The Development of an On-Site Container*

R. E. Glass, M. E. McAllaster, and P. L. Jones

Transportation Systems Technology Department, Sandia National Laboratories,**
Albuquerque, New Mexico, United States of America

A. L. McKinney

U.S. Army Chemical Materials Destruction Agency, Aberdeen Proving Ground, Maryland, United States of America

INTRODUCTION

Sandia National Laboratories (SNL) has developed a package for the on-site transport of chemical munitions for the U.S. Army. This package was designed to prevent the release of lethal quantities of chemical agents during transportation of munitions to the demilitarization facilities on-site. The packaging prevents auto-ignition of the munitions by limiting the thermal and structural assault on the munitions during an accident. This package, with some modifications to account for contents, may be suitable for the on-site transport of mixed wastes at United States Department of Energy facilities. This paper discusses the design and verification testing of the package.

The safety criteria for the package were modeled after the International Atomic Energy Agency (IAEA) hypothetical accident sequence and modified to take credit for operational controls. The modified accident sequence consisted of drop, puncture, and thermal events. The post-accident leak rate was established to prevent harm to an exposed worker.

The packaging has a mass of 8600 kg and can accommodate up to 3600 kg of contents. The interior of the package is 188 cm in diameter and 232 cm long. Two sample ports can be used to sample the interior of the package prior to opening the closure and an o-ring test port can be used to determine the leak rates prior to and after transport.

DESIGN CRITERIA

The objectives of the design criteria (Klevans, 1988) were to produce a packaging design that was safe, operationally efficient, and provided appropriate interfaces with loading and unloading facilities. The safety of the packaging was assured by designing the package to meet specific performance criteria that consisted of a set of hypothetical accident conditions including drop, puncture, crush, and fire after which the leak rate was not to exceed 1×10^{-1} std cc/s. Normal conditions specify a leak rate not to exceed 1×10^{-3} std cc/s (ANSI, 1987).

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The hypothetical accident sequence included crush, drop, puncture, and burn tests. The crush test consisted of subjecting the package to a compressive load of 22,700 kg applied to the top of the package. The drop test consisted of a 3-m free drop of the package onto a flat, essentially unyielding surface. The drop height was based on a maximum convoy velocity of 28 km/hr during munitions transport. The puncture test consisted of a 1-m free drop of the package onto a 15.2-cm-diameter mild steel bar. The drop and puncture tests were required to be performed with the package orientation such that maximum damage would occur. To prevent auto-ignition, the maximum rigid body deceleration of the containment vessel during the drop and puncture testing could not exceed 300 g.

The fire test consisted of fully engulfing the package in a JP-4 fuel/air fire for a period of 15 min. The 15-min fire is consistent with the maximum amount of fuel that will be available to fuel a fire during the munitions transport. The fuel source was to extend horizontally at least 1 m beyond any external surface of the package, and the package was positioned 1 m above the surface of the fuel source. The package was not to be artificially cooled following the 15-min exposure. To prevent auto-ignition, the inner wall of the vessel was not to exceed 120°C.

The criteria imposed logistics requirements on the package design. These included: (1) the maximum exterior envelope of the package was 2.6 m wide x 2.6 m tall x 3.66 m long, (2) the interior vessel was 1.88 m in diameter and 2.32 m in length, (3) the package was to contain a sample port to allow routine monitoring of the containment vessel for agent, (4) the sample was to be obtained prior to opening the door, (5) the package was to incorporate a leak-testable seal design to allow periodic testing of the closure seals, and (6) the package was to incorporate ISO corners to facilitate package handling and transport.

DESIGN

The package design criteria resulted in several features that will be discussed in this section. Figure 1 shows the side view of the packaging. The packaging is 3.57 m long and 2.59 m on a side. The left side of the figure shows the closure. It consists of a commercially available 1.27-cm-thick stainless steel pressure vessel head. The pressure vessel head is welded to a flange that transitions from 1.27 to 10.8 cm thick. This flange contains the modular swing bolts, sample ports, o-ring test ports, and o-ring seals. The closure is hung on a hinge that provides smooth operation of the closure. On the body side of the package is the mating flange that transitions back to the 1.27-cm-thick stainless steel cylindrical shell. The right end uses the same pressure vessel head. For ease of handling, there are eight ISO corners attached to the package via stainless steel tubing in a tripod arrangement. The tubing allows loads on the ISO corners to be transmitted directly to the cylindrical portion of the package which provides a strong, integrated response to lifting loads.

A cross-sectional view through the flange of the packaging is shown in Figure 2. This figure shows the ISO corners at the top and bottom, the hinge on the right-hand side, and the cylindrical vessel. The closure is secured with seventeen swing bolts. In the lower half of the view, two sample ports are shown on the left- and right-hand sides. The munitions that are loaded in the package are placed on aluminum trays. The trays are placed on a honeycomb insert which rests on a rail in the bottom of the package. The rail prevents the insert from rotating in the package during transport. The trays are guided by a guide rail into the packaging to ensure that the munitions fit.

A cross-sectional view through the longitudinal axis of the package is shown in Figure 3. From outside to inside, the features of the wall include a 1.27-cm-thick cylindrical, stainless steel containment vessel; a 7.5-cm-thick ceramic fiber insulating layer; 10.5 cm of polyurethane foam; and a 0.48-cm-thick stainless steel inner shell. The outer stainless steel containment

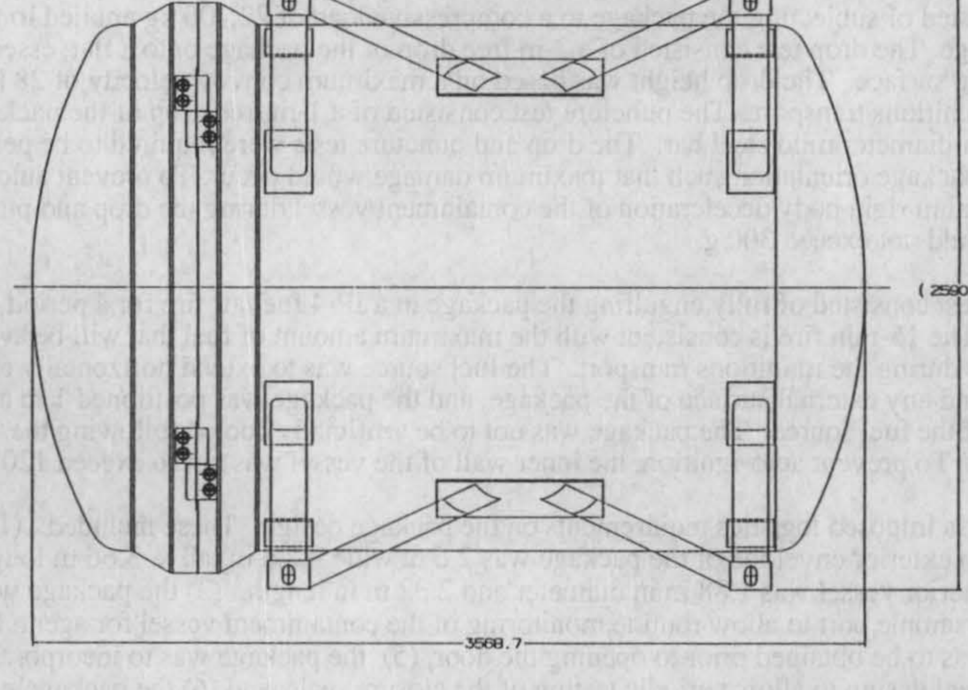

Figure 1. Side View of the On-Site Container

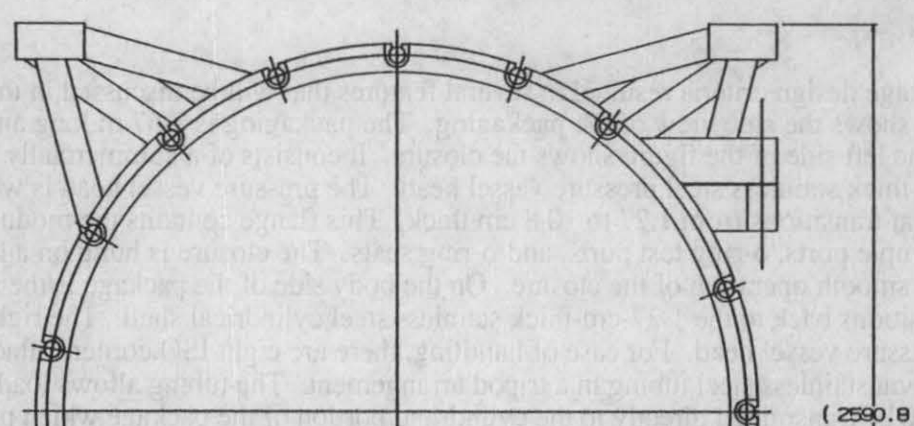

Figure 2. Cross-Sectional View Through the Closure Joint of the On-Site Container

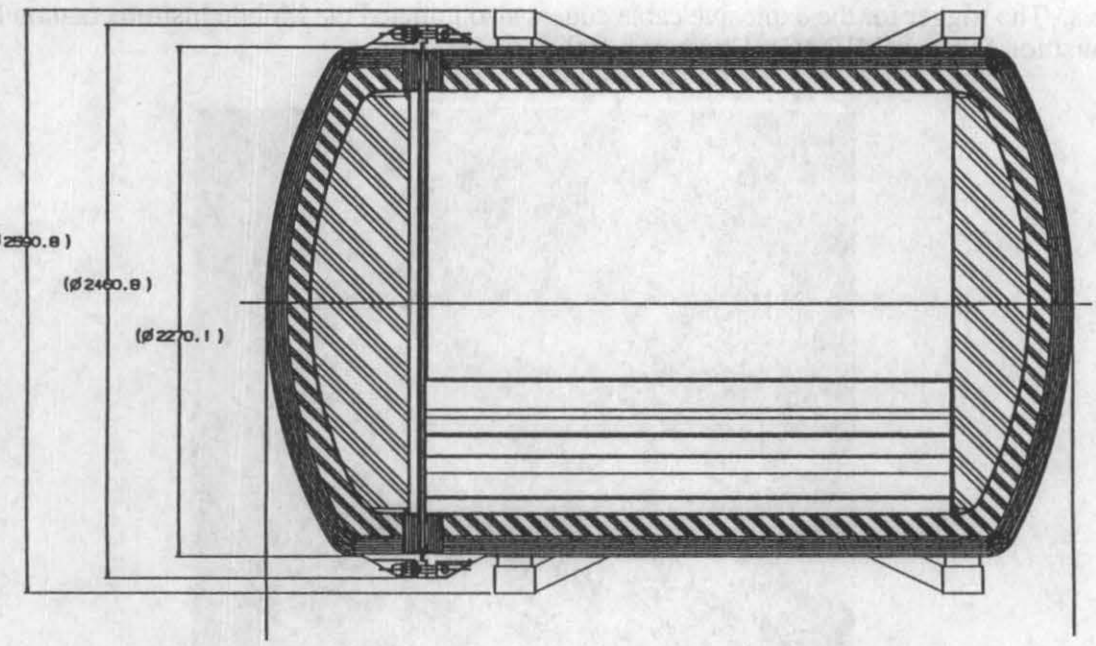

Figure 3. Longitudinal Cross-Sectional View of the On-Site Container

vessel provides puncture protection and impact resistance. The ceramic fiber limits the heat input to the package's contents during the fire and in particular keeps the fiber/foam interface temperature below 175°C. The foam provides both internal and external impact-limiting features and thermal protection that keeps the interior of the vessel below 120°C during the fire test. The inner shell provides an easily decontaminated and impact-limiting surface for the contents. The interior front and rear of the package contain foam-filled, steel clad internal impact limiters that limit the deceleration of the munitions during accident conditions.

VERIFICATION TESTING

A prototype packaging was fabricated for SNL at Gregory Enterprises, Inc. in Carlsbad, New Mexico. This packaging was subjected sequentially to (1) a 22,700-kg static crush test, (2) three 3-m free-drop tests, (3) three 1-m puncture tests, and (4) an all-engulfing JP-4 pool-fire test. The swing bolt assemblies failed during the fire test due to liquid metal embrittlement of the cadmium-plated 4340 bolt material (Robino and Van Den Avyle, 1992). Following the pool-fire test, the bolts were redesigned to use A286 steel which does not require plating for this application and which has stable structural response up to 650°C. The prototype was rebuilt by replacing the fiber insulation, foam, and interior shell. During the rebuild, it was determined that there was no thermal degradation of the foam. Following the rebuild, the prototype was again subjected to a pool-fire test. The results of this test included a package leak rate of 8.9 x 10^{-2} std cc/s and thus successful completion of the design phase of the project.

The static crush test consisted of placing a concrete slab weighing 22,750 kg on the four upper ISO corners. The slab was left in place for 5 min and then removed. No visible damage resulted from this test.

The setup for the free-drop tests is shown in Figure 4. This photograph shows the package suspended above the target. The distance from the target to the lowest point on the packaging was measured and recorded. Photographic coverage included video and still photography with 400 frame/s and 2000 frame/s cameras. The package was dropped using explosive cable cutters. The trigger for the explosive cable cutters also initiated the Mobile Instrumentation Data Acquisition System (MIDAS) (Uncapher, 1990).

Figure 4. On-Site Container Suspended 3 m Over the Unyielding Target

The design criteria required that the free-drop test of the packaging occur in the most damaging orientation. To ensure that the drop test sequence met this requirement, the package, loaded with 155-mm projectiles, was dropped in three orientations. These orientations included a: (1) flat side, (2) center-of-gravity over corner, and (3) flat end drop. The criteria also required that the containment vessel's rigid body decelerations be less than 300 g. The flat side drop generated the largest decelerations. Figure 5a shows the wide band data for the accelerometer that measured the vertical deceleration through the center-of-gravity. This accelerometer was mounted on the outside of the containment vessel. The wide band data show total accelerometer peak response of approximately 800 g. The wide band data also show the package's primary and secondary impacts on the target at 0, 60, 310, and 350 ms. Figure 5b shows the accelerometer data filtered at 500 Hz. The data show the package's rigid body deceleration of 240 g. Comparing the rigid body responses for the three drop events, the center-of-gravity over corner drop had a rigid body deceleration of 70 g and the flat end drop had a deceleration of 80 g. The lower decelerations for these two events were expected due to the larger deformations that occurred in those tests.

The setup for the puncture tests was similar to that shown in Figure 4 for the free-drop tests. The setup for the center-of-gravity over the closure joint test is shown in Figure 6. This figure shows the test article just after release from the explosive cable cutters. Note the smoke drifting away from the severed cables. Data acquisition and photometric coverage was identical to that of the free-drop tests.

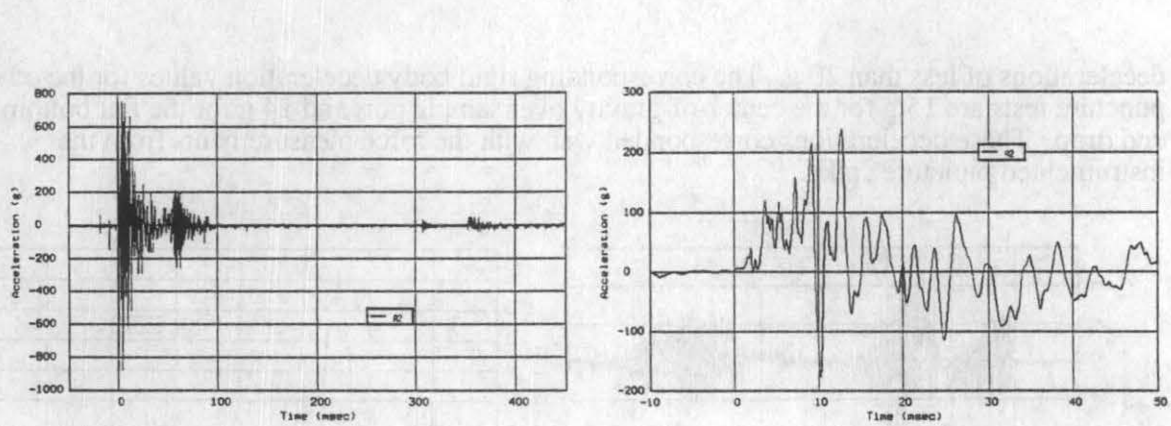

Figure 5. Accelerometer Data for the Flat Side Drop: (a) wide band data and (b) data filtered with a cut-off frequency of 500 Hz

Figure 6. On-Site Container at Release for the Center-of-Gravity Over Closure Joint Puncture Test

As in the drop tests, the requirement to test the package in the most damaging orientation resulted in multiple puncture tests. These included a: (1) center-of-gravity over closure joint test, (2) center-of-gravity over sample port test, and (3) flat bottom puncture. The purpose of the center-of-gravity over closure joint test was to attempt to create a gap in the closure joint resulting in loss of containment. The center-of-gravity over sample port test similarly was intended to attempt to damage the sample port with a resulting loss of containment. The bottom end puncture was an attempt to damage the wall by tearing the containment boundary. None of these tests resulted in loss of containment. The results from the puncture events indicated rigid body decelerations of less than 20 g. The response of the center-of-gravity over closure joint test from the accelerometer mounted to measure the decelerations through the center-of-gravity are given in Figure 7. The wide band data (Figure 7a) indicate that the total decelerations were less than 50 g. The corresponding data for the rigid body decelerations (Figure 7b) indicate decelerations of less than 20 g. The corresponding rigid body deceleration values for the other puncture tests are 15 g for the center-of-gravity over sample port and 14 g for the flat bottom end drop. These decelerations corresponded well with the force measurements from the instrumented puncture spike.

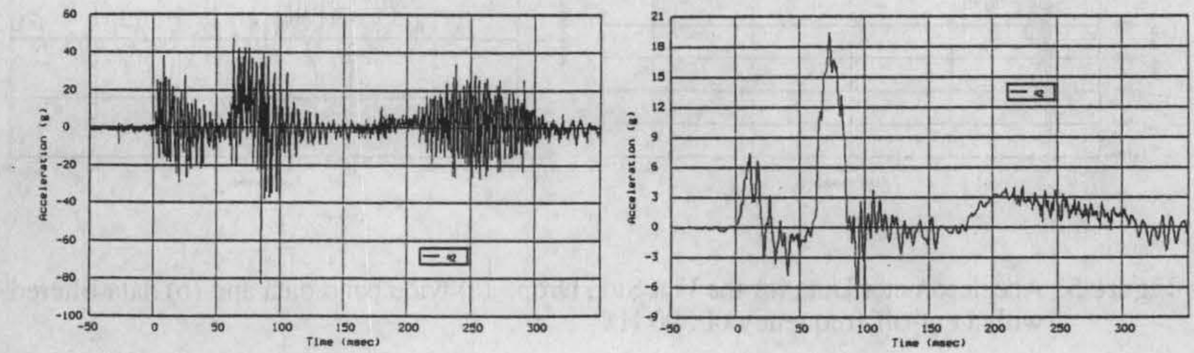

Figure 7. Accelerometer Data for the Center-of-Gravity Over Closure Joint Puncture Test: (a) wide band data and (b) data filtered with a cut-off frequency of 100 Hz

The final test in the sequence was the pool-fire test. The first pool-fire test resulted in loss of containment due to the liquid metal embrittlement of the cadmium-plated 4340 steel bolts. This resulted in the previously mentioned rebuild of the package. The bolt material was replaced with A286 steel and the second pool-fire test was performed. The package was placed on the support as shown in Figure 8. The pool was partially filled with water and a layer of JP-4 fuel was floated on the top. The fire (Figure 9) was ignited and burned for 22.5 min. Thermocouples were used to monitor the external and internal temperatures of the packaging and passive thermal indicators were used as back-up for the internal temperature readings. The interior shell remained below 85°C even though the fire exceeded the design criteria requirement of 15 min by 50%.

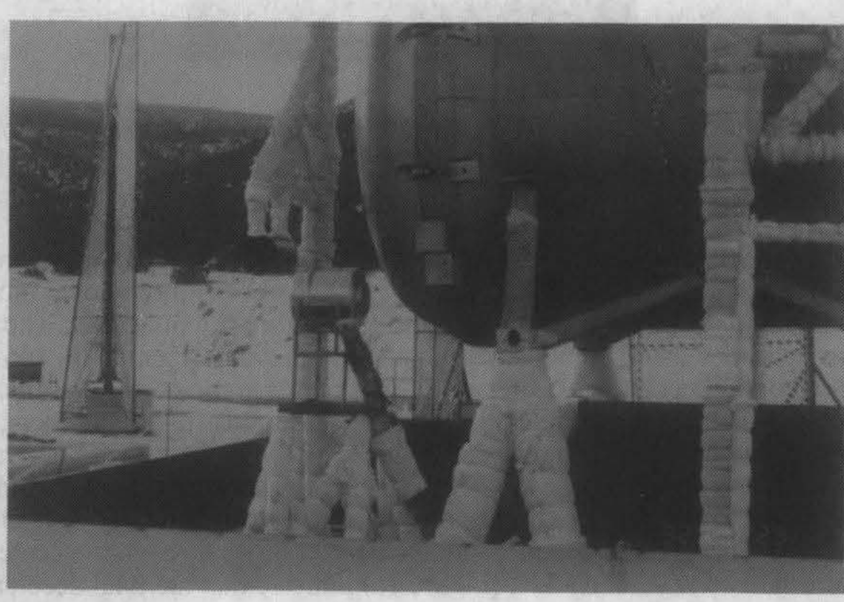

Figure 8. Pool-Fire Test Setup

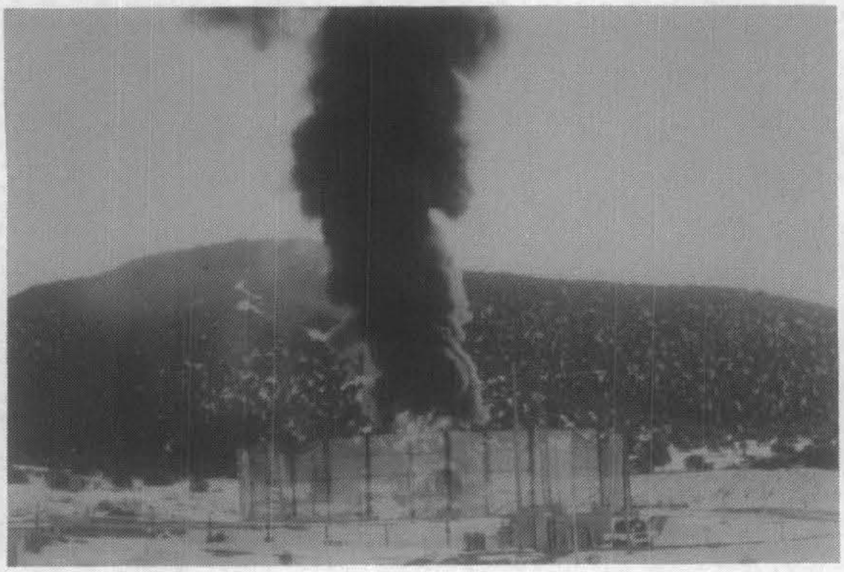

Figure 9. All-Engulfing JP-4 Fuel Pool-Fire Test

The results of the second fire leak test indicated a packaging leak rate of 8.9×10^{-2} std cc/s. The successful completion of the test sequence resulted in completion of the design phase of the project.

CONCLUSIONS

This paper describes the results of the development of a packaging designed for on-site transportation of chemical munitions. The criteria for the package were patterned after the requirements for Type B packagings, but were modified to take credit for the operational controls that could be applied on-site. The design phase has been completed and a contract has been placed for fabrication of 165 units. In addition to the tests completed during the design phase, a complete sequence of verification tests will be performed on the first fleet unit. This sequence will consist of: (1) a 22,700-kg load placed on the packaging for 24 hours, (2) the flat side free drop, (3) the center-of-gravity over closure joint puncture test, and (4) a 15-min all-engulfing JP-4 pool-fire test. At the completion of the test sequence, the package will be required to meet the less than 1×10^{-1} std cc/s leak test.

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