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REVIEW OF THE TRUPACT-III TYPE B SHIPPING PACKAGE

May 2007



PECOS MANAGEMENT SERVICES, INC.

**ISO-2 Project
Carlsbad, NM**

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ACRONYMS

ALARA	As Low As Reasonably Attainable
ANSI	American National Standard Institute, Inc.
ASTM	American Society for Testing and Materials
CG	Center of Gravity
CH	Contact Handled
CTU	Certified Test Unit
DOE	U. S. Department of Energy
HAC	Hypothetical Accident Conditions
NCT	Normal Conditions of Transport
NRC	Nuclear Regulatory Commission
PECOS	PECOS Management Services, Inc.
psig	Pound/Square Inch Gauge
SLB	Standard Large Box
SNL	Sandia National Laboratory
SS	Stainless Steel
TRU	Transuranic
TRUPACT-III	Transuranic Container Transporter Model 3
UNS	Unified Numbering System
VOC	Volatile Organic Compound
WIPP	Waste Isolation Pilot Plant

REVIEW OF THE TRUPACT-III TYPE B SHIPPING PACKAGE

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I. PURPOSE AND SCOPE

The purpose of this report is to provide a review of the testing, safety considerations, and compliance with procedures used for Nuclear Regulatory Commission (NRC) certification of the TRUPACT-III shipping package. The TRUPACT-III is an NRC-defined Type B package designed to retain the integrity of containment and shielding required for its radioactive contents when subjected to normal conditions of transport and hypothetical accident conditions (HAC) set forth in 10 CFR 71. This review addresses the design and testing of TRUPACT-III, which will be used for shipment of contact handled (CH) transuranic (TRU) waste to the Waste Isolation Pilot Plant (WIPP). Original design specifications and revisions to the design in response to changes and concerns from the NRC were evaluated, as were testing procedures and results. PECOS Management Services, Inc. (PECOS) conducted reviews of publicly available literature, regulatory submittals and responses, drawings, and specifications, including those listed in the *References* and *Bibliography* sections. TRUPACT-III drop tests were observed by PECOS, and design and testing personnel were interviewed.

II. BACKGROUND

Nearly 25 percent of the current inventory of CH TRU waste pending disposal at WIPP is packed in boxes that are too large to fit in existing NRC-certified TRUPACT-II or HalfPACT transportation packages. The boxes that currently contain the CH TRU waste are nominally between 1.22- × 1.22- × 2.13-m and 1.52- × 1.52- × 2.44-m in size (4 x 4 x 7 ft to 5 x 5 x 8 ft). Unless a new shipping container is designed and certified by the NRC, waste contained in these oversized boxes will have to be repackaged into smaller containers before they can be transported. Repacking will increase worker exposure and the risk for unplanned releases. The rectangular parallelepiped geometry of the oversized boxes also dictates use of a rectangular cross-section for the payload cavity of a new shipping container rather than the cylindrical cavity of the TRUPACT-II.

The three basic design objectives of the TRUPACT-III are: 1) it must match the geometry of the oversized containers; 2) it must meet the requirements of 10 CFR 71 and the As Low As Reasonably Attainable (ALARA) objectives for exposure of workers, the public, and the environment; and 3) it has to be transportable by highway without obtaining oversized permits. The TRUPACT-III is designed and fabricated by Packaging Technology, Inc.

III. DESIGN AND TESTING REQUIREMENTS

Design and testing requirements for the TRUPACT-III are specified in 10 CFR 71 and fall into three categories, as exemplified in the following three tables. The general design requirements for all radioactive material packages, as stated in 10 CFR 71.43,¹ are presented in *Table 1*. Test procedures and testing requirements for Type B packages for normal conditions of transport (NCT), as stated in 10 CFR 71.71,² are presented in *Table 2*. Test procedures and testing requirements for Type B packages for hypothetical accident conditions (HAC), as stated in 10 CFR 71.73,³ are presented in *Table 3*.

TABLE 1. General Standards for all Radioactive Material Transport Packages.

STANDARD	CRITERIA
Dimension	The smallest overall dimension of a package may not be less than 10 cm (4 in).
Tamper Evidence Seal	The outside of a package must incorporate a feature, such as a seal, that is not readily breakable and that, if intact, would be evidence the package has not been opened by unauthorized persons.
Containment System	Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package.
Materials and Construction	A package must be made of materials and construction that ensure there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents—including possible reaction resulting from inleakage of water—to the maximum credible extent. Account must be taken of the behavior of material under irradiation.
Package Valve	A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage.
Radioactive Release	A package must be designed, constructed, and prepared for shipment to ensure that under the tests specified in part 71.71, there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging.
Surface Temperature	A package must be designed, constructed, and prepared for shipment so that in still air at 38°C (100°F) and in the shade, no accessible surface of a package would have a temperature exceeding 50°C (122°F) in a nonexclusive use shipment, or 85°C (185°F) in an exclusive use shipment.
Continuous Venting	A package may not incorporate a feature intended to allow continuous venting during transport.

Evaluation of each package design under NCT must include a determination of the effect on that design of the conditions and tests specified in *Table 2*. Separate specimens may be used for the free drop test, the compression test, and the penetration test if each specimen is subjected to the water spray test before being subjected to any of the other tests.

TABLE 2. Evaluation for Normal Conditions Incident to Transport.

EVALUATION	CRITERIA	DURATION
Ambient Heating	38 degrees C (100 degrees F)	<i>12 hours</i>
Ambient Cooling	-40 degrees C (-40 degrees F)	<i>12 hours</i>
Reduced External Pressure	25 kPa (3.5 lbf/in ²) absolute	<i>N/A</i>
Increased External Pressure	140 kPa (20 lbf/in ²) absolute	<i>N/A</i>
Vibration	Vibration normally incident to transport	<i>Not specified</i>
Water Spray Test	5 cm/h (2 in/h)	<i>At least 1 hour</i>
Free Drop	Less than 5,000 Kg (Less than 11,000 lbs) - 1.2 m (4 ft.) 5,000 to 10,000 Kg (11,000 to 22,000 lbs) - 0.9 m (3ft.) 10,000 to 15,000 Kg (22,000 to 33,100 lbs) - 0.6 m (2 ft.) More than 15,000 Kg (More than 33,100 lbs) - 0.3 m (1 ft.)	<i>1.5 to 2.5 hours after the conclusion of the water spray test</i>

Evaluation for HAC is to be based on sequential application of the tests specified in 10 CFR 71.73, in the order indicated, to determine their cumulative effect on a package or array of packages. An undamaged specimen may be used for the water immersion test. To demonstrate compliance, for both the NCT and HAC requirements, the ambient air temperature before and after the tests (with the exception of the water immersion test) must remain constant at a value between -29° C (-20° F) and +38° C (+100° F). The most unfavorable conditions for the feature under consideration must be used. The initial internal pressure within the containment system must be the maximum normal operating pressure of 25 psig (as stated in Packaging Technology, Inc.’s Draft Certification Test Plan),⁴ or the most unfavorable pressure, consistent with the testing temperature.

TABLE 3. Evaluation for Hypothetical Accident Conditions.

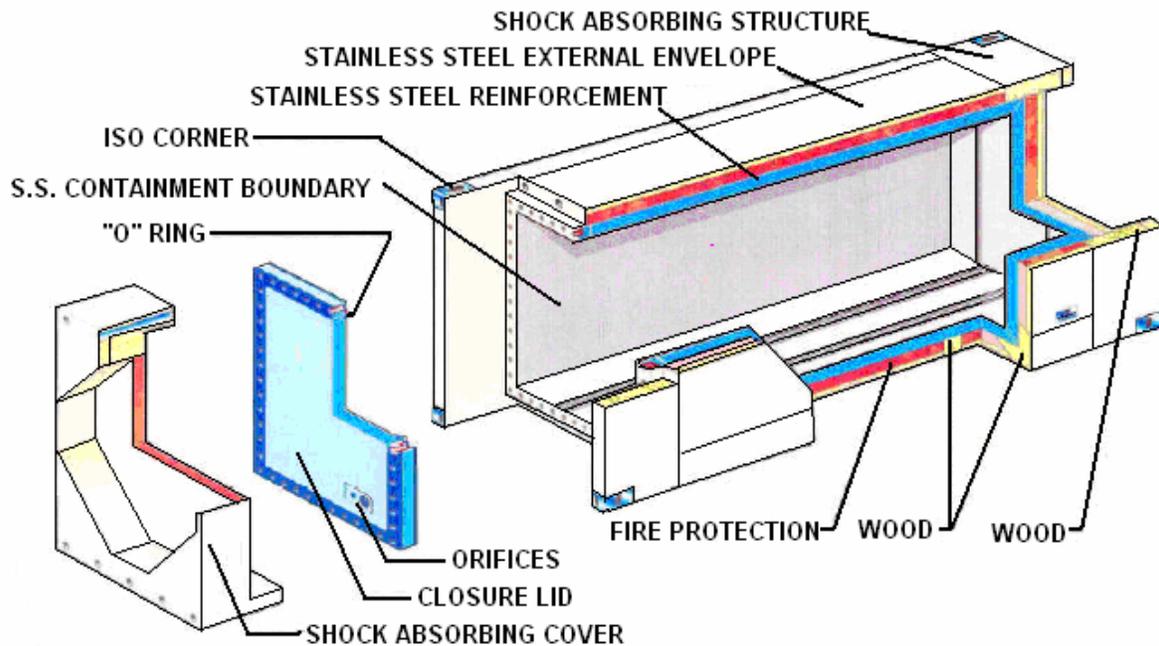
EVALUATION	CRITERIA
Free Drop	9 m (30 ft)
Crush	Drop of a 500-kg (1100-lb) mass from 9 m (30 ft) onto the specimen The crush test is required only when the specimen has a mass not greater than 500 kg (1100 lb), an overall density not greater than 1000 kg/m ³ (62.4 lb/ft ³) based on external dimension, and radioactive contents greater than 1000 A ₂ * not as special form radioactive material.
Puncture	A free drop of the specimen through a distance of 1 m (40 in) 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. The bar must be 15 cm (6 in) in diameter, with the top horizontal and its edge rounded to a radius of not more than 6 mm (0.25 in), and of a length as to cause maximum damage to the package, but not less than 20 cm (8 in) long. The long axis of the bar must be vertical.
Thermal	Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800 degrees C (1475 degrees F).
Immersion	All packages. A separate, undamaged specimen must be subjected to water pressure equivalent to immersion under a head of water of at least 15 m (50 ft). For test purposes, an external pressure of water of 150 kPa (21.7 lbf/in ²) gauge is considered to meet these conditions. For fissile material subject to Section. 71.55, in those cases where water in-leakage has not been assumed for criticality analysis, immersion under a head of water of at least 0.9 m (3 ft) in the attitude for which maximum leakage is expected.

* A₂ means the maximum activity of radioactive material, other than special form material, LSA, and SCO material, permitted in a NRC defined Type A package. This value is either listed in Appendix A, Table A-1, (10 CFR 71), or may be derived in accordance with the procedures prescribed in Appendix A of this part.

To be approved as a Type B package, all the requirements of 10 CFR 71 must be satisfied, and the validated testing results submitted to the NRC for review and certification.

IV. DESIGN

TRUPACT-III was originally designed to be very similar in external configuration to a 2.44 × 2.59 × 6.10-m (8 x 8.5 x 20-ft.) shipping package commonly used for highway transportation. *Figure 1* presents an exploded view of the TRUPACT-III. As the drawing illustrates, the package includes a containment boundary structure, a closure lid, and a shock-absorbing cover.



*Figure 1. TRUPACT-III Transportation Package.*⁴

The containment boundary and all primary structural members of the body are fabricated from Unified Numbering System (UNS) S31803 stainless steel (SS). The containment boundary structure consists of an inner shell that is backed by a corrugated sheet of UNS S31803 SS and an outer structural shell. Completely surrounding the containment boundary structure is a unique combination of energy absorbing and insulating materials that provide both structural and thermal protection. Wood and foam are enclosed between the containment boundary structure and an outer packaging skin, which is also fabricated from UNS S31803 SS. Embedded within the wood and foam components are UNS S31803 SS plates of varying thickness to mitigate the consequence of an HAC puncture event (1-m [3.28 ft.] drop onto a 15-cm [6 in.] diameter puncture bar).

In the immediate vicinity of the closure lid O-ring seal, calcium silicate insulation is employed along with a closure bolt protection plate structure to protect the closure area both structurally and thermally. Butyl O-ring seals, in a face seal configuration, form a single level of containment. Lid closure is achieved using 44 American Society for Testing and Materials (ASTM) A320 Grade L43 fasteners tightened to 1,600 N-m (1,181 ft-lbs) torque each. The protective overpack is secured using 10 ASTM A320 Grade L43 bolts, also tightened to 1,600 N-m (1,181 ft-lbs) torque each.

The original overall external dimensions for the TRUPACT-III were 2.50-m (8.2 ft.) wide, 2.65-m (8.69 ft.) high, and 6.06-m (19.9 ft.) long. The internal cavity was 1.84-m (6.04 ft.) wide, 2.00-m (6.56 ft.) high, and 4.51- m (14.8 ft.) long. The maximum gross weight of the loaded TRUPACT-III was 30,000 kg (66,139 lbs), including the maximum allowed payload weight of 5,800 kg (12,787 lbs). At this size and weight, most shipments would not meet standard weight specifications for highway transport.

Preliminary package evaluation was based on half-scale model testing and computer analysis. The NRC identified several structural and thermal issues during its review of this evaluation. Consequently, the TRUPACT-III was redesigned to meet highway weight limits and to rectify the structural and thermal issues raised by the NRC. The design was shortened by 6 feet, resulting in an overall external dimension of 2.50-m (8.2 ft.) wide, 2.65-m (8.69 ft.) high, and 4.3-m (14.0 ft.) long. The internal cavity is 1.84-m (6.04 ft.) wide, 2.00-m (6.56 ft.) high, and 2.77- m (9.1 ft.) long. The maximum gross weight of the loaded, redesigned TRUPACT-III is 24,993 kg (55,100 lbs) including a maximum allowed payload weight of 5,126 kg (11,300 lbs). These dimensions allow the TRUPACT-III to accommodate the existing oversized boxes of CH TRU waste, while meeting highway weight and safety standards.

The specific NRC concerns and the changes made to resolve them by the manufacturer, Packaging Technology, Inc.,⁴ are summarized below.

NRC Concern: Non-linear analysis showed yielding in the seal region.

Design Changes: As shown in *Figure 2*, the seal region design changes are as follows:

- Thickened inner and outer body flange by 50 percent
- Thickened outer flange plate by 25 percent
- Extended bolting bosses through body flange
- Added “dogleg” to radial rib
- Conduct full-scale impact test and demonstrate leak tightness

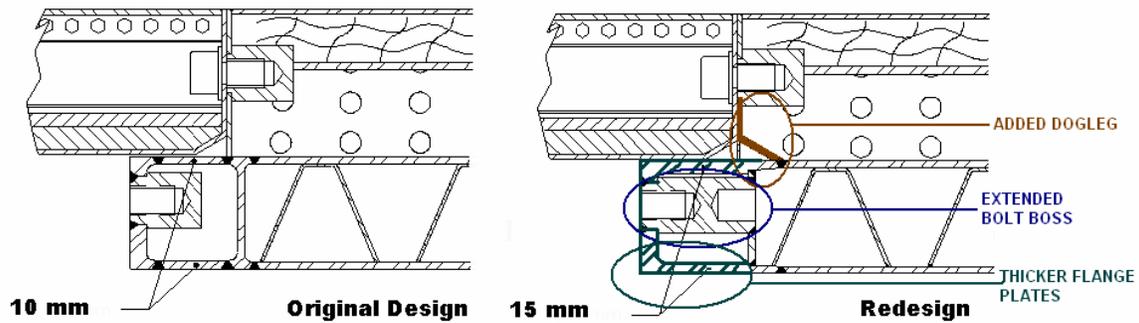


Figure 2. Original and redesign of body flange region.⁴

NRC Concern: Margins were too small given variability of impact limit strength:

Design Changes: The design changes as shown in Figure 3 are as follows:

- Strengthened flanges
- Improved properties of impact absorbing materials (e.g., foam)

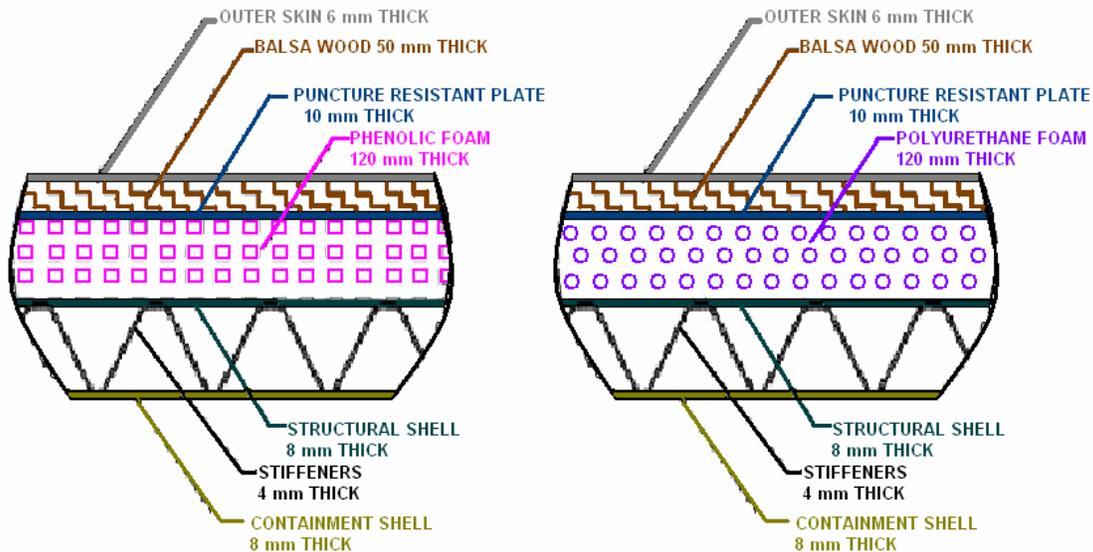


Figure 3. Original and redesign of wall cross-section.⁴

NRC Concern: Puncture tests were not performed on revised overpack

Design Response: Puncture drop tests will be performed on a prototypic certification test unit.

NRC Concern: Temperature limits were exceeded for materials used in the containment structural assembly.

Design Changes

Included:

- Refined thermal analysis using finer mesh
- Changed from phenolic foam to polyurethane foam

V. TESTING

The TRUPACT-III Transportation Package Certification Test Plan⁵ states, “There are two primary objectives for the certification test program.” They are:

- To demonstrate that after a worst-case series of free drop and puncture events, the package containment is leak-tight.
- To further demonstrate that no deformations will be incurred that would lead to failure of the containment under the subsequent HAC fire event.

The test program was conducted according to the following protocol.

The licensing basis for the TRUPACT-III package will be primarily a demonstration by test as stated in the TRUPACT-III Transportation Package Certification Test Plan.⁵ The following measurements must be taken to support this demonstration:

1. **Helium Leakage Rate Testing.** *A helium leakage rate test of the containment seal, per American National Standard Institute, Inc. (ANSI) N14.5 will be performed after closing the package and prior to opening the package. At intermediate points in the test program, helium leakage rate testing or the application of a hard vacuum may be employed as a check. At the conclusion of all testing, the vent/sampling port and containment boundary will also be helium leakage rate tested at or very slightly above atmospheric pressure. The acceptance criterion is leak-tight, or 1×10^{-7} atm-cc/sec, air.*
2. **Measurements of the crushed overpack.** *Detailed photographs or hand sketches of the free drop and puncture damage, including length of any split weld seams, will be created.*
3. **Accelerations of the free drop impacts.** *Several accelerometers will be arranged redundantly on the package surface. Signals will be recorded and filtered to capture the rigid body deceleration of impact. The filtering frequency will be chosen after analysis of the raw data.*

4. **Temperature.** *For the cold tests, the temperature of several locations of the certified test unit (CTU) will be monitored to ensure that relevant portions of the impact limiting materials are at or below the required temperature. The temperature will also be monitored in the ambient temperature tests to ensure the package has been allowed to warm as much as possible prior to the two ambient free drop tests.*

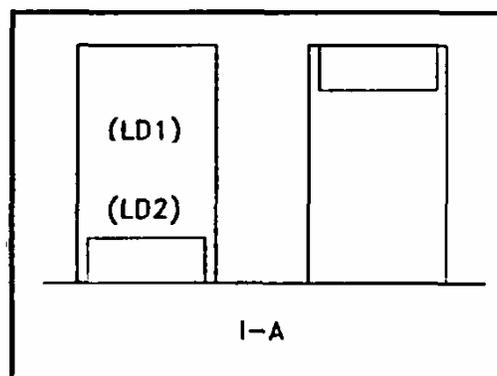
The free drop and puncture testing was performed at Sandia National Laboratory (SNL). The payload was simulated using 6,746 kg [14,875 lb] of aluminum bars (30% overweight). As described below, several orientations were tested to ensure that the worst-case series of free and puncture drop events have been taken into account. The primary means used to record results of the certification testing consisted of physical measurements and observations of the CTU before and after each free drop and puncture test. Each free drop impact was recorded using accelerometers. Conventional speed video cameras and still photography recorded each event. High-speed filming was also used.

VI. FINDINGS

The following describes the nine (9) tests that were performed by SNL and the observations made by PECOS. Due to unexpected changes in scheduling, PECOS personnel were only able to observe five of the nine tests. The drawings are taken from the TRUPACT-III Transportation Package Certification Test Plan.⁵

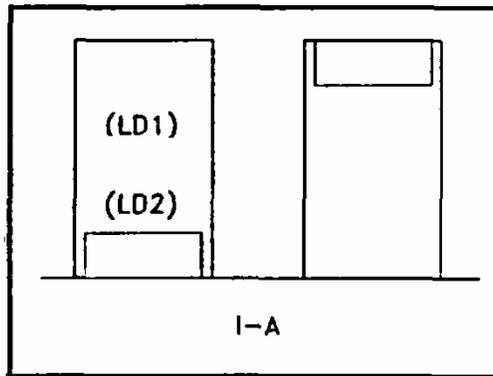
ONE-FOOT DROP TEST:

- **One-Foot Free Drop (I-A):** The CTU was oriented vertically and dropped from a height of 0.3-m striking flat on the lid end. Damage was negligible.

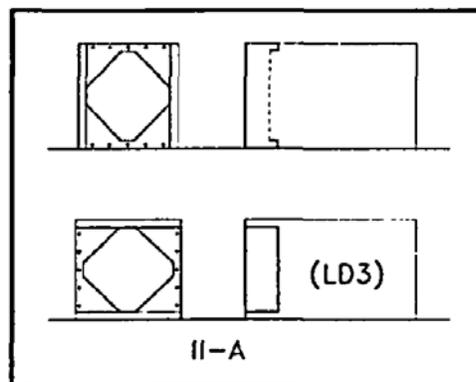


THIRTY-FOOT DROP TESTS:

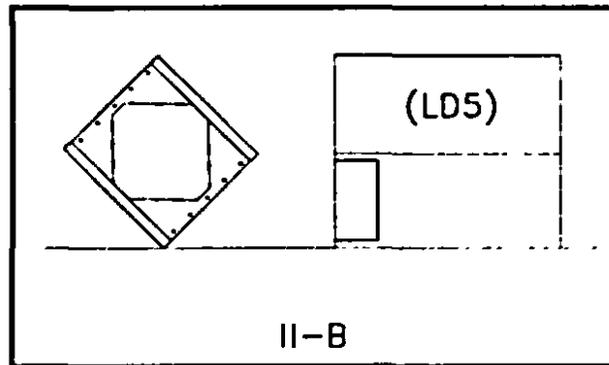
- **Flat End Free Drop (I-A):** The CTU was tested in a lid-down orientation under maximum-impact conditions. Resulted in 1.15-inch crush of the shock absorbing cover. Vacuum test results were acceptable.



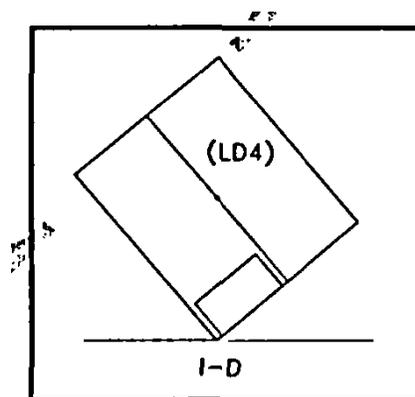
- **Flat Side Free Drop (II-A):** The CTU was dropped in the side orientation, with the impact surface horizontal under maximum-impact conditions. Dr. Jerry Fox, Director, ISO-2 Project Director, observed the test and reported that it was performed in accordance with the Draft Certification Test Plan. The CTU was chilled to a temperature of -20° F. Inspection of the cask after the drop showed an estimated 12 inch tear along a weld on the outside skin at the bottom leading up from the plane of contact. There were a few other very small indications of damage to the outside skin. The vacuum test results were acceptable, and there was negligible crush damage to the CTU.



- **Side Angle Free Drop (II-B):** The CTU was tested in the side-edge orientation. To obtain maximum deformation, the test was performed at ambient temperatures with results extrapolated to maximum temperatures by analysis. Julie Archuleta, PECOS Staff Engineer, observed the test and reported that it was performed in accordance with the Draft Certification Test Plan. The CTU bounced several times and then tilted onto its side. This resulted in a 12-inch-wide dent; the vacuum was not tested.

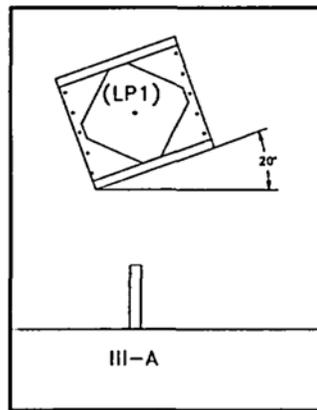


- **Center of Gravity (CG) Over Corner (I-D):** The CTU was tested in a lid-down, CG over corner orientation at ambient temperature. Vicente Rojas, PECOS Staff Engineer, observed the test and reported that it was performed in accordance with the Draft Certification Test Plan. The CTU sustained a crushed corner, and a weld used to repair a 12-inch-long gash sustained during the flat side free drop test failed. The CTU did not pass the vacuum test.

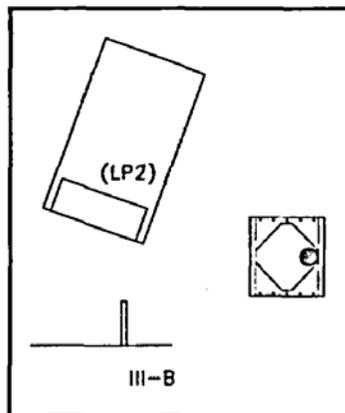


PUNCTURE TESTS:

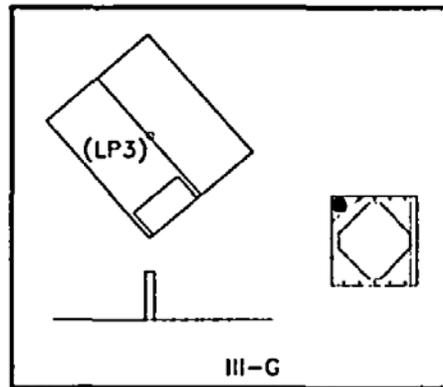
- **Puncture on the Side (III-A):** In this orientation, the bar axis was aimed through the CG of the package, and was oriented at 70° to the package surface (or 20° off the normal). The puncture took place on the side of the package that experienced the flat side free drop impact. The side sustained minor damage with no breach of containment.



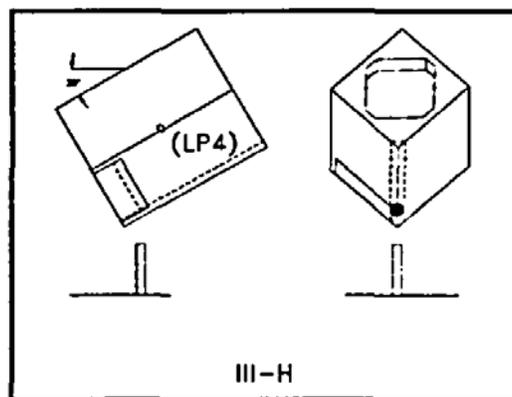
- **Puncture on the Overpack Cover (III-B):** In this orientation, the bar axis was aimed through the CG of the package, at an angle that was as oblique as possible considering the geometry of the overpack-cover octagonal recess. The impact point was on the recessed octagonal surface. This puncture challenged the puncture-resistant plate near its edge. The test resulted in minor damage with no breach of the puncture-resistant plate.



- **Puncture on the CG-over-Corner Drop Damage (III-G):** The damage from the CG over-corner free drop was expected to result in the greatest crush distance. Therefore, this puncture could have penetrated deeper than any other orientation. Vicente Rojas, PECOS Staff Engineer, observed the test and reported that it was performed in accordance with the Draft Certification Test Plan. A stationary 6-inch solid mild steel punch penetrated 5 inches into the outer skin of the package.



- **Puncture on the Side-Edge Drop Damage (III-H):** The side-edge drop damage could result in deformation in the vicinity of the thermal shield. This test resulted in a 4-inch penetration depth, with minor damage to the CTU.



Evaluation for HAC is based on sequential application of the tests specified in *Table 3*, in the order indicated. PECOS confirmed that the tests were performed in the prescribed manner and order. The drop tests were performed on a single package; the damage resulting from each test was recorded and repaired before proceeding to the next test.

The maximum combination of free and puncture drop deformation will be used in the thermal analysis to show that under these worst-case conditions, the elastomer O-ring seal temperature does not exceed safe limits during the HAC fire event. In addition, the drop test results will be analyzed to ensure that the prototype TRUPACT-III CTU structure does not exceed the temperature limit for the structural material.

At the completion of the drop tests, the TRUPACT-III package was returned to Carlsbad for an autopsy and performance of post-impact helium leakage rate testing, which was executed to demonstrate that the containment boundary is leak-tight per ANSI N14.51.

The autopsy found a 36-inch-long break in the outer weld seam, which exposed the polyurethane foam and wood between the containment boundary structure and the outer packaging skin. To resolve this problem, Packaging Technology, Inc. will only use the gas tungsten arc welding process and will eliminate vertical down welding for root passes of all bevel and groove welds.⁶

Upon removal of the shock-absorbing cover from the shipping package, small aluminum bits (from the simulated contents) were found on the outside of the outer Butyl O-ring. These aluminum shavings were also found between the O-rings, suggesting that a breach occurred during a drop test. It is believed that the breach may have occurred during a drop test performed at -20° F. As a result, the post-test helium leakage rate test of the closure lid containment O-ring seal was not successful. Packaging Technology, Inc. and the Department of Energy (DOE) have suggested several possible reasons for the breach of the O-rings. First, the clamping bolts were found to have been deformed 0.015 inches in length and were 0.007 inches out of alignment; this may have affected the seal. The closure bolt washers were also found to be deformed under the bolt heads. It is also possible there was too much space behind the O-rings themselves, causing compression into the seating and a breach in the seal. It was concluded by the DOE that debris and not structural inadequacy was the sole cause of post-test leakage rate test failure.⁶ Packaging Technology, Inc. will replace the original design washers used with the closure bolts with hardened washers. The debris shield shown in *Figure 4* will be incorporated into the TRUPACT-III design to block particles from entering the closure lid joint during a free drop impact.

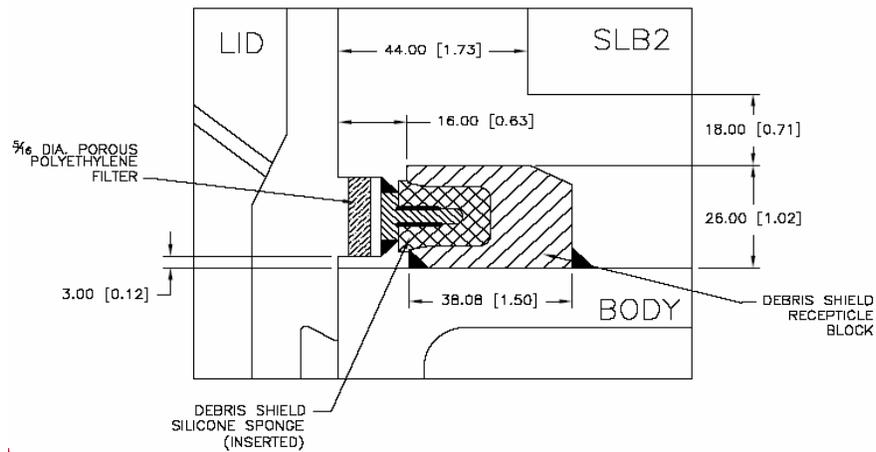


Figure 4. Debris shield design.⁶

Four Gas Pressure Rise tests were performed by independent ANSI-certified technicians according to ANSI N14.5-1997,⁷ leakage rate test standards. This standard states: “One problem with this method is outgassing (the release of gases from the surfaces of the test item when the item is evacuated).” To alleviate this problem, the inner containment vessel was evacuated for three weeks prior to testing to ensure accuracy of test results. After being evacuated, the TRUPACT-III was pressurized to 14.7 pounds force/square inch (psi) for each test, and the pressure was monitored for 10 hours to observe any changes. The TRUPACT-III passed these four leakage rate tests.

The required thermal analysis and the HAC fire event computer simulation have not been made available at this time. Packaging Technology, Inc. and DOE plan to demonstrate the effectiveness of the debris shield by discussion and analysis. The seal design will be tested using either the bench seal test or full scale testing. The intent of Packaging Technology, Inc. is to request that design changes be taken into consideration without additional retesting of a prototype.

TRUPACT-III was intended to have an inner standard large box (SLB) to contain the TRU waste; the SLB was not used during testing and may have affected the results of the drop tests.

VII. CONCLUSIONS

PECOS concludes that Packaging Technology, Inc. has made appropriate design changes to address the design faults exposed by the drop tests.

VIII. RECOMMENDATIONS

Given the issues related to the drop tests, it is the recommendation of PECOS that the TRUPACT-III design should be modified, and that the redesigned TRUPACT-III should be retested as required by 10 CFR 71. It is also recommended that DOE incorporate the SLB in any additional testing, as it was intended to be included in TRUPACT-III shipments.

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