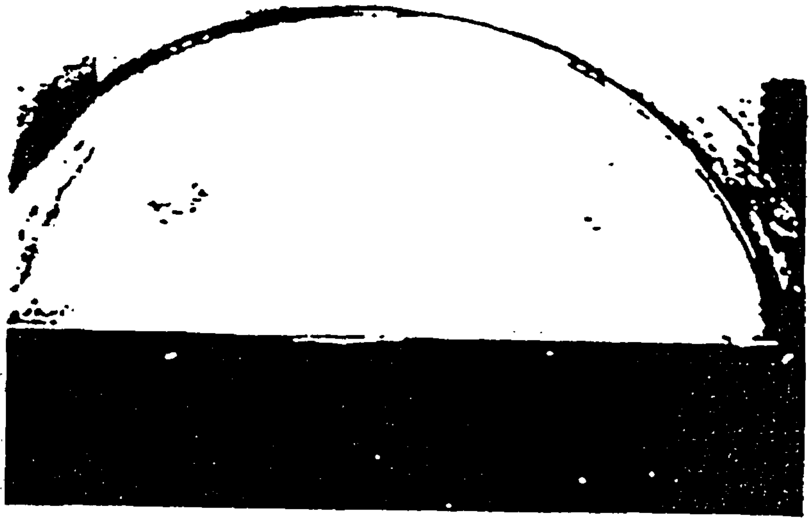


PHOTO #12

Inside surface of UX-30 damage
during Drops #4 and #5

PHOTO #13

Impact on Closure Interface.

PHOTO #14

Damage to UX-30 from drop #6 showing minor skin tearing.

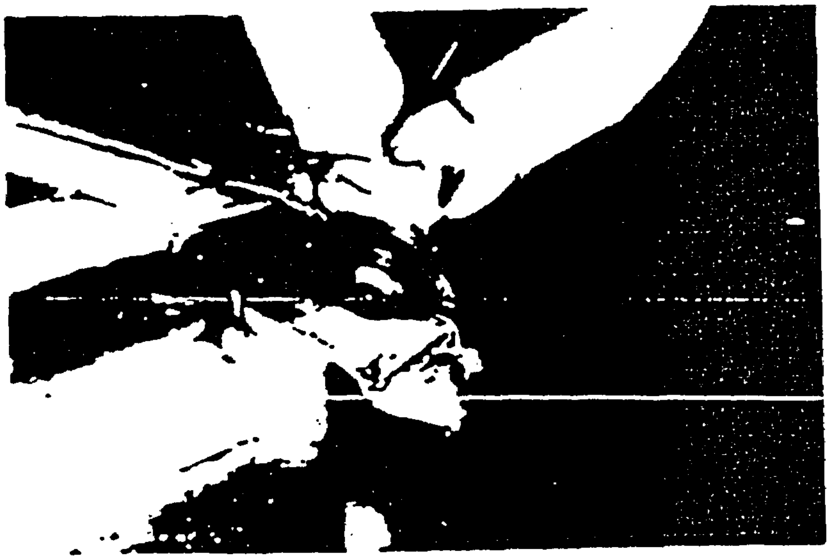


PHOTO #15

Damage to UX-30 alignment pin. One of two so damaged.

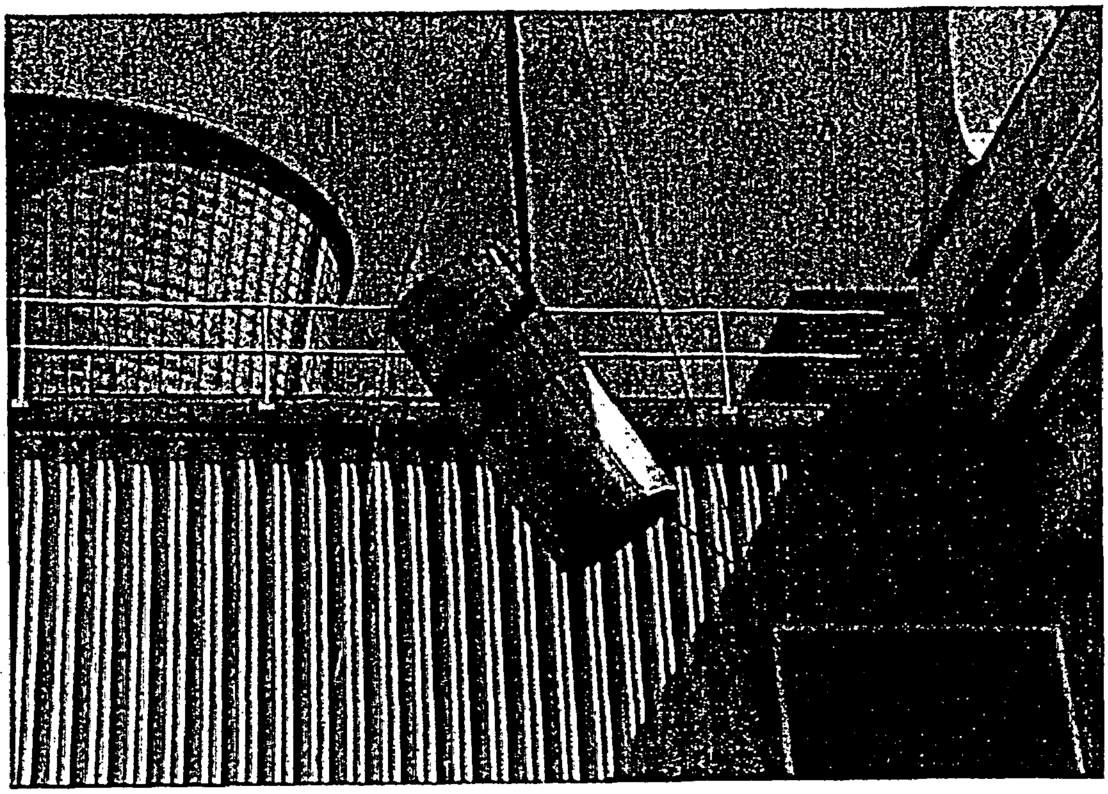


Photo No. 16

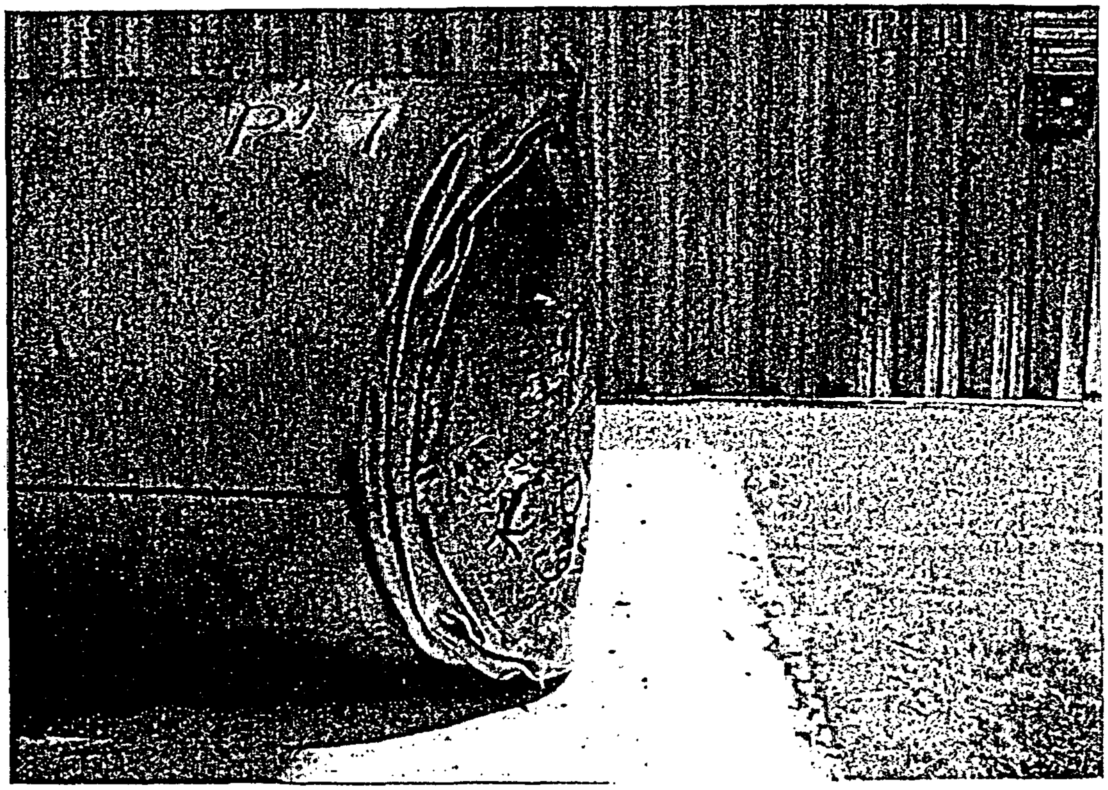


Photo No. 17

Drop B1

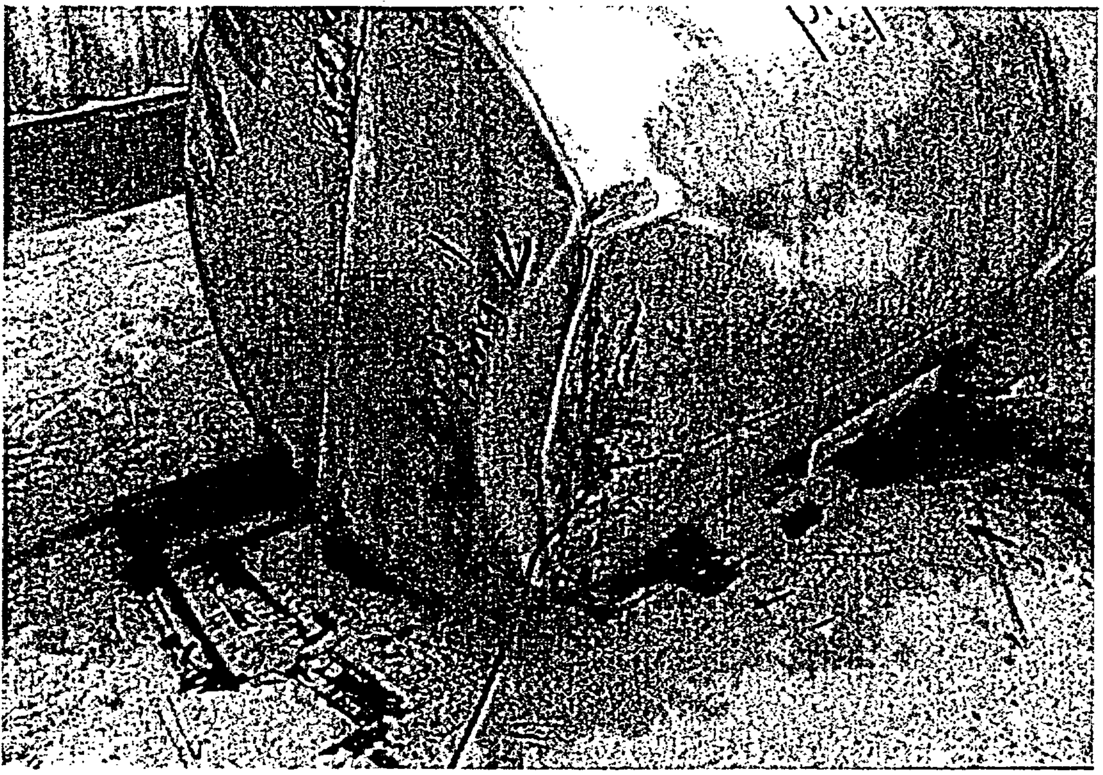


Photo No. 18

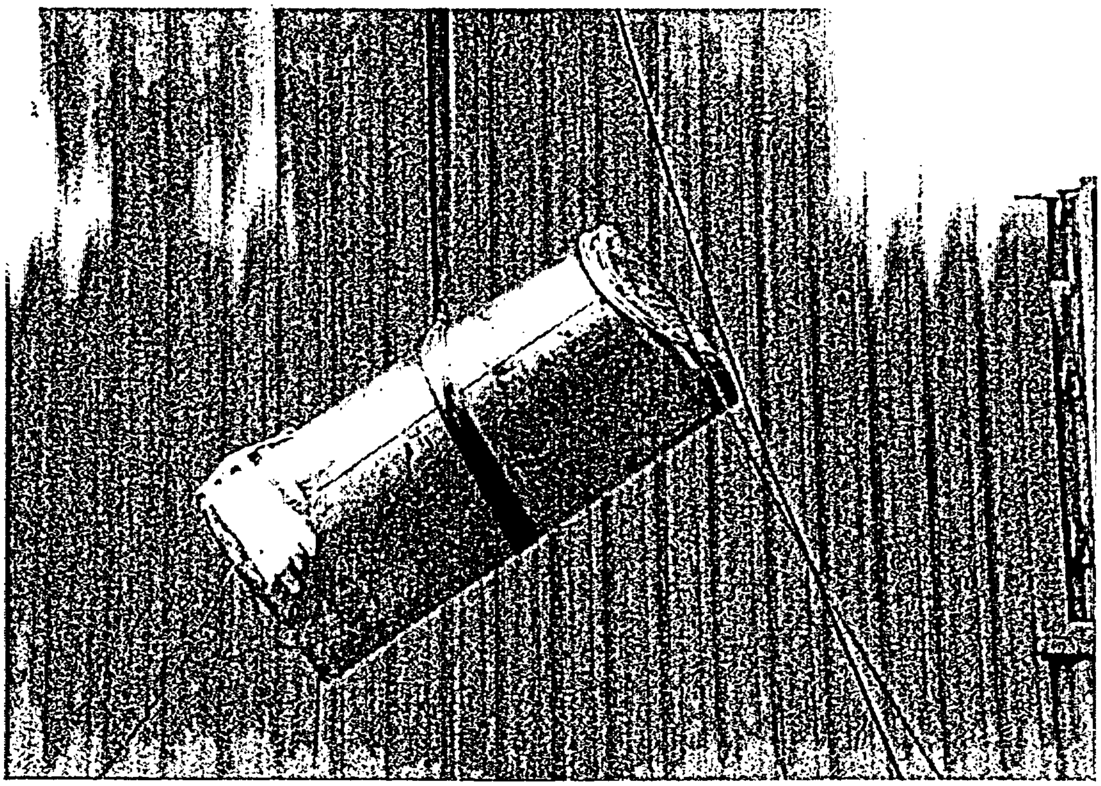


Photo No. 19 (B2)

Drop B1 & B2

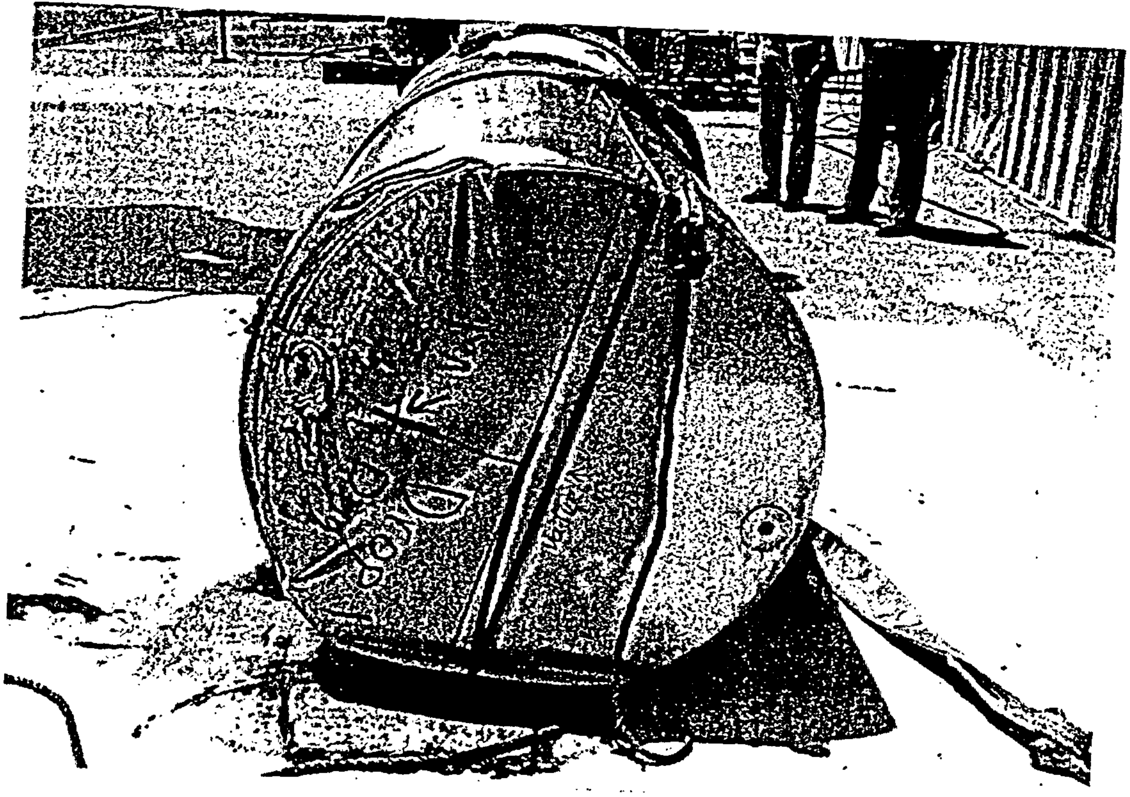


Photo No. 20

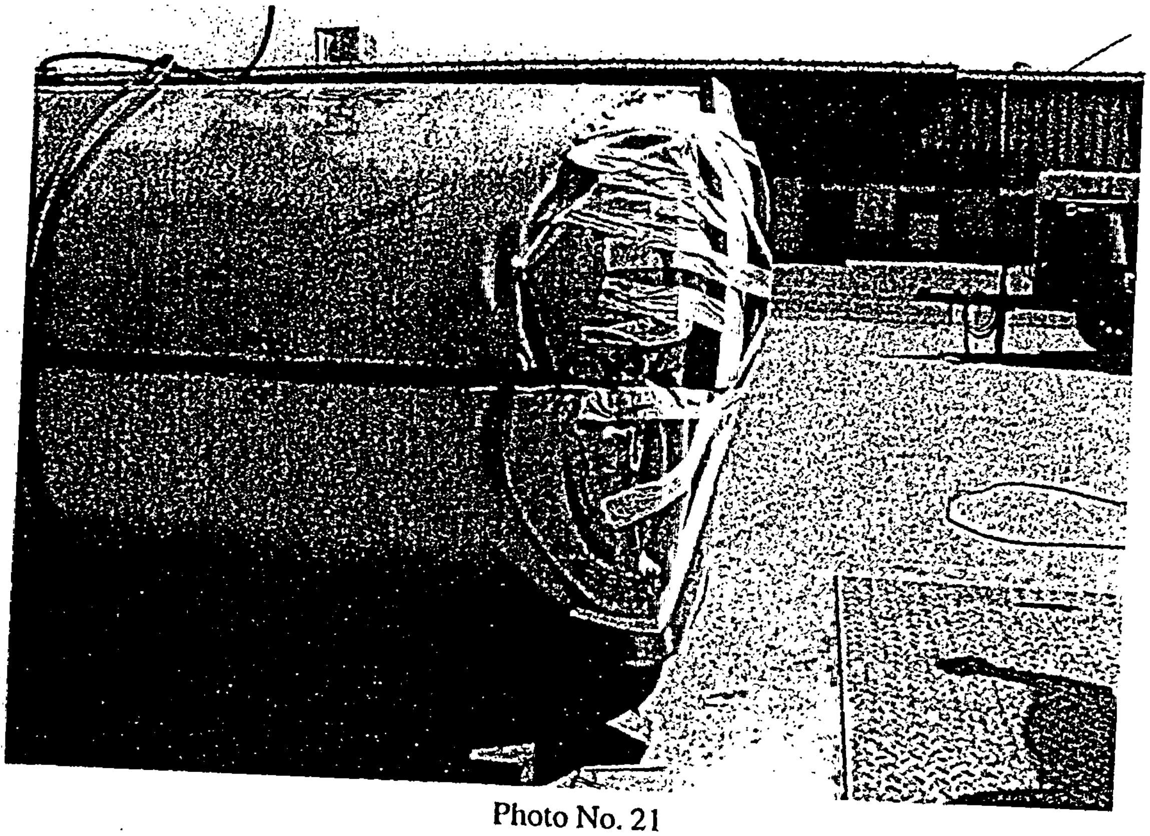


Photo No. 21

Drop B2

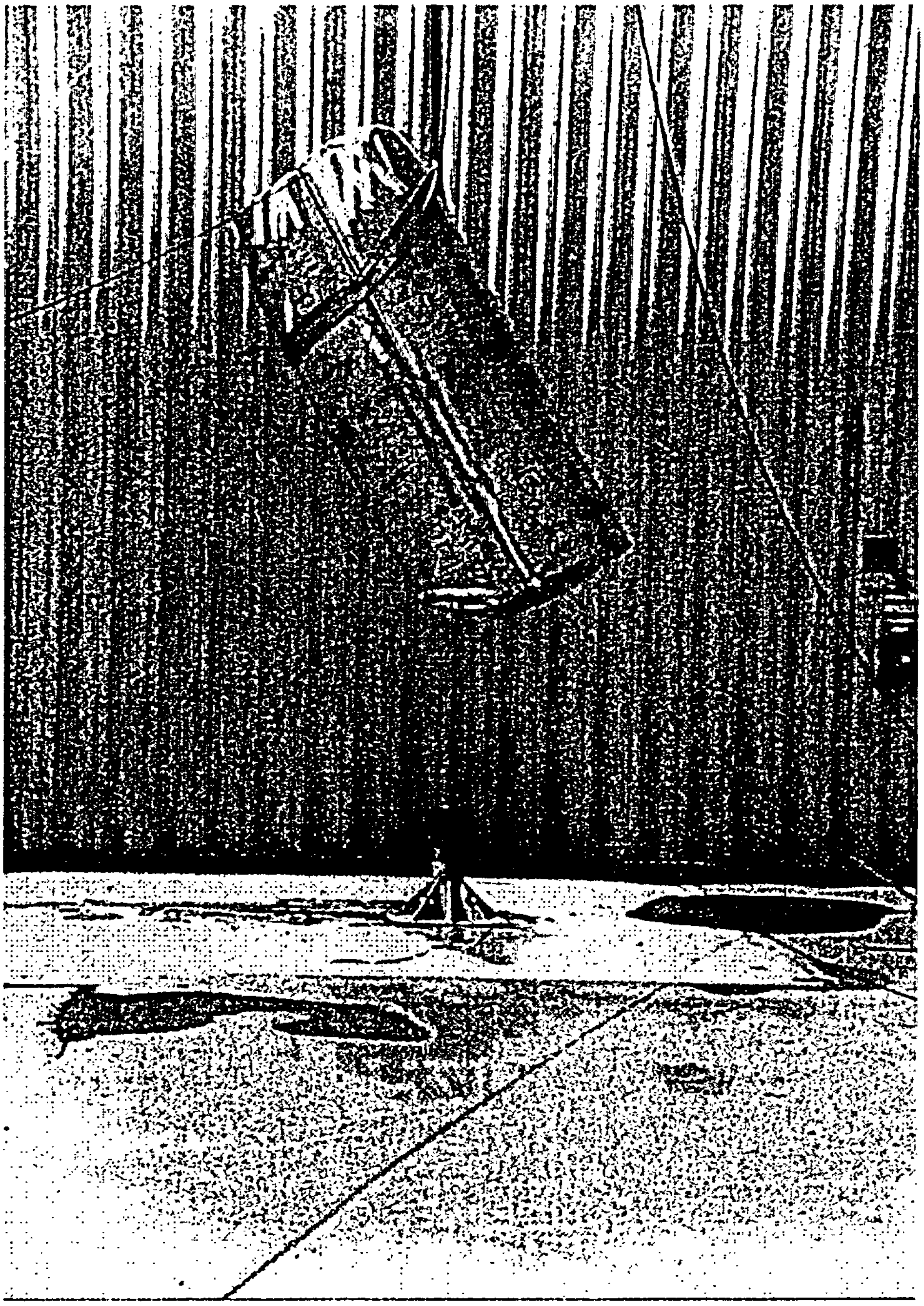


Photo No. 22
Drop B3

Photo No. 23 (B3)

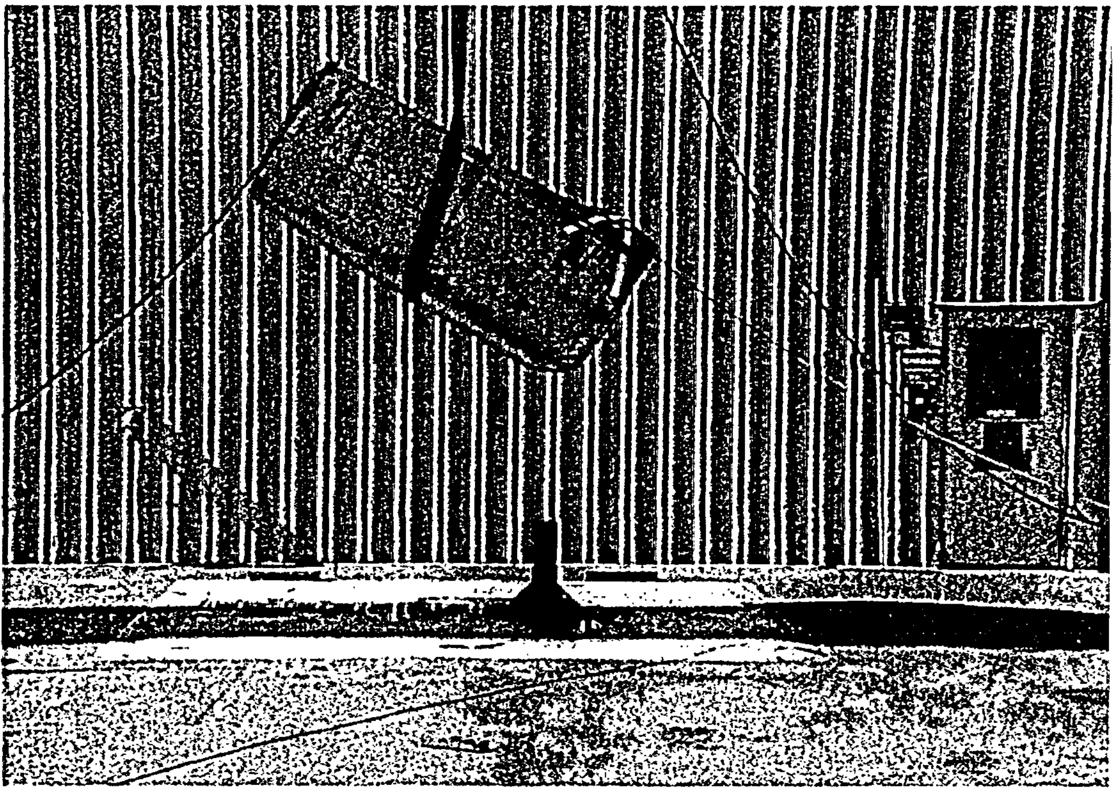


Photo No. 24 (B4)

Drop B3 & B4

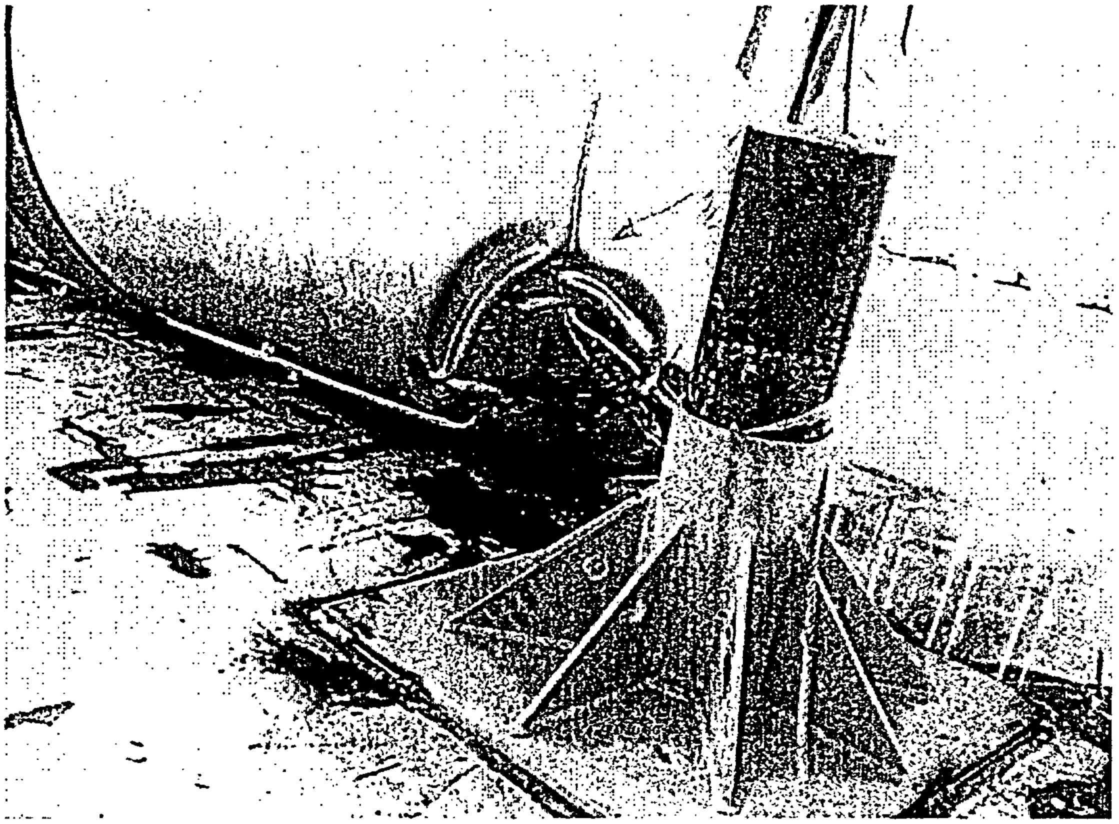


Photo No. 25 (B4)

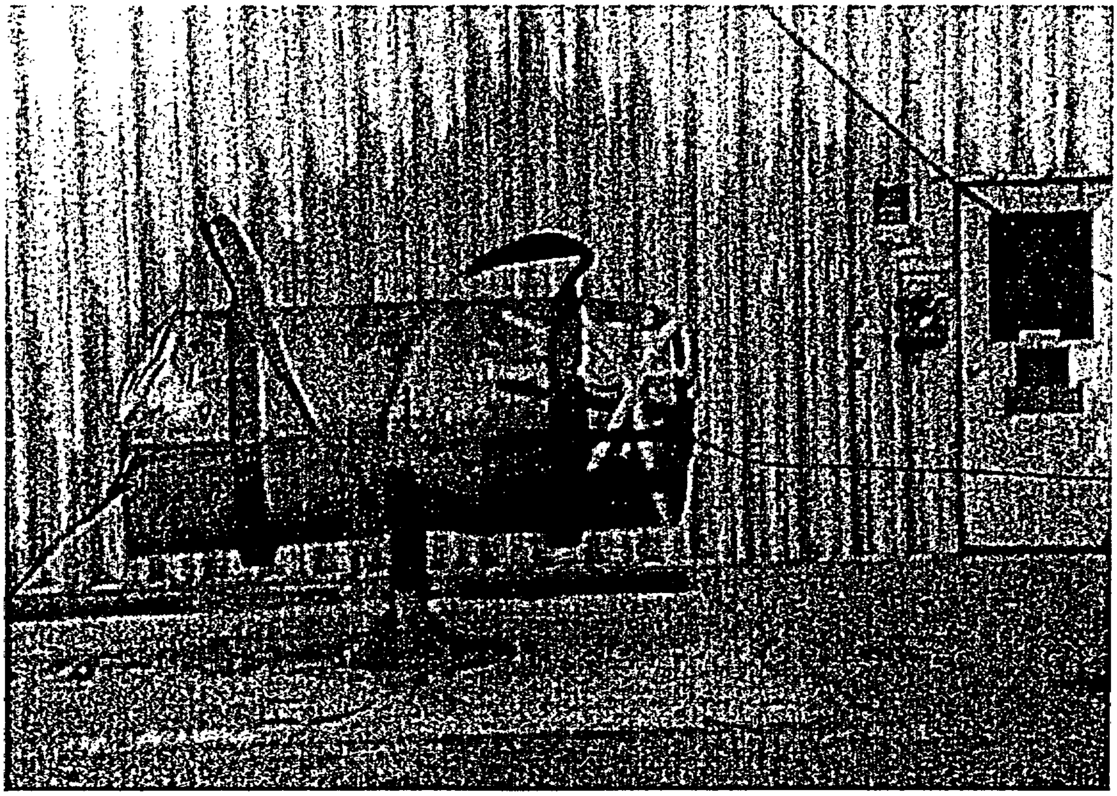


Photo No. 26 (B5)

Drop B4 & B5

Photo No. 27 (B5)

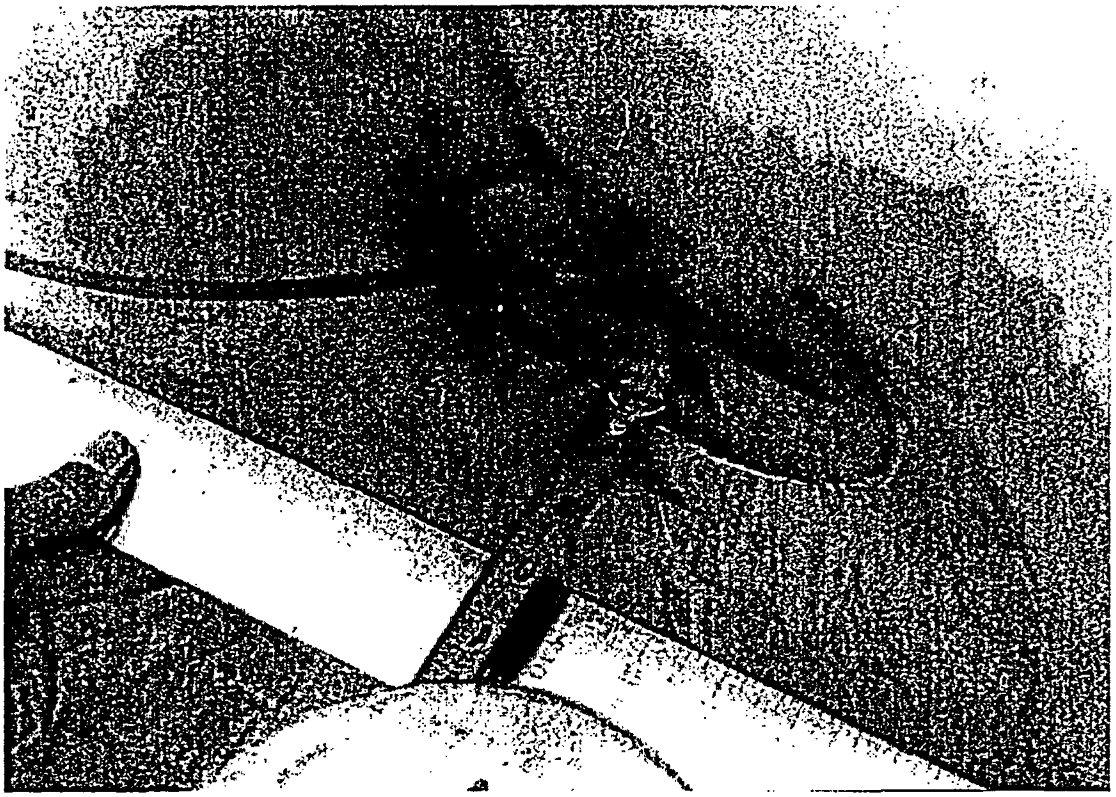


Photo No. 28 (B5)

Drop B5

# APPENDIX 2.10.3

# WEIGHT VARIANCE ANALYSIS OF THE UX-30 OVERPACK

### 2.10.3.1 Introduction

The purpose of this appendix is to provide a basis for permissible weight variances of the UX-30 overpack. These variances are within approved standards and do not compromise the safety of the packaging.

The loaded UX-30 package is composed of three components: the $UF_6$, the Type 30B cylinder, and the UX-30 protective overpack. The $UF_6$ makes up over 60% of the weight; each of the other two components make up less than 20% each. The variance in weight that the package can experience is controlled by the limits imposed on each of these components. Each of these components have limits that are unique.

#### $UF_6$

The $UF_6$ payload is controlled at a maximum weight of 5,020 lbs. $UF_6$ is weighed very accurately to verify criticality control and to account properly for its extremely high-value. This weight takes into account "heels", or material that can not be removed during each unloading. Accurate control of the $UF_6$ payload stipulates accurate weight measurements of the Type 30B cylinders used for shipment.

## Type 30B Cylinder

Type 30B cylinders are built to the specifications of ANSI N14.1. These cylinders are pressure vessels made from relatively heavy, 1/2 and 5/8 inch plate, and provide containment for the package. Tolerances on the vessel itself are relatively large; ± 1/2 inch axially, and ± 1/4 inch diametrically. Plate thickness can vary from - 0.010 to + 0.060 inches. The expected weight of this ASME code stamped vessel is 1400 pounds. Actual weights have been reported as high as 1600 lbs.

## UX-30 Overpack

The UX-30 overpack is fabricated of relatively lightweight material (sheetmetal and polyurethane foam). The total weight of the overpack is influenced significantly by the metal, which makes up about two-thirds of the empty overpack weight. The total overpack weight is more sensitive to the thickness of the material than to its linear dimensions. For example, the weight would vary by less than 8 pounds for a one half-inch change in length of the overpack. In addition, since the overpack must be interchangeable with shipping saddles and all Type 30B cylinders, diametrical tolerances are also tightly controlled. These requirements confirm that dimensionally, weight is controlled by material thickness and density rather than length and diameter. Package weight is most sensitive to material thickness since mill tolerances for thickness have a large relative effect on sheet metal. An example is the 12 gauge stainless steel sheet, which constitutes most of the metal in the overpack. It is specified by ASTM A-240 as 0.1054 ± 0.009 inch in thickness, which can vary overpack weight plus or minus 3.49%. The total foam weight can vary by plus or minus 8.6%, which varies overpack weight by only plus or minus 2.6%.

### 2.10.3.2 UX-30 Overpack Protection Features and Weight Effects

To evaluate the effect of UX-30 weight variance on its performance, the purpose of the overpack must be clear. Once the purpose is understood, the effect on the overpack protective mechanisms can be evaluated. There are three main purposes of the UX-30 overpack: 1) to provide overall thermal protection for postulated accident conditions; 2) to provide impact protection for the valve; and 3) to provide minimum spacing for criticality control. In accomplishing these purposes, it also provides overall impact protection for the cylinder as a containment boundary. Impact protection is secondary, however, since the cylinder has been dropped without the overpack to certify its containment function. For these reasons precise weight distribution between the inner components of the UX-30 and the Type 30B cylinder have not previously been a concern. The concern during qualification testing was to ensure that there was sufficient total package weight to provide an adequate test for the foam and outer skin. In addition, the total weight used in the analysis for lifting and tiedown mechanisms, which did not require testing, was large enough to bound the expected values and had sufficient margin to cover any reasonable variances.

#### Thermal Protection

To provide thermal protection, the UX-30 is designed such that the combination of exterior skin and the foam absorbs the puncture impact energy for the total package without rupturing the skin. The components inside the foam, i.e., the reinforcement, the inner skin, and the Type 30B cylinder, absorb very limited energy. Primarily, these internal components contribute to total package weight, which affects the magnitude of energy that must be absorbed by the outer foam and skin. For a given total package weight, outer skin thickness, and foam density, the foam and outer skin deform identically, regardless of the weight contributor; a heavier Type 30B cylinder, or heavier overpack internal components. Analyzing results from the puncture tests, the combination of foam and outer skin performed as designed to resist puncture. In fact, for the end puncture, considered to have the higher potential for failure, the skin and foam performed successfully, even with the outer skin .004

inch below nominal and total package weight 100 pounds over proposed maximums. A margin of safety is indicated.

## Valve Protection

The outer skin and foam again provide primary valve protection, backed up by the inner backing plate to provide secondary protection. The test results showed that these components provided primary protection since there was no intrusion from puncture, nor was there significant inward collapse of the ends toward the cylinder during other drop events. The 0.25 inch inner backing plate was bowed inward only slightly, yet provided a significant margin-of-safety for valve protection.

## Criticality Control

As shown previously, the total package contains its payload and the overpack does not separate from the Type 30B cylinder; therefore, criticality control is maintained. The number of total packages that may be placed on a truck transport is restricted by weight or volume. Minimum criticality separation is maintained by virtue of the fact that the overpack does not separate.

### 2.10.3.3 Package Weight Analysis

The purpose of this section is to develop an acceptable nominal overpack tare weight and present the weight variance effects to approved material tolerances.

The basic differences between the UX-30 test unit and that specified under Certificate of Compliance 9196 are described in Section of 2.7.1.5. At the time of the original license application, the expected weight of these features was subtracted from the empirically determined test unit weight. The estimation of these component weights was based on the nominal or expected weight of each item. Prior to revision 5 of the C of C, which specified both a minimum and maximum weight, production units were not weighed. It has been determined by production experience that it may be physically impossible to comply with the weight restrictions and previously approved material tolerance requirements of the C of C. Steel industry practice further complicates the weight issue by making it nearly impossible to purchase material that is controlled to tolerances more restrictive than those specified by ASTM for quantities applicable to fabrication of the UX-30. Also, weight variances that can be specifically accounted for and controlled, do not affect package safety. Hence, the purpose of this analysis.

To substantiate permissible weight variations of the UX-30, a detailed analysis of the weight differences between the test and production units was performed. Test unit data was retrieved from as-built fabrication data and a detailed examination of test unit components. This examination included re-weighing and dissection to obtain material thicknesses. Production unit information was obtained from as-built fabrication data.

As documented in the CSAR, the gross weight of the test package was 8,550 pounds, which included a Type 30B cylinder and contents weighing 6,405 pounds. The difference yields a UX-30 overpack weighing 2,145 pounds.

The test package was subjected to a series of qualification tests, which included drop and puncture tests. The test unit also received additional testing to respond to questions during the licensing process. After the completion of the licensing process, the overpack was yet further tested with a shipping saddle arrangement, at the request of a potential customer. To prevent interference with the saddle, the temporary lifting attachments added for the original test were removed. The tested overpack was subsequently re-weighed on September 2, 1992 at 2,049 pounds, which properly reflects the removal of the temporary lifting attachments. Examination also showed that the UX-30 internal end plates were carbon steel, clad with 14 gauge stainless steel. The prototype also had valve protection reinforced on the bottom half that was determined not to be needed since the valve of the 30B cylinder is always shipped upright. Even though the outer skin was not violated due to the puncture, the valve protection reinforcement was left on the upper half. The following are the weight calculations for the test-only features based on actual dimensions where available:

| <u>Test-Only Feature</u> (Attached Proprietary Sketch) | <u>Added Weight</u> |
|---|---|
| 1/2 inch inner end plate in one end | |
| t = 0.507 inches diameter = 35 inches | |
| density = 0.292 $lb/in^3$ | |
| $(35/2)^2$ (p)(0.507 - 0.25)(0.292) = | 72.2 lbs. |
| | |
| 1/4 in. internal shell skirts | |
| length = 12.1 inches t = 0.256 | |
| mean diameter = 31.58 inches | |
| (p)(31.58)(2)(12.1)(0.256)(.292) = | 179.9 lbs. |
| | |
| End Plate Crush Tubes | |
| 10 tubes 3 in. long 2 in. O.D. 1-11/16 I.D. | |
| 3.1 lbs./ft | |
| (10)(3)(3.1)/12 = | 7.8 lbs. |
| | |
| Difference in 12 gauge inner skin tested and 14 gauge specified. | |
| test unit interior length = 82.9 inches | |

shell thickness 0.110

mean shell diameter = 31.210

(31.21 inches)(p) (82.9)(0.1110 - .0751)(0.292) = 82.8 lbs.

End plate cladding

t = 0.076 inches

[(31.1/2)$^2$(p)(2)+(31.1)(2)(0.507+0.256)](.292)(.076) = 34.8 lbs.

Bottom Half Internal Reinforcements

effective length = 28 inches

weight per foot = 12.25 lbs.

(2)(28)(12.25)/(12) = 57.2 lbs.

Weld differences

Circumferential cladding attachment weld

(.707)(31.1)(.13)(p)(0.292)(2) = 5.2 lbs.

Diametrical cladding attachment weld

(31.1)(2)(.076)(4)(.707)(0.292) = 1.9 lbs.

Inner shell welds

[4(82.9)+2(p)(31.1)+2(31.1)]

(.110-.0751)(.707)(0.292) = 4.2 lbs.

Lower half reinforcement attachment

10 inches of 1/8 inch weld per piece

(10)(2)(.125)(.707)(.29) = 0.5 lbs.

Skirt weld

The skirt was attached with a

full penetration weld and a cover 1/4 inch

fillet.

O.D. of skirt = 31.84 inches

Diameter of centroid of weld = 32.0 inches

(32)(.25)(.707)(2)(.292)(p) = 10.3 lbs.

Total extra weld for addition of test features = 24.1 lbs.

Total Test-Only Features Weight = 475.1 lbs.

To obtain an expected UX-30 production weight
the test features must be subtracted: 2,049 lbs.

\- 459 lbs.

Expected Production UX-30 Weight
removing test-only features = 1,590 lbs.

This weight is based on the premise that all test unit material was received at specified thickness. Dissection, measurement of the material thickness, and review of the manufacturing records show that several components varied from the nominal, or specified value. All material was within thickness specifications but did affect the weight.

| Feature Variance | Effect on expected weight |
|---|---|
| Outer Shell 12 gauge (specified 0.1054 ± 0.009 in.)<br>actual - 0.109 | -17.1 lbs. |
| Outer End Cap 12 gauge (specified 0.1054 ± 0.009 in.)<br>actual - 0.101 | + 3.4 lbs. |
| 1/4 in. end plate (specified .240-.300 in)<br>actual - .280 in. | - 8.4 lbs. |
| Foam (specified 8.75 lbs/ft$^3$, allowed 8.0-9.5 lb/ft$^3$);<br>actual 9.43 lbs/ft$^3$. | -36.9 lbs. |
| **Total:** | **- 59 lbs.** |

| | |
|---|---|
| Expected weight of test overpack with test-only features removed | 1,590 lbs. |
| Actual variance from nominal of test unit features | - 59 lbs. |
| "nominal" specification overpack weight | 1,531 lbs. |

The minimum and maximum weight of production units will then vary by the approved allowables for the material:

| | |
|---|---|
| 12 gauge outer shell- 0.1054 ± 0.009 | ± 52.4 lbs. |
| 14 gauge inner shell- 0.0751 + 0.006 | ± 16.3 lbs. |
| 1/4 inch end plates- 0.250 -.010, +.050 | -4.4 lbs., +22.0 lbs. |
| Internal Reinforcements- $^+$2.5% | ± 1.4 lbs. |
| Foam density (8.75 lb./ft$^3$ ± 0.75 lb./ft$^3$) | ± 40.5 lbs. |
| Total: | -115 lbs., + 133 lbs. |

The minimum allowable tare weight becomes:

| | |
|---|---|
| Nominal Weight | 1531 lbs. |
| Low End of ASTM Tolerances | -115 lbs. |
| Minimum Weight | 1,416 lbs. |

In a like fashion, the maximum material tolerance tare weight becomes:

| | |
|---|---|
| Nominal Weight | 1531 lbs. |
| High End of ASTM Tolerances | +133 lbs. |
| Maximum Weight | 1664 lbs. |

### 2.10.3.4 The Effect of Weight Variance

Minimum weight shown in 2.10.3.3 is recognized to be an extreme. It is composed of minimum thickness material in all components. Even at minimum values, the test program provided positive indications that the outer shell will perform. The end plates of the test unit were measured to be .004 to .005 inch below the specified value. Yet these end plates were able to provide puncture resistance for a much heavier package.

The other component critical to package performance is the foam. Again, with the test unit much heavier than normal, the foam did not bottom out in any of the drop orientations. In all orientations there was additional foam that could be crushed. Though the foam density of the test unit was established at 9.43 $lb/ft^3$, performance of the overpack varies only slightly with changes in foam density over the specified range of 8.0 $lb/ft^3$ to 9.8 $lb/ft^3$. Figures 2.10.3-1 and 2.10.3-2, and 2.10.3 provide typical actual stress-strain performance data of UX-30 polyurethane foam densities near the top and bottom of the range. Comparison of curves shows very little difference in compressive strength over the allowed range of foam densities.

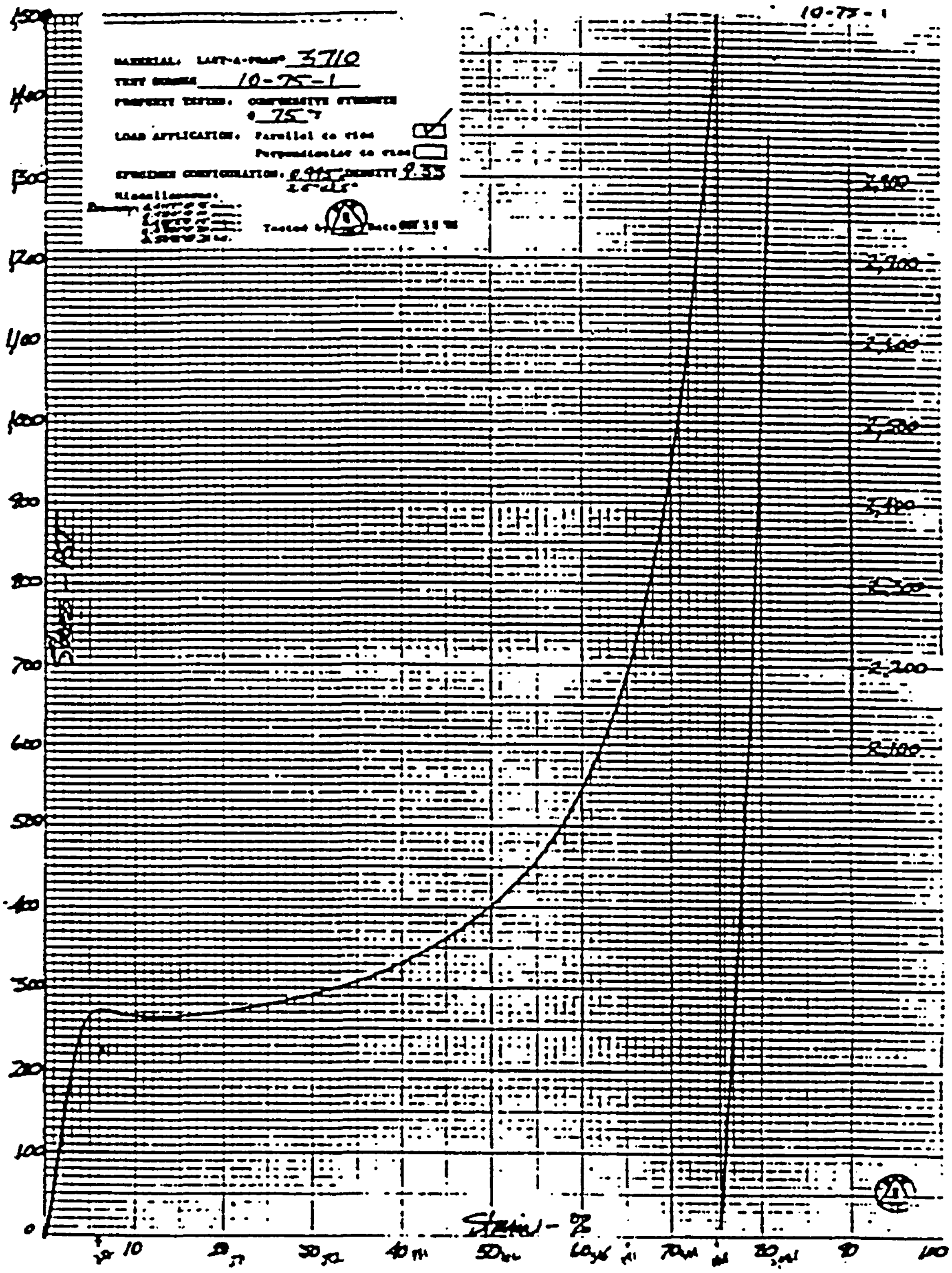
The maximum weight of the overpack, as long as the total package weight is less than the tested weight, has little effect on overall package performance. The maximum theoretical weight of 1,664 lbs. is slightly higher than the maximum weight allowed for the package of 1,650 lbs. This is due to the fact that not all material thicknesses are expected to occur at maximum for any given package.

### 2.10.3.5 Acceptable Weight Variances

The probability of fabricating an overpack with all minimum materials is very low. Therefore, by including allowable dimensional variations in selected components, a reasonable minimum tare weight for the overpack would be 1,450 lbs., with a maximum of 1,650 lbs. A minimum allowable weight is approximately 30 lbs. higher than minimum expected weight since realistically, it is not probable that all materials could be at their minimums. A maximum weight of 1,650 lbs. bounds the maximum expected weight of 1,664 lbs. and is over 250 lbs. less than the overpack in its as-tested condition. These weights are consistent with gained experience in material thicknesses, and are easily achievable when dimensions in selected components are monitored and adjusted. Minimums are established for the thickness of the inner end plates, and the interior shell.

### 2.10.3.6 Conclusion

Polyurethane foam and the outer skin achieve the protective purpose of the UX-30. By analyzing how each component and its weight variations affect the protective capability of the overpack, it has been shown that a minimum overpack tare weight of 1,460 lbs. does not compromise the effectiveness of these protective features. Test results show that nearly all components excluding the outer skin and foam, only contribute to total package weight without adversely affecting overpack performance.



MATERIAL: LAST-A-FOAM® 3710

TEST NUMBER 10-75-1

PROPERTY TESTED: COMPRESSIVE STRENGTH @ 75°F

LOAD APPLICATION: Parallel to rise ☑

Perpendicular to rise ☐

SPECIMEN CONFIGURATION: Ø 9.95 DENSITY 9.33

Miscellaneous: [illegible]

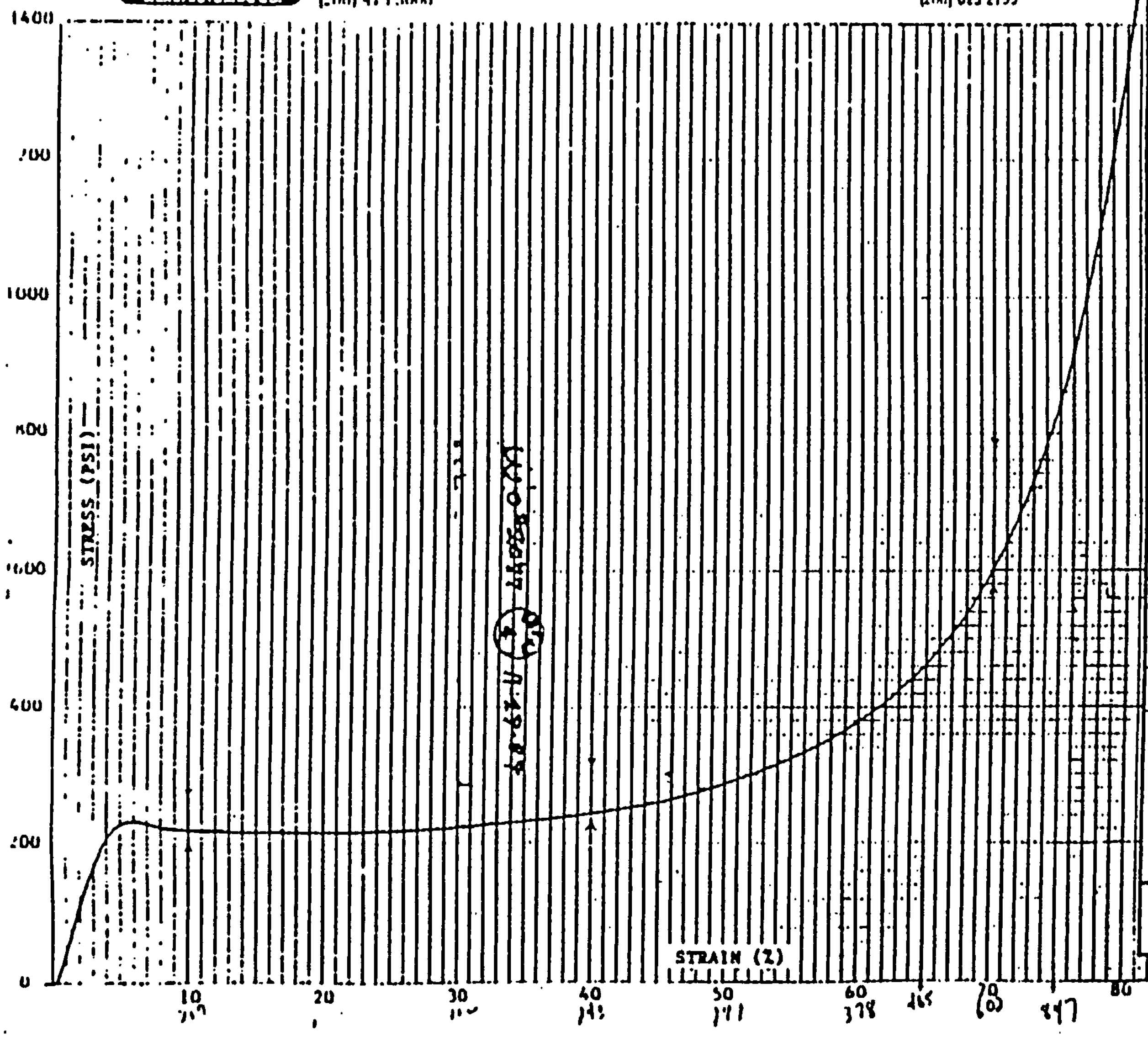
Tested by [illegible] Date [illegible]

Figure 2.10.3-1

MANUFACTURING COMPANY
4910 BURLINGTON WAY/P.O. BOX 9097
TACOMA, WASHINGTON 98409
(206) 473-5000

FAX (206) 473-5104
TOLL FREE FROM
Seattle Renton Area
(206) 623 2795

*DR



MATERIAL:
LAST-A-FOAM FR-3708

PROPERTY TESTED:
COMPRESSIVE STRENGTH AT 75°F

TEST METHOD:
ASTM D-1621; MP1.F22, Rev 5

TEST PARAMETERS:
Crosshead Speed 0.10 in/min.
X-Axis 1.00 Inches
Y-Axis 5600 lbs.
Load Cell 10K# @ 56%
Shunt Calibration
Input Module 165.30
Recorder 56.00
Load
Parallel to Rise ✓
Perpendicular

SPECIMEN CONFIGURATION
1.00" (‖) x 2.00" x 2.00"

NuPak Trupack II

Pour # 1
Pour Date: 11/8/99

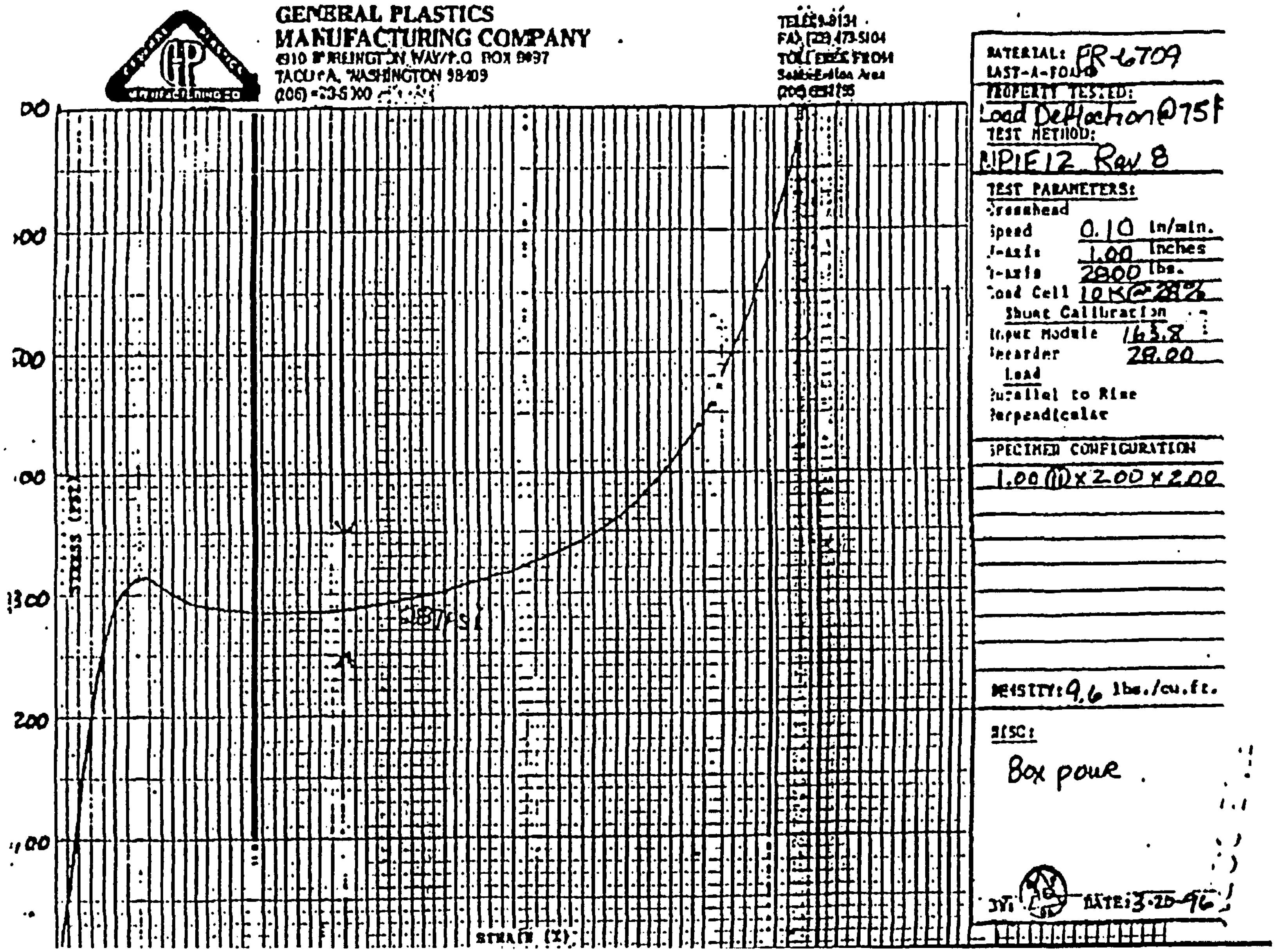
Sample # 1

DENSITY: 8.04 lbs./cu.ft.

MISC: Unit SN: 013
Upper Unit
~~[illegible]~~
P.O. # CB312
SJO: 9430

BY: DATE: NOV 9 1999

Figure 2.10.3-2



**GENERAL PLASTICS MANUFACTURING COMPANY**
4910 BURLINGTON WAY/P.O. BOX 9097
TACOMA, WASHINGTON 98409
(206) 473-5000

TELEX 9-9134
FAX (206) 473-5104
TOLL FREE FROM Seattle-Tacoma Area
(206) [illegible]

MATERIAL: FR-6709
LAST-A-FOAM

PROPERTY TESTED:
Load Deflection @ 75F

TEST METHOD:
NPIE12 Rev 8

TEST PARAMETERS:
Crosshead
Speed 0.10 in/min.
X-axis 1.00 inches
Y-axis 2800 lbs.
Load Cell 10K @ 28%
Shunt Calibration
Input Module 163.8
Recorder 28.00
Load
Parallel to Rise
Perpendicular

SPECIMEN CONFIGURATION
1.00 (T) x 2.00 x 2.00

DENSITY: 9.6 lbs./cu.ft.

MISC:
Box pour

BY: DATE: 3-20-96

Figure 2.10.3-3

# APPENDIX 2.10.4

## Hypothetical Accident Drop Testing

## Overview of Hypothetical Accident Drop Testing (Drop Test, Fire Test and Immersion Test)

Hypothetical accident drop testing was performed at the Rancho Seco Nuclear Power Plant drop test facility on July 21 and 22, 1995.

Drop testing was performed using a UX-30 package fabricated in accordance with current fabrication drawings conforming to the licensing drawings presented in Appendix 1.3.1. A 30B cylinder certified to the requirements of ANSI N14.1 was used as the payload for the test. The cylinder was filled with steel stampings and steel shot to simulate the $UF_6$ payload. A total weight of 5254 lbs. of steel was loaded into the cylinder through the 1" pipe fitting for the cylinder valve. A helium pressure of 16.7 psia was established in the cylinder prior to closure. This allowed for placement of the cylinder in an evacuated vessel for helium leak testing. Thermocouples were placed on the 30B cylinder surface and routed through the parting plane of the UX-30 (See Figure 2.10.4.1 for the location of thermocouples). A helium leak test was performed prior to drop testing. This test confirmed a leak rate of $1.6 \times 10^{-8}$ atm-cc/sec. A detailed listing of package preparation activities is provided in section I of this appendix. The cylinder was inspected per the requirements of the SAR, ORO-651 and ANSI N14.1. The valve protector was removed prior to testing as is required during loading of a cylinder in the UX-30.

The following drop configurations were tested in the order listed below (see Figure 2.10.4.2 for a sketch of the drop configurations and the damage zones associated with each test):

1 - 30 ft drop, Center of Gravity over valve

2 - 30 ft drop, 30 degree slapdown on parting plane

3 - 40 in puncture, Center of Gravity over valve

4 - 40 in puncture, on parting plane

5 - 40 in puncture, horizontal on undamaged area of away from parting plane

Damage due to 30 ft drops is shown as the shaded are of the package in Figure 2.10.4.2. Detailed description of each test and the damage sustained is provided in Section II through VI in this appendix. Pictures of the damaged areas are provided in Appendix 2.10.2.

Subsequent to drop testing the UX-30 was shipped to Richland, Washington for fire testing at the Siemens Fuel Fabrication Facility. The fire test was performed in a 10' x 14' x 12" steel pan. The UX-30 was placed on a fire test stand which allowed the bottom of the UX-30 to be 40" above the surface of the combustible liquid. A sketch of the test stand used in the test is provided in Figure 2.10.4-1. Wind conditions were monitored and verified to be less than 4.5 mph as required by IAEA Series 37. The duration of the test was 30 minutes from the time that complete flame cover was achieved. Thermocouple readings were recorded throughout the fire test and during the cooldown. The maximum observed cylinder temperature was 190 degrees F. Photographs of the fire testing are provided in Figure 3.6.4-2. A detailed description of the fire test is provided in Appendix 3.6.3.

Subsequent to the fire test the 30B cylinder was removed from the UX-30 and inspected for damage. Discoloration of paint near the parting plane was the only damage observed. The cylinder was then placed in a vessel for immersion testing. The vessel was filled with water and maintained a water head of 6 ft of water for over 8 hours. No leakage into the cylinder was noted. The vessel and cylinder were then dried and the vessel evacuated in preparation for the helium leak testing. The helium leak rate was confirmed to be less than 5 x $10^{-8}$ at-cc/sec.

The following is a summary of deviations between the tested configuration and an actual production UX-30 with $UF^6$ payload:

- Weight of payload higher than maximum $UF^6$ payload. Conservative for drop test. No significant impact on fire test.

- Thermocouples mounted on 30B cylinder penetrated weather seal at UX-30 parting plane. This would tend to increase 30B cylinder temperatures, the impact, however would be expected to be small.

- - The testing was performed without a transportation cradle.

- The foam used was in accordance with manufactured in accordance with Chem-Nuclear Specification No. ES-M-170.

- Measurement of differential distance between OD of top of skirt and cylinder OD (ANSI N14.1, Figure 7, Standard Chime Ring Detail) subsequent to completion of testing indicated a dimension o .85" while ANSI N14.1 requires 1" minimum. This measurement was not taken prior to the test. Based on observations of lack of damage to cylinder it can be concluded that the original dimension was approximately .85" no significant deformation toward the cylinder valve occurred as a result of the testing performed.

These deviations are conservative or have minor impact as discussed above. Therefore, the data is expected to conservatively envelope the requirements of 10 CFR 71. The positive test results obtained support qualification of the UX-30 for Type B payloads.

See Appendix 3.6.3 for results of cylinder inspection after drop test, fire test and immersion test.

## I. Drop Test Preparation

### VECTRA Procedure UX-30-TEST-1, Revision 0, 2/17/95

1. Filled 30B cylinder with approximately 5254 lbs. of steel stampings and steel shot. Weighed the loaded 30B cylinder. Verified by qualified QA inspector as 6627 lbs.

2. Installed K type thermocouples per Figure 2.10.5.1 using 304 SS sheathed thermocouple cable.

3. Thermocouple cables routed to minimize impact during drop testing.

4. Installed heat sensitive tape to various locations on the cylinder surface to provide secondary indication of maximum temperatures. These indicators were used to evaluate test response of the 30B cylinder for areas where thermocouple indicators were lost during the drop testing.

5. Performed helium leak test. Performed by qualified QA inspector.

   Verified 30B valve packing nut torque within N14.1 criteria - 90 ft-lbs.
   Verified 30B valve torque and valve plug torque - 350/350 ft-lbs.
   30B cylinder helium pressure - 16.7 psia
   Test chamber pressure - 100 milli-Torr
   Helium Leak rate - 1.6 x 10-8 cc/sec

6. Inspected 30B cylinder per ANSI N14.1, ORO-651 and SAR section 8.2 guidance to baseline pretest configuration. Performed by qualified QA inspector.

7. Verified that the 30B cylinder valve protector was removed prior to placement in UX-30.

8. Placed 30B cylinder in UX-30 overpack.

## II. Drop Test No. 1 - 30 ft Corner Drop Over 30B Cylinder Valve

### VECTRA Procedure UX-30-TEST-2, Revision 0, 7/21/95

1. Oriented package per Figure 2.10.52 for Drop 1 orientation.
2. Installed quick release mechanism.
3. Prepared photographic equipment.
4. Moved thermocouple wire to an area away from impact zone and rigging.
5. Recorded overpack angle. Verified by qualified QA inspector.
   60 degrees from horizontal
6. Installed pre-measured 30 ft. rope.
7. Dampened drop pad and swept to verify no loose debris in the drop area.
8. Raised overpack until pre-measured rope cleared the pad. Verified by qualified QA inspector.
9. Removed pre-measured rope.
10. Ensured package is steady and photographers were ready.
11. Energized quick release mechanism and dropped package.
12. Recorded damage:
    a - Valve corner deformation - 10" along longitudinal axis, 19" along radial axis
    b - Opposite corner deformation - 19" along longitudinal axis, 7" along radial axis

## III. Drop Test No. 2 - 30 ft Slapdown Over Parting Plane

### VECTRA Procedure UX-30-TEST-2, Revision 0, 7/21/95

1. Oriented package per Figure 2.10.5.2 for Drop 2 orientation.
2. Installed quick release mechanism.
3. Prepared photographic equipment.
4. Moved thermocouple wire to an area away from impact zone and rigging.
5. Recorded overpack angle. Verified by qualified QA inspector.
   31 degrees from horizontal
6. Installed pre-measured 30 ft. rope.
7. Dampened drop pad and swept to verify no loose debris in the drop area.
8. Raised overpack until pre-measured rope cleared the pad. Verified by qualified QA inspector.
9. Removed pre-measured rope.
10. Ensured package is steady and photographers were ready.
11. Energized quick release mechanism and dropped package.
12. Recorded damage.
    a - Valve end (secondary impact) deformation - 20.5" along longitudinal axis, 2" along radial axis
    b - Opposite corner (primary impact) deformation - 12" along longitudinal axis, 7" along radial axis
    c - Parting Plane Gap Max - 1"

## IV. Drop Test No. 3 - 40" Puncture at Valve Corner

### VECTRA Procedure UX-30-TEST-2, Revision 0, 7/21/95

1. Oriented package per Figure 2.10.52 for Drop 3 orientation.
2. Installed quick release mechanism.
3. Prepared photographic equipment.
4. Moved thermocouple wire to an area away from impact zone and rigging.
5. Recorded overpack angle. Verified by qualified QA inspector.
   60 degrees from horizontal
6. Dampened drop pad and swept to verify no loose debris in the drop area.
7. Raised overpack until height was greater than pre-measured 40" rod height. Verified by qualified QA inspector.
8. Ensured package is steady and photographers were ready.
9. Energized quick release mechanism to drop package.
10. Recorded damage:
    a - Puncture Depth - 1"
    b - Cone Diameter - approximately 12"

Note:The pin was welded to the pad (Figure 2.10.4-2)

## V. Drop Test No. 4 - 40" Puncture at Slapdown Drop Primary Impact Area

### VECTRA Procedure UX-30-TEST-2, Revision 0, 7/21/95

1. Oriented package per Figure 2.10.5.2 for Drop 4 orientation.
2. Installed quick release mechanism.
3. Prepared photographic equipment.
4. Moved thermocouple wire to an area away from impact zone and rigging.
5. Recorded overpack angle. Verified by qualified QA inspector.

   30 degrees from horizontal
6. Dampened drop pad and swept to verify no loose debris in the drop area.
7. Raised overpack until height was greater than pre-measured 40" rod height. Verified by qualified QA inspector.
8. Ensured package is steady and photographers were ready.
9. Energized quick release mechanism to drop package.
10. Recorded damage:

    a - Puncture Depth - 2"

    b - Cone Diameter - approximately 12"

Note:The pin was welded to the pad (Figure 2.10.4-2)

## VI. Drop Test No. 5 - 40" Puncture at Center of Undamaged Base

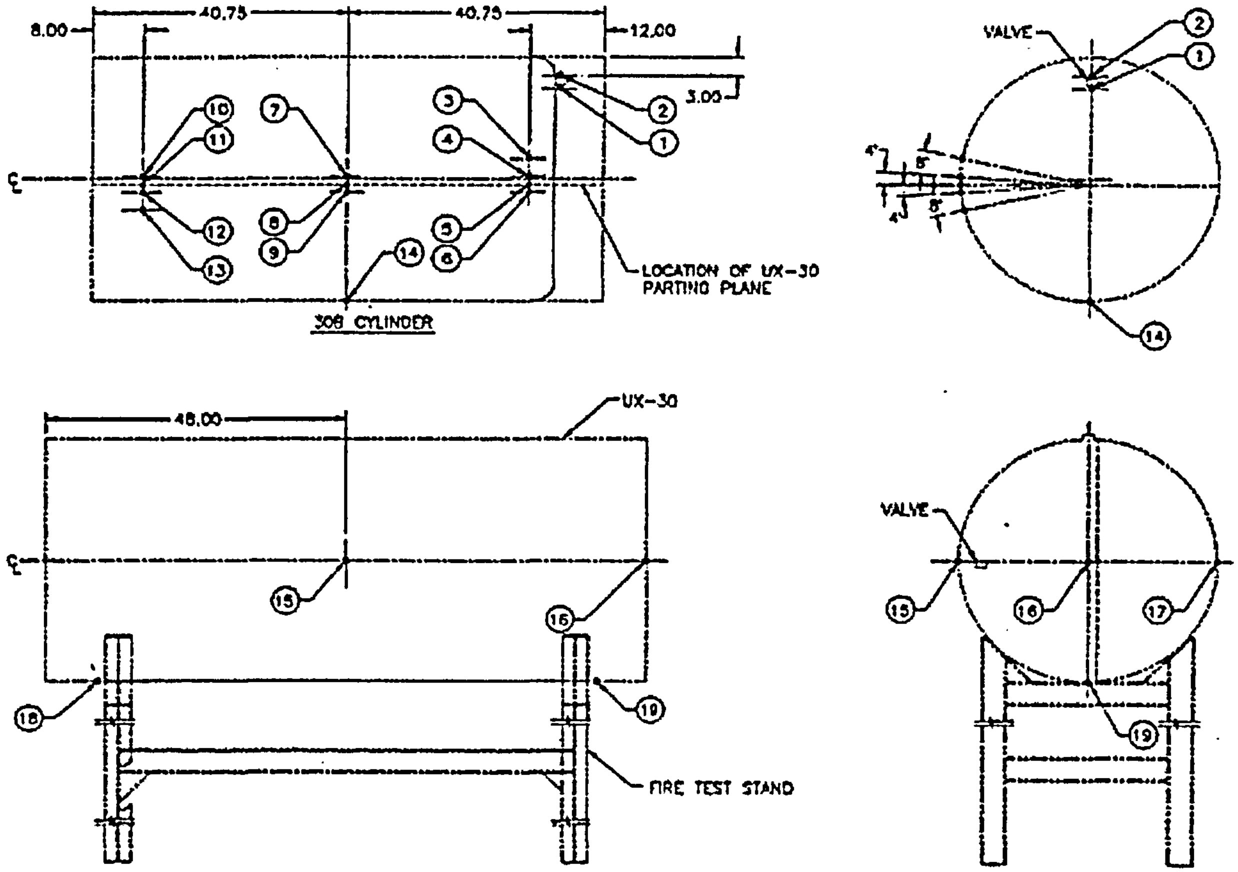
### VECTRA Procedure UX-30-TEST-2, Revision 0, 7/21/95

1. Oriented package per Figure 2.10.52 for Drop 5 orientation.
2. Installed quick release mechanism.
3. Prepared photographic equipment.
4. Moved thermocouple wire to an area away from impact zone and rigging.
5. Recorded overpack angle. Verified by qualified QA inspector.
   0 degrees from horizontal
6. Dampened drop pad and swept to verify no loose debris in the drop area.
7. Raised overpack until height was greater than pre-measured 40" rod height. Verified by qualified QA inspector.
8. Ensured package is steady and photographers were ready.
9. Energized quick release mechanism to drop package.
10. Recorded damage.
    a - Puncture Depth - 3"
    b - Cone Diameter - approximately 25"

Note:The pin was welded to the pad (Figure 2.10.4-2)

A Helium leak test performed by placing the 30B cylinder inside a test chamber and drawing a vacuum on the chamber. The leak test performed by a qualified QA inspector.

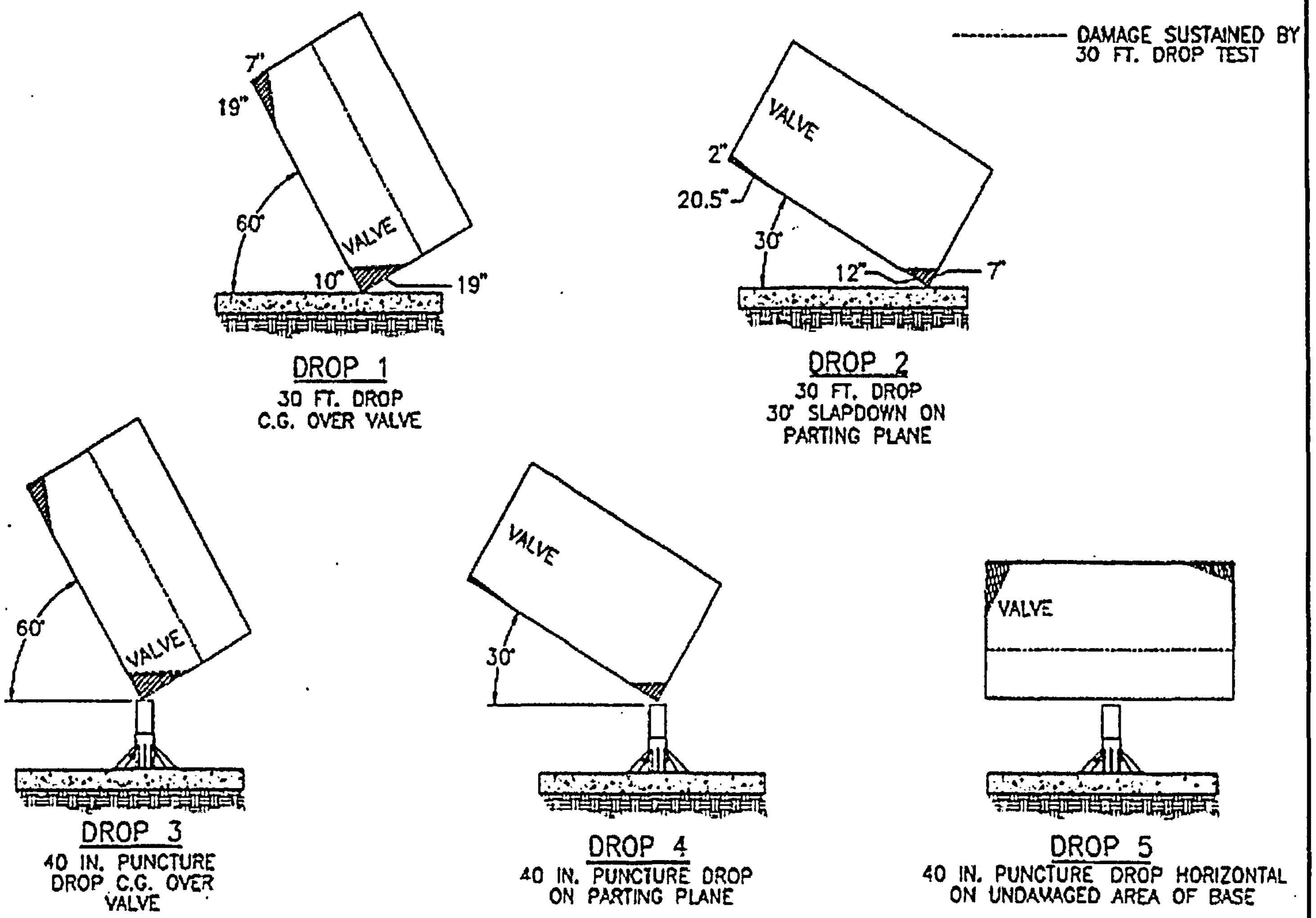
Helium Leak Rate = $4.2 \times 10^{-8}$ cc/sec (leaktight per ANSI N14.5)



NOTE: CHANNELS 3, 7, 8, 9, 11 & 12 WERE DAMAGED DUE TO DROP TESTING AND WERE UNAVAILABLE FOR FIRE TEST.

Figure 2: TYPE B FIRE TEST THERMOCOUPLE LOCATIONS

Figure 2.10.4-1



DROP 1
30 FT. DROP
C.G. OVER VALVE

DROP 2
30 FT. DROP
30° SLAPDOWN ON
PARTING PLANE

DROP 3
40 IN. PUNCTURE
DROP C.G. OVER
VALVE

DROP 4
40 IN. PUNCTURE DROP
ON PARTING PLANE

DROP 5
40 IN. PUNCTURE DROP HORIZONTAL
ON UNDAMAGED AREA OF BASE

Figure 1: SUMMARY OF UX-30
TYPE B DROP TEST ORIENTATIONS

Figure 2.10.4-2

# APPENDIX 2.10.5

# Regulatory Testing of the 30C $UF_6$ Cylinder

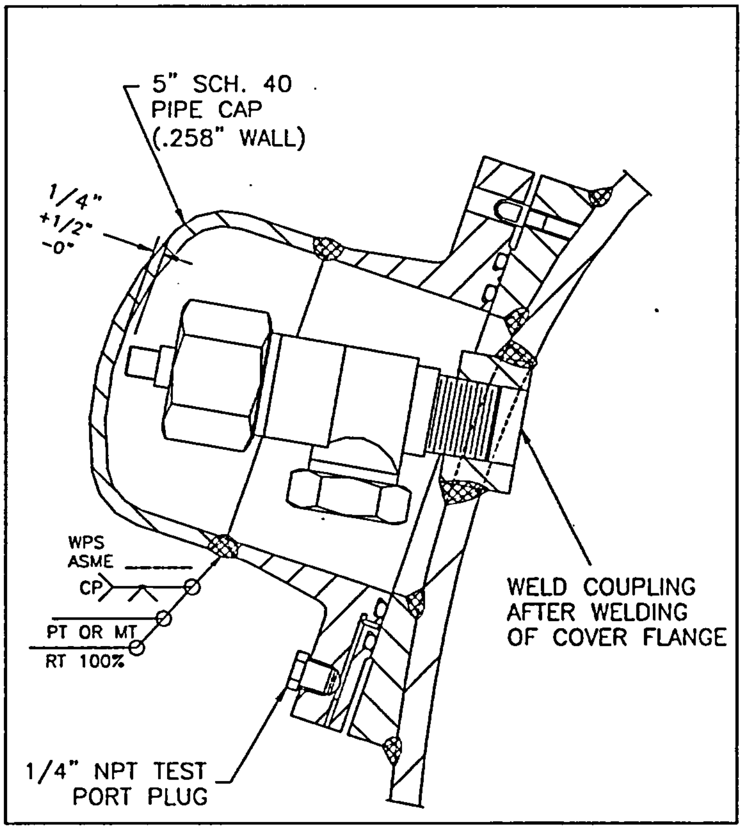
# Glossary of Acronyms and Terms

| | |
|---|---|
| CBC | The Columbiana Boiler Company |
| CBC Watertight™ | A trademark for metal containers for the shipment and storage of chemical materials, including $UF_6$ |
| CBC Watertight™ Cylinder | A 30B cylinder fitted with a VPC and having 100% verified welds (equivalent to the standard 30C cylinder) |
| ESP | Eco-Pak Specialty Packaging, a wholly-owned Division of CBC |
| ESP 30X | Type B Package with a filled $UF_6$ cylinder (USA/9284/BF-85) |
| HAC | Hypothetical Accident Conditions as defined by 10CFR71 |
| NOC | Normal Conditions of Transport as defined by 10CFR71 |
| NRC | The U.S. Nuclear Regulatory Commission |
| Standard 30B cylinder | A standard 2-1/2 ton $UF_6$ cylinder, as defined in USEC-651, Rev. 8 |
| TI | Transportation Index |
| $UF_6$ | Uranium Hexafluoride |
| UX-30 | Type A Package with a filled $UF_6$ cylinder (USA/9196/AF-85) |
| VPC | Valve Protection Cover, designed to provide a water-tight enclosure around the cylinder valve, effectively excluding water from the cylinder valve for the immersion depth required by 10CFR71 for fissile packages. |

## Executive Summary

CBC's 30C Cylinder features a Valve Protective Cover (VPC) to augment the 30B $UF_6$ cylinder shipped in UX-30s. The objective of the VPC is to provide enhanced assurance that the $UF_6$ cylinder shipped in the UX-30 remains free of water inleakage during transport, thus allowing the assignment of a reduced TI for criticality consistent with recent evaluations. Specifications for the 30C are in Addendum 2-2004 for ANSI N14.1.

Extensive qualification testing has been completed for the Standard 30B cylinder in the UX-30 without the VPC in place. The results of these tests demonstrate that the UX-30 maintains the cylinder's containment boundary in a leak-free condition during and following NOC and HAC. There was no deformation reported for the Standard 30B cylinder in the UX-30 at the valve or chime locations. Fire testing of a Standard 30B cylinder in a UX-30 indicates that the average maximum temperature of the Standard 30B cylinder does not exceed 200°F at any time for the regulatory specified fire conditions.



**Valve Protective Cover**

The 30C Cylinder is nearly identical to the Standard 30B cylinder. The tare weight of the 30C Cylinder is well within the allowable for the Standard 30B cylinder; both the Standard 30B cylinder and the 30C Cylinder are within the gross weight limitation of the UX-30 (USA/9196/AF-85). The VPC fits within the envelope of the cylinder chime; thus, it does not encroach upon the nominal clearance between the cylinder and the UX-30 inner shell. The dimensional envelope of the 30C Cylinder is the same as that of a Standard 30B cylinder. Additionally, the O-rings utilized in the VPC are serviceable to 400°F; thus, the O-ring seal will not degrade at the temperatures reported for a HAC fire. Thus, the free drop and fire test results for the Standard 30B cylinder in a UX-30 are also applicable to the 30C Cylinder in the UX-30.

However, in order to verify the performance of the 30C Cylinder under the NOC and HAC drop events proscribed by 10CFR71, a series of drop tests were completed using a full-scale 30C Cylinder prototype in a UX-30. The results demonstrated that the VPC is capable of maintaining a water-tight seal around the cylinder valve during NOC and HAC. The cylinder valve did not contact any other component of the packaging during or following the test sequence, and the VPC O-rings remained leak-free prior to and following the test sequence. Additionally, the total effective volume of the packaging was maintained to within 95% of the original, the effective spacing of the fissile contents remained unchanged, and the packaging remained closed, effectively excluding the entry of a 10 cm (4 in) cube. There was no loss or dispersal of the simulated contents, no changes to the packaging that would result in a significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. Thus, the design satisfies the regulatory requirements for licensing of the packaging.

## 1.0 Scope and Objectives

The series of drop tests performed, as shown in Figures 1*a* to 1*c*, encompassed both NOC and HAC as required by 10CFR71, with the exception of the water spray test, the penetration rod drop test, and the fire test. The test series was conducted to demonstrate:

- The cylinder valve does not contact any other component of the packaging during and following the test sequence, and
- The VPC O-rings remain leak-free prior to and following the test sequence.

Additionally, although the UX-30 has been tested previously, the test series was conducted for the UX-30 with the 30C Cylinder payload to demonstrate:

- No more than 5 percent reduction in the total effective volume of the packaging on which nuclear safety is assessed;
- No more than 5 percent reduction in the effective spacing between the fissile contents and the outer surface of the packaging;
- No occurrence of an aperture in the outer surface of the packaging large enough to permit the entry of a 10 cm (4 in) cube; and
- No loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging.

## 2.0 Drop Test Pad

The drop test was conducted on CBC's pad located at CBC's Ohio office. It is an 8' x 24' x 4'-6" deep reinforced concrete slab embedded in the ground. It weighs approximately 129,600 lb and consists of 3,000 psi concrete reinforced with ASTM A-615 Gr. 60 rebar. The upper surface of the pad is covered by a 1-1/4" thick A36 carbon steel plate.

## 3.0 Instrumentation and Measurements

All length measurements, with the exception of diameters, were made using a standard 25-foot tape measure having 1/16-inch graduations. Diameter measurements were made using a diameter tape having 1/64-inch graduations. The package attitude was measured using a magnetic angle locator that was graduated in 1-degree segments. The magnetic angle locator was not formally calibrated; however, the instrument was checked for accuracy with a 3-foot carpenter's bubble level and was found to be accurate within 1 degree. Video recording equipment was used to provide a record of the test, and photographs of the accumulated damage were taken following each drop event. The external accumulated damage sustained was measured and recorded following each drop. In addition, the accumulated interior damage was measured and recorded following the completion of the test sequence. Leakage testing of the VPC seals was accomplished using a gas pressure rise procedure. This procedure is described in detail in Section 6.1.

## 4.0 Test Prototype

A full-scale representative prototype was used for the test series.

### 4.1 30C Cylinder

Pre-test Inspection data is recorded on Figure 2.

The 30C Cylinder (CBC#3436) was fabricated and qualified to the standards set forth in ANSI N14.1, with the exception that the interior and exterior surfaces were not grit blasted and inspected for cleanliness. The VPC assembly was fabricated and installed on the cylinder using quality measures that will be applied to the same mass-manufactured items, as practicable. Prior to the drop test, the cylinder chime was bent and repaired adjacent to the valve to simulate the worst-case chime condition. The empty 30C Cylinder (with the VPC in place) weighed 1432 lb. Prior to the test, the cylinder was measured and visually inspected for damage, including dents, creases, weld flaws, and corrosion. No damage was noted, with the exception of the repaired chime.

### 4.2 UX-30

The UX-30 (ESP#0248) was fabricated using the dimensions, quality measures, and qualification tests detailed in the current SARP for the packaging, with the exception that several small brackets were welded to the outer skin of the UX-30 cover to allow for handling during the test. The as-fabricated weight of the UX-30 cover and bottom were 793 and 671 lb, respectively. The pretest weight of the UX-30 cover and bottom were 797 and 671 lb, respectively. The 4 lb weight gain of the cover is attributed to the handling brackets. The average foam density in the UX-30 was 9.14 pcf, and its average compressive strength was 281 psi. Therefore, the density and the compressive strength of the foam were both approximately average for the packaging allowable variation. The package's support saddles were not attached during testing, as previous tests demonstrate that the saddles act to protect the package.

Prior to the test, the UX-30 was visually inspected for damage, including dents, creases, weld flaws, and corrosion. All findings were recorded on the Pre-Test Inspection sheet, as shown in Figure 2. The UX-30 had sustained some damage during its service lifetime: the lift lugs at each end of the cover were dented, and the area surrounding was depressed (approximately 3"L x 2"W x 9/16"D) as noted on Figure 2.

## 4.3 Simulated Payload

The 30C Cylinder was loaded with 5329 lb of lead shot, 309 lb more than the maximum allowable payload weight. Although many previous tests used lead shot in paraffin to simulate the payload, this test utilized lead shot only.

## 5.0 Initial Conditions

## 5.1 Temperature

The demonstration of compliance with the requirements of 10CFR71 and 73 must be based on the ambient temperature preceding and following the tests remaining constant at that value between -29°C (-20°F) and +38°C (+100°F) which is most unfavorable for the feature under consideration.

For the 30C Cylinder, the selection of the package initial temperature considered four key components: the stainless steel UX-30 skin, the UX-30 polyurethane foam, the steel 30C Cylinder, and the Viton O-ring seal. The Viton O-ring exhibits stable mechanical material properties over the regulatory range of initial condition test temperatures, and is therefore not the critical component for temperature selection. The stainless steel's mechanical material properties do not change appreciably over the range of temperatures considered. The carbon steel used to fabricate the CBC Watertight™ cylinder is impact tested to assure that the toughness is maintained throughout the temperature range of interest. However, the polyurethane foam used exhibits a marked decrease in strength as the temperature is increased at all strain levels.

For the NOC and HAC free drops, the extent of the resultant deformation is largely dependent on the foam strength. For the HAC puncture drop, the maximum damage is usually attained when the skin of the package is breached, and is thus dependent on the UX-30 steel strength and ductility. Because the UX-30 skin material properties remain essentially constant, the critical component is thus determined to be the polyurethane foam. Since its compressive strength is lower at higher temperatures, an initial ambient temperature of +100°F presents the worst regulatory condition. The local ambient temperature at the test location was approximately 87°F preceding the test. The difference in the foam strength between 87°F and 100°F is negligible; therefore, no artificial heating was applied pre-test.

## 5.2 Initial Conditions – Internal Pressure

The applicable federal regulations state that the initial internal pressure within the containment system must be considered to be the maximum normal operating pressure, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable.

The UX-30 is not a closed system; therefore, the applicable pressure for the UX-30 is atmospheric pressure. On the other hand, the 30C Cylinder normally operates at a pressure below atmospheric. However, the cylinder is more vulnerable during impact when the cylinder is positively pressurized. A positive internal pressure provides additional stiffness to the cylinder, damping the flexibility of the structure and redirecting the impact energy to plastic deformation. Additionally, the presence of a cylinder vacuum may have provided erroneous leakage test measurements, had the cylinder valve seal been compromised during the test. Also, applying a positive pressure to the cylinder allowed for pre- and post-test leakage testing of the cylinder valve using a soap bubble test without operating the cylinder valve. Finally, the presence of a positive pressure within the cylinder provided an additional check for cylinder leakage by measuring the cylinder pressure before and after the series of drop tests. Therefore, the cylinder was pressurized to approximately 140 psig prior to the test.

## 6.0 Test Procedure

### 6.1 Package Assembly

After the cylinder was filled with lead shot, the cylinder valve was installed. The package was then pressurized to approximately 140 psig and tested for leakage using a soap bubble test (estimated sensitivity of $1 \times 10^{-3}$ std-cc/sec). No leaks were found.

Next, the internal and external surfaces of the VPC (excepting the flanges) were coated with approximately 1/4" of white window glazing compound. The purpose of the glazing compound was to indicate contact with other parts of the package during impact. Addition of the glazing material did not provide any additional strength to the VPC.

After applying the glazing material, the O-ring was inspected for flaws. The O-ring was then seated into the O-ring groove machined into the surface of the VPC flange. The surfaces of the O-ring were lightly coated with a silicone-based lubricant/sealant specifically made to aid in seating O-ring seals. Any excess O-ring sealant was removed from the O-ring and flange surfaces using a clean rag. The VPC was then attached to the mating flange on the cylinder. Bolts with washers were placed at each of the six bolt locations, and each was torqued to 30 ft-lbs, alternating sides. Following bolting, the O-ring seal was leakage tested.

### 6.1.1 VPC O-ring Leakage Tests

The O-ring seal was leak tested using a gas pressure rise method having a minimum calculated sensitivity of $5 \times 10^{-6}$ std-cc/sec. The gas pressure rise test procedure incorporates the use of a calibrated volume (52cc), a 2 to 0.001 Torr pressure sensor having an accuracy of 3 mTorr, and a 2 to 1500 Torr pressure sensor having an accuracy of 2 Torr. Use of the calibrated volume allows a very accurate measurement of the air volume between the o-ring seals and in the test equipment at the beginning of the test.

The pass/fail leakage rate of $1 \times 10^{-5}$ std-cc/sec is equivalent to 8 mTorr-cc/sec. Thus, for the measured volume of the test equipment (on the order of 25cc), the change in pressure indicating a leakage rate of $1 \times 10^{-5}$ std-cc/sec is about [(8mTorr-cc/sec)(25cc)] = 1mTorr every 3.3 seconds.

In this case, the primary factor influencing the sensitivity and applicability of the gas pressure rise test is the internal volume of the system being tested – the sensitivity varies inversely with test volume, thus a smaller volume yields a much higher sensitivity. Additionally, the system is evacuated to near vacuum prior to the test. The low absolute pressure allows a higher resolution for pressure change measurement during the test.

Because the equipment air volume is measured every time the test is performed, variations due to temperature are captured. Temperature variations over the span of the test itself (<10 minutes) are considered negligible. The sensitivity of the gauge used is 3 mTorr. Thus, the pressure must be monitored over at least 13 seconds to achieve the leakage test sensitivity of $5x10^{-6}$ ref-cc/sec. The Model No.195 pre- and post-test leakage test pressures were monitored for several minutes.

The average pressure increase over the test is used to determine the leakage rate. Out-gassing from the o-rings is minimized by evacuating the test volume for several hours prior to the test being performed. It should be noted, however, that out-gassing errs on the conservative side, indicating a larger leakage rate than actual.

Prior to implementation, the uncertainty of the calculated pass/fail criteria (nominal) was estimated using the Kline-McClintock Method. The overall uncertainty is on the order of 5% (±0.14 sec, or 1mTorr rise for every 3.149 to 3.429 sec). The overall uncertainty is primarily influenced by the calibrated volume uncertainty (±2.5cc), which represents the largest relative uncertainty value for the equipment used. However, the duration of the test more than offsets this uncertainty value.

### 6.1.2 Loading the 30C Cylinder into the PSP

The cylinder was then loaded into the UX-30 PSP. This was accomplished in the reverse position, loading the cylinder into the cover, rather than the bottom, to allow the position of the valve to be marked on the exterior of the UX-30 for more accurate positioning during the drop testing. The valve was oriented in the 12 o'clock position (had the package been upright).

## 6.2 Drop Test Orientation and Sequence

In order to determine the worst-case drop orientation, previous testing results for several similar packages (including the UX-30 PSP) were evaluated. Three orientations were identified by these sources as the potential worst-case: center-of-gravity over corner (cgc), center-of-gravity over valve (cgv), and a 30-degree slapdown onto the parting plane (slapdown).

In order to determine which orientation caused the largest deformation, the reported results for each of the previous tests were used to calculate the actual package deformation of the PSP directly above the valve. Table 1-Supplimentary provides a tabular form of the data. As shown in Figure 1-Supplimentary, the total deformation depth resulting from a cgc drop was expected to be greater than the other orientations considered. Since the objective of the test was to produce the largest damage in the vicinity of the valve, it was determined that the cgc drop was appropriate for testing the Watertight™ Cylinder. This angle was determined to be 27° from vertical.

Figures 1*a* to 1*c* provide an illustration of the sequence and geometry of the tests that were performed. The impact point for the free drops was at the edge location nearest the valve. The puncture impact site was directly above the valve location, slightly off-center of the VPC. This location was easily targeted, since it was marked on the exterior of the UX-30 prior to closure.

The packaging was positioned for angle and rotation on the ground, and the rigging was locked in place after the required orientation was accomplished. The distance from the lowest point of the test article to the impact surface was determined using a plumb bob, string, and a standard 50-foot tape measure. A quick-release device was used to release the packaging without imparting rotational motion.

## 7.0 Data Collection/Observations

Figures 4 though 30 provide photographic documentation of the test.

## 7.1 Pre-drop Leakage Testing

The VPC O-rings were tested prior to the drop tests. The measured leakage rate was 7 mtorr/minute, which correlates to 3.4 $x10^{-6}$ atm-cc/sec. The leakage rate was monitored for more than 10 minutes, and the leakage rate remained stabilized throughout the test period.

## 7.2 NOC Free Drop

Following leakage testing, the package was transported to the test pad. The package was moved into position for the NOC Free Drop. The package was dropped from an elevation of 48", at an attitude of 27.5 degrees, onto the package corner nearest the valve. The package was permanently deformed 3.5" longitudinally and 8" radially at the impact site. The slapdown that followed the initial impact caused the handling brackets to be pushed into the overpack approximately 0.5". All welds remained intact, the package remained closed, and the package outer skin was not breached.

## 7.3 HAC Free Drop

Following the NOC Free Drop, the package was moved into position for the HAC Free Drop. No repairs or modifications were made to the package. The package was dropped from an elevation of 30', at an attitude of 27 degrees, onto the package corner nearest the valve (same impact site as the NOC Free Drop). The accumulated permanent deformation extended 11" longitudinally and 18" radially. A secondary impact occurred at the opposite end and corner from the initial impact, deforming the package approximately 1.75". All welds remained intact, the package remained closed, and the package outer skin was not breached.

## 7.4 HAC Puncture Drop

Following the HAC Free Drop, the package was moved into position for the HAC Puncture Drop. No repairs or modifications were made to the package. A 6"OD x 18" mild steel puncture pin was bolted in place on the drop pad.

The package was dropped from an elevation of 58" (40" above the 18" tall puncture pin), at an attitude of 27 degrees, onto the site directly above and slightly off-center of the VPC. The puncture pin indented the package outer skin a maximum of 1.5", perforating the outer skin over approximately 5" of the pin circumference.

In addition to the primary pin impact, a secondary impact mark appeared. The secondary pin imprint was triangular, rather than circular; thus, it appears that the package bounced after the primary impact and landed a second time on the puncture pin at a skewed angle. There did not appear to be additional damage to the off-end of the package due to the final slapdown. All welds remained intact, and, with the exception of the puncture pin tear, the package outer skin was not breached. The packaging remained closed. A single closure pin was wedged in place.

## 7.5 Post-Drop Internal Damage Measurements

Following completion of the drop sequence, the UX-30 was opened. The wedged closure pin had to be cut to allow the package to be opened. It appeared that the interior wall of the UX-30 at the impact locations had deformed both elastically and plastically. A significant amount of clearance (approximately 1") was visible between the VPC and UX-30 wall; however, it was clear that they had made contact during impact, since the glazing material was missing from the top of the VPC and traces of it were on the UX-30 wall. Additionally, the VPC left a small, dished impression in the buckled UX-30 interior wall at the impact site, approximately 0.125" deep. No damage was visible on the VPC. The UX-30 interior wall was bowed inward across the entire end of the cover approximately 0.625". The location of the puncture pin impression was measured, as was the impression left by the VPC. A comparison of these two impression locations shows that the puncture impact occurred as planned, slightly off-center from the VPC. The cylinder was measured and the results were recorded on Figure 3.

## 7.6 Post-Drop Leakage Testing

Following the damage measurements, the VPC O-ring seal was leakage tested, and the measured rate was 12 mtorr/minute, which correlates to $5.9 \times 10^{-6}$ atm-cc/sec. The leakage rate was monitored for more than 10 minutes, and the leakage rate appeared to be decreasing over time, indicating that the seal was secure.

## 7.7 VPC Removal and Inspection

Following the post-drop leakage testing, the VPC was removed and inspected. The glazing material on the interior of the VPC showed no impressions, indicating that the valve did not contact the VPC at any time during the testing.

## 7.8 Cylinder Valve Inspection

After removal of the VPC, the cylinder valve was visually inspected for traces of the glazing compound. None was found; therefore, it was further concluded that the valve did not contact the VPC during the testing. The cylinder valve was attached to a pressure gauge, and the post-test cylinder pressure was measured to be approximately 140 psig. Thus, the internal pressure of the cylinder was maintained throughout the test.

## 8.0 Summary and Conclusions

The objective of the testing conducted with the 30C was to verify the capabilities of the Valve Protection Cover (VPC). Previous testing provides evidence that the standard 30B cylinder in the UX-30 packaging remains leak-tight following HAC (see Appendices 2.10.1, 2.10.2, and 2.10.4). Since the 30C is identical to the standard 30B cylinder, with the exception of the VPC, this evidence is directly applicable to the 30C, provided that the VPC does not contact the cylinder valve during HAC. In order to validate this previous evidence, the internal surface of the VPC (excepting the flanges) was coated with approximately 1/4" of white window glazing compound to indicate contact with other parts of the package during impact. The post-HAC inspection of the 30C concluded that contact with the cylinder valve did not occur. The pre- and post-test leakage rate tests of the cylinder valve were completed to rule out any gross leakage from the valve that might influence the VPC leakage tests. The internal pressure of the cylinder was also measured pre- and post-test as an overcheck.

The full-scale prototype testing of the 30C Cylinder demonstrated that the VPC is capable of maintaining a water-tight seal around the cylinder valve during NOC and HAC. The cylinder valve did not contact any other component of the packaging during or following the test sequence, and the VPC O-rings remained leak-free prior to and following the test sequence. Additionally, the total effective volume of the packaging was greater than 95% of the original, the effective spacing of the fissile contents remained unchanged, and the packaging remained closed, effectively excluding the entry of a 10 cm (4 in) cube. There was no loss or dispersal of the simulated contents, no changes to the packaging that would result in a significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. Additionally, the damage sustained to the UX-30 is consistent with previous drop tests for the same model. Therefore, the fire test results for the previous tests remain applicable for the 30C cylinder design, and the maximum packaging temperature is below the design limits for the UX-30.

## 9.0 References

1. Title 10, Code of Federal Regulations for the Packaging and Transport of Radioactive Material, Part 71.
2. IAEA Safety Standards Series 6, Regulations for the Safe Transport of Radioactive Material, 1996 Edition, ST-1, IAEA.
3. UX-30 Consolidated Safety Analysis Report, Revision 1, USA/9196/AF-85, February, 1999.
4. ANSI N14.5-1997, For Radioactive Materials - Leakage Tests on packages for Shipment.
5. Test Plan for the Regulatory Testing of the CBC Leak Tight™ $UF_6$ Cylinder, July 17, 2001.
6. CBC-WT-DT, "Regulatory Testing of the 30C Cylinder, The Columbiana Boiler Company, August 7, 2001.
7. UX-30 Consolidated Safety Analysis Report, Revision 0, USA/9196/AF-85, February, 1999.

8. Safety Analysis Report for the Model ESP-30X Protective Shipping Package for 30-Inch $UF_6$ Cylinders, Revision2, USA/9284/BF-85, March 2000.

9. Safety Analysis Report for the NCI 21-PF-1 Protective Shipping Package for 30-Inch UF6 Cylinders, Revision 6, USA/9234/AF-85, March 2000.

10. Safety Analysis Report for the MST-30 Protective Shipping Package, submitted to DOT for U.S. re-certification, January 2001.

## Table 1-Supplementary Deformation at the Valve Calculated based on Data Recorded from Previous Testing of Similar Packages [References 7 through 10]

| Package | 30-ft Drop Angle (degrees) | Reported Longitudinal Deformation . (in) | Reported Radial Deformation (in) | Calculated Deformation Depth at Valve for 30-ft drop (in) | Average Reported Puncture Depth (in) | Total Deformation Depth, 30-ft Drop and Puncture Drop (in) |
|---|---|---|---|---|---|---|
| NCI PF 21 | 13.5 | 3.5 | 18 | 2.41 | 0.12 | 2.10 |
| 30X | 14 | 5 | 22.5 | 2.60 | 0.50 | 3.36 |
| MST-30 | 15 | 3.8 | 20.7 | 2.00 | 1.60 | 3.60 |
| UX-30 | 31 | 7 | 12 | N/A | N/A | N/A |
| UX-30 | 30 | 10 | 19 | 2.60 | 1.00 | 3.60 |
| NCI PF 21 | 30 | 5.4 | 20.5 | 3.26 | 1.25 | 5.16 |

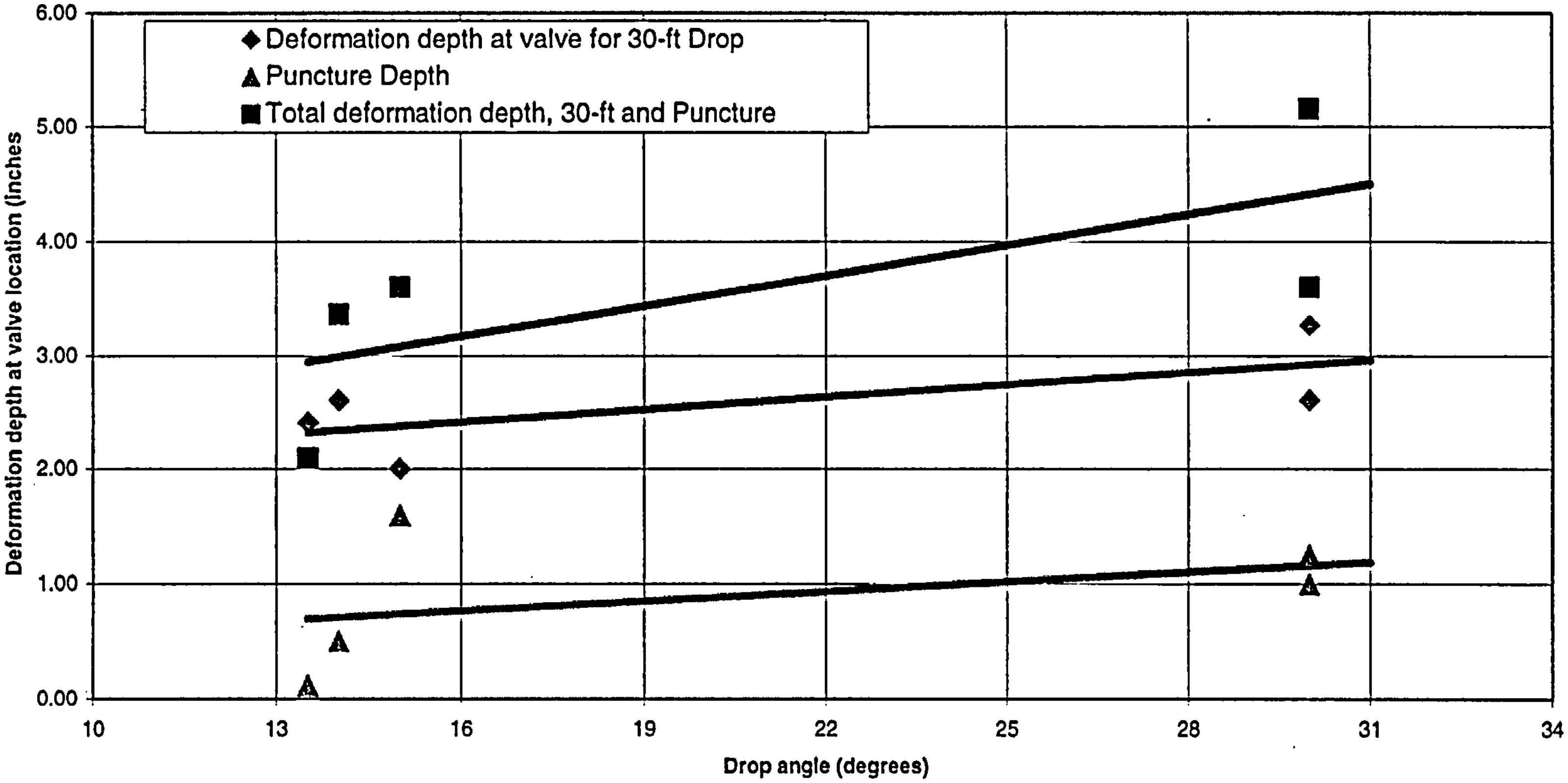
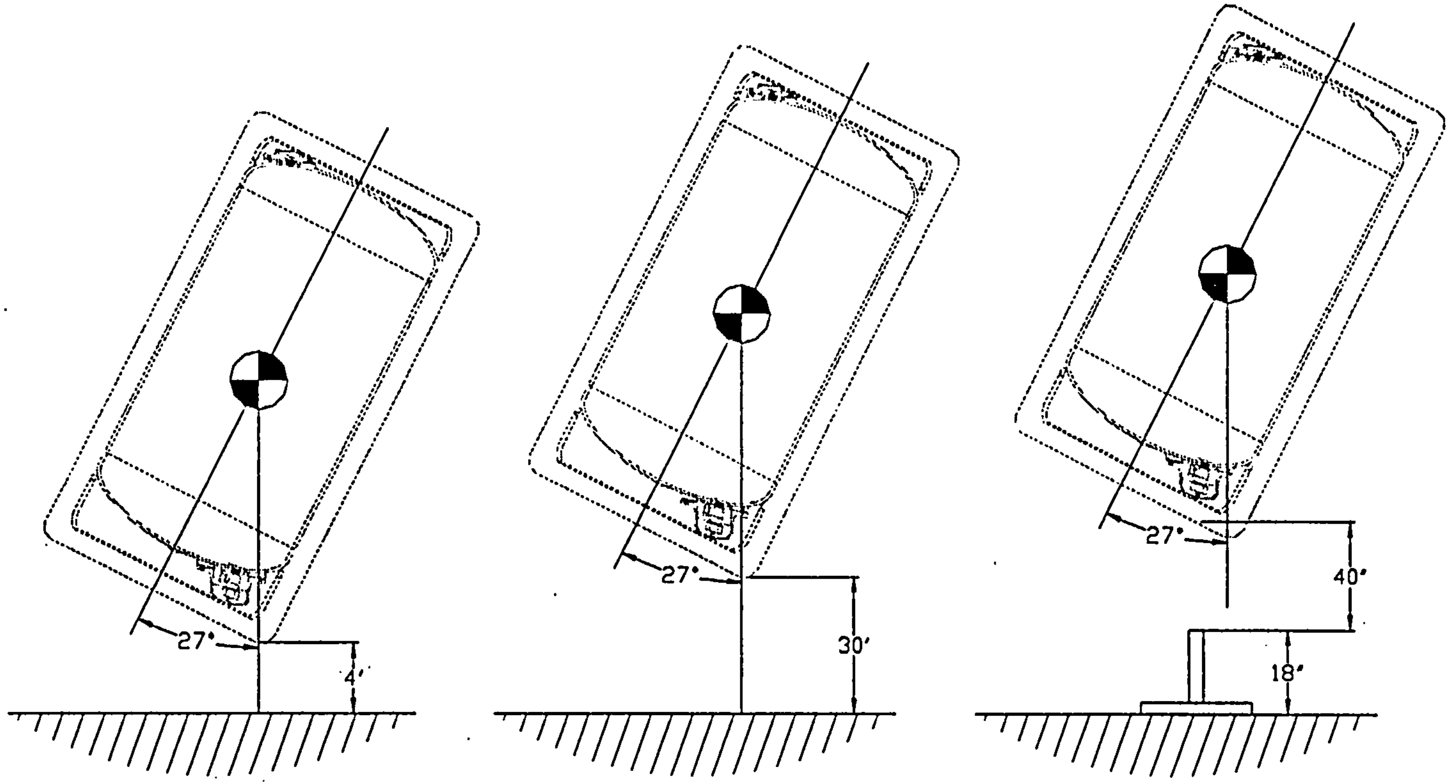


Figure 1-Supplimentary Deformation at the Valve Calculated based on Data Recorded from Previous Testing of Similar Packages



A) NORMAL CONDITION
DROP, 4-FOOT
CG OVER CORNER

ACTUAL ANGLE:

27.5 degrees

B) HAC, 30-FOOT
CG OVER CORNER

ACTUAL ANGLE:

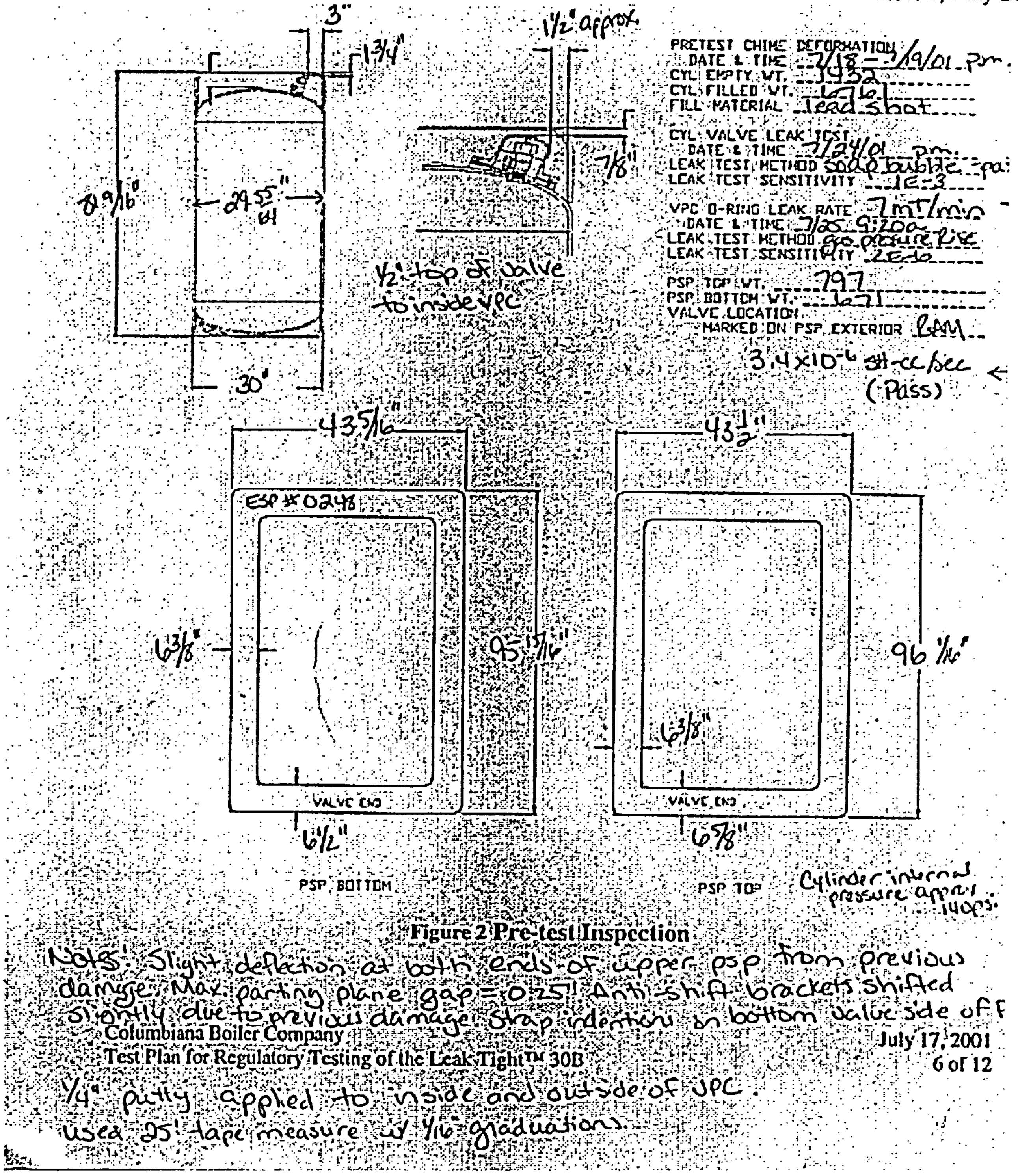
27.0 degrees

C) PUNCTURE
CG OVER CORNER, PIN BELOW
VALVE LOCATION

ACTUAL ANGLE:

27.0 degrees

**Figure 1, *a* to *c* Drop Orientation and Sequence**



PRETEST CHIME DEFORMATION
DATE & TIME 7/18 - 7/19/01 pm.
CYL EMPTY WT. 1932
CYL FILLED WT. 6761
FILL MATERIAL lead shot

CYL VALVE LEAK TEST
DATE & TIME 7/24/01 pm.
LEAK TEST METHOD soap bubble - pa
LEAK TEST SENSITIVITY 1E-3

VPC O-RING LEAK RATE 7 mT/min -
DATE & TIME 7/25 9:20a
LEAK TEST METHOD gas pressure rise
LEAK TEST SENSITIVITY 2E-6

PSP TOP WT. 797
PSP BOTTOM WT. 1271
VALVE LOCATION
MARKED ON PSP EXTERIOR RAM

3.4x10⁻⁶ std-cc/sec ←
(Pass)

Cylinder internal pressure approx. 140psi.

Figure 2 Pre-test Inspection

Note: Slight deflection at both ends of upper psp from previous damage. Max. parting plane gap = 0.25". Anti-shift brackets shifted slightly due to previous damage. Strap indention on bottom valve side of F

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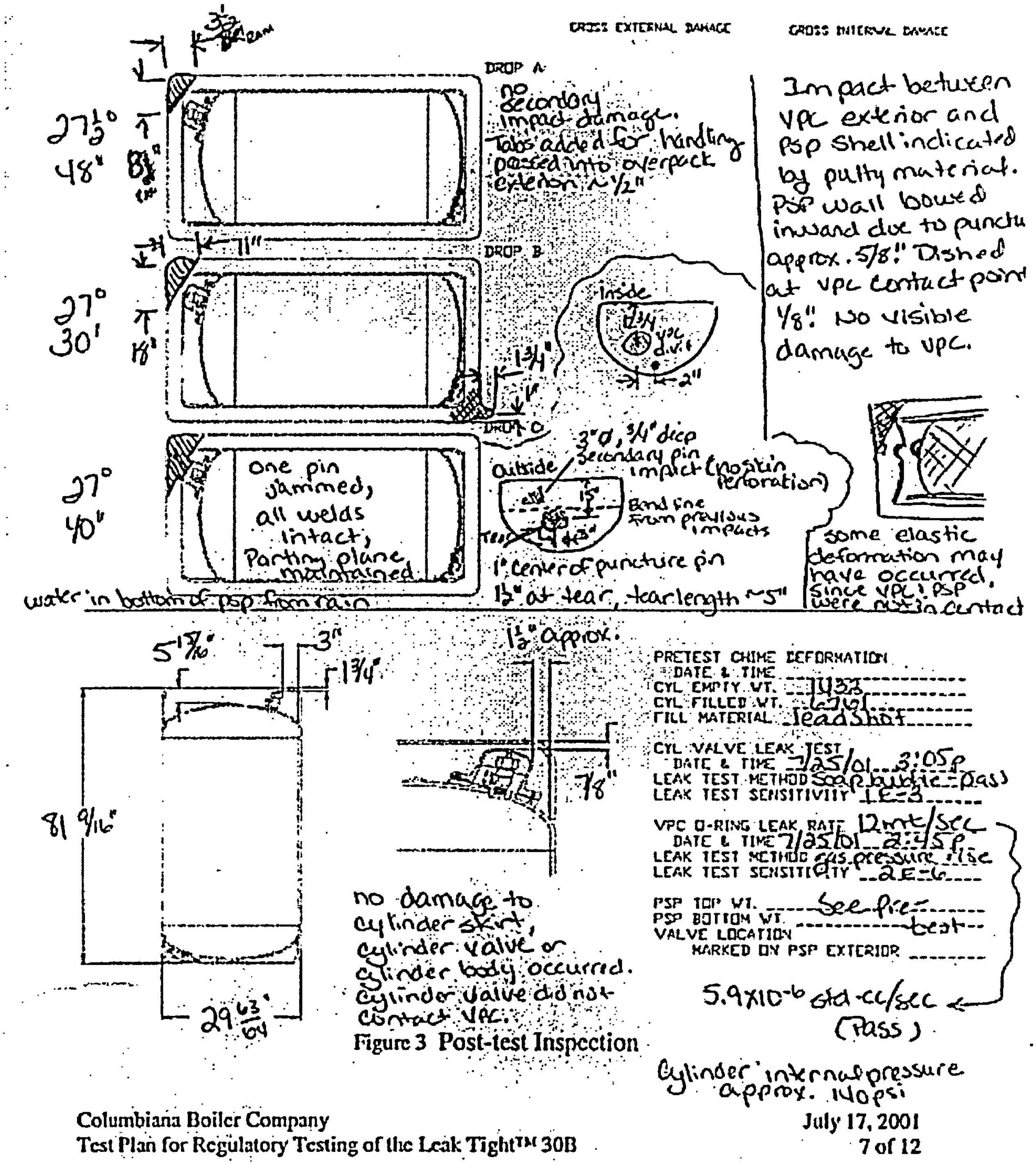
1/4" putty applied to inside and outside of VPC.
Used 25' tape measure w/ 1/16" graduations.

Figure 2 Pre-Test Inspection



no secondary impact damage. Tabs added for handling pressed into overpack exterior ~1/2"

Impact between VPC exterior and PSP shell indicated by putty material. PSP wall bowed inward due to puncture approx. 5/8". Dished at VPC contact point 1/8". No visible damage to VPC.

3"Ø, 3/4" deep secondary pin impact (no skin perforation)

1" center of puncture pin 1 1/2" at tear, tear length ~5"

some elastic deformation may have occurred, since VPC & PSP were ~~not~~ in contact

one pin jammed, all welds intact, Parting plane maintained

water in bottom of psp from rain

PRETEST CHIME DEFORMATION
DATE & TIME
CYL EMPTY WT. 1433
CYL FILLED WT. 6761
FILL MATERIAL lead shot

CYL VALVE LEAK TEST
DATE & TIME 7/25/01 3:05p
LEAK TEST METHOD Soap bubble - pass
LEAK TEST SENSITIVITY 1E-3

VPC O-RING LEAK RATE 12mt/sec
DATE & TIME 7/25/01 2:45p
LEAK TEST METHOD gas pressure rise
LEAK TEST SENSITIVITY 2E-6

PSP TOP WT. See pre-
PSP BOTTOM WT. test
VALVE LOCATION
MARKED ON PSP EXTERIOR

5.9x10⁻⁶ std-cc/sec (Pass)

no damage to cylinder skirt, cylinder valve or cylinder body occurred. Cylinder valve did not contact VPC.

Figure 3 Post-test Inspection

Cylinder internal pressure approx. 140psi

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Figure 3 Post-Test Inspection

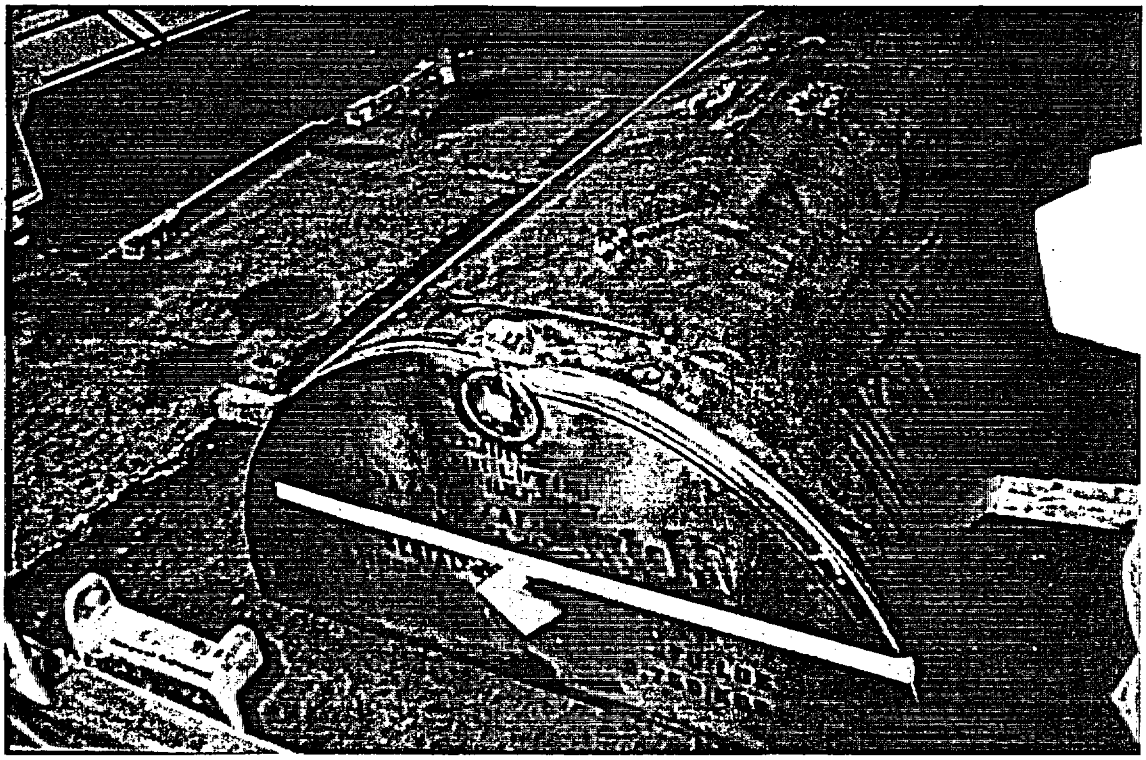


Figure 4 UX-30 Cover, Pre-Test

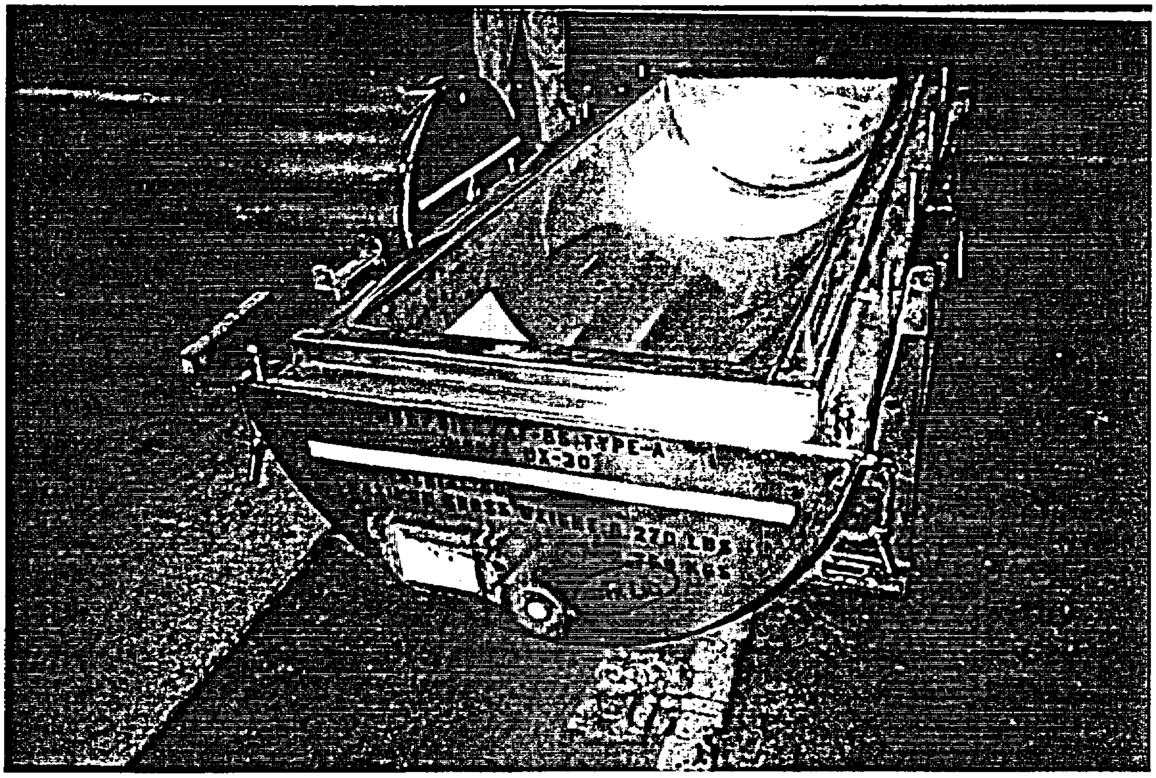


Figure 5 UX-30 Bottom, Pre-Test

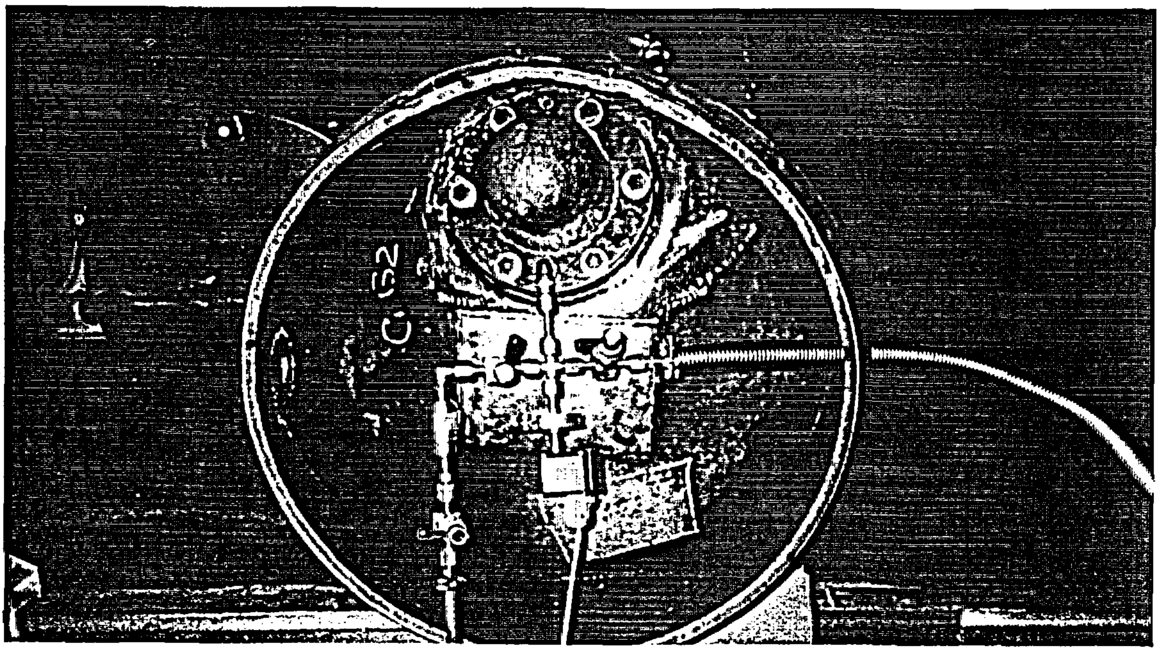


Figure 6 Pre-Drop Leakage Test

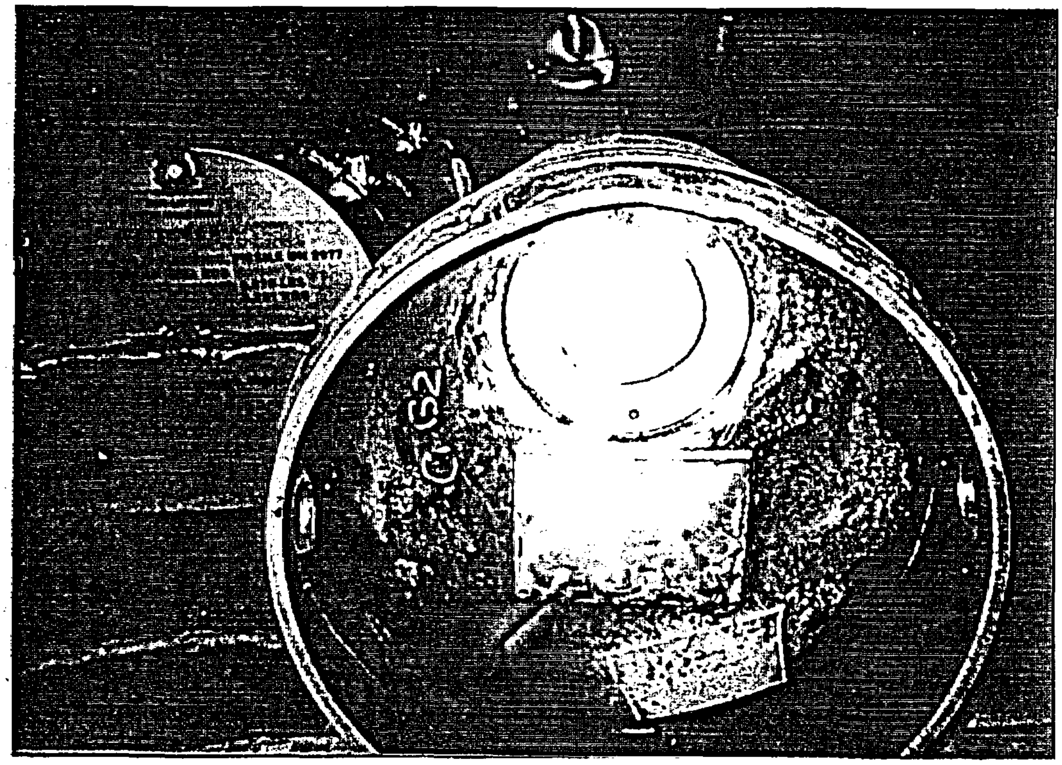


Figure 7 30C Cylinder with VPC and Glazing Compound in place

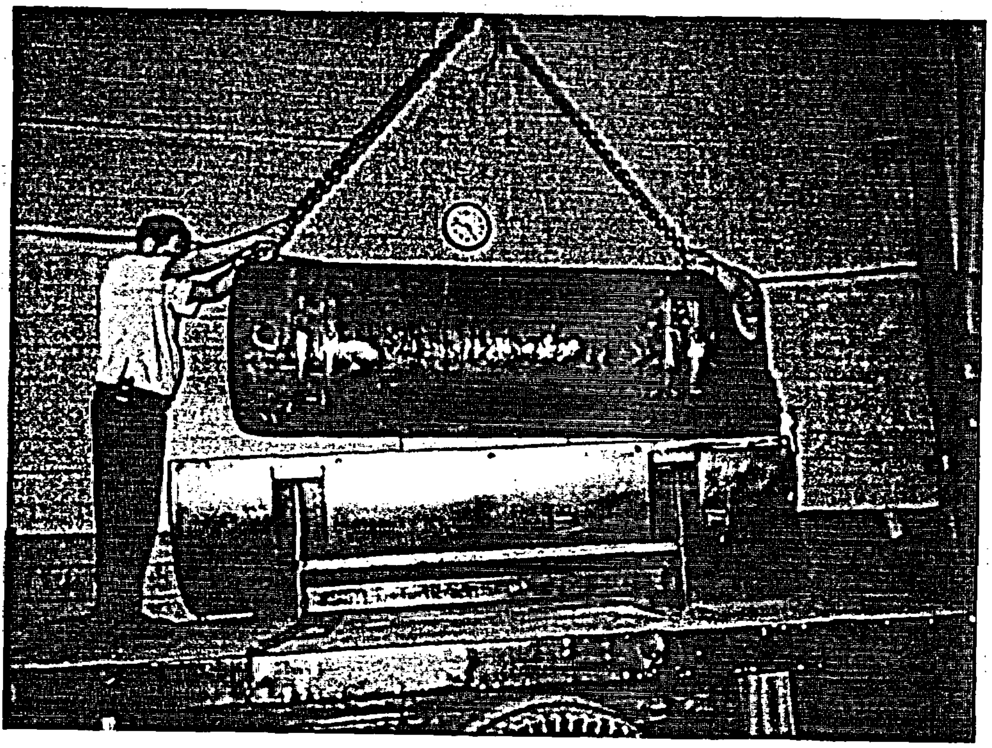


Figure 8 Loading the 30C Cylinder into the UX-30 Cover

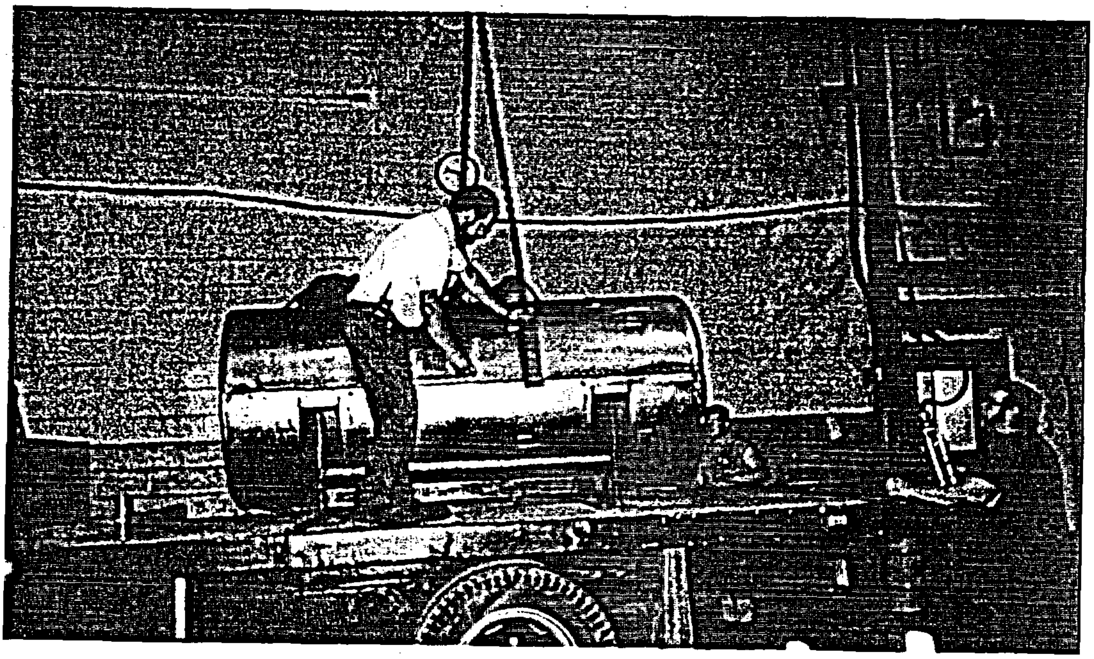


Figure 9 Securing the UX-30 Bottom in place

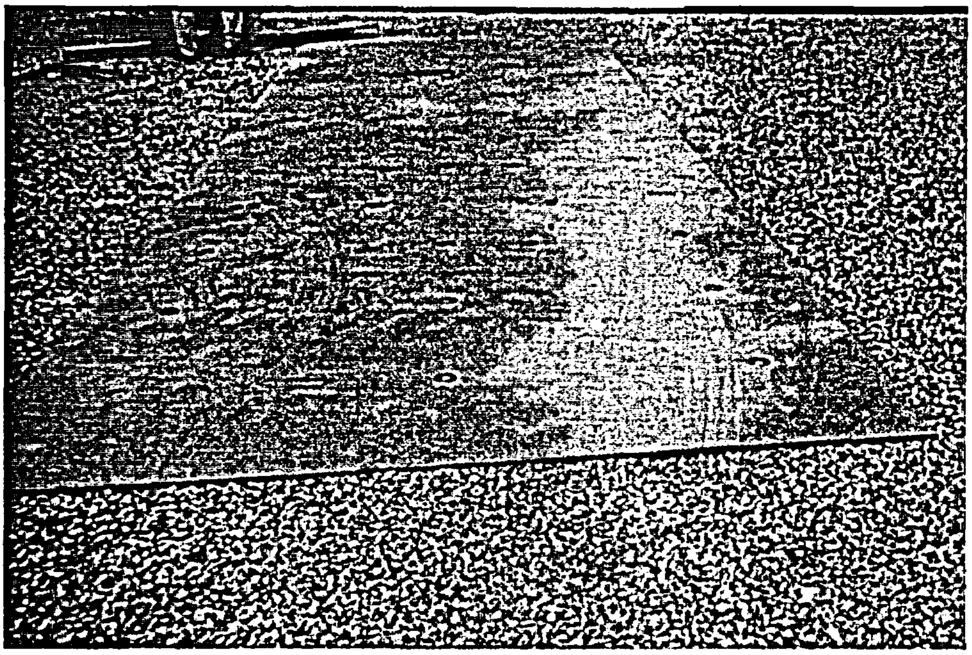


Figure 10 The Columbiana Boiler Company's Drop Test Pad

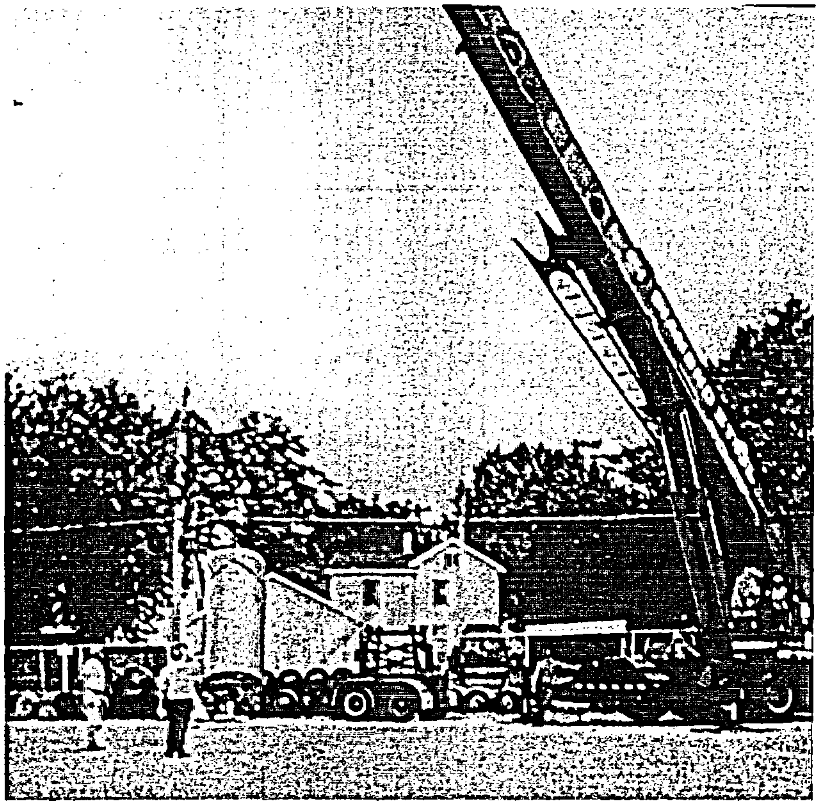


Figure 11 The Package Aligned for the NOC Free Drop

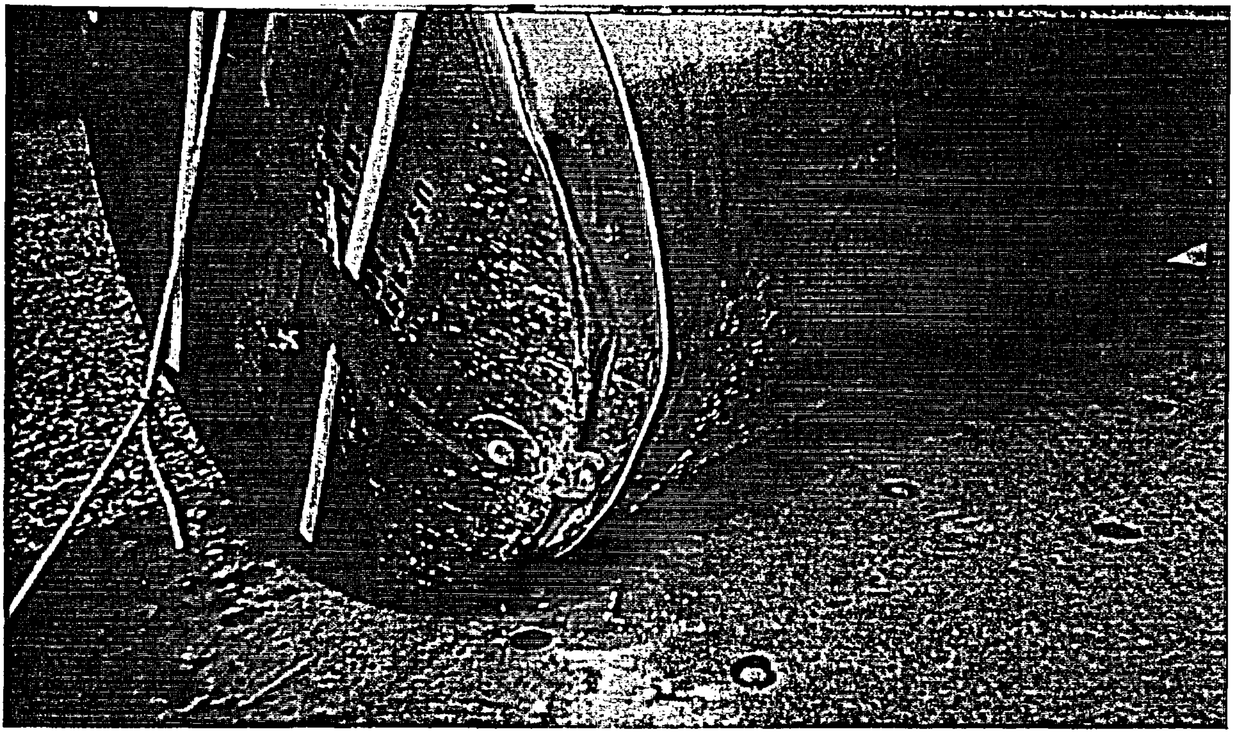


Figure 12 Primary Impact Damage from the NOC Free Drop

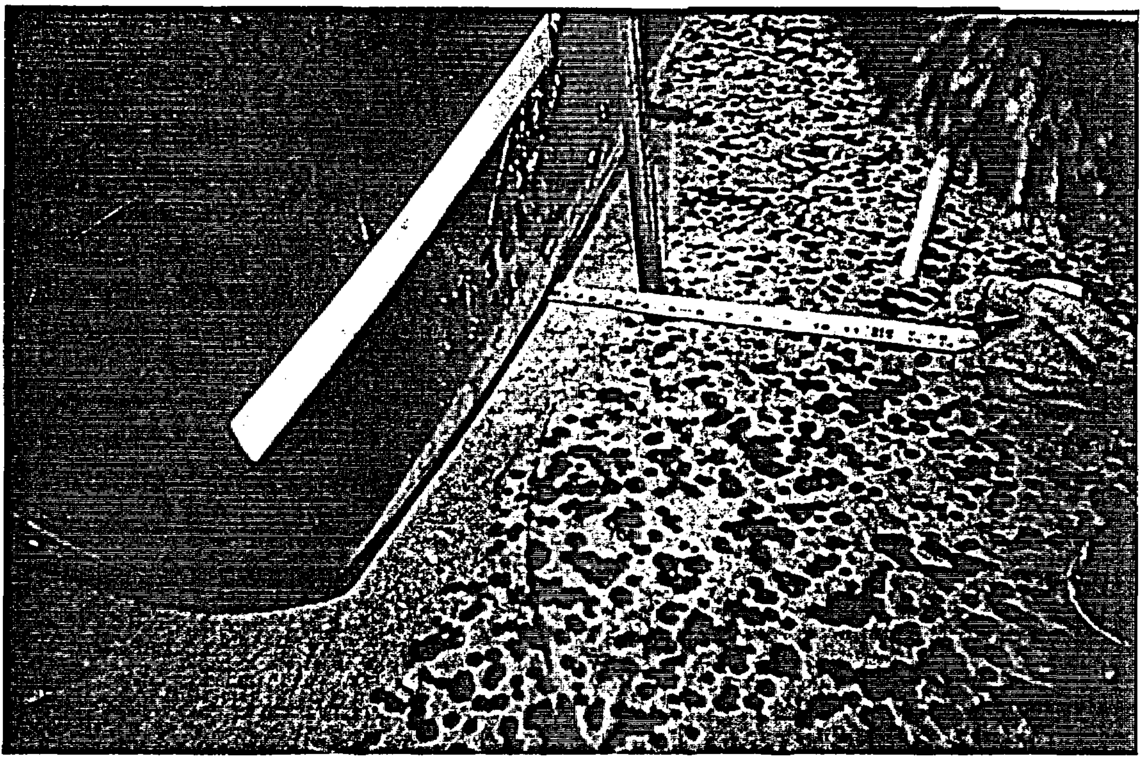


Figure 13 Measuring the Impact Depth for the NOC Free Drop

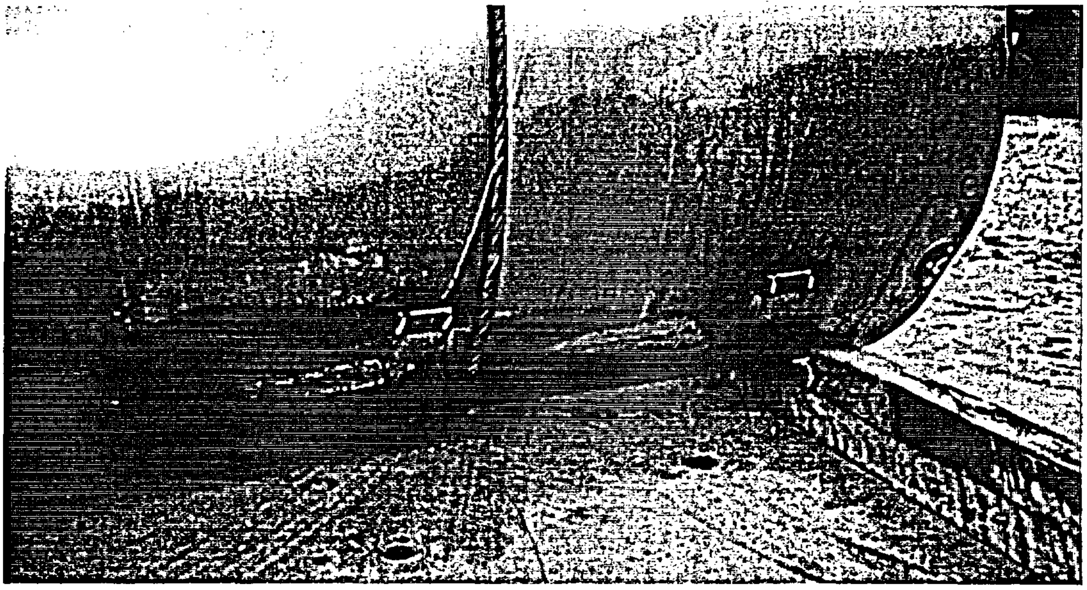


Figure 14 Drop Test Handling Tabs were pressed into the Package Shell

Figure 15 The Package Aligned for the HAC 30-foot Free Drop

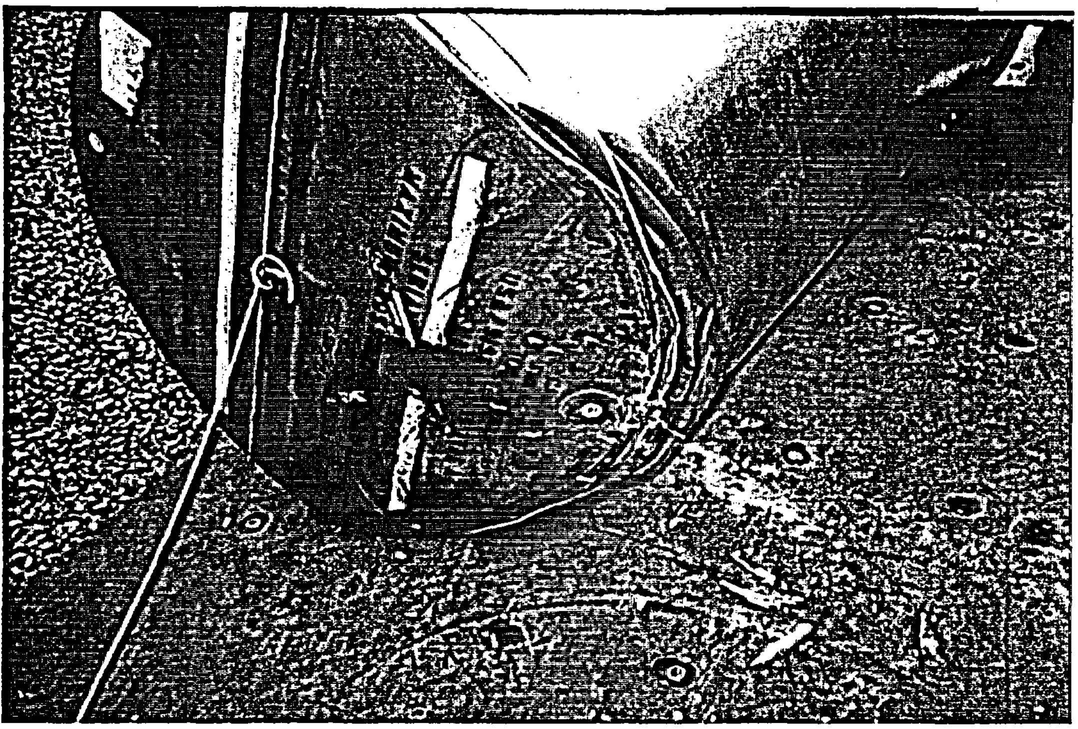


Figure 16 Primary Impact Damage from the HAC 30-foot Free Drop (a)

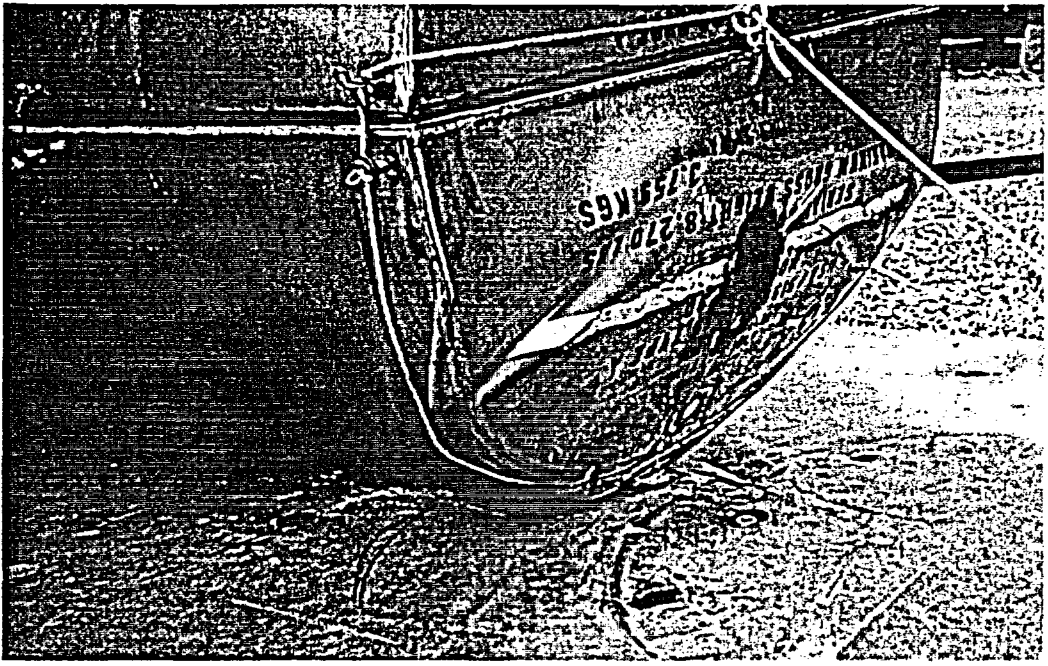


Figure 17 Primary Impact Damage from the HAC 30-foot Free Drop (b)

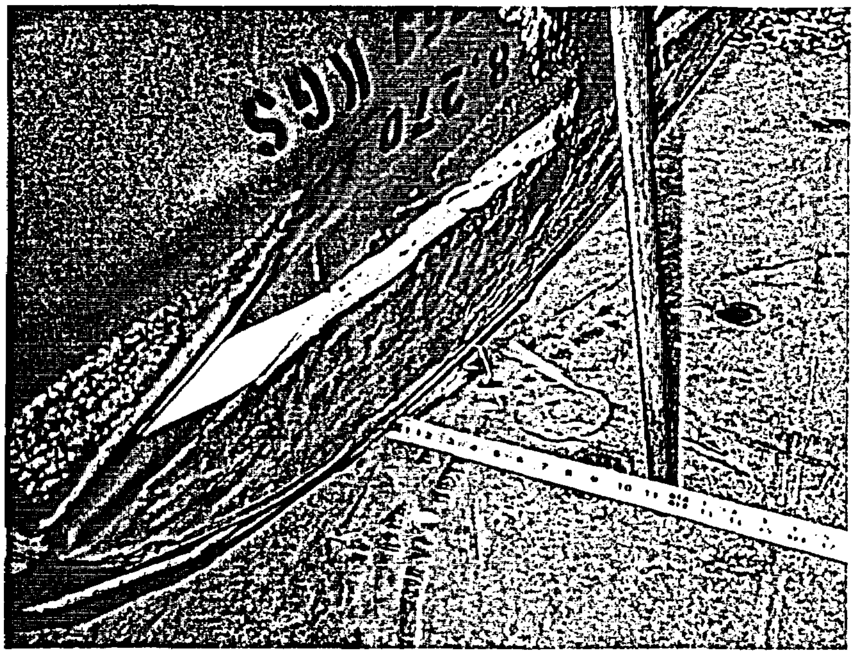


Figure 18 Measuring the Impact Depth for the HAC 30-foot Free Drop

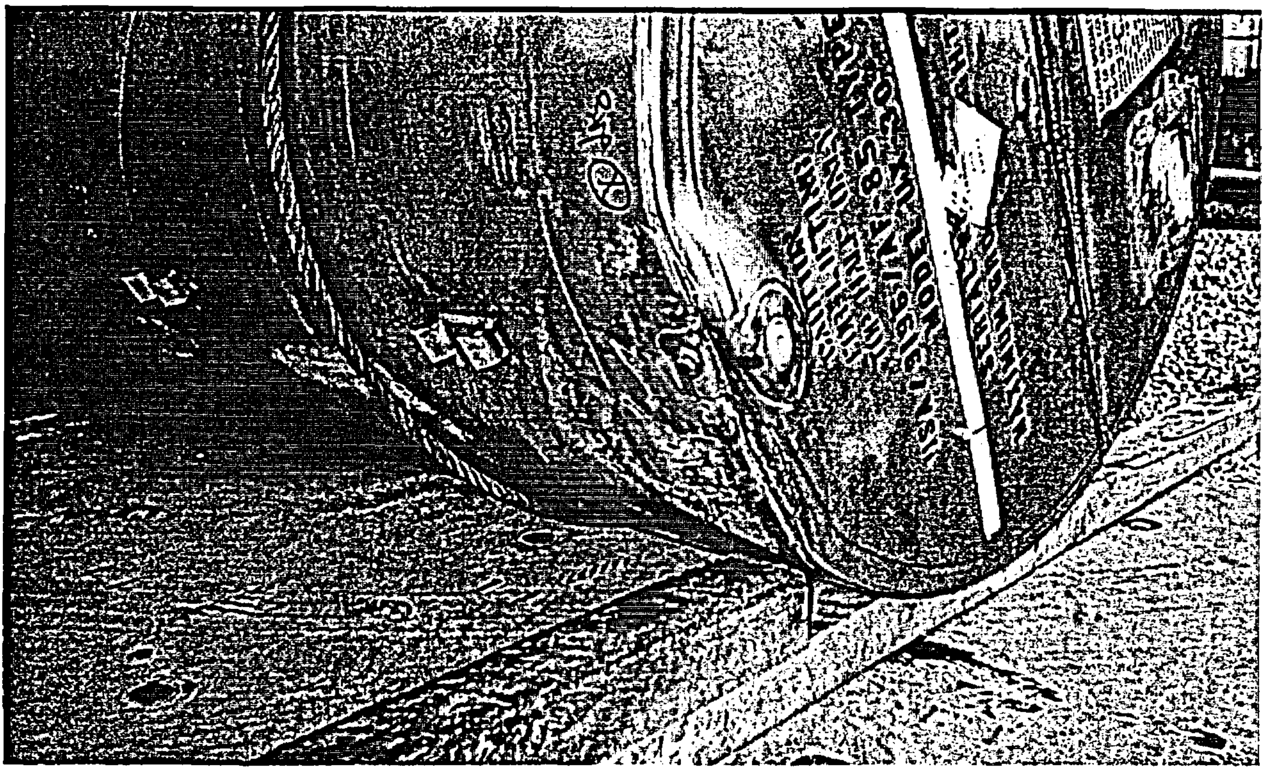


Figure 19 Secondary Impact Damage from the HAC 30-foot Free Drop (a)

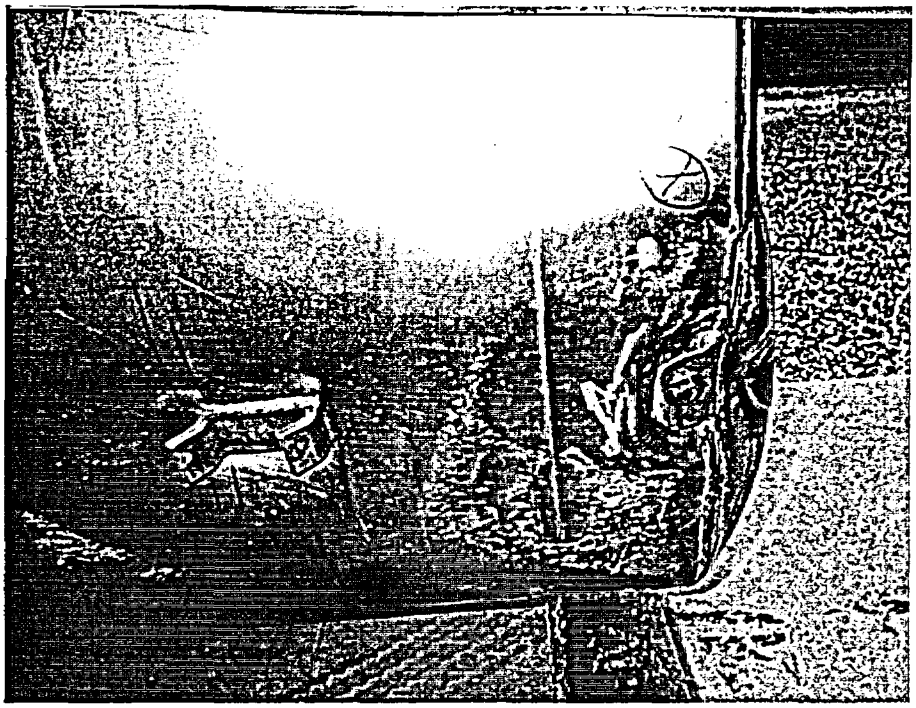


Figure 20 Secondary Impact Damage from the HAC 30-foot Free Drop (b)

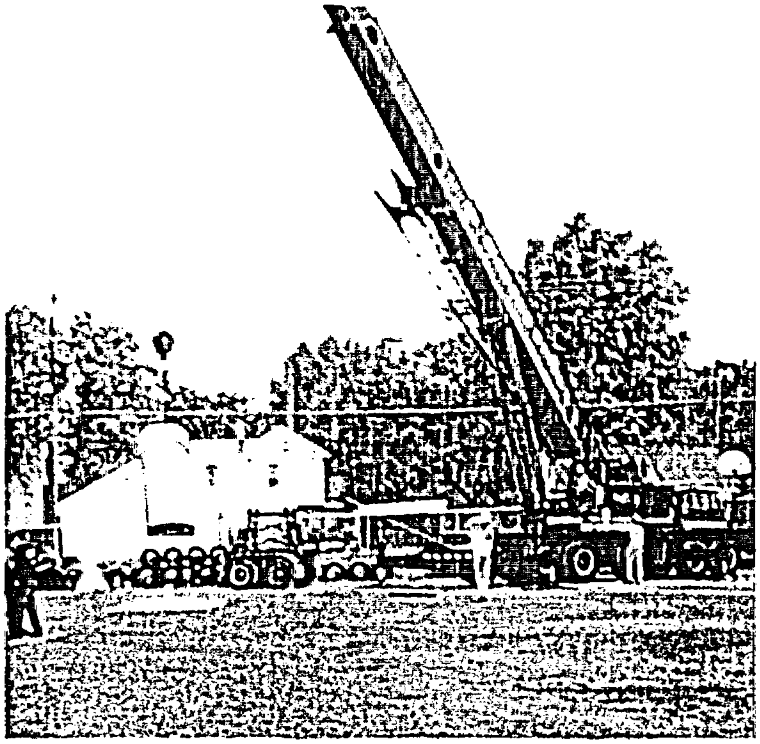


Figure 21 The Package Aligned for the HAC Puncture Drop

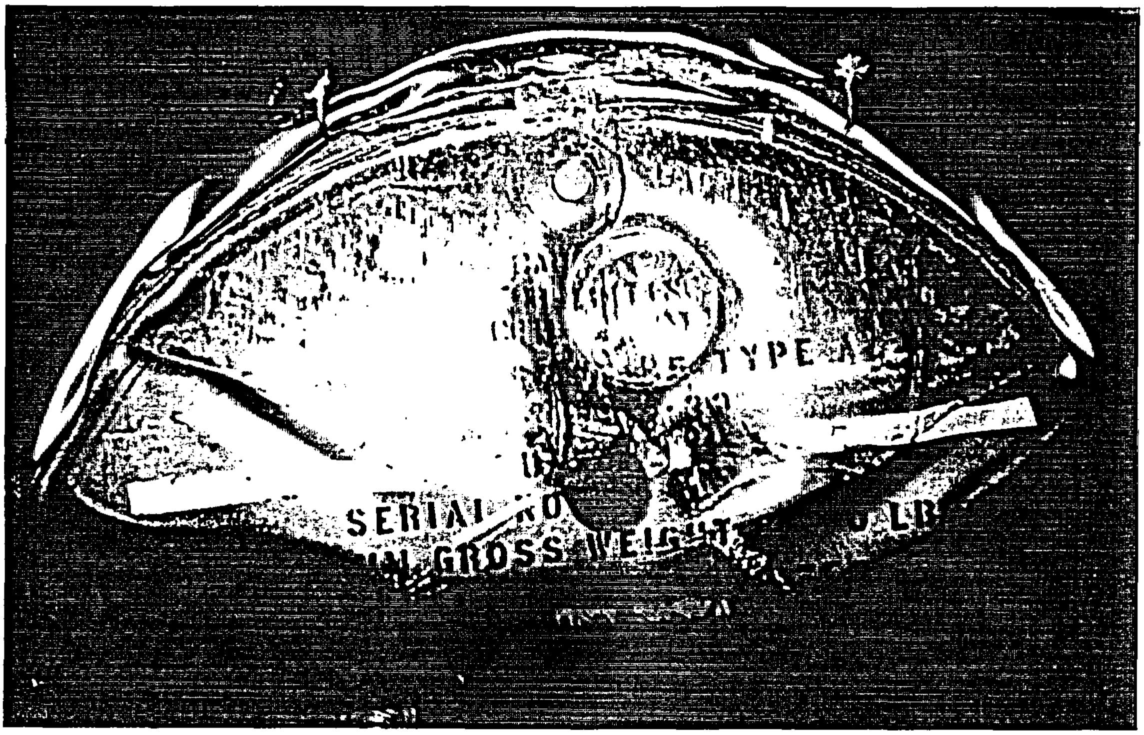


Figure 22 Impact Damage from the HAC Puncture Drop (a)

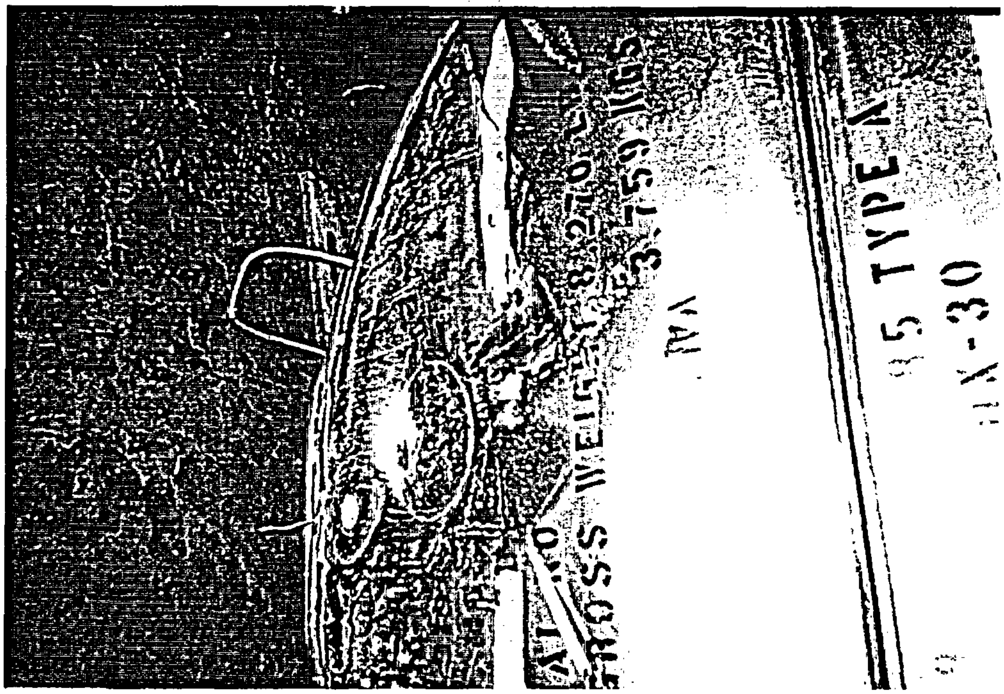


Figure 23 Impact Damage from the HAC Puncture Drop (b)

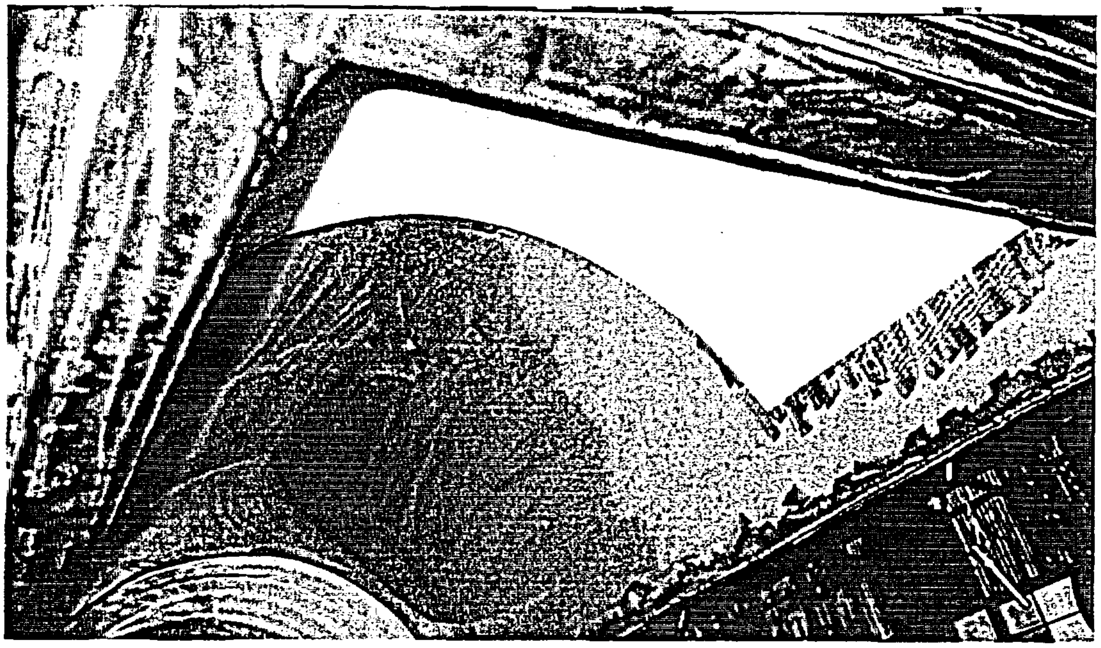


Figure 24 The UX-30 Bottom is removed Post-Test

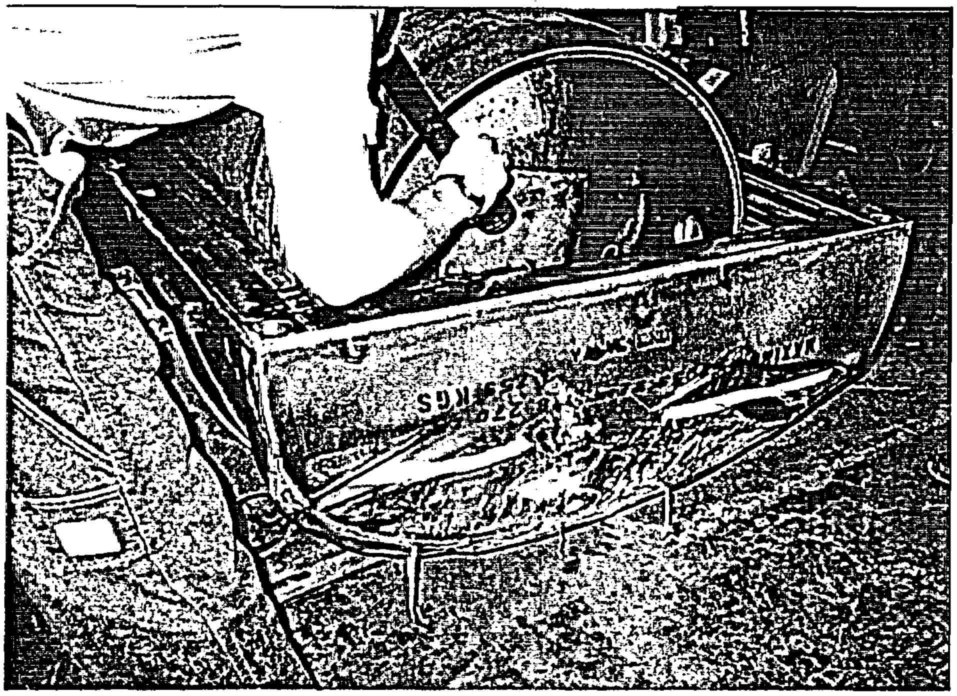


Figure 25 Inspecting the UX-30 Cover prior to Removal of the 30C Cylinder

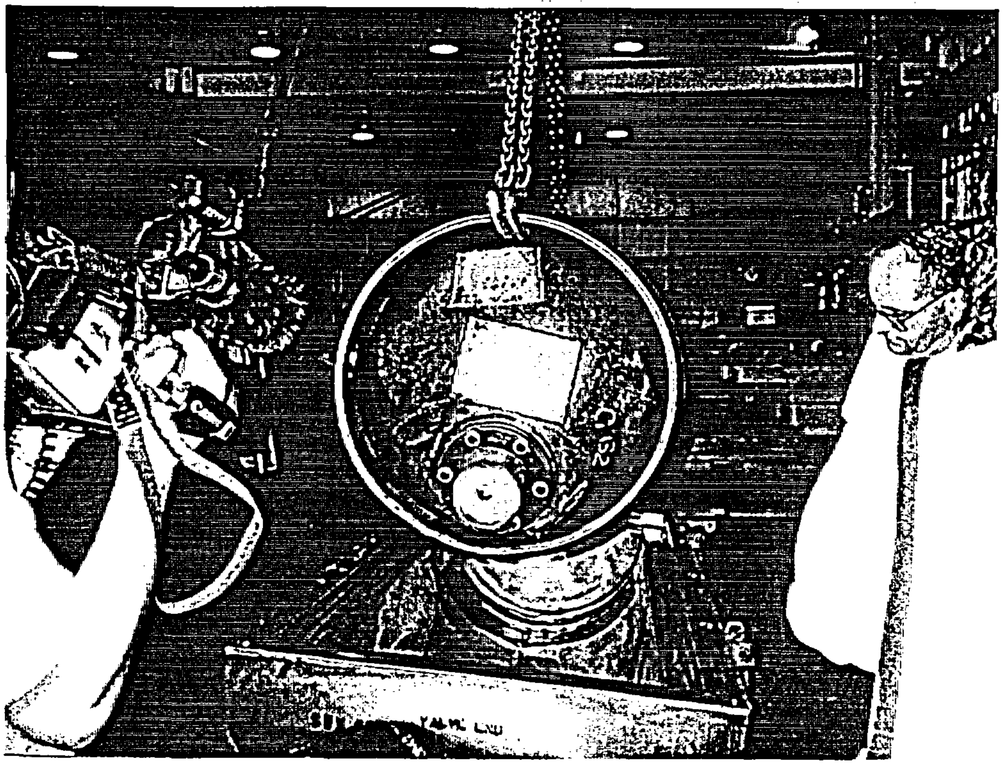


Figure 26 Removing the 30C Cylinder from the UX-30 Post-Drop

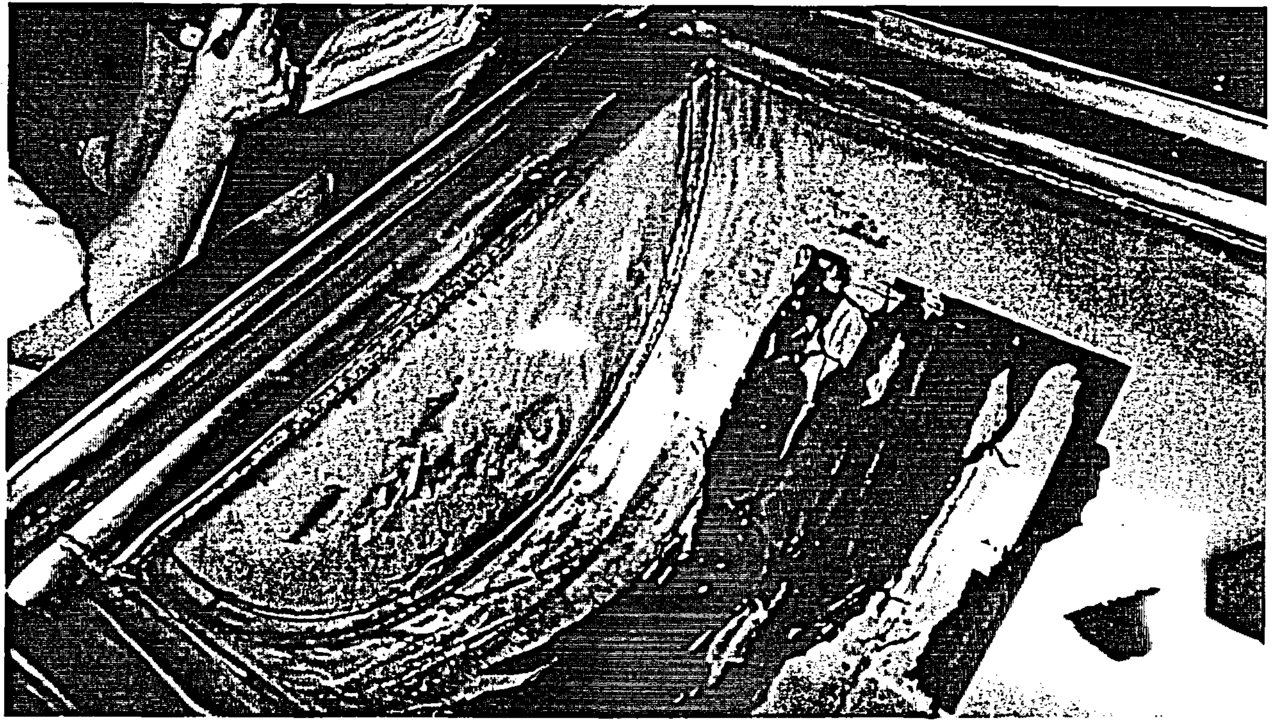


Figure 27 UX-30 Cover Buckling and VPC Contact Indications

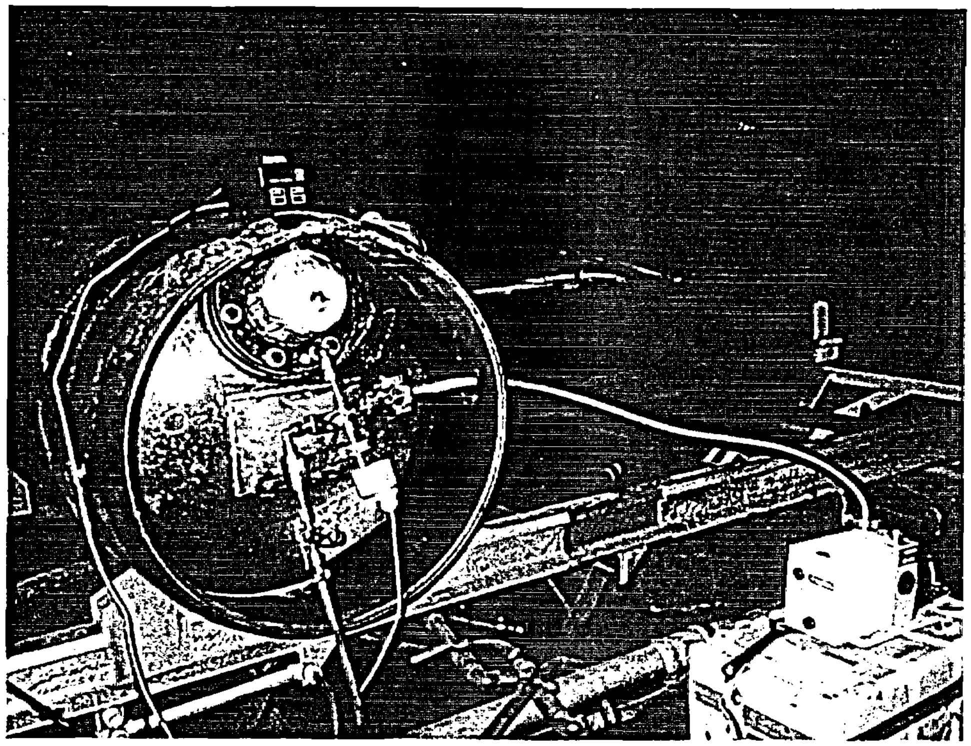


Figure 28 Post-Drop Leakage Test

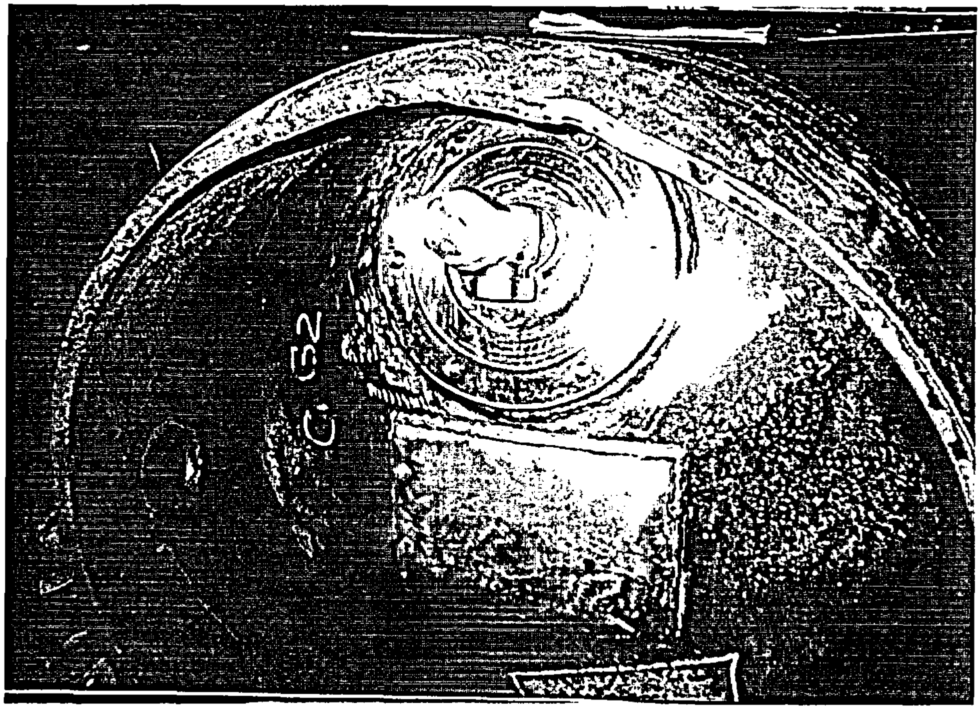


Figure 29 30C Cylinder Valve Post-Test

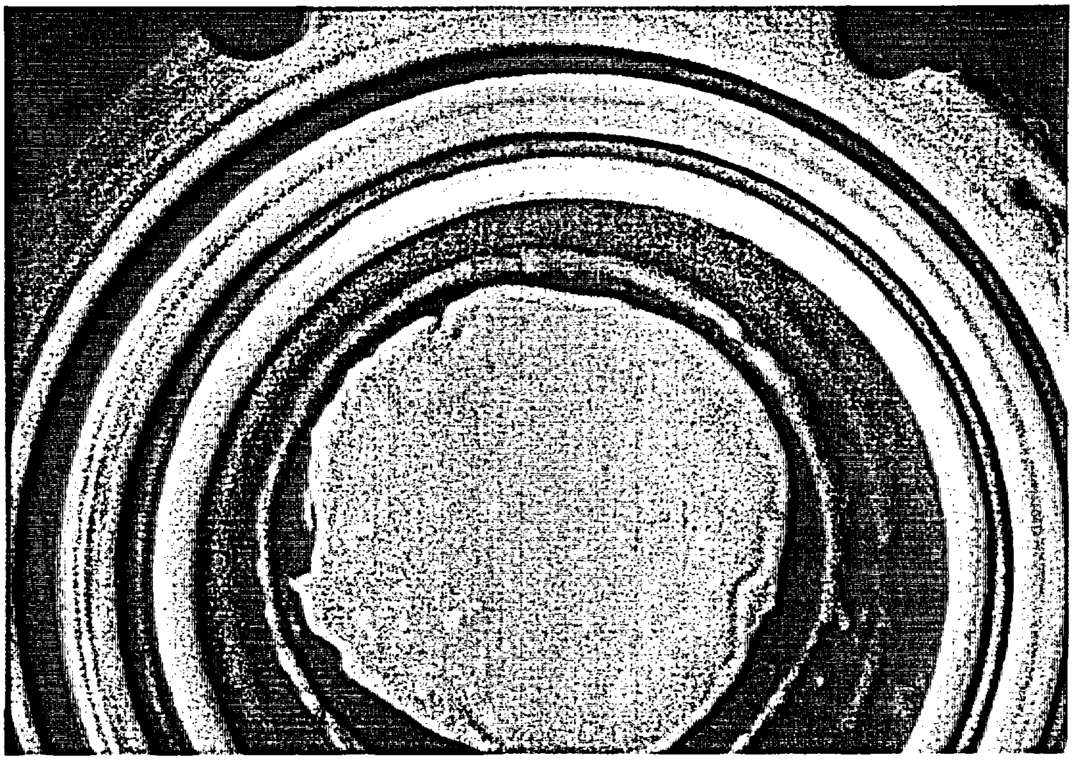


Figure 30 VPC Internal Glazing Compound Layer shows no sign of Valve contact

# 3.0 THERMAL EVALUATION

## 3.1 Description of Thermal Design

The UX-30 overpack has been designed for all normal and hypothetical accident conditions defined in 10 CFR 71 without exceeding any design limits on the cylinder payload. The following discussion presents the results of a HEATING[9,10] evaluation of the UX-30 package under normal conditions of transport and hypothetical accident conditions. The analysis performed acknowledged that $UF_6$ does not display a significant decay heat generation rate. Therefore, there are no internal thermal gradients under normal conditions except those induced by solar loads. Hypothetical accident conditions, per 10 CFR 71 requirements, included a damaged package initially at 100 ° F without solar insolance, subjected to a fire at 1475 ° F for 30 minutes followed by a reduction to 100 ° F ambient and solar insolance. The detailed thermal model used for the hypothetical accident condition evaluations includes a conservative assessment of the cumulative impact damage to the UX-30 from the specified drop events.

The physical properties of the $UF_6$ payload material require that the internal temperature of the payload cylinder be kept quite low during the transient. $UF_6$ will melt at 147.3 °F into a liquid considerably less dense than the solid. Also, the maximum permissible temperature and pressure of the 30B cylinder is 250 °F and 200 psig, respectively, per ANSI 14.1 requirements. Thus, if it can be shown that the 30B cylinder temperature and pressure remains below this level, then the UX-30 package will satisfy the requirements of 10 CFR Part 71.

Maximum temperatures at various points on the package for normal and accident conditions are given in Table 3.1-1, below:

TABLE 3.1-1

Maximum Normal and Hypothetical Accident Condition Temperatures

| | Normal | Hypothetical Accident |
|---|---|---|
| External Surface | 145.3°F | 1474.2°F |
| Internal Surface | 125.7°F | 705.6°F |
| $UF_6$ Cylinder | 124.0°F | 182.7°F |
| $UF_6$ Solid | 124.0°F | 181.4°F |

These analyses demonstrate that the UX-30 package safely protects $UF_6$ cylinders from exceeding the maximum design temperature under normal transport conditions and hypothetical accident condition. Under normal conditions of transport, the maximum temperature of the $UF_6$ is well below the melting point and the maximum temperature of the 30B cylinder is well below design limits. Under hypothetical accident conditions, the maximum 30B cylinder temperature was less than 200 °F. This is well within the design of the 30B cylinder. Also, local hot spots around the parting plane raise the temperature of the $UF_6$ above the melting point. Actual $UF_6$ temperature would be significantly less than 200 °F since local hot spots would dissipate heat to surroundings and a significant portion of the heat applied would be absorbed by the localized change in phase of the $UF_6$. Actual bulk temperature inside 30B cylinder would be significantly lower than 200 °F. Therefore, the resulting temperature for the $UF_6$, when conservatively assumed to be 200 °F, is acceptable and does not adversely affect the 30B cylinder thereby confirming adequacy of the UX-30 overpack for protection of a 30B cylinder.

Demonstration of the adequacy of the UX-30 overpack and validation of the hypothetical accident conditions thermal model was done by comparison to an actual full-scale fire test of the UX-30 package with simulated contents. The details are present in Section 3.6.4. The fire test was subsequent to the drop tests described in Section 2.7 and, thus, included the cumulative effects of the hypothetical accident drops per 10CFR71 requirements. In addition, the average fire temperature, 1900 °F, was well above 10CFR71 requirements. The maximum temperatures on the surface of the 30B cylinder were measured at less than 200° F. These maximum temperatures were observed at in the vicinity of the overpack parting plane which was damaged during the drop testing. The parting plane was open and was oriented to face the fire in order to provide conservative results. The damage and orientation enhanced heat transfer through the parting plane to the 30B cylinder. The maximum temperatures observed during the fire test were well below the design temperature of the 30B cylinder and as such would not result in adverse impact to the cylinder or its payload. This is particularly true given the conservative and localized nature of the cylinder temperature observed in the fire test. HEATING thermal model results compared well with both the magnitude and time of the maximum 30B cylinder temperatures.

## 3.2 Material Properties and Component Specifications

### 3.2.1 Material Properties

The UX-30 material thermal properties used in the analysis shown in Table 3.2-1, below:

TABLE 3.2-1

UX-30 Material Thermal Properties

| Material | Conductivity (BTU/hr-ft-°F) | Specific Heat (BTU/lb.-°F) | Density (lb/ft$^3$) | Surface Emissivity |
|---|---|---|---|---|
| $UF_6$ Solid | 0.33(3) | 0.114(1) | 317.8(1) | Not Used |
| $UF_6$ Liquid | 0.093(4) | 0.130(1) | 227.7(1) | Not Used |
| Stainless Steel (Type 304) | Table 3.2-3 | 0.11(5) | 488(5) | 0.5(6) |
| Carbon Steel | 25.0(5) | 0.113(5) | 487(5) | 0.8(5) |
| Polyurethane Foam* | 0.015-<br>0.046(7) | 0.275-<br>0.535(7,8) | 7.8-(7)<br>9.8 | Not Used |
| Air | Table 3.2-2(9) | 0.240 | 0.059 | Not Used |

* The highest value for foam conductivity and the lowest value for foam specific heat and density were conservatively used in all evaluations.

TABLE 3.2-2

Thermal Conductivity of Air

| Temperature, °F | Thermal (BTU/hr-ft-°F) Conductivity |
|---|---|
| 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 |
| 900 | 0.0303 |
| 1,000 | 0.0319 |
| 1,500 | 0.0400 |

The thermal conductivity of solid $UF_6$ is difficult to determine from the literature. C. F. Hale and E. T. Barber report a conductivity of 0.33 BTU/hr-ft-°F in a classified report, according to D. H. Stitt of Union Carbide. B. Duret and J. C. Bonnard report it to be 0.23 BTU/hr-ft-°F in a paper presented at the Seventh International Symposium on Packaging and Transportation of Radioactive Materials in May, 1983. A General Atomics' report, GAT-280, reports the conductivity of $UF_6$ liquid as 0.093 BTU/hr-ft-°F, but does not give the solid conductivity. For analysis purposes, the 0.33 valve was chosen to conservatively maximize the heat absorbed by the $UF_6$ mass during the transient, resulting in a maximum $UF_6$ temperature prediction.

The closed-cell polyurethane foam is of a self-extinguishing and fire resistant variety. Tests were performed on it to prove its thermal performance under conditions such as those required by 10 CFR 71. The results of these tests are presented in Appendix 3.6.1

Between 400°F and 600°F, the foam will char, leaving a flame-smothering residue which continues to insulate the payload while exhibiting considerable residual strength and stability. It is conservatively assumed that fully conducting polyurethane foam remains in the UX-30 overpack above 400 °F.

Since the steel shell of the UX-30 overpack achieves temperatures in excess of 1400 °F during the fire accident, the thermal conductivity of steel as a function of temperature is accounted for in the thermal evaluations. Table 3.2-3 presents this data..

TABLE 3.2-3

Thermal Conductivity of Stainless Steel 304[12]

| Temperature, °F | Thermal (BTU/hr-ft-°F) Conductivity |
|---|---|
| 32 | 8.1 |
| 212 | 8.7 |
| 392 | 8.7 |
| 572 | 9.4 |
| 752 | 10.0 |
| 1112 | 11.0 |
| 1472 | 13.0 |

### 3.2.2 Component Specifications

The $UF_6$ containment vessel (the 30B cylinder or its equivalent) is designed to limits set out in ANSI N14.1, Packaging of Uranium Hexafluoride for Transport. The service pressure limit for the vessel in 200 psig, and the service temperature range is from -40°F to 250°F. The one-inch valve on the cylinder is rated to the same temperature and pressure limits as the cylinder.

## 3.3 General Considerations

### 3.3.1 Evaluation by Analysis

Normal and accident thermal conditions of transport are analyzed with the HEATING code, version 7.2 embedded in the SCALE4.4 code package.[9,10] HEATING is a multidimensional, finite difference, general-purpose heat transfer code written in FORTRAN 77. HEATING solves steady-state and/or transient problems in one-dimensional (1-D), two-dimensional (2-D), or three-dimensional (3-D) Cartesian, cylindrical, or spherical coordinates.

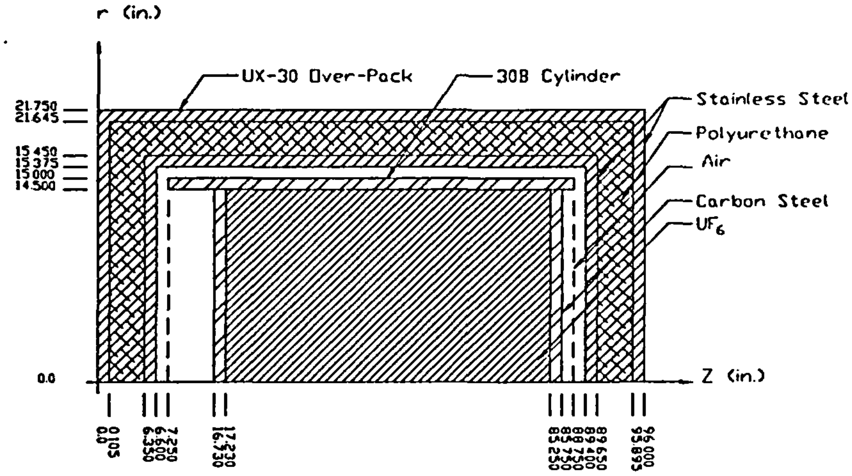


FIGURE 3.3-1
UX-30 Package HEATING Model

A three-dimensional (r-θ-Z) HEATING model of the UX-30 package was developed for the normal conditions of transport. A sketch of the model is shown in Figure 3.3-1 and a detailed description is given in Appendix 3.6.2. The thermal boundary conditions associated with the normal conditions of transport were imposed on the model, and the resultant steady-state temperature distributions are reported for over-pack, the 30B cylinder and the $UF_6$. The normal conditions of transport included a maximum ambient temperature of 100 °F and solar insolance on the top curved surface and vertical sides of the UX-30 overpack.

The thermal model used to evaluate the transient thermal response of the UX-30 packaging to the hypothetical fire accident event described in 10 CFR 71 is based on the model used for the normal conditions evaluation. The hypothetical accident conditions model is described in detail in Appendix 3.6.2. The full-scale thermal testing of the UX-30 package with simulated contents and the corresponding HEATING model analysis is provided in Appendix 3.6.3.

### 3.3.2 Evaluation by Testing

A discussion of the thermal testing performed on the UX-30 is given in Appendix 3.6.3.

### 3.3.3 Margins of Safety

Normal thermal conditions of transport do not exceed any established design conditions of the $UF_6$ cylinder when packaged within the UX-30. Internal pressure under these conditions does not reach one atmosphere.

Filling procedures described in USEC-651 impose much more severe temperature and pressure loadings on the cylinder than normal conditions of transport. Therefore, the UX-30 satisfactorily protects the $UF_6$ cylinder for normal thermal conditions of transport.

Evaluation of the UX-30 has been performed for the standard 30B cylinder. The 30C Cylinder is identical in dimensions and configuration, except for the Valve Protective Cover (VPC) (see Addendum 2-2004, ANSI N14.1). Therefore the analysis performed in Section 3.4 for normal conditions of transport is also applicable to the 30C Cylinder.

The analyses presented indicate that the UX-30 packaging will survive the hypothetical accident thermal conditions in a satisfactory manner.

Significantly:

- The $UF_6$ cylinder containment vessel temperature will not exceed 200°F and the pressure will not exceed 9 psia.

- The $UF_6$ within the cylinder will not exceed 180 °F locally and 117 °F bulk temperature.
- A thickness of 2 - 4 inches of foam will remain substantially unaffected by the transient, except in the impact damage zone, where approximately 1 to 1-1/2 inches would remain.
- There will be no loss of shielding since no shielding is required.
- Thermal loads on the UF6 cylinder containment vessel from the hypothetical accident are less severe than those imposed during filling operations, where cylinder temperatures are required to be above 200 oF.

The analysis and testing in Section 3.5 for hypothetical accident conditions was performed for the standard 30B cylinder. As discussed in Chapter 1, the 30C Cylinder is an optional cylinder for transport in the UX-30. This cylinder is identical in dimensions and configuration to the standard 30B cylinder, except that it is equipped with a Valve Protective Cover (VPC) for protecting the cylinder valve. Since the 30C Cylinder is identical to the standard 30B cylinder, the conclusions regarding the ability of the UX-30 to withstand hypothetical accident conditions with the 30B cylinder are also applicable to the 30C Cylinder. An additional consideration for the 30C Cylinder is that VPC has two Viton O-rings to prevent water leakage past the seating surface of the VPC on the cylinder body. However, Viton has an upper temperature limit of 400°F, which is well in excess of the maximum cylinder temperature during hypothetical accident conditions of 200°F.

## 3.4 Thermal Evaluation Under Normal Conditions of Transport

### 3.4.1 Heat and Cold

A steady-state analysis of the UX-30 was performed using the HEATING model described in Sections 3.3.1 and 3.5.1, assuming a maximum ambient temperature of 100°F and solar insolance on the top of the curved surface of the overpack and on the vertical sides per 10 CFR 71 requirements.

Significant points on the model and associated temperatures for normal conditions of transport are shown in Table 3.4-1, below. Importantly, temperatures within the UX-30 are well below the melting point of $UF_6$.

Since there is no significant internal heat load, the minimum temperature distribution from the regulatory minimum normal ambient condition of -40°F is a uniform temperature of -40°F. The minimum temperature distribution to be applied in combination with other loads per 10 CFR 71 is a uniform distribution of -20°F.

TABLE 3.4-1

Significant Points on Thermal Model Solution

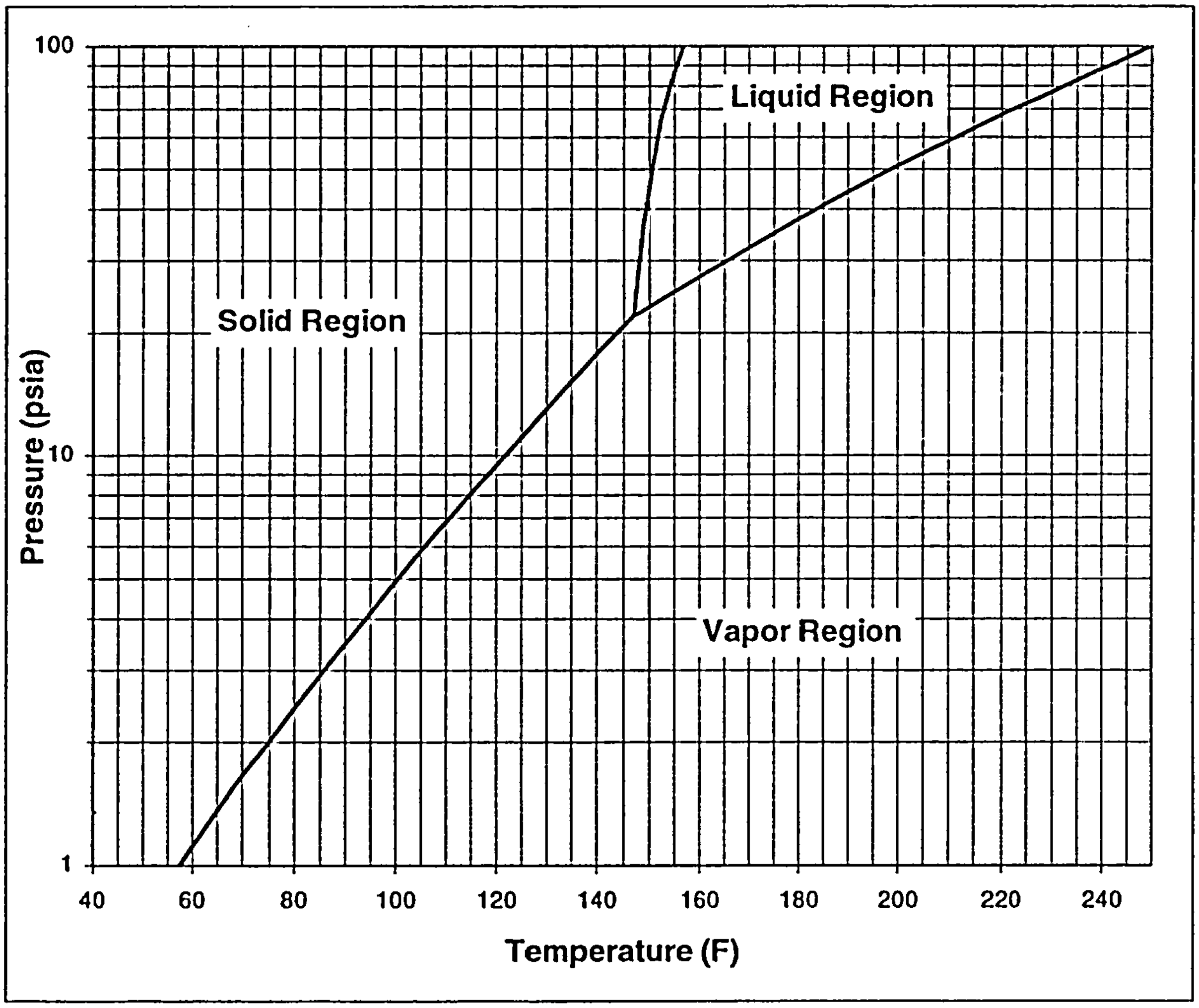
| Location | Temperature (°F) |
|---|---|
| Top of the outer surface of the UX-30 | 145.3 |
| Closure interface on the outer surface | 125.4 |
| Bottom of the outer surface | 101.5 |
| Top of the inner surface of the UX-30 | 125.7 |
| Closure interface of the inner surface | 121.7 |
| Top of the $UF_6$ cylinder | 124.0 |
| $UF_6$ | 124.0 |
| Valve Location | 123.1 |
| Plug Location | 120.6 |

### 3.4.2 Maximum Normal Operating Pressure

The maximum $UF_6$ cylinder internal pressure during the defined normal conditions occurs at the maximum $UF_6$ temperature to be expected for normal conditions of transport. This temperature is 124.0 °F. The internal pressure corresponds to the $UF_6$ vapor pressure at this temperature.

The vapor pressure as a function of temperature is shown in Figure 3.4-1, which is taken from USEC-651, Reference 1. From the Figure 3.3-2, the internal pressure can be seen to be less than 11 psia, or 0.75 atmospheres.

FIGURE 3.4-1
Phase Diagram of $UF_6$



### 3.4.3 Maximum Thermal Stresses

Thermal stresses in the $UF_6$ cylinder for normal conditions of transport are insignificant. The top surface of the UX-30 will expand relative to the rest of the package due to the higher temperatures there, but the light gage ductile stainless steel shell has enough flexibility that no significant thermal stress would develop in it. See Section 2.7.4 for a discussion of stress induced during the more severe hypothetical accident conditions.

## 3.5 Thermal Evaluation Under Hypothetical Accident Conditions

### 3.5.1 Initial Conditions

Because 10 CFR 71 requires that the transient thermal event be applied to the package after having been subjected to the drop and puncture events, the hypothetical accident conditions model has been modified from the normal conditions model to account for damage incurred during the impact events. The damage zones produced by the drops are approximated in the HEATING model as shown in Figure 3.5-1. Four damage zones are modeled: one from the Drop 1, two from Drop 2 and one from Drop 5, the pin puncture. Damage zone 3 is neglected since the others are more limiting. In general, the length of the damage zone is maintained and the depth of the foam crush is averaged. In the case of the pin punch zone, the depth is maintained and the length is averaged.

The most severe damage to the package from a thermal standpoint occurs on the overpack parting plane during the side impact from 30-feet. Due to this drop, the parting plane was opened 1 inch, and during the fire test, this opened parting plane was oriented into the fire. As a result of this, the fire is closer to the cavity and a significant part of the parting plane surface is adding energy to the cavity by convection on the surfaces of the parting plane.

In addition, because the polyurethane foam is compressed in the damage zones, its density and conductivity increase locally. To account for this deformation, the conductivity of the foam in the damaged zones have been factored up by the ratio of the undamaged to damaged foam thickness. A detailed description of these changes is presented in Appendix 3.6.2.

### 3.5.2 Fire Test Conditions

As described above, the analytic model for predicting the UX-30 transient response had several zones of damage including an opening in the UX-30 overpack parting plane. The parting plane damage, in particular, maximized the localized heat flow into the $UF_6$ cylinder.

In keeping with 71.73 of 10 CFR 71, the model is subjected to an ambient environment of 1,475 °F for 30 minutes, allowing for both radiant and convective heat transfer between the package surface and the environment. The emissivity of the radiation source was conservatively taken as 0.9, and the emissivity of the package was taken as 0.8 as specified in 10 CFR 71. Because 10 CFR 71, paragraph 71.73 (c) (3) states, '...The effects of solar radiation may be neglected prior to and during the test', the initial temperature distribution was assumed to be 100°F throughout the model.

After 30 minutes, the temperature of the ambient environment was returned to 100°F and the package allowed to cool with solar insolance as in the normal conditions of transport. No artificial cooling was applied at any time during the transient. The transient response was calculated using HEATING for the first 8-1/2 hours after initiation of the transient, after which reasonable estimates of maximum temperatures could be made.

### 3.5.3 Maximum Temperatures and Pressures

The most severe temperature distribution in the UX-30 overpack occurs approximately 30 minutes after the start of the fire. When the ambient temperature is returned to 100°F after 30 minutes, the temperatures within the package proceed initially very quickly toward equilibrium. After 1-1/2 hours, all temperatures in the package are less than 200°F, as shown in Figures 3.5-2, 3.5-3 and 3.5-4. Maximum temperatures experienced during the hypothetical accident for various points on the package are given in Table 3.5-1, below.

Under hypothetical accident conditions, the maximum 30B cylinder temperature was less than 200 °F. This is well within the design of the 30B cylinder. Also, local hot spots around the parting plane raise the temperature of the $UF_6$ above the melting point. Actual $UF_6$ temperature would be significantly less than 200 °F since local hot spots would dissipate heat to surroundings and a significant portion of the heat applied would be absorbed by the localized change in phase of the $UF_6$. Actual bulk temperature inside 30B cylinder would be significantly lower than 200 °F (maximum of ~117 °F after 120 minutes). Therefore, the resulting temperature for the $UF_6$, when conservatively assumed to be 200 °F, is acceptable and does not adversely affect the 30B cylinder thereby confirming adequacy of the UX-30 overpack for protection of a 30B cylinder.

TABLE 3.5-1

Maximum Hypothetical Accident Condition Temperatures

| Location | Temperature (°F) | Time After Fire Start (minutes) |
|---|---|---|
| Top of Outer Surface | 1466 | 30 |
| Closure Interface on Outer Surface | 1474 | 20 |
| Top of Inner Surface of UX-30 | 131.9 | 135 |
| Closure interface on Inner Surface | 705.6 | 30 |
| 30B cylinder at parting plane | 182.7 | 35 |
| 30B cylinder 90° from parting plane at 35 minutes | 100.0 | 35 |
| 30B cylinder 90° from parting plane, maximum | 120.6 | 340 |
| $UF_6$ adjacent to parting plane | 181.4 | 35 |
| $UF_6$ Bulk | 117 | ~120 |
| Valve Location | 145.2 | 95 |
| Plug Location | 120.6 | 340 |

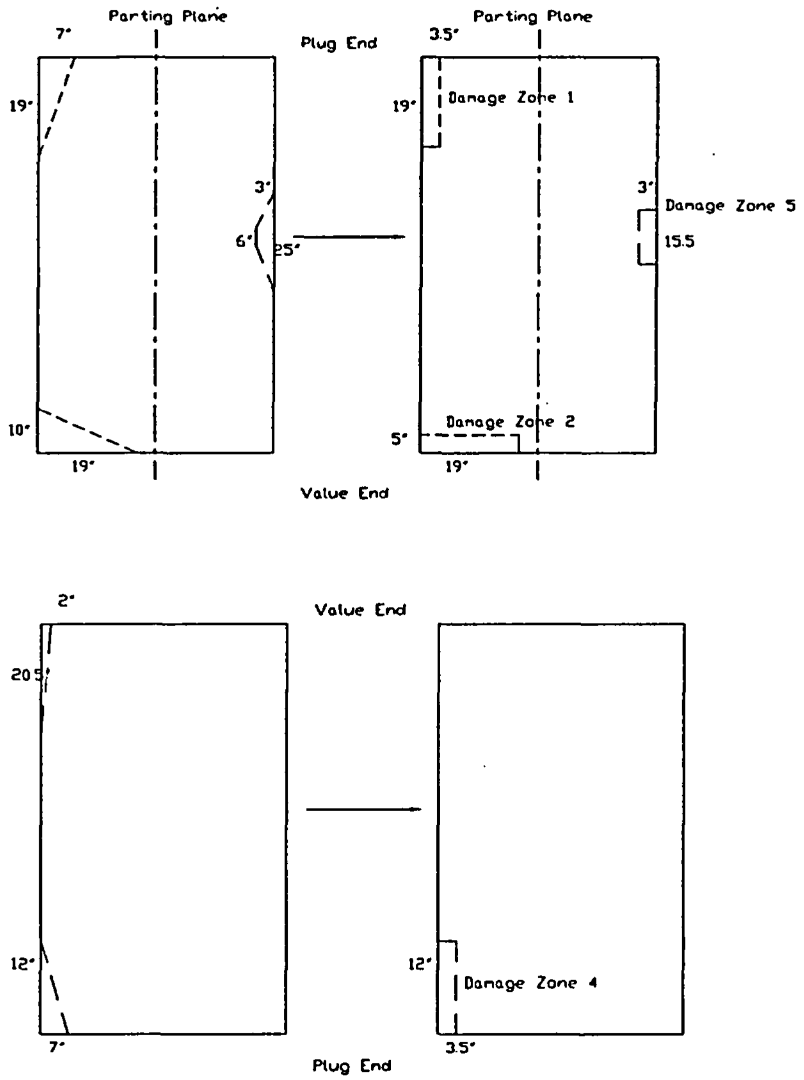


FIGURE 3.5-1

Hypothetical Accident Conditions Model Damage Zones

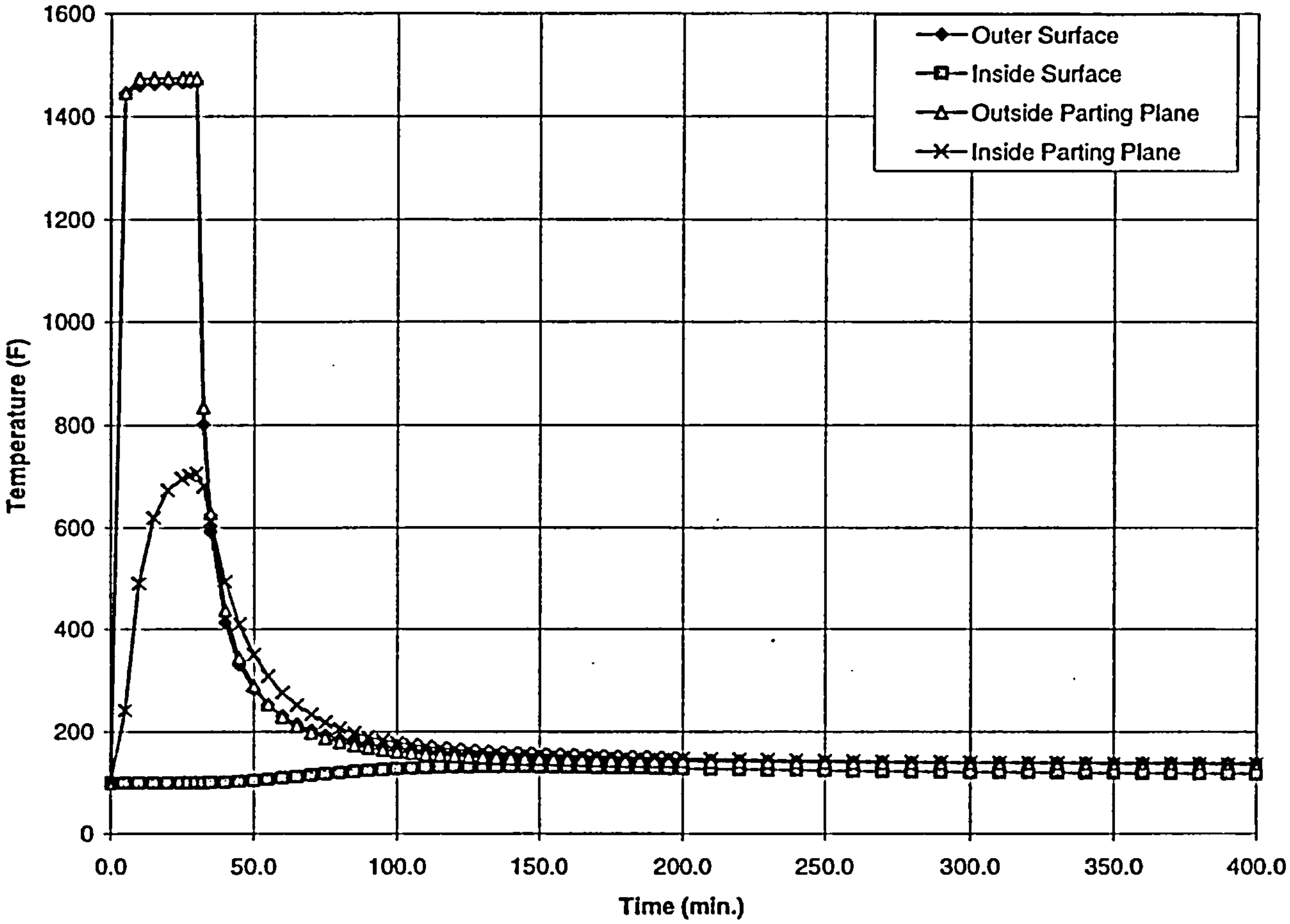


FIGURE 3.5-2

Hypothetical Fire Accident, UX-30 Overpack Temperatures

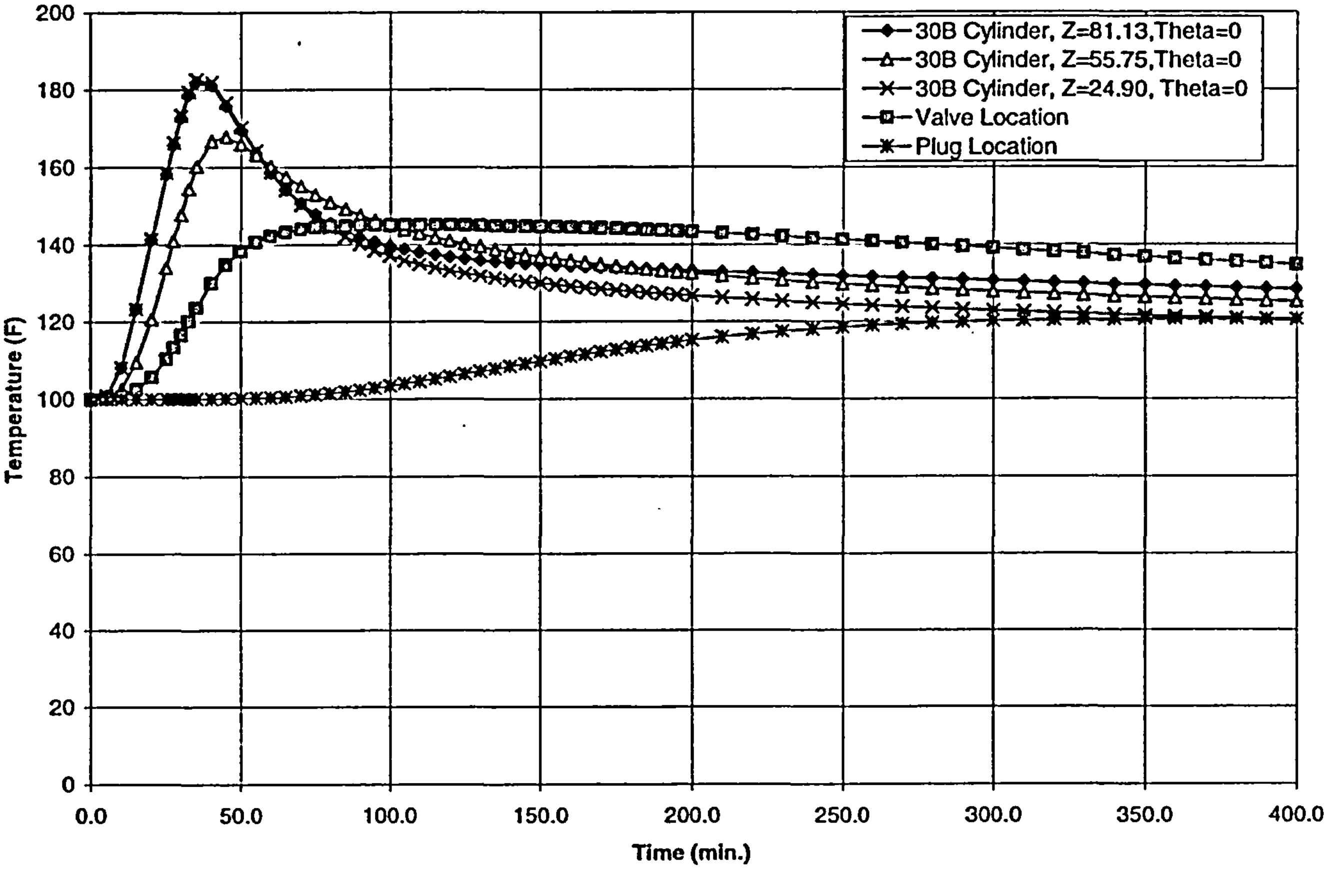


FIGURE 3.5-3

Hypothetical Fire Accident, 30B Cylinder Temperatures

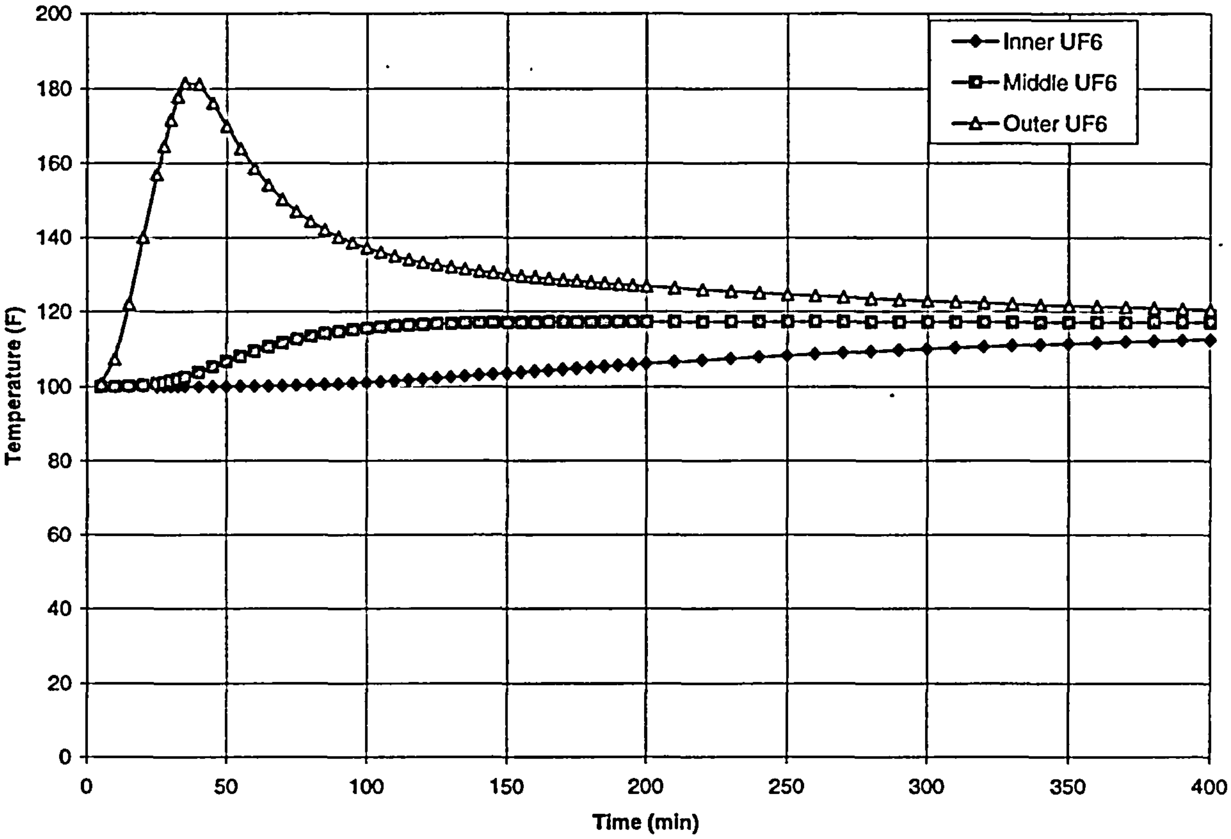


FIGURE 3.5-4

Hypothetical Fire Accident, $UF_6$ Temperatures

The maximum internal pressure within the $UF_6$ cylinder during the hypothetical accident thermal transient corresponds to the vapor pressure of the $UF_6$ at its maximum bulk temperature, reported as 117 °F in this section. From Figure 3.4-1, this pressure is approximately 9 psia, 6 psi less than atmospheric.

### 3.5.4 Maximum Thermal Stresses

The most severe thermal gradient in the UX-30 package occurs 30 minutes after the beginning of the hypothetical accident thermal transient, when the outer surface of the 30B cylinder ranges between 100°F and 180°F. The complete temperature distribution is given in Table 3.5-1. Filling procedures described in USEC-651 impose much more severe temperature and pressure loadings on the cylinder than hypothetical accident conditions. See Section 2.7.4 for a discussion of stress induced during hypothetical accident conditions.

References:

1. USEC-651, The $UF_6$ Manual: Good Handling Practices for Uranium Hexafluoride, Revision 8, USEC, January 1999.
2. (not used)
3. Personal conversation with D. H. Stitt, Union Carbide Plant, Paducah, Tenn. Mr. Stitt's source was a classified report by C. F. Hale and E. T. Barber.
4. GAT-280, Uranium Hexafluoride: A Survey of the Physio-Chemical Properties, Goodyear Atomic Corporation, 1960.
5. Holman, J. P.: Heat Transfer, First edition, McGraw Hill Book Company, 1963.
6. W. D. Wood, Thermal Radiation Properties of Selected Materials, Volume 1, Battelle Memorial Institute, 1962 (Emissivity = 0.8 on outer surfaces per 10 CFR 71).
7. Manufacturer's data. See Appendix 8.3.1 for the polyurethane foam material specification.
8. Sand 83-7073, TRUPACT Insulation Evaluation, Acurex Corporation, 1983.
9. Kreith, Principles of Heat Transfer, Third Edition, Intext Educational Publishers, 1973.
10. NUREG/CR-0200, SCALE 4.4 for the PC, September 1998.
11. NUREG/CR-0200, Volume 2, Section F10, "HEATING 7.2 User's Manual," K. W. Childs, September 1998.
12. NUREG/CR-0200, Volume 2, Section H1, "HTAS1: A Two-Dimensional Heat Transfer Analysis Of Fuel Casks, Version 4.0, J Giles, September 1998

# APPENDIX 3.6.1

## High Temperature Response of ES-M-170 Polyurethane Foam

Note

*This Appendix 3.6.1 refers to testing performed on "NPI.F12" foam. The designation and the specification number for this foam has changed to "ES-M-170." ES-M-170 foam is identical to NPI.F12. A copy of ES-M-170 is included in Appendix 8.3.1.*

## 3.6.1 High Temperature Response of NPI.F12 Polyurethane Foam

### 3.6.1.1 Introduction

Specially formulated polyurethane foam has been used for years as a shock absorbing and thermal insulating material in radioactive material packaging systems. The chemical make-up of the foam has been chosen specifically to optimize the material's performance under the high temperatures encountered during the hypothetical accident thermal transient, as described in 10 CFR 71.

Polyurethane foams of similar composition have been tested repeatedly over several years to demonstrate their fire-retardant qualities. Continuing research and refinement of the chemistry has resulted in a foam with highly favorable characteristics when subjected to high temperatures.

To fully appreciate these characteristics, a six-inch thick, ten-inch diameter cylindrical sample, fabricated from the same batch as the foam in the UX-30 prototype, was subjected to conditions simulating those required by 10 CFR 71. This test was carried out under very controlled conditions, and may be repeated with similar results. The test was conducted to verify and demonstrate properties and assumptions used in Section 3.5 to predict payload temperatures during the hypothetical accident scenario.

### 3.6.1.2 Test Conditions

The test sample was placed within a short section of 12-inch steel pipe. The ends of the specimen were covered with 0.1-inch thick steel sheet, with suitable thermocouples mounted centrally on the sheets to facilitate continuous temperature monitoring during the test. A large propane burner was used as the heat source. The end of the test assembly was equipped with a ceramic insulator to prevent the flame from surrounding the test cylinder, concentrating the heat input on the flat face of the cylinder. See Figure 3.6.1-1.

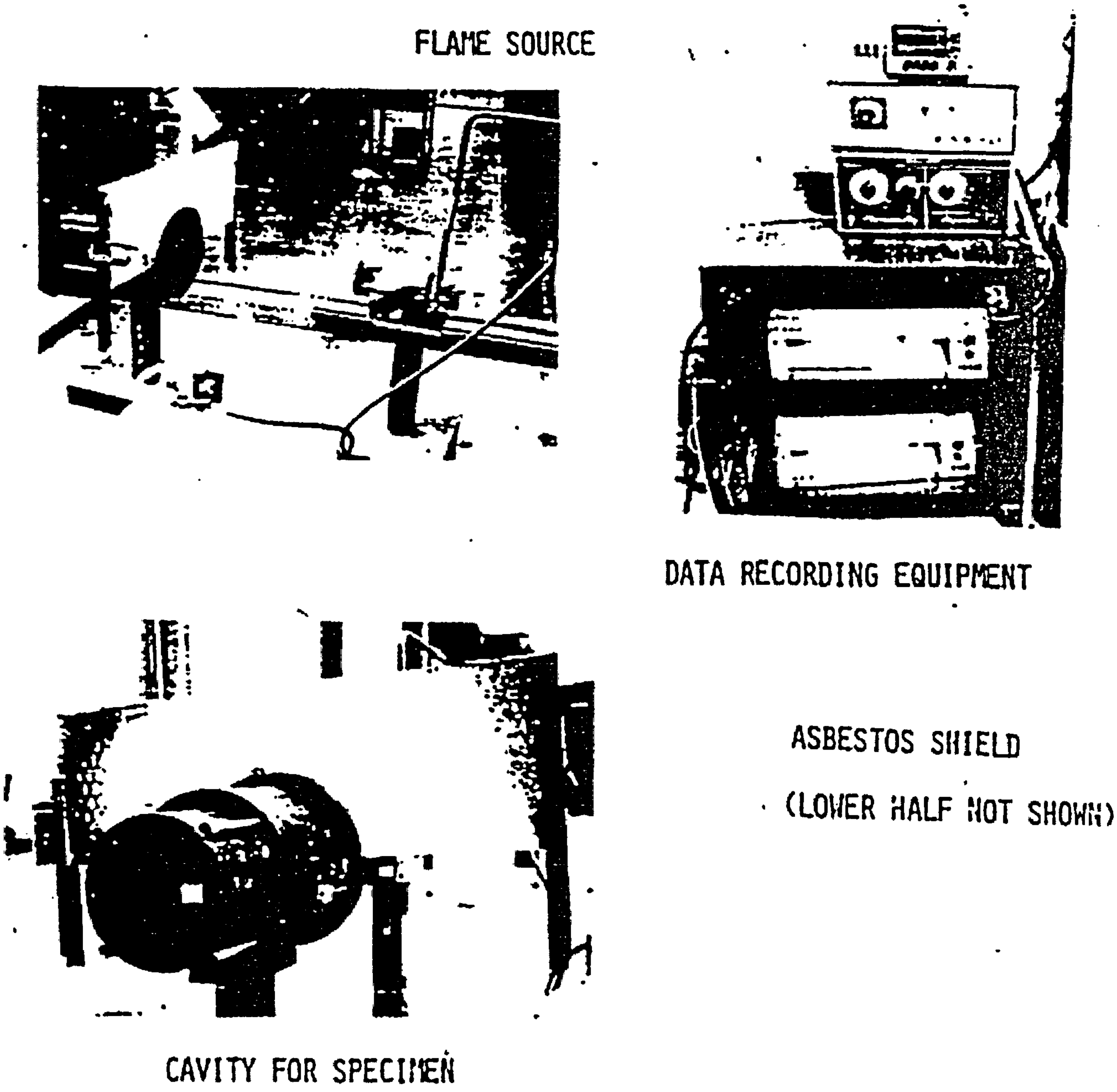


FIGURE 3.6.1-1

Thermal Testing Assembly

The initial conditions for the test has the test sample at 94°F. The test was performed outside in direct sunlight with the ambient temperature in excess of 80°F. A plot of the temperature of both thermocouples as a function of time is shown in Figure 3.6.1-2.

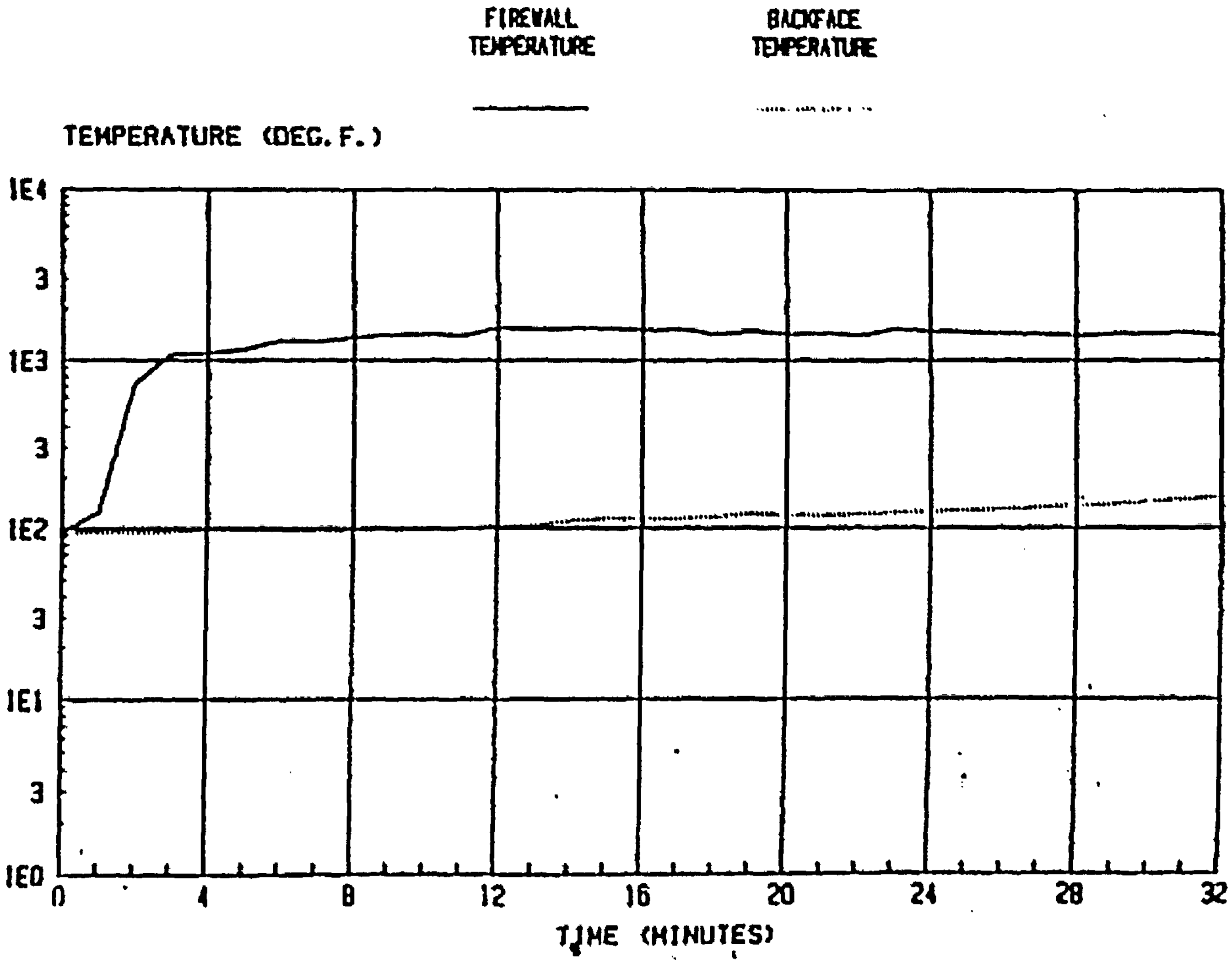


Figure 3.6.1-2
Thermal Test Temperatures

### 3.6.1.3 Test Results

The maximum backface temperature recorded during the test was 153°F, 32 minutes after the initiation of the test. Figure 3.6.1-3 shows the test specimen after the test. Note that approximately 3.5 inches of foam thickness remained unaffected by the test. Also, the foam that was affected by the heat transformed into a porous char, such that approximately 5.5 inches of foam and char thickness remained to insulate the backface from the heat source.

Importantly, the foam did not sustain flame. In the temperature range involved, the foam extinguishes oxidation (burning) reactions by developing flame-smothering dense char on the surface of the foam exposed to heat. The char formed actually deprives the remainder of the foam of oxygen, resulting in a very slow reaction while heat is applied, and halting the reaction very quickly after heat removal.

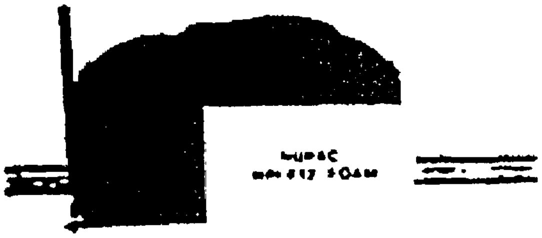


FIGURE 3.6.1-3

Thermal Test Specimen

The test specimen, being only 10-inches in diameter, was not large enough to provide a good correlation between the analyzed UX-30 inside surface temperature and the backface temperature of the test specimen. The thick steel walls of the test apparatus provide a significant heat transfer path around the foam specimen, contributing to the backface temperature rise. Therefore, the temperature rise determined by test is a conservative estimate of the actual interior surface temperature of the UX-30 under hypothetical accident conditions.

Despite the conservative nature of the test conditions, the backface temperature determined in this way indicates the effectiveness of the NPI.F12 foam to protect the payload. The thermally massive $UF_6$ payload, separated as it is from the inside surface of the UX-30 by a 1/2-inch air gap, would not increase in temperature fast enough for any potentially dangerous phase changes to occur. This assertion can be verified by examining the THAN analysis results presented in Section 3.5, especially the response of the cylinder walls as a function of the temperature of the overpack inside surface.

The results of this test indicate that a 6-inch jacket of NPI.F12 foam will satisfactorily insulate a $UF_6$ cylinder from the effects of the hypothetical accident thermal transient.

# APPENDIX 3.6.2

## Detailed Thermal Model Description

## 3.6.2 Detailed Thermal Model Description

The following is a detailed description of the HEATING thermal analysis models used in Sections 3.4 and 3.5 to calculate the response of the UX-30 to the requirements of 10CFR71. Thermal properties of materials are taken as given in Section 3.2, and the general philosophy is as stated in Sections 3.4.1 and 3.5.1. The HEATING thermal models and associated normal and hypothetical accident boundary conditions are described in detail below.

### 3.6.2.1 Analytical Method

Normal and accident thermal conditions of transport are analyzed with the HEATING code, version 7.2 embedded in the SCALE4.4 code package.[9,10] HEATING is a multidimensional, finite difference, general-purpose heat transfer code written in FORTRAN 77. HEATING solves steady-state and/or transient problems in one-dimensional (1-D), two-dimensional (2-D), or three-dimensional (3-D) Cartesian, cylindrical, or spherical coordinates. The mesh spacing may be variable along each axis. A model may include multiple materials, and the thermal conductivity, density, and specific heat of each material may be both time- and temperature-dependent. Thermal conductivity may be anisotropic. Materials may undergo up to five changes of phase for transient calculations involving either of the explicit procedures. The heat-generation rates may be dependent on time, temperature, and position. Boundary temperatures may be dependent on time and position. Boundary conditions include specified temperatures or any combination of prescribed heat flux, forced convection, natural convection, and radiation. The boundary condition parameters may be time- and/or temperature-dependent. In addition, one may model either 1-D radiative heat transfer directly across gaps embedded in the model or multidirectional radiation within enclosures using externally calculated radiation exchange factors.

Three-dimensional (r-θ-Z) HEATING models of the UX-30 package are developed for both normal and accident conditions. The normal and hypothetical accident thermal boundary conditions are imposed on each model, and the resultant temperature distributions are reported for over-pack, the 30B cylinder and the $UF_6$. Comparison is also made to an actual fire test performed on the UX-30 package.

HEATING solves the following heat balance equation in three dimensions for a node i surrounded by six neighbors:

$$C_i\left[\frac{T_i^{n+1}-T_i^n}{\Delta t}\right]=P_i^n+\sum_{m=1}^{6}{}_iK_m\left(T_m^n-T_i^n\right)$$

where,

$$C_i=\sum_{l=1}^{8}c_{pl}\rho_l V_l$$

$$P_i=\sum_{l=1}^{8}Q_l V_l$$

$${}_iK_m=\frac{1}{L_m}\sum_{\gamma=1}^{4}k_{m,\gamma}A_{m,\gamma}$$

| | |
|---|---|
| $c_{pl}$ | is the specific heat of material in the l<sup></sup>th octant surrounding node i, |
| $\rho_l$ | is the density of material in the lth octant, |
| $V_l$ | is the volume of the lth octant of node i, |
| $Q_l$ | is the heat generation rate per unit volume in lth octant, |
| $L_m$ | is the distance between node i and adjacent node m, |
| $K_{m,\gamma}$ | is the thermal conductivity of material in the $\gamma^{th}$ of four heat-flow paths between nodes i and m, |
| $A_{m,\gamma}$ | cross-sectional area of the $\gamma^{th}$ heat flow path between nodes i and m. |

In steady state, the heat balance equation becomes:

$$P_i^n+\sum_{m=1}^{6}{}_iK_m\left(T_m^n-T_i^n\right)=0$$

HEATING can accommodate a variety of boundary conditions. A boundary condition is applied along a surface of a region, and heat is transferred from a surface node to a boundary node or from a node on one face of a region to a node on the opposing face of the region. Surface nodes are nodes on the face of a region that are not covered by another region containing a material. Boundary nodes are dummy nodes used to represent the temperature of the environment to which a surface is exposed. Boundary temperatures are specified as input to the code. These temperatures are only used to calculate the heat flow across a boundary surface. The boundary condition types are the following:

1. the temperature on the surface of a region can be constant or a function of time and/or position;

2. the heat flux across the surface of a region can be constant or a function of time, position, and/or surface temperature;

3. the surface heat flux for a region can be specified indirectly by defining the heat transfer mechanism to be forced convection, radiation and/or natural convection; or

4. a combination of 2 and 3.

The temperatures of nodes on surfaces whose temperatures are specified are not calculated from but are set equal to the specified value. The specified heat flux is multiplied by each node's surface area, and the result is added to the heat generation term. The boundary condition types are surface-to-environment (Type 1), specified surface temperature (Type 2), or surface-to-surface (Type 3). Boundary conditions of the surface-to-environment type are used to define heat transfer between a surface node and a boundary node. Surface-to-surface boundary conditions are used to define heat transfer between opposing surfaces. In this case, heat is transferred between a node on one surface to the corresponding node on the opposing surface.

For both surface-to-environment and surface-to-surface boundary conditions, the heat flow term in is calculated as:

$${}_iK_m\left(T_m^n - T_i^n\right) = {}_iK_b\left(T_b^n - T_i^n\right)$$

where ${}_iK_b$ is the effective conductance from surface node i to boundary node b or the opposing surface node b. $T^n_b$ is either the temperature of boundary node b or the opposing surface node b at time $t_n$. The effective conductance is calculated as:

$${}_iK_b = h_{eff} A_i$$

where $h_{eff}$ is the effective heat transfer coefficient, and $A_i$ is the surface area of node i associated with the boundary condition. The effective heat transfer coefficient is calculated as

$$h_{eff} = h_c + h_r\left[T_i^2 + T_b^2\right]\left[T_i + T_b\right] + h_n\left|T_i - T_b\right|^{h_e}$$

where,

$h_c$ = the forced convective coefficient,
$h_r$ = the radiative heat transfer coefficient
$h_n$ = the natural convective coefficient,
$h_e$ = the natural convective exponent.
$T_i$ = the node i surface temperature
$T_b$ = the ambient boundary node temperature for the thermal analysis involved,

The parameters $h_c$, $h_r$, $h_n$, and $h_e$ must be specified by the user and can be time- and/or temperature dependent. When $h_c$, $h_r$, $h_n$, and $h_e$ are temperature-dependent, they are evaluated at the average temperature of the opposing surface-nodes for surface-to-surface boundary conditions. For surface-to-environment boundary conditions, $h_c$, $h_n$, and $h_e$ are evaluated at the average temperature of the related surface node and boundary node, whereas $h_r$ is evaluated at the temperature of the surface node. For surface-to-environment boundary conditions, the boundary temperature, $T^n_b$ , must also be supplied by the user and may be a function of time and/or position. If the temperatures are entered in either °F or °C, the code converts them to absolute degrees when calculating the effective thermal conductance due to radiation. In computing the effective conductance for a surface-to-surface boundary condition across a radial gap, the code uses the surface area at the smaller radius bounding the gap. One may simultaneously model surface-to-surface heat transfer across a region, as well as conduction through the region.

HEATING allows any dimensions as long as all the input data is self consistent, i.e. dimensions must be in either ft, inch, centimeter or meter throughout the input, including property data. For this thermal evaluation, dimensions are in inches; time is in minutes; density is in lb./in$^3$; conductivity is in BTU/(min-in-°F), and specific heat is in BTU/(lb.-°F). Conversions to this standard are made throughout this section, and the material properties given in the calculations input section are also converted to this standard at the end of this section.

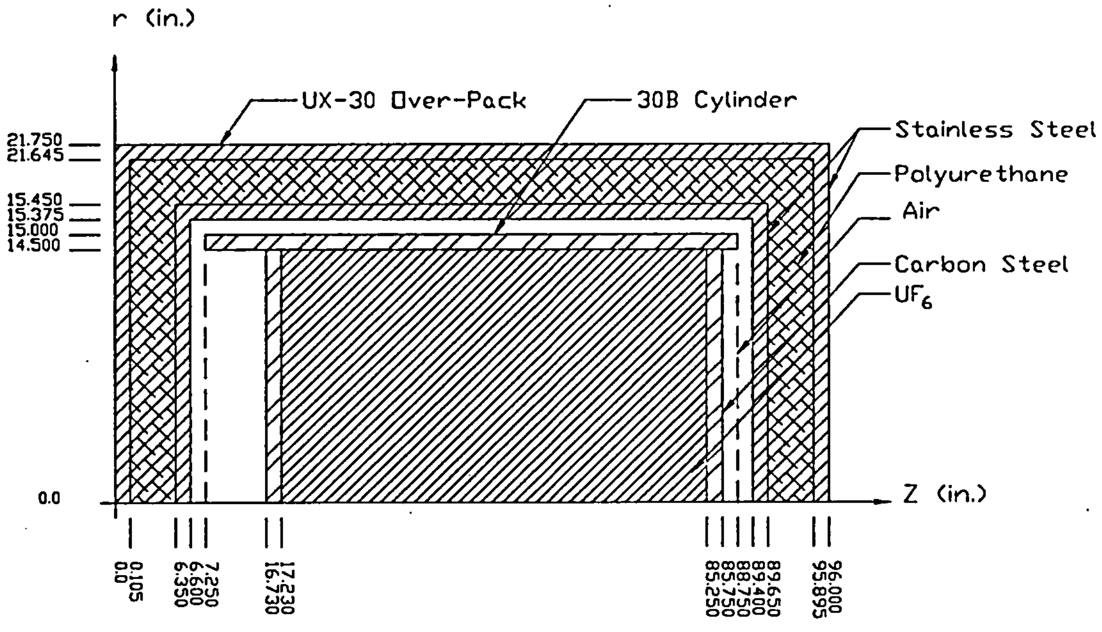
Both NCT and HAC models are based on the nominal dimensions of the UX-30 package. In both cases (r-θ-z) HEATING models are developed with some approximations to the normal and damaged geometry. In this geometry, the z-axis represents the horizontal axis during transport of the package. See Figure 3.6.2-1. The model represents the 30B cylinder with flat rather than spherical ends. The length of the cavity is based on the fact that the minimum volume is 26 ft$^3$. This yields a cavity length for the 30B cylinder of:

$$L_{eq} = \frac{26\,\text{ft}^3 * (12\,\text{in/ft})^3}{\pi * (14.5\,\text{in})^2} = 68.02\,\text{in.}$$

The model includes a top skirt of 3 inches and a bottom skirt of 9.48 inches. These are approximately the average lengths of the skirts if the 30B ends were flat. The over all length of the 30B including skirts, 81.5 inches, is preserved in the model. There is, conservatively, a little less thermal mass from the skirts.

**Figure 3.6.2-1**

**UX-30 Package HEATING Model – Nominal Dimensions**



Another modeling issue concerns the configuration of the $UF_6$ within the 30B cylinder. $UF_6$ in a liquid state is loaded into the 30B cylinder horizontally. The maximum weight of $UF_6$ that is allowed in the 30B cylinder is 5020 lbs. The density of liquid $UF_6$ is 227.7 lb/ft$^3$ and 5020 lbs. occupies 22.05 ft$^3$ within the cylinder. Presumably, this fills the cylinder such that a horizontal crescent forms the length of the cylinder. After the $UF_6$ cools, it solidifies with a density of 317.8 lb/ft$^3$ and 5020 lbs. occupies 15.80 ft$^3$ within the cylinder. This later volume is about 61% of the total volume of the 30B cylinder. Studies have shown that, depending on how fast the $UF_6$ cools, voids can form and a significant amount of low density $UF_6$ is created. Also, as the $UF_6$ solidifies it adheres to the cylinder walls, this creates a roughly circular void throughout the length of the cylinder. In this evaluation, the voids in the 30B cylinder (due to solidification of $UF_6$) are modeled in three ways: conical crescent a central void and a homogeneous mixture of void and $UF_6$. This is shown in Figure 3.6.2-2. Of these possibilities, the central void configuration has the $UF_6$ in contact with the cylinder all the way around the side. This central void configuration has the most contact with the cylinder and provides the highest temperatures, particularly if solar insolance is imposed on the top surface.

In both cases the total void volume is 26 $ft^3$ - 15.80 $ft^3$= 10.2 $ft^3$ and the total void area, assuming it occupies the entire equivalent length of the 30B cavity, is:

$$10.2\ ft^3 * (12\ in/ft)^3/68.02\ in = 259.12\ in^2$$

In the case of the conical crescent void, the angle of the cresent, $\theta_c$ is found from:

$$259.12\,\text{in}^2 = \frac{(14.5\,\text{in})^2 \theta_c}{2}$$

$$\theta_c = 2.4649\ \text{radians}$$

This crescent is configured between 0.3384 and 2.8033 radians in the model.
In the case of the central void, the radius, $r_v$, is found from:

$$259.12\,\text{in}^2 = \pi r_v{}^2$$

$$r_v = 9.082\ \text{inches}$$

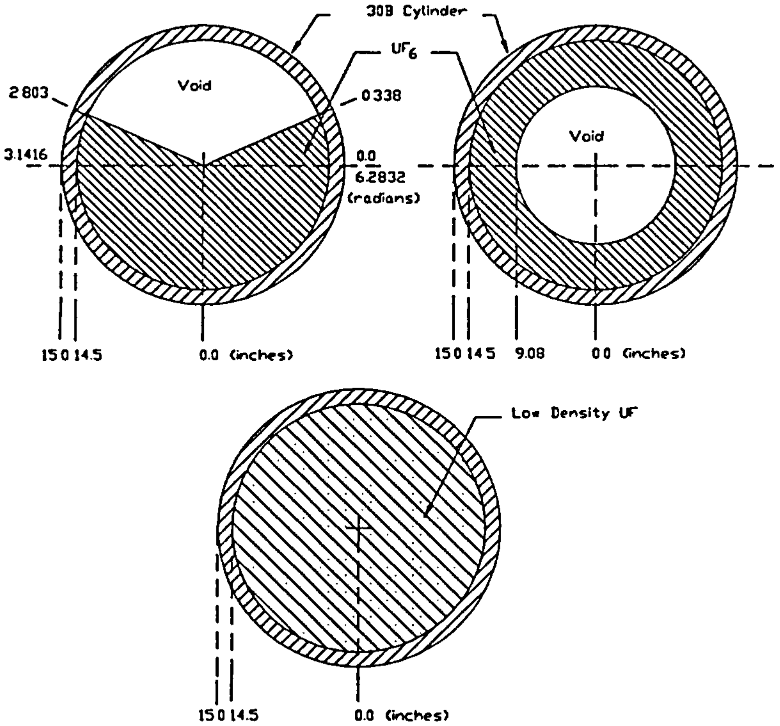
Since filling procedures for the UX-30 cylinder require the initial pressure to be 5 psia or less, the void region in both cases is assumed to be vacuum. In the case of the homogeneous mixture of void and $UF_6$, the mixture fills the 30B cavity and the effective density becomes:

$$\frac{5020\,\text{lbs}}{26\,\text{ft}^3 \times (12\,\text{in./ft})^3} = 0.1117\frac{\text{lb}}{\text{in.}^3}$$

The conductivity of this mixture is ratioed by the effective density to the solid density.

**Figure 3.6.2-2**

**UX-30 Package HEATING Model – Possible Solid $UF_6$ Configurations**



Input to the HEATING models requires that for each region in the model the initial temperature, heat generation and surface boundary conditions are specified. The initial temperature in both NCT and HAC models is set to 100 °F per assumptions 1 and 3. In this particular package, heat generation from the $UF_6$ is negligible. Thus, the heat generation rate in all regions are zero. HEATING allows three types of boundary conditions: 1) surface to environment, 2) prescribed surface temperature and 3) surface to surface. Surface to environment and surface to surface boundary conditions are employed in the UX-30 thermal evaluations. Both conditions also allow a prescribed such heat flux such as solar insolance to be included. The surface-to-environment boundary conditions are applied on the outer surfaces of the UX-30 package. This condition includes: natural convection, radiation and a prescribe heat flux (solar insolance). Surface-to-surface boundary conditions are applied across the radial, top and bottom air gaps between the UX-30 inner surface and the 30B cylinder.

Natural convection cooling for a cylinder is assumed for the outer surfaces of the UX-30 overpack under normal conditions and after the fire accident. The natural convection coefficient and natural convection exponent values are based on the standard formula for a cylinder under turbulent natural convection conditions. For the radial outer surface of the UX-30 over-pack, the values of $h_n$ and $h_e$ are 0.18 Btu/(hr-ft$^2$-°F$^{4/3}$)=2.083E-5 BTU/(min-in$^2$-°F$^{4/3}$) and 1/3, respectively, to simulate the turbulent natural convective heat transfer in air on the radial surface of a long horizontal cylinder. For the axial outer surfaces of the UX-30 overpack, $h_n$ and $h_c$ are 0.19 Btu/(hr-ft$^2$-F$^{4/3}$)=2.199E-5 BTU/(min-in$^2$-°F$^{4/3}$) and 1/3, respectively, to simulate the turbulent natural convective heat transfer in air on the end of a horizontal cylinder. All other interior surfaces and void regions conservatively neglect convection.

In order to comply with IAEA Safety Series No. 6, 1985 requirements and with the recommendations of the IAEA Safety Series No. 37, a forced convection coefficient for a pool fire based on the Colburn relation is used during the fire accident. For the UX-30 overpack , the forced convection heat transfer coefficient is computed using the following correlation :

$$\mathrm{Nu} = \frac{h_c d}{k} = 0.036 \times \mathrm{Pr}^{0.333} \times \mathrm{Re}^{0.8}$$

where

$h_c$ = the force convection coefficient for a pool fire

d = the diameter of the overpack= 43.5 in. = 1.105 meters

k = conductivity of air

$$\mathrm{Pr} = \text{Prandlt Number} = \frac{c_p \mu}{k}$$

$$\mathrm{Re} = \text{Reynolds Number} = \frac{v \rho d}{\mu}$$

A pool fire gas velocity of 10 m/s is assumed. Substituting for the for the Reynolds number in the above correlation and solving for the forced convection coefficient gives:

$$h_c = 0.036 \times \mathrm{Pr}^{0.333} \times \left( \frac{(10\,\mathrm{m/s})\rho(1.105\,\mathrm{m})}{\mu} \right)^{0.8} \times \frac{k}{1.105\,\mathrm{m}}$$

Based on the properties of air at atmospheric pressure and the temperature conditions of both the fire test and 10CFR71, the force convection heat transfer is calculated to be 4.240E-4 Btu/min-in$^2$-°F for the fire test evaluation, and is calculated to 4.609E-4 Btu/min-in$^2$-°F for the 10CFR71 evaluations.

The radiative heat transfer coefficient at the surfaces of the has the form:

$$h_r = \sigma\varepsilon$$

where,

$\sigma$ = the Stefan-Boltzmann constant

= $0.173 \times 10^{-8}$ Btu/(hr-ft$^2$-R$^4$) = $2.002\times10^{-13}$ BTU/(min-in$^2$-R$^4$),

$\varepsilon$ = the emissivity of the material on the surface of the model.

Under normal conditions it is assumed that $\varepsilon$=0.5 for the surface of the UX-30 package and, thus,

$h_r = 0.5\times2.002\times10^{-13}$ BTU/(min-in$^2$–R$^4$) =$1.001\times10^{-13}$ BTU/(min-in$^2$–R$^4$).

In the case of the fire accident, the radiative heat transfer coefficient has the form:

$$h_r = \frac{\sigma}{\left(\frac{1}{\varepsilon_s}+\frac{1}{\varepsilon_f}-1\right)}$$

where,

$\varepsilon_s$ = the emissivity of the surface during the fire =0.8,

$\varepsilon_f$ = the emissivity of the fire =0.9.

Thus, for the accident thermal analysis:

$$h_r = \frac{\sigma}{\left(\frac{1}{\varepsilon_s}+\frac{1}{\varepsilon_f}-1\right)} = \frac{2.002\times10^{-13}\ \mathrm{BTU/(min\text{-}in^2\text{-}R^4)}}{\left(\frac{1}{0.8}+\frac{1}{0.9}-1\right)} = 1.4708\times10^{-13}\mathrm{BTU/(min\text{-}in^2\text{-}R^4)}$$

In both normal and accident conditions, radiation exchange across the air gap between 30B cylinder and the UX-30 inner surface is modeled with a surface to surface radiation coefficient. This assumes a narrow gap approximation in which radiation exchange occurs between nodes directly across from each other. For this boundary condition, the radiative heat transfer coefficient has the form:

$$h_r = \frac{\sigma}{\left[\frac{1}{\varepsilon_1}+\left(\frac{A_1}{A_2}\right)\left(\frac{1}{\varepsilon_2}-1\right)\right]}$$

where,

$\varepsilon_1$ =the emissivity of the 30B carbon steel surface =0.8,

$\varepsilon_2$ = the emissivity of UX-30 stainless steel inner surface =0.5.

Since the surfaces in communication have very nearly the same area, the above expression simplifies to:

$$h_r = \frac{\sigma}{\left(\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1\right)} = \frac{2.002\times10^{-13}\ \mathrm{BTU/(min\text{-}in^2\text{-}R^4)}}{\left(\frac{1}{0.8}+\frac{1}{0.5}-1\right)} = 8.890\times10^{-14}\,\mathrm{BTU/(min\text{-}in^2\text{-}R^4)}$$

Under normal conditions and after the HAC fire, the solar heat flux is equal to

0.5×122.92 Btu/(hr-ft$^2$) = 61.46 Btu/(hr-ft$^2$) =7.113×10$^{-3}$ Btu/(min-in$^2$)

This solar heat flux is applied on the upper half of the cylindrical surface ($0 \leq \theta \leq \pi$). A solar heat flux that is applied to the two side surfaces (at Z=0 and at Z=96) is given by the following equation:

0.5×61.46 Btu/(hr-ft$^2$) =30.73 Btu/hr-ft$^2$=3.557×10$^{-3}$ Btu/(min-in$^2$)

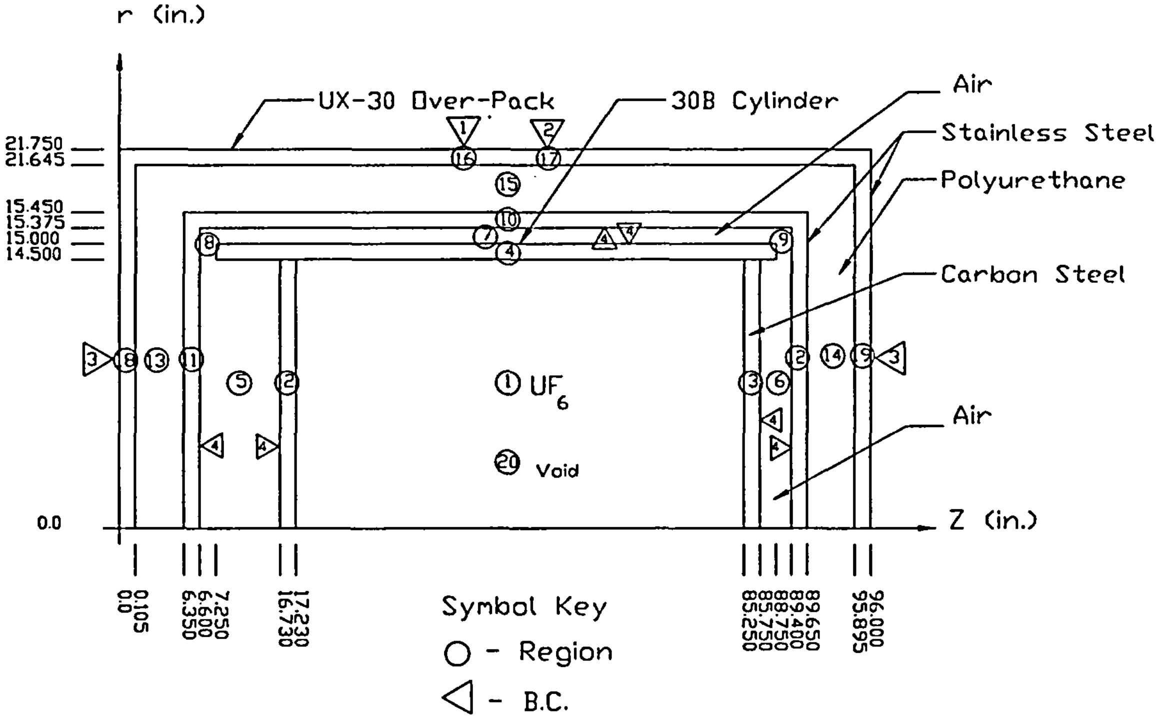
Both heat fluxes (at the upper half and the two sides) are computed based on the information provided in 10CFR71. 10CFR71 requires to use 12 hr solar insolance of 1475 Btu/ft$^2$ and 737.5 Btu/ft$^2$ for curved and vertical surfaces, respectively. The surface emissivity of 0.5 is used for stainless steel.

The normal conditions of transport HEATING model of the UX-30 package is shown in Figure 3.6.2-3. This model comprises 20 regions of 5 materials. This is summarized in Table 3.6.2-1 below.

**Table 3.6.2-1**
**HEATING Model Material and Region Assignments**

| Mat. ID | Material | Regions |
|---|---|---|
| 1 | $UF_6$ | 1 |
| 2 | Iron | 2-4 |
| 3 | Air | 5-9 (gap between UX-30 and 30B)<br>20 (central void) |
| 4 | Stainless Steel | 10-12 (inner shell)<br>16-19 (outer shell) |
| 5 | Polyurethane | 13-15 |

**Figure 3.6.2-3**
**Normal Conditions of Transport**
**HEATING Model Regions and Boundary Conditions**



Four boundary conditions are imposed: three of Type 1 (surface-to-environment) on the outer surfaces of the UX-30 over-pack and one Type 3 (surface-to-surface) on the inner surface of the UX-30 over-pack and the outer surface of the 30B cylinder. See Table 3.6.2-2 below. Boundary condition 1 includes a solar heat flux for a curved surface. This is applied to region 16 (r=21.75 and $0 \leq \theta \leq \pi$), which is the top part of the outer shell. Boundary condition 2 does not include solar heat flux and is applied to region 17 (r=21.75 and $\pi \leq \theta \leq 2\pi$), which is the lower part of the outer shell. Thus, solar insolance is applied over half of the radial outer surface of the package. Boundary condition 3 includes a solar heat flux for a vertical surface. This is applied to the outer surfaces of Regions 18 (side with Z=0.0), 19 (side with Z=96), 16 (left and right corner of the upper half of the shell) and 17 (left and right corner of the lower) half of the shell. Thus, solar insolance is applied completely over both vertical end surfaces of the package.

Table 3.6.2-2
NCT HEATING Model Boundary Conditions and Assignments

| BC | Type | $h_c$ Btu/(min- in$^2$) | $h_r$ Btu/(min-in$^2$–R$^4$) | $h_n$ Btu/(min-in$^2$-F$^{4/3}$) | $h_e$ | Heat Flux Btu/(min-in$^2$) | Region/ Surface Applied |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.0 | 1.001-13 | 2.083-5 | 0.333 | 7.113-3 | 16/r=21.75 |
| 2 | 1 | 0.0 | 1.001-13 | 2.083-5 | 0.333 | 0.0 | 17/r=21.75 |
| 3 | 1 | 0.0 | 1.001-13 | 2.199-5 | 0.333 | 3.557-3 | 18/z=0.0<br>19/z=96.0<br>16/z=0.0,96.0<br>17/z=0.0,96.0 |
| 4 | 3 | 0.0 | 8.890-14 | 0.0 | 0.0 | 0.0 | 5/z=6.6,16.73<br>6/z=85.75, 89.4<br>7/r=15.0, 15.375 |

Based on the regional boundaries as shown in Figure 3.6.2-1, a gross grid is defined and additional meshes are introduced in region where strong temperature gradients are expected, such as in the polyurethane insulation foam. The resultant models have 29,325, 29289 and 29,478 nodes for the cylindrical void, conical void and homogeneous mixture configurations, respectively. In the case of the cylindrical void model, the major nodal points for reporting temperature data are shown in Table 3.6.2-3 below. The Z=51.24 elevation was selected to be roughly at the axial center of the package. θ=1.57 radians was selected to be at the maximum orientation for solar insolance and θ=4.71 is at the shaded side (bottom) of package. For the left and right side of the cylinder, the radius was select to be roughly at the value and plug locations.

**Table 3.6.2-3**
**Major Model Nodal Points**

| Location | R | θ | Z | Node |
|---|---|---|---|---|
| Top Surface of Over-Pack | 21.75 | 1.57 | 51.24 | 15125 |
| Inside Surface of Over-Pack | 15.375 | 1.57 | 51.24 | 15103 |
| Outside Closure Surface | 21.75 | 0.0 | 51.24 | 14993 |
| Inside Closure Surface | 15.375 | 0.0 | 51.24 | 14971 |
| Top of Cylinder | 15.0 | 1.57 | 51.24 | 15101 |
| Top of $UF_6$ (Central Void) | 14.50 | 1.57 | 51.24 | 15099 |
| Bottom of Cylinder | 15.0 | 4.71 | 51.24 | 15365 |
| Left Side of Cylinder (valve) | 10.44 | 1.57 | 16.73 | 11699 |
| Right Side of Cylinder (plug) | 9.08 | 4.71 | 85.75 | 18553 |
| Inside Surface of Over-Pack | 15.375 | 4.71 | 51.24 | 15367 |
| Bottom Surface of Over-Pack | 21.75 | 4.71 | 51.24 | 15389 |

The hypothetical accident conditions HEATING models also includes the effects of damage to the over-pack due to the drop testing. The drops cause five zones of damage that had to be approximated in r-θ-z geometry.

The damage zones produced by the drops are approximated in the accident HEATING model as shown in Figure 3.6.2-4. Four damage zones are modeled: one from the Drop 1, two from Drop 2 and one from Drop 5, the pin puncture. Damage zone 3 is neglected since the others are more limiting. In general, the length of the damage zone is maintained and the depth of the foam crush is averaged. In the case of the pin punch zone, the depth is maintained and the length is averaged. In addition, because the polyurethane foam is compressed its density and conductivity increase locally. The adjustment of the polyurethane properties is discussed in subsequent sections.

The cross sectional area of the damage zones is transformed into an equivalent r-θ sector as shown in Figure 3.6.2-5. Equating the damage areas:

$$\frac{\pi r^2}{2} - (r - d) \times \sqrt{2dr - d^2} - r^2 \sin^{-1}\left(\frac{r - d}{r}\right) = \frac{\theta}{2}\left[r^2 - (r - d)^2\right]$$

where,

d is the depth of the damage in inches

r is the radius of the UX-30 over-pack =21.75 inches

θ is the angle of the equivalent damage in radians

The left sized of the above equation is the area of the original damage (2 times the area under a circle of radius r from x=r to x=r-d) and the right side is an equivalent r-θ sector. Solving for θ gives:

$$\theta = \frac{\pi r^2 - 2(r - d)\sqrt{2dr - d^2} - 2r^2 \sin^{-1}\left(\frac{r - d}{r}\right)}{(2rd - d^2)}$$

The density and conductivity of the foam just behind the damage zone is increased in proportion to the damage depth, d, i.e.,

$$k' = \frac{6.2}{6.2 - d} k = \frac{6.2}{6.2 - d} \times 6.389 \times 10^{-5} \text{ BTU/(min-in-°F)}$$

$$\rho' = \frac{6.2}{6.2 - d} \rho = \frac{6.2}{6.2 - d} \times 4.514 \times 10^{-3} \text{ lb/in}^3$$

The transformation values are summarized in Table 3.6.2-4 below.

### Table 3.6.2-4
### Damage Zone Properties

| Damage Zone | Material No. | D (inches) | θ (radians) | k' (Btu/min-in- °F) | rho' (lbs/in$^3$) |
|---|---|---|---|---|---|
| 1 | 6 | 3.5 | 0.8025 | 1.467E-04 | 1.037E-02 |
| 2 | 7 | 5 | - | 3.301E-04 | 2.332E-02 |
| 2 | | 19 | 2.6800 | - | - |
| 3 | 8 | 1 | 0.4110 | 7.618E-05 | 5.382E-03 |
| 4 | 6 | 3.5 | 0.8025 | 1.467E-04 | 1.037E-02 |
| 5 | 9 | 3 | 0.7364 | 1.238E-04 | 8.746E-03 |

Assuming the parting plane is at θ=0 and the value end of the package is starts as z=0 as in Figure 3.6.2-1, the damage zone dimensions are shown in Table 3.6.2-5. Damage zones 1 and 2 are centered at θ=π/2 =1.5708, and zone 5 is centered at θ=3π/2 =4.7124. The zones affect the regional description of the polyurethane and the outer steel shell of the UX-30 over-pack. Boundary condition 1 and 3 are imposed on all radially and axially exposed damage surfaces, respectively.

### Table 3.6.2-5
### Damage Zone Dimensions

| Damage Zone | $R_{low}$ | $R_{high}$ | $\theta_{low}$ | $\theta_{high}$ | $Z_{low}$ | $Z_{high}$ |
|---|---|---|---|---|---|---|
| 1 (void) | 18.25 | 21.75 | 1.1696 | 1.9721 | 77 | 96 |
| 1 (mat. 6) | 15.45 | 18.25 | 1.1696 | 1.9721 | 77 | 96 |
| 2 (void) | 2.75 | 21.75 | 0.2308 | 2.9108 | 0.0 | 5.0 |
| 2 (mat. 7) | 2.75 | 21.75 | 0.2308 | 2.9108 | 5.0 | 6.35 |
| 4 (void) | 18.25 | 21.75 | 5.882 | 0.4013 | 77 | 96 |
| 4 (mat. 6) | 15.45 | 18.25 | 5.882 | 0.4013 | 77 | 96 |
| 4 (void) | 15.45 | 18.25 | 6.2558 | 0.0274 | 77 | 96 |
| 5 (void) | 18.75 | 21.75 | 4.3442 | 5.006 | 40.25 | 55.75 |
| 5 (mat. 9) | 15.45 | 18.75 | 4.3442 | 5.006 | 40.25 | 55.75 |

# Figure 3.6.2-4
# UX-30 Drop Damage Approximations in HAC Heating Model

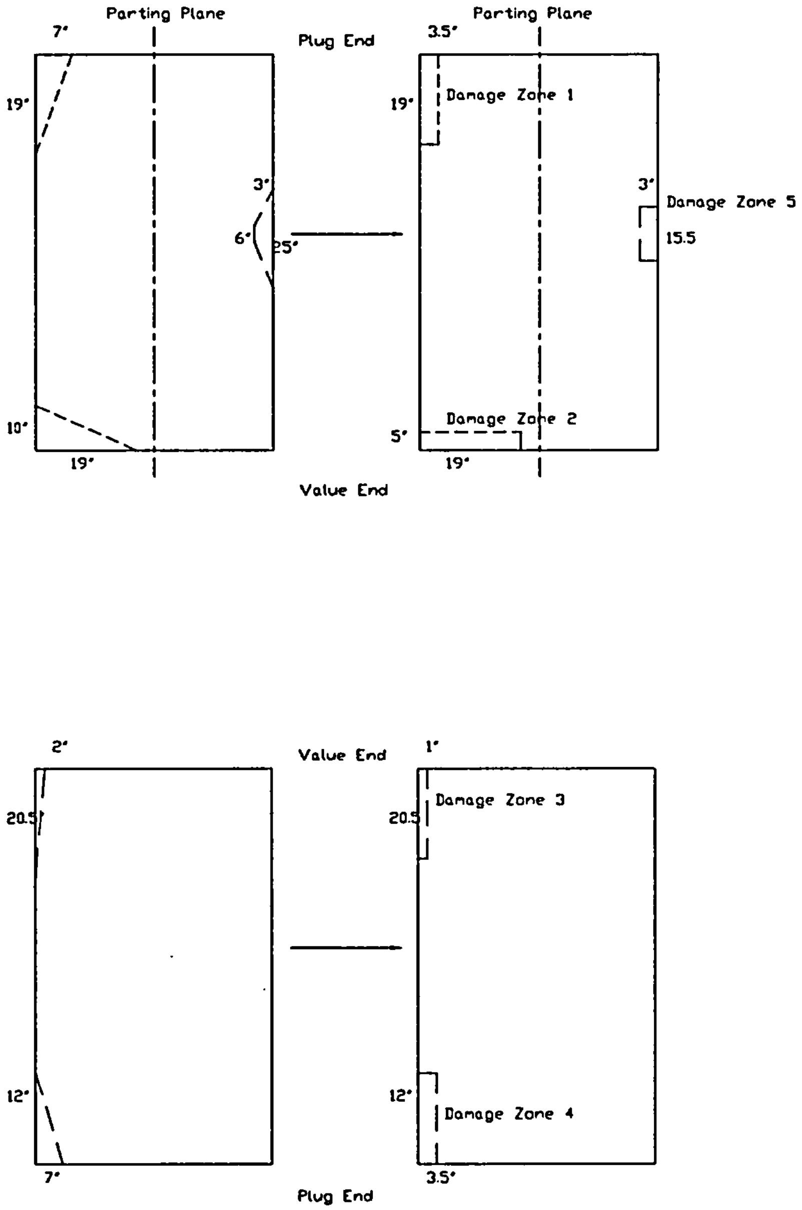
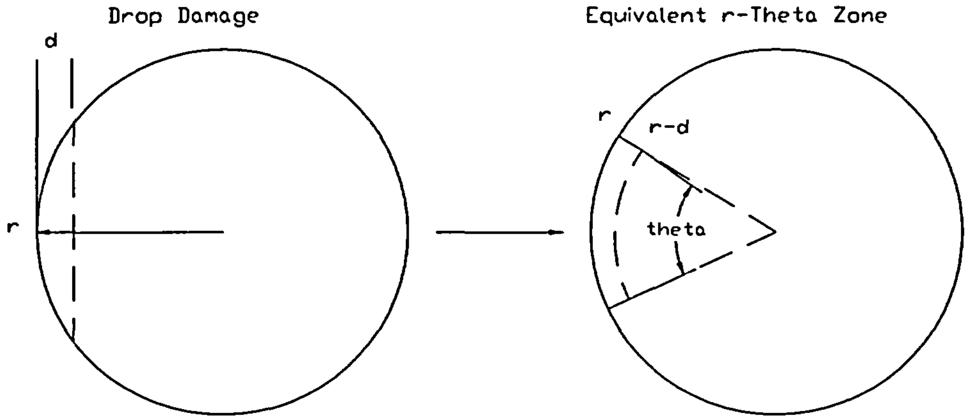


Figure 3.6.2-5
Damage Zone r-θ Approximation



Another important aspect of the UX-30 cask modeling is the metallic connection of the parting plane surface with the inner and outer surfaces of the UX-30 over-pack. The parting plane of the UX-30 over-pack is a stepped configuration which is covered with 12 gauge stainless steel 304. Even though this steel is 0.105 inch thick, it provides a thermal connection between the outside surface and the inside of the cavity of the UX-30. In fact the two halves of the UX-30 over-pack provide almost a ¼ inch connection of stainless steel between the inside an outside surfaces all the way around the over-pack. Modeling of this thermal connection is important to calculating conservative temperatures for HAC fire accident and is important to calculating accurate temperatures for the fire test.

Also important to achieving accurate temperatures during the UX-30 fire test is modeling of the damaged parting plane. As a result of Drop 2, the parting plane was opened 1 inch, and during the fire test, this opened parting plane was oriented into the fire. As a result of this, the fire is closer to the cavity and a significant part of the parting plane surface is adding energy to the cavity by convection on the surfaces of the parting plane. Recall the parting plane is approximately 8.73 inches in width and 96 inches in length on the side, i.e. 838 in$^2$.

Two simple parting plane models were adopted for used in subsequent evaluations. These are shown in Figure 3.6.2-6. The first model is a simple stainless steel connection between the inner and outer shell 0.21-inch thick. This is a simple model of two undamaged parting planes in direct contact. Only conduction is allowed between the inner and outer surfaces. The second model is two 0.10-inch thick stainless steel connections between the inner and outer shells with a 1" gap between. Conduction and convection are permitted in this model. The boundary conditions on the gap side of the steel connections are set to convection with the ambient conditions.

In the case of the fire test model, the cavity is filled with 6627 lbs of steel shot. The minimum volume the shot could occupy is:

$$\frac{6627\,\text{lb}}{488\,\text{lb/ft}^3}=13.58\,\text{ft}^3.$$

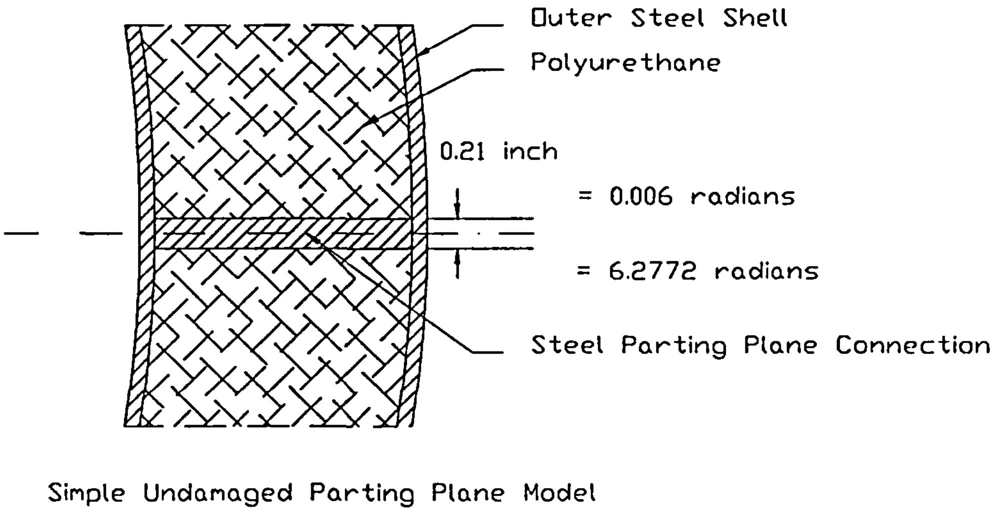
In actuality steel shot would have a packing fraction at best 60 to 65% or a volume of 22.6 to 20.9 $\text{ft}^3$. For simplicity, it is assumed that the steel shot will occupy the entire 26 $\text{ft}^3$ volume of the 30B cylinder. This yields an average density of:

$$\frac{6627\,\text{lb}}{26\,\text{ft}^3}=254.88\,\text{lbs/ft}^3=0.1475\ \text{lbs/in}^3.$$

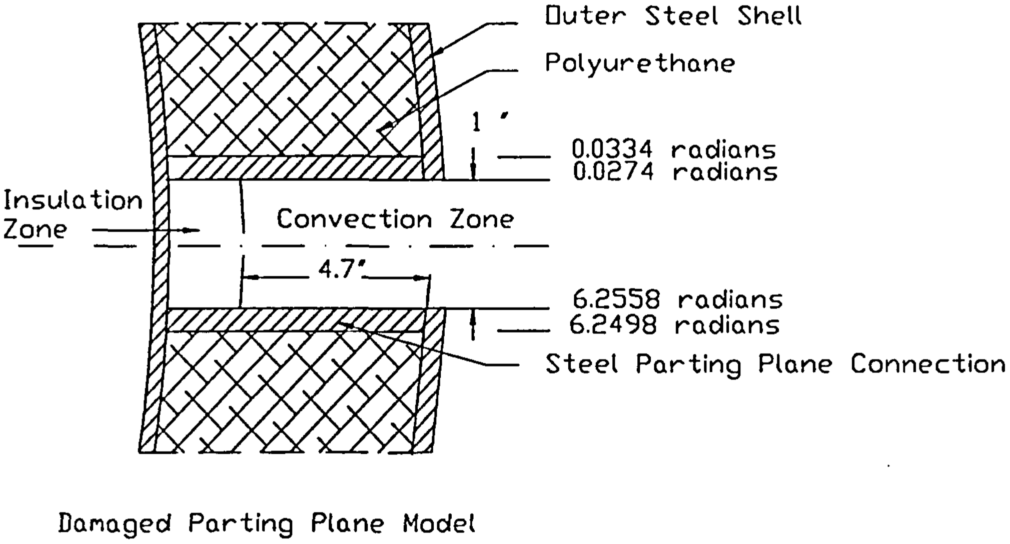
The conductivity of this cavity steel is ratioed by this density and is:

$$\left(9.4\frac{\text{Btu}}{\text{hr-ft-°F}}\right)\frac{254.88\,\text{lbs/ft}^3}{488\,\text{lbs/ft}^3}=4.9\frac{\text{Btu}}{\text{hr-ft-°F}}=6.819\text{-}3\frac{\text{Btu}}{\text{min-in-°F}}.$$

# Figure 3.6.2-6
# Parting Plane Models



Simple Undamaged Parting Plane Model



Damaged Parting Plane Model

# APPENDIX 3.6.3

## Hypothetical Accident Fire Test

## 3.6.3 Hypothetical Accident Fire Test

### 3.6.3.1 Introduction

A testing program has been performed for the UX-30 package which includes a hypothetical accident fire test performed in conformance with 10 CFR 71.73 requirements. This testing was performed subsequent to a series of drop tests (see Appendix 2.10.4 for a description of the drop testing performed) to evaluate the effect of the fire scenario on a damaged UX-30 package. The 30B cylinder was leak tested to confirm a leakage rate of less than 1 x $10^{-7}$ atm-cc/sec prior to performance of the drop testing and was also tested subsequent to performance of the fire test to evaluate the effect of the testing program on the package containment function. This Appendix provides a summary of the fire test.

See Appendix 2.10.5 (Drop Testing) for a summary of the testing configurations.

### 3.6.3.2 Test Facility

The test facility used for performing the fire test was a pool fire facility at Siemens Power Corporation in Richland, Washington. The facility consisted of a steel pan (10' x14' x 12") in which gasoline was floated over a volume of water. The quantity of gasoline used was based on ensuring a 30 minute fire duration. The UX-30 cylinder was placed on a test stand which positioned the bottom of the UX-30 40" above the surface of the fuel. No suppression activities were attempted during the test. The fire was allowed to self extinguish upon depletion of the fuel in the pan. Flaming from the package was also allowed to self extinguish. Temperature monitoring was performed using thermocouples placed on the surface of the 30B cylinder and on the test stand, to measure flame temperature.

### 3.6.3.3 Test Procedure

1. The fire test stand (Figure 3.6.3-2) was protected with a minimum of 2" of *Kaowool* fire retardant blanket to protect it from fire test temperatures.
2. Thermocouples were installed at the ends of the test fixture to measure fire test flame temperatures (see Figure 2.10.5-1 for thermocouple locations).
3. The UX-30 was placed on the fire test stand with the slapdown test parting plane toward the fire. This oriented the area of greatest damage and highest potential for heat transmission into the 30B cylinder towards the fire.
4. Thermocouples were provided to measure UX-30 surface temperature during the fire test (indication from these thermocouples was lost during the test due to failure of the material used to attach the thermocouples to the UX-30). See Figure 2.10.5-1 for thermocouple placement.
5. The fire test pan was filled with 4" of water, 582 gallons of gasoline and 30 gallons of diesel fuel (with an approximate 7" depth).
6. Satisfactory wind conditions were verified (less than 4.5 mph per IAEA Safety Series 37, Section A-628.5).
7. Fire was ignited.
8. Time at which good flame cover was achieved (unit could not be seen through flames) was recorded and confirmed by a qualified QA inspector.

   <u>4:56 am 7/25/95</u>

9. Thermocouple data was recorded throughout fire test and during the cooling down period.
10. Wind speed was recorded during fire test (maximum wind speed was 6 mph for brief periods 30-minutes after end of fire; maximum wind speed during fire was 5 mph with an average wind speed of less than 2 mph)
11. Recorded time at which fuel burned out and confirmed by a qualified QA inspector.

<u>5:26 am 7/25/95</u>

12. Recorded time at which flames extinguished on unit and confirmed by a qualified QA inspector.

<u>5:58 am 7/25/95</u>

13. Recorded temperature data during the cooling down period until all temperatures had peaked.
14. Removed 30B cylinder from UX-30 and photographed condition of unit (Noted discoloration of 30B cylinder paint in the vicinity of the UX-30 parting plane; no damage to 30B cylinder was observed).
15. 30B cylinder was placed in an immersion test chamber. 6 ft head of $H_2O$ maintained for over 8 hours (3 ft of head required for 8 hours per 10 CFR 71.73(c)(4)). No indication of leakage into 30B cylinder.
16. Helium leak test performed after drying of 30B cylinder and test chamber. Leak test performed by a qualified QA inspector.

    Helium Leak Rate - 4.2 x $10^{-8}$ cc/sec (leaktight per ANSI N14.5)

17. Confirmed helium overpressure maintained in 30B cylinder after completion of leak test.

    Cylinder pressure - 16.5 psia

18. Performed 30B cylinder inspection per ANSI N14.1 and USEC-651. No damage or change in configuration from initial inspection noted.

Note:

Differential distance between OD of top of skirt and cylinder OD (ANSI N14.1, Figure 7, Standard Chime Ring Detail) subsequent to completion of testing to confirm no deformation of skirt in test. Verified no deformation of skirt towards cylinder valve.

### 3.6.3.4 Test Results

The maximum 30B cylinder surface temperature was measured in the vicinity of the parting plane which was opened by the drop testing. The open parting plane was oriented toward the flame to maximize internal temperatures. The fire data for this location is plotted in Figure 3.6.3-1 for thermocouple channel 4, the average of channels 4, 5 and 6, and the average of channels 10 and 13. The maximum observed temperature with thermocouple channel 4 was less than 190 degrees F. Photographs of the fire test are provided in Figure 3.6.3-2.

### 3.6.3.5 Fire Test Analytical Model

A heat transfer model was prepared using drop test damage data and flame temperature data from the fire test. The HEATING code was used in the analysis. Appendix 3.6.2 includes a detailed discussion of the fire test HEATING model and damage zone modeling. In particular, the fire test HEATING model included a damaged parting plane with at 1" opening. The model also included the 30B cylinder cavity is filled with 6627 lbs of steel shot simulating UF6. The ambient fire test temperature, which was considerably higher than 10 CFR 71 requirements, was closely followed in order to achieve accurate surface and internal temperatures.

The maximum cylinder temperature predicted by this model was in good agreement with test results. See HEATING results plotted in Figure 3.6.3-1. This agreement validates the hypothetical accident conditions HEATING model. This hypothetical accident conditions model (with $UF_6$ contents) was then used in the 10 CFR 71 evaluations presented in Section 3.5.

### 3.6.3.6 Conclusions

The 30B cylinder sustained no damage and passed the leaktight inspection criteria subsequent to drop test sequence, fire test and immersion test. Maximum 30B cylinder temperature was less than 200 degrees F. This is well within the design of the 30B cylinder. Actual $UF_6$ temperature would be significantly less than 200 degrees F since local hot spots would dissipate heat to surroundings and a significant portion of the heat applied would be absorbed by the localized change in phase of the $UF_6$. Actual bulk temperature inside 30B cylinder would be significantly lower than 200 degrees F. Therefore, the resulting temperature for the $UF_6$, when conservatively assumed to be 200 degrees F, is acceptable and does not adversely affect the 30B cylinder thereby confirming adequacy of the UX-30 overpack for protection of a 30B cylinder for Type B qualification.

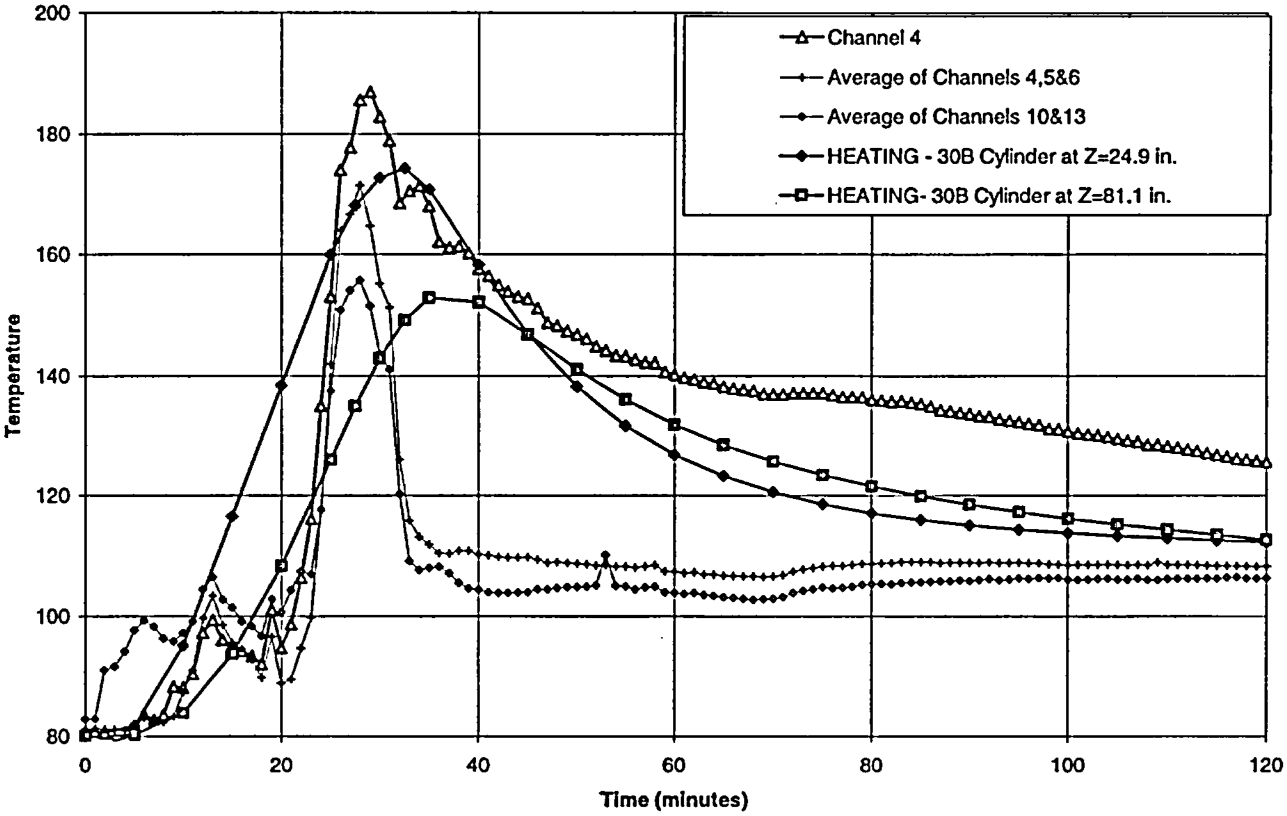


Figure 3.6.3-1
UX-30 Fire Test Data and Comparison to HEATING Model

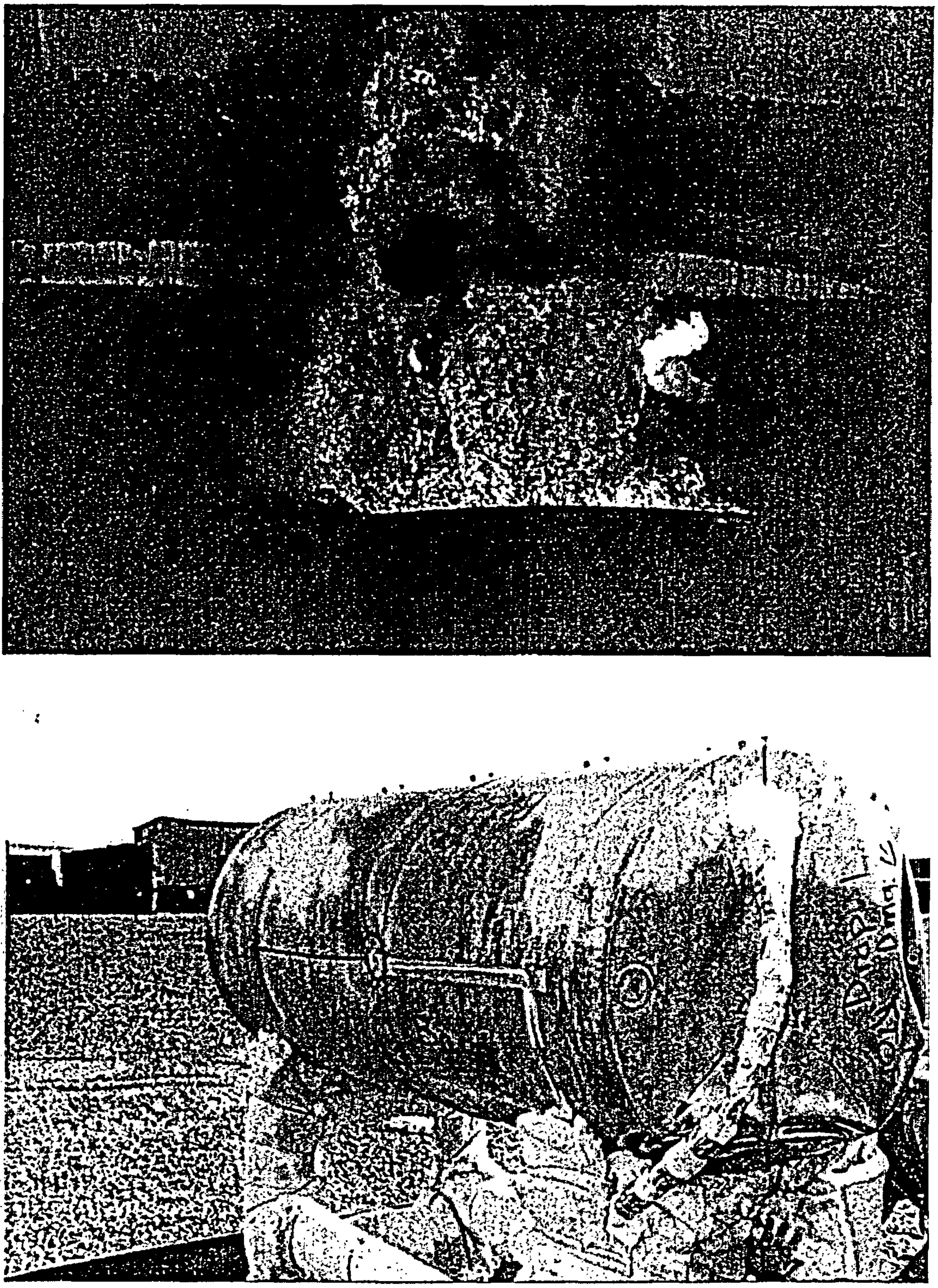


Figure 3.6.3-2
UX-30 Fire Test

Figure 3.6.3-2
(Continued)

Figure 3.6.3-2
(Continued)

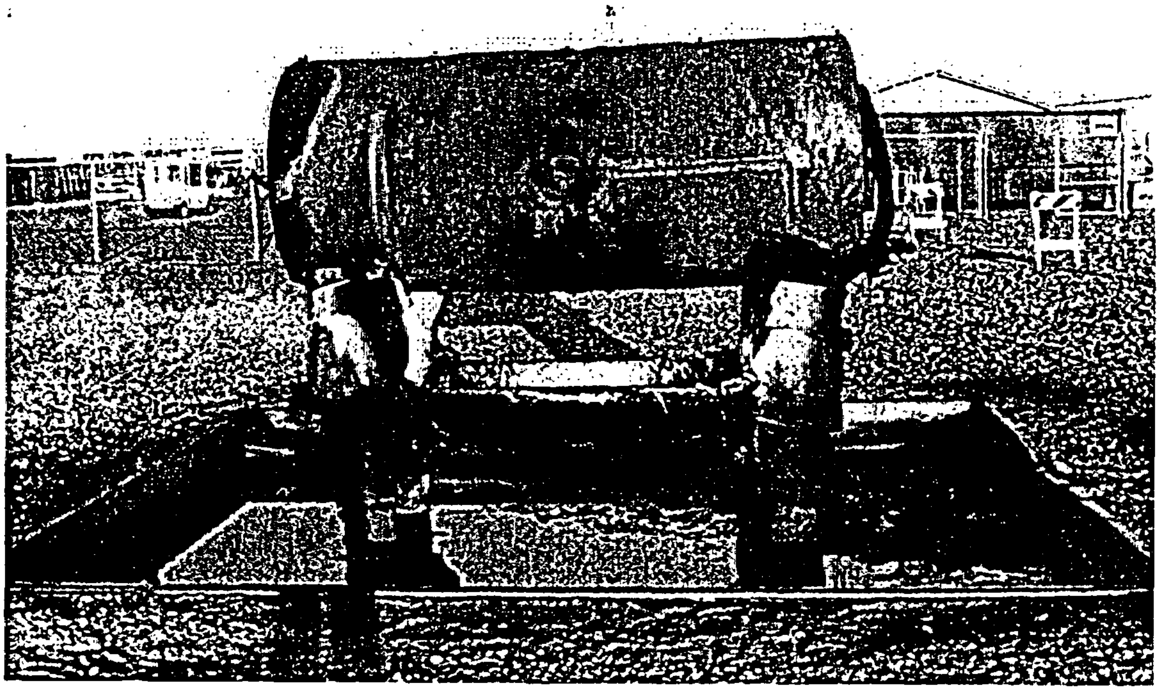
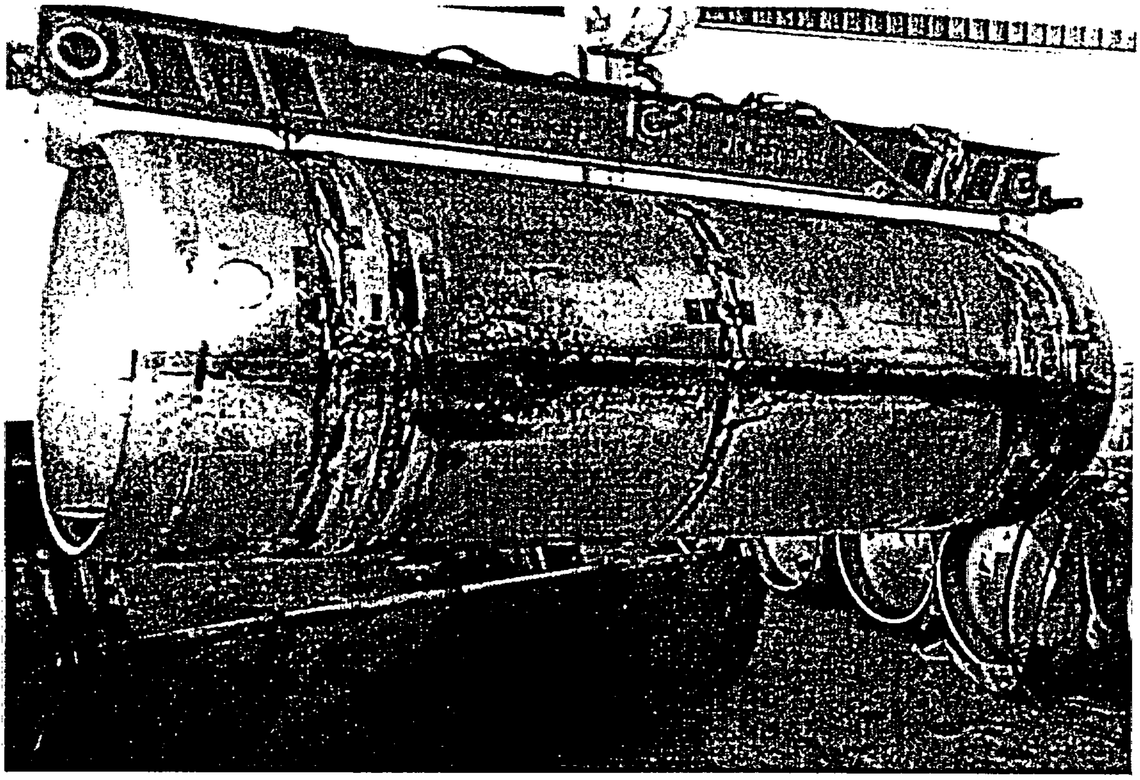


Figure 3.6.3-2
(Continued)



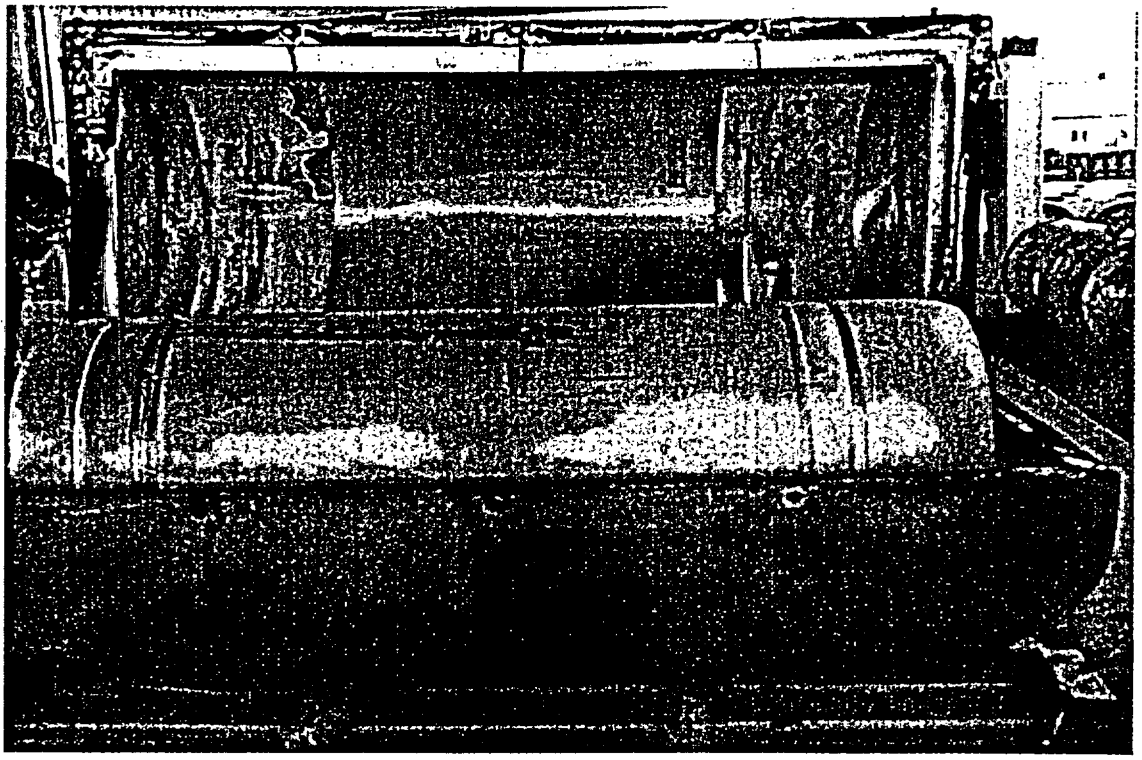


Figure 3.6.3-2

(Continued)

# 4.0 CONTAINMENT

## 4.1 Description of Containment System

The UX-30 is designed for use in conjunction with a standard 30-inch $UF_6$ cylinder such as the models 30B or 30C described in ANSI N14.1, Packaging of Uranium Hexafluoride for Transport. The cylinder provides the containment boundary for the package. See drawings of the cylinders in Figure 4.1-1 and 4.1-2 or ANSI N14.1.

### 4.1.1 Containment Boundary

Containment Vessel

The design specifications for the $UF_6$ cylinder are given in ANSI N14.1, and as shown in Figure 4.1-1 for the 30B or 4.1-2 for the 30C, which are taken from ANSI N14.1. These documents list the following design conditions for the cylinders:

| | |
|---|---|
| Design Pressure: | 22 psig external<br>200 psig internal |
| Design Temperature: | -40°F to 250°F |

Containment Penetrations

The 30B and 30C cylinders are penetrated in two places: the fill valve on one end and a drain plug on the other end. The performance specifications of these components are the same as for the cylinder.

Note: The 30C cylinder has a Valve Protective Cover (VPC) to provide additional assurance against water intrusion into the cylinder. However, the VPC is not part of the containment boundary for the package.

Seals and Welds

Welds on the containment vessel are as shown in Figure 4.1-1 for the 30B, and in Figure 4.1-2 for the 30C cylinder. Pipe thread seals are indicated around the valve and drain plug threads. Performance specifications for all containment welds and threads are identical to those for the cylinder.

Closure

The fill valve and drain plug are used as closure devices on the cylinder. They shall be installed (as per the requirements of ANSI N14.1-2001) using 200 - 400 ft-lbs. of torque. The valve shall have 7 - 12 threads engaged, and the plug shall have 5 - 8 threads engaged.

### 4.1.2 Special Requirements for Plutonium

Not Applicable.

## 4.2 General Considerations

### 4.2.1 Type A Fissile Packages

Containment for the UX-30 is provided by the 30B or 30C cylinders. Fabrication, examination, and testing requirements for these cylinders are established by the standard by which they are designed and fabricated, ANSI N14.1, "American National Standard for Nuclear Material – Uranium Hexafluoride – Packaging for Transport." Periodic and pre-shipment leak rate testing requirements of the cylinders are also set by ANSI N14.1.

### 4.2.2 Type B Packages

Not Applicable.

### 4.2.3 Combustible Gas Generation

There are no materials used in the cavity of the cylinders that can generate combustible gases.

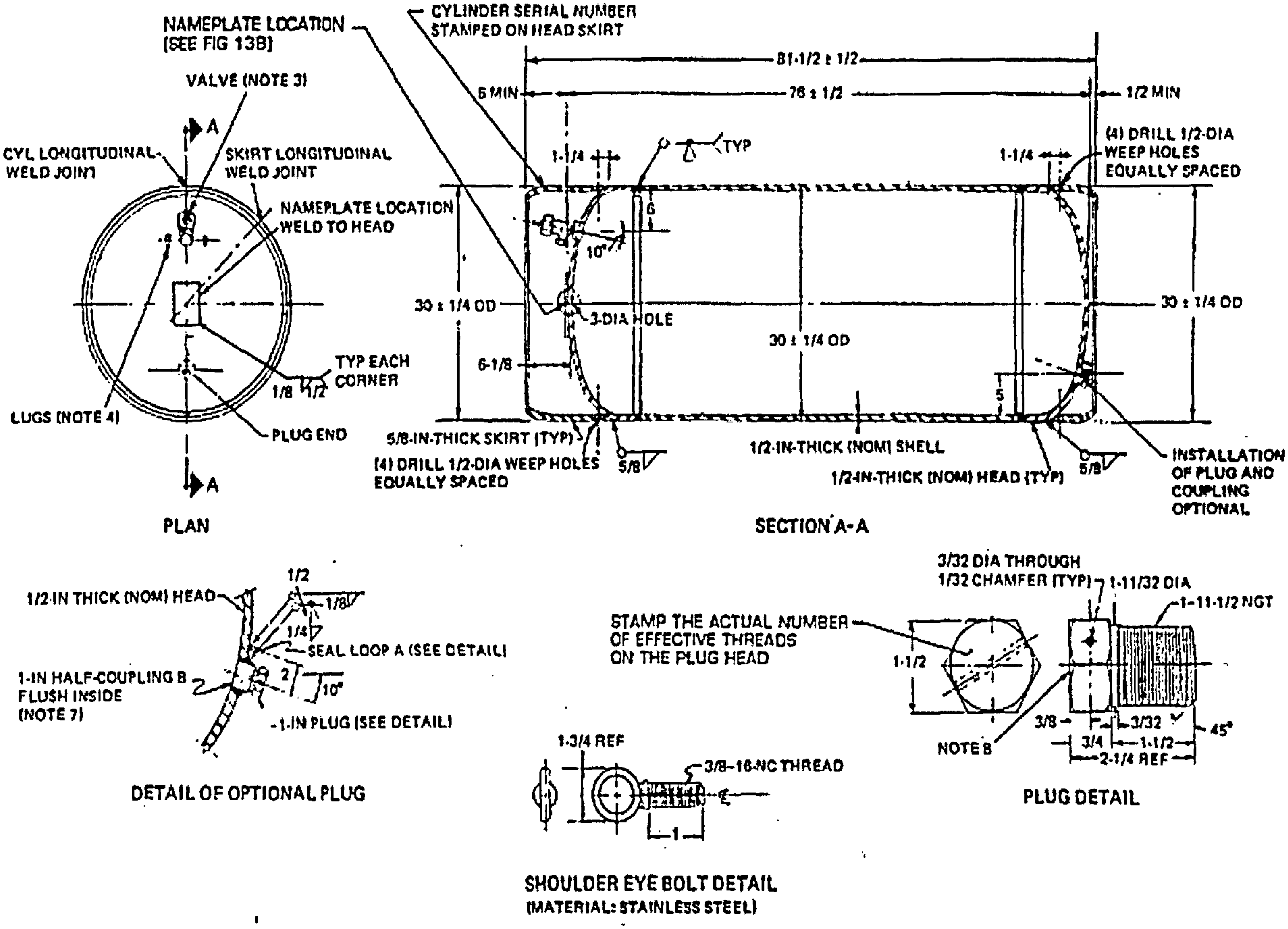


FIGURE 4.1-1
Standard $UF_6$ Cylinder ANSI N14.1-30B

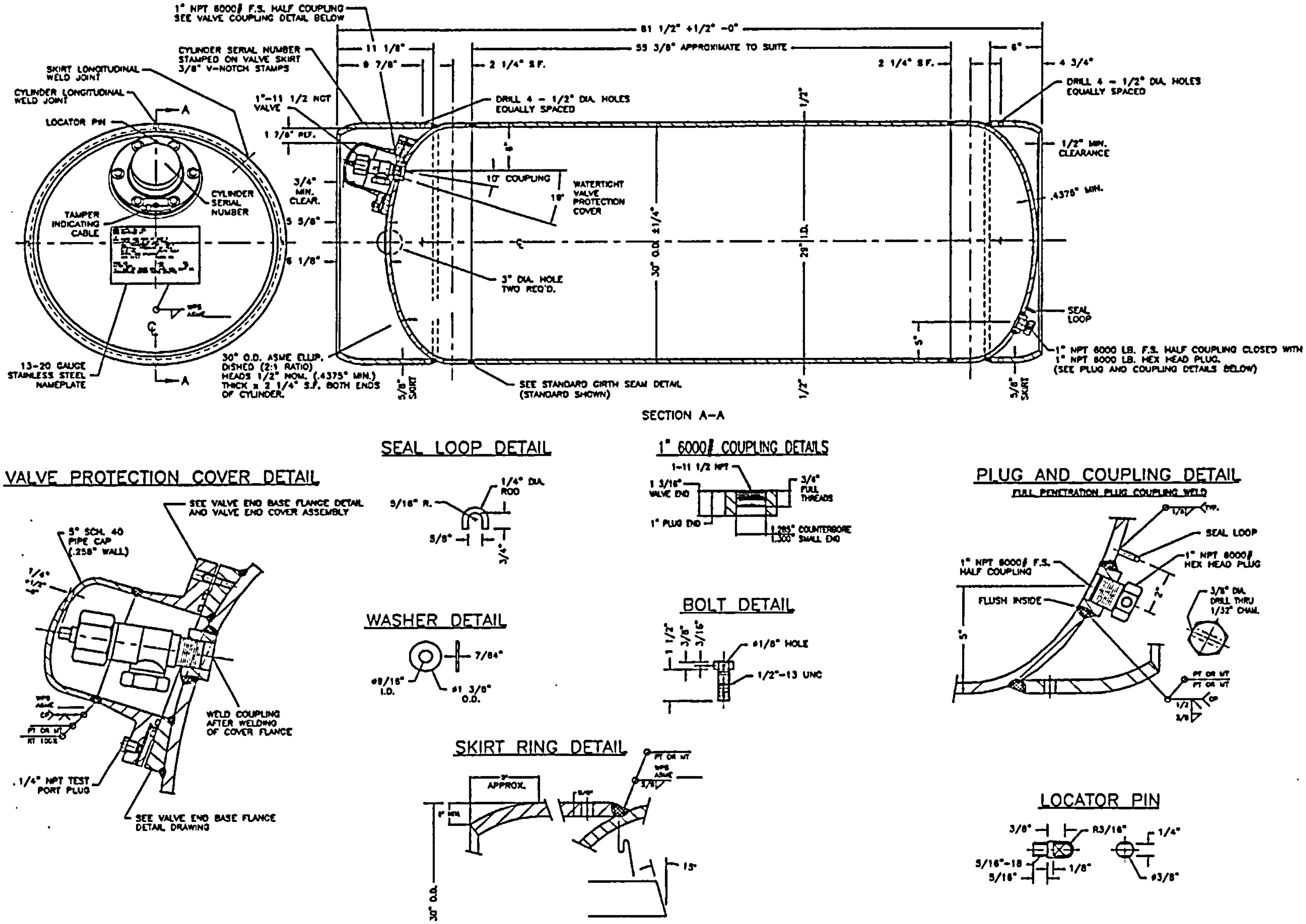


Figure 4.1 - 2
ANSI N14.1 30C Cylinder

## 4.3 Containment Under Normal Conditions of Transport

### 4.3.1 Containment Design Criterion

Containment criterion for the 30B and 30C cylinders are established by the requirements of ANSI N14.1.

### 4.3.2 Demonstration of Compliance with Containment Design Criterion

Sections 2.6 and 3.4 demonstrate that the containment vessel is unaffected by Normal Conditions of Transport. There will therefore be no direct release of radioactive material from the cylinder.

## 4.4 Containment Under Hypothetical Accident Conditions

### 4.4.1 Containment Design Criterion

Containment criteria for the Type 30B and 30C cylinders are the requirements of ANSI N14.1.

### 4.4.2 Demonstration of Compliance with Containment Design Criterion

Sections 2.7 and 3.5, and Appendices 2.10.4 and 3.6.3, indicate that the containment vessel is unaffected by the hypothetical accident conditions required by 10 CFR 71. Therefore, there will be no release of radioactive materials from these events.

## 4.5 Leakage Rate Tests for Type B Packages

Not Applicable

## 4.6 Appendix

None

# 5.0 SHIELDING EVALUATION

The $UF_6$ payload of the UX-30 does not require any neutron or gamma shielding.

# 6.0 CRITICALITY EVALUATION

## 6.1 Description of Criticality Design

The UX-30 package is designed for the same payloads as the 21PF-1 or -2 package as described in 49CFR173.417. This Section gives the maximum U-235 enrichment as 5.0 weight percent, and the minimum criticality safety index as 5.0.

As discussed in Chapter 1 of this Safety Analysis Report, the 30C Cylinder is also an optional cylinder for transport in the UX-30. The dimensions and configuration of the 30C Cylinder are identical to the standard 30B cylinder, except the 30C Cylinder is equipped with a Valve Protective Cover (VPC) that provides additional assurance against water intrusion into the cylinder. Since the 30C Cylinder is otherwise identical to the standard 30B cylinder, the permitted payloads for it are also as described in 49CFR173.417. Also, criticality analysis described in this Chapter 6 for the standard 30B cylinder are also applicable to the 30C Cylinder. However, as discussed in the remainder of this Chapter, because the 30C Cylinder has additional assurances against water intrusion, the criticality index for it is 0.0 (zero).

### 6.1.1 Design Features

For criticality control, the UX-30 package relies upon:

- specification of maximum H/U ratio, or equivalently, minimum $UF_6$ purity,
- impact absorption by the protective overpack, which prevents damage to the 30B cylinder sufficient to cause water in-leakage or reduction of package volume under normal and accident conditions, and
- thermal protection of the cylinder by the overpack, which prevents damage to the cylinder which could cause the contents to leak out or water to leak in.
- In addition, the VPC and other measures on the 30C Cylinder provide "special features" as allowed by 10CFR71.55(c) that are additional assurance against water intrusion into this model of cylinder, and against the contents leaking out.

### 6.1.2 Summary Table of Criticality Evaluation

### 6.1.3 Criticality Safety Index

A criticality evaluation is provided in ORNL/TM-1 1947 (Reference 6.8.3). This evaluation is directly applicable to this packaging. The report evaluates $k_{eff}$ using the SCALE4 computer code system for an infinite array of packages with optimum interspersed moderation, and finds the worst case to be $k_{eff} = 0.817 \pm 0.003$. The results of this evaluation are also applicable to UX-30 package and have already been approved by the NRC. The worst case calculation is summarized in Table 6-2. An infinite array of damaged or undamaged packages remaining subcritical corresponds to a criticality safety index for criticality control of zero. However, the assigned criticality safety index of 5 is retained from those specified in 49 CFR 173.417, Table 6, for the standard 30B cylinder.

For the 30C Cylinder, a criticality safety index of 0.0 (zero) will be assigned. The following is justification of the 0.0 criticality safety index for the 30C Cylinder.

Concerning criticality for a package, 10CFR71.55(b) states, "...a package used for the shipment of fissile material must be so designed and constructed and its contents so limited that it would be subcritical if water were to leak into the containment system...".

However, 10CFR71.55(c) states:

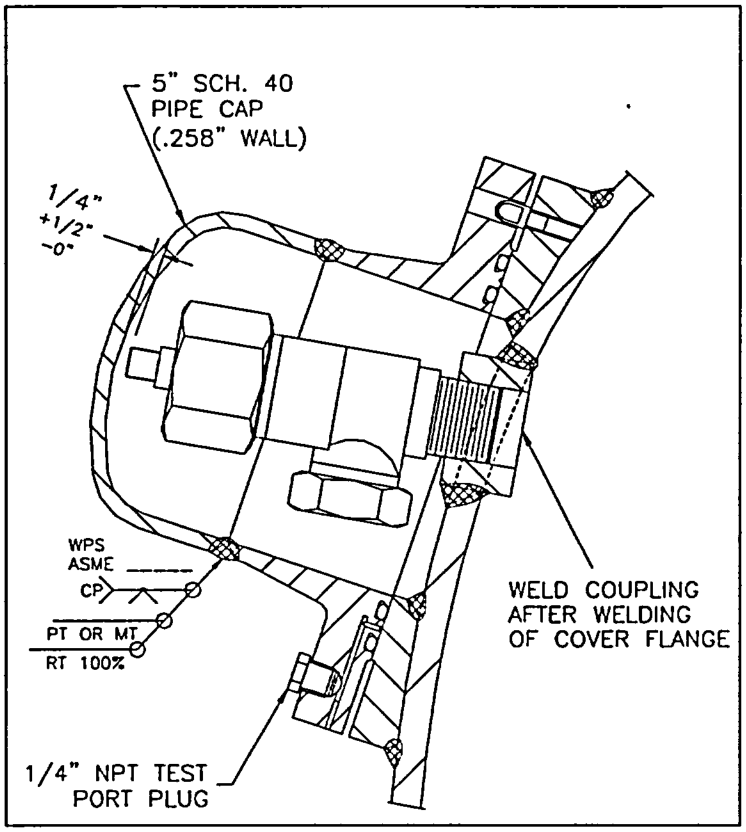
> "The commission may approve exceptions to the requirements of paragraph (b) of this section if the package incorporates special design features that ensure that no single packaging error would permit leakage, and if appropriate measures are taken before each shipment to ensure that the containment system does not leak.."

The standard 30B cylinder already incorporates features that preclude water in-leakage:

- As discussed in Sections 2.6, 2.7, and 3.5 of this Safety Analysis Report, the UX-30 has been tested and shown to protect the standard 30B cylinder from damage against the hypothetical accident conditions. Visual inspections after the tests revealed no damage to the cylinder, including the cylinder skirt, and no contact by UX-30 wall with the cylinder valve. Additionally, a leak test showed no leakage developed from the impact testing.
- As discussed in Operating Procedures in Section 7.1.4, the cylinder valve is leak tested to an acceptance criteria of $1x10^{-3}$ ref-$cm^3$/sec prior to shipment.

In addition to the features of standard 30B cylinder that protect against water in-leakage, the VPC on the 30C Cylinder provides additional assurance against water in-leakage that qualifies the cylinder for having the "special design features" of 10CFR71.55(c). This was demonstrated by a series of successful drop tests described in Sections 2.6 and 2.7 that were performed on the UX-30 with the 30C Cylinder. (A complete report on the tests is provided in Appendix 2.10.5.) Drops onto the corner of package were conducted from 4' and 30', followed by a drop from 40" onto a steel post.

Post-test inspection of The 30C Cylinder revealed no damage to the cylinder. This demonstrates that the 30C Cylinder is as rugged as the standard 30B cylinder in withstanding normal and hypothetical accident conditions for transport.



Valve Protective Cover

30C *Cylinder Special Design Features*

The additional protection afforded by the VPC was demonstrated by the tests on the 30C Cylinder described above. The results of this testing, plus additional testing as well as preshipment and periodic test procedures discussed in the following paragraphs, qualify the UX-30 when transporting the 30C Cylinder as having the "special design features" as required by 10CFR71.55(c) to preclude water in-leakage. The VPC assures against water intrusion in two ways:

- It provides physical protection for the cylinder valve so that the cylinder valve will remain an effective barrier against water intrusion during normal and hypothetical accident conditions. This was demonstrated by the drop testing discussed in Appendix 2.10.5. The drop testing resulted in no damage to the cylinder, and none to the cylinder valve even though the 40" pin drop was conducted with the UX-30 being dropped directly onto its end in the region of the VPC. Thus, the VPC assures additional protection against damage to the cylinder valve, and consequently against it being a potential source of water in-leakage during normal and hypothetical accident conditions.

- The Cylinder VPC is itself a barrier against water intrusion. This was demonstrated by conducting a hydrostatic test on the Cylinder VPC to 400 psig, which resulted in no leakage. (The report on this hydrostatic test is provided in Appendix 6.9.1.) These tests demonstrate that the VPC is as effective barrier to water intrusion.

The fact that the Cylinder VPC is an effective barrier against water intrusion in normal and hypothetical accident conditions is also demonstrated by the testing described in Appendix 2.10.5. The Cylinder VPC passed a leak test with an acceptance criteria of $1x10^{-5}$ ref $cm^3/sec$ before and after the drop testing. Furthermore, the VPC will be assured to remain an effective barrier over the life of the package by requiring periodic leak testing to this acceptance criteria (Chapter 8).

An acceptance criteria of $1x10^{-5}$ ref $cm^3/sec$ is shown to be "water tight" by the testing in Appendix 6.9.2. Effectiveness of a barrier leak tested to $1x10^{-5}$ ref-$cm^3/sec$ with air as a barrier to water was also demonstrated. Testing was conducted to show that a capillary of the diameter that leaks $1x10^{-5}$ std-$cm^3$/sec of air will not leak water (Appendix 6.9.2). The test showed that when one side of a capillary of this diameter is pressurized to 22 psig with water, the pressure corresponding to the regulatory requirement of 10CFR71.73(c)(5) for immersion depth, that water will not leak through the capillary. In fact, the orifice was pressurized to greater than 400 psig with no evidence of leakage.

10CFR71.55(c) states that in order for an exception to paragraph 10CFR71.55(b) to be approved, "...appropriate measures are taken before each shipment to ensure that the containment system does not leak." These additional measures for the 30C Cylinder include installation of the VPC and requiring a pre-shipment leak test with an acceptance criteria of $1x10^{-3}$ ref-$cm^3$/sec prior to each shipment.

Chapter 7 of this Safety Analysis Report, Operating and Maintenance Procedures, requires installation and testing of the VPC as part of loading the 30C Cylinder. The VPC is an additional barrier to water intrusion in series with the cylinder valve during transport. Leak testing of the VPC prior to transport verifies that it has been properly installed. (Note: Chapter 7 also requires testing the cylinder valve to a $1x10^{-3}$ ref-$cm^3$/sec acceptance criteria of prior to shipment.)

The VPC has been shown to remain intact for normal and hypothetical accident conditions of transport as discussed above and in Appendices 2.10.5 and 6.9.1. Effectiveness of the VPC is verified by leak-testing (with air) at fabrication and annually thereafter with a maximum permitted leak rate of $1x10^{-5}$ ref-$cm^3$/sec. A leak test is also performed prior to each shipment to $1x10^{-3}$ ref-$cm^3$/sec.

In addition to the VPC and pre-shipment leak tests described above, the 30C Cylinder also is fabricated with additional controls not used for the standard 30 B cylinder. Table 6.1 below describes these.

Table 6-1

Comparisons of Standard 30B Cylinder and 30C Cylinder Properties

| | Standard 30B Cylinder | 30C Cylinder |
|---|---|---|
| Meets ANSI N14.1 Specifications | Yes | Yes |
| Base Metal | SA-516, Gr. 55, 60, 65, or 70 | Same |
| VPC | No | Yes |
| Redundant Seal | No | Yes, including VPC O-Rings |
| 100% Weld X-ray and QC | Spot X-ray only. | Yes; 100% X-ray plus liquid penetrant (pt) or magnetic particle (mt) examination of all butt-weld joints; all other joints examined by pt or mt except for nameplate and seal loop fillet welds. |

In summary, the criticality evaluation in ORNL/TM-1 1947 (Reference 6.8.3) shows that an infinite array of packages like the UX-30 remain subcritical, which corresponds to a criticality safety index for criticality control of 0.0. As shown in Table 6-2 below, this criticality evaluation was performed by assuming no internal moderation. This is a valid assumption for the 30C Cylinder because of the special design features and preshipment measures taken to preclude water in-leakage, as allowed by 10CFR71.55(c). The additional features of the 30C Cylinder assure exclusion of water as an internal moderator and justify assignment of a criticality safety index 0.0, as calculated by Reference 6.8.3, for the UX-30 when transporting the 30C Cylinder.

Note: The 30C Cylinder is identical to the standard 30B cylinder in dimensions and configuration, therefore the criticality calculation in Reference 6.8.3 is also valid for the 30C Cylinder.

*30C Cylinder Bottom Plug*

The cylinder's bottom port opening (plug) is normally only operated for maintenance activities. The seal at the plug is checked following fabrication using the 400 psig hydro test and the 100 psig air test. The seal at the plug is checked following fabrication, maintenance, and periodic inspections using a 100 psig test. Some plugs are seal welded. Unlike the fill valve, defects in the closure that might cause leakage of the plug are readily visible during the pre-shipment inspection (a damaged plug, too many unengaged threads, deposits of material). Additionally, the plug projects only about 2" from the body of the cylinder, while the valve projects as much as 9" from the cylinder body. The low profile of the plug minimizes its vulnerability to impact breakage.

Cylinder valves have many failure modes, and thus the likelihood of valve leakage is relatively high in comparison with the cylinder plug. USEC-651 mentions that one of the most critical items in containment of the $UF_6$ is the cylinder valve. A major contributor to failure is the regular exposure of the valves sealing surfaces to the corrosive payload. "Although most unacceptable valves exhibited material defects that contributed to cracking and breaking, some defects were attributable to dimensioning, processing, or testing of the valves prior to use in $UF_6$ service." In addition to wear and tear on the valve surfaces due to regular use, debris and deposits can form, preventing proper sealing of the valve. Since the cylinder plug threads are not regularly operated and the sealing surfaces have a much more limited exposure to the $UF_6$, the plug is not subject to these types of failures.

A review of previous cylinder failures shows that the large majority of failures are attributable to the cylinder valve. Other failures, due to overfilling, have split open the cylinder wall during over-pressurization. There are no reported failures of cylinder plugs known to Duratek. The conclusion reached from this review is that the cylinder plug is rarely the mode of cylinder leakage.

In order to provide a cover for the cylinder plug, the capacity of the cylinder would have to be reduced (the overall length must be preserved) to provide sufficient clearance for the cover, and this is undesirable to the users. Therefore, due to the lower frequency of operation, the operational history of failures, and lesser likelihood of failure at the plug location, special features are not provided for the bottom port opening of the cylinder.

## 6.2 Fissile Material Contents

The UX-30 package contents may be either fresh or recycled $UF_6$. The loading is

| | |
|---|---|
| Cylinder Type: | Model 30B or 30C |
| Maximum Weight of $UF_6$: | 5,020 lb |
| Maximum U-235 Enrichment: | 5 wt% |
| Minimum $UF_6$ purity | 99.5 wt% |
| Criticality Safety Index: | |
| Standard 30B cylinder | 5.0 |
| 30C Cylinder | 0.0 |

Recycled $UF_6$ can only be packaged in these overpacks if the activity levels of the various isotopes contained in it do not exceed the $A_2$ limits found in 49 CFR 173.433.

Because the contents are loaded as a liquid which solidifies upon cooling before shipment, the geometric configuration of the contents can vary somewhat. The form of the contents is the same for both normal and accident conditions, except for variation of density with temperature. Several possible geometric configurations of the solid $UF_6$ and the variation of density with temperature are evaluated in the criticality calculation.

Hydrostatic testing has verified that water will not leak into the 30B or 30C cylinder after accident testing. The only moderation internal to the 30B or 30C cylinder is provided by the impurities, which may include HF, and which are limited as noted above. For the purpose of the criticality calculation, the maximum H/U ratio, 0.088, is assumed.

Purity control is provided according to ASTM C787 and C996 (References 6.8.1 and 6.8.2, respectively), which require minimum 99.5% purity. The maximum H/U atomic ratio of 0.088 allowed according to 49 CFR 173.417, Table 6, corresponds to 0.5% impurity, with all the impurity being hydrogen fluoride (HF). Drop, puncture, and fire testing described in Chapter 2.7 demonstrate that water will not leak in, nor will the contents leak out under accident conditions. They also demonstrate that the overall dimensions of the overpack will remain essentially the same, so that the spacing assumed in modeling an array of packages is valid for both normal and accident conditions.

## 6.3 General Considerations

The model is described in Section 3.1 of ORNL/TM- 11947 (Reference 6.8.3). The model is based upon the UX-30 Type overpack.

## 6.4 Single Package Evaluation

The calculations described in Reference 6.8.3 were performed using the CSAS25 sequence from the SCALE4 computer code system with the SCALE 27 group ENDF/B-IV cross sections. The calculations first assume an internal geometric configuration of the contents, an infinite square lattice array, and a temperature of $20^0$C, and vary the water density to find the optimum interspersed moderation. At and near that water density, sensitivity studies are performed varying contents configuration, temperature and corresponding $UF_6$ density, and closer package spacing to simulate triangular pitch arrays.

The results are summarized in Table 4 of the report, and the worst case is summarized in Table 6-2 below.

Table 6-2
Summary of Criticality Evaluation

| | |
|---|---|
| Model conditions | normal and accident, same model |
| Number of packages in contact | infinite |
| $k_{eff} \pm \sigma$ | 0.817 ±0.003 |
| Optimum interspersed moderation | water, specific gravity = 0.015 |
| Close reflection by water | Not applicable to infinite array |
| Package size, including overpack | 54.8 1 cm radius, 231.14 cm height |
| Internal size of 30B cylinder | 36.83 cm radius, 172.78 cm height |
| Overpack material | water, same as interspersed |
| Package contents | $UF_6$, 5% enriched, 99.5% pure, 5.1 g/cm$^3$, 5030 lb. |
| Temperature | 20 $^0$C |
| Contents geometry | Solid $UF_6$ cylinder with central cylindrical void |
| Internal moderation | No water; 0.5 % impurity entirely HF; H/U=0.088 |

## 6.5 Evaluation of Package Arrays Under Normal Conditions of Transport

This evaluation is performed in Reference 6.8.3.

## 6.6 Evaluation of Package Arrays Under Hypothetical Accident Conditions

This evaluation is performed in Reference 6.6.3.

## 6.7 Benchmark Evaluations

The validation of the computer code and cross sections against 51 critical experiment benchmarks is described in Sections 2.2 and 3.2.5 of Reference 6.6.3.

## 6.8 REFERENCES

6.8.1 ASTM Standard C787, "Specification for Uranium Hexafluoride for Enrichment."

6.8.2 ASTM Standard C996, "Standard Specification for Uranium Hexafluoride Enriched to Less Than 5% 235U."

6.8.3 ORNL/TM-I 1947, Criticality Safety Review of 2 1/2-. 10-. and 14-Ton UF6 Cylinders. B.L. Broadhead, Martin Marietta Energy Systems, Oak Ridge National Laboratory, October 1991.

## 6.9 APPENDICES

# Appendix 6.9.1

## Valve Protection Cover Hydro-Test Report

## VPC-HT

Note: This report refers to testing performed on a "CBC Watertight™" Cylinder. The CBC Watertight™ was the predecessor, and identical to, the standard 30C cylinder that was later approved for ANSI N14.1 by Addendum 2-2004.

CBC Columbiana Boiler Company

*Containers & Cylinders for Chemicals & Gases*
*UF₆ & UO₂ Packaging • Galvanizing & Tinning Kettles*

200 W. Railroad Street
PO Box 68
Columbiana, OH 44408 USA
Tel: 888-266-5125 or 330-482-3373
Fax: 330-482-3390
E-mail: sales@cbco.com

# VALVE PROTECTION COVER HYDRO-TEST REPORT

## INTRODUCTION:

The purpose of this test was to determine the water tightness of the Valve Protection Cover (VPC) on the CBC Watertight ™ Model 195 Cylinder. Please note that this test was performed on August 7, 2001 after a series of drop tests as described in the test report, "The CBC Regulatory Testing of the CBC Watertight ™ Cylinder". It was determined that the sealing capabilities of the o-rings is multi-directional, thus the test was performed by pressurizing the inside of the bonnet with water.

## SCOPE:

To prove that the Valve Protection Cover would not show evidence of water leakage after pressurizing the inside of the VPC up to and including 400 psi.

## EQUIPMENT and MATERIAL:

0-30 lb. Pressure Gauge, #G-13

0-800 lb. Pressure Gauge, #G-35

Fluorescent Tracer Dye, #FT 175, manufactured by American Gas & Chemical Co., Ltd., instructions state 1 oz. solution to 100 gallons of water produce yellow fluorescent solution visible to the eye. 1 oz. to 1000 gallons of water produces colorless solution with bluish white fluorescence under ultra-violet or black light.

Black Light Source, 365 NM

Hydro-Test Pump Station, rated up to 2,500 psi

Torque Wrench, rated up to 175 ft/lbs.

## PREPARATION:

Both the valve and plug were removed from the cylinder. A garden hose was inserted in the plug hole, through the cylinder, and out the valve hole. This was done to ensure complete evacuation of air from the VPC. The flange surface was cleaned with acetone. The o-rings were wiped with a clean dry rag. Dow Corning #55 o-ring lubricant was applied to the exposed surfaces of both o-rings. The excess lubricant was wiped off with a clean dry rag.

The VPC was attached using bolts and washers. The bolts were torqued, by alternating bolt pattern, to 30 ft/lbs. The cylinder was tilted with the bonnet placement at the lowest point. Two ounces of tracer dye was injected into the hose. The cylinder was then filled with water through the hose. After the cylinder was filled, the test fittings with 0-30 lb. Pressure Gauge were attached.

TEST:

Test pressures and hold times were as follows:

| TIME | HOLD TIME | PRESSURE |
|---|---|---|
| 8:20 am | 14 minutes | 2# |
| 8:34 am | 14 minutes | 4# |
| 8:46 am | 14 minutes | 6# |
| 9:03 am | 15 minutes | 8# |
| 9:16 am | 13 minutes | 10# |
| 9:29 am | 13 minutes | 12# |
| 9:44 am | 15 minutes | 14# |
| 9:59 am | 15 minutes | 16# |
| 10:13 am | 14 minutes | 18# |
| 10:24 am | 11 minutes | 20# |
| 10:50 am | 26 minutes | 22# |

At this time, the pressure was removed and the 0-30 lb. Pressure Gauge was replaced with 0-800 lb. Pressure Gauge.

Pressure was reapplied as follows.

| TIME | HOLD TIME | PRESSURE |
|---|---|---|
| 11:18 am | 12 minutes | 100# |
| 11:30 am | 10 minutes | 200# |
| 11:48 am | 23 minutes | 300# |
| 12:03 am | 12 minutes | 400# |

Immediately after each pressure setting and prior to a pressure change, the Valve Protection Cover was inspected with flashlight and black light by both Shannon Koontz, Quality Control Supervisor and Ralph Fabrizio, Vice President Manufacturing. The inspection at each increment did not indicate any signs of leakage. This was also confirmed by maintaining a constant pressure at each pressure increment. With no evidence of leakage up to and including 400 psi, it was decided to stop the test so as not to exceed the specified cylinder hydrostatic pressure. Upon conclusion of the hydro test, the VPC was removed and inspected with a flashlight and black light. This inspection also did not indicate any signs of leakage.

THE COLUMBIANA BOILER COMPANY

Ralph Fafi
Ralph Fabrizio, VP Manufacturing

Shannon Koontz
Shannon Koontz, QC Supervisor

VPC-HT, Rev. 0

# Appendix 6.9.2

## Test Procedure for Rate of Rise/Hydrostatic Comparison

## LT-CBC-1

LEAK TESTING SPECIALISTS, INC.
www.leaktestingspec.com
5790 Hoffner Ave. Suite 505 Orlando, FL 32822-4801 Phone 407.737.6415 Fax 407.737.6416
Offices in: Washington, DC – Portland, OR – Orlando, FL

# TEST PROCEDURE

FOR

# RATE OF RISE/HYDROSTATIC COMPARISON

**PROCEDURE NUMBER: LT-CBC-1**
**REVISION 0**

APPROVED BY: Trevor Rummel DATE: 8-17-01
Columbiana Boiler Co.

APPROVED BY: Gary R Elder DATE: 8-17-01
Gary R. Elder LT Level III

## 1.0 Purpose

1.1. The purpose of this procedure is to compare the test results of the Rate of Rise leak test performed on the 30B $UF_6$ cylinder to a hydrostatic leak test. This procedure shall set forth the sequence of operations for the two tests.

1.2. A comparison of the two test results should confirm that a 1 x $10^{-5}$ std-cc/sec acceptance criteria for a pressure change leak test with air will not leak water for hydrostatic pressures less than 22 psig.

## 2.0 Responsibility

2.1. Leak tests shall be performed and evaluated by leak test personnel approved by Columbiana Boiler Co., who are qualified as a LT Level III in accordance with Leak Testing Specialists' (LTS) Written Practice for the Qualification and Certification of NDE Personnel, NDE-QUAL-LTS (latest revision). LTS meets the guidelines of the American Society for Nondestructive Testing Recommended Practice No. SNT-TC-1A (1984 thru 1992 Edition

## 3.0 References

3.1. The following codes, standards, and specifications shall form a part of this procedure to the extent required herein.

3.1.1. American National Standards Institute (ANSI) N14.5-1997, "Leakage Tests on Packages for Shipment."

3.1.2. ASNT-SNT-TC-1A, Qualification and Certification of NDE Personnel, 1984 - 1992 Edition (most strident requirements).

## 4.0 Equipment and Materials

4.1. A vacuum gauge (TCVG or Capacitance Manometer) shall be used to make pressure readings. The vacuum gauge shall be capable of obtaining an ultimate pressure of 1 millitorr (micron) and have a read out in 1 millitorr (micron) increments, and shall have been calibrated within 12 months of the test.

4.2. A mechanical vacuum pump shall be capable of obtaining and maintaining the required vacuum pressure for the Rate of Rise leak test.

4.3. A hydrostatic pump capable of hydrostatic pressures to 500 psig.

4.4. A fluorescent tracer dye additive No. 175 manufactured by American Gas & Chemical. The dye concentration to water shall be 1 ounce dye to 100 gallons of water.

4.5. A capillary Leak Standard of $1.0 \times 10^{-5}$ std-cc/sec (atm-cc/sec) ± 15% for air. The standard shall be calibrated traceable to NIST.

## 5.0 Rate of Rise Leak Test

5.1. Connect the capillary Leak Standard and vacuum pump to vacuum change leak tester at valve V-4 per Figure 1.

5.2. Open valve V-4 and start vacuum pump to evacuate back side of capillary leak standard.

5.3. Run pump for minimum of 1 minute and then close V-4.

5.4. Disconnect vacuum hose at standard and connect to V-3.

5.5. Verify the following valves are open:

5.5.1.1. V-1, (Vent Valve)

5.5.1.2. V-2, (Volume Valve)

5.5.1.3. V-3, (Vacuum Pump Valve)

5.6. Record the ambient pressure in torr ($P_{atm}$) as read from the Digital Readout on the Vacuum Change Leak Tester (VCLT).

5.7. Close the following valves:

5.7.1.1. V-1, (Vent Valve)

5.7.1.2. V-2, (Volume Valve)

5.8. Start the vacuum pump and evacuate the Test Port to less than 10 millitorr as read on the Digital Readout or until pressure is stable. This time will vary depending on when the usage.

NOTE:

To reduce the time for VCLT outgassing, connect pump to VCLT with V-1 closed and cap on test connector. Evacuate VCLT for several hours prior to test.

5.9. Close V-3 (Vacuum Pump Valve), and secure the vacuum pump.

5.10. If the pressure is greater than 1 millitorr/second, then stop the test, determine the cause of the leakage and restart the test.

5.11. Record the Test Port pressure in torr ($P_{test}$) on the Test Report.

5.12. Open V-2, (Volume Valve).

5.13. Record the mixed pressure in torr ($P_{mix}$) on the Test Report.

5.14. Calculate Test Port Volume ($V_{test}$) by performing the equation shown on the Test Report.

5.15. Calculate the Test Time in seconds ( $t$ ) by performing the equation shown on the Test Report.

5.16. Close V-2, (Volume Valve).

5.17. Open V-3, (Vacuum Pump Valve).

5.18. Start the vacuum pump; evacuate the Test Port to less than 10 millitorr or stable reading.

5.19. Close V-3 and secure the vacuum pump. If a pressure rise is noted due to outgassing, measure outgassing rate in millitorr per minute.

5.20. Open V-4

5.21. At the next change in pressure record pressure and start time measurement ($T_1$).

5.22. Record on Test Report the pressure reading at one minute intervals for ten minutes. If outgassing was observed in Step 5.19, verify post test outgassing rate and correct 10 minute pressure change for outgassing.

5.23. Open V-1, V-2, and V-3.

5.24. Disconnect the test hose from the Test Port.

5.25. Calculate the leakage rate for the ten minute test and record on the Test Report.

## 6.0 Hydrostatic Leak Test

6.1. Connect capillary leak standard and low pressure gauge to water reservoir per Figure 2.

NOTE

This hydrostatic pressure test will require changing the pressure gauges in order to span the pressure range of 22 psig to 400 psig. All pressure gauges shall be calibrated with a calibrated deadweight tester traceable to NIST.

6.2. Fill reservoir with water mixed with fluorescent dye through the vent valve V-6. The dye concentration shall be one ounce to 100 gallons of water.

6.3. Assure all air is vented from water reservoir and then close V-6.

6.4. Verify pressure valve V-5 is closed.

6.5. Start hydrostatic test pump.

6.6. Slowly open V-5 and pressure reservoir to 22 +2-0 psig. Hold pressure for ten minutes.

6.7. Check end of capillary tube in leak standard with a fluorescent light for any indication of water leakage. Record the inspection results on test report.

6.8. Open V-5 until pressure is slowly increased in reservoir to 100 +5-0 psig. Hold pressure for ten minutes.

6.9. Check end of capillary tube in leak standard with a fluorescent light for any indication of water leakage. Record the inspection results on test report.

6.10. Repeat steps 6.8 and 6.9 for pressures of 200 psig, 300 psig and 400 psig (+10% -0). Hold pressure for ten minutes at each pressure.

6.11. Shut off pump and reduce pressure by opening V-6.

6.12. Compete test report.

Figure 1

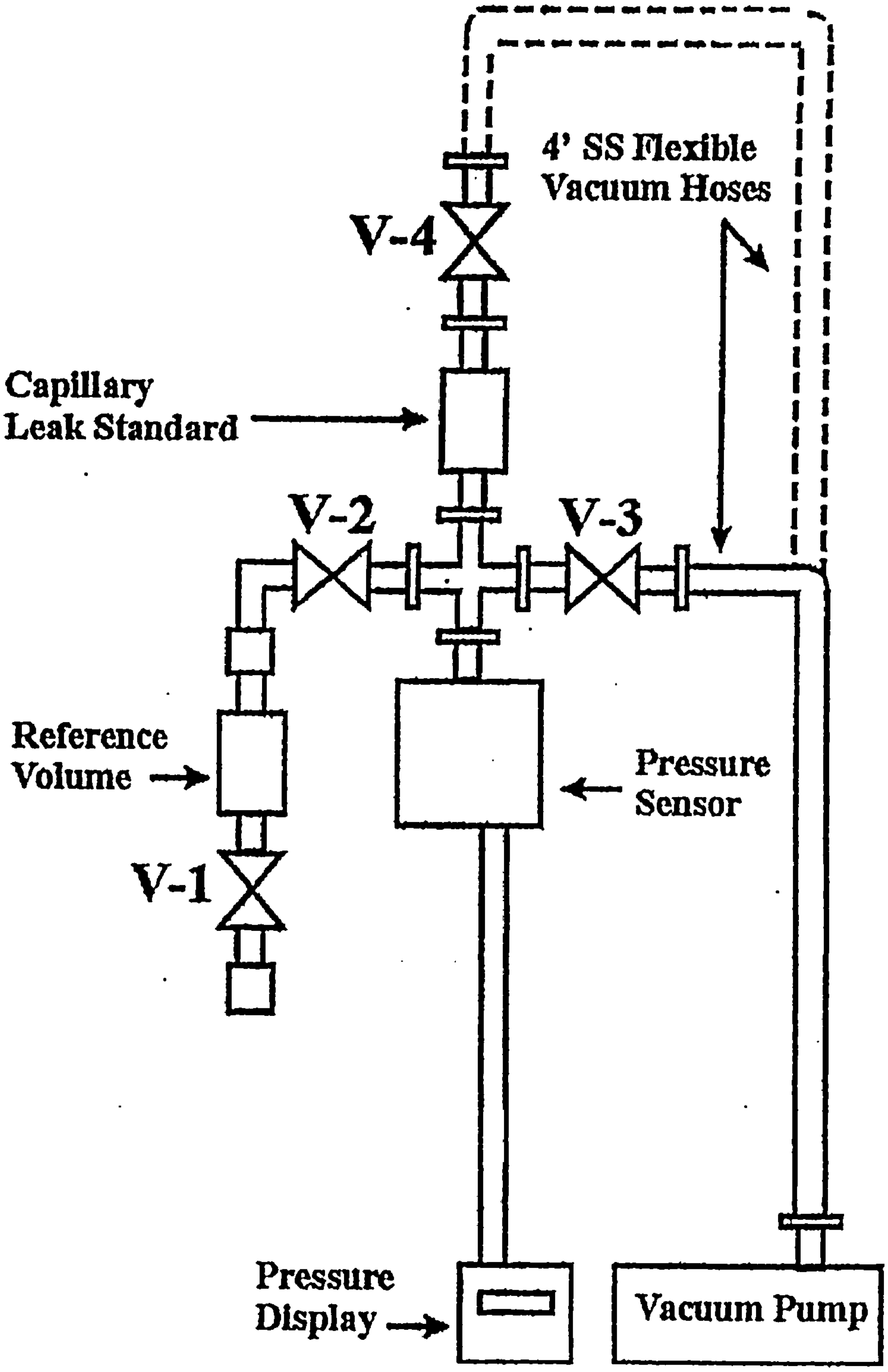
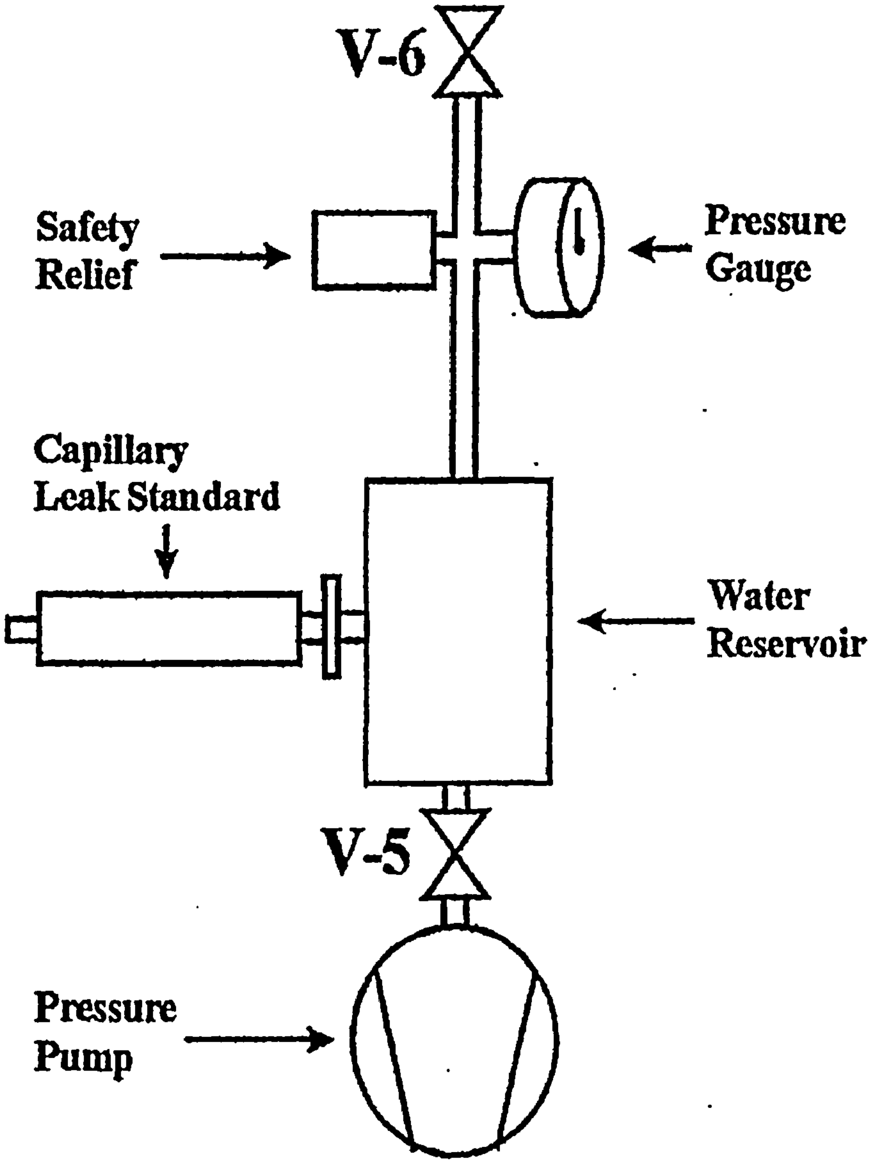

4' SS Flexible
Vacuum Hoses
V-4
Capillary
Leak Standard
V-2
V-3
Reference
Volume
Pressure
Sensor
V-1
Pressure
Display
Vacuum Pump

Figure 2


V-6
Safety Relief
Pressure Gauge
Capillary Leak Standard
Water Reservoir
V-5
Pressure Pump

| | | |
|---|---|---|
| **Procedure**<br>LT-CBC-1 | **Date**<br>August 17, 2001 | **Customer**<br>Columbiana Boiler |
| **Revision**<br>CBC-0 | **Page**<br>8 of 8 | **Project**<br>30B $UF_6$ cylinder |

# Test Report

**Standard Leak SN:** 8062 **Calibration Date:** 8-15-01 **Leakage rate:** 1.1 x $10^{-5}$ atm-cc/sec
**Vacuum Gauge SN:** 803004 **Calibration Due Date:** 10-2-01
**Pressure Gauge No:** G-13 **Pressure Range:** 0 - 30 **psig Calibration Date:** *8-6-01*
**Pressure Gauge No:** G-21 **Pressure Range:** 0 - 200 **psig Calibration Date:** 8-20-01
**Pressure Gauge No:** G-10 **Pressure Range:** 0 - 600 **psig Calibration Date:** 8-16-01

| **STEP** | **DESCRIPTION**<br>**O-RING SEAL TEST** | |
|---|---|---|
| 5.6 | Ambient Pressure $(P_{atm})$: 760 torr | |
| 5.11 | Test Port Pressure $(P_{test})$: .005 torr | |
| 5.13 | Mixed Pressure $(P_{mix})$: 604 torr | |
| 5.14 | $(V_{cal})\,52cc\times\left[\frac{(P_{atm})760-(P_{mix})604}{(P_{mix})604-(P_{test}).005}\right]=(V)\ 13.4cc$ | |
| 5.15 | Test Time $(t)$: $.132\times(V)\underline{13.4}=(t)\underline{1.8}$ *seconds*<br>Pressure change in one minute = 60 / t = 33.8 millitorr / minute | |
| 5.21<br>5.22 | Start Time: 1:32 Initial Pressure: 10 millitorr Pretest outgassing rate:<br>1 minute: 1:33 Pressure: 50 millitorr 7 mt/min<br>2 minute: 1:34 Pressure: 91 millitorr<br>3 minute: 1:35 Pressure: 130 millitorr<br>4 minute: 1:36 Pressure: 183 millitorr<br>5 minute: 1:37 Pressure: 238 millitorr<br>6 minute: 1:38 Pressure: 288 millitorr<br>7 minute: 1:39 Pressure: 334 millitorr<br>8 minute: 1:40 Pressure: 375 millitorr<br>9 minute: 1:41 Pressure: 427 millitorr Posttest outgassing rate:<br>10 minute: 1:42 Pressure: 488 millitorr 9 mt/min<br>Total pressure change in ten minutes = 478 – outgassing 90 = 388 millitorr (P) | |
| 5.25 | Leakage Rate = (P x V) x 2.2 x $10^{-9}$ = 1.14 x $10^{-5}$ std-cc/sec | |

| | Test Pressure (actual) | | Gage No.: | (6.7and 6.9) Indication of water at capillary |
|---|---|---|---|---|
| 6.6 | 22 psig test | 22.4 | G-13 | None |
| 6.8 | 100 psig test | 104 | G-21 | None |
| 6.10 | 200 psig | 217 | G-10 | Slight indication of dye at tube end |
| | 300 psig | 321 | | Same indication ( no growth ) |
| | 400 psig | 421 | | Same indication |

**Summary:** The Rate of Rise leak test (PCMT) on the 1.1 x $10^{-5}$ atm-cc/sec capillary standard verified the accuracy of the air PCMT and test equipment. The capillary standard was then hydrostatic leak tested with a fluorescent dye tracer in the water and it showed no indications at the test pressures of 22 psig and 100 psig. A dye indication was observed at the capillary tip starting at 200 psig but no flow was seen even at 400 psig. Since the hydrostatic tests were a short duration of only ten minutes, a four hour test at 400 psig was performed and showed no change in the size of the indication. The capillary leak is apparently clogged since no water flow,was occurring.

| | | |
|---|---|---|
| Test Performed by: Gary R Elder | Level: III | Date: 8-20-01 |

# 7.0 OPERATING PROCEDURES

Loading and unloading procedures for Type 30B cylinders are well established and published in USEC-651, *The $UF_6$ Manual: Good Handling Practices for Uranium Hexafluoride*. However, an outline of those procedures will be presented here. Proper operation of the UX-30, assuming a properly filled cylinder, is described below.

The 30C cylinder is identical to the 30B in all respects except for the addition of a Valve Protection Cover (hereinafter referred to as the "VPC"); therefore the loading and unloading procedures are essentially identical to the 30B. Incremental steps applicable to the 30C cylinder for the VPC are added.

## 7.1 Package Loading

### 7.1.1 Preparation for Loading

#### 7.1.1.1 Receipt and Filling of 30B or 30C Cylinder

Receipt and filling of the cylinder shall be performed in accordance with in plant operating procedures, ANSI N14.1, and appropriate provisions of the 30C cylinder specification (Addendum 2-2004 to ANSI N14.1-2001).

#### 7.1.1.2 Cylinder Inspection

Complete an inspection of the 30B cylinder as described in USEC 651 (or equivalent in-plant operating procedures) and ANSI N14.1 prior to insertion into the UX-30 Overpack. Any defective conditions must be corrected, and the cylinder must be recertified prior to use.

If a 30C Cylinder is being used, the VPC assembly and O-Rings shall be visually inspected for defective conditions including irregular surface conditions of the VPC, Flange, and O-rings. Any defective conditions must be corrected, and the cylinder must be re-tested in accordance with the provisions of paragraph 7.1.2.3. Defective O-Rings must be replaced with new O-Rings in accordance with the 30C cylinder specification (Addendum 2-2004 to ANSI N14.1-2001).

### 7.1.1.3 Overpack Inspection

The UX-30 package must be prepared for shipment in accordance with the requirements of 10CFR71.87. Inspect base and lid of package prior to loading. The following shall be cause for further investigation or removal from service until the defective condition is satisfactorily corrected:

- Excessive distortion, warping, or other damage of the inner or outer shell preventing closure of the package or proper installation of all 10 closure pins.
- Failure of ball-lock pins to lock in place.
- Damaged alignment pins.
- Large dents (more than 0.5-inch deep).
- Damaged dust seal.
- Failed welds.
- Excessive wear of inner shell steel or rubber pads.
- The overpack base and supports are sound with no broken welds or components.
- The overpack inner and outer shells are intact with no broken welds and no holes, tears, or deformations greater than ½ inch. Visual indications of corrosion or oxidation causing a through wall pitting in two (2) or more locations within a six (6) by six (6) inch area shall be cause for the rejection of the Overpack.
- The inner liner is free of debris and standing water.
- The inner liner is intact and is not in a deteriorated or damaged condition.
- The gaskets and cylinder support pads are in place and intact and are not in a deteriorated or damaged condition.
- The gasket surfaces are free from nicks and deep scratches.
- The cover plates and welds are sound and undamaged.
- The overpack halves fit together properly without gaps.
- All vent seals/plugs are securely in place.
- The tie-down and lifting/stacking supports are in place and are not in a deteriorated or damaged condition.
- The tamper-indicating seal apparatus is undamaged.

### 7.1.2 Loading of Contents

PROCEDURE FOR LOADING THE 30B OR 30C CYLINDER

7.1.2.1. Prior to loading the cylinder, the inspection required in Section 7.1.1.2 and 7.1.1.3 shall be completed and documented.

7.1.2.2 The 30B or 30C UF6 cylinder is filled, tested, and handled in accordance with standard, in-plant operating procedures at the facility. As a minimum, the procedures described in USEC-651, or other equivalent in-plant procedure, ANSI Standard N 14.1, and appropriate provisions of the 30C cylinder specification (Addendum 2-2004 to ANSI N14.1-2001) shall be used.

7.1.2.3 Leak tightness of the filled cylinder valve shall have been previously verified using a test having a sensitivity of at least 1 x $10^{-3}$ std-cc/sec per ANSI Standard N14.5-1997, or a Regulatory or Competent Authority approved in-plant leak test, with an equivalent sensitivity. Leak tightness of the filled cylinder valve shall be verified by leak rate testing of the pigtail before disconnection and after closing the cylinder valve.

Alternatively, a vacuum test may be performed on the cylinder (Note: the cylinder's outer surface shall be approximately at ambient temperature and its vapor pressure below atmospheric pressure) by attaching a pigtail to the closed valve and drawing a vacuum. The continued presence of $UF_6$ in the pigtail is an indication that the valve is not fully closed or is defective, and corrective measures shall be taken to remedy the leak as prescribed by the facility's operating procedures.

7.1.2.4 If the 30C cylinder has been filled, the VPC shall be installed over the valve using the locator pin.

Note: The VPC is a component of the 30C cylinder and is unit-specific, with the same serial number as the cylinder. The VPC shall not be transferred to any other cylinder. Prior to installation of the VPC, it shall be verified that the serial numbers on the VPC and 30C cylinder are the same.

Prior to installation of the VPC a silicone-based lubricant shall be applied to the VPC O-rings

Prior to installation, the VPC bolts shall be lubricated with a polytetrafluorethylene (PTFE) - based lubricant. The six bolts tightened to a finger tight condition, followed by a tightening procedure using a calibrated torque wrench, where each bolt shall be tightened to 30 foot pound (+5/-0 tolerance}. Bolt tightening sequence shall be a star pattern, followed by rotational and reverse rotational tightening until stable at final toque value.

Note: Inspection for deposits on the valve and boss/coupling shall be accomplished per the procedure set forth in paragraph 7.1.2.8 prior to installing the VPC.

7.1.2.5 The VPC shall be leak tested prior to each shipment with an acceptable method per ANSI Standard N14.5-1997 having a sensitivity of 1 x $10^{-3}$ std-cc/sec or less, such as the pressure drop or pressure rise methods.

Note: A soap-bubble test cannot be used for testing the VPC because of the configuration of the VPC and its O-rings.

7.1.2.6 The cylinder shall be weighed using the procedures and standards outlined in USEC-651, or other equivalent in plant operating procedure, to assure that the capacity of the cylinder has not been exceeded.

7.1.2.7 After verifying leak tightness of the filled cylinder, the cylinder shall be allowed to cool until the vapor pressure of the cylinder is below atmospheric pressure.

7.1.2.8 Prior to loading into the UX-30 Overpack, the valve port and valve boss/coupling shall be inspected for solid deposits. Solid deposits around the valve port or valve boss/coupling indicate a leak condition, and the cylinder shall not be loaded into the overpack. Corrective measures shall be taken to remedy the leak as prescribed by the facility's operating procedures. If the valve port and valve boss/coupling are free of solid deposits, the cylinder may be loaded into the Overpack.

7.1.2.9 A tamper-indicating seal shall be installed on the 30B cylinder prior to loading it into the Overpack.

Note: On the 30C cylinder the tamper-indicating seal shall be installed on the VPC.

PROCEDURE FOR LOADING THE OVERPACK

7.1.2.10 The inspection required by Section 7.1.1.2, 7.1.1.3, and 7.1.2 shall be performed and documented prior to loading the UX-30 Overpack with a 30B or 30C cylinder.

7.1.2.11 Before loading, the $UF_6$ inside the cylinder shall be completely solidified.

7.1.2.12 The UX-30 lower half shall be resting in its shipping and handling cradle.

7.1.2.13 Using a suitable crane, the cylinder shall be carefully placed in the lower half of the UX-30. The cylinder valve shall be located at the top of the overpack, intersecting a vertical plane through the overpack centerline, on either side of the enclosure.

NOTE: IF A STANDARD 30-B CYLINDER IS BEING TRANSPORTED, ENSURE THAT THE VALVE COVER ("VALVE PROTECTOR") IS REMOVED PRIOR TO SHIPMENT.

NOTE: THE VPC ON THE 30C CYLINDER SHALL NOT BE REMOVED PRIOR TO SHIPMENT

7.1.2.14 Place the upper half of the UX-30 onto the lower half.

7.1.2.15 Secure the upper half of the Shipping and Handling Cradle. Tighten as required.

7.1.2.16 Install the 10 ball-lock pins in their receptacles, thereby securing the two package halves together.

CAUTION: ENSURE EACH PIN IS PROPERLY INSTALLED. VERIFY THAT THE PUSH-BUTTON IS IN THE NORMAL, RETRACTED POSITION WHEN RELEASED (NOT STUCK IN THE "IN" POSITION). VERIFY THAT THE PIN IS LOCKED IN PLACE (CANNOT BE REMOVED BY TUGGING ON THE PIN OR LANYARD). BALL-LOCK PINS NOT OPERATING PROPERLY SHALL BE REMOVED FROM SERVICE.

7.1.2.17 Install the two standard tamper-indicating seals in their proper positions. Install the bolt plugs in the optional lid lifting lugs as shown in the General Arrangement Drawings, Appendix 1.4.1.

### 7.1.3 Preparation for Transport

7.1.3.1 The UX-30 is now ready for shipment.

7.1.3.2 Perform the following inspections of the overpack after placement of the lid:

Perform a radiation survey of the package per the requirements of 10 CFR 71.47. Contamination levels on the external surfaces of each package shall be kept as low as practicable. The level of non-fixed radioactive contamination shall meet the requirements of 10 CFR 71.87(i).

Ensure that labeling and placarding requirements of DOT regulations, as defined in 49 CFR 172, are met.

Note that the loaded UX-30 package may only be handled via the shipping cradle or a sling placed underneath the package

## 7.2 Package Unloading

### 7.2.1 Receipt of Package from Carrier

7.2.1.1 Inspect the exterior of the overpack for possible damage:

- The overpack inner and outer shells are intact with no broken welds and no holes, tears, or deformations greater than ½ inch. Visual indications of corrosion or oxidation causing a through wall pitting in two (2) or more locations within a six (6) by six (6) inch area shall be cause for the rejection of the Overpack.
- The cover plates and welds are sound and undamaged.
- The overpack halves fit together properly without gaps.
- The tie-down and lifting/stacking supports are in place and are not in a deteriorated or damaged condition.
- The tamper-indicating seal apparatus is undamaged.

Document any damage observed. Complete the receiving report as required by facility operating procedures.

7.2.1.2 Note that the loaded UX-30 package may only be handled via the shipping cradle or a sling placed underneath the package.

### 7.2.2 Removal of Contents

7.2.2.1 Break the tamper indicating seals.

7.2.2.2 Remove the 10 ball-lock pins from the perimeter of the UX-30.

7.2.2.3 Release the package from the base shipping and handling cradle. Remove the bolt plugs from the lid lifting lugs, if lid lugs are present. If lid lift clips are present, install 4 lifting pins in upper half of shipping cradle.

7.2.2.4 Remove the lid from the package.

7.2.2.5 Remove the payload cylinder.

7.2.2.6 Remove the 30B cylinder security seal (which is on the VPC on the 30C cylinder).

Note: The VPC is a component of the 30C cylinder and is unit-specific, with the same serial number as the cylinder. The VPC shall not be transferred to any other cylinder.

7.2.2.7 Prior to unloading the cylinder, cylinder shall be inspected and weighed as required by USEC 651 or equivalent in plant operating procedures.

7.2.2.7 The $UF_6$ cylinder is emptied and handled in accordance with standard, in- plant, operating procedures at the facility. As a minimum, the procedures described in USEC-651 or equivalent in plant operating procedures, and ANSI Standard N14.1, shall be used.

## 7.3 Preparation of an Empty Package for Transport

7.3.1 Visually inspect the overpack prior to each use. The following shall be cause for further investigation or removal from service until the defective condition is satisfactorily corrected:

- Excessive distortion, warping, or other damage of the inner or outer shell preventing closure of the package and proper installation of all 10 closure pins.
- Failure of ball-lock pins to lock in place.
- Damaged alignment pins.
- Large dents (more than 0.5-inch deep).
- Damaged dust seal.
- Failed welds.
- Excessive wear of inner shell steel or rubber pads.

7.3.2 The UX-30 lower half shall be resting in its shipping and handling cradle.

NOTE: IF A STANDARD 30-B CYLINDER IS BEING TRANSPORTED, ENSURE THAT THE VALVE COVER ("VALVE PROTECTOR") IS REMOVED PRIOR TO SHIPMENT.

NOTE: THE VPC ON THE 30C CYLINDER SHALL NOT BE REMOVED PRIOR TO SHIPMENT

7.3.3 Place the upper half of the UX-30 onto the lower half. Ensure that all requirements of 49 CFR 173.428 for Empty Radioactive Materials Packaging are met.

CAUTION: ENSURE EACH PIN IS PROPERLY INSTALLED. VERIFY THAT THE PUSH-BUTTON IS IN THE NORMAL, RETRACTED POSITION WHEN RELEASED (NOT STUCK IN THE "IN" POSITION). VERIFY THAT THE PIN IS LOCKED IN PLACE (CANNOT BE REMOVED BY TUGGING ON THE PIN OR LANYARD). BALL-LOCK PINS NOT OPERATING PROPERLY SHALL BE REMOVED FROM SERVICE.

7.3.4 Secure the upper half of the Shipping and Handling Cradle. Tighten as required.

7.3.5 The empty UX-30 is now ready for transport.

7.3.6 Note that the UX-30 package may only be handled via the shipping cradle or a sling placed underneath the package.

## 7.4 Other Procedures

Not Applicable

## 7.5 Appendix

Not Applicable

# 8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

## 8.1 Acceptance Tests

ACCEPTANCE TESTS FOR THE 30B OR 30C CYLINDER:

Acceptance Tests For The 30B Cylinder – Designed and Manufactured per ANSI N14.1 (appropriate edition), "Uranium Hexafluoride – Packaging for Transport". Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1 (appropriate edition).

Acceptance Tests For The 30B Cylinder – Designed and Manufactured per ANSI N14.1 – 1995, "Uranium Hexafluoride – Packaging for Transport" and ISO 7195:1993(F), "Packaging of Uranium Hexafluoride ($UF_6$) for Transport". Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1 – 1995 and ISO 7195:1993(F).

Acceptance Tests For The 30C Cylinder - Designed and manufactured in accordance with Addendum 2-2004 to ANSI N14.1-2001.

ACCEPTANCE TESTS FOR THE UX-30:

The following acceptance tests are for the UX-30

### 8.1.1 Visual Inspections and Measurements

8.1.1.1 See Appendix 8.3.1 for acceptance criteria and inspections associated with polyurethane foam manufacturing.

8.1.1.2 Prior to the first use of the package, the following inspection shall be performed:

Dimensional compliance with the drawings referenced in the Certificate of Compliance.

Verify that the packaging is free of cracks, pinholes, or defects that could reduce the effectiveness of the package.

Verify that the packaging is marked in accordance with 10 CFR 71.85 (c).

### 8.1.2 Weld Examinations

Prior to the first use of the package, a visual inspection of all welds to AWS D1.1 shall be performed.

### 8.1.3 Structural and Pressure Tests

None.

### 8.1.4 Leakage Tests

None.

### 8.1.5 Component and Material Tests

Prior to the first use of the package, an assembly test showing proper operation of closure interface and all ball-lock pins shall be performed.

### 8.1.5 Shielding tests

None.

### 8.1.7 Thermal Tests

None.

## 8.2 Maintenance Program

MAINTENANCE PROGRAM FOR THE 30B OR 30C CYLINDER:

Maintenance Program For The 30B Cylinders Manufactured per ANSI N14.1 (appropriate edition), "Uranium Hexafluoride – Packaging for Transport".

Maintenance of the 30B Cylinders shall be performed in accordance with ANSI NI4.1 (appropriate edition).

Maintenance Program For The 30B Cylinders Manufactured In Accordance With ANSI N14.1–1995, "Uranium Hexafluoride – Packaging for Transport" and ISO 7195:1993(F), "Packaging of Uranium Hexafluoride (UF6) for Transport".

Maintenance of the 30B Cylinders shall be performed in accordance with ANSI NI4.1 - 1995 and ISO 7195:1993(F).

Maintenance Program for the 30C Cylinder.

Maintenance of the 30C Cylinder shall be performed in accordance with Addendum 2-2004 to ANSI N14.1-2001.

# 8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

## 8.1 Acceptance Tests

ACCEPTANCE TESTS FOR THE 30B OR 30C CYLINDER:

Acceptance Tests For The 30B Cylinder – Designed and Manufactured per ANSI N14.1 (appropriate edition), "Uranium Hexafluoride – Packaging for Transport". Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1 (appropriate edition).

Acceptance Tests For The 30B Cylinder – Designed and Manufactured per ANSI N14.1 – 1995, "Uranium Hexafluoride – Packaging for Transport" and ISO 7195:1993(F), "Packaging of Uranium Hexafluoride ($UF_6$) for Transport". Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1 – 1995 and ISO 7195:1993(F).

Acceptance Tests For The 30C Cylinder - Designed and manufactured in accordance with Addendum 2-2004 to ANSI N14.1-2001.

ACCEPTANCE TESTS FOR THE UX-30:

The following acceptance tests are for the UX-30

### 8.1.1 Visual Inspections and Measurements

8.1.1.1 See Appendix 8.3.1 for acceptance criteria and inspections associated with polyurethane foam manufacturing.

8.1.1.2 Prior to the first use of the package, the following inspection shall be performed:

Dimensional compliance with the drawings referenced in the Certificate of Compliance.

Verify that the packaging is free of cracks, pinholes, or defects that could reduce the effectiveness of the package.

Verify that the packaging is marked in accordance with 10 CFR 71.85 (c).

### 8.1.2 Weld Examinations

Prior to the first use of the package, a visual inspection of all welds to AWS D1.1 shall be performed.

### 8.1.3 Structural and Pressure Tests

None.

### 8.1.4 Leakage Tests

None.

### 8.1.5 Component and Material Tests

Prior to the first use of the package, an assembly test showing proper operation of closure interface and all ball-lock pins shall be performed.

### 8.1.5 Shielding tests

None.

### 8.1.7 Thermal Tests

None.

## 8.2 Maintenance Program

MAINTENANCE PROGRAM FOR THE 30B OR 30C CYLINDER:

Maintenance Program For The 30B Cylinders Manufactured per ANSI N14.1 (appropriate edition), "Uranium Hexafluoride – Packaging for Transport".

Maintenance of the 30B Cylinders shall be performed in accordance with ANSI NI4.1 (appropriate edition).

Maintenance Program For The 30B Cylinders Manufactured In Accordance With ANSI N14.1-1995, "Uranium Hexafluoride – Packaging for Transport" and ISO 7195:1993(F), "Packaging of Uranium Hexafluoride (UF6) for Transport".

Maintenance of the 30B Cylinders shall be performed in accordance with ANSI NI4.1 - 1995 and ISO 7195:1993(F).

Maintenance Program for the 30C Cylinder.

Maintenance of the 30C Cylinder shall be performed in accordance with Addendum 2-2004 to ANSI N14.1-2001.

### 8.2.1 Structural and Pressure Tests

8.2.1.1 Visual inspection of all welds shall be carried out every 6 months.

8.2.1.2 Excessive accumulations of dirt, oil, and other debris shall be removed from the inner and outer surfaces after each use.

8.2.1.3 The dust seal and all rubber pads shall be inspected every 6 months for wear. The dust seal shall be replaced when excessive wear renders the seal ineffective.

8.2.1.4 Inner and outer surfaces shall be inspected for penetrations every 6 months. If any skin failure is observed, these may be repaired using a suitable stainless steel welding procedure. Care should be taken to avoid application of heat for an excessive duration, causing the package to change shape.

### 8.2.2 Leakage Tests

None.

### 8.2.3 Component and Material Tests

None.

### 8.2.4 Thermal Tests

None.

### 8.2.5 Miscellaneous Tests

8.2.5.1 The following inspections shall be performed to verify acceptability of the foam:

Plastic overpack foam-filling-hole plugs should be removed every 12 months to allow inspection of foam condition for indications of foam deterioration (e.g., presence of solid foam on inside of plug). Verify tight fit of plug after replacement (plug should not turn freely by hand).

Overpacks are to be weighed every 12 months to determine if water has leaked into the overpack. A weight gain of more than 25 pounds per base or lid is reason for rejection (per USEC-651, "Uranium Hexafluoride: A Manual of Good Handling Practices", DOE Field Office, Oak Ridge).

8.2.5.2 In addition to the requirements of Section 7.1.1.3 to check the ball-lock pins before each use, the pins shall also be checked for proper operation annually.

This annual check shall consist of at least:

1. Depressing the push button and verifying the ball locks operate properly and that the push button retracts when it is released.
2. Inserting each pin into a receptacle on the UX-30 and verifying that it properly locks into place
3. Cleaning each pin by wiping it down with a clean cloth and, if necessary, lubricating it with a clean lightweight oil such as WD-40.

Malfunctioning ball-lock pins identified during this annual maintenance shall be immediately removed from service.

## 8.3 APPENDIX

### 8.3.1 Polyurethane Foam Specification ES-M-170

(Proprietary)