Historical Background – Early Deliberations on and Assessments of the Need for a Dynamic Crush Test

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ABSTRACT

Beginning in the late 1970s, discussions were fostered by the International Atomic Energy Agency (IAEA) on the need for additional tests for some Type B packages. Consideration at the international level of these early deliberations and tests ultimately led to the inclusion in the IAEA Regulations for the Safe Transport of Radioactive Material of the third mechanical (drop) test for demonstrating the ability of the package design to withstand accident conditions of transport, commonly known as the "dynamic crush test". This test included the requirement that the package be positioned so as to sustain maximum damage. Recently discussions have been occurring as to what constitutes positioning on an unyielding target, where considerations are being put forward for clarifying this phrasing and possibly changing the test requirement. Some of these proposed changes could make the test more demanding than originally envisioned. This paper, developed in support of a panel discussion at PATRAM 2010, provides an overview of some of the very early thinking behind the crush test. It includes a graphic demonstration that was used at the time to demonstrate the concerns that then existed. It also provides a brief review of the results of various tests performed in the US, UK and Canada from the mid-1960s through the early 1980s.

INTRODUCTION

Beginning in the late 1970s, two technical committee meetings were convened by the International Atomic Energy Agency (IAEA) with a view to deliberating on the adequacy of, and potential need for changing the Type B package test standards. The two Package Test Standards meetings, which were convened in Vienna and Tokyo, considered arguments brought forth by various delegates on the possible need for (a) an additional mechanical test for some Type B packages, and (b) an additional deep water immersion test for some package contents.

The additional mechanical test, which is now commonly known as the "dynamic crush test", resulted – in part – from consideration of the results of:

- (a) early analyses by J.D. McClure of Sandia National Laboratories/Albuquerque (SNLA) in the United States (US); and
- (b) testing of various packages to different crushing environments performed from the mid-1960s through the early 1980s by various groups including:
  - (i) Amersham International, United Kingdom (UK);
  - (ii) the US Atomic Energy Commission (AEC) and the US Department of the Army (DOA);
  - (iii) SNLA, USA;
  - (iv) the Atomic Energy Control Board (AECB), Canada; and
  - (v) BAM/West Germany,

Deliberation at the international level, including consideration of these early analyses and tests ultimately led to the inclusion in the 1985 edition of the IAEA Regulations for the Safe Transport of Radioactive Material of the dynamic crush test. The new test requirement specified that, for certain low-density, light-weight Type B packages, they be tested "*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*", where the specimen (representing the package design under consideration) would be positioned appropriately on an unyielding target so as to suffer maximum damage [see para 727(c) of TS-R-1][1].

Recently, discussions have been occurring as to what constitutes "positioning on an unyielding target", with a view to potentially changing the test requirement. Some of these changes could make the test more demanding than originally envisioned. As originally envisioned, the package to be tested would rest on the target with no additional support, whereas recent deliberations at the IAEA have considered additional support to the package to attain a more severe crush than would be obtained with the package sitting the target with no additional support.

This paper provides an overview of some of the very early thinking behind the crush test, including a review of the results of some of the analyses performed in the US and the tests performed in the US, the UK and Canada from the mid-1960s through the early 1980s.

EARLY ANALYSES AND TESTS

The deliberations regarding the need for an additional test for some packages were based upon the results of both analyses and testing. The following summarizes some of these efforts.

ANALYSES BY McCLURE, SNLA (1978)

The analyses by McClure[2,3], in which road, rail and air modes were analyzed,can be summarized by the following quotes there from:

- For road only: "*…..essentially all occurrences of crush loading in a truck accident can be protected against with an 35600 to 44500 N (8,000 to 10,000 lb) static load*."
- For both road and rail: "*…the force which would provide protection against essentially all occurrences of crush is about 310 000 N (~70,000 lb).*"
- For air: 310 000 N (~70,000 lb) to "millions of newtons"

The report stated that these conclusions were based on considerations of both static and dynamic loading in the analyses that had been performed.

EARLY TESTS

The following briefly summarizes the results of early tests which demonstrated the potential for "dynamic" crush occurring during accidents involving packages of radioactive material. The tests illustrated how, when smaller, light weight packages were located toward the front of a vehicle with other cargo located behind and were then involved in a high-speed impact, the crushing of the forward-located packages by the cargo behind could have a significant, deleterious effect on the "impacted" packages.

Tests in the US (1966)

Tests were performed in 1966 by the US AEC and the US DOA at the Aberdeen Proving Grounds, USA. These tests were initially documented in two papers[4,5], and were later summarized in a paper presented at PATRAM 2007 and then published in 2007[6]. In these tests, a vehicle loaded with 33 packages of six different designs was impacted into a barrier at a velocity of 66 km/h (41 mph).

Examples of two of the six package designs used in the test are depicted in Figure. 1 (all six designs can be seen in Reference 5). A photograph of the damage to the packages is shown in Figure 2.

The results of this test further illustrated the damage that can be incurred by packages. The dynamic forces applied by the packages in the rear of a vehicle to those in the front can cause significant damage to the front-loaded packages when the transporting vehicle is involved in a head-on impact. This was determined to be especially true when the packages loaded in the front of the vehicle were of the light weight, low density type of designs such as is depicted in Figure 1.

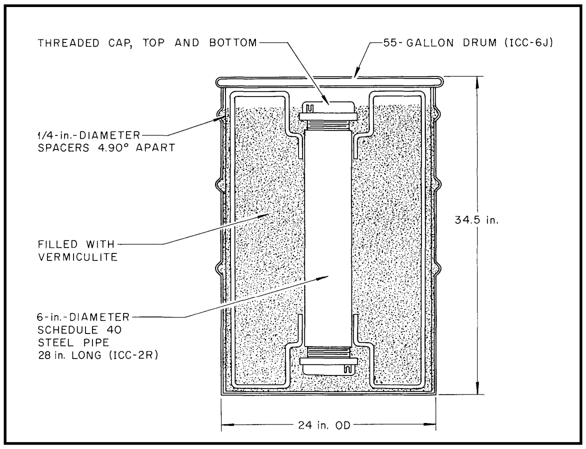

Fig. 1(a). US DOT Specification Package ICC-6L package (copied from Ref. 6).

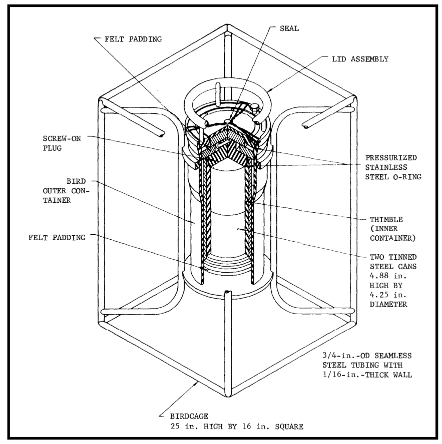

Fig. 1(b). US AEC KKD-1 package (copied from Ref. 6).

As shown in a detailed table[6] summarizing the test results, many of the packages were significantly crushed; some lost packaging top covers.

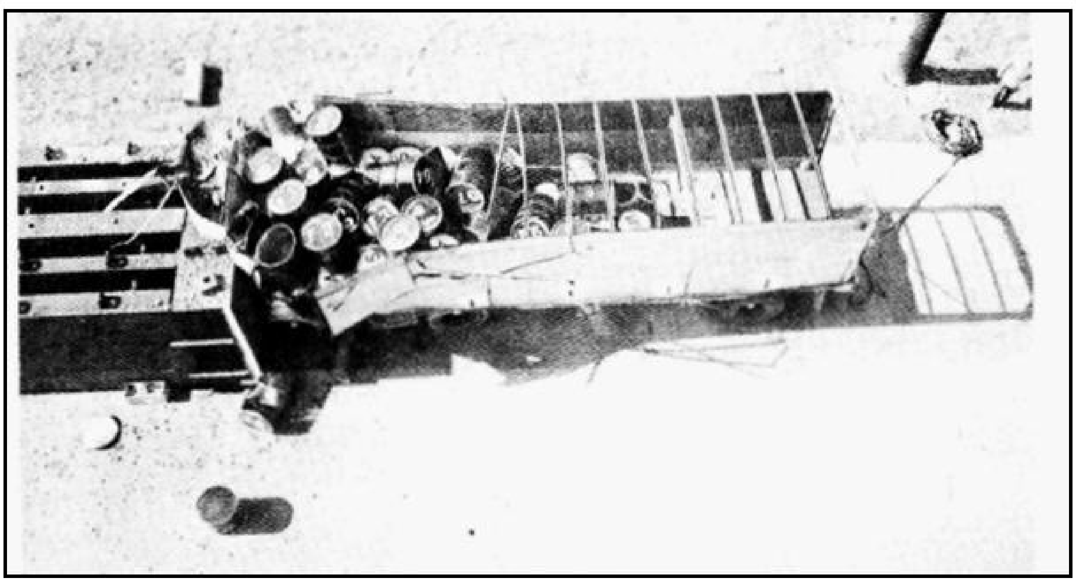

Fig. 2. Photograph of the packages following impact in the 1966 US vehicle impact test (copied from Ref. 6).

Tests in the UK (late 1970's)

Tests were performed by Amersham International at a Motor Industries Research Association (MIRA) facility, located in the UK. These tests were initially documented in a paper presented at PATRAM 1980[7], and were later summarized in a paper presented at PATRAM 2007 and then published in 2007[6].

In these tests, a vehicle was loaded with 300 Type A packages and ten Type B packages; where 140 of the Type A packages were stacked loosely and 160 of them were placed in overpacks, and the Type drums, weighing 50 to 58 kg each, were located behind the Type A packages at the rear of the vehicle. The vehicle was then impacted into a barrier at a velocity of 111 km/h (69 mph). A photograph of the vehicle during impact is shown in Figure 3(a), and some of the results of the impact on the Type A packages resulting from the impact is shown in Figure 3(b).

Fig. 3(a). UK impact test at 111 km/h
(copied from Ref. 6).

Fig. 3(b). Photograph of packages damaged in the 111 km/h impact
(copied from Ref. 6).

Many of the Type A packages were severely damaged, where the damage incurred was primarily due to the dynamic forces from the Type B packages initially located behind the Type A packages.

The results of the US and UK tests just summarized, in part, prompted the discussions at the IAEA of the need for a possible additional mechanical test for Type B packages.

GRAPHICAL DEMONSTRATION OF CONCERNS

During the deliberations at the Packaging Test Standards meeting, a graphical demonstration of what could happen to light-weight, low-density packages was provided using a golf ball and a table tennis (ping-pong) ball. The demonstration consisted of:

- First, dropping both of the balls from shoulder height onto a rigid floor. In this case, both balls rebounded with the golf ball rebounding to a greater height than the table tennis ball. Neither ball was affected structurally by the drops. This was symbolic of how a heavy, high-density package (i.e. represented by the golf ball) and a light-weight, low-density package (i.e. represented by the table tennis ball) will typically react in the 9 m regulatory drop test.
- Second, dropping a rigid weight from a similar height onto the two balls sitting on the rigid floor. In this case, the golf ball (representing the heavy, high-density package designs) was unaffected by the drop of the rigid weight, whereas the table tennis ball (representing the light-weight, low-density package designs) was severely damaged by this drop.

In support of the panel discussion at PATRAM 2010, this graphical demonstration was re-created by the lead author of this paper; which was video-taped and recorded with photographs. The undamaged golf ball and the damaged table tennis ball that resulted from this re-created demonstration are shown in Figure 4. The damage to the table tennis ball following the drop of the rigid weight onto the ball can be clearly seen, while the golf ball remained un-damaged after a similar impact.

Fig. 4(a). Table tennis ball and golf ball, respectively following the drop of the balls from shoulder height.

Fig. 4(b0. Table tennis ball and golf ball, respectively, following the drop of a rigid weight from should height onto the balls.

This graphical demonstration allowed a clear understanding to be reached quickly by the attendees at the IAEA meeting as to the concerns that needed to be addressed.

TEST OF STACKED WASTE DRUMS IN THE US

During technology development, in the late 1970's, for the design of a package to transport multiple storage drums of radioactive waste, results were obtained[7] that illustrate the effects of drums dynamically crushing drums when a line (or stack) of the drums impacts a target. In the test of interest, eight "*320-kg (700-lb) nominal-weight drums were held in the vertical configuration by a special frame constructed from heavy steel plate and angle plate*". "*The frame was designed to keep the drums in a vertical orientation, but not to prevent vertical drum motion within the frame*". Prior to release for the drop, the bottom of the frame was 9.1 m (30 ft) above the target.

Figure 5(a) shows the stack of drums prior to the drop test, and Figure 5(b) shows the deformed drums following the drop test. It can be clearly seen that the top drum experienced essentially no deformation, but that the succeeding drums experienced greater crushing.

Specifically, Huerta, et. al.[8] reported that "*The lower six drums sustained about the same deformation, ~60% of their original height. The seventh drum was deformed to ~75% of its height, and the top drum underwent a very minor, almost undetectable, deformation.*"

Figure 5(c) provides a graphical depiction of the idealized deformed shapes of the drums in the stack of eight following the drop test.

These results offered further evidence that the drum-type packages are susceptible to dynamic crushing under extreme accident environments.

CRUSH TESTING OF PACKAGES IN THE US IN THE EARLY 1980'S

Following the deliberations on crush testing at the IAEA in the late 1970's, a series of tests were performed on eight existing light-weight, low-density package designs to determine how they would respond to the proposed dynamic crush test[9].

One of the packages tested was the 9B package designed by Y-12 in the US. Photographs of the package before and after the performance of the then-proposed dynamic crush test on this package are shown in Figure 6. The results of this test showed that the "*…external deformation under a crush environment is as much as an order of magnitude greater (based on deformation) than the deformation resulting from a 9-m drop….*".

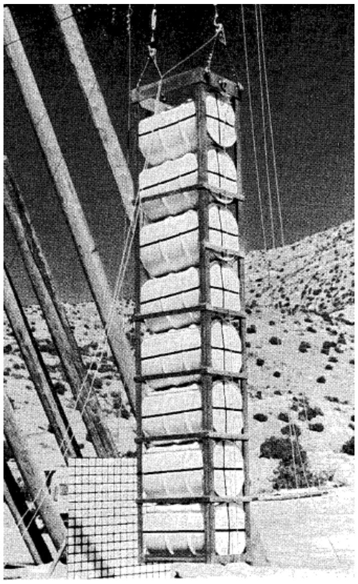

Fig. 5(a). Photograph of drums in frame prior to the 9.1 m drop onto an unyielding target (copied from Ref. 8).

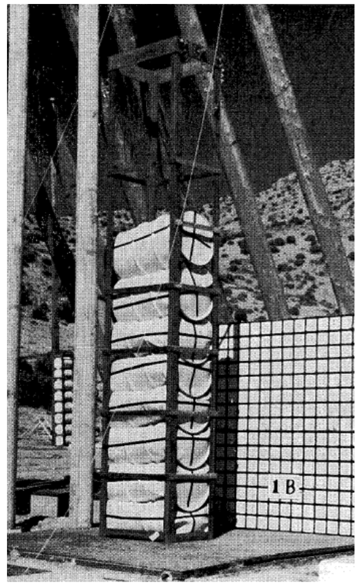

Fig. 5(b). Photograph of drums in frame after the 9.1 m drop onto an unyielding target (copied from Ref. 8).

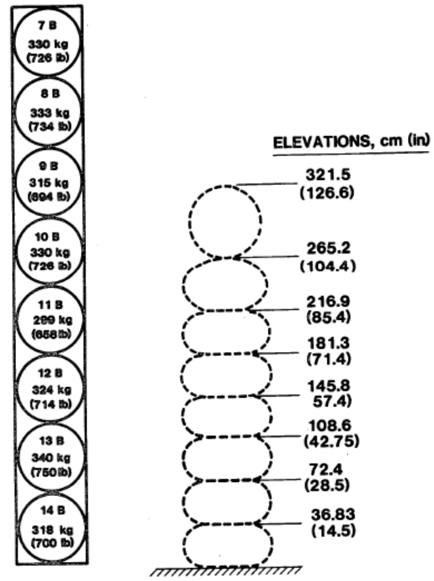

Fig. 5(c). Idealized deformed shapes for the stacked drum test (copied from Ref. 8).

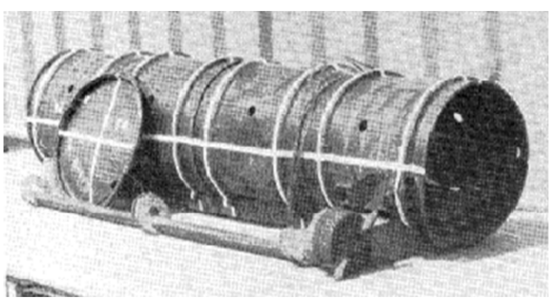

Fig. 6. The Y-12 package prior to the dynamic crush test (copied from Ref. 9).

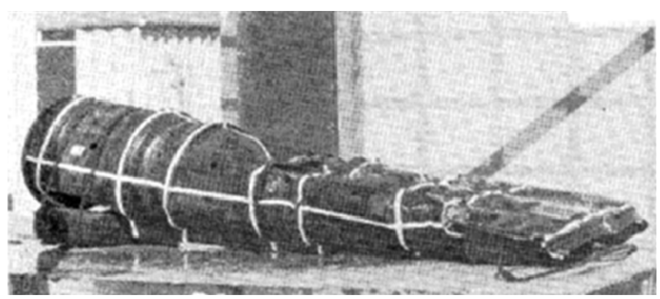

Fig. 6. The Y-12 package after the dynamic crush test (copied from Ref. 9).

CRUSH TESTING OF PACKAGES IN CANADA

A crush test of a package was also performed in Canada[10]. As a result of this test and other regulatory tests on the same package design (as shown in the photographs in Figure 7), it was concluded that **"…***for the particular specimens tested, the dynamic crush test is more severe than the 9m drop test and that…after being subjected to the crush test [the package] would most likely not successfully withstand the fire test…..***".** In the figure, one package specimen after the 9 m drop test, shown on the left of the photograph, showed little deformation; whereas, another package specimen that was exposed to the dynamic crush test showed much more significant deformation.

Fig. 7. Photograph of two package specimens; the package on the left was exposed to the 9 m drop test, the package on the right was exposed to the dynamic crush test (copied from Ref. 10).

CONCLUSION

This brief summary was prepared to support discussion of the current dynamic crush test required of Type B packages in the Transport Regulations[1]. This summary was intended to show that all considerations discussed at the IAEA viewed the damage to packages as being caused by the dynamic environments resulting from the packages being located in normal transport configurations. Thus, as envisioned during the IAEA deliberations, it was conceived that the package to be tested would rest on the target with no additional support.

ACKNOWLEDGEMENTS

The many individuals who participated in the deliberations at the IAEA and those who performed the analyses and tests discussed in this paper are acknowledged and thanked for their efforts. It is further noted that the photographs and drawings shown here are the best quality available from the documents that were produced as much a five decades ago.

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