Crush Testing at Oak Ridge National Laboratory

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Abstract

The dynamic crush test is required in the certification testing of some small Type B transportation packages. International Atomic Energy Agency regulations state that the test article must be "subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage." Oak Ridge National Laboratory (ORNL) Transportation Technologies Group performs testing of Type B transportation packages, including the crush test, at the National Transportation Research Center in Knoxville, Tennessee (United States). This paper documents ORNL's experiences performing crush tests on several different Type B packages.

Introduction

The so-called "crush" test was first stipulated by the International Atomic Energy Agency (IAEA) in paragraph 627 (c) of Safety Series No. 6, *Regulations for the Safe Transport of Radioactive Material,*[1] as drop III in 1985 as follows:

> *"the specimen shall be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass shall consist of solid mild steel plate 1 m by 1 m and shall fall in a horizontal attitude. The height of the drop shall be measured from the underside of the plate to the highest point of the specimen . . .."*

When U.S. transportation regulations were "harmonized" with IAEA regulations in 1996, 10 CFR 71.73(c)(2) Crush[2] read:

> *"Subjection of the specimen to a dynamic crush test by positioning the specimen on a flat, essentially unyielding horizontal surface so as to suffer maximum damage by the drop of a 500-kg (1100-lb) mass from 9 m (30 ft) onto the specimen. The mass must consist of a solid mild steel plate 1 m (40 in) by 1 m (40 in) and must fall in a horizontal attitude . . .."*

While the descriptions above from IAEA and the U.S. *Code of Federal Regulations* are similar, their application is notably different. In the IAEA regulations a package is **either** exposed to the crush test **or** to a 9 m drop test (known as *drop I*). In the United States, small, nondense packages must be subjected to **both** the 9 m drop test **and** the crush test.

In both IAEA and U.S. regulations, packages that weigh more than 500 kg (1,100 lb) or are denser than water are exempt from crush testing. Thus, the typical Type B package exposed to the *crush* test is a relatively lightweight (as compared to a Type B cask) drum-type package design and often transports unirradiated fissile material.

The Oak Ridge National Laboratory (ORNL) has a long history of testing Type B packages as some of the first radioactive material (RAM) packaging tests were performed there in the 1950s, and testing has continued ever since.[3] The Transportation Technologies Group of the Global Nuclear Security Technology Division currently operates the Packaging Research Facility (PRF) at the National Transportation Research Center in Knoxville, Tennessee (United States). The PRF is a purpose-built facility dedicated to the testing of Type B shipping containers. The PRF contains facilities for testing a wide variety of Type B shipping packages but specializes in the testing of small, drum-type shipping packages. Typically, these packages must be exposed to the crush test during the “hypothetical accident conditions” (HAC) sequence of certification tests.

Crush Testing of Packages at ORNL

Over the past several years, ORNL has performed several sets of tests on various Type B shipping packages which required exposure to the crush test. Initially, the ES-2100 was crush tested in 2002, and the DPP-2, MD-1, and ES-3100 package designs followed soon after. More recently the MD-2 was crush tested.

ES-2100

The ES-2100 shipping package, designed by the Y-12 National Security Complex, was exposed to the crush test in December of 2002. A very similar package design (ES-2) had undergone HAC testing before adoption of the crush test in the United States. The tests in 2002 were to prove the package’s design worthiness and to ensure its ability to be used internationally. Four test units (TUs) were subjected to crush testing, two to the crush test stipulated in the U.S. regulations, and two to the crush test as described in IAEA ST-1.[4] A tabular description of the tests performed is provided in Table 1. Preparations for crush testing ES-2100 TU 3 (TU-3) are shown in Figure 1, and the resulting damage from that crush test is shown in Figure 2.

Table 1. Description of ES-2100 Crush Tests

ES-2100 Test Unit	Test Description			
	Regulations	Orientation	HAC Sequence	Plate CG†
TU-1	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-2	U.S.	CGOC‡	Drop-Crush-Puncture-Thermal	Through Package CG
TU-3	IAEA	Horizontal	Crush-Puncture-Thermal	Through Package CG
TU-4	IAEA	CGOC	Crush-Puncture-Thermal	Through Package CG

†Center of gravity
‡Center of gravity over corner

In an attempt to cause maximum damage during these tests, the center of gravity (CG) of the plate was always lined up through the CG of the TU. Theoretically, this alignment represents maximum transfer of energy from the plate to the TU. The crush test caused far greater deformation of the outer drum in the ES-2100 than did the 9 m drop test. TUs 3 and 4 showed greater damage after being crush tested than TUs 1 and 2 did after the 9 m drop test. When TUs 1 and 2 were subsequently exposed to the crush test, their overall deformation was only slightly worse after both the 9 m drop and crush tests than TUs 3 and 4, which had only undergone the crush test. All four TUs were subsequently exposed to both the HAC puncture and HAC thermal tests. After HAC testing was complete, all four units passed operational leak tests.

Figure 1. The CG of the crush plate is aligned with the CG of ES-2100 TU-3 before crush testing.

Figure 2. Crush test damage to ES-2100 TU-3.

DPP-2

The DPP-2 shipping package, designed by the Y-12 National Security Complex, was exposed to the crush test in July of 2003 during certification testing of the package design. Six DPP-2 TUs were subjected to the crush test. As with the ES-2100 , the CG of the crush plate was aligned through the CG of the DPP-2 TU for every crush test performed A tabular description of the tests performed is provided in Table 2. A picture of the crush testing of DPP-2 TU-2 is shown in Figure 3, and damage to DPP-2 TU-6 from the crush test is shown in Figure 4.

As with the ES-2100, the CG of the plate was always in alignment with the CG of the TU. Again, the crush test caused far greater deformation to the outer drum than did the 9 m drop test when the DPP-2 package design was tested. The DPP-2 package design included two crush-resistant hoops welded to the outside of the packaging’s drum. These hoops appeared to help limit crush test damage but did not prevent it. All six TUs were subsequently exposed to both the HAC puncture and HAC thermal tests. After testing was complete all six units passed helium leakage tests, indicating they were “leaktight” units.

Table 2. Description of DPP-2 Crush Tests

DPP-2 Test Unit	Test Description			
	Regulations	Orientation	HAC Sequence	Plate CG
TU-1	U.S.	Vertical w/Top Down	Drop-Crush-Puncture-Thermal	Through Package CG
TU-2	U.S.	CGOC	Drop-Crush-Puncture-Thermal	Through Package CG
TU-3	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-4	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-5	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-6	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG

Figure 3. DPP-2 TU-2 recoils off of the drop pad in response to initial impact of crush plate.

Figure 4. Crush test damage to DPP-2 TU-6.

MD-1

The MD-1 shipping package, designed by the Y-12 National Security Complex, was exposed to the crush test in February of 2004 during certification testing of the package design. Five MD-1 TUs were subjected to the crush test. A tabular description of the tests performed is provided in Table 3. Preparations for crush testing MD-1 TU-4 are shown in Figure 5, and the resulting damage from that crush test is shown in Figure 6.

The MD-1 testing was the first time that crush tests were performed in which the CG of the plate was not aligned with the CG of the package. For MD-1 testing two other perceived vulnerabilities of the package were tested during the crush test. For TU-1, the CG of the crush plate was aligned directly through the location of the containment vessel (CV) flange, and for TU-5, the CG of the plate was aligned through the lower weld on the CV. In the other three crush tests (TU-2 through TU-4) the CG of the plate was aligned with the CG of the package. Again, the crush test caused far greater deformation to the outer drum than did the 9 m drop test when the MD-1 package design was tested. The MD-1 package design also included two crush-resistant hoops welded to the outside of the packaging's drum. These hoops appeared to help limit crush test damage but did not prevent it. All five TUs were subsequently exposed to both the HAC puncture and HAC thermal tests. After testing was complete, all five units passed helium leakage tests, indicating they were "leaktight" units.

Table 3. Description of MD-1 Crush Tests

MD-1 Test Unit	Test Description			
	Regulations	Orientation	HAC Sequence	Plate CG
TU-1	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through CV Flange
TU-2	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-3	U.S.	CGOC	Drop-Crush-Puncture-Thermal	Through Package CG
TU-4	U.S.	Vertical w/Top Down	Drop-Crush-Puncture-Thermal	Through Package CG
TU-5	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Lower CV Weld

Figure 5. The crush plate is centered over MD-1 TU-4 before crush testing.

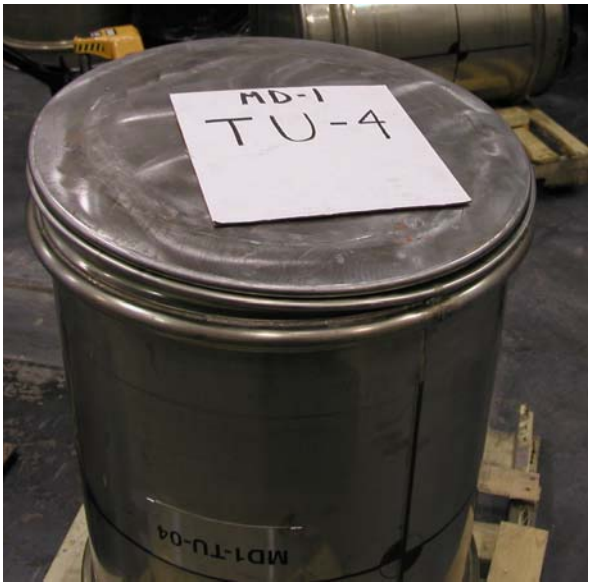

Figure 6. Crush test damage to MD-1 TU-4.

ES-3100

The ES-3100 shipping package, designed by the Y-12 National Security Complex, was exposed to the crush test in May of 2004 during certification testing of the package design. Five ES-3100 TUs were subjected to the crush test. A tabular description of the tests performed is provided in Table 4.

Preparations for ES-2100 TU-1 crush testing are shown in Figure 7, and the resulting damage from that crush test is shown in Figure 8.

For TU-1, the CG of the crush plate was aligned with the CV flange. For all other crush tests (TU-2 through TU-5), the CG of the plate was aligned with the CG of the TU. Again, the crush test caused far greater deformation to the outer drum than did the 9 m drop test when the ES-3100 package design was tested. All five TUs were subsequently exposed to both the HAC puncture and HAC thermal tests. After testing was complete, all five units passed helium leakage tests, indicating they were "leaktight" units.

Table 4. Description of ES-3100 Crush Tests

ES-3100 Test Unit	Test Description			
	Regulations	**Orientation**	**HAC Sequence**	**Plate CG**
TU-1	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through CV Flange
TU-2	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG
TU-3	U.S.	CGOC	Drop-Crush-Puncture-Thermal	Through Package CG
TU-4	U.S.	Vertical w/Top Down	Drop-Crush-Puncture-Thermal	Through Package CG
TU-5	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Package CG

Figure 7. The crush plate is centered over the CV flange of ES-3100 TU-1.

Figure 8. Cumulative 9 m drop and crush test damage to ES-3100 TU-1.

<u>MD-2</u>
The MD-2 shipping package, designed by the Y-12 National Security Complex, was exposed to the crush test in December of 2007 during certification testing of the package design. Six MD-2 TUs were

subjected to the crush test. A tabular description of the tests performed is provided in Table 5. A picture of MD-2 TU-3 crush testing is shown in Figure 9, and damage to the MD-2 TU-1 drum weld seam from the crush test is shown in Figure 10.

Four of the MD-2 TUs were tested with the CG of the plate aligned somewhere other than the CG of the package. For TUs 2, 5, and 8, the CG of the plate was aligned through the flange of the CV, and for TU-3, the CG of the plate was aligned through the upper weld seam on the CV. As with previously tested package designs, the crush test caused far greater deformation to the outer drum than did the 9 m drop test when the MD-2 package design was tested. All six TUs were subsequently exposed to both the HAC puncture and HAC thermal tests. After testing was complete, all six units passed helium leakage tests, indicating they were "leaktight" units.

Table 5. Description of MD-2 Crush Tests

MD-2 Test Unit	Test Description			
	Regulations	**Orientation**	**HAC Sequence**	**Plate CG**
TU-1	U.S.	Vertical w/Top Down	Drop-Crush-Puncture-Thermal	Through Package CG
TU-2	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through CV Flange
TU-3	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through Upper CV Weld
TU-4	U.S.	CGOC	Drop-Crush-Puncture-Thermal	Through Package CG
TU-5	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through CV Flange
TU-8	U.S.	Horizontal	Drop-Crush-Puncture-Thermal	Through CV Flange

Figure 9. The crush plate just before impact with MD-2 TU-3.

Figure 10. Split drum weld seam on MD-2 TU-1 after crush test.

Conclusions

ORNL has crush tested five different drum-type package designs, continuing its 60 year history of RAM package testing. A total of 26 crush tests have been performed in a wide variety of package orientations and crush plate CG alignments. In all cases, the deformation of the outer drum created by the crush test was significantly greater than the deformation damage caused by the 9 m drop test. The crush test is a highly effective means for testing structural soundness of smaller nondense Type B shipping package designs. Further regulatory guidance could alleviate the need to perform the crush test in a wide range of orientations and crush plate CG alignments.

References

1. U.S. *Code of Federal Regulations*, Title 10, *Energy*, Part 71, Washington, D.C., U.S.A., 1996.
2. International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material,* Safety Series No. 6. Vienna, Austria, 1985.
3. Shappert, L., Ludwig, S., *44 Years of Testing Radioactive Materials Packages at ORNL*, PATRAM 2004, Berlin, Germany, 2004.
4. International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material,* No. ST-1. Vienna, Austria, 1996.