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380-B Transport Packaging Testing for NRC and IAEA Compliance

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Abstract

AREVA Federal Services LLC, under contract to the Los Alamos National Laboratory's Offsite Source Recovery Program, has developed a new Type B(U)-96 package for the transport of unwanted or abandoned radioactive sealed sources. The Offsite Source Recovery Program recovers US origin sources domestically and internationally in the interest of national security, public health and safety. The package, denoted the 380-B, is designed to accommodate the sources within internal gamma shields, including those with gamma shields having unknown condition. The package includes gamma shielding and provides leak tight containment.

Certification testing for the 380-B was performed on half-scale impact limiters using one dummy cask and four impact limiters. A test plan was developed that identified the specific free drop and puncture tests necessary to evaluate both 10 CFR 71 and SSR-6 requirements. The NRC regulations state that the free drop impact takes place before the puncture test, while the IAEA tests must be completed in a sequence such that any damage suffered is the worst-case for the following thermal testing. A total of three 9-m (30-ft) HAC free drops, and four 1-m (40-inch) puncture drops were performed. Free drop accelerations were recorded for use in finite element model benchmarking and other structural analyses. The deformations of the impact limiters that could have an effect on performance in the HAC fire event were also recorded. This paper reviews the test planning and results with a discussion of how the NRC and IAEA tests were combined.

Introduction

The 380-B packaging has been developed to transport unwanted or abandoned radioactive sources contained in shielded exposure devices. It includes a conventional, austenitic stainless steel cask shielded by lead and closed by a bolted lid. Physical testing focused only on the impact limiters and attachments because the free drop and puncture drop damage of steel-shell, polyurethane foam-filled impact limiters can be adequately tested using scaled specimens. The test unit configuration therefore consisted of a half-scale dummy cask and half-scale impact limiters and attachments. Testing included three free drops and four puncture drops, as shown in Figure 1 and Figure 2, respectively. Test data collected included measured accelerations and measurements of the damaged configuration.

Tests involving only one impact limiter (i.e., tests where the package center of gravity was aligned with the impact location and relatively static with respect to rotation) were performed utilizing a ballast plate on the non-impact end to facilitate simpler and safer drop orientation rigging. The ballast plate had the same weight as an impact limiter, and consequently the test unit had the same dynamic behavior as if both impact limiters had been present. The test unit configuration with the ballast plate can be seen in Figure 3.

Testing included one half-scale dummy cask and four half-scale impact limiters. Three of the impact limiters contained 0.24 g/cm^3 (15 lb/ft^3) polyurethane foam and were heated to approximately 38 °C (100 °F), which yielded foam crush strength which was equivalent to the production density of 0.26 g/cm^3 (16 lb/ft^3) and the

Normal Conditions of Transport (NCT) foam temperature of 54 °C (130 °F). One impact limiter contained 0.27 g/cm^3 (17 lb/ft^3) polyurethane foam and was cooled to approximately -18 °C (0 °F), which yielded foam crush strength which was equivalent to the production density of 0.26 g/cm^3 (16 lb/ft^3) and the minimum foam temperature of -40 °C (-40 °F). This technique facilitated testing and increased safety by avoiding the need to achieve extreme temperatures at the test site.

The objective of the test program was to demonstrate adequate safety, for 10 CFR 71 [1] and SSR-6 [2], of the 380-B package impact limiters and attachments by subjection to the following criteria:

1. The impact limiter shells had to retain their general integrity for all impacts and deformations. Ripped welds or other tears or fissures were acceptable as long as they were limited in extent and accounted for in the Hypothetical Accident Condition (HAC) fire thermal analysis. Full puncture perforation of the impact limiter shells by the puncture bar was considered acceptable.
2. The impact limiter attachments had to retain the limiters on the cask. A limited degree of distortion or dislodging of the limiters was acceptable, but had to be accounted for in the HAC fire thermal analysis.
3. The impact limiters had to maintain package deceleration to acceptable levels. The safety analyses utilized the results of the testing as input.
4. The maximum damage to the limiter from the single worst-case free drop and puncture test sequence had to fall within the bounding assumptions used in the HAC fire thermal analysis.

Because it was desired to accomplish the safety demonstration to both 10 CFR 71 and SSR-6 using the same test sequence, the bounding requirements of each regulation were used to ensure compliance. This resulted in two differences from a typical certification test aimed solely at 10 CFR 71 requirements:

- The minimum temperature used for the maximum free drop impact was -40 °C (-40 °F), to satisfy SSR-6, whereas 10 CFR 71 requires only a minimum temperature of -29 °C (-20 °F).
- One test was configured for the sequence: puncture-before-free drop (to address SSR-6 requirements) and another test was configured for the sequence: puncture-after-free drop (to address 10 CFR 71 requirements). To maximize efficiency, both tests were combined on the same test unit and occurred during the same free drop. This subject is discussed further in Section 2.0.

Certification Tests and Methodology

An exhaustive consideration of the packaging design was conducted to identify the specific free drop and puncture tests necessary to evaluate both 10 CFR 71 and SSR-6 worst-case testing requirements. NRC regulations state that the free drop impact must occur prior to the puncture test, while IAEA free drop and puncture tests must be completed in a sequence such that any damage suffered is the worst-case for the following thermal testing. The following sections provide a summary of the free drop and puncture test orientations and sequences considered relative to the packaging's susceptibility to damage.

Free Drop

End Drop (D1) – As shown in Figure 1 and Figure 2, the impact limiter end design is tapered and hollow to limit impact loads while providing sufficient energy absorption stroke. The end drop impact is highly important to the analysis of the cask body shells, the closure lid bolts, and lead slump. Thus, this drop test was performed with the impact absorbing material at the minimum temperature. This test quantifies the maximum end drop impact acceleration, and generates damage to the impact limiter for the subsequent puncture (test P1).

Near Vertical End Drop – In a near vertical end drop, the impact limiter would have a smaller initial contact area and larger available stroke. Thus, the free drop impact accelerations would be bounded by the end drop. Additionally, due to the tapered impact limiter design, this orientation cannot apply any significant additional loading on the impact limiter attachments beyond that applied by the vertical end drop orientation. Therefore, this orientation did not need to be tested.

CG-over-Corner Drop (D2) – The center of gravity (cg)-over-corner orientation presents the smallest impact limiter cross section and therefore was anticipated to govern the free drop deformation. This drop test was performed with the impact absorbing material at the maximum temperature. This test quantifies the maximum impact limiter crush strain in the cg-over-corner orientation, and generates damage to the impact limiter for the subsequent puncture (test P2).

Slapdown – The aspect ratio of the cask length to outer diameter of the impact limiters is 0.68. With this shorter type package, the secondary impact would not be greater than the primary impact in a slapdown free drop orientation. This orientation was therefore not limiting for either the free drop impact accelerations or free drop deformation. Therefore, this orientation was not tested.

Side Drop (D3) – The side drop has the most limited available stroke of any orientation and thus this drop test was performed with the impact absorbing material at the maximum temperature. This test quantifies the maximum deformation of the impact limiters, both damaged from a preceding puncture (test P3) and undamaged prior to a subsequent puncture (test P4).

Puncture Drop

The impact limiter shell thickness was not designed to prevent penetration of the puncture bar for the 1-m (40-inch) puncture tests. Therefore, the stainless steel shell was expected to perforate in most orientations. To satisfy 10 CFR 71, consideration was given to puncture tests occurring after each free drop orientation. In addition, to satisfy SSR-6, consideration was given to the effect of puncture testing both prior to, and subsequent to each free drop, relative to its effect on the subsequent fire event. The temperature of the impact limiter specimens was not controlled for the puncture tests, since the metal is expected to perforate and the foam has little puncture resistance at any temperature.

End Drop Puncture (P1) – The cask design includes a vent port located in the cask lid. The vent port is sealed using an elastomeric O-ring seal that may be damaged in the HAC fire event. Therefore, damage of the impact limiters in the region of the vent port could allow excessive temperatures in the vent port seals. The purpose of this test was to quantify the worst-case damage around the location of the vent port for the thermal analysis. Due to the large size of the impact limiter area relative to the diameter of the puncture bar, this puncture test would have a negligible influence on the end drop if it were performed prior to the end drop. Thus, this puncture was performed after the end drop. This test order satisfied both the test order requirement of 10 CFR 71 as well as the worst-case test order requirement of SSR-6.

CG-over-Corner Puncture (P2) – The cask lid is closed using an elastomeric O-ring face seal that may be damaged by excessive heat in the HAC fire event. The worst-case damage to the impact limiter in the cask lid area would be a puncture towards the side of the lid of the cask in the cg-over-corner drop damage. The purpose of this test was to quantify the worst-case damage around the cask lid elastomer seal for the thermal analysis. This puncture test would have a negligible influence on the free drop if performed before the drop for the same reason as stated above. Thus, this puncture was performed after the cg-over-corner drop. This test order satisfied both the test order requirement of 10 CFR 71 as well as the worst-case test order requirement of SSR-6.

Oblique Side Puncture (P3 and P4) – The 90-degree outside radial joint of the impact limiter is comprised of a relatively stiff structural angle, as compared to the rest of the impact limiter skin materials. This joint may be weakened by a side drop. The worst-case damage to the impact limiter would occur if the puncture bar was aligned with the side drop damage, such that the c.g. of the cask was essentially over the bar, and so it would obliquely strike the side shell near the reinforcement. Puncture (P4) was performed after the side free drop, which satisfied both the test order requirement of 10 CFR 71 as well as the worst-case test order requirement of SSR-6.

Consideration of the effects of a puncture prior to the side drop yielded the possibility that puncture damage to the side drop crush region could increase free drop deformation, which could lead to hard contact and high impact, or loss of thermal protection in the elastomer seal region. An essentially axial puncture orientation was expected to create the most damage to the side crush area. Since the bar axis would not be toward the c.g., further damage would occur if the package tipped off of the bar. Puncture (P3) was performed prior to the side free drop, to additionally consider and satisfy the worst-case test order requirement of SSR-6.

To reduce the total number of test articles necessary, puncture tests (P3) and (P4) were combined with free drop (D3). Test (P3) was performed *prior* to (D3) on one end of the test cask, for a sequence satisfying SSR-6, and test (P4) was performed *after* (D3) on the other end of the test cask, for a sequence satisfying 10 CFR 71.

Test Plan Summary

A complete summary of the certification tests is provided in Table 1. The free drop orientations are shown in Figure 1, and the puncture orientations are shown in Figure 2.

Table 1 – Summary of Certification Tests

No.	Test Description	Test Limiter	Temperature
D1	End Drop	1	Cold
P1	End Drop Puncture	1	Not controlled
D2	CG-over-Corner Drop	2	Warm
P2	CG-over-Corner Puncture	2	Not controlled
P3	Oblique on Taper *prior* to drop D3	3	Not controlled
D3	Side Drop	3 and 4	Warm
P4	On Test D3 Damage	4	Not controlled

Certification Test Results

The test results are now discussed relative to the criteria outlined in Section 1.0.

1. The impact limiter steel shells maintained general integrity under all conditions. It was expected that the puncture bar would penetrate the shells, but the penetrations produced by the puncture bar were of limited extent, and small enough to be sealed by the expanding char of the polyurethane foam absorbing material in the case of the HAC fire event. The impact limiting material was retained within the shells and performed its function.

   In particular, there was no "tear-out" of foam from the off-cg puncture test (P3) which had the potential to rip a large gash during roll-off from the puncture bar following impact. The actual result was that the limiter retained integrity, but the puncture bar did not – see Figure 3.

   One shell weld joint was shown to have inadequate penetration, even though a backing bar was used in the joint design. This weld was reinforced with a lap joint splice, and subsequent tests were successful. With this small modification, impact limiter shell design was demonstrated to be adequate.

2. The impact limiter attachment bolts held the impact limiters very securely in place in all free drop and puncture tests. After all tests were complete, the attachment bolts and related structures were virtually undamaged. Thus, the attachment bolts can be depended on to hold the impact limiters securely in place at the ends of the cask.

3. The impact limiter design successfully limited maximum impact under cold conditions while limiting excessive deformation under warm conditions. The maximum full-scale equivalent impact was approximately 80 g in the cold end drop. It was also determined that the puncture hole created by the puncture-before-free drop test had essentially no effect on the subsequent free

drop behavior. In fact, the crush deformation of the impact limiter with the prior puncture damage was essentially identical to that of the impact limiter without prior puncture damage, as shown by Figure 4.

Thus, the only sequence which was determined to offer a potential for worse damage if the puncture was performed first, proved not to be worse after all. This seems to imply that the sequence ’puncture-before-free drop‘ very rarely, if ever, presents a worse final damage scenario than does the sequence ’puncture-after-free drop‘.

4. The worst-case damage to the shell from the combination of free drop and puncture damage was made a part of the HAC fire event thermal analysis. The resulting component temperatures were acceptable.

Conclusions

Strategic consideration of the 380-B packaging’s design susceptibility to damage when subjected to free drop and puncture tests lead to a single program where both 10 CFR 71 and SSR-6 testing requirements were evaluated. The resulting performance of the impact limiters was acceptable.

References

1. Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Energy — Packaging and Transportation of Radioactive Material*.
2. Specific Safety Requirements, No. SSR-6, *Regulations for the Safe Transport of Radioactive Material*, International Atomic Energy Agency (IAEA), 2012 Edition.

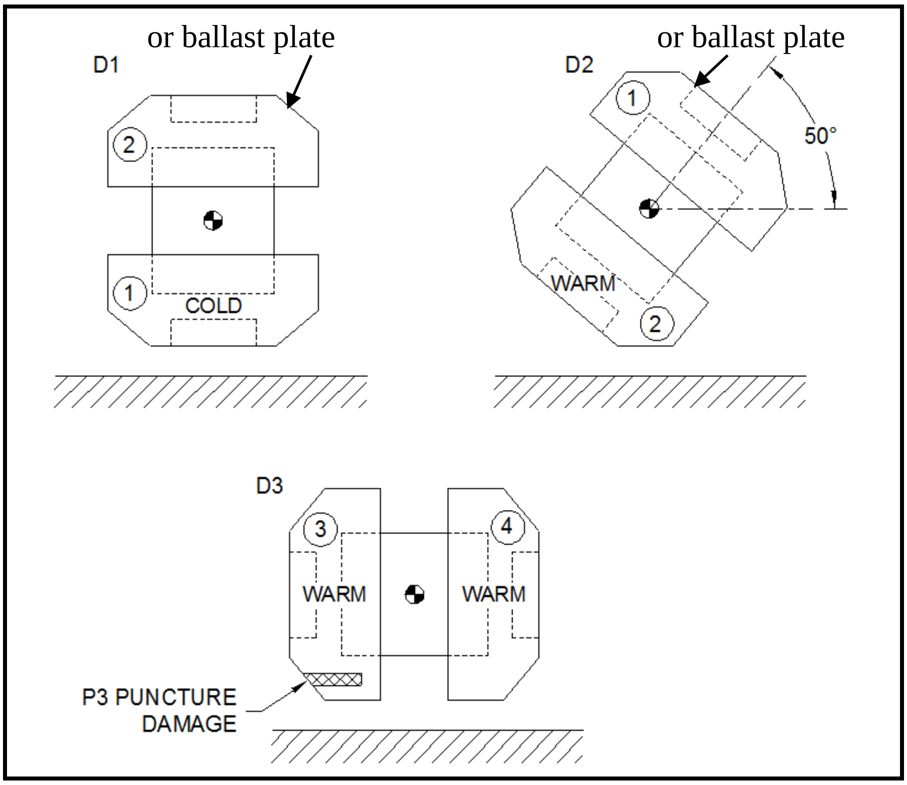

Figure 1 – Free Drop Summary

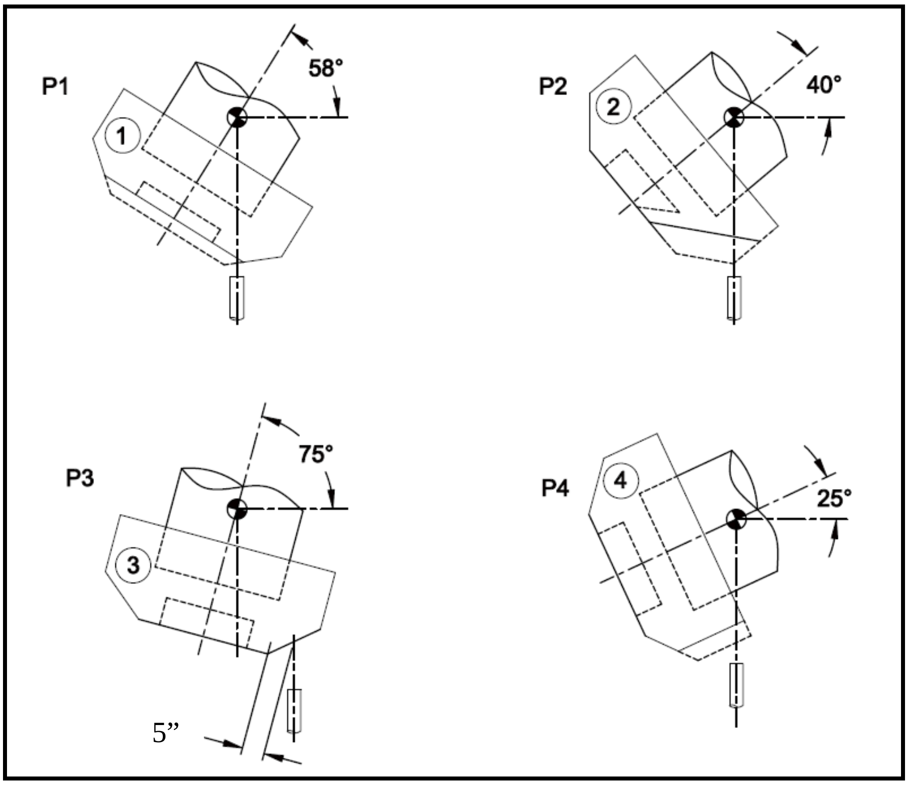

Figure 2 – Puncture Drop Summary

Figure 3 – CTU Condition after P3 Puncture Drop Test

Figure 4 – CTU Condition after D3 Free Drop Test