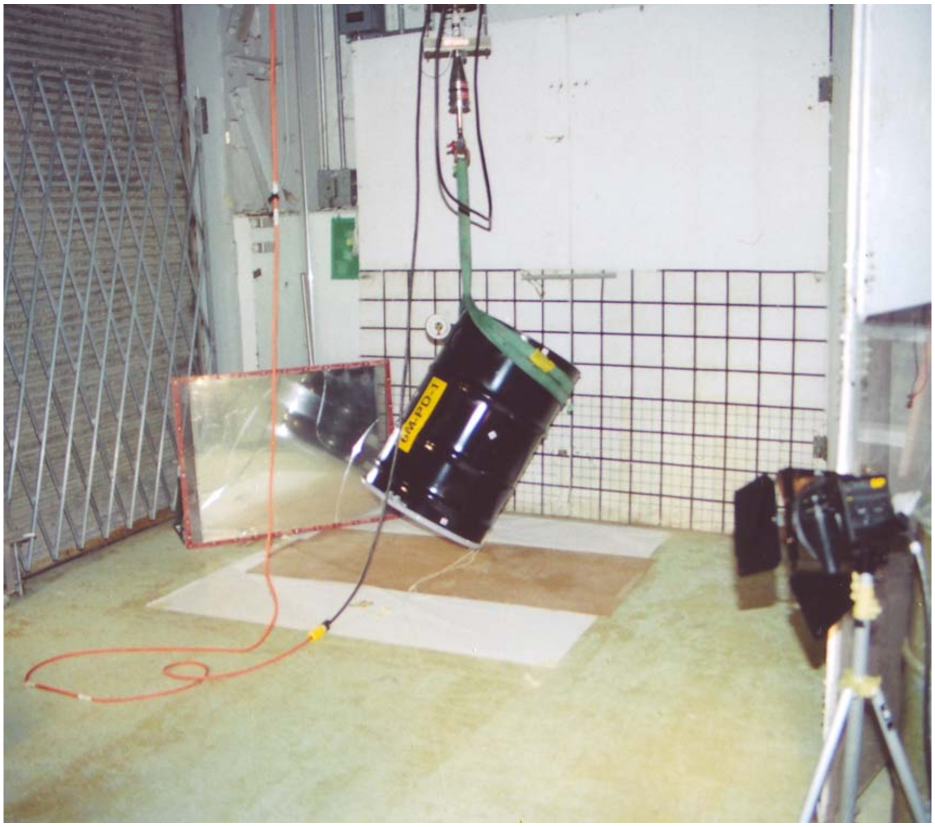
Drop Tests for the 6M Specification Package Closure Investigation (U)



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Summary

Results of previous tests of drum-type RAM packages employing the standard clamp-ring closures have caused concern within the DOE Complex over the DOT 6M Specification Package. To clarify these issues, the Savannah River Site's Radioactive Material Packaging Technology Group was commissioned to conduct a series of tests to determine the response of the clamp-ring closure to the regulatory Hypothetical Accident Condition (9m) drop tests, for packages at maximum allowable weight, 640-lb. Additionally, three enhanced closure designs were also tested: the Clamshell, plywood disk reinforcement, and J-Clip. The results of the tests showed that the standard closure was unable to retain its lid for both Center-of-Gravity-Over-Corner and Shallow-Angle cases, for the standard package, at its maximum allowed weight. Similar results were found for packages dropped from a reduced height. The Clamshell design provided the best performance of the enhanced closures.

1.0 Background

Results of tests of drum-type RAM packages employing conventional clamp-ring closures have shown that the clamp-ring design may not be adequate in some cases. These results have caused concern within the DOE Complex over the DOT 6M Specification Package, which is widely used in the Complex, and which employs the clamp-ring closure. To clarify the issues associated with use of the 6M for DOE contents, a series of tests were performed to determine the response of the clamp-ring closure on the 6M to the regulatory Hypothetical Accident Condition (9m) drop tests.

2.0 Test Program

The objective of the test program was to determine the comparative performance of standard and enhanced closures for 6M Specification Packages subjected to HAC drop tests. [1, 2] To accomplish this objective, packages were dropped in orientations which have resulted in large openings, or complete loss of the lids in earlier tests of drum type packages. [3-6] The 55 gallon drum size 6M package was chosen as the representative case for these tests.

Following the pattern of earlier package testing with clamp-ring closures, each test was preceded by a Normal Conditions of Transport (NCT) test from a height of four feet. These preconditioning tests were planned to challenge the drum's lock ring closure arrangement so that the effects of the subsequent thirty foot drop would be maximized.

The ratio of internal weight (containment vessel and contents) to the overall package weight has been shown to be an important parameter in determining the probability of a significant lid opening or lid loss occurring in a drop test. [4] For this reason, the 6M tests were performed with the packages at the maximum weight allowed by the specification for the 55 gal. Drum configuration (640 lb).

Because the object of the test was to investigate the closure response, the details of the internals were not important. Accordingly, stainless steel cylinders were used to simulate the 2R Containment vessel and to ballast the package to the required weight. However, the 6M test specimens were fully compliant with the DOT general construction requirements in §178.354-3

Earlier tests of drum type packages have shown that the Center-of-Gravity-Over-Corner (CGOC) orientation and the Shallow-Angle (SA) orientation challenge the closure in different ways. To capture both types of response, tests were conducted at 55º and 17.5º for the CGOC and SA cases respectively.

As noted above, earlier tests have shown that prior damage from an NCT 4-ft free drop may impair the effectiveness of a clamp ring on the subsequent HAC free drop. Based on this experience, the 6M test packages were subjected to NCT pre-conditioning drops prior to the 30-ft HAC drops. The target point for each NCT drop was located 90 degrees, circumferentially, from the target point for the HAC drops.

Baseline tests were performed on 6M packages with standard clamp-ring closures. Identical tests were performed on packages with the enhanced closure designs. The planned program is shown in Table 1 below.

Table 1 Drop Test Conditions

6M Drum Lid Retention Test Matrix All test packages subjected to NCT and HAC tests.	
Package ID#, Closure Configuration	Orientation
6M-S-1, Baseline (Standard 6M)	CGOC, 30 ft (9m)
6M-S-2, Baseline (Standard 6M)	Shallow Angle, 30 ft (9m)
6M-CS-1, Clamshell	CGOC, 30 ft (9m)
6M-CS-2, Clamshell	Shallow Angle, 30 ft (9m)
6M-PD-1, Plywood Disk	CGOC,30 ft (9m)
6M-PD-2, Plywood Disk	Shallow Angle, 30 ft (9m)ft
6M-JC-1, J-Clip	CGOC, 30 ft (9m)
6M-JC-2, J-Clip	Shallow Angle, 30 ft (9m)
6M-PD-3, Plywood Disk	CGOC, 30 ft (9m)
6M-S-7, Standard 6M	Shallow Angle, 20 ft (6.1m)
6M-S-6, Standard 6M	CGOC, 20 ft (6.1m)
6M-S-5, Standard 6M	CGOC, 15 ft (4.6m)
6M-S-8, Standard 6M	Shallow Angle, 25 ft (7.6)

The performance acceptance criterion for the test specimens was to retain the lid in such a way that a significant reduction in effectiveness of the overpack did not occur.

3.0 Test Apparatus

3.1 Test Specimens

WSRC purchased 16, 6M packages from a manufacturer regularly involved in the production of 6M packages.

The packages were assembled with dummy contents (representing the maximum content weight) by the Site Rigging Department using a 2-Ton overhead crane. The dummy contents consisted of stainless steel round sections, 10-in diameter and 19.25-in long, for a typical contents weight of approximately 458 lb. The riggers then installed the closure using the instructions provided by the 6M manufacturer. The torque value employed for the tightening the closure ring bolt was, 40 ft lb, and the gap between the ends of clamp-ring was between 1/8 and ¼-in. The closure bolt was oriented to coincide with the longitudinal seam of the body of the drum.

After the closure was fully assembled, the test drum was weighed using the overhead crane and a calibrated dynamometer.

Finally, the test drums were marked with reference points, measured from the drum seam line, as specified in the test procedures, L9.5-9150. [7] Pretest measurements were made to characterize the package.

3.2 Package Identification Numbers

The packages were assigned unique identification numbers by the lead Test Engineer. The nomenclature used to identify the test specimens is as follows:

> ***6M*** *- closure type or configuration - test specimen number*
> Where the closure types or configuration are:

S - Standard 6M closure
CS - Savannah River Site Clamshell Closure
JC - Savannah River Site J-Clip Closure
PD - Standard 6M closure and plywood in place of the fiberboard under the lid.

For example, ***6M-S-1***, is a 6M with the standard closure, test specimen number 1.

4.0 Drop Tests

4.1 Procedure and Facility

The drop tests were performed in the SRS Building 723-A high bay drop test facility in accordance with Field Procedure L9.5-9150. [7] The test sequence consisted of a 4-ft NCT preconditioning drop, followed by a 30-ft HAC drop. The NCT drop was conducted at the same orientation as the 30-ft drop (CGOC or shallow angle). The point of contact for the NCT drop was 135º clockwise from the drum seam. The point of contact for the HAC drop was 45º clockwise from the drum seam. Previous testing has shown that the HAC drop typically produces a buckle across the lid having an angular width of around 90º. The orientations selected will cause this buckle to occur midway between the NCT and HAC contact points. In addition, the buckle will coincide with the clamp-ring closure bolt and lug assembly.

For each drop, the package was aligned to within one degree of its nominal orientation prior to the drop. Each drop was recorded at 1,000 frames per second using a high speed video camera, as well as normal speed video. Following each drop test, the package was measured and photographed to document the extent of damage.

The drop test surface was constructed from a 6.25-in thick armor plate, approximately 5-ft square, anchored in a 36-in thick reinforced concrete slab. The target slab is isolated from the concrete floor of the building. The target slab weighs approximately 15,600 lb., which is over 24 times the weight of the test packages (640 lb.).

4.2 Testing

The 6M Closure drop tests were performed between August 20 and 27, 2003. The packages were subjected to 4-ft NCT drops followed by 30-ft HAC drops. The first set of test specimens consisted of two with standard 6M closures and two each of the proposed enhanced closure designs. Each configuration was tested in the CGCO orientation and in the SA orientation.

The second set of tests explored the behavior of the standard closure at free drop heights lower than 30-ft. Each of these test packages was subjected to a 4-ft NCT preconditioning drop, as in the first set of tests. The second set of tests also included one specimen for which testing was not completed in the first group of tests, 6M-JC-2, and a plywood disk reinforced package with a thicker plywood disk (i.e., 2-in) than the plywood disk reinforced packages tested in the first group (i.e., 1-in).

The results of the tests are described in the order in which the 30-ft HAC drops were performed in the following section.

5.0 Results

5.1 Tests of Package 6M-S-1

Results of these tests are illustrated in the Figures 1 through 4 photographs.

5.1.1 NCT Preconditioning Test for 6M-S-1

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release, Figure 1. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-1 weighed 633 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 7-in. at the point of impact. Minor flattening of the rolling rings and the bottom chime of the drum resulted from the drum falling over after the initial impact. The upper rolling hoop was collapsed in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch, from 32 ½ to 31 5/8-in. All other reference dimensions on the drum were essentially unaffected . The results of this drop are shown in Figure 2.

5.1.2 30-ft Drop Test for 6M-S-1

The 30-ft drop was performed with the package oriented so that its axis was 55°, lid down, at release. The angle of the drum at impact was 54º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the "corner" of the package around the point of contact and separation of the lid from the drum over the remainder of its circumference (approximately 270º). The Cane fiberboard overpack disks were separated and damaged, and the interior cavity was exposed. Minor flattening (about 8-in width) of the rolling rings and the chime of the drum resulted from the second hit, following the initial impact. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 3 ½-in, from 32 3/4 to 29 ¼-in. The damage was typical of CGOC drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the drum over about half of the separated periphery, but remained engaged with the lid over the other half of the region where the lid was separated. The results of this drop are shown in Figures 3 and 4.

5.2 Tests of Package 6M-S-2

The results of the drop testing of package 6M-S-2,are shown in Figures 5 through 9.

5.2.1 NCT Preconditioning Test for 6M-S-2

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release, Figure 5. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-2 weighed 637 lb. The preconditioning drop resulted in slight flattening, about 7-in wide, and associated broadening of the closure ring at the impact point and associated flattening on the side of the drum. The flattened region of the lower rolling ring was about 7-in wide, and at the bottom chine also about 7-in wide. The outside diameter of the drum was reduced from 22 5/8 to 22 ¼-in measured through the point of contact. The outside diameter of the drum measured perpendicular to this axis remained unchanged at 22 ½-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figures 6 and 7.

5.2.2 30-ft Drop Test for 6M-S-2

The 30-ft drop was performed with the package oriented so that its axis was 17.5°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 18º. The drop resulted in separation of the lid and flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The flattened region of the upper rolling hoop was about 12-in wide, the center rolling hoop about 10.5-in wide, the lower rolling hoop about 11-in wide, and that of the bottom chine was about 11-in wide. The outside diameter of the drum was reduced from 22 1/2 to 21 7/16-in measured through the point of impact. The width of the flattened region of the closure ring was 14-in. The axial distance between the reference marks on the impact side was not changed, remaining at 32 ½-in. The damage was typical of low angle drops, with local buckling of the drum and lid in the damage region. The lid buckled outwards along a line parallel to the flattened side. This buckling resulted in the lid pulling out from under the closure ring on both ends of the flattened region produced by the 30-ft drop. These openings then propagated around the lid, so that it became disengaged from the clamp-ring and the drum over its full circumference. The raised and curved (inverted J) rim of the lid was buckled inward and folded down on to the horizontal, disk section of the lid, at the point of impact. The region where the raised rim was folded back was lightly pinched between the curl of the drum and the cane fiberboard disks, in the vicinity of the impact point, preventing the lid from falling completely away from the drum. A light tug was sufficient to remove the lid, during post-test disassembly. The results of this drop are shown in Figures 8 and 9.

5.3 Tests of Package 6M-CS-1

The results of the drop testing of package 6M-CS-1, are shown in Figures 10 through 12.

5.3.1 NCT Preconditioning Test for 6M-CS-1

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-CS-1 weighed 635 lb. The preconditioning drop resulted in bending the drum lid, clamshell and rim assembly downward over a width of approximately 8-in at the point of impact. No damage was incurred on the sides of the drum because the package stood on its lid, following the impact. The upper rolling hoop was collapsed in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch, from 30 ¾ to 29 ¾-in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 10.

5.3.2 30-ft Drop Test for 6M-CS-1

The 30-ft drop was performed with the package oriented so that its axis was 55°, lid down, at release. The angle of the drum at impact was 53º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the "corner" of the package around the point of impact. Minor flattening, about 8-in in width, of the lower rolling rings and 10-in in width at the chime of the drum resulted from the bottom striking the impact surface, following the initial hit. The vertical distance between reference marks 1 and 5 (point of impact) was reduced from 30 ¾ to 28 ¼-in. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and lid in the damage region. However, the lid remained securely retained all around its circumference, with no openings present. The results of this drop are shown in Figures 11 and 12.

5.4 Tests of Package 6M-CS-2

The results of the drop testing of package 6M-CS-2, are shown in Figures 13 through 15.

5.4.1 NCT Preconditioning Test for 6M-CS-2

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-CS-2 weighed 633 lb. The preconditioning drop resulted in slight flattening, about 4 ½-in wide, and associated broadening of the closure ring at the impact point and associated flattening on the side of the drum. The flattened region of the lower rolling ring was about 8-in wide, and at the bottom chime about 10-in wide. The outside diameter of the drum was reduced by one inch, from 22 5/8 to 21 5/8-in, measured through the point of contact. The outside diameter of the drum, measured perpendicular to this axis, remained unchanged at 22 5/8-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figure 13.

5.4.2 30-ft Drop Test for 6M-CS-2

The 30-ft drop was performed with the package oriented so that its axis was 17.5°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 17º. The drop resulted in flattening of the closure ring of the package at the point of contact, and associated flattening along the length of the drum. The width of the flattened region of the closure ring was 14-in. The flattened regions of the drum are as follow: the upper rolling hoop was about 14-in wide, the center rolling hoop about 10-in wide, the lower rolling hoop about 11-in wide, and the bottom chime was about 12-in wide. The outside diameter of the drum was reduced from 22 5/8 to 21 ¾-in, measured through the point of impact. The axial distance between the reference marks on the impact side was not changed, remaining at 31-in. The damage was typical of low angle drops, with local buckling of the drum and lid in the damage region. The lid was retained securely all around and no openings resulted from the deformation. The results of this drop are shown in Figures 14 and 15.

5.5 Tests of Package 6M-PD-1

The results of the drop testing of package 6M-PD-1, are shown in Figures 16 through 19.

5.5.1 NCT Preconditioning Test for 6M-PD-1

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release, Figure 16. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-PD-1 weighed 643 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 7-in at the point of impact. No further damage occurred because to package settled on its lid, following the impact. The upper rolling hoop was collapsed in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch, from 32 to 31 1/8-in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 17.

5.5.2 30-ft Drop Test for 6M-PD-1

The 30-ft drop was performed with the package oriented so that its axis was 55°, lid down, at release. The angle of the drum at impact was 55º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the "corner" of the package around the point of contact and separation of the lid from the drum over an arc of approximately 120º. The maximum height of the opening was about 3 inches, exposing the Plywood disk and the cane fiberboard overpack disks. The separation extended from the end of the NCT damage region closest to the HAC damage region clockwise for 120º. The maximum width of the flattened area of the lid (measured along the buckle) was approximately 21-in. Minor flattening of the chime of the drum, (about 4-in wide) resulted from the second hit, following the initial impact. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 3-in, from 32 to 29-in. Other dimensions between reference marks were little affected by the damage. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the lid all around, including the separated region. The results of this drop are shown in Figures 18 and 19.

5.6 Tests of Package 6M-PD-2

The results of the drop testing of package 6M-PD-2,are shown in Figures 20 through 22.

5.6.1 NCT Preconditioning Test for 6M-PD-2

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-PD-2 weighed 638 lb. The preconditioning drop resulted in slight flattening, about 7 ½-in wide, and associated broadening of the closure ring at the impact point and associated flattening on the side of the drum. The flattened region of the lower rolling ring was about 7-in wide, and at the bottom chine also about 7-in wide. The outside diameter of the drum was reduced about 5/8 in, measured through the point of contact. The outside diameter of the drum measured perpendicular to this axis remained unchanged at approximately 22 5/8-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figure 20.

5.6.2 30-ft Drop Test for 6M-PD-2

The 30-ft drop was performed with the package oriented so that its axis was 17.5°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 15.2º. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The flattened region of the upper rolling hoop was about 11.5-in wide, the center rolling hoop about

11.5-in wide, the lower rolling hoop about 11-in wide, and that of the bottom chine was about 11-in wide. The outside diameter of the drum was reduced approximately 0.5-in, from 22 9/16 to 22 1/16-in, measured through the point of impact. The width of the flattened region of the closure ring was 13-in. The axial distance between the reference marks on the impact side was not changed, remaining at 32 1/8-in. The damage was typical of low angle drops, with local buckling of the curl of the drum and the rim of the lid in the damage region. The raised and curved (inverted J) rim of the lid was buckled inward and folded down on to the horizontal, disk section of the lid, at the point of impact. The flattened side of the disk section of the lid, near the contact point, was less extensive with the plywood disk than in the previous shallow angle tests. The region where the raised rim of the lid was folded back was smaller than in the previous shallow angle tests. The lid remained securely attached, without openings. The results of this drop are shown in Figures 21 and 22.

5.7 Tests of Package 6M-JC-1

The results of the drop testing of package 6M-JC-1, are shown in Figures 23 through 25.

5.7.1 NCT Preconditioning Test for 6M-JC-1

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-JC-1 weighed 637 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 7 ½-in at the point of impact. The J-Clip located at the impact point was loosened by the impact. The upper rolling hoop was collapsed in the vicinity of the impact point. No further damage occurred because to package settled on its lid, following the impact. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 23.

5.7.2 30-ft Drop Test for 6M-JC-1

The 30-ft drop was performed with the package oriented so that its axis was 56°, lid down, at release. The angle of the drum at impact was 55º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the “corner” of the package around the point of contact and flattening of the J-Clip closest to the point of contact. The maximum width of the flattened area of the lid was approximately 20-in. No further damage was incurred because the package bounced and landed on its bottom. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 2-in, from 31 1/2 to 29 ¼-in. The vertical distance between marks 2 and 6, on the NCT damage side, was reduced by 1.5 in., from 31 3/4 to 30 ¼-in for the sequential drops. Other dimensions between reference marks were little affected by the damage. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the lid all around, and the J-Clips retained the lid securely. However, narrow openings occurred between some of the J-Clips, exposing the cane fiberboard material. These openings were similar to those which occurred on the UC-609 (which uses J-Clips) in its drop tests. The results of this drop are shown in Figures 24 and 25.

5.8 Tests of Package 6M-JC-2

The results of the drop testing of package 6M-JC-2,are shown in Figures 26 through 28.

5.8.1 NCT Preconditioning Test for 6M-JC-2

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release, Figure 5. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-JC-2 weighed 631 lb. The preconditioning drop resulted in slight flattening, about 7-in wide, and associated broadening of the closure ring at the impact point and associated flattening on lower side of the drum. The J-Clip at the point of contact was loosened. The flattened region of the lower rolling ring was about 7-in wide, and at the bottom chine also about 9-in wide. The outside diameter of the drum was reduced about 1/4 in., from 22 5/8 to 22 7/16 in., measured through the point of contact. The outside diameter of the drum measured perpendicular to this axis remained unchanged at approximately 22 5/8-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figure 26.

5.8.2 30-ft Drop Test for 6M-JC-2

The 30-ft drop was performed with the package oriented so that its axis was 17°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 18.4º. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The flattened region of the clamp ring was about 15 in, that of the upper rolling hoop was about 15-in wide, the center rolling hoop about 11-in wide, the lower rolling hoop about 11-in wide, and that of the bottom chine was about 9-in wide. The outside diameter of the drum was reduced approximately 1 in., from 22 5/8 to 21 5/8 in., measured through the point of impact. The width of the flattened region of the closure ring was 15-in. The axial distance between the reference marks on the impact side was essentially unchanged. The damage was typical of low angle drops, with local buckling of the curl of the drum and the rim of the lid in the damage region. The raised and curved (inverted J) rim of the lid was buckled inward and folded down on to the horizontal, disk section of the lid, at the point of impact. The lid buckled along a line parallel with the flattened section. The lid pulled out from under the clamp ring over a length of approximately 5-in at each end of the buckle. The clamp ring remained engaged with the curl of the drum, all around, and lid was securely retained. The results of this drop are shown in Figures 27 through 28.

5.9 Tests of Package 6M-PD-3

The results of the drop testing of package 6M-PD-3, are shown in Figures 29 through 31.

5.9.1 NCT Preconditioning Test for 6M-PD-3

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 57°, lid down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-PD-3 weighed 645 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 8-in at the point of impact. The upper rolling hoop was collapsed in the vicinity of the impact point. No further damage occurred because to package settled on its lid, following the impact. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch, from 32 7/8 to 31 ¾-in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figures 29.

5.9.2 30-ft Drop Test for 6M-PD-3

The 30-ft drop was performed with the package oriented so that its axis was 56°, lid down, at release. The angle of the drum at impact was 54.5º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the "corner" of the package around the point of contact and separation of the lid from the drum over an arc of approximately 100º. The maximum height of the opening was about 2 inches, exposing the Plywood disk and the Cane fiberboard overpack disks. The separation extended from the end of the NCT damage region closest to the HAC damage region clockwise for 100º. Minor flattening (about 6-in in width) of the rolling rings and the chime of the drum resulted from the second hit, following the initial impact. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 4 in, from 32 ¾ to 28 3/16-in. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the lid all around its circumference. The results of this drop are shown in Figures 30 and 31.

5.10 Tests of Package 6M-S-7

Following the unsatisfactory results of the 30-ft drop tests of the packages with standard closures, 6M-S-1 and 6M-S-2, drop tests from lower heights were planned, to more closely characterize the response of the package closure under impact conditions. As the first part of this additional characterization, drop tests of packages with standard clamp-ring closures were performed from a height of 20 ft, in the Shallow Angle and CGOC orientations. The packages for these tests were 6M-S-7 and 6M-S-6, respectively. The results of the drop testing of package 6M-S-7 are shown in Figures 32 through 34.

5.10.1 NCT Preconditioning Test for 6M-S-7

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-7 weighed 637 lb. The preconditioning drop resulted in slight flattening, about 7 1/2-in wide, and associated broadening of the closure ring at the impact point and associated flattening on the side of the drum. The flattened region of the lower rolling ring was about 8-in wide, and at the bottom chine also about 8-in wide. There was some minor deformation of the middle rolling ring. The outside diameter of the drum was reduced from 22 5/8 to 21 7/8 in., measured through the point of contact. The outside diameter of the drum measured perpendicular to this axis remained unchanged at 22 ½-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figure 32.

5.10.2 20-ft Drop Test for 6M-S-7

The 20-ft drop was performed with the package oriented so that its axis was 17.5°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 18º. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The width of the flattened region of the closure ring was about 13-in. The flattened region of the upper rolling hoop was about 12-in wide, the center rolling hoop about 10-in wide, the lower rolling hoop about 12-in wide, and that of the bottom chine was about 11-in wide. The outside diameter of the drum was reduced by 1 1/8 in., from 22 1/2 to 21 3/8-in, measured through the point of impact. The axial distance between the reference marks on the impact side was essentially unchanged, at 32 ¾-in. The damage was typical of low angle drops, with local buckling of the drum and lid in the damage region. The lid buckled outwards along a line parallel to the flattened side. This buckling resulted in the lid pulling out from under the closure ring between the NCT damage region and the flattened region produced by the 30-ft drop. The resulting opening was approximately 7-in long with a maximum height of approximately ½-in. The raised and curved (inverted J) rim of the lid was bent inward, but remained retained under the clamp-ring, across the width of the flattened region on either side of the impact point. The results of this drop are shown in Figures 33 through 34.

5.11 Tests of Package 6M-S-6

The 20 ft-drop test in the CGOC orientation (explained in Section 5.10) used package 6M-S-6. The results of this test, are shown in Figures 35 through 38.

5.11.1 NCT Preconditioning Test for 6M-S-6

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-6 weighed 636 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 8-in at the point of impact. The upper rolling hoop was collapsed in the vicinity of the impact point. Minor flattening of the lower rolling rings and the bottom chime of the drum resulted from the drum falling over after the initial impact. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately one inch, from 32 7/8 to 31 ¾-in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figures 35 and 36.

5.11.2 20-ft Drop Test for 6M-S-6

The 20-ft drop was performed with the package oriented so that its axis was 55°, lid down, at release. The angle of the drum at impact was 57.6º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the “corner” of the package around the point of contact and separation of the lid from the drum over an arc of approximately 120º. The maximum height of the opening was about 3 inches, exposing the cane fiberboard overpack disks. The separation extended from the end of the NCT damage region closest to the HAC damage region clockwise for approximately 120º. Minor flattening (about 6-in in width) of the chime of the drum resulted from the second hit, following the initial impact. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 3 ½-in, from 33 to 29 3/8-in. The damage was typical of CGOC drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the lid all around its circumference. The results of this drop are shown in Figures 37 and 38.

5.12 Tests of Package 6M-S-5

The results of the reduced height drops showed that the standard closure was marginal in its ability to retain the lid for shallow angle impact. The opening that resulted from the 20-ft CGOC drop revealed that, for the standard closure, the threshold of failure was significantly less than 20-ft. To further examine this behavior a CGOC drop from 15-ft was performed. The 15-ft drop test in the CGOC orientation used package 6M-S-5. The results of this test are shown in Figures 39 through 41.

5.12.1 NCT Preconditioning Test for 6M-S-5

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 55°, lid down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-5 weighed 638 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 8-in at the point of impact. The upper rolling hoop was collapsed in the vicinity of the impact point. No further damage occurred because to package settled on its lid, following the impact. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 1 ¼-in, from 32 7/8 to 31 5/8-in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 39.

5.12.2 15-ft Drop Test for 6M-S-5

The 15-ft drop was performed with the package oriented so that its axis was 56°, lid down, at release. The angle of the drum at impact was 57.6º. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The drop resulted in crushing of the "corner" of the package around the point of contact and separation of the lid from the drum over an arc of approximately 120º. The maximum height of the opening was about 2 ½-in, exposing the cane fiberboard overpack disks. The separation extended from the end of the NCT damage region closest to the HAC damage region clockwise for 120º. Minor flattening (about 6-in in width) of the rolling rings and the chime of the drum resulted from the second hit, following the initial impact. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 3-in, from 32 3/4 to 29 7/8-in. The damage was typical of CG over corner drops with extensive local buckling and folding of the drum and lid in the damage region. The clamp-ring remained engaged with the lid all around its circumference. The results of this drop are shown in Figures 40 through 41.

5.13 Tests of Package 6M-S-8

The results of the reduced height drops showed that the standard closure was marginal in its ability to retain the lid for shallow angle impact. To further examine this behavior a Shallow Angle drop from 25-ft was performed. The results of the drop testing of package 6M-S-8, are shown in Figures 42 through 44.

5.13.1 NCT Preconditioning Test for 6M-S-8

The preconditioning drop was performed from an elevation of 4-ft, with the package oriented so that its axis was 17.5°, lid down (Shallow Angle), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 6M-S-8 weighed 633 lb. The preconditioning drop resulted in slight flattening, about 7-in wide, and associated broadening of the closure ring at the impact point and associated flattening on the side of the drum. The flattened region of the lower rolling ring was about 8-in wide, and at the bottom chine also about 8-in wide. There was some minor deformation of the middle rolling ring. The outside diameter of the drum was reduced from 22 5/8 to 22-in, measured through the point of contact. The outside diameter of the drum measured perpendicular to this axis remained essentially unchanged at 22 7/16-in. The vertical height of the drum was essentially unaffected by the NCT drop. The results of this drop are shown in Figure 42.

5.13.2 25-ft Drop Test for 6M-S-8

The 25-ft drop was performed with the package oriented so that its axis was 17.5°, lid down, at release. The circumferential orientation of the target contact point was 45º from the clamp-ring bolt (and the seam line of the drum). The angle of the drum at impact was 18º. The drop resulted in separation of the lid and flattening of the rim and closure ring of the package at the point of contact, and associated flattening along the length of the drum. The width of the flattened region of the closure ring was about 13-in. The flattened region of the upper rolling hoop was about 12-in wide, the center rolling hoop about 12-in wide, the lower rolling hoop about 12-in wide, and that of the bottom chine was about 12-in wide. The outside diameter of the drum was reduced by 1-in, from 22 7/16 to 21 7/16-in, measured through the point of impact. The axial distance between the reference marks on the impact side was essentially unchanged, at 32 ¾-in. The damage was typical of low angle drops, with local buckling of the drum and lid in the damage region. The lid buckled outwards along a line parallel to the flattened side. The lid separated from the drum over an arc beginning at the end of the HAC damage region closest to the clamp-ring lugs, and extending counter-clockwise for over 120º. The resulting opening had a maximum height of approximately 1 inch. The raised and curved (inverted J) rim of the lid was bent inward, and folded inward and downward onto the horizontal, disk section of the lid, at the impact point. The results of this drop are shown in Figures 43 through 44.

Figure 1 Typical Rigging for a Center-of-Gravity-Over-Corner (CGOC) drop test of a 6M Package.

Figure 2 Results of CGOC NCT drop of standard 6M Package.

Figure 3 Effect of CGOC 30 ft HAC drop on 6M Package with standard closure.

Figure 4 The 30 ft drop of the standard 6M resulted in separation of the lid over most of its circumference.

Figure 5 Typical rigging for a Shallow Angle drop test of a 6M Package.

Figure 6 Result of a Shallow Angle NCT Drop of a standard 6M Package.

Figure 7 Typical flattening of the side of a 6M Package subjected to a Shallow Angle Drop Test.

Figure 8 Effect of Shallow Angle 30 ft HAC drop on 6M Package with standard closure.

Figure 9 The Shallow Angle HAC drop resulted in separation of the lid all around its circumference.

Figure 10 Effect of CGOC NCT drop on 6M Package with Clamshell closure

Figure 11 Effect of CGOC 30 ft HAC drop on 6M Package with Clamshell closure.

Figure 12 The Clamshell closure retained the lid securely, with no openings being formed.

Figure 13 Effect of Shallow Angle NCT drop on 6M Package with Clamshell closure.

Figure 14 6M Package with Clamshell closure following Shallow Angle 30 ft HAC drop.

Figure 15 The Clamshell closure retained the lid securely, with no openings being formed.

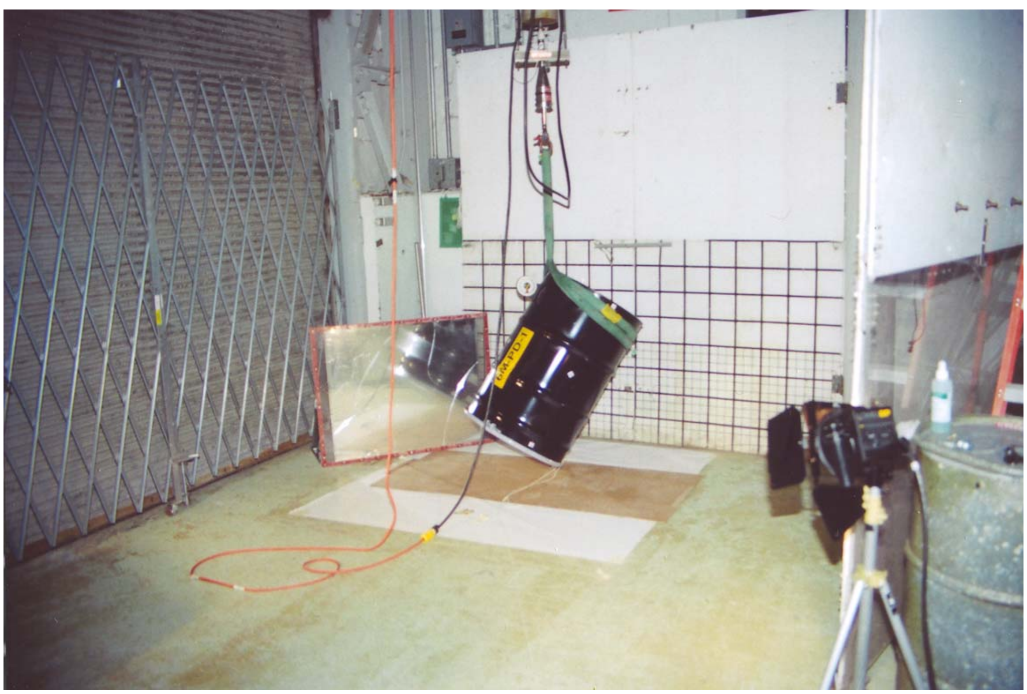

Figure 16 6M Package with Plywood Disk enhance closure, rigged for CGOC drop test.

Figure 17 Effect of CGOC NCT drop on 6M Package with Plywood Disk enhanced closure.

Figure 18 Results of CGOC 30 ft HAC drop on 6M Package with Plywood Disk enhanced closure.

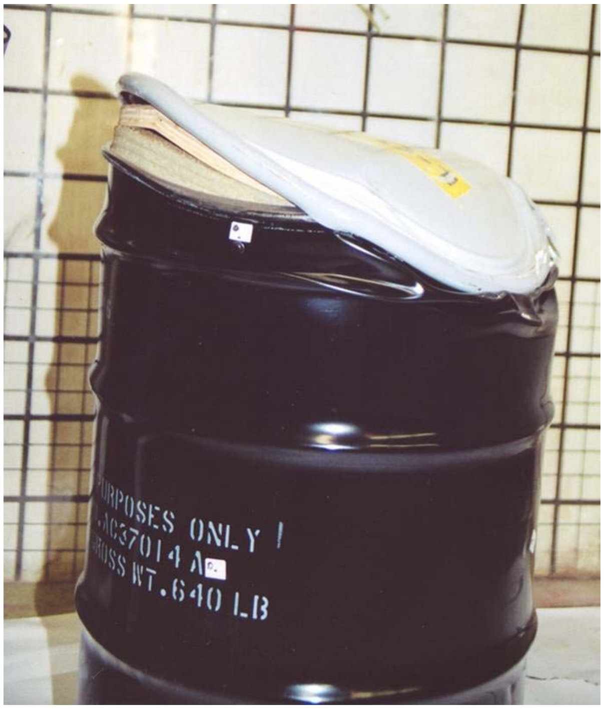

Figure 19 The lid separation for the Plywood Disk case was less than for the standard closure.

Figure 20 Effect of Shallow Angle NCT drop on 6M Package with Plywood Disk enhanced closure.

Figure 21 Effect of Shallow Angle 30 ft HAC drop on 6M Package with Plywood Disk enhanced closure.

Figure 22 The Plywood Disk enhance closure successfully retained the lid for the Shallow Angle HAC drop test. Flattening of the side of the package is typical for Shallow Angle tests.

Figure 23 Effect of CGOC NCT drop test on 6M Package with J-Clip enhanced closure.

Figure 24 Effect of CGOC 30 ft HAC drop test on 6M Package with J-Clip enhanced closure.

Figure 25 The J-Clip enhanced closure successfully retained the lid. Gaps formed between the clips were comparable to those observed in testing of the UC-609.

Figure 26 Effect of Shallow Angle NCT drop on 6M Package with J-Clip enhanced closure.

Figure 27 Effect of Shallow Angle 30 ft HAC drop on 6M Package with J-Clip enhanced closure.

Figure 28 The J-Clip enhanced closure successfully retained the lid. Gaps formed between the clips were comparable to those observed in testing of the UC-609.

Figure 29 Effect of CGOC NCT drop on 6M Package with 2 in Plywood Disk.

Figure 30 Effect of CGOC 30 ft HAC drop on 6M Package with 2 in Plywood Disk enhanced closure.

Figure 31 The 2 in Plywood Disk package following the CGOC 30 ft HAC drop.

Figure 32 Standard 6M Package following Shallow Angle NCT preconditioning drop.

Figure 33 Effect of 20 ft Shallow Angle drop on maximum weight 6M Package with standard closure.

Figure 34 The 20 ft Shallow Angle drop resulted in an opening about 7 in. long and ½ in. wide.

Figure 35 Effect of CGOC NCT drop on 6M Package with standard closure.

Figure 36 Damage to standard 6M from CGOC NCT preconditioning drop.

Figure 37 Effect of 20 ft CGOC drop test of maximum weight 6M Package with standard closure.

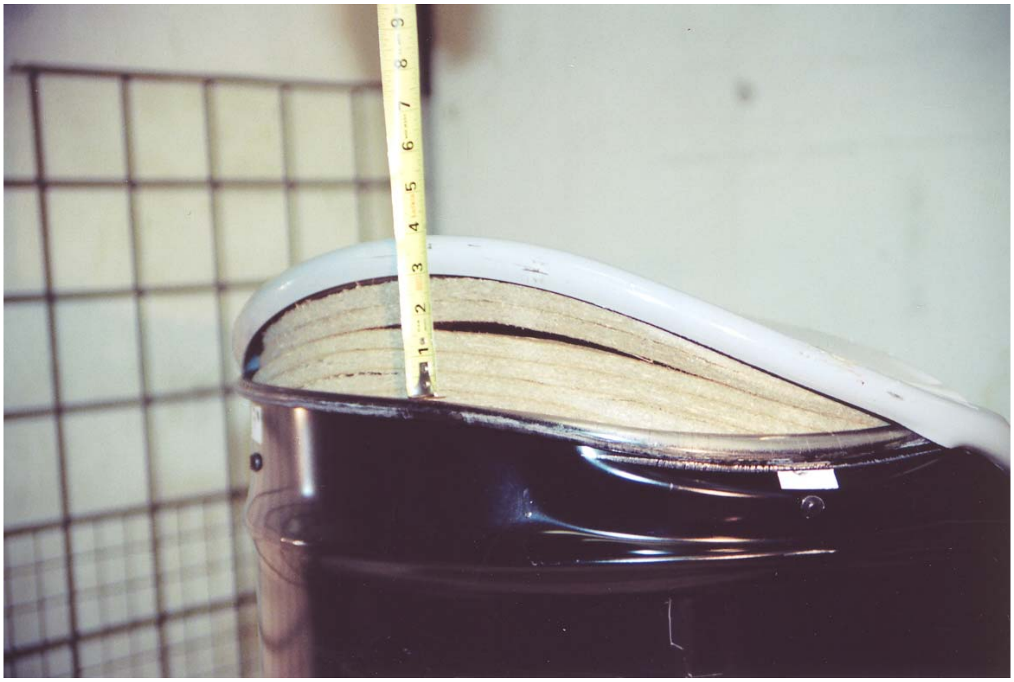

Figure 38 The 20 ft CGOC drop produced an opening extending for over 120º, with a maximum width of 3 in.

Figure 39 Effect of CGOC NCT preconditioning drop on Package 6M-S-5.

Figure 40 Effect of 15 ft CGOC drop on maximum weight 6M Package with standard closure.

Figure 41 The 15 ft CGOC drop resulted in an opening extending over an arc of approximately 120º, with a maximum width of about 2.5 in.

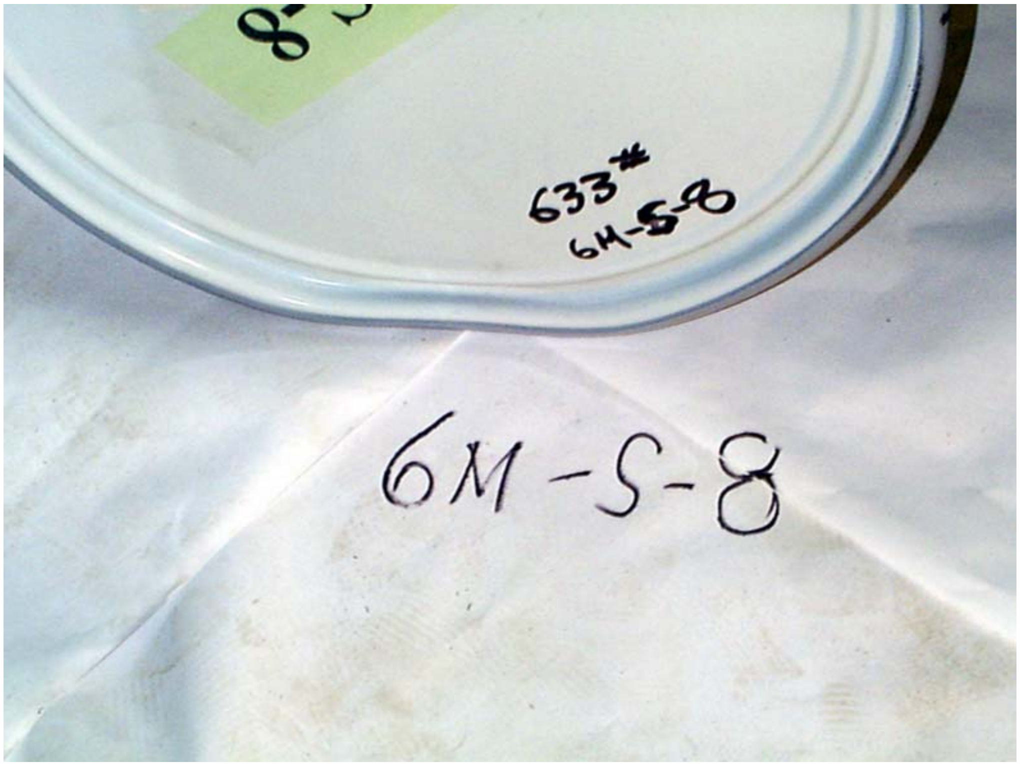

Figure 42 Results of Shallow Angle NCT preconditioning drop of Package 6M-S-8.

Figure 43 Effect of 25 ft Shallow Angle drop of maximum weight 6M Package with standard closure.

Figure 44 The 25 ft Shallow Angle drop resulted in separation of the lid over an arc of more than 120º.

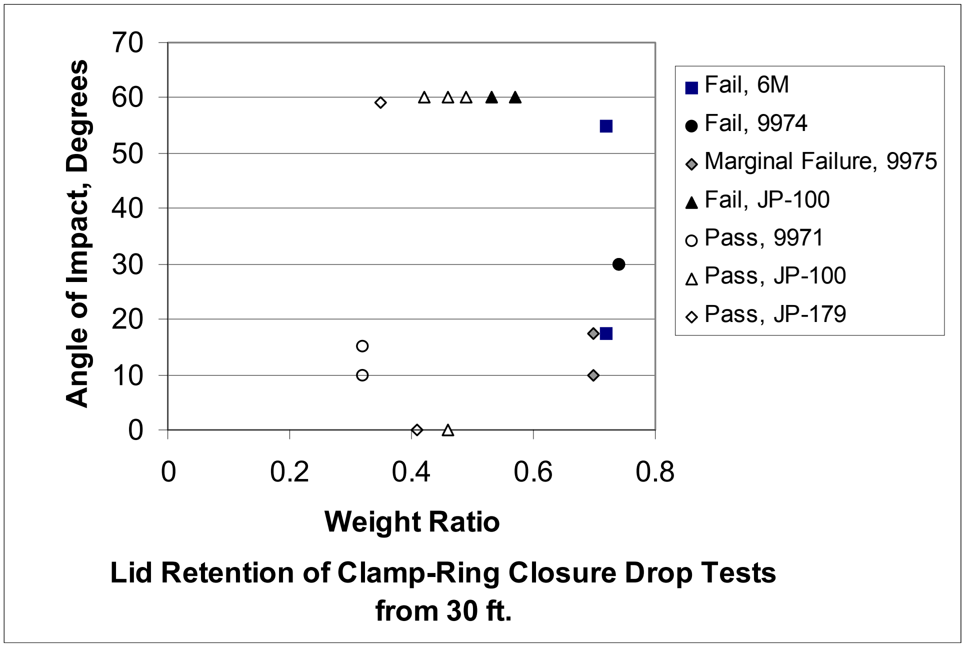

Figure 45 Effect of Weight Ratio and Angle of Impact on retention of lids of drum type packages subjected to the regulatory 30 ft drop test.

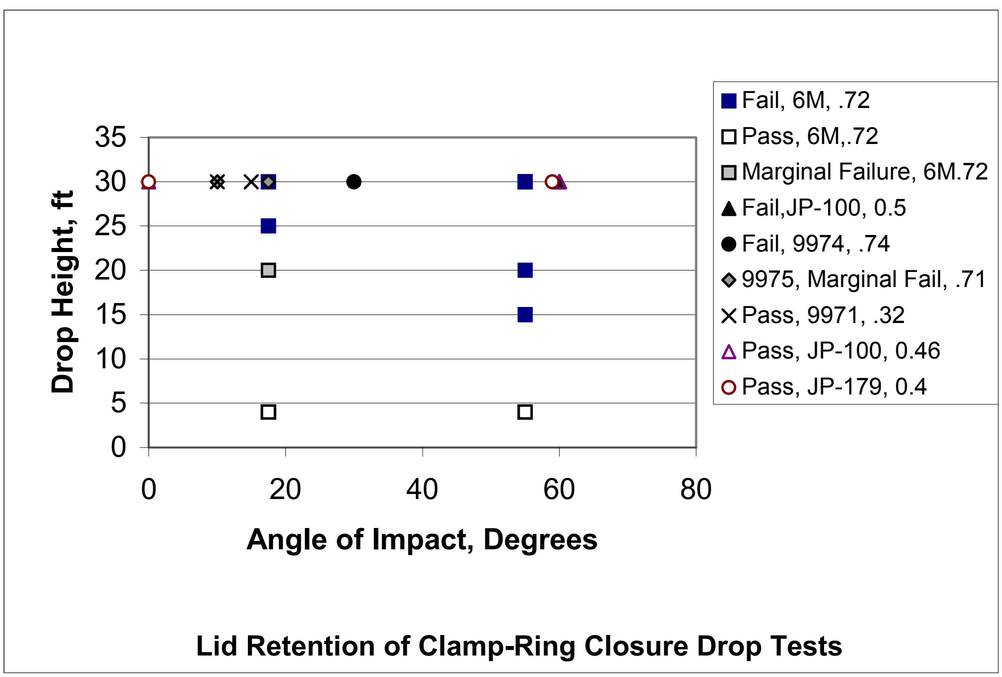

Figure 46 Effect of Drop Height and Angle of Impact on retention of tops of drum type packages subjected to drop tests. The Legend indicates outcome (pass or fail), package tested and ratio of internal to overall package weight.

6.0 Discussion

The objective of the test was to investigate the ability of the standard 6M closure ring assembly to provided adequate margin against loss of the lid from the package during the 30-ft HAC drop test. Loss of the lid from a 6M could result in loss of geometric control of the contents, a potential criticality issue, and loss of protection for the containment vessel seals during a subsequent fire, with resulting loss of containment.

Although no gap size was set as a failure criterion, the results of earlier tests are useful guidelines for interpretation of marginal results. For example, occurrence of an opening 4 1/2-in long and 9/16-in high led to redesign and adoption of a bolted flange closure for the 9975 package. Fish-mouth openings approximately 6-in long and 3/8-in wide occurred between the J-Clips in HAC drop tests of the UC-609 package were found acceptable, since the lid was securely retained.

The results of this testing showed that the lid-retention performance of the standard clamp-ring closure was inadequate for 6M packages loaded to the maximum allowed by the DOT specification (49 CFR 178.354). This testing also showed that the lid-retention performance of the enhanced closure designs varied from marginal improvement to excellent (i.e., fully successful).

There are many factors which affect the performance of a drum closure during drop tests. Important test conditions are: weight of package, height of drop, and impact angle. Structural characteristics of the package determine its ability to withstand the test conditions imposed. These characteristics include: package diameter, shell material and thickness, strength of internal fill material (e.g., cane fiberboard), and configuration of closure (clamp-ring, bolted flange, etc.).

For the clamp-ring closure configuration, like that employed by the 6M, the performance of drum type packages subjected to drop tests have been compared [4] and the ratio of internal weight to overall package weight has been found to be an important guideline for package performance. Packages having a weight ratio of less than 50% were typically able to retain their lids in HAC drop tests; those having weight ratios greater than 50% typically failed. [4] Because the object of the present testing was to challenge the closure, the packages were tested at the maximum weight allowed by the 6M specification, 640 lb, resulting in a weight ratio of 71%.

The results of the present tests are compared with those for other drum type packages subjected to drop tests and plotted in Figures 45 and 46. This comparison considers all three of the principal test conditions: weight and weight ratio, impact angle, and drop height. These figures provide insight into the shape of the pass-fail threshold surface defined by these test parameters. Figure 45 shows that packages having weight ratios less than 50% are typically able to withstand the HAC 30-ft drop test, regardless of package orientation. For some packages, such as the 9975 [5], shallow angle drops are more challenging, while the CGOC orientation is more challenging in other cases. For the 55-gallon 6M with standard clamp-ring closure, used in these tests, the CGOC orientation was more challenging than the shallow angle case.

The drop height is a significant factor in lid retention performance, as would be expected. For example, all Type B radioactive material packages are expected to survive a 4-ft NCT drop test, including specification packages such as the 6M. The magnitude of the 6M failure at 30-ft suggested that the failure threshold would be at a lower elevation; consequently, the 20-ft drops were performed to better define this threshold. The 20-ft CGOC case resulted in a failure due to large lid opening. The 20-ft Shallow Angle case resulted in a marginal pass, yielding an opening about 7-in long and ½-in wide. As noted above, to further explore the performance boundary, the Shallow Angle test was repeated from a drop height of 25-ft. and the CGOC was repeated from 15-ft. Large lid openings occurred for both of these additional cases, which are considered failures.

The 15-ft drop test of package 6M-S-5 was chosen to provide the same potential energy as a 320 lb package (reported to be typical of DOE shipments) dropped from the 30-ft regulatory test height. Based on the weight ratio criterion, such a lighter weight package would be expected to withstand the HAC drop test. However, the lid opening, as shown in Figure 41, indicates that structural parameters have a significant effect on the pass-fail threshold.

The mechanism for lid loss appears different for the CGOC and Shallow Angle cases. Proposed mechanisms include volume change induced pressurization of the air in the package, translation of the internal components, and the combination of load applied by bending of the lid and closure ring with unloading of the ring due to deformation. Examination of the high-speed video indicates that various combinations of these factors are the probable cause.

For typical CGOC cases, the lid is observed to first pullout from beneath the clamp-ring at one or both ends of the flattened region caused by the HAC drop. This location is where the plane of the damaged region intersects the plane of the undeformed region of the lid of the drum. The opening then grows progressively and rapidly from the initial openings, and may propagate completely around the circumference of the lid. The internal pressurization resulting from reduction in volume results in a load on the lid on the order of 30 lb, which is not likely to contribute significantly to the loss of the lid, for the CGOC case. Translation of the cane fiberboard fill material is prevented in the crush region, but the cane fiberboard disks are bent out of plane by the impact and tend to fan-out. The central mass is observed to translate, breaking the center of the cane fiberboard layers immediately ahead of it. The lid opening mechanism consists of the following processes: The deformation relaxes the grip of the clamp-ring on the lid in the buckled zone at the ends of the impact region. The bending loads associated with the deformation of the lid and clamp-ring, combined with the loading caused by translation of the central mass, result in the lid pulling out from the clamp ring. If the lid is completely separated from the clamp-ring, the bending load in the lid causes it to continue opening, beyond the influence of the displaced central mass.

The Shallow Angle impact results in a different set of conditions. To a greater extent than the CGOC case, the shallow angle impact relaxes the tension in the clamp-ring (at least as a transient effect). The radial deformation of the lid results in a buckled region, parallel to the impact surface. The combination of these effects results in the lid pulling out from under the clamp-ring at one, or both ends of the buckled region. Though not as great as the CGOC case, the bending load associated with the buckle tends to cause the opening to propagate. For the shallow angle case, loading due to translation of the central mass is not observed. However, the increased internal pressure caused by volume change (resulting from deformation of the drum) can impose a load on the lid on the order of 150 lb. The relaxation of the clamp-ring tension, combined with the bending load and pressure load can result in complete loss of the lid, in some cases.

The Plywood Disk enhancement had the objective of strengthening the closure radially, so that the clamp-ring would remain engaged with the curl of the drum and the lid. The higher weight of these packages was due to the weight of the plywood disks. The Plywood Disk package subjected to the Shallow Angle test successfully withstood the impact. Although their performance was better than the standard closure package, neither the 1-in nor the 2-in Plywood Disk packages were successful in the CGOC drop tests.

The J-Clip enhancement drew from the UC-609 concept and was intended as an add-on to the “specification package”. The J-Clip packages withstood both CGOC and Shallow Angle tests, retaining the lid securely in both cases. Like the UC-609, narrow fish mouth openings were formed between some of the clips, in both cases. Although not large, such openings were judged undesirable, since they could impair the ability of the package to withstand a fire.

The Clamshell Closure enhancement was highly successful in both orientations. The extended skirt of the Clamshell integrated its response with that of the drum , while the annular lid extension prevented separation of the lid from the drum.

The enhanced closures all resulted in better retention of the lid and corresponding less dissipation of energy upon impact. As a result, the packages rebounded much more energetically than the standard closure packages, which experienced lid separation.

7.0 Conclusions

It was concluded that the 6M standard closure ring design, tested at the maximum package weight, does not adequately retain the lid during the regulatory free drop test sequence and below regulatory free drops heights performed for this testing.

For large heavy packages, the CGOC case is more challenging to the closure than the Shallow Angle case.

Of the enhanced closure designs, both the J-Clip and the Clamshell designs securely retained the lid. However, the J-Clip design allowed formation of narrow openings between the J-clips, which may compromise the ability of the package to withstand a fire.

The Clamshell design securely retained the lid for all HAC test cases, and prevented formation of any opening which could compromise fire test performance.

8.0 References

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9.0 Appendices

Appendix 1 Finite Element Analysis

Appendix 2 Sketch of J-Clip Closure

Appendix 3 Sketch of Blanton Clamshell Closure