IMPACT, PUNCTURE AND THERMAL TESTING OF TRUPACT-I

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Abstract

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The Transuranic Package Transporter (TRUPACT-I) is a packaging developed by the United States Department of Energy (DOE) for transporting contact-handled transuranic waste (CH-TRU) in the USA. A full scale prototype was built and subjected to a series of drop, puncture and thermal tests to evaluate the package's resistance to normal handling and hypothetical accident conditions. A thermal redesign and component test programme was conducted when the prototype failed to maintain containment after the thermal test. A thermal test particle which included previously incurred structural damage was tested to demonstrate the adequacy of the new design features in an open pool-fire environment. Since no detectable leaks were measured from the filter seals and valves and the seal leak rate was less than the maximum allowable, containment was demonstrated.

1.0 INTRODUCTION

The TRansUranic PACkage Transporter (TRUPACT-I) is a type B packaging compatible with both truck and rail transport (bimodal). The ability of the TRUPACT-I to restrict leakage to less than the maximum allowable rate of A_2/week (equivalent to 1.0 E-2 atm-cc/s of air) was demonstrated by fabricating a full-scale prototype unit (Unit 0) and subjecting it to a series of regulatory tests (Refs. 1 and 2). The TRUPACT-I system was in the developmental stage and these were the first tests of a full-scale unit under controlled and monitored conditions. As a result, the test program was established to provide design information as well as to demonstrate compliance with the regulations. The following impact, puncture, and thermal tests were performed consecutively to evaluate the package response in a variety of orientations:

- three impacts of 5.9 kg (13 lb) bar onto the outer surface,
- 0.3 m (12 in.) drop onto bottom surface,
- 9 m (30 foot) drop onto top left edge,

- 9 m (30 foot) drop center-of-gravity over outer door corner,
- four 1 m (40 in.) drops onto a 15 cm (6 in.) diameter puncture bar,
- 30 minute JP-4 fuel pool fire.

The damage was recorded by measuring strain and seal leak rates. After the pool fire, the leak rate exceeded the allowable rate due to inner door seal degradation resulting from excessive burning of the polyurethane foam in the outer door. Design changes were made to address these problems and the prototype was refabricated to incorporate the design changes. The rebuilt test article was subjected to a second pool fire test to verify the thermal redesign. Results of the initial TRUPACT-I design tests are summarized followed by a description of the redesign and results of the successful final thermal test. More details are presented in Refs. 3 and 4.

2.0 TRUPACT-I DESCRIPTION

The major components of TRUPACT-I, Unit 0, are illustrated in Figure 1. The waste containers are placed inside of the containment system which is protected by the outer protective structure.

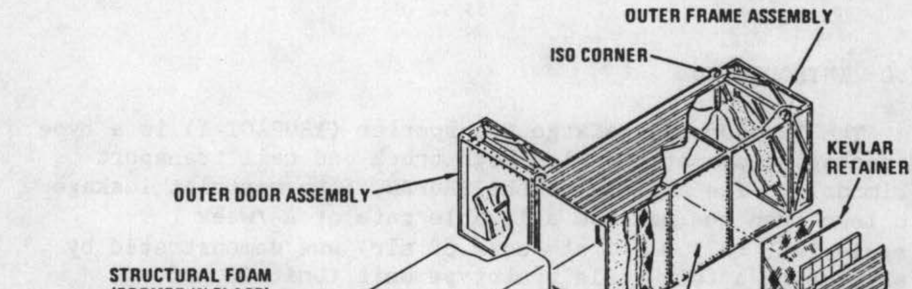

FIG. 1. TRUPACT-I, Unit O, prototype schematic.

2.1 Containment System

The containment system has an interior cavity 5.8 m long, 1.9 m wide, and 2.2 m high (19' 2" x 6' 2" x 7' 2"). The high integrity system prevents release of contact handled transuranic radionuclides. The containment liner is 4.8 mm (3/16 in.) welded stainless steel plate supported by an inner frame built with longitudinal, circumferential, and diagonal stainless steel structural tubing. The open end is sealed by a bolted and hinged 10 cm (4 in.) thick inner door. The inner door has a tubular steel edge frame and center panel of sandwich construction; the sandwich panel has bonded stainless steel face sheets and an aluminum honeycomb core. Leakage between the inner door and the inner frame is prevented by compressing three concentric elastomeric seals when the 36 door bolts are tightened. Seal quality is checked using a pressure rise test. Quick connect fittings are provided to connect leak testing equipment. Four high efficiency filters are located in the top of the inner door frame to equilibrate cavity pressure while preventing release of airborne particulate.

2.2 Outer Protective Structure

The outer protective structure's primary function is to protect the containment system during normal and accident conditions by absorbing structural and thermal assaults. Components of the outer structure are 1) outer frame assembly, 2) stainless steel plates, 3) Kevlar (Registered Trade Mark of Dupont), 4) insulation, 5) exterior skins, 6) foam, and 7) an outer door. Stainless steel is used throughout the outer protective structure. Outside dimensions are 7.6 m x 2.4 m x 2.7 m (25' 1" x 8' 0" x 9' 0") LWH.

The outer framework is built of 75 mm (3 in.) square tubing and provides corner castings for handling and tie-down per the International Organization for Standardization Technical Committee 104 (ISO/TC 104). The rectangular frame is covered with 3.8 mm (0.15 in.) stainless steel plate and panels of Kevlar 30 layers thick to form the puncture protection system and to provide in-plane stiffness to the frame. Because of the position of the puncture protection system in the ends, the stainless steel was increased to 4.8 mm (0.19 in.) and the Kevlar increased to 44 layers in each end.

Outside the puncture protection system a 25 mm (1.0 in.) thick ceramic fiber insulation blanket of 96 kg/m^3 (6 lb/ft^3) is installed. The complete assembly is covered with a skin of 0.31 mm (0.012 in.) stainless steel to prevent weather exposure.

Rigid polyurethane foam is poured-in-place between the inner and outer frame. The foam performs both structural and thermal functions and has a nominal density of 96.0 kg/m^3 (6 lb/ft^3). TRUPACT-I, Unit 0 ends contain a total of 760 mm (30 in.) of foam and the sidewalls contain 190 mm (7.5 in.).

The Unit 0 outer door provides impact protection. It is built of square tubing and rigid foam, and includes the stainless steel/Kevlar puncture protection system. The outer door is hinged from the outer frame and is attached in the closed position by a rapid actuating system of worm gear driven locking pins. The door is sealed with an elastomeric weather seal which is not intended to provide a level of containment.

2.3 Weight Limits

The gross weight of the TRUPACT-I is limited to 22.7 tonne (50,000 lbs) for a legal weight package for highway transport. The resultant cargo capacity at the maximum weight is 7.0 tonne (15,400 lbs). The tests described herein were performed with a variety of simulated waste products in 55-gallon drums at a gross package weight of 22.6 tonne (49,800 lbs).

3.0 TRUPACT-I, UNIT 0 TESTS AND RESULTS

3.1 5.9 kg (13 lb) Bar

A mild steel bar weighing 5.9 kg (13 lb) having a 4 cm (1.5 in.) hemispherical end was dropped onto the TRUPACT-I top surface from a height of 1 m (41 in.) to simulate normal handling abuse. The outer skin is supported on the tubular steel outer frame assembly. Impact positions were selected in the center, corner, and along the edge of a region of the frame.

These tests produced minimal damage on the outer skin and none were considered to render the package incapable of continuing in service. Minor indentations were produced, rivet holes were slightly elongated, an edge of a segment of skin buckled between rivets, and a 0.6 cm (1/4 in.) tear occurred at one rivet.

3.2 0.3 m (12 in.) Bottom Drop

The 0.3 m (12 in.) drop flat onto the bottom surface of TRUPACT-I demonstrated the ability of the package to withstand abuse that might be encountered during normal handling. The test target for this, and all other impact tests, was the Drop Test Facility at Oak Ridge National Laboratories, TN. The target is a massive pour of heavily reinforced concrete weighing 670 tonne covered with 0.6 m (24 in.) of armor steel plate. It is considered to be an essentially unyielding horizontal surface.

Results of the test indicated no unacceptable damage. Passive accelerometers on the ISO corners of the outer frame indicated peak G-loads between 50 and 100. The lower surface ISO corners moved upward an average of 0.2 cm (0.08 in.). Seal leak rates measured for the inner and outer seal cavities were unchanged after the test and were below the maximum allowable.

3.3 9 m (30 ft) Drop on Edge

The 9 m (30 ft) hypothetical accident free drop on the top left edge of TRUPACT-I was included in the test sequence because of the large loads and deformations that are input perpendicular to the containment centerline. This orientation was one of the two most severe tests on a quarter-scale model. Large deformations in the inner door seal area could potentially cause excessive leak rates.

Results of the test indicated that the containment leakage limit of 1.0E-2atm-cc/s was not exceeded. Leak rates measured after the event were 4.0E-3 and 2.3E-3 atm-cc/s for the inner and outer seal cavities, respectively. The edge of the package was crushed inward an average of 7.6 cm (3 in.) resulting in a flattened region averaging 15 cm (6 in.) wide and covering the full length of the edge. Deformation of the outer door and outer frame caused a gap at their interface measuring from 0.3 cm (0.12 in.) to 2.2 cm (0.9 in.). The smallest gaps measured were at the impacted edge and the area diagonally opposite. The other two corners had the largest gaps and were about equal.

3.4 9 m (30 ft) Drop on Corner

A second 9 m (30 ft) drop, although not required by the regulations, was performed to examine the package response in a region essentially undamaged by the previous test. This orientation was of engineering interest because of the large out-of-plane loads that develop in the inner door due to the interaction of the cargo. The package was suspended with the center-of-gravity above the bottom left corner of the outer door and dropped. Results verified the impact design adequacy. The corner of the outer door was crushed inward 0.8 m (31.5 in.) and the triangular footprint went completely across the bottom edge of the door and about 2/3 of the distance up the left vertical edge. A portion of the outer frame in the TRUPACT-I body was also deformed behind the impacted corner. The original position of the bottom left corner of the packaging body was pushed in 7.0 cm (2.75 in.).

The inner door and containment were found to be undamaged when the package was disassembled. The acceptable leakage rates measured after the event were 5.3E-3 and 3.1E-3 atm-cc/s for the inner and outer seal cavities on the inner door, respectively.

3.5 1 m Drop Puncture Tests

Four puncture tests were performed on TRUPACT-I. The positions impacted were 1) bottom center--normal impact, 2) aft end--normal impact, 3) bottom left corner of outer door--oblique impact, and 4) top middle of outer door--oblique impact. The third test attacked the inner door seal and frame in the corner that had been predamaged in the 9 m (30 ft) corner drop. The fourth test attacked the inner door in the region of the potentially vulnerable inner door seals and containment filter/vent stressing the door frame and seal housing. In all of the puncture tests, the line of action of the puncture bar was approximately through the center-of-gravity of the package.

The first 1 m (40 in.) puncture test caused the side wall puncture panel to deflect inward a distance of 22 cm (8.7 in.) and caused no unacceptable damage. Similarly, the second test produced an inward deflection of the aft end puncture panel of 19 cm (7.5 in.). Although some exterior skin detached upon slap-down, there was no unacceptable damage. Two or three surface layers of Kevlar were cut along the perimeter of the punch. During disassembly the containment liner behind the punched areas was slightly bowed inward but there was no torn metal or failed welds. The third puncture test impacted onto the previously damaged corner of the outer door and resulted in an oblique impact which aligned the inner door frame, seals, and center-of-gravity along the line of action for the puncture bar. The oblique angle between the puncture bar face and the puncture panel caused large side loads and bent the punch. The surface of the outer door Kevlar puncture panel was abraded but was not torn. In the fourth puncture test, the puncture bar passed through the outer door making minimal contact with the structural tubing. The edge connection of the puncture protection system was torn from the frame thus exposing the foam. Containment was not breeched and the seal leak rate did not exceed the maximum allowable after the final puncture test.

3.6 Pool Fire

The damaged package was then exposed to an open-pool fire test at Sandia National Laboratories Lurance Canyon Burn Site. The package was centered in a 9 m x 18 m (30 ft x 60 ft) open concrete-lined pool and supported 1 m (40 in.)

above the JP-4 fuel surface (Ref. 3). The burn duration was 35 minutes. Flame temperatures varied from 260°C (500°F) to 1310°C (2400°F) with the average being about 980°C (1800°F). After the test, TRUPACT-I no longer met the required containment leak rate limits. The thermal design criteria for the hypothetical accident condition were not met. Excessive temperatures for safety-related components and the resulting loss of containment was primarily due to foam burning in the outer door. A large tear in the stainless steel puncture plate weld at the top edge resulting from the fourth puncture test exposed foam to the fire and provided air access to support combustion (Ref. 4). As a result, the seals overheated and were no longer capable of maintaining an acceptable leak rate.

4.0 TRUPACT-I THERMAL REDESIGN

Design changes were made to (1) improve the attachment of the outer skin by doubling the number of rivets and adding an adhesive bond, (2) eliminate foam burning in the outer door by replacing organic foam with aluminum honeycomb, (3) prevent material from burning adjacent to the inner door by reinforcing the edge connection of the outer door puncture panel and by replacing organic foam behind the outer door puncture panel with welded stainless steel honeycomb, (4) reduce charring and burning of sidewall foam by adding insulation boards behind outer frame tubes, adding foam flame retardant, and adding inorganic insulation in areas of potentially high structural damage, (5) reduce seal, filter, and inner door temperatures by improving the convection seal, replacing organic materials with inorganic ones, and by changing to higher temperature rated silicone seal material, (6) improve the temperature rating of the covering and stitching material used in sidewall insulation blankets, and (7) eliminate a leak that developed during the full scale prototype tests by removing an adhesive bond line. Adequacy of the thermal redesign was indicated by analysis and component tests (Ref. 5) before the final pool fire test.

5.0 POOL FIRE (SECOND TEST)

To demonstrate compliance with federal regulations (Refs 1 and 2), a TRUPACT-I test article incorporating the new design features was engulfed in a JP-4 fuel fire. To simulate the cumulative effect of the regulatory accident sequence, the test article modeled the structural damage found in TRUPACT-I, Unit 0 after the two 9 m (30 ft) drops and the puncture testing of the seal area. The previously tested Unit 0 containment liner, puncture plates, inner and outer frames, and inner and outer door frames were reused to fabricate the

Table 1

Maximum Temperatures in TRUPACT-I Test Article

Location	Maximum Temp. °C (°F)
Inner Door Seal	149 (300)
Filter	171 (340)
Inner Door	171 (340)
Containment Liner	135 (275)
Surface of Contents	77 (170)

test article. Structural damage to those members was retained. Damage to other components was added based on Unit 0 damage or damage predicted for the modified design. The test procedure was similar to the first pool fire test. More instrumentation was installed in this test. Twenty-six thermocouples were located on four 6 m (20 ft) tall water-cooled towers in the pool to monitor the fire environment. A total of 116 thermocouples were installed in the test article. Temperature indicating paints and labels were installed, in addition to thermocouples, on drums and on surfaces of the inner and outer doors and on the containment liner.

The test article was engulfed for 46 minutes and was allowed to cool unhindered. Data acquisition continued for 51 hours until all temperatures had peaked and were less then 93°C (200°F). Maximum temperatures recorded by the passive paints and labels are given in Table 1 for critical locations. The peak seal temperature of 149°C (300°F) occurred at the top left corner of TRUPACT-I. Silicone seal material has a continuous operating temperature limit of 232°C (450°F) so it was not affected. A post-test leak rate of 4.3 $\times 10^{-3}$ atm-cc/s ANSI standard air verified success of the silicone seals in the test article. Since no detectable leaks were measured on the filter seals or valves post-test, the total TRUPACT leakage rate was less than the maximum allowable 1×10^{-2} atm-cc/s, thus demonstrating regulatory compliance.

6.0 CONCLUSION

A transportation system has been designed, analyzed, and tested to demonstrate that containment is maintained through normal handling and hypothetical accident conditions. The packaging offers a safe and efficient method of transporting contact-handled transuranic waste.

REFERENCES

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