KY-665

LOCKHEED MARTIN

PADUCAH GASEOUS DIFFUSION PLANT

SAFETY ANALYSIS REPORT ON THE "PADUCAH TIGER" PROTECTIVE OVERPACK FOR 10-TON CYLINDERS OF URANIUM HEXAFLUORIDE

Revision 1

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LOCKHEED MARTIN UTILITY SERVICES, INC.
UNDER CONTRACT WITH THE
UNITED STATES ENRICHMENT CORPORATION

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1.0 GENERAL INFORMATION

The Paducah Gaseous Diffusion Plant accepts natural assay uranium hexafluoride (UF_6) and converts it into low enriched UF_6. The low enriched UF_6 is placed in large steel cylinders for shipment to the Portsmouth Gaseous Diffusion Plant. The Portsmouth Plant further enriches the UF_6 to the levels required for fuel fabrication.

The large steel cylinders used to ship the UF_6 from the Paducah Plant to the Portsmouth Plant are known as Model 48X 10-ton UF_6 cylinders (48X cylinders). During shipment, the 48X cylinder is encased in an outer protective package known as the Paducah Tiger overpack (PTO). The Paducah Tiger overpack provides thermal, puncture, and impact protection for the 48X cylinder during transport.

The Paducah Tiger overpack with the 48X cylinder, referred to as a "package," is shipped by either truck or rail. A truck shipment contains one package and a rail shipment contains up to 5 packages per railroad flatcar. The package is typically transported between the Paducah and Portsmouth plants.

The package is a Type AF radioactive material package with a maximum shipping weight of 40,000 pounds, which meets the requirements specified in 10 CFR 71.73. The transport index required for criticality safety purposes is 0.0.

1.1 Introduction

The Paducah Tiger overpacks are fabricated to transport 48X 10-ton UF_6 cylinders. The 48X cylinder is a DOT Specification 7A container [1], fabricated from low-carbon steel. The Paducah Tiger overpack, shown in Figure 1.1-1, provides protection for the 48X cylinders under normal conditions of transport and hypothetical accident conditions. The overpack completely envelopes the 48X cylinder using a removable lid that attaches to the body of the overpack. The overpack body supports the 48X cylinder. The overpack utilizes steel and aluminum plates and polyurethane foam to provide puncture protection, structural support, and thermal protection. The 48X cylinder, shown in Figure 1.1-2, is fabricated in accordance with ANSI N14.1 [2], except as noted in Section 1.2.1.9, and is the package containment boundary.

The Paducah Tiger overpacks consist of an outer skin (also referred to as an "outer steel shell") and an inner liner (also referred to as an "inner steel shell") with polyurethane foam filling the space between the two shells. Both low- and high-density foams are used in the overpacks. High-density foam is used along each edge and at each corner of the lid and body. Low-density foam is used for the remainder of the overpack.

The package design incorporates rubber shock isolators for cylinder support and alignment; stainless steel breakaway plates for puncture protection; a high strength aluminum stiffening plate for both puncture protection and structural support; closure mechanisms; a tamper-indicating device; and tie-down features. These components are described in Section 1.2.1.

The 48X cylinder may contain up to 21,030 pounds of UF_6 enriched up to 4.5 wt % U-235 when filled. To be considered empty, cylinders may contain no more than 50 pounds of residual UF_6 (a heel cylinder). The isotopic content of full and heel cylinders is discussed in Section 1.2.3.

During design, a Paducah Tiger overpack prototype was built for physical testing. Results from the prototype testing were used to optimize the Paducah Tiger overpack design. To supplement the test data, computer modeling and analyses were performed. A description of the tests, and a summary of the results of the tests and analyses, are presented in Section 2.7.1. The Paducah Tiger license drawings are provided in Section 1.4. The dimensions indicated in Section 1 are generally nominal dimensions. Subsequent chapters may present dimensions that contain exact tolerances based on more detailed requirements.

Figure 1.1-1 Paducah Tiger Overpack for the 48X 10-ton UF_6 Cylinder

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1.1-2 48X 10-ton UF_6 Cylinder

FIGURE WITHHELD UNDER 10 CFR 2.390

NOTES: - ALL DIMENSIONS SHOWN ARE APPROXIMATE
- FIGURE NOT-TO-SCALE
- ACTUAL 48X CYLINDERS ARE FABRICATED IN ACCORDANCE WITH ANSI N14.1

SIDE ELEVATION

1.2 Package Description

The Paducah Tiger overpack is a rectangular shaped box with a cylindrical internal cavity sized to hold one 48X cylinder. The overpack has a removable lid that disengages along a horizontal separation plane to permit vertical removal of both the lid and cylinder individually. The external dimensions of the overpack are approximately 72 inches high by 76 inches wide by 153 inches long. Polyurethane foam fills the space between the inner liner and outer skin of the overpack. Drain lines at each end of the overpack permit draining of incidental water and allow cleaning of the interior cavity when necessary. The breakaway plates and valve protector plates are described in Section 1.2.1.3. The aluminum stiffening plate, which provides puncture and impact protection at the valve end of the overpack cavity, is described in Section 1.2.1.4. The structural materials used in the overpack are identified in Table 1.2-1. The 48X cylinder is described in Section 1.2.1.9.

1.2.1 Packaging

The package consists of the Paducah Tiger overpack and the 48X cylinder. The gross weights of the loaded Paducah Tiger overpack and the loaded 48X cylinder are:

Package Component	Weight (pounds)
48X Cylinder	
• Nominal Weight (Empty Cylinder)	4,500
• Maximum Net Weight (Max. UF_6 Content)	21,030
• Nominal Gross Weight (Loaded Cylinder)	25,530
Maximum Overpack Weight	14,470
Maximum Gross Weight of Loaded Package	40,000

1.2.1.1 Frame and Shells

The external edges of the overpack are reinforced with a 1-1/2-inch by 1-1/2-inch by 3/16-inch thick angle frame, as shown in Figure 1.2-1. The outer skin and the International Organization for Standardization (ISO) corners are welded to the angle frame. Corner brace plates (inside) are welded at each interior corner and edge brace plates are welded along each edge of the package to form a triangular, prism-like space that is filled with high-density foam. High-density foam is also inserted in the space behind each ISO corner. Corner brace plates (outside) are welded to the outside of the outer skin at each of eight corners for additional strength. All edges and corners are butt-welded along the edge. A standard ISO steel casting is set into cutouts in each corner. The ISO steel castings are welded to the side plates, external corner reinforcements, and frame angles.

The internal cylindrical cavity of the overpack is formed with rolled 3/16-inch steel sheet. The dimensions of the cavity, which accommodates the 48X cylinder, are approximately 60 inches in diameter by 130 inches in length. The end plate used in the body of the overpack at the nonvalve end of the cylinder is fabricated from 3/16-inch steel sheet. The end plate used in the lid of the overpack at the nonvalve end of the cylinder is fabricated from 1/2-inch steel plate. Both the lid and body end plates at the valve end of the cylinder are fabricated from 1/2-inch steel plate. The end plates are shown in Figure 1.2-2.

The lid and body of the Paducah Tiger overpacks are designed to align to ensure positive closure and direct load transfer paths. This alignment is achieved using two sizes of steel tubing and angle frames to create the basic framework of the overpack lid and body. The steel tubing also provides a welding surface for the outer skin, the angle frames, and top cover plates. These top cover plates, which contain a water-resistant seal, provide a connection point for the inner liner which forms the interior cylindrical cavity. All welds are made in accordance with the American Welding Society's structural welding code, AWS D1.1.

1.2.1.2 Foam

The overpack is a steel structure consisting of an inner liner and outer skin. The space between the two shells is filled with fire-retardant polyurethane foam. The foam absorbs impact energy and provides an efficient high-temperature insulation.

The overpack uses low- (nominally 8 lb/ft^3) and high- (nominally 18 lb/ft^3) density foam. The high-density foam protects the edges and corners from excessive deformation during impact. Low-density foam is used for the remainder of the overpack. Figures 1.2-1 and 1.2-2 show the locations of the low- and high-density foams.

The outer skin of the overpack prevents direct exposure of the foam to flame in the event of a fire accident. Vents in the outer skin are provided to prevent internal pressure buildup in the overpack due to off-gassing of the foam that could occur due to high temperatures in fire accident events. These vents do not relieve any pressure in the 48X cylinder.

1.2.1.3 Breakaway Plates

A pair of different-sized stainless steel plates are tack-welded to the inside surface of the outer skin of the overpack lid and body before the foam is poured. These plates, known as "breakaway plates," provide puncture protection for the 48X cylinder. The breakaway plates also protect the foam from exposure to fire should there be a puncture of the outer skin. The plates, shown in Figures 1.1-1 and 1.2-1, are welded to the top of the lid, on the bottom of the body, and along both longitudinal walls of the lid. Plates measuring approximately 72 inches by 36 inches and 52 inches by 24 inches are welded to the top of the lid and to the bottom of the body. A pair of steel plates measuring approximately 72 inches by 28 inches and 52 inches by 19 inches are welded along each longitudinal wall of the lid.

Two end reinforcing plate designs are used in the overpacks. In the first 32 overpacks fabricated (Serial Nos. 001 through 032), a puncture-resisting end plate was welded to the valve end of the lid. This plate (commonly referred to as the "valve protector plate") protects the cylinder valve from damage due to puncture, while another end plate was added to the opposite end (nonvalve end) to balance the lid during lifting operations. The valve protector plate is fabricated with 3/8-inch stainless steel, while the plate at the opposite end is fabricated from 3/8-inch low carbon steel. Overpacks fabricated later incorporate a single stainless steel end plate inside the outer skin of the lid at the valve end. In these overpacks, the positioning of the lifting fixtures is adjusted so that a counter-balancing plate at the opposite end is not required.

1.2.1.4 Stiffening Plate

A 2-inch thick stiffening plate fabricated from high-strength aluminum is inserted in the valve end of the overpack cavity adjacent to the 1/2-inch thick carbon steel end plate. The aluminum stiffening plate provides puncture protection for the cylinder valve during a hypothetical accident event. The stiffening plate is shown in Figure 1.2-3.

1.2.1.5 Closure System

The closure system, shown in Figure 1.2-4 consists of ratchet turnbuckles (not shown), guide pins, and ball lock pins. For transport, the lid is attached to the body of the overpack by eight spring-loaded ball lock pins inserted through holes in the welded guide pins. After the overpack lid is lowered into place over a cylinder, ratchet turnbuckles are used to draw the lid and body together. A seal consisting of a soft neoprene sponge rubber gasket is compressed between the top cover plates to provide a weather seal. The guide pins, welded to and protruding from the tube steel frame of the overpack body, engage match-drilled holes in the tube steel frame of the lid. The ball lock pins are inserted and secured by their spring-loaded ball lock mechanism. The ball lock pins ensure that the overpack halves remain together even if the turnbuckles are accidentally destroyed. The ratchet turnbuckles have 1-3/8-inch clevis jaws. The quick-release ball lock pins are 3/4 inch in diameter and are fabricated from high strength steel. The guide pins are 1-3/4 inches in diameter, fabricated of high strength steel, and welded to the tube steel frame of the overpack body.

1.2.1.6 Rubber Shock Isolators

The rubber shock isolators support the cylinder both axially and radially during transit and provide a flexible guiding system for the cylinders during loading. They also isolate the cylinder from the overpack, preventing metal-to-metal contact, and provide lateral alignment.

Rubber shock isolators are used to form a cradle for the 48X cylinder and to secure the cylinder in transport. Thirty-two pre-formed radial shock isolators, 5 inches thick by 6-1/2 inches wide, are installed in the internal cavity of both the body (12 shock isolators) and lid (20 shock isolators) of the overpack. There are nine axial shock isolators, 4 inches long by 4 inches wide by 2 inches thick, installed on the nonvalve end of the overpack. There are no axial shock isolators on the valve end of the overpack. The axial shock isolators are approximately evenly spaced to engage the end skirt of the 48X cylinder. All rubber shock isolators are fabricated from ethylene-propylene diene terpolymer (EPDM).

1.2.1.7 Lifting Brackets

Four lifting brackets on the lid of the overpack are fabricated from mild steel and welded to 3/8-inch mild steel plates. These plates are in turn welded to the outer skin of the overpack. The lid lifting brackets are centered on the balance point of the overpack and inclined 10° from vertical towards the balance point. The lid lifting brackets are not intended for lifting the Paducah Tiger overpack containing a filled or empty 48X cylinder.

1.2.1.8 Tie-downs

The tie-down system consists of four ISO corner fittings on the body of the overpack and a tie-down bracket welded to each of the four ISO corners. All of the ISO corners or tie-down brackets at the base of the overpack body may be used to secure the package. These tie-down brackets also serve as a transport tie-down point as shown in Figure 1.2-5 where they are used to bolt the package to the deck of the transporter.

1.2.1.9 48X 10-ton UF_6 Cylinder

The 48X 10-ton UF_6 cylinder, shown in Figure 1.1-2, forms the containment boundary for the Paducah Tiger package. Material specifications for the 48X cylinder are shown in Table 1.2-2. The 48X cylinder is a DOT Specification 7A container. The nominal diameter of the 48X cylinder is 48 inches, and the length is approximately 119 inches. The wall thickness is nominally 5/8 inch. The nominal gross loaded weight of the cylinder is 25,530 pounds. The minimum volume is 108.9 ft^3. Figure 1.1-2 also shows the valve, stiffening rings, lifting lugs, and the drain plug. Because of brittle fracture concerns as discussed in Section 2.3, all ASTM A-285 cylinders used for shipment of UF_6 have been replaced with ASTM A-516 normalized steel cylinders.

A 1-inch angle drum (cylinder) valve, shown in Figure 1.2-6, is installed at one end of the 48X cylinder for filling and emptying the UF_6 from the cylinder.

The 48X cylinder valve stem and plug may be tinned with ASTM B32, alloy 50A or Sn50 solder material, or a mixture of alloy 50A or Sn50 with alloy 40A or Sn40A material, provided the mixture has a minimum tin content of 45 percent. Except for the makeup of the tinning materials, the 48X cylinder is fabricated in accordance with ANSI N14.1.

As shown in Figure 1.1-2, three stiffening rings are welded to the 48X cylinder to provide protection during handling. Four lifting lugs are attached to the outer stiffening rings for handling of the cylinder.

A 1-inch hex head drain plug is installed on the cylinder at the end opposite the valve. This plug is used to drain cleaning solution from the cylinder during cleaning operations. It is screwed into a 1-inch half-coupling that is welded to the inside of the cylinder head.

1.2.2 Operational Features

The Paducah Tiger overpack is a simply designed and easily operated package with no active systems and few operational features. The primary operational features of the Paducah Tiger overpack pertain to loading and unloading the 48X cylinder into and out of the overpack. Many of these features are described in Section 1.2.1, and are shown in Figure 1.1-1. The lid of the overpack is designed to be removed as a single unit using four lifting points, two on either side of the lid. The lid is secured to the body of the overpack using eight ball lock pins that are manually installed and removed. No torque is applied to the pins. Drain ports at either end of the overpack allow the removal of any residual water that may inadvertently enter the overpack during periods of storage or use, and allow cleaning of the overpack inner liner when necessary. Cylinder guides are incorporated into the inner liner to facilitate the alignment of the cylinder with its cradle during loading of the cylinder into the overpack. A lid guide is used to ensure the correct orientation of the lid to the overpack body. Vent holes in the outer skin of the overpack prevent the overpack from becoming pressurized during fire accident events.

The overpack is designed so that the 48X cylinder is loaded into or unloaded from the overpack while the overpack is on the transporter, which may be either a truck flatbed or a railroad flatcar. Consequently, the overpack is not lifted or moved while it contains a 48X cylinder.

Proper operation of the package takes advantage of the physical properties of the UF_6 material. The 48X cylinder is filled with the UF_6 in a liquid state. As the UF_6 cools, it solidifies and reduces in volume. After cooldown, the vapor pressure of the solidified UF_6 is subatmospheric. A 5-day cooldown is required to assure that the UF_6 has solidified, and that there is no liquid within the cylinder. The thermal protection afforded by the polyurethane foam during the hypothetical accident event ensures that the UF_6 does not overpressurize the cylinder.

1.2.3 Contents of Packaging

The 48X cylinder is filled with liquid UF_6, which is allowed to cool and solidify inside the cylinder for at least 5 days before transport. Table 1.2-2 lists the physical properties of UF_6. Once the UF_6 solidifies in the cylinder, the cylinder pressure is below atmospheric pressure. Solid UF_6 has a density of approximately 317.8 lb/ft and occupies approximately 60% of the volume of the cylinder, because of the large density change between the solid and liquid phases. The UF_6 may not have more than 4.5 wt % U-235 isotopic enrichment and an H/U ratio of no more than 0.088. The remainder of the cylinder volume, approximately 40%, contains UF_6 vapor plus minor quantities of impurities such as HF, refrigerant gases, and air. The amount of UF_6 loaded into the cylinder is governed by weight. The weight control of UF_6 ensures that hydrostatic rupture of the cylinder will not occur even if the UF_6 is heated up to the rated temperature of the cylinder.

Figure 1.2-1 Transverse Section of the Paducah Tiger Overpack

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1.2-2 **Longitudinal Section of the Paducah Tiger Ovepack and 48X Cylinder**

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1.2-3 Aluminum Stiffening Plate

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1.2-4 Guide/Ball Lock Pin Closure on Paducah Tiger Overpack

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 1.2-5 Reinforced Corner with ISO Corner and Tie-down Bracket

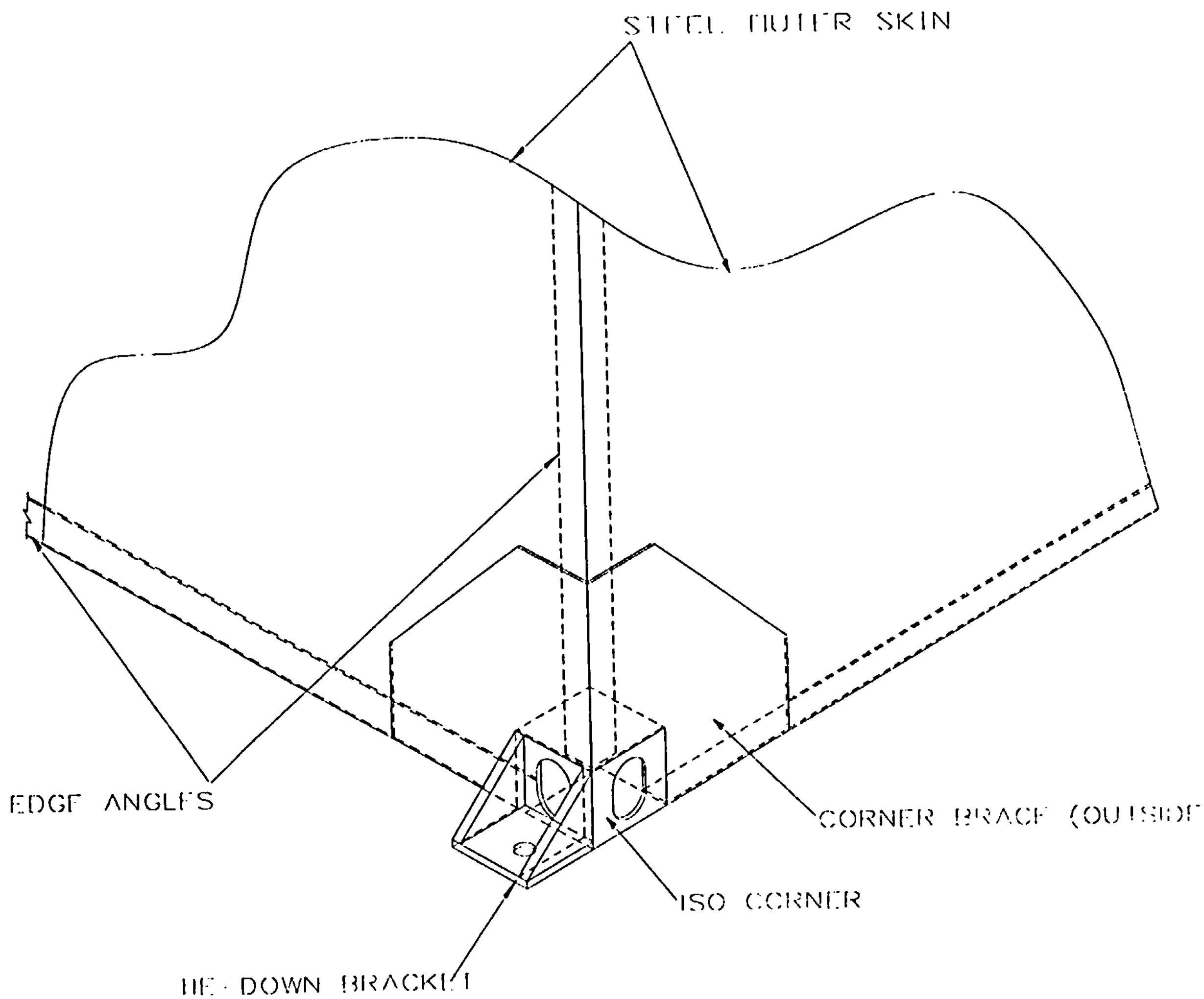


Figure 1.2-6 1- Inch UF_6 Cylinder Valve

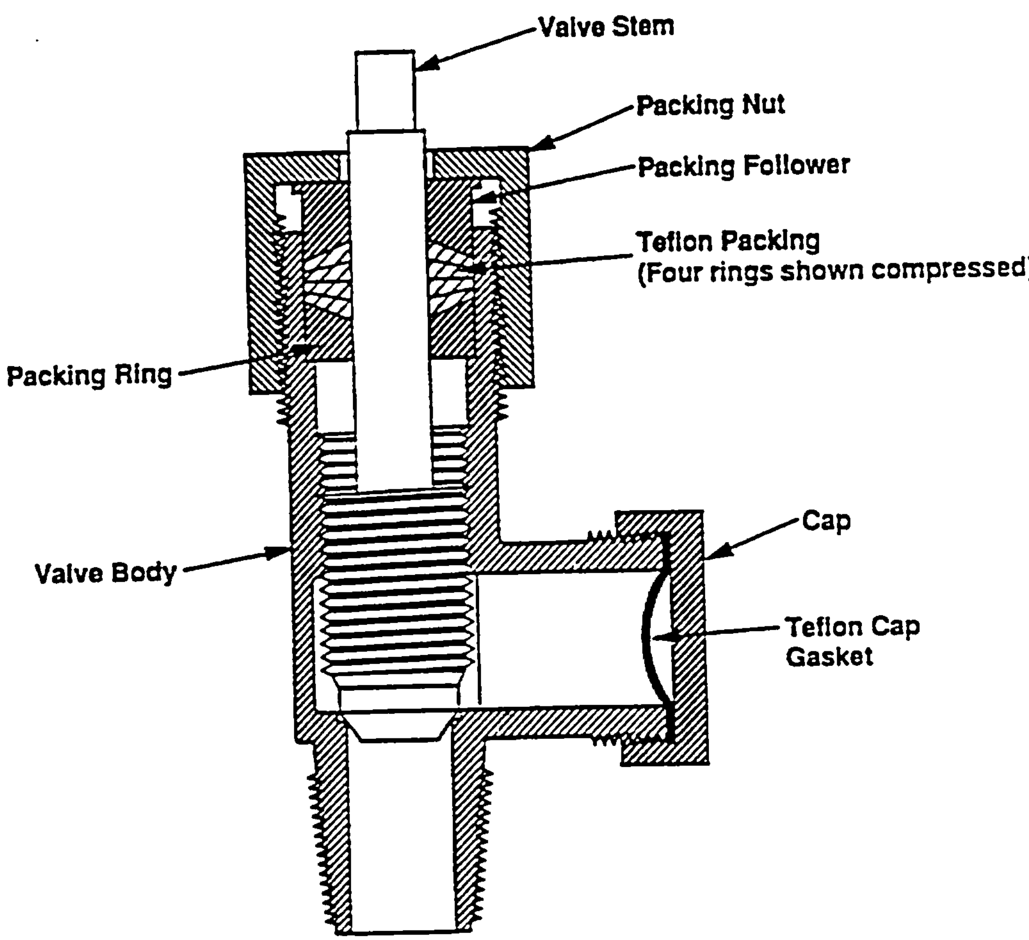


Table 1.2-1 Material Specification for the Paducah Tiger Overpack

Item	Material
Tubing Frame (Body and Lid)	Square steel tubing, ASTM A-500 Grade B
Inner Liner	3/16-inch ASTM A-36
Top Cover	12-gauge ASTM A-569
End Plate	1/2-inch ASTM A-36 (except at nonvalve end of overpack body which is 3/16-inch ASTM A-36)
Valve Protector Plate	3/8-inch, ASTM A-240 Type 304 Stainless Steel (valve end)
Stiffening Plate	2-inch Aluminum Plate – 6061-T6 or 6061-T651
Guide Pin	1-3/4-inch Cold Rolled Steel Bar - AISI 1018
Corner Brace Plate (Outside)	11-gauge ASTM A-569
Corner Brace Plate (Inside)	12-gauge ASTM A-569
Hold Down Bracket	3/4-inch and 3/16-inch Plates – ASTM A-36
Breakaway Plate	10-gauge, ASTM A-240 Type 304 Stainless Steel Sheet Annealed
Outer Skin (Sides and Bottom)	11-gauge ASTM A-569
Foam	LAST-A-FOAM
Angle Framing	1-1/2 x 1-1/2, and 1-1/2 x 2, Angle – AISI M-1020
Edge Brace Plate	12-gauge ASTM A-569 Steel
ISO Corner	Cast Steel ASTM A-27 -62 (Grade 70-40)
Rubber Shock Isolator	2-inch and 5-inch Ethylene-Propylene Diene Terpolymer (EPDM) - ASTM D-2000/SAE J200 3BA 720 A14, B13, C12, F19
Seal	Neoprene sponge rubber - Commercial Grade
Ratchet Turnbuckle	Assembly 85,000 pounds breaking strength
Ball Lock Pin	3/4-inch Ball Lock Pins (58 ksi tensile strength)

Table 1.2-2 48X Cylinder Material Specification

Component	Specifications
Cylinder Body	5/8-inch Steel Plate - ASTM A-516 Grade 55, 60, or 65 normalized
Semi-Ellipsoidal Heads (2 ea)	5/8-inch Steel Plate - ASTM A-516 Grade 55, 60, or 65 normalized
Stiffening Rings (3 ea)	7/8 x 2-1/2-inch Steel Bar - ASTM A-516 Grade 55, 60, or 65 normalized, or ASTM A-131, Grade E normalized
Skirt, Cylindrical	5/8-inch Steel Plate - ASTM A-516 Grade 55, 60, or 65 normalized
Skirt, Conical	5/8-inch Steel Plate - ASTM A-516 Grade 55, 60, or 65 normalized
Lifting Lugs (4 ea)	1-inch Steel Plate - ASTM A-516 Grade 55, 60, or 65 normalized
Half Couplings (2 ea)	1-inch NPS, Class 6000, Steel - ASTM A-105 - ANSI B16.11, Threads - ANSI B57.1
Hex Head Plug	1-1/2-inch Hex Bar, Aluminum Bronze CDA Alloy 613 - ASTM B-150, Threads - ANSI B2.1
Seal Loops (2 ea)	1/8 or 1/4 inch diameter Steel Bar, ASTM A-36
Valve	1-inch Angle Drum (Cylinder) Valve

Table 1.2-3 Physical Properties of UF_6

Property	Value
Sublimation point (14.7 psia) (76 cm Hg)	133.8°F (56.6°C)
Triple point	22 psia (114 cm Hg), 147.3°F (64.1°C)
Density, solid (68°F) (20°C)	317.8 lb/ft^3 (5.1 g/cc)
Liquid (147.3°F) (64.1°C)	227.7 lb/ft^3 (3.6 g/cc)
Liquid (200°F) (93°C)	215.6 lb/ft^3 (3.5 g/cc)
Liquid (235°F) (113°C)	207.1 lb/ft^3 (3.3 g/cc)
Liquid (250°F) (121°C)	203.3 lb/ft^3 (3.3 g/cc)
Heat of sublimation (147°F) (64°C)	58.2 Btu/lb
Heat of fusion (147°F) (64°C)	23.5 Btu/lb
Heat of vaporization (147°F) (64°C)	35.1 Btu/lb
Heat of solution in water (77°F) (64°C), Heat evolves	258.2 Btu/lb
Critical pressure	668.8 psia (3458 cm Hg)
Critical temperature	446.4°F (230.2°C)
Specific heat solid (81°F) (27°C)	0.114 Btu/lb
Specific heat liquid (162°F) (72°C)	0.130 Btu/lb

1.3 References

1. D. E. Edling, D. R. Hopkins, and R. L. Williams, *DOE Evaluation Document for DOT 7A Type A Packaging,* MLM-3245, DOEIDP/000S3-H1, U.S. Department of Energy, DOE Radioactive Materials Packaging Certification Office, March 1978.

2. American National Standards Institute, *American National Standard for Nuclear Materials, Uranium Hexafluoride - Packaging for Transport,* ANSI N14.1, New York, NY, 1990.

1.4 License Drawings

This section contains the License Drawings pertinent to the Paducah Tiger overpack. The license drawings are:

Drawing Number	Revision Number	Title
M-1209-NRC-1	0	Paducah Tiger Overpack
M-1209-NRC-2	0	Paducah Tiger Overpack
M-1209-NRC-3	A	Paducah Tiger Overpack
M-1209-NRC-4	1	Paducah Tiger Overpack Repair Details
M-1209-NRC-5	0	Paducah Tiger Overpack Repair Details

The dimensions indicated on the drawings are generally rounded off to the nearest whole number. Subsequent chapters may present dimensions that contain additional significant digits based on more detailed engineering drawings.

FIGURE WITHHELD UNDER 10 CFR 2.390

9811020198-01

REV. NO.	ISSUE / REVISION DESCRIPTION										
0	AS-BUILT FOR ESO 218740, INCORPORATED DCN 'S A1 & A2	X	X	X	X	X	X	X	X	X	X
C	CHANGED REFERENCING NOE FOR DETAIL "H"	8/98	DJW	RJW	CTJ	X	X	MS	WAW	PAB	X
B	REFERENCING OPTIONAL TYPICAL REPAIR MODIFICATION-CFC	8/98	DJW	RJW	CTJ	X	X	MS	JRB	PAB	X
A	REVISED NOTE 2 AND 4 FOR CLARIFICATION	8/98	RJR	JWO	RAG	X	X	MS	JRB	PAB	X

REVISION OR ISSUE APPROVALS

DRW, CHKR, RED, TR, APPD, TRANS, SA, SE — DRAWING APPROVALS — DATE

LOCKHEED MARTIN UTILITY SERVICES, INC.
P.O. BOX 1410 PADUCAH, KENTUCKY 42001
ACTING UNDER CONTRACT USEC-HQ-93-C-0001 WITH THE U.S. ENRICHMENT CORPORATION

PADUCAH TIGER OVERPACK

PRIORITY 3

SCALE	PLANT	BLDG	FL	SHEET OF	CLASS
X	PGDP	X	X	X	U

ID: M-1209-NRC-1 — REV 0

FIGURE WITHHELD UNDER 10 CFR 2.390

9811020198-02

REV	DATE	REV OR ISSUE DESCRIPTION/APPROVAL	DRN	CA	RED	DIV	DEPT	TRANS	SE	SA	PE	SECT
0	X	AS-BUILT PER ESO Z10740. INCORPORATED DCN A1	X	X	X	X	X	X	X	X	X	X
A	8/98	DRV. 13 TO 13 1/4" TO INCREASE CONSERVATISM DELETED LUG RECESS DIM. OF 3" MIN.	X	TW	X	JMB	RAG	MB	JRB	PAB	AIR	JWO

DIMENSIONAL TOLERANCE

DIMENSIONS MAY VARY ±1/16
WELD DIMS ARE NOM & NOT INCLUDED IN TOLERANCES.

APPROVALS/DATE	
DRN J.D. Page	10/98
CHKR [illegible]	10/98
RED [illegible]	[illegible]
TR [illegible]	10/98
APPD [illegible]	10/98
TRANS [illegible]	10/98
SA [illegible]	10/98
SE [illegible]	[illegible]

MARTIN MARIETTA ENERGY SYSTEMS, INC.

Oak Ridge, Tennessee - Paducah, Kentucky

PADUCAH TIGER OVERPACK

BLDG. NO.

PLANT PGDP

M-1209-NRC-2 REV.0

FIGURE WITHHELD UNDER 10 CFR 2.390

9811020198-03

DIMENSIONAL TOLERANCE

DIMENSIONS MAY VARY ±1/16
WELD DIMS ARE NOM & NOT
INCLUDED IN TOLERANCES.

A	5/98	REVISED [illegible] TO [illegible] TO INCREASE CONSERVATISM. ADDED	MS	RIR	JWD	MAQ	JMB	PAB
REV	DATE	REV OR ISSUE DESCRIPTION/APPROVAL	TRANS	PE	SECT	DEPT	DIV	SA

TRANS	M SAMPSON	10/1[illegible]
P E	R I REYNOLDS	10/1[illegible]
SECT	B O WARRINER	10/0[illegible]
DEPT	B O WARRINER	10/1[illegible]
DIV	R R VEAZEY	10/1[illegible]
SA	P A BURDICK	10/1[illegible]
SE	J R BAGWELL	10/1[illegible]
CA	T A WALKER	10/1[illegible]
APPROVALS/DATE		1995

JMB | TAW
SE | CA

[illegible] MARTIN MARIETTA ENERGY SYSTEMS, INC.
operated for the [illegible] under U.S. [illegible] contract [illegible]
Oak Ridge, Tennessee - Paducah, Kentucky

PADUCAH TIGER OVERPACK

BLDG. NO.
PLANT PGDP

M-1209-NRC-5 REV.A

FIGURE WITHHELD UNDER 10 CFR 2.390

9810-20198-04

DIMENSIONAL TOLERANCE
DIMENSIONS MAY VARY ±1/16 WELD DIMS ARE NOM & NOT INCLUDED IN TOLERANCES.

REV	DATE	REV OR ISSUE DESCRIPTION/APPROVAL	TRNG	PE	SECT	DEPT	DIV	MA	SE	QA
1		ADDED DETAIL "J"								
A	8/96	DELETED DRAWING REFERENCE ON DETAIL "F"	MG	DJW	RJW	CTJ	JHB	PAB	VAW	TAW
0	8/96	ORIGINAL ISSUE - CFC	MG	DJW	RJW	CTJ	JHB	PAB	JRB	TAW

APPROVALS		DATE
TRNG		
PE	D.J. WARRINER	8/96
SECT	R.J. WIMAKE	8/96
DEPT	C.T. JONES	8/96
DIV	J.H. BROWN	[illegible]
MA	P.A. BURDICK	8/96
SE	J.R. BADWELL	8/96
QA	T.A. WALKER	8/96

[illegible] MARTIN MARIETTA ENERGY SYSTEMS, INC.

[illegible]

Oak Ridge, Tennessee • Paducah, Kentucky

PADUCAH TIGER OVERPACK REPAIR DETAILS

BLDG. NO.

PLANT PGDP

M-1209-NRC-4 REV. 1

FIGURE WITHHELD UNDER 10 CFR 2.390

9811020198-05

REV. NO.	ISSUE / REVISION DESCRIPTION									
		X	X	X	X	X	X	X	X	X
0	AS BUILT PER ESO 298740	10/98	TOP	DJV	AMC	DJV	TLF	MS	WAW	HDA
A3	APPROVED FOR RELEASE: FOR NRC APPROVAL	4/98	TOP	JH	AE	TLF	RJW	X	X	X
A2	APPROVED FOR RELEASE: FOR NRC APPROVAL	X	X	X	X	X	X	X	X	X
A1	APPROVED FOR RELEASE: FOR NRC APPROVAL									

REVISION OR ISSUE APPROVALS

DRAWING APPROVALS	DATE
DRW	10/98
CHKR	10/98
RED	10/98
TR	10/98
APPD	10/98
TRANS	10/98
SE	11/98
SA	10/98

LOCKHEED MARTIN — LOCKHEED MARTIN UTILITY SERVICES, INC.
P.O. BOX 1410 PADUCAH, KENTUCKY 42001
ACTING UNDER CONTRACT USEC-90-13-C-0001, WITH THE U.S. ENRICHMENT CORPORATION

PADUCAH TIGER OVERPACK
REPAIR DETAILS
PRIORITY 3

SCALE	PLANT	BLDG	FL	SHEET	OF	CLASS
NONE	PGDP	-	-	-	-	U

ID	DRAWING NO.	REV
264280	M-1209-NRC-5	0

2.0 STRUCTURAL EVALUATION

This chapter provides a structural evaluation of the Paducah Tiger overpack with a 48X 10-ton UF_6 cylinder ("48X cylinder" or "cylinder") under normal conditions of transport and hypothetical accident conditions. The Paducah Tiger overpack is qualified by physical testing [1] and by analysis to ensure that it complies with the requirements of 10 CFR 71.73(c).

This evaluation summarizes the results of analyses and tests performed to demonstrate that the Paducah Tiger shipping package satisfies the requirements for a Type AF package as specified in 10 CFR 71.13.

2.1 Structural Design

The Paducah Tiger packaging shown in Figures 1.1-1 and 1.2-1 consists of an outer skin and an inner liner fabricated primarily from stainless steel filled with a polyurethane foam, and a separate, removable inner cylinder that contains the UF_6 and residual "heel" material. The overpack provides thermal insulation and drop and puncture impact protection for the cylinder. The cylinder provides the containment boundary for the UF_6 material, and is a DOT Specification 7A container. The overpack provides fixtures for lifting and handling the overpack. Separate fixtures are provided for lifting and handling the cylinder.

2.1.1 Discussion

The Paducah Tiger overpack is a rectangular-shaped box with a cylindrical internal cavity sized to hold one 48X cylinder. A detailed description of the overpack and its major components is provided in Section 1.2.

The overpack lid and body are joined at an interface plane below the geometric centerline of the 48X cylinder by a pair of unequal tube steel frames as shown in Figure 1.2-1. Each of these tube steel frames is connected to the outer skin by continuous welding. The tube steel frames are the main source of strength in the overpack and serve as a shear and tension joint between the overpack lid and body, as well as a direct load transfer path for attachment of the closure and lifting devices. The tube steel frames also serve as a connection point for the horizontal interior 12-gauge top cover plates attached to the lid and body as shown in Figure 1.2-2. A neoprene sponge rubber seal installed between the lid and body of the overpack minimizes the amount of dirt and water entering the assembled package.

2.1.2 Design Criteria

Load combinations and load factors for packaging used in the transport of radioactive materials are defined in Sections 71.43 through 71.51 of 10 CFR 71. The particular loads applicable to the Paducah Tiger overpack are described herein.

Design criteria call for compliance with applicable federal regulations as well as requirements of the Paducah Tiger overpack Certificate of Compliance. Operational requirements stipulated the need for easy loading and unloading of both the cylinder and the overpack as well as the need for a design that could be transported by either truck or rail. The prime function of the overpack is to protect the 48X cylinder by providing structural and thermal protection to the 48X cylinder to ensure that it can adequately withstand both the Normal Conditions of Transport (NCT) and the Hypothetical Accident Conditions (HAC) as described in 10 CFR 71.71 and 10 CFR 71.73, respectively.

The impact of the transportation environment on the overpack design has been successfully demonstrated in the field during more than 25 years of service. All of the Paducah Tiger overpacks in service have performed satisfactorily.

The 48X cylinders are DOT Specification 7A containers (49 CFR 178.350 [2]). Cylinders are fabricated using A-516 steel subject to the requirements of ANSI N14.1 [3], with the exception of tinning materials used on the valve and plug threads.

Material specifications are presented in Table 1.2-1 for the Paducah Tiger overpack and in Table 1.2-2 for the 48X cylinder. Allowable stresses for these materials are from the ASME Boiler and Pressure Vessel Code where applicable. NRC Regulatory Guide 7.6 outlines a procedure for identifying and combining loads, classifying stresses, and comparing the stress results with the acceptance criteria. These criteria were used for normal and accident loadings to determine the acceptable stress intensities. The effects of brittle fracture, fatigue, and vibration on the 48X cylinder (i.e., the containment boundary) are addressed in the following sections. Material properties for the polyurethane foam and the various steels used in the overpack are described in Section 2.3.

The qualification of the Paducah Tiger overpack is demonstrated by analysis together with actual testing of a prototype model. Stress limits were obtained from the ASM International Metals Handbook [4] and were followed wherever appropriate and possible for all load cases except free drops, the penetration test, and the fire test, which use stress limits developed in the evaluations as described in Sections 2.6 and 2.7. The maximum calculated stress intensity, which combines general shear and general bending stress from sustained loads, is limited to the specified minimum yield stress of the material.

2.2 Weights and Centers of Gravity

The center of gravity was determined to be approximately 5 inches below the geometric centerline of the shipping package when the 48X cylinder is filled to the maximum weight. The total weight of the package cannot exceed 40,000 pounds. Individual component weights and location of the center of gravity are shown in Table 2.2-1.

Table 2.2-1 Weights and Centers of Gravity

Item	Weight (pounds)	Center of Gravity relative to base plane (inches)
Overpack	14,470	36
48X Cylinder	4,500	36
Contents (61% solid)	21,030	27
Total Package	40,000	31[a]

a) Equivalent to approximately 5 inches below the geometric centerline of the shipping package.

2.3 Mechanical Properties of Materials

The static properties for the metallic components of the package are listed in Table 2.3-1. Mechanical and dynamic properties for the polyurethane foam are listed in Tables 2.3-2 and 2.3-3. All foam types were tested and qualified before use in the overpack. The computer models generated for the structural evaluation used generic foam properties based on manufacturer's test data. The key mechanical property of EPDM rubber shock isolators is a durometer hardness of 70 ± 5 durometer.

For hypothetical accident events such as free drop, puncture, and thermal tests, 10 CFR 71.73(b) stipulates that the ambient air temperature during the conduct of the tests must remain constant at values between -20°F (-29°C) and 100°F (38°C) which are most unfavorable for the feature under consideration. In recent years, concerns have been raised by the scientific community regarding the potential for brittle fracture of packages made of low-carbon steel under impact loading (i.e., impact and puncture testing) at low temperatures (i.e., -20°F).

No specific requirements pertaining to brittle fracture evaluation of package materials are provided in 10 CFR 71. NUREG/CR-1815 [5] offers some guidance for evaluating ferritic steel for brittle fracture. Three categories are specified for fracture protection for a package, based upon the radiological severity of the contents. The UF_6 contents of the 48X cylinder are classified as Category III (based upon activity), the category requiring the lowest margin of safety.

To address concerns pertaining to brittle fracture, all 48X cylinders in use have been fabricated from ASTM A-516 normalized steel. The ASTM A-516 normalized steel cylinders meet the requirements of ANSI N14.1 and the criteria specified in NUREG/CR-1815 for brittle fracture. 48X cylinders fabricated of ASTM A-285 steel are not used.

The ASTM A-516 normalized steel exhibits favorable low temperature ductility characteristics. The transition for this steel occurs over the range of -30 to -50°F [6]. This transition is defined in terms of the material exhibiting less of a ductile fibrous-fracture characteristic (i.e., fibrous-fracture percentage less than 50% at -50°F) and more of a brittle fracture characteristic when subjected to a Charpy impact test.

Table 2.3-1 Mechanical Properties of Metals at 70°F

Mechanical Property	304 SS Steel	A-36 Steel	1018 Steel	A-516 Steel	A-569 Steel	6061-T6 or T651 Aluminum
Yield Stress (ksi)	30	36	54[a]	30	N/A	32
Ultimate Tensile Strength, S_u (ksi)	75	58	64[a]	55	N/A	38
Design Stress Intensity, S_m (ksi)	16.7[b]	19.3[c]	21.3[c]	18.3[c]	18.3[c]	14[e]
Young's Modulus of Elasticity (psi)	28×10^6	30×10^6	30×10^6 [d]	29.5×10^6	29.5×10^6	9.9×10^6
Poisson's Ratio	0.3	0.3	0.3[d]	0.3	0.3	0.33
Density (lb/in³)	0.29	0.283	0.283[d]	0.293	0.279	0.098
Coefficient of Thermal Expansion (in/in/°F)	9.6×10^{-6}	8.4×10^{-6}	8.4×10^{-6} [d]	6.4×10^{-6}	8.4×10^{-6}	12.6×10^{-6}

(a) Values taken from the ASM International Metals Handbook, Vol. 1, *Properties and Selection of Metals*, 8th Edition [4].
(b) Values taken from Table I-1.2 of the Appendices to Section III, Division 1 of the ASME Boiler & Pressure Vessel Code [7].
(c) Values determined by the method outlined in Appendix III, Article III-2110 of Section III, Division 1 of the ASME Boiler & Pressure Vessel Code.
(d) Values determined by conservative comparison with similar materials.
(e) Values taken from the Appendices to Section III, Division 1 of the ASME Boiler & Pressure Vessel Code [7].

Table 2.3-2 Mechanical Properties of LAST-A-FOAM Relative to Density

Mechanical Property	Low-density Foam[b]	High-density Foam[b]
Density Range	5.4 - 8.8 lb/ft^3	16.2 - 20.16 lb/ft^3
Nominal Density[a]	6 - 8 lb/ft^3	18 lb/ft^3
Physical Property Test Data[c]		
Compressive Strength at 75°F	120 – 180 psi	700 – 1200 psi
Compressive Modulus at 75°	3,716 - 7,888 psi	20,205 - 30,299 psi
Tensile Strength at 75°F	110 psi	650 psi
Tensile Modulus at 75°F	6,767 - 12,050 psi	24,786 - 32,095 psi
Shear Strength at 75°F	55 psi	250 psi
Shear Modulus at 75°F	1,461 - 2,923 psi	7,113 - 10,672 psi
Flexural Strength at 75°F	138 - 310 psi	858 - 1,235 psi
Flexural Modulus at 75°	3,192 - 7,719 psi	23,272 - 32,718 psi
Coefficient of Thermal Expansion	(3.5 - 5.0x10^{-5} in./in./ °F over temperature range of -310°F to +200°F)	

a) For the 74 total packages in service, 29 have low-density foam with a nominal value of 6 lb/ ft^3, and 45 have a value of 8 lb/ft^3.
b) Properties shown are nominal ultimate values in the strongest direction only.
c) Data obtained from the manufacturer, General Plastics Manufacturing Company of Tacoma, Washington.

Table 2.3-3 Dynamic Properties of LAST-A-FOAM

Dynamic Property	Low-density Foam	High-density Foam
Maximum Dynamic Compressive Strength[a]	400 psi at 70% compression	1,855 psi at 65% compression
Impact Energy[a]	14.3 ft-lb/in^3	72.8 ft-lb/in^3
Absorbed Energy[a]	13.4 ft-lb/in^3	69.1 ft-lb/in^3

a) Data obtained from the manufacturer, General Plastics Manufacturing Company of Tacoma, Washington.

2.4 General Standards for All Packages

The general standards for all packages include an evaluation of the following: (1) minimum package size; (2) tamper-proof features; (3) the method used for positive closure; and (4) the chemical and galvanic reactions between the material of construction and the intended package contents. The Paducah Tiger shipping package meets the general standards for all packages in accordance with 10 CFR 71.43 as detailed below.

2.4.1 Minimum Package Size

The smallest dimension of the container as specified in 10 CFR 71.43(a) must be greater than 4 inches (10 cm). The smallest dimension of the Paducah Tiger overpack is 72 inches; therefore, this requirement is met.

2.4.2 Tamper-proof Feature

Tamper-indicating devices (TIDs) are required as evidence that the package has not been opened by unauthorized personnel. A matching pair of welded rings is provided on the lid and body of the overpack for attachment of TIDs. The TIDs are numbered seals. These numbers are verified on receipt. The presence of these seals demonstrate that unauthorized entry into the package has not occurred.

2.4.3 Positive Closure

A closure system that cannot be opened unintentionally is required. The containment vessel (48X cylinder) is completely enclosed by the overpack. The overpack is equipped with a positive closure system that includes four ratchet turnbuckles and eight guide/ball lock pins connecting and restraining the opening of the overpack lid and body.

2.4.4 Chemical and Galvanic Reactions

The materials used to construct the Paducah Tiger overpack will not cause chemical, galvanic, or other reactions in the overpack or between the overpack and its contents. The shipping package is inspected at the time the 48X cylinder is loaded into the overpack to verify that the package does not contain any standing water. Section 8.2 describes the maintenance program that is utilized to ensure that the overpacks and cylinders are monitored for corrosion and that repairs are made when necessary. The 48X cylinder is maintained in accordance with ANSI N14.1.

2.5 Lifting and Tie-down Standards for All Packages

2.5.1 Lifting Devices

The Paducah Tiger overpack can only be lifted when it is empty. The intended manner of lifting is by the four inclined lifting attachments provided at the package balance points. To prevent lifting of the package by the top ISO corners, steel plates have been welded over all four upper corners.

When the four inclined lifting attachments are used, the lifting load is transferred to the top section by a redundant system consisting of four ratchet turnbuckle assemblies attached to the outer skin and eight guide pin locking devices using 3/4-inch diameter ball locking pins in shear. The load is then distributed to four lifting attachments welded at the sides on a 10° incline from vertical.

A safety factor of at least 3 against yielding when lifting the package in the intended manner is required by 10 CFR 71.45(a). This safety factor was assured in the analysis by multiplying the actual package load by a factor of 3. The effects of these lifting forces on the major packaging components are documented in Table 2.5-1, where,

Calculated Stress	=	stress resulting from an applied load equal to the package weight times a factor of 3
Factor of Safety	=	allowable stress/calculated stress
Design Margin	=	Factor of Safety - 1

2.5.2 Tie-down Devices

The tie-down system on the overpack consists of a heavy steel bolting bracket welded to the ISO corners at the base of the overpack body, perpendicular to the longitudinal sides of the overpack as shown in Figures 1.2-1 and 1.2-4. The bracket consists of a 1-inch thick base plate with a 2-1/2-inch diameter hole, braced with two 3/4-inch side gussets. The bracket assembly is welded to the ISO corners with full penetration welds at the base plate and partial penetration welds on the side gussets.

The tie-down load path passes from the bolts to the four brackets through the ISO corners. The load is then distributed through triangular corner reinforcement plates welded to six edges of the ISO corners. From the reinforcement plates, the load is distributed throughout the body's outer skin to the 4-inch by 4-inch and 3-1/2-inch by 3-1/2-inch tubular steel frames. The top cover plates and ratchet turnbuckle/ball lock pin devices transfer shear and tension loads between the lid and body of the overpack.

The requirements of 10 CFR 71.45(b) specify that a static force must be applied to determine stresses in the tie-down devices that are a structural part of the package. The static force applied at the center of gravity of the package consists of a vertical component equal to two times the package weight with its contents, a horizontal component applied in the direction of travel equal to ten times the package weight with its contents, and a horizontal component applied in the transverse direction equal to five times the package weight with its contents. The effects of these loads on the tie-down devices such as the tie-down bracket, bracket-to-ISO corner weld, and ISO corner-to-package weld are summarized in Table 2.5-2. As identified in Table 2.5-2, the bracket is the weakest link in the tie-down system. Failure of this particular component, however, will not impair the integrity of the package to meet other requirements as stipulated in 10 CFR 71.45(b)(3). The Paducah Tiger overpack is capable of withstanding HAC events described in Section 2.7. Therefore, it is concluded that the tie-down system utilized for the Paducah Tiger overpack is structurally adequate to safely accommodate the specified loads.

The requirements of 10 CFR 71.45(b)(2) specify that any other structural part of the shipping package which could be used to tie down the package must be rendered inoperable for tying down the package during transport. For the Paducah Tiger, the lifting brackets on the overpack could possibly be used for tie-down purposes. Therefore, to prevent this misuse of the lifting brackets, decals are attached to the side of the overpack, at the location of each lifting bracket, clearly specifying that these brackets are to be used for lifting only and not for tie down of the package.

Table 2.5-1 Response of Lifting Devices to Requirements of 10 CFR 71.45(a)

Item	Calculated Stress[a] (psi)	Allowable Stress (psi)	Design Margin
Skin/foam beam stress	8,393	36,000	3.29
Lid bending stress	25,894	36,000	0.39
Shear at ball locking pins	13,093	14,500	0.11
Weld stress through ratchet turn buckles alone	10,937	11,200	0.02
Combined tee/ratchet assembly			1.13
Weld lift skin to tube	7,778	11,200	0.44
Lid skin stress	5,737	21,600	2.76
Lifting base/skin weld	5,283	11,200	1.12
Lifting bracket stress			
• Bending	29,420	36,000	0.22
• Shear through lug	9,139	14,500	0.59
• Bracket welds	10,098	11,200	0.11

a) Calculated stress values were based on a package weight of 36,000 pounds.

Table 2.5-2 Response of Tie-down Devices to Requirements of 10 CFR 71.45(b)

Item	Margin to Yield
Bracket: Combined bending, tension, and shear stress	2.6 %
Bracket/ISO Corner Weld: Combined bending, tension, and shear stress	5.9 %
ISO Corner/Package Weld: Combined bending, tension, and shear stress	49 %

2.6 Normal Conditions of Transport

The regulations for normal conditions of transport (NCT) for a single package require that the effectiveness of the package not be substantially reduced under normal transport conditions. Additionally, the overpack and 48X cylinder must be so designed that the contents will not be vented to the atmosphere under NCT. These normal conditions include the effects of heat, cold, pressure, vibration, free drop, penetration, water spray, and compression. As described in the following pages, current packages meet the NCT specified in 10 CFR 71.71.

2.6.1 Heat

The thermal evaluation for the Paducah Tiger overpack and the 48X cylinder is described in Chapter 3. This section presents the thermal response of the package, when exposed to NCT, as it pertains to maintaining structural integrity.

2.6.1.1 Summary of Pressures and Temperatures

During NCT, the maximum temperature of the 48X cylinder outer wall is approximately 135.4°F at the top mid-plane of the cylinder as described in Section 3.4.2. Temperature gradients across the cylinder wall are less than 1°F.

After the 48X cylinder is filled with liquid UF_6 and allowed to cool and solidify, the internal cylinder pressure ranges from 3 to 7 psia. Since the UF_6 does not experience a large temperature increase during normal transport, the UF_6 will remain in solid and vapor form (UF_6 melts at 147°F) at approximately 15 psia. Therefore, the pressure and temperature increases within the cylinder will not result in liquifaction of the cylinder contents.

2.6.1.2 Differential Thermal Expansion

The effects of differential thermal expansion during NCT are minimal. Thermal stresses resulting from non-uniform expansion of the 48X cylinder during heating are negligible, since there is a very small temperature gradient (approximately 1°F) across the cylinder wall and relatively uniform heating of the cylinder surface. The outward expansion of the cylinder will not generate stresses against the overpack, due to corresponding outward expansion of the overpack cavity. The linear coefficient of thermal expansion (CTE) of the steel that comprises the 48X cylinder and the overpack outer skin is 6.4×10^{-6} in/in/°F and 8.4×10^{-6} in/in/°F, respectively as shown in Table 2.3-1. The CTE of the foam insulation within the overpack steel shells is within the range of 3.5×10^{-5} to 5.0×10^{-5} in/in/ °F as shown in Table 2.3-2. Due to the somewhat larger coefficient of thermal expansion for the foam, stresses occur as the foam expands radially outward against the inner and outer overpack steel shells. However, these stresses are negligible, since the coefficients of thermal expansion are very small and the temperature rise in the package components during normal transport is not significant.

2.6.1.3 Stress Calculations

No significant stresses resulting from combined thermal gradients or pressure loads experienced during normal transport are expected to compromise the structural integrity of the Paducah Tiger overpack or the 48X cylinder. As discussed in Section 2.6.1.1, the temperature gradient across the 48X cylinder wall is less than 1 °F. Therefore, thermal stresses across the cylinder wall will not adversely impact the integrity of the structure. Since the maximum internal pressure is approximately 15 psia during NCT, any pressure-induced stresses are not expected to compromise the integrity of the cylinder.

The 48X cylinders are subject to fatigue. The effects of fatigue were considered and analyzed in accordance with NRC Regulatory Guide 7.6 [8]. The fatigue calculations were based on thermal cycling during filling and emptying, and pressure-induced stresses during hydrostatic testing. All of the repeated load situations that could occur in the cylinder were considered and were found to be significantly below the fatigue limit.

NRC Regulatory Guide 7.6 requires that fatigue calculations be performed according to Section III of the ASME Boiler and Pressure Vessel Code. Design fatigue curves found in Appendix 1 of the Code are used to determine the fatigue life of the cylinder based on the load. Cumulative damage resulting from the combination of more than one load cycle is considered in Article NB-3222.4 of Section III of the Code.

Results of the calculations predicted a life of 7500 cycles based on the hydrostatic load case. The cylinder can maintain a life of 47,000 cycles, considering only the normal filling and emptying load case. Considering a combination of these two load cases, the Code predicts a useful life of approximately 10,000 years for the 48X cylinders.

2.6.1.4 Comparison with Allowable Stresses

The maximum 135°F temperature and 15 psia internal pressure in the 48X cylinder are not great enough to compromise the integrity of the cylinder. Therefore, stresses generated in the cylinder are deemed negligible.

2.6.2 Cold

The Paducah Tiger package must be able to withstand an ambient temperature of -40°F (-40°C) in still air and shade in accordance with 10 CFR 71.71(c)(2). Type 304 stainless steel has no intrinsic reduction of capacity due to a drop in temperature to -40°F in a static state. The foam manufacturer, General Plastics, indicated that there is a 38% increase in compressive strength of FR-3700 foam for a temperature drop from an ambient temperature of 75°F (24°C) to -20°F (-29°C). Other foams are expected to behave similarly. Therefore, the above considerations indicate that cold temperatures will not reduce the effectiveness of the overpack to perform its intended function during NCT.

2.6.3 Reduced External Pressure

The regulations for NCT specify that the package must be able to withstand an atmospheric pressure of 3.5 psia. The 48X cylinder is specified as a pressure vessel capable of withstanding 200 psig internal service pressure. The vapor pressure of liquid UF_6 is above atmospheric during cylinder filling. However, subsequent cooling solidifies the UF_6, yielding a subatmospheric pressure. All cylinders are cooled for at least 5 days before shipping. Reduced external pressure on the cylinder will be a very small fraction of its design pressure (200 psig) or hydrostatic test capability (i.e., 400 psig).

2.6.4 Increased External Pressure

The requirements of 10 CFR 71.71(c)(4) specifies that the design of the package be adequate to ensure that it will suffer no loss of contents if subjected to an external pressure of 20 psia. The 48X cylinder has been tested to the guidelines of ANSI N14.1, which tests the package to an external pressure of 25 psig. Since the overpack does not function as a pressure boundary, only the effect on the 48X cylinder was considered.

2.6.5 Vibration

The rubber shock isolators mitigate the dynamic loads produced during rail transport of the Paducah Tiger overpack and 48X cylinder. Since the cylinder surface is in direct contact with the radial rubber shock isolators on both the overpack lid and the body, the rubber shock isolators prevent damage to the 48X cylinder as a result of vibration loads during transport.

2.6.6 Water Spray

Under NCT, as described in 10 CFR 71.71(c)(6), the overpack must resist normal rainfall of 2 inches per hour for one hour. The materials and method of construction of the shipping package prevent a water spray (rain) from having any significant effect on the structural integrity of the package. The Paducah Tiger overpack shell is seal welded along seams and joints to prevent water intrusion to the foam filled cavity. The mating surfaces of the overpack lid and body are joined at a closure joint using a soft neoprene sponge rubber gasket to act as a weather seal to keep water out of the overpack cavity containing the 48X cylinder. The seams and joints of the 48X cylinder are seal welded and threaded valves are utilized to provide a gas leak-tight interface. As a result, the Paducah Tiger overpack and 48X cylinder conform to the requirements of water spray conditions for normal transport.

As described in Section 2.7, pertaining to the analysis of the water immersion requirement of 10 CFR 71.73(c)(5) & (6), water immersion does not adversely impact the Paducah Tiger overpack or 48X cylinder. Therefore, it is demonstrated by comparison that for the water spray condition of normal transport, which is less severe than the hypothetical accident water immersion condition, there would be no adverse impact on the overpack and 48X cylinder.

2.6.7 Free Drop

The regulations for NCT specify that the Paducah Tiger overpack containing a 48X cylinder shall be able to withstand, without significant detrimental effects to the package integrity, a free drop from a height of 1 foot onto a flat, essentially unyielding, horizontal surface. The orientation of the package at the time of impact shall be the one that is considered to yield the maximum damage. The test is to be performed between 1-1/2 and 2-1/2 hours after the water spray test.

As described in Section 2.7.1, the 30-foot hypothetical accident drops, which are performed in the orientation for which maximum damage is expected to occur, do not result in damage to the cylinder which would permit the release of radioactive materials. Therefore, it is demonstrated by comparison that for the 1-foot free drop, which is less severe than the hypothetical accident drops, there would also be no loss or dispersal of radioactive contents.

The damage inflicted upon the overpack due to the 30-foot drops was localized and would not prevent the Paducah Tiger overpack or 48X cylinder from performing their intended function. The pressure boundary of the cylinder will remain intact. Clearance will also be maintained between the cylinder valve and the overpack inner end plate and 2-inch aluminum stiffening plate throughout the impact. The 1-foot free drop is much less severe than the 30-foot drops. Evaluating the damage from the 30-foot free drops, reported in Section 2.7, indicates that the normal condition drop test would not substantially reduce the effectiveness of the packaging. Since only the 48X cylinder is required to meet the shielding requirements, there would be no significant increase in external surface radiation levels.

2.6.8 Corner Drop

The corner drop test is not applicable to this package, because it is not a fiberboard or wood rectangular package which is less than 110 pounds as specified in 10 CFR 71.71(c)(8).

2.6.9 Compression

A compressive load test is not applicable for this shipping package, because it weighs more than 11,000 pounds as specified in 10 CFR 71.71(c)(9).

2.6.10 Penetration

Regulations in 10 CFR 71.71(c)(10) for NCT require that the overpack be capable of withstanding the impact from the hemispherical end of a vertical steel cylinder that weighs 13 pounds, has a 1-1/4-inch diameter, and is dropped from a height of 40 inches onto the part of the overpack most vulnerable to puncture.

From this information, the maximum energy imparted to the overpack was calculated to be 520 in.-lb. To determine how effective an impact absorber the foam is, an analysis was performed considering the 13-pound steel cylinder impacting the foam without the protection of the steel shell. Assuming a conservative 90 psi crush strength for the foam, the resultant amount of crush was determined to be only 4.71 inches using the following formula:

Distance crushed = (drop height)(drop weight)/(area)(foam crush strength)
= (40 inches)(13 pounds)/(1.227 in.^{2})(90 psi)
= 4.71 inches

Based on the above results, it was concluded that the crush distance was not great enough to cause any damage to the cylinder or other components (e.g., the valve) of the containment boundary.

2.7 Hypothetical Accident Conditions

The federal regulations in 10 CFR 71.73 impose accident conditions that a package must withstand without detrimental effects to the integrity of the package. The hypothetical accident condition (HAC) events are performed sequentially on the package so that damage from each test is cumulative. The package must maintain adequate shielding, criticality control, and ensure containment of the radioactive material. It is concluded that the hypothetical accident tests and analyses performed on the Paducah Tiger overpack demonstrate that the overpack provides adequate structural protection for the 48X cylinder when exposed to the hypothetical accident events specified in 10 CFR 71.73(c), thus ensuring that the structural integrity of the 48X cylinder is not compromised.

Testing of a prototype Paducah Tiger package was performed and documented in 1971 to demonstrate compliance with these federal regulations [1]. The test provided empirical data useful in demonstrating compliance with current regulations. The design of the prototype subjected to physical testing was different from the current configuration. The prototype design did not include: the valve protector plate; aluminum stiffening plate; or breakaway plates incorporated into the current design. In addition, and as discussed below, the foam configuration was different from the current design. To supplement the test data, a half model and a full model of the 48X cylinder encased in a Paducah Tiger overpack were generated and analyzed using the LS-DYNA nonlinear dynamic analysis computer code [9].

For analysis of the end drop and edge drop cases, a 3-D finite element model representing one-half of the overpack and 48X cylinder was sufficient, because of the symmetry of the overall package and the drop orientation. In the half model, the valve end of the 48X cylinder and the corresponding half of the overpack (lid and body) were modeled. For the corner drop case, a full 3-D finite element model was developed in order to accurately compute the behavior of the overpack and 48X cylinder during the drop and puncture events. A finite element model was not generated and analyzed for the side drop case, because it was determined from evaluating previous test results that a drop on the valve end of the overpack is the most vulnerable location.

Analytically, three different orientations of the package have been rigorously analyzed for the 30-foot free drop (Section 2.7.1) to assess the effects of the postulated hypothetical accident (i.e., end drop, corner drop, and oblique drop). The package was then evaluated for a pin puncture drop of 40 inches, in a position for which maximum damage is expected, onto the upper end of a solid, vertical, cylindrical mild steel bar mounted on an essentially unyielding horizontal surface (Section 2.7.2). Section 2.7.3 describes the thermal test and Section 2.7.4 describes the immersion analysis which were performed sequentially in accordance with 10 CFR 71.73.

In summarizing the analyses performed, three drop orientations (Cases A, B, and C as shown in Figures 2.7-1 through 2.7-3, respectively) were evaluated, because they bound the sequential 30-foot free drop and pin puncture drop events. The matrix below highlights the drop orientations.

Hypothetical Accident Event	0° End Drop (Half Model)	28° Corner Drop (Full Model)	26.7° Top Edge Drop (Half Model)
30-foot Free Drop	Case A-1	Case B-1	Case C-1
40-inch Pin Puncture Drop	Case A-2 (Pin under Center)	Case B-2 (Pin under Skirt)	Case C-2 (Pin under Valve)
	Case A-3 (Pin under Valve)		Case C-3 (Pin under Skirt)

2.7.1 Free Drop

First in the sequence of HAC events to which the package must be subjected is a free drop through a distance of 30 feet onto a flat, essentially unyielding horizontal surface, striking that surface in a position for which the maximum damage is expected to occur. The end, side, corner, and oblique (edge) drop orientations were considered in order determine which would produce the greatest amount of damage to the overpack in accordance with the requirements of 10 CFR 71.73 for hypothetical accidents.

2.7.1.1 End Drop

A computer analysis of the package has been performed to evaluate the damage from a 30-foot end drop. This drop orientation is shown in Figure 2.7-1 (Case A-1). During the impact, as the inertial loads from the cylinder were absorbed, the valve protector plate and end plate remained flat due to the rigid plane and the 2-inch thick aluminum stiffening plate. The 48X cylinder shell remained elastic during the impact. A positive clearance was observed between the 48X cylinder valve, the overpack's 1/2-inch carbon steel end plate, and the 2-inch aluminum stiffening plate throughout the impact.

During performance of the 30-foot end drop analysis, the overpack and the 48X cylinder decelerated rapidly. The maximum decelerations of the cylinder for the end drop were computed for all three translational directions (i.e., axial, radial, and lateral) and are summarized in Table 2.7-1. The combined maximum acceleration, computed by taking the vector sum of acceleration components computed from the analyses, is 95.1 g. This value is substantially less that the allowable stress on the weld connecting the cylinder skirt to the cylinder shell (i.e., allowable stress equivalent to 200 g). The results of the 30-foot end drop analysis indicate that the skirt-to-cylinder shell weld is capable of withstanding the drop without failure and that the cylinder will not lose containment integrity.

2.7.1.2 Side Drop

As specified in Section 2.7, a finite element model was not generated and analyzed for the side drop case, because it was determined from evaluating previous test results [10] that a drop on the valve end of the overpack represents the bounding sequential drop and puncture event.

2.7.1.3 Corner Drop

Using the nonlinear dynamic analysis computer code, LS-DYNA [9], a full model of the 48X cylinder encased in a Paducah Tiger overpack was created and analyzed for a CG over corner drop as shown in Figure 2.7-2 (Case B-1). The cylinder valve is located nearer to an edge of the overpack than to a corner; therefore, the valve is not in the local corner impact region. The crush plane determined by the corner drop analysis was a substantial distance from the outer extremes of the cylinder skirt, which provided sufficient clearance to prevent damage to the 48X cylinder.

During performance of the 30-foot corner drop analysis, the overpack and the 48X cylinder decelerated rapidly. The maximum decelerations of the cylinder for the corner drop were computed for all three translational directions (i.e., axial, radial, and lateral) and are summarized in Table 2.7-1. The combined maximum acceleration, computed by taking the vector sum of acceleration components computed from the analyses, is 63.6 g. This value is substantially less that the allowable stress on the weld connecting the cylinder skirt to the cylinder shell (i.e., allowable stress equivalent to 200 g). The results of the 30-foot corner drop analysis indicate that the skirt-to-cylinder shell weld is capable of withstanding the drop without failure and that the cylinder will not lose containment integrity.

2.7.1.4 Oblique/Top Edge Drops

As part of the testing [1] performed in the early 1970s, a prototype Paducah Tiger overpack was dropped two times from a height of 30 feet onto its edge. The purpose of the first 30-foot edge drop test was to evaluate the amount of protection the prototype overpack provided to the valve. The second drop was conducted in the same manner as the first test; however, the package was dropped on the opposite edge in order to determine the crush resistance of the overpack in an area filled with low-density foam. The prototype package had approximately 13 inches of high-density foam on the valve end of the overpack and 10 inches of low-density foam on the opposite end. The most critical loading was determined to result from an impact on the lid along the edge near the valve, because a small leak developed in the valve body threads. As a result of that test, design modifications were implemented to assure valve integrity as discussed below.

In the first 30-foot drop, the package was raised 30 feet and released at about a 20° angle from vertical so that the impact would occur on the lid along the edge. Upon impact, the outer steel shell of the package compressed locally, along the edge, coming to rest in the vertical position. Measurements indicated that the ISO corners were displaced 3-1/2 inches and 4-1/2 inches. Neither ISO corner showed signs of fracture. Each of the ratchet turnbuckles and locking pins remained securely fastened, with no evidence of overstress or fracture. General damage to the package's outer surface was minimal, with shell distortions and buckling being limited to the immediate area of the corner double plates. No holes or tears exposing the foam were observed.

A second edge drop test was conducted in the same manner as the first drop test, but on the opposite edge of the other end of the overpack. Upon impact, two ratchet turnbuckles became detached from the lid due to local distortion at the edge of the overpack body. However, the locking pins remained in place, and the lid remained securely locked to the body of the overpack.

As a result of the oblique drops, the overpack end plates were distorted to conform to the shape of the cylinder skirt. The presence of foam and rubber shock isolators limited the internal damage to some minor buckling of the cylinder wall and stiffening rings. As a consequence of damage to the ratchet turnbuckles, the design was modified to move the ratchet turnbuckle assemblies away from the end of the overpack to a position that will not be damaged in an edge drop. The center ratchet turnbuckle assembly was removed from the production models, because it was considered redundant.

Based on actual test results [1], it was concluded that by changing to low-density foam and increasing the foam depth, the valve integrity would be assured. It was reasoned that replacing the high-density foam with low-density foam and increasing the foam depth on the valve end would reduce the deceleration forces on the cylinder. This rationale was accepted by the regulators, and further edge drop testing and analysis were not considered necessary to verify the design modifications that were implemented.

Estimates of the shear load in the guide pins were made based on accelerations of the components of the overpack and cylinder models. However, the shear loads in the guide pins obtained by these methods exceeded the allowable shear capacity of the guide pins. It is felt that several factors that were conservatively ignored in these analyses should have been considered in the determination of the guide pin adequacy. First, no consideration was given for the clamping forces exerted by the four turnbuckles that clamp the overpack lid and body together. After actual drop tests on the top and bottom edges of the overpack, the overpack stayed together with no visible damage observed to the guide pins and surrounding area. Additionally, the holes into which the guide pins mate are oversized. Therefore, no load could be transferred into the guide pins unless lateral movement occurred between the top and bottom portions of the overpack. This type of movement is precluded because of the step design of the mating surfaces. Even if the mating surfaces could move laterally with respect to each other, the frictional component of the clamping forces produced by the turnbuckles would have to be overcome before any movement could occur.

Finally, hand calculations were performed and a simple finite element model was used to investigate the relative strengths of the guide pin and the steel tube into which it fits under a shear load. The weak link in the load path was found to be the tube steel section, which begins to yield at a load approximately 2 to 8 times less than the load that causes pin yielding, depending on the failure mechanism and pin location (tear-out versus bending). This indicates that if pin stresses had been excessive during the drop tests, damage should have been visible to the tube steel section around the guide pin. Since no damage was visible, guide pin stresses were demonstrated to be well below the yield value for the pin. Based on the actual results of the drop testing and the above reasoning, it is concluded that an adequate margin of safety exists for the guide pins.

In 1998, a half model of the 48X cylinder encased in a Paducah Tiger overpack was created using the LS-DYNA computer code. A 26.7° top edge drop was evaluated. This free drop is commonly referred to as the "CG over top edge drop" as shown in Figure 2.7-3 (Case C-1).

During performance of the 30-foot top edge drop analysis, the overpack and the 48X cylinder decelerated rapidly. The maximum decelerations of the cylinder for the 26.7° top edge drop were computed for all three translational directions (i.e., axial, radial, and lateral) and are summarized in Table 2.7-1. The combined maximum acceleration, computed by taking the vector sum of acceleration components computed from the analyses, is 53.0 g. This value is substantially less that the allowable stress on the weld connecting the cylinder skirt to the cylinder shell (i.e., allowable stress equivalent to 200 g). The results of the 26.7° top edge drop analysis indicate that the skirt-to-cylinder shell weld is capable of withstanding the drop without failure and that the cylinder will not lose containment integrity.

2.7.1.5 Summary of Results

Based on evaluation of analysis results for the end drop, it can be concluded that the valve structure did not make contact with the overpack's 1/2-inch end plate nor the 2-inch aluminum stiffening plate, and that the structural integrity of the cylinder was not compromised. The overpack, including the aluminum stiffening plate, was deformed at the points where the cylinder skirt made contact; however, clearance between the valve structure and the package was maintained. The top cover plates between the top and bottom lid were crushed locally by the cylinder skirt. The foam was crushed by deceleration forces of the cylinder skirt on the aluminum stiffening plate and carbon steel end plate.

The corner drop was evaluated by finite element analyses using the LS-DYNA computer code. A full model of the 48X cylinder encased in the Paducah Tiger overpack was generated. Analysis results indicated that the crush plane developed would not contact the cylinder skirt and that no damage to the cylinder and cylinder valve will occur.

The oblique/top edge drop was also evaluated by finite element analyses using the LS-DYNA computer code. A half model of the 48X cylinder encased in the Paducah Tiger overpack was created and a 26.7° top edge drop analysis was performed. The results indicated that the top edge drop produced decelerations less than the end drop, so the end drop is the bounding case for cylinder buckling.

2.7.2 Puncture

Applicable regulations require that the package be subjected to a puncture test in a manner expected to induce the most damage. The puncture test is defined as a 40-inch drop onto a 6-inch diameter steel punch. The punch is to be of a length expected to produce the worst damage but must be at least 8 inches long with a vertical longitudinal axis.

The puncture test [1] and a puncture analysis were performed to examine the worst possible damage to the package. In the puncture test, the package was oriented to impact the punch along the longitudinal side of the overpack on the stainless steel breakaway plates where nearly all available kinetic energy is spent in puncturing the overpack. In the puncture analysis, a computer simulation was used to determine if valve damage would occur and result in a loss of the containment boundary if the puncture were to occur adjacent to the valve.

Analytically, after performing the 30-foot free drops of the loaded overpack for the three orientations described in Sections 2.7.1.1 (End Drop), 2.7.1.3 (Corner Drop), and 2.7.1.4 (Oblique Drop), the pin puncture drops were performed sequentially to ensure that the package strikes the rigid pin in an orientation to maximize damage to the package. Following these sequential drop analyses, the clearances between the end of the cylinder valve and the edges of the 2-inch aluminum stiffening plate valve clearance hole were determined.

The maximum axial (Z), radial (Y) and lateral (X) displacements for the end drop, corner drop and oblique (edge) drop were computed. These values were then used to compute the clearances between the cylinder valve and the stiffening plate hole edges. The clearances are summarized in Tables 2.7-2 through 2.7-4. The minimum clearances calculated are greater than the recommended clearances. Therefore, the valve tip integrity is not compromised and it can be concluded that the cylinder valve will not be damaged.

2.7.3 Thermal

The thermal evaluation of the Paducah Tiger overpack and the 48X cylinder is described in Chapter 3. This section presents the thermal response of the package to hypothetical thermal accident conditions. Physical testing was performed on the package under thermal accident conditions per 10 CFR 71.73. The thermal accident testing of the package was performed on the damaged prototype package following both the drop and puncture tests.

2.7.3.1 Summary of Pressures and Temperatures

As discussed in Section 3.5.1.2, physical testing of the prototype package under hypothetical thermal accident conditions indicated that no temperatures or pressures were developed in the 48X cylinder that compromised its structural integrity. Inspection of the 48X cylinder after testing revealed only a slight discoloration of the cylinder resulted from the applied heat load, with no visible distortions resulting from thermal stresses. Temperature-indicating labels on the cylinder wall during testing showed that the majority of the cylinder reached a temperature of approximately 275°F. The area on the cylinder adjacent to the hole created by the pin puncture, that was directed to the side of the prototype overpack with carbon steel breakaway plates, reached a temperature between 400 and 450°F. This hole in the overpack also contributed to other areas of the cylinder reaching 275°F. These temperatures would have been lower if UF_6 had been in the cylinder, because UF_6 would remove surface heat through sublimation. Based on the test temperatures, pressures developed within the cylinder during the test would have been approximately 135 psia if the test cylinder contained UF_6 (Section. 3.5.4). The 135 psia pressure is well below the cylinder design pressure of 200 psig and therefore is not considered to compromise the structural integrity of the cylinder.

During a hypothetical accident fire, it is possible that the extreme heat on the exterior of the overpack may cause decomposition of the urethane foam in the package. If this occurred, pressure build-up from off-gassing would build up within the overpack wall and then be released through the vent holes and not compromise the overpack outer skin and inner liner.

2.7.3.2 Differential Thermal Expansion

No damage to the 48X cylinder was observed following the hypothetical accident testing that could be attributed to differential thermal expansion. The foam insulation was free to expand through the puncture hole in the inner liner of the overpack and into the gaps between the cylinder and inner liner. Distortions in the overpack shell resulted from thermally induced stress. However, the 48X cylinder integrity is not a function of the overpack shell distortions, and thus the containment was not compromised.

2.7.3.3 Stress Calculations

Physical testing (Section 3.5.1.2) of the package in accordance with the HAC requirements outlined in 10 CFR 71.73 revealed no damage to the 48X cylinder that would compromise its structural integrity.

No stresses resulting from combined thermal gradients or pressure loads experienced during hypothetical thermal accident conditions compromised the structural integrity of the 48X cylinder.

2.7.3.4 Comparison with Allowable Stresses

No calculations were performed to determine the stresses resulting from thermal gradients and pressure loads in the 48X cylinder during testing. The conclusions concerning stresses were drawn from the results of the physical testing.

2.7.4 Immersion - Fissile Material

The water immersion requirement of 10 CFR 71 for fissile material specifies that for cases where water in-leakage has not been assumed for criticality analysis [10CFR71.55(b)], the package must be immersed under a head of water of at least 3 feet (0.9 meter) for a period of not less than 8 hours and in the orientation for which maximum leakage is expected. The criticality analysis described in Section 6.1 assumed no leakage of water into the cylinder. Therefore, the water immersion requirements for fissile material specified in 10 CFR 71.73 must be met.

The 48X cylinder provides the containment boundary against water in-leakage; therefore, the effect of in-leakage through the overpack was not considered. Physical test damage to the cylinder resulting from the hypothetical accident conditions was limited to a minor deformation within the region of the puncture. Since some leakage along the threads of the cylinder valve was identified during a pressure test following the end drop test, two design enhancements to the overpack were made to protect the valve from incurring any damage during the sequential hypothetical accident drop events. A 3/8-inch stainless steel valve protector plate was welded to the exterior end of the overpack lid, and a 2-inch thick aluminum stiffening plate was inserted in the valve end of the overpack cavity between the cylinder skirt and the 1/2-inch carbon steel end plate.

With the addition of these two design enhancements, the expected level of damage to a cylinder under hypothetical accident conditions would not affect the ability of the cylinder to withstand external pressures up to the cylinder design pressure (25 psig) and probably much higher (Section 2.6.4). The hydrostatic pressure experienced by the cylinder under the 3-foot head of water (approximately 1.3 psig), called for in the immersion test for fissile material, is much lower than the cylinder external design pressure (25 psig). Additionally, cylinders made of A-516 normalized steel are not susceptible to corrosion or any other mechanisms of deterioration in water that could lead to in-leakage during the 8 hour time period of exposure.

2.7.5 Immersion - All Packages

The water immersion requirements of 10 CFR 71 specify immersion of an undamaged package under 50 feet (15 meters) of water for 8 hours. An external gauge pressure of water of 21 psig (145 kPa) is considered to meet these conditions.

The neoprene sponge rubber gasket which is situated between the lid and the body of the overpack is designed to resist water spray, not immersion. As a result, water is expected to leak into the inner cavity of the overpack. The overpack is made of water-resistant materials; and, because of the nature of the gasket, the internal and external pressure will quickly equalize, resulting in no structural damage to the overpack.

All structural components of the 48X cylinder containment boundary are made of water-resistant materials. In fact, the cylinders are pressure tested hydrostatically and have a critical external buckling pressure capability of 506 psi, far in excess of the 21 psig immersion condition.

2.7.6 Summary of Damage

The final results of the sequential 30-foot free drop and 40-inch pin puncture test indicate that:

- The 48X cylinder shell can adequately withstand a longitudinal buckling force of 91.3 g.
- The key weld joining the cylinder skirt to the cylinder shell can withstand the deceleration force of 95.1 g.
- The 3/8-inch stainless steel valve protector plate, the 1/2-inch carbon steel end plate, and the 2-inch aluminum stiffening plate all deformed permanently due to the 30-foot drop and 40-inch pin puncture. However, none of the three plates was penetrated by the pin, and the cylinder valve was still sufficiently protected by the plates.

- Since no penetration of the overpack end plate occurred during the worst case free drop and pin puncture drop, and adequate valve clearances remained during and after the combined drops as shown in Figures 2.7-2 through 2.7-4, the 48X cylinder maintained containment.

No damage to the 48X cylinder could be attributed to differential thermal expansion, and no stresses resulting from combined thermal gradients or pressure loads experienced during hypothetical thermal accident conditions compromised the structural integrity of the containment vessel (48X cylinder).

The overpack subjected to the free drop, puncture, and fire tests would not prevent water from surrounding the cylinder during the immersion test. Damage to the cylinder was considered insufficient to result in in-leakage of water at the immersion test pressure. To preclude any possibility of brittle fracture, all 48X cylinder shipments are currently required to use A-516 steel.

It is concluded that the hypothetical accident tests and analyses performed on the Paducah Tiger overpack demonstrate that the overpack provides adequate structural protection for the 48X cylinder when exposed to the hypothetical accident events specified in 10 CFR 71.73(c), thus ensuring that the structural integrity of the 48X cylinder is not compromised.

Figure 2.7-1 Case A (0° End Drop)

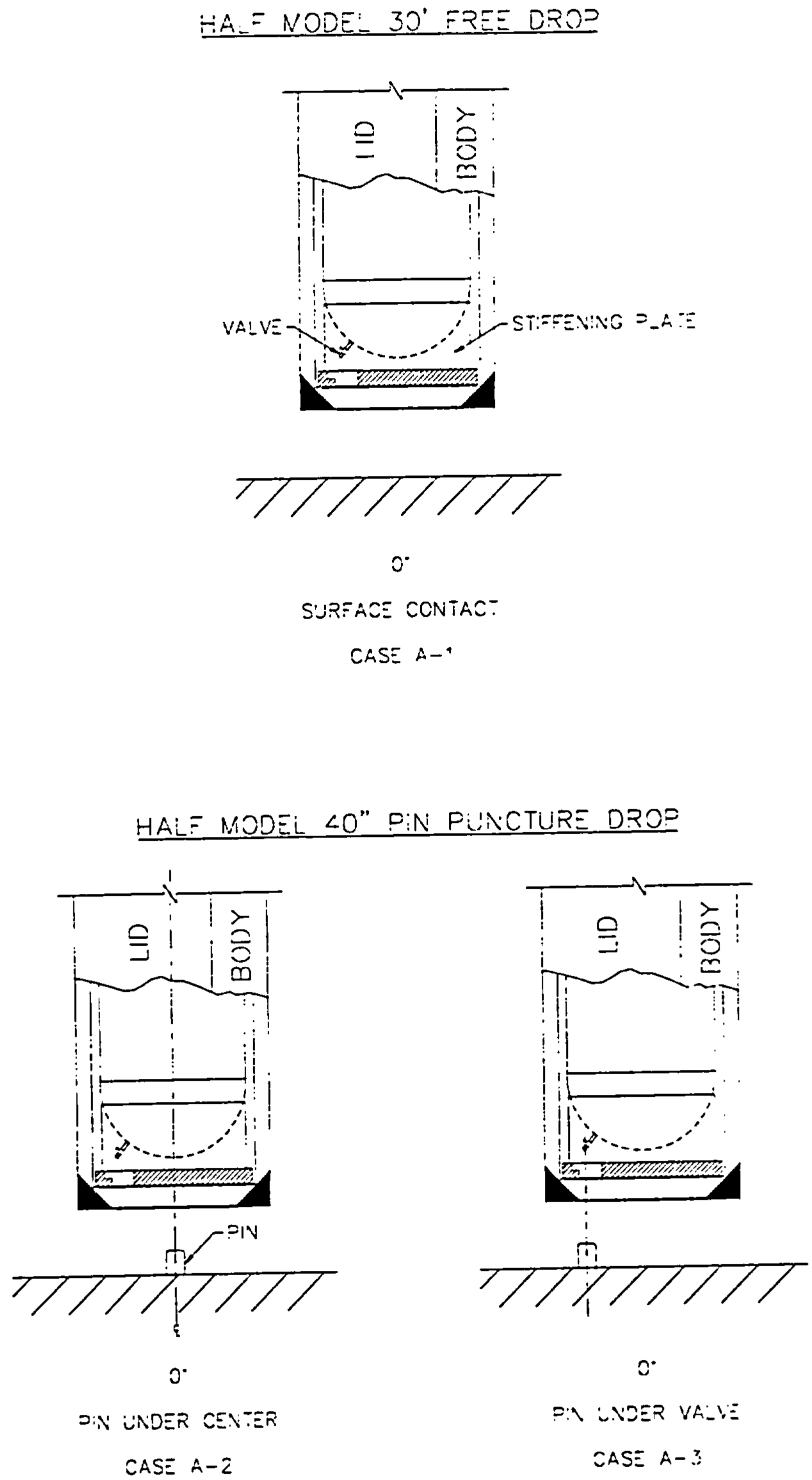
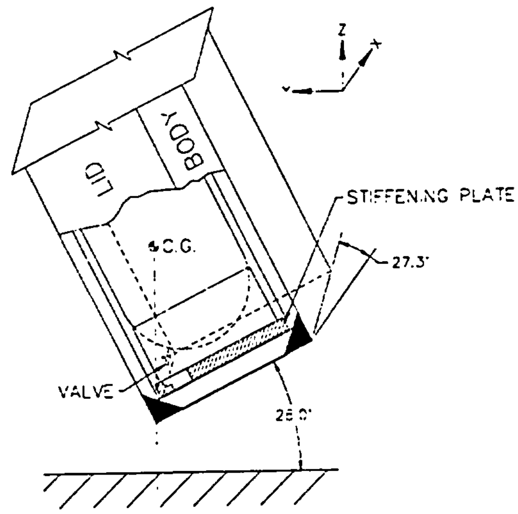


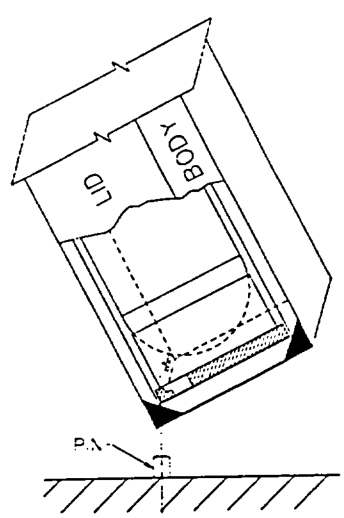
Figure 2.7-2 Case B (28° Corner Drop)

FULL MODEL 30' FREE DROP



28.0° ABOUT Y, 27.3° ABOUT X
CORNER CONTACT
CASE B-1

FULL MODEL 40" PIN PUNCTURE DROP



28.0° ABOUT Y, 27.3° ABOUT X
PIN UNDER CORNER OF SKIRT
CASE B-2

Figure 2.7-3 Case C (26.7° Top Edge Drop)

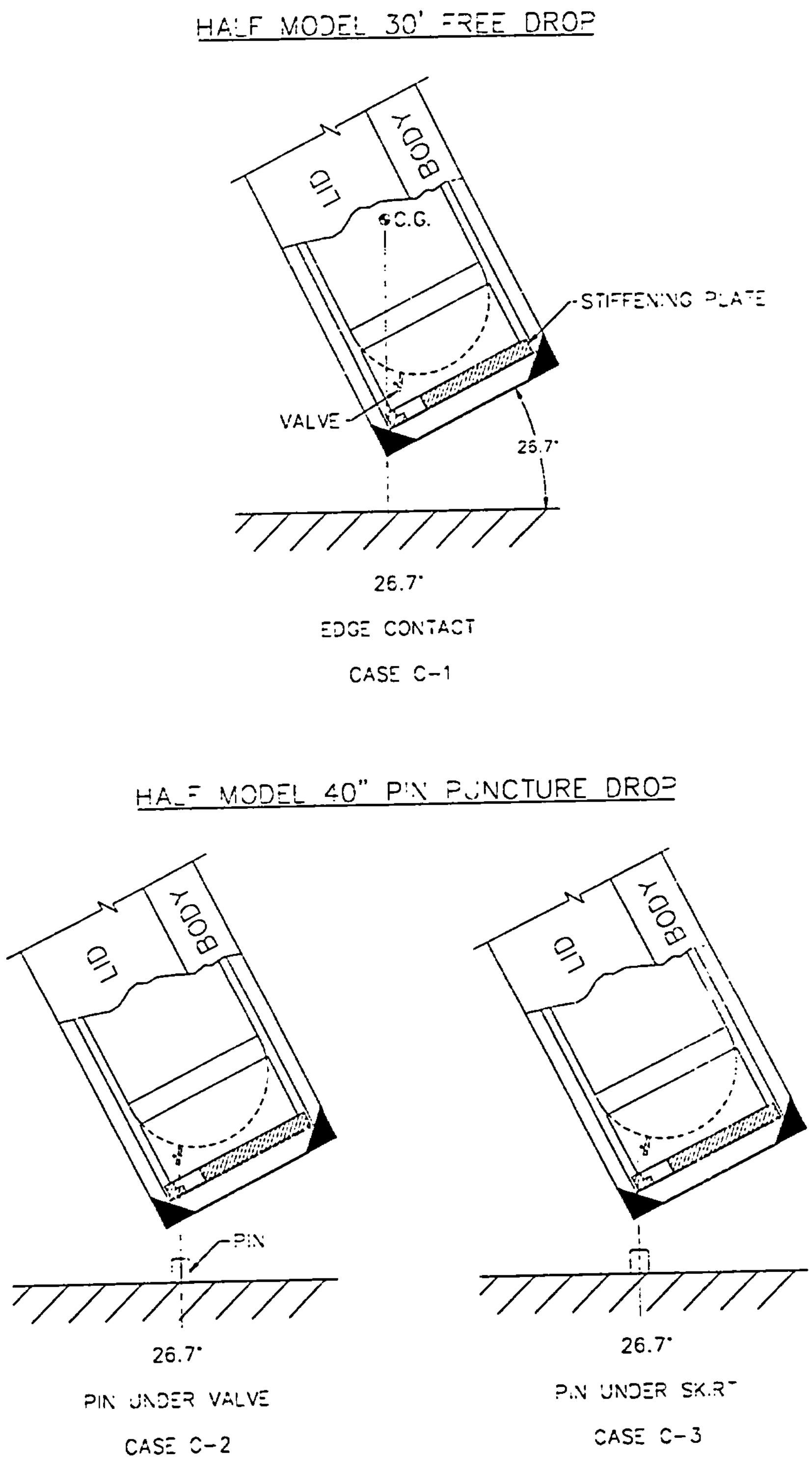


Table 2.7-1 Summary of Decelerations on the 48X Cylinder Induced by the 30-foot Free Drop

Drop Orientation (Case No.)	Deceleration (g) in the Axial (Z) Direction	Deceleration (g) in the Radial (Y) Direction	Deceleration (g) in the Lateral (X) Direction	Combined Maximum g
0° on End (A-1)	91.3	26.6	0	95.1
28° on Corner (B-1)	52.9	20.3	28.9	63.6
26.7° on Edge (C-1)	49.6	18.6	0	53.0

Table 2.7-2 Summary of AXIAL Clearances Between Valve and 1/2" End Plate

	A	B	C		D	E
30' Free Drop (Case No.)	Initial Axial Clearance[a] (in)	Maximum Differential Displacement (in)	Net Minimum Clearance (in) = A – B	40" Pin Puncture Drop (Case No.)	Combined[b] Maximum Differential Displacement (in)	Combined Net Minimum Clearance (in) = A - D
0° on End[c] (A-1)	2.000	0.138	1.862	Pin under Center (A-2)	0.509	1.491
	2.000	0.138	1.862	Pin under Valve (A-3)	0.837	1.163
28° on Corner[c] (B-1)	2.000	0.005	1.995	Pin under Skirt (B-2)	0.005	1.995
26.7° on Edge[c] (C-1)	2.000	0.0	2.000	Pin under Valve (C-2)	0.660	1.340
	2.000	0.0	2.000	Pin under Skirt (C-3)	0.0	2.000

Notes:

a) Initial axial (z-direction) clearance between cylinder valve and 1/2" carbon steel end plate consists of the 2-inch deep hole in the aluminum stiffening plate.

b) Combined maximum differential displacement = Cumulative displacement of 30' drop plus 40" pin puncture drop.

c) Two puncture drop orientations were analyzed for Case A (0° on End) and Case C (26.7° on Edge) in order to ensure that the worst case loading was evaluated. From parametric studies, the worst case puncture loading for Case B (28° on Corner) was the "pin under valve" drop orientation.

Table 2.7-3 Summary of RADIAL Clearances Between Valve and Edge of 2" Stiffening Plate

	A	B	C		D	E
30' Free Drop (Case No.)	Initial Radial Clearance[a] (in)	Maximum Differential Displacement (in)	Net Minimum Clearance (in) = A - B	40" Pin Puncture Drop (Case No.)	<u>Combined</u>[b] Maximum Differential Displacement (in)	<u>Combined</u> Net Minimum Clearance (in) = A - D
28° on Corner[c] (B-1)	4.006	2.099	1.907	Pin under Skirt (B-2)	2.099	1.907
26.7° on Edge[c] (C-1)	4.006	1.474	2.532	Pin under Valve (C-2)	1.517	2.489
	4.006	1.474	2.532	Pin under Skirt (C-3)	1.474	2.532

<u>Notes:</u>

a) Initial radial (y-direction) clearance between cylinder valve tip (0.5 in diameter) and edge of 2" aluminum stiffening plate with a 10 x11 cut-out hole = 4.256-0.5(0.5)=4.006".

b) Combined maximum differential displacement = Cumulative displacement of 30' drop plus 40" pin puncture drop.

c) Two puncture drop orientations were analyzed for Case C (26.7° on Edge) in order to ensure that the worst case loading was evaluated. From parametric studies, the worst case puncture loading for Case B (28° on Corner) was the "pin under valve" drop orientation.

Table 2.7-4 Summary of LATERAL Clearances Between Valve and Edge of 2" Stiffening Plate

	A	B	C		D	E
30' Free Drop (Case No.)	Initial Lateral Clearance[a] (in)	Maximum Differential Displacement (in)	Net Minimum Clearance (in) = A – B	40" Pin Puncture Drop (Case No.)	Combined[b] Maximum Differential Displacement (in)	Combined Net Minimum Clearance (in) = A - D
28° on Corner (B-1)	5.250	2.601	2.649	Pin under Skirt (B-2)	2.601	2.649

Notes:

a) Initial lateral (x-direction) clearance between cylinder valve tip (0.5 in diameter) and edge of 2" aluminum stiffening plate with a 10 x 11 cut-out hole = 5.500-0.5(0.5)= 5.250".

b) Combined maximum differential displacement = Cumulative displacement of 30' drop plus 40" pin puncture drop.

2.8 Special Form

This section is not applicable since no special form radioactive material is transported in the Paducah Tiger overpack.

2.9 Fuel Rods

This section is not applicable since no fuel rods are shipped in the Paducah Tiger overpack.

2.10 References

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6. Battelle Columbus Laboratory, *Structural Alloys Handbook,* Volume 1, p. 12, Columbus, OH, 1981.

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8. U.S. Nuclear Regulatory Commission, Regulatory Guide 7.6, *Design Criteria for the Structural Analysis Shipping Cask Containment Vessels,* March 1978.

9. LS-DYNA, Version 940, KBS2 Inc., Burr Ridge, IL.

10. W. R. Pedigo, et al, AEC Research and Development Report KY-500, *Testing of Ten-Ton Uranium Hexafluoride Cylinders*, Union Carbide Corporation Nuclear Division, Paducah, Kentucky, October 22, 1965.

3.0 THERMAL EVALUATION

This chapter describes the performance of the Paducah Tiger under thermal loads. Thermal loads include heat from initial UF_6 fill conditions, solar insolation and from the hypothetical accident fire event.

3.1 Discussion

Solid uranium hexafluoride (UF_6) is transported inside a carbon steel 48X cylinder encased in the Paducah Tiger protective overpack that contains rigid foam insulation. Thermal analyses were performed to show that the package, including the 48X cylinder with its UF_6 contents, complies with the requirements of 10 CFR 71.

The dimensions and materials of construction of the Paducah Tiger overpack and 48X cylinder are provided in Chapter 1. Information on the construction and fabrication of the Paducah Tiger is presented in Chapter 2. The objective of the thermal evaluation of this package is to confirm the ability of the overpack to protect the 48X cylinder containment during the Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) stipulated in 10 CFR 71.71 and 10 CFR 71.73, respectively. The overpack protects the 48X cylinder by surrounding it with a thermal barrier in the form of metal sheets and heat-resistant foam, which also provides protection during the hypothetical accident impact events.

Figure 1.1-1 shows the transport configuration of the 48X cylinder in the overpack. Figures 1.1-1 and 1.1-2 provide dimensions and features pertinent to the thermal analysis of the overpack and 48X cylinder.

3.2 Summary of Thermal Properties of Materials

3.2.1 Physical Properties of Low-Density Polyurethane Foam

A nominal density of 8.0 lb/ft^3 is used in the thermal analyses for the low-density foam. The actual density of the low-density foam ranges from 5.4 to 8.8 lb/ft^3. The specific heat or heat capacity is estimated to be 0.225 Btu/lb-°F based on data from the DuPont booklet on Properties of Rigid Urethane Foam.[1]

3.2.2 Physical Properties of High-Density Polyurethane Foam

The high-density polyurethane foam, which has a greater thermal conductivity than low-density foam, was not represented in the thermal model for NCT conditions, since its effect on the thermal response of the package would be minimal. The density of the heavier, high-density foam used as corner wedges in the overpack ranges from 16.2 to 20.16 lb/ft^3. The thermal conductivity of the high-density foam is 1.57 times greater than the thermal conductivity of the low-density foam, based on room temperature thermal conductivity-density data (Figure 3.2-1).

3.2.3 Physical Properties of Ethylene-Propylene Diene Terpolymer (EPDM)

The rubber shock isolators used in the overpack are constructed of EPDM. The density of EPDM is approximately 53.66 lb/ft^3.[2] The specific heat of EPDM is 0.5303 Btu/lb-°F.[2] The thermal conductivity of EPDM, calculated from the thermal diffusivity, density, and specific heat, is 0.2092 Btu/(hr-ft-°F).[2]

3.2.4 Thermal Properties of Uranium Hexafluoride

UF_6 is not modeled in the thermal analysis. Figure 3.2-2 presents a phase diagram for UF_6. The vapor pressure of UF_6 is shown graphically in Figure 3.2-2.

3.2.5 Thermal Properties of Steel

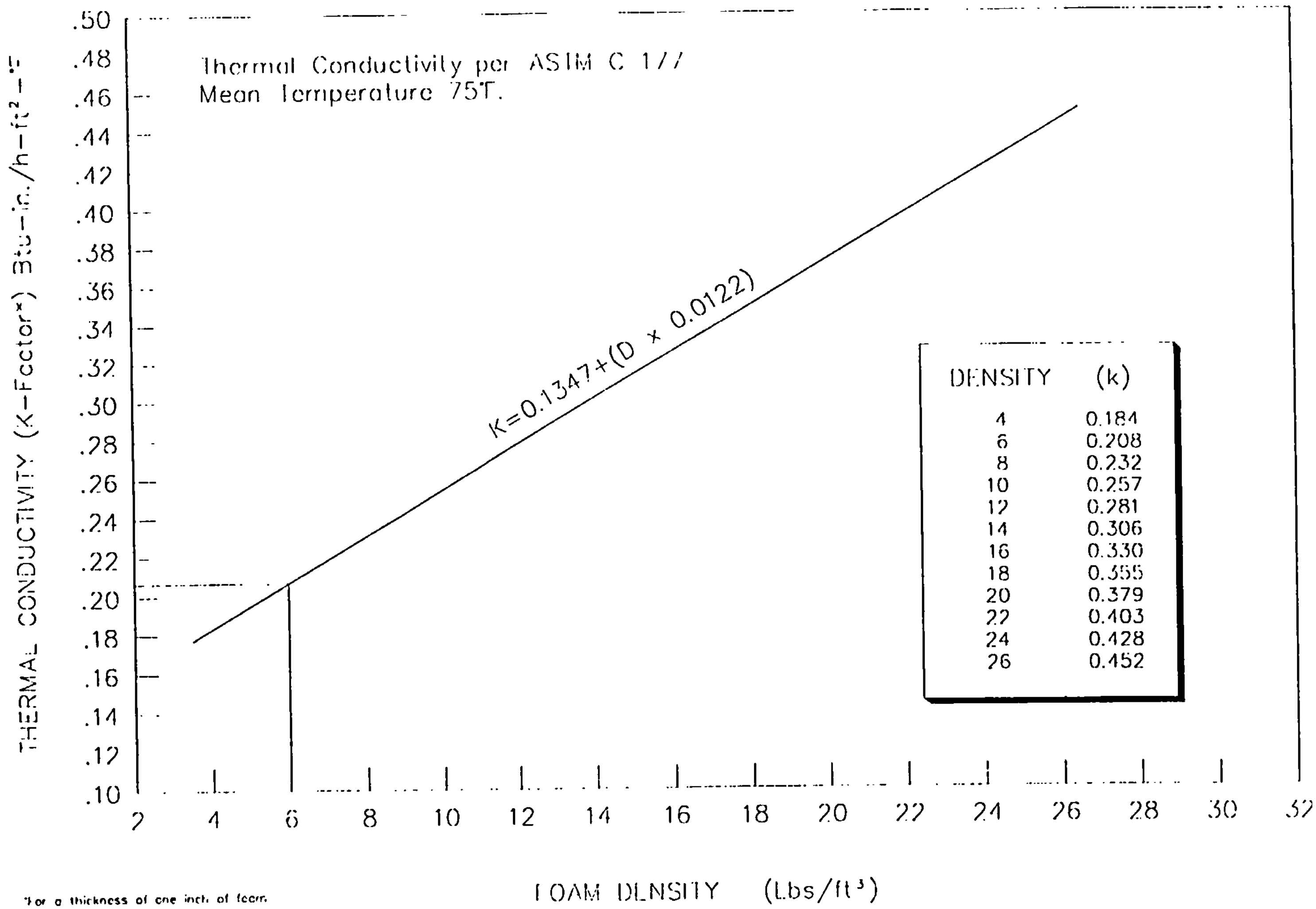
The thermal properties for ASTM A-36 steel which is used to form the inner liner of the Paducah Tiger overpack, and the thermal properties for ASTM A-285 Grade C carbon steel and ASTM A-516 normalized steel which are used to fabricate the 48X cylinders are presented in Table 3.2-1.

The properties of ASTM A-285 carbon steel are used in the thermal analysis based on the original 48X cylinder design. The difference in the thermal properties of A-285 carbon steel and A-516 normalized steel is of minor significance to the overall analysis. The thermal diffusivity of A-516 is less than that of A-285. Therefore, lower cylinder temperatures result if A-516 properties are used.

3.2.6 Thermal Properties of Air

The density of air is taken as constant at 0.08053 lb/ft^3. The actual density of air decreases from this value as temperature increases. The thermal conductivity, specific heat, and viscosity of air increase as temperature increases.

Figure 3.2-1 Thermal Conductivity of Polyurethane Foam (LAST-A-FOAM FR-3700) as a Function of Density



NOTE: **Data shown above was taken from "Physical Property Data for Last-A-Foam FR-3700," supplied by General Plastics Manufacturing Company, Tacoma, WA.**

Figure 3.2-2 Phase Diagram for Uranium Hexafluoride

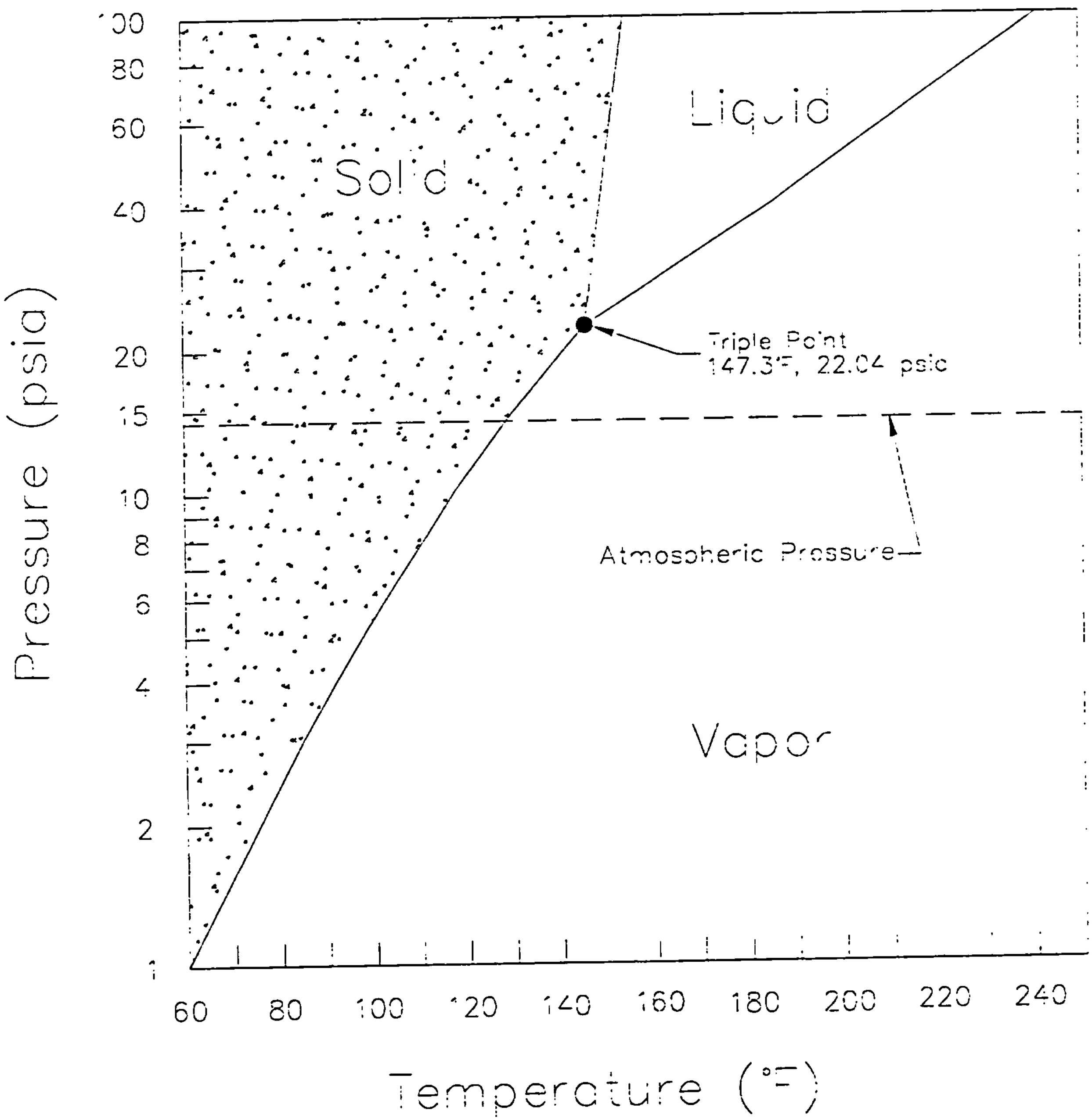


Table 3.2-1 Thermal Properties of Steel

Thermal Properties	**ASTM A-36[a]**	**ASTM A-285[b]**	**ASTM A-516**
Thermal Conductivity, Btu/(hr-ft-°F)	30.0	27.0	23.7
Density, lb/ft^3	488.0	483.8	507.6
Specific Heat, Btu/lb-°F	0.107	0.115	0.104

Notes:

a) Values taken from Incopera and DeWitt's *Fundamentals of Heat and Mass Transfer*, 2nd Edition [3].

b) Values taken from Materials Selector's *Materials Engineering* [4].

3.3 Technical Specifications of Components

The properties of the materials used in the thermal evaluation of the Paducah Tiger overpack are presented in Section 3.2. There are no other technical specifications that are important to the thermal evaluation of the overpack.

3.4 Thermal Evaluation for Normal Conditions of Transport

The containment boundary is provided by the 48X cylinder. The 48X cylinder is contained in the overpack. The overpack is fabricated using a 3/16-inch carbon steel cylindrical inner liner and an ll-gauge steel rectangular outer skin, with rigid low-density foam insulation inserted between the two metal surfaces, and high-density foam placed in the corners and along the edges of the package. In the thermal evaluation, the properties of low-density foam are included in all foam locations in the model.

3.4.1 Thermal Model

3.4.1.1 Analytical Model

PATRAN [5] was used to create a two-dimensional (x-y) model shown in Figure 3.4-1 for the normal transport analysis. The P/THERMAL 2.5 computer code [6] is used for the thermal analysis. P/THERMAL 2.5 was chosen because of its capability to model combinations of Cartesian and radial geometries like those of the Paducah Tiger overpack. The P/VIEWFACTOR [7] computer code is used in conjunction with P/THERMAL to calculate the complex configuration factors inside the overpack.

The model represents a symmetrical cross-section of the Paducah Tiger overpack. The breakaway plates of the overpack and the skirts at each end of the cylinder were not modeled, since their effect on the overall thermal response of the package is not significant. Models with and without the rubber shock isolators were constructed. Solar heat fluxes of 800 and 200 cal/cm^2 are imposed on the top and sides of the overpack, respectively, for a 12-hour period using a steady-state analysis. The steady-state analysis provides the maximum possible temperature distribution in the overpack.

The UF_6 contents of the 48X cylinder are not modeled. The inner surface of the cylinder is modeled as an insulated adiabatic surface. This assumption is conservative, since any heat transfer to the contents (UF_6) would tend to lower the cylinder wall temperature. The overpack and the cylinder are assumed to be at an initial temperature of 100°F, and the ambient temperature is assumed to be 100°F.

3.4.1.2 Test Model

No physical testing of the thermal performance of the Paducah Tiger overpack for normal conditions of transport was performed.

3.4.2 Maximum Temperatures

The two-dimensional model of the overpack is evaluated for NCT using the P/THERMAL computer code. Models with and without the rubber shock isolators predict nearly identical temperature distributions for the overpack and the 48X cylinder. The calculations indicate that a maximum temperature of 178.6°F occurs on the top horizontal surface of the package. The maximum temperature on the side of the package is 156.0°F. The maximum temperature attained by the 48X cylinder during the imposed conditions is calculated to be 135.4°F, which is well below the triple point of UF_6 (147.3°F). This indicates that the UF_6 will not melt under normal conditions of transport.

The requirements of 10 CFR 71.43 also stipulate that, when the package is exposed to a 100°F ambient temperature and no solar heat, no accessible surface of the package can have a temperature exceeding 180°F since it is an exclusive use shipment. Since the decay heat generation of the UF_6 is negligible, all temperatures throughout the package will equilibrate at the ambient temperature of 100°F with no solar heat load applied. Therefore, the package meets the requirement.

3.4.3 Minimum Temperatures

As required in 10 CFR 71.71, a package must be able to withstand an ambient temperature of -40°F in still air and shade. Assuming no decay heat generation within the package, steady-state temperatures throughout the package equilibrate at -40°F when exposed to this cold condition. The carbon steel used in the construction of the package can tolerate a temperature of -40°F with no load applied. In addition, the insulating foam is not adversely affected by this minimum temperature, since its compressive strength increases as the temperatures decreases.

3.4.4 Maximum Internal Pressures

Since the 48X cylinder never reaches temperatures exceeding the triple point of UF_6 during NCT, the pressure in the cylinder remains below the triple point pressure of 22.04 psia (7.3 psig). This pressure is well below the design pressure of the cylinder (200 psig).

3.4.5 Maximum Thermal Stresses

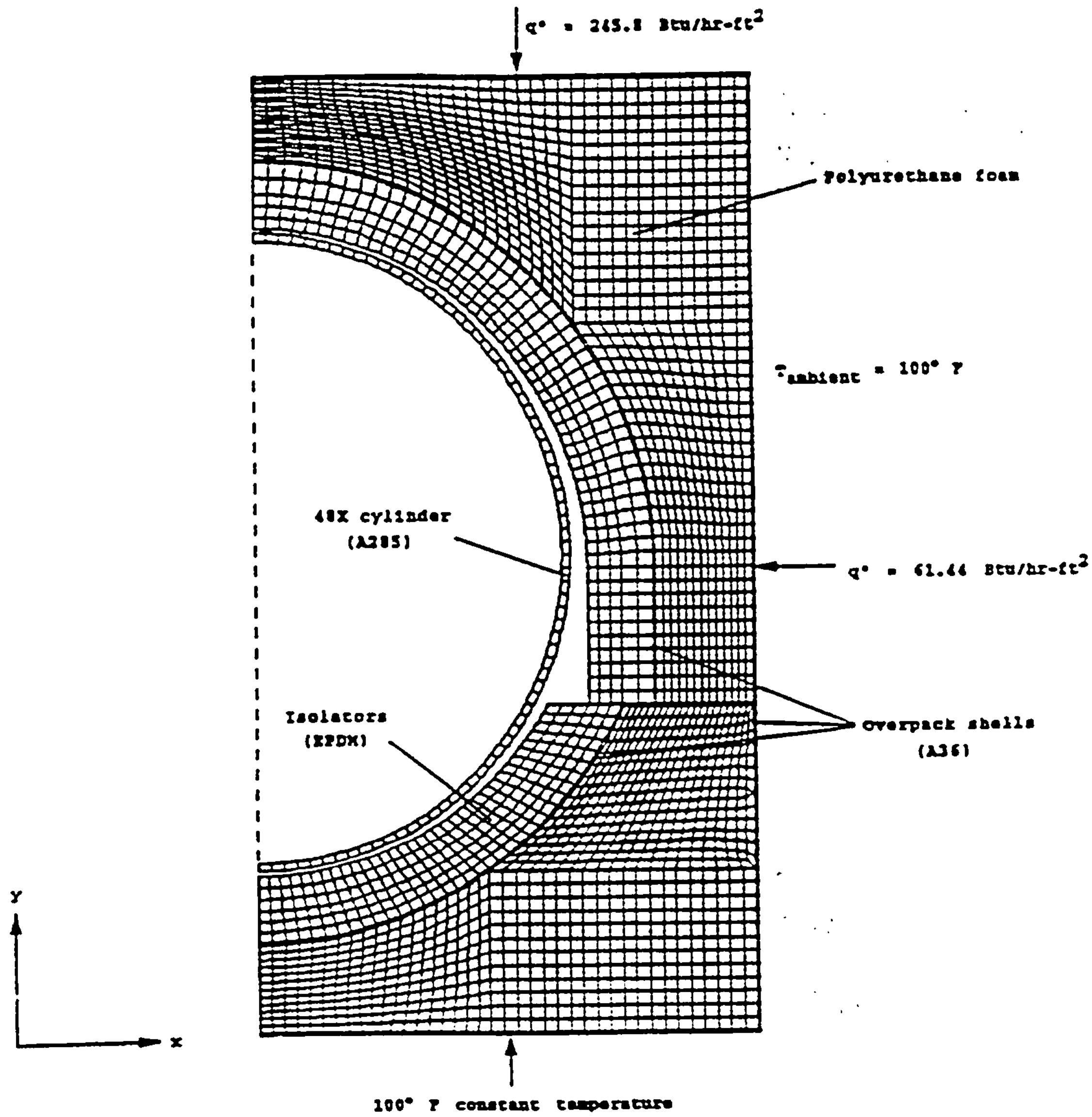
The thermal stresses in the cylinder are a function of the coefficient of thermal expansion, the modulus of elasticity, Poisson's ratio, and the temperature gradient across the cylinder wall. Results from the analyses show that the thermal gradients across the cylinder wall are less than 1°F. Correlations for thermal stresses in a "thin-shell" cylinder [8] predict thermal stresses of less than 150 psi, which are negligible.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The analysis of the Paducah Tiger overpack for NCT shows that it complies with the 10 CFR 71.71 thermal requirements for protection of the 48X cylinder under NCT. It also shows that the temperature of the accessible surface of the overpack, with no imposed heat load and in 100°F ambient still air and in the shade, meets the regulatory requirements of 10 CFR 71.43.

In summary, under the NCT, no loss or dispersal of radioactive contents, no increase in external radiation levels, and no reduction in the effectiveness of the Paducah Tiger overpack and 48X cylinder occurs.

Figure 3.4-1 Two-Dimensional Model of Paducah Tiger Overpack for Normal Transport Analysis



3.5 Hypothetical Accident Thermal Evaluation

The Hypothetical Accident Condition (HAC) specifies that the container be subjected to a 30-minute fire at a temperature of 1475°F (800°C) using a flame emissivity of 0.9. A surface absorptivity coefficient of no less than 0.8 must be used for the container surfaces. After the fire, the container is allowed to cool by radiation and convection to the ambient conditions at a temperature of 100°F.

3.5.1 Thermal Model

3.5.1.1 Analytical Model

No analytical model was developed and analyzed to evaluate the thermal performance of the Paducah Tiger overpack for hypothetical accident events.

3.5.1.2 Test Model

A damaged package, consisting of a prototype Paducah Tiger overpack and a 48X cylinder filled with more than 20,000 pounds of steel shot and $BaSO_4$ to simulate an actual fully loaded cylinder, was subjected to a 1475°F fire test conducted by Protective Packaging, Inc., of Tacoma, Washington in November 1971.[9] Before undergoing the fire test, this single test package was subjected to two different series of drop tests. Each series of drop tests involved a 30-foot free drop test followed by a 40-inch pin puncture test. In addition, each series of drop tests was performed on opposite edges of the overpack, one on the lid and the other on the body. [10] Therefore, the prototype incurred twice as much physical damage as required by the 10 CFR 71.73 hypothetical accident conditions.

The second series of drop tests, where mild carbon steel breakaway plates were used on the bottom of the overpack body, caused the greatest damage to the package. The 6-inch diameter bar penetrated the outer skin, breakaway plates, foam, and 3/16-inch carbon steel inner liner of the overpack, thus exposing the foam insulation and the 48X cylinder to the external environment. Due to design changes since the development of the prototype which was actually tested, this level of damage would not occur to a production overpack. The carbon steel breakaway plates which were punctured on the prototype were not used in the production overpacks. In addition, a steel valve protector plate and an aluminum stiffening plate have been added to protect the valve end of the 48X cylinder.

3.5.2 Package Conditions and Environment

The thermal accident conditions of 10 CFR 71.73(c)(4) were applied to the prototype damaged package in a natural gas furnace. Since the furnace achieved its heating with six gas burners that could produce "hot spots" on an object within the furnace, a secondary chamber of corrugated steel flame shields was placed around the Paducah Tiger overpack to provide a more uniform radiant heat source to the package. The maximum temperatures attained by the package were evaluated by placing permanent temperature-indicating labels on the cylinder and within the overpack. These labels indicate only the maximum temperature reached by the surface to which they are attached, and consequently the time-temperature history of the package is not recorded.

The package was initially placed in the furnace at a temperature of about 1000°F. The package was in the preheated furnace for approximately 15 minutes while the furnace temperatures were elevated to 1475°F. When the furnace temperatures reached 1475°F, the 30-minute time interval began. During this period of time, the furnace temperatures approached 1820°F.

3.5.3 Package Temperatures

Inspection of the overpack after the fire test revealed that thermal stresses had produced large distortions of the outer skin. It was also noted that some of the exposed foam insulation from the puncture on the side with the mild carbon steel breakaway plates continued to outgas and burn for approximately 30 minutes after removal from the furnace. Inspection of the temperature-indicating labels indicated that most of the 48X cylinder wall temperatures reached 275°F. The area on the cylinder wall adjacent to the puncture in the package reached a temperature between 400 and 450°F. When the overpack was removed, a slight discoloration of the cylinder was noted in the vicinity of the puncture; however, no detrimental effects to the structural integrity of the 48X cylinder were observed. The localized hot spot was due to direct exposure of the 48X cylinder to the furnace environment. As demonstrated in Section 2.7, this degree of damage to the overpack would not occur due to design changes made since construction of the prototype. Therefore, this localized hot spot may be discounted as a testing anomaly due to the excessive damage experienced by the prototype during drop and puncture testing.

3.5.4 Maximum Internal Pressures

The maximum cylinder wall temperature of interest recorded during the prototype fire test was approximately 275°F. This equates to a UF_6 vapor pressure of approximately 135 psia, considerably less than the UF_6 cylinder's design pressure of 200 psig.

3.5.5 Maximum Thermal Stresses

As discussed in Section 3.5.3, no distortion of the cylinder was observed following the fire test. Therefore, it is concluded that no significant thermal stresses were present in the cylinder during the fire test. Although the outer skin of the overpack exhibited distortions resulting from high thermal stresses associated with the fire test, the containment boundary remained intact. Therefore, no significant thermal stresses are generated that could cause failure or rupture of the 48X cylinder.

3.5.6 Evaluation of Package Performance for Hypothetical Accident Thermal Conditions

The structural evaluation described in Chapter 2 of the Paducah Tiger overpack shows that the overpack experienced the most critical structural damage during the 30-foot corner drop followed by the 40-inch pin puncture test. Results of the analyses indicate that the 3/8-inch stainless steel valve protector plate compresses locally, crushing all of the high-density and low-density polyurethane foam in its immediate path, and coming to rest against the 1/2-inch carbon steel end plate and aluminum stiffening plate. Although the 3/8-inch valve protector plate stretched and deformed greatly, the plate was not penetrated by the puncture bar. Therefore, since no penetration of the overpack inner liner occurred during the worst case free drop and puncture event, the thermal evaluation of the Paducah Tiger overpack design is enveloped by the more conservative fire test and thermal analysis described above.

The full-scale fire test performed on the overpack and 48X cylinder demonstrates that the Paducah Tiger overpack provides adequate thermal protection for the 48X cylinder when exposed to the fire test conditions specified in 10 CFR 71.73(c)(4).

The fire test resulted in temperatures that exceed the cylinder design temperature (250°F). However, the physical testing exposed the overpack to temperatures well in excess of the testing requirements (1820°F vs 1475°F), portions of the overpack were exposed to elevated temperatures for almost an hour, and no credit is taken for the high heat of fusion of UF_6. Even if the entire cylinder and contents reached a temperature of 275°F, the resulting pressure (approximately 135 psia) is well within the design pressure of the cylinder of 200 psig. Cylinders partially loaded with UF_6 were also evaluated, and it was determined that 48X cylinders must contain a "minimum fill" level of 12,000 pounds (approximately 60% of the UF_6 in a nominally filled cylinder) of UF_6. An equivalent amount of energy is required to heat 12,000 pounds of UF_6 to 275°F as is required to heat the 20,000 pounds of barium sulfate/steel mixture that was used in the actual fire testing to 275°F.

The density of UF_6 vapor at 1475°F and 200 psia (the cylinder design pressure) is 3.35 lb/ft^3. Given a minimum certified volume of 108.9 ft^3 for 48X cylinders, this density would yield about 365 pounds of UF_6. Consequently, it is recommended that a heel cylinder must contain no more than 350 pounds of UF_6.

3.6 References

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3. F. P. Incopera and D. P. DeWitt, *Fundamentals of Heat and Mass Transfer*, 2nd ed., Table A.1, p. 756, John Wiley & Sons, New York, NY, 1985.

4. *Materials Engineering*, Materials Selector, 1988, p. 35.

5. *PATRAN PLUS User Manual*, Publication No. 2191023, PDA Engineering, September 1989.

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7. *P/VIEWFACTOR User Manual*, Publication No. 2190048, PDA Engineering, April 1991.

8. R. J. Roark and W. C. Young, *Formulas for Stress and Strain*, 5th ed., McGraw-Hill Book Company, New York, NY, 1982.

9. Paducah Tiger Fire Test Report, Appendix A of *Engineering Evaluation and Test Report (EETR) of Paducah Tiger for Shipment of Enriched UF_6 (10-Ton Cylinder)*, prepared by Protective Packaging, Inc., Tacoma, WA.

10. L. J. Hansen and C. King, Protective Packaging, Inc. *Engineering Evaluation and Test Report (EETR) of Paducah Tiger for Shipment of Enriched UF_6 (10-Ton Cylinder)*, Tacoma, WA.

4.0 CONTAINMENT

Containment of the UF_6 and heel material is provided by the Model 48X 10-ton cylinder. The cylinder is transported in the Paducah Tiger overpack which provides thermal, puncture and impact protection for the 48X cylinder during transport. The Paducah Tiger overpack does not provide a containment function.

4.1 Containment Boundary

The containment boundary of the Paducah Tiger is the 48X 10-ton UF_6 cylinder. This boundary consists of a steel cylinder (containment vessel), welds on that vessel, a valve for loading and unloading the contents, and a plug used for cleaning purposes. The components of the containment boundary are described in the following sections.

The Paducah Tiger shipping package also includes an overpack. This overpack does not provide a containment boundary. The Paducah Tiger overpack protects the cylinder from significant thermal and impact stresses in accident conditions.

4.1.1 Containment Vessel

The containment boundary for this package is the 48X cylinder which is described in ANSI N14.1.[1] These cylinders are fabricated from ASTM A-516 steel and have a nominal 0.625-inch wall thickness. The cylinders are designed to withstand an internal pressure of 200 psig and are hydrostatically tested at 400 psig in accordance with ANSI N14.1. In other testing, the cylinders have withstood hydrostatic pressures in excess of 1200 psig.[2]

4.1.2 Containment Penetrations

The containment boundary (i.e., the 48X cylinder) has two penetrations. One is the valve used in filling and emptying the UF_6. The other is a 1-inch plug located on the end of the cylinder opposite the valve. This plug is used to drain cleaning solution from the cylinder during cleaning operations. The valve and plug meet the performance requirements specified in ANSI N14.1.

4.1.3 Seals and Welds

The 48X cylinders are qualified under the ASME Boiler and Pressure Vessel Code and follow the specifications of ANSI N14.1. Welding procedures and operator qualifications are required to be in accordance with Section IX of the ASME Code. A minimum of one spot X-ray is required for each cylinder, in accordance with Section VIII, Subsection UW-52 of the ASME Code.

4.1.4 Closure

The 48X cylinder is closed by means of a threaded plug fitting on one end and a 1-inch cylinder valve on the opposite end which is fabricated, inspected, tested, and maintained in accordance with Section 6.11 of ANSI N14.1. ANSI N14.1 specifies that the valve and plug inlet threads be tinned; 7 - 12 threads be engaged on the valve using between 200 - 400 ft-lb of torque; and 5 - 8 threads be engaged on the plug using between 150 - 650 ft-lb of torque.

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The A_2 quantity for uranium enriched to 5 wt % is specified as unlimited in 10 CFR 71, Table A-1. Therefore, if a full 48X cylinder has an activity less than an A_2 quantity, then the package is considered a Type A package. However, the A_2 quantity for a cylinder containing only a heel must be calculated. The A_2 is determined by applying the methodology given in Appendix A, Section IV(a), of 10 CFR 71.

In a UF_6 cylinder, the buildup of uranium daughter products occurs over time. These must be considered as part of the cylinder contents since some uranium and uranium daughter products remain in the cylinder as part of the UF_6 heel after the UF_6 has been unloaded (e.g., ThF_6 requires a higher temperature than the UF_6 to be drawn off).

The daughter products present in the heel occur from the decay of U-235, U-236, and U-238. The concentration of the heel mixture assumes that all the daughter products remain in the cylinder. This is conservative, since some of the daughter products are drawn off with the UF_6. The mass quantities in the heel are also conservative, because it is assumed that a full 50-pound heel remains, when, in actuality, heels are typically 20 to 30 pounds. The result of these assumptions is a higher concentration of daughter products in the heel than would generally occur.

The data presented in Table 4.2-1 show that the individual isotopes in the UF_6 heel have activities much less than an A_2 quantity, and that the curie content of the mixture (2.72 curies) is much less than the A_2 value of the mixture (5.11 curies). Since the cylinder, with a heel, contains less than an A_2 quantity of material, it is demonstrated that the heel cylinder (containing up to 50 pounds of UF_6 heel) is a Type A package. Since this analysis is conservative, it is not likely that a build-up of any daughter products in the cylinder from repeated cycles causes the activity of the heel to exceed an A_2 quantity.

4.2.2 Pressurization of Containment Vessel

During filling with liquid UF_6, the maximum temperature inside the 48X cylinder is 180°F. This temperature corresponds to an internal UF_6 gas pressure of 40 psia. As the UF_6 cools and solidifies, the pressure in the cylinder drops below atmospheric prior to shipment.

At the maximum normal temperature for UF_6, 135.4 °F, the vapor pressure is considerably less than 22 psia (Section 3.4.4). At the maximum temperature for a fire accident, 275°F, the vapor pressure is approximately 135 psia (Section 3.5.4). These values are below the ANSI N14.1 design pressure of 200 psig.

4.2.3 Containment Criterion

The 48X cylinder is air pressure tested to 100 psig. A soap bubble test is used to test for air leaks.

The 1-inch cylinder valve is pressure tested to 400 psig. The pressure test is applied to both the valve seat and to valve stem packing by partly opening the valve with the valve outlet port capped. A bubble test, using either a soap bubble test method or immersion in water, is used to demonstrate a leak-tightness of the valve seat and valve stem packing.

Since the cylinder contains less than the A_2 value of the mixture, no leak rate calculation is required. These tests demonstrate that the cylinder and valve adequately contain the UF_6 and heel contents.

Table 4.2-1 Determination of the Composite A_2 Value for a Heel Cylinder.

Isotope[3]	Activity (Ci)	A_2	Fractional Activity	F/A_2
Th-230	6.70E-04	0.00541	0.00025	0.0462
Th-231	6.25E-01	24.3	0.22976	0.0095
Th-234	2.05E+00	5.41	0.75362	0.1393
Pa-231	6.31E-05	0.00162	0.00002	0.0123
U[1]	4.45E-02	∞	0.01635	0.0000
Total	2.72E+00		1.00000	0.2073
Composite A_2 =	1 / 0.2073 =	4.82[2]		

1) The A_2 for Uranium enriched to 5% is unlimited.
2) Since the total activity of the mixture is less than the composite A_2 value, the package is Type A.
3) The buildup of uranium daughter products was based on a 1 year load/unload cycle and the concentration was maximized after 5 years of cylinder operation.

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Fission Gas Products

The UF_6 and heel contents do not generate fission gas products. Consequently, there is no increase in cylinder pressure due to fission gases.

4.3.2 Containment of Radioactive Material

Both the full and heel cylinders are classified as Type A packages, since they both carry less than one A_2 quantity of radioactive material (Table 4.2-1). In addition, the analyses in Chapters 2 and 3 demonstrate that the cylinder remains intact during hypothetical accident events. Consequently, there is no release of radioactive material in the accident events.

4.3.3 Containment Criterion

The 48X cylinder is a Type AF container. There are no accident leak rate limits that apply to the package. The 48X cylinder and 1-inch cylinder valve are tested as specified in Section 4.2.3. Since the containment is not breached in the accident events, these tests demonstrate that there is no loss of contents in accident conditions.

4.4 Special Requirements

The Paducah Tiger overpack and 48X cylinder are not used for the transport of plutonium.

4.5 References

1. American National Standards Institute, *American National Standard for Nuclear Materials, Uranium Hexafluoride - Packaging for Transport,* ANSI N14.1, New York, NY, 1990.

2. K. T. Ziehlhe and C. R. Barlow, *Rupture Testing of UF_6 Transport and Storage Cylinders*, K/SS-504.

5.0 SHIELDING EVALUATION

Gamma and neutron shielding are not required for 48X cylinders containing UF_6 because the 5/8-inch thick cylinder walls provide more than adequate shielding for low enriched uranium. However, it is the responsibility of the shipper to assure compliance with 10 CFR 71.47 regarding radiation standards for each shipment.

6.0 CRITICALITY EVALUATION

This chapter identifies and describes the nuclear criticality safety evaluation of the Paducah Tiger shipping package. The evaluation demonstrates compliance with the performance requirements specified in 10 CFR 71.55.

6.1 Discussion and Results

For criticality control, the Paducah Tiger relies upon the following features:

- specification of maximum H/U ratio, or equivalently, minimum UF_6 purity,
- impact absorption by the protective overpack, which prevents damage to the 48X cylinder sufficient to cause water in-leakage or reduction of package volume under normal and accident conditions, and
- thermal protection of the 48X cylinder by the overpack, which prevents damage to the 48X cylinder that could cause the contents to leak out or water to leak in.

Purity control is provided in accordance with ASTM C787 [1] and ASTM C996 [2] which requires a minimum 99.5% UF6 purity. The maximum hydrogen to uranium atomic ratio (H/U) of 0.088 which is allowed in accordance with 49 CFR 173.417, Table 6, corresponds to 0.5% impurity, with all the impurity being hydrogen fluoride (HF). The drop, puncture, and fire testing described in Chapter 2 demonstrates that the containment provided by the 48X cylinder is not breached. Consequently, water will not leak in, nor will the contents leak out, under accident conditions. The testing also demonstrates 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.

A criticality evaluation for 10-ton cylinders is provided in ORNL/TM-11947.[3] This evaluation is directly applicable to the 48X cylinder and Paducah Tiger overpack. The report evaluates K_{eff} using the SCALE4 computer code system for an infinite array of packages with optimum interspersed moderation, and identifies the worst case to be $K_{eff} = 0.768 \pm 0.002$. The worst case calculation is summarized in Table 6.1-1. An infinite array of damaged or undamaged packages remaining subcritical corresponds to a transport index for criticality control of zero.

Table 6.1-1 Summary of Criticality Evaluation

Model conditions	Normal and accident using same model[1]
Number of packages in contact	Infinite
$k_{eff} \pm \sigma$	0.768 ± 0.002
Optimum interspersed moderation	Water, specific gravity = 0.005
Close reflection by water	Not applicable to infinite array
Package size, including overpack	96.84 cm radius, 389.26 cm height
Internal size of 48X cylinder	60.96 cm radius, 264.16 cm height
Overpack material	Water, same as interspersed
Package contents	UF_6, 4.5% enriched, 99.5% pure, 5.1 g/cm^3, 21,069 pounds
Temperature	20 °C
Contents geometry	Solid UF_6 cylinder with central cylindrical void
Internal moderation	No water; 0.5 % impurity entirely HF; H/U = 0.088

(1) The Paducah Tiger overpack was conservatively modeled as a cylindrical and not a rectangular overpack.

6.2 Package UF_6 Loading

The Paducah Tiger overpack is used to transport UF_6. The loading consists of:

- Cylinder Type: Model 48X
- Maximum Weight of UF_6: 21,030 pounds
- Maximum U-235 Enrichment: 4.5 wt %
- Minimum UF_6 Purity: 99.5 wt %
- Transport Index for Criticality Control: 0.0

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 variations in density relative to temperature. Several possible geometric configurations of the solid UF_6 and the variations of density with respect to temperature were evaluated in the ORNL criticality calculation.

The 48X cylinder is hydrostatically tested and does not suffer any damage after accident testing is performed which would invalidate the hydrostatic test results. Hydrostatic testing has verified that water will not leak into the 48X cylinder after accident testing. The only moderation internal to the 48X 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.

6.3 Model Specification

The model is described in Section 4.1 of ORNL/TM-11947. The model is based upon the Paducah Tiger overpack and most of the calculations, including the worst case, used the outer dimensions of the overpack to maintain the spacing between packages, but replaced the actual overpack materials by water at the density of the interspersed moderator. This materials substitution is conservative, and makes the model applicable to the Paducah Tiger despite any material differences between the overpacks. The external dimensions of the Paducah Tiger are approximately 72 inches high by 76 inches wide by 153 inches long. The dimensions used in the model are slightly smaller (72.25 inches in diameter and 153.25 inches in length), resulting in closer, and therefore conservative, spacing between packages in the model array.

6.4 Criticality Calculation

The calculations described in the ORNL/TM-11947 report are performed using the CSAS25 sequence from the SCALE 4 computer code system with the 27 energy group ENDF/B-IV cross-section library. The calculations assume an internal geometric configuration of the contents to approximate a triangular pitch lattice arrangement, a temperature of 20 °C, and a varying water density to determine the optimum interspersed moderation. The k_{eff} values are found to be insensitive to temperature effects, fuel location in the cylinder, and cylinder spacing. The results of the study are summarized in Table 7 of the ORNL/TM-11947 report, and the worst case is summarized in Table 6.1-1.

7.0 OPERATING PROCEDURES

This chapter outlines the procedures for conducting the receiving inspection of the Paducah Tiger overpack, loading and unloading the overpack, and preparing the overpack for transport following loading or unloading. These procedures represent the minimum requirements to ensure safe and reliable operation of the overpack in accordance with this SAR and its Certificate of Compliance.

The Paducah Tiger overpack is designed to transport the 48X 10-ton UF_6 cylinder. The overpack provides thermal and impact protection of the cylinder in the normal conditions of transport and in the hypothetical accident conditions. Safe transport of the UF_6 requires that the cylinder be in good condition prior to transport in the overpack. Consequently, these procedures address the inspection and handling of the cylinder to the extent required for safe transport in the overpack. In preparation for transport, the cylinder must conform to ANSI N14.1 [1] which contains standards for inspecting and repairing the 48X cylinder.

7.1 Loading the Paducah Tiger

The Paducah Tiger is intended for the shipment of a 48X 10-ton cylinder. The cylinder may be full or contain a heel. Cylinders containing UF_6 must be inspected in accordance with ANSI N14.1. Cylinders which are empty (i.e., net weight less than 50 pounds) need not be handled in accordance with this procedure.

Prior to loading the cylinder into the overpack, the lower half (body) of the overpack must be secured to the floor or bed of the conveyance. The conveyance may be a dedicated rail car or a truck trailer.

7.1.1 Inspection of the Overpack and 48X Cylinder

Inspection of the overpack and the 48X cylinder is required to verify that both are acceptable for use. Defects identified in the inspection must be corrected before use.

1. Inspect the overpack in accordance with Table 8.2-1.
2. Inspect the 48X cylinder in accordance with the requirements of ANSI N14.1.
3. Visually inspect the cylinder lifting lugs prior to attachment of the lifting slings.
4. Perform a surface contamination survey and a radiation survey, and record the survey results.

7.1.2 Loading the Overpack

Loading of the overpack requires a suitable lifting device. The body of the overpack must be secured to the bed or floor of the conveyance prior to loading the cylinder into the overpack. Prior to loading the 48X cylinder into the overpack, verify that the UF_6 weight is either less than 350 pounds, or between 12,000 and 21,030 pounds; and that the pressure within the cylinder is less than 0 psig.

1. Using a suitable lifting device, place the cylinder into the overpack body with the valve end of the cylinder facing the lid guide in the body.
   CAUTION: The opposite (nonvalve) end of the cylinder is tapered. The tapered end of the cylinder must rest in the matching tapered shape of the body of the overpack. The body of the overpack may be damaged if the cylinder is not correctly oriented.

2. Using a suitable lifting device, install the aluminum stiffening plate between the cylinder skirt and the end plate, at the valve end of the overpack cavity.
   CAUTION: Ensure that the stiffening plate is oriented such that the larger opening is facing the cylinder.
3. Using a suitable lifting device, install the lid on the overpack body using the lid guide and guide pins to aid alignment.
4. Hook each of the 4 ratchet turnbuckles attached to the lower hold-down bracket in the body to the corresponding upper hold-down bracket in the lid to secure the two halves.
5. Tighten the 4 turnbuckles in any sequence to the point that allows the insertion of the 8 ball lock pins.
6. Insert the ball lock pins.
   NOTE: Ball lock pins are installed at 8 locations corresponding to the 8 guide pins in the body of the overpack.
7. Latch the turnbuckle handles to the side of the overpack using the rubber retainer straps.
8. Install a tamper-indicating device (TID) through the seal loops on one side of the overpack.
9. Perform a surface contamination survey and a radiation survey, and record the survey results.
   NOTE: The radiation levels may not exceed 200 mrem/hr (2 mSv/hr) at the overpack surface, or 10 mrem/hr (0.1 mSv/hr) at 1 meter from the overpack. Wipe samples must verify that removable radiological contamination on the package surface does not exceed 22 dpm/cm^2 for beta, gamma, and low toxicity alpha emitters, and 2.2 dpm/cm^2 for all other alpha emitting radionuclides. If these limits are exceeded, the controls specified in 10 CFR 71.47 are followed.

7.2 Unloading the Paducah Tiger

This procedure provides for inspecting the overpack upon receipt, opening the overpack, and removing the 48X cylinder.

7.2.1 Receiving Inspection

1. Perform radiation and contamination surveys on the conveyance and overpack(s) and record the results.
2. Visually inspect the overpack(s) for signs of damage and verify the presence of the tamper-indicating device (TID). Record any damage found.
3. If not already done, position the conveyance so that the overpack lid and the cylinder can be removed by a suitable lifting device.

7.2.2 Opening and Unloading the Overpack

This procedure provides for removing the 48X cylinder from the overpack. Once the cylinder is removed, it must be inspected in accordance with the requirements of ANSI N14.1.

1. Record the TID serial number and remove the TID.
2. Disengage the 8 ball lock pins securing the lid to the body of the overpack. If necessary, adjust tension on the ratchet turnbuckles.
3. Disengage the turnbuckle handle retainer straps.
4. Loosen the 4 turnbuckles in any sequence until each turnbuckle can be unlatched from the upper hold-down bracket in the overpack lid. Unlatch the turnbuckles.
5. Using a suitable lifting device, carefully lift the lid to clear the cylinder and move the lid to a suitable storage area.
   NOTE: Care should be taken to ensure that the lid is lifted vertically to avoid side pressure on the guide pins, and to avoid contact between the lid and the cylinder or aluminum stiffening plate.
6. Survey the cylinder for contamination and visually inspect the cylinder for signs of leakage of UF_6 and for damage.
7. Using a suitable lifting device, remove the aluminum stiffening plate from the overpack cavity and move it to the designated area.
8. Perform a contamination survey of the aluminum stiffening plate and record the results.
9. Visually inspect the 4 lifting lugs attached to the cylinder for damage.

10. Using a suitable lifting device, lift the cylinder from the overpack body and move it to the designated area.
    NOTE: Care should be taken to ensure the cylinder is lifted vertically from the body to avoid side pressure on the rubber shock isolators and isolator mounts.
11. Perform a contamination survey of the interior of the overpack body and record the results. Inspect the body for damage and foreign material and for signs of UF_6 leakage.

7.3 Preparing the Empty Paducah Tiger for Transport

The Paducah Tiger overpack may be transported with or without the 48X cylinder. If a filled cylinder, or a cylinder containing residual product ("heel") is to be transported in the overpack, then the overpack is prepared for transport in accordance with the procedures provided in Section 7.1. An empty Paducah Tiger overpack (i.e., one containing no 48X cylinder) is prepared for shipment in the following manner:

1. Using a suitable lifting device, install the aluminum stiffening plate between the cylinder skirt and the end plate, at the valve end of the overpack cavity.
2. Using a suitable lifting device, install the lid on the body using the lid guide and guide pins to aid alignment.
3. Hook the 4 ratchet turnbuckles attached to the lower hold-down brackets in the body to the corresponding upper hold-down brackets in the lid to secure the two halves.
4. Tighten the 4 turnbuckles in any sequence to the point that allows the insertion of the 8 ball lock pins.
5. Insert the ball lock pins.
   NOTE: Ball lock pins are installed at 8 locations corresponding to the 8 guide pins in the body of the overpack.
6. Latch the turnbuckle handles to the side of the overpack using the rubber retainer straps.
7. Perform a surface contamination survey and a radiation survey, and record all survey measurements.
   NOTE: This survey is required even if the overpack does not contain a 48X cylinder. A TID is not required for overpacks that do not contain a cylinder.

7.4 References

1. American National Standards Institute, *American National Standard for Nuclear Materials, Uranium Hexafluoride - Packaging for Transport*, ANSI N14.1, New York, NY, 1990.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This chapter describes the acceptance tests and maintenance program used to assure compliance of the Paducah Tiger with this SAR and its Certificate of Compliance. The Paducah Tiger is an overpack which provides protection for the 48X 10-ton UF_6 cylinder during normal conditions of transport and during hypothetical accident conditions.

Containment of the UF_6 is provided by the 48X cylinder. The acceptance test and maintenance requirements of the 48X cylinder are described in this section for completeness. These requirements are in accordance with the requirements of ANSI N14.1, "Uranium Hexafluoride - Packaging for Transport." [1]

8.1 Acceptance Tests

Prior to first use of the Paducah Tiger overpack, the inspections, measurements and component tests specified in this section are completed.

8.1.1 Visual Inspection

Each Paducah Tiger overpack is visually inspected to document compliance with the overpack license drawings.

The inspection includes:

- Overpack outer skin for corrosion, cracks, dents and holes
- Welds for finish
- Guide pins
- Turnbuckles
- Lifting brackets
- Neoprene sponge rubber seal
- Rubber shock isolators
- ISO corners and tie-down brackets
- Dimensions important to 48X cylinder interchangeability between overpacks
- Overpack nameplate
- Aluminum stiffening plate and tabs

8.1.2 Structural and Pressure Tests

There are no structural or pressure tests that are conducted on the Paducah Tiger overpack.

8.1.3 Leak Tests

The Paducah Tiger overpack components do not form a containment boundary. Consequently, no leak tests are performed on the overpack.

Containment of the UF_6 and any residual heel material is provided by the 48X cylinder. The containment boundary is formed by the cylinder body, the 1-inch cylinder valve used for filling and emptying the cylinder, and the cylinder plug.

8.1.4 Component Tests

Individual components of the overpack are tested as described in this section. The principal components are the urethane foam used in fabricating the overpack shell to provide for impact and thermal protection of the cylinder during a hypothetical fire accident event, the rubber shock isolators which prevent damage from vibrations during transport only, and the stiffening plate which provides impact and puncture protection for the cylinder during a hypothetical drop accident event. Test acceptance criteria are established based on the design requirements of the component.

8.1.4.1 Valves, Rupture Disks, and Fluid Transport Devices

The Paducah Tiger has a drain plug at either end of the overpack used for decontamination and for draining water from the body of the overpack, if necessary. The drain plugs are an operational convenience and do not serve a safety function. There are no other valves, rupture disks or fluid transport devices in the overpack.

8.1.4.2 Gaskets

The Paducah Tiger uses a neoprene sponge rubber gasket as a weather seal at the seam of the lid and body, which is intended to preclude the entry of rain water and water spray. The weather seal does not provide containment, and is not leak tested. The gasket is visually inspected for form and fit. It should be flat without gaps or tears.

8.1.4.3 Shock Isolators

The rubber shock isolators are visually inspected for proper configuration/installation and are tested for hardness using a durometer. The hardness must be 70 ± 5 durometer.

8.1.4.4 Urethane Foam

Thermal and impact protection of the 48X cylinder is provided by the overpack steel shells (outer skin and inner liner) and a polyurethane closed cell foam that is batch mixed and poured in place in the lid and body sections of the overpack. The material density, and mechanical and thermal properties, of the foam are determined by physical testing performed on specimens poured from the batch mix. Two nominal material densities, 18 lb/ft^3 and 6 lb/ft^3 are used in the overpack. Specimens of both foam densities are tested. Foam density is calculated and reported in accordance with ASTM D 1622.[2]

Mechanical properties, including compressive, tensile and shear strength, are tested in accordance with ASTM D 1621, D 1623, and C 273, respectively.[3, 4, 5] A specimen of low-density foam is tested for puncture resistance using a compression testing fixture, and for water absorption. The water absorption test conforms to ASTM D 2127 [6], or the maximum water absorption is certified by the fabricator. In either case, water absorption does not exceed 6%.

8.1.4.5 Stiffening Plate

The aluminum stiffening plate is inspected for conformance with dimensional requirements.

8.1.5 Tests for Shielding Integrity

The Paducah Tiger has no features that are intended to provide shielding. No tests for shielding integrity are required.

8.1.6 Thermal Acceptance Test

The Paducah Tiger has no features that are intended to provide thermal protection of the contents in normal conditions of transport. In the hypothetical accident events, the contents are protected in the thermal event by the overpack shells and by the urethane foam enclosed between the inner liner and outer skin of the overpack. Tests performed on the foam are described in Section 8.1.4.4.

8.2 Maintenance Program

The maintenance program for the Paducah Tiger overpack consists of a series of inspections performed prior to each shipment, and inspections and tests performed every 5 years. The required inspections and tests for the overpack are shown in Table 8.2-1.

The general periodic inspection and test requirements for the overpack are provided in Section 7.4 of ANSI N14.1. Similar requirements for the 48X cylinder are provided in Section 6.3 of the Standard. The required visual inspections of the Paducah Tiger and 48X cylinder are described in Section 8.2.7 of this SAR.

8.2.1 Structural and Pressure Tests

There are no structural or pressure tests that are conducted on the Paducah Tiger overpack.

8.2.2 Leak Tests

There are no leak tests performed on the Paducah Tiger overpack. Containment of the UF_6 is provided by the 48X cylinder. The cylinder and its 1-inch cylinder valve are leak-tested in accordance with ANSI N14.1, Sect. 6.3, during the 5-year recertification inspection.

8.2.3 Subsystem Maintenance

The Paducah Tiger overpack, and the 48X cylinder, have no subsystem maintenance requirements.

8.2.4 Valves, Rupture Disks, and Gaskets on the Containment Vessel

The Paducah Tiger overpack does not have a containment boundary. Containment of the UF_6 and residual heel material is provided by the 48X cylinder, which has one valve and one drain plug, but no rupture disks or gaskets. The valve is periodically tested and maintained in accordance with the requirements of ANSI N14.1, Section 6.3.

8.2.5 Shielding

The Paducah Tiger does not have any features that are intended to provide shielding. Consequently, there are no shielding component maintenance requirements.

8.2.6 Thermal

There are no periodic maintenance requirements for the foam insulation material. As shown in Table 8.2-1, the tare weight of the overpack is measured every 5 years, coincident with recertification, to verify that the foam has not absorbed any significant quantity of water through defects in the outer steel skin that encases the foam. Any increase in measured weight over 150 pounds must be evaluated to determine its cause.

8.2.7 Visual Inspections and Periodic Maintenance

The required periodic visual inspections are shown in Table 8.2-1. The inspection requirements include those specified in Section 7.4 of ANSI N14.1 for outer protective packaging. Inspections are documented using written inspection procedures and checklists. Nonconforming conditions must be evaluated, and repaired if required. Compliance with the acceptance criteria specific to the repair assures that the repaired overpack conforms to the as-certified configuration.

An inspection for degradation of welds is performed in conjunction with the five year inspections. Any damaged or degraded weld is subject to further examination, such as dye penetrant testing. Damaged welds are repaired by removing the defect and re-welding according to the applicable ASME code requirements, in accordance with Section 7.4.3 of ANSI N14.1.

An inspection for corrosion or severe pitting shall be performed. The inspection shall include assurance that severe pitting has not reduced the wall thickness of the overpack inner liner or outer skin by more than 10% of the nominal wall thickness of the general area inspected. A stainless steel plate may be welded to the base of those Paducah Tiger overpacks where severe pitting of the steel outer skin on the base of the overpack exists. If the reduction in wall thickness cannot be determined by visual inspection and measurement, other test methods, such as ultrasonic testing, shall be used.

During the periodic and 5-year inspections, the overpack is inspected for warping, distortion, or other penetration damage of the outer skin that would prevent an adequate closure of the package (body and lid mating surfaces are flush along entire perimeter), or that reduce the effectiveness of the overpack by allowing water to enter the foam. Marks and small dents (~ 1/2 inch deep) in the outer skin are acceptable. Other damage or conditions require evaluation and correction as necessary.

The 48X cylinders are inspected internally and pressure tested at 400 psig at intervals not to exceed 5 years, except cylinders already filled prior to the 5-year expiration date, in accordance with ANSI N14.1, Section 6.3.2. Cylinders requiring repair of welds and other defects to the cylinder shell, are repaired in accordance with ANSI N14.1, Section 6.3.3. Repaired cylinders must meet the inspection and hydrostatic test requirements of ANSI N14.1, Section 6.3.2, before being returned to service.

8.2.8 Maintenance Program Schedule

Table 8.2-1 presents the overall maintenance inspection schedule for the Paducah Tiger overpack.

Table 8.2-1 Paducah Tiger Overpack Maintenance Inspection Schedule

Item	Prior to Each Shipment	Five Year Recertification
Visually inspect guide pins and lid guide	X	X
Visually inspect turnbuckles and ball lock pins	X	X
Visually inspect lifting brackets	X	X
Visually inspect overpack outer skin for holes, distortions, and dents	X[4]	X
Visually inspect neoprene sponge rubber seal	X	X
Visually inspect aluminum stiffening plate and tabs	X	X
Visually inspect overpack cavity for excessive debris, standing water, or other foreign objects	X	X
Visually inspect rubber shock isolators	X	X
Measure hardness of rubber shock isolators		X
Visually inspect welds[1]		X
Visually inspect ISO corners[1,2]		X
Visually inspect for corrosion[3]	X[4]	X
Measure tare weight		X

1. Depending on what damage can be determined visually, these features may also require nondestructive examination (i.e., ultrasonic, dye penetrant).
2. Upper ISO corners have been rendered inoperable.
3. Depending on what level of corrosion can be determined visually, ultrasonic inspection may be required to verify that the wall thickness of the overpack inner liner or outer skin has not been reduced to less than 90% of the nominal wall thickness of the general area inspected.
4. Inspection is applicable to accessible surfaces only, except for the bottom of the overpack.

8.3 References

1. American National Standards Institute, *American National Standard for Nuclear Materials, Uranium Hexafluoride - Packaging for Transport,* ANSI N14.1, New York, NY, 1990.

2. American Society for Testing and Materials, *Apparent Density of Ridge Cellular Plastics*, ASTM D 1622, Philadelphia, PA.

3. American Society for Testing and Materials, *Compressive Properties of Ridge Cellular Plastics*, ASTM D 1621, Philadelphia, PA.

4. American Society for Testing and Materials, *Tensile Properties of Ridge Cellular Plastics*, ASTM D 1623, Philadelphia, PA.

5. American Society for Testing and Materials, *Shear Test in a Flatwise Plane of Flat Sandwich Constructions or Sandwich Cores*, ASTM C 273, Philadelphia, PA, 1991.

6. American Society for Testing and Materials, *Water Absorption of Ridge Cellular Plastics*, ASTM D 2127, Philadelphia, PA.