Drop Tests of 325 Pound 6M Specification Packages

December 2003

Keywords: 6M Package, Drop Test, Ring Closure

Prepared by: A. C. Smith, R.N. Lutz, L. F. Gelder

SAFETY • RESPONSIBILITY • SECURITY
SRS
SAVANNAH RIVER SITE

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract NO. DE-AC09-96SR18500

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

DISCLAIMER

Table of Contents

List of Figures

Summary

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 angle of impact. 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., fiberboard), and configuration of closure (clamp-ring, bolted flange, etc.). For the clamp-ring closure configuration, like that employed by the 6M, a study of published drop test results has shown that packages having a weight ratio of less than 50% were typically able to retain their lids in hypothetical accident condition (HAC), 30-ft drop tests. Those having weight ratios greater than 50% typically failed.

Prior testing of 6M specification packages, performed by the Savannah River Site's Packaging Technology Group in response to the Department of Energy's (DOE) concerns over the integrity of the clamp-ring closure, consistently demonstrated that the clamp-ring is unable to retain the drum lid in thirty foot drop tests of packages containing the maximum allowed weight (640 lb), which confirms the previous studies.

To determine if the clamp-ring closure is adequate for packages with lower weight contents, a series of tests were performed by the Packaging Technology Group on 6M packages weighing 325 lb ± 5 lb (i.e., a typical shipping weight for DOE packages) at a range of impact angles as detailed in this report. The test results consistently demonstrated that the standard clamp-ring closure is unable to retain the drum lid of standard 6M packages weighing 325 lb.

Additionally, three 6M packages were modified with a one-inch plywood disk to enhance the closure performance. These packages were dropped from 30 ft and impacted the test target pad at 6.5º, 30º, and 55º (CGOC). Two of these packages retained their lids at impact angles of 6.5º and 30º; however, the package impacting at its CGOC did not retain its lid.

1.0 Background

The loss of lids during drop tests of drum type packages with bolted ring closures [1,2] raised questions about the adequacy of the use of the 6M specification package in the DOE Complex. Consequently, a drop-testing program was conducted to evaluate proposed enhancements to the bolted ring closure and evaluate the performance improvement provided by the enhancements. The test specimens used in those evaluations were DOT 6M Specification Packages that weighed 640 pounds, which is the maximum authorized gross weight for 55-gallon specification packages. The results of that testing provided strong indication that the bolted ring closure performance is inadequate.[3] There is no certainty that lighter weight packages will exhibit identical behaviors, or require any closure system changes. To proactively meet potential questions from the transportation community and stakeholders, additional performance demonstration drop testing of 6M Specification Packages more representative of those typically shipped by DOE was requested. This report documents the approach, methodology, and test results for these more representative 6Ms.

2.0 Test Program

The objective of the test program was to determine the ability of standard clamp-ring closures, of 6M Specification Packages weighing 325 lb, to retain the drum lid when subjected to hypothetical accident condition (HAC) drop tests at various impact angles.[4,5] Earlier tests of drum type packages have shown that the Center-of-Gravity-Over-Corner (CGOC) orientation and the Shallow Angle orientation challenge the closure in different ways.[2,6] The impact angles for the tests were selected to capture the range of responses; therefore, HAC drop tests were planned for 10º, 20º, 30º, 45º and Center-of-Gravity-Over-Corner (CGOC) orientations.

Following the pattern of earlier testing of packages with clamp-ring closures, each test was preceded by a Normal Conditions of Transport (NCT) test from a height of four feet in the CGOC orientation. These preconditioning tests were performed to challenge the drum's clamp-ring closure arrangement so that the effects of the subsequent 30-ft drop would be maximized. The impact point for each NCT drop was located 90 degrees, circumferentially, from the target point for the HAC drops.

Because the object of the test was investigation of the response of the closures for typical; DOE shipments, the test specimens were procured under the same specification as that used for typical DOE 6M shipments, complete with a standard 2R containment vessel. The 2R containment vessels were delivered with surrogate contents (i.e., steel rounds) such that the overall packaging test weight was 325 lb. The 55 gallon 6M package was chosen as the representative case for these tests and to be consistent with the previous testing.

The final test matrix is shown in Table 1 below.

Table 1 Drop Test Conditions

325 lb 6M Test Matrix All test packages subjected to NCT at CGOC, and HAC tests as noted below.	
Package ID#	HAC Orientation (Impact Angle)
325-5	10°
325-4	20°
325-3	20° (Repeat Test)
325-6, with plywood disk[a]	20° (6.5° Actual[b])
325-2	30°
325-1	55° (CGOC)
325-7, with plywood disk[c]	30°
325-8, with plywood disk[a]	55° (CGOC)

a. One inch of cane fiberboard insulation was replaced with one inch of plywood.
b. This package drifted from 20° such that the actual impact angle was 6.5°.
c. One-and-one-half inches of fiberboard was replaced with one inch of plywood due to stack up tolerances.

The acceptance criterion for the performance or the overpack was that the lid be retained in such a way that a significant reduction in effectiveness of the overpack did not occur.

3.0 Test Apparatus

3.1 Test Specimens

Ten test packages were purchased from an experienced 6M supplier.

As noted above, the packages were assembled with surrogate contents to provide a test specimen weight of 325 lb ± 5 lb. The surrogate contents within the 2R vessel consisted of a steel slug and fiberboard disks, which prevented internal movement of the slug.

The drum was closed using the supplier's closure instructions. The clamp-ring bolts were torqued to 40 ft lb, and the maximum gap of ¼ in measured between the ends of clamp-ring. The closure bolt was oriented to coincide with the longitudinal seam of the body of the drum. Three of the clamp rings required filing to insure that the ring ends were not in contact with each other. The drum manufacturer was contacted (after testing) and concurred that it was acceptable to file or grind away the excess material or they would replace the ring.

The drums were marked with radial and axial reference points, numbers 1-12, 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:

325-1 through 325-8

4.0 Drop Tests

4.1 Procedure and Facility

The drop tests were performed in the SRS 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 test drop was conducted in the CGOC orientation. 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 drum top 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 raising it to the test height. Each HAC 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 30-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 35 times the weight of the test packages (400 lb.).

4.2 Testing

Drop tests were performed on October 27-28, and December 8, 2003 by the Savannah River Site's Packaging Technology Group. The packages were subjected to 4-ft NCT drops followed by 30-ft HAC drops. The test plan called for a repeat of the first test which resulted in a failure of the closure.[5] Additionally, a provision was made in the test plan for performing tests with the plywood disk enhancement, in case the standard package failed the repeated test. A total of eight packages were tested.

The testing began with the 10°, shallow angle test, with subsequent tests planned with increasing impact angles. The second 30-ft drop was performed at 20° and resulted in a lid retention failure. In accordance with the test plan, the next (third) test was repeated at 20°, and resulted in a nearly identical failure. Following the test plan, a package (fourth) was prepared with the plywood disk enhancement and tested at 20° impact angle. The enhanced package successfully retained the drum lid when subjected to the 30-ft drop; however, this package drifted from the initial 20° angle after it was released from the

drop-test mechanism such that the actual impact angle was approximately 6.5° as observed on the high speed video. The fifth and sixth tests were performed at 30° and 55° (CGOC) using standard 6Ms (i.e., fiberboard only), and both resulted in failure of the closure in the 30-ft drop. The final two tests (seventh and eighth) were performed at impact angles of 30° and 55° (CGOC) respectively using 6Ms modified with a 1-in plywood disk enhancement. The package dropped at 30° retained its lid; however, the lid opened on the package dropped at 55° (CGOC).

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

5.0 Results

5.1 Tests of Package 325-5 (10° Impact Angle)

The results of the drop testing of package 325-5, are shown in Figures 1 through 6.

5.1.1 NCT Preconditioning Test for 325-5

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release, Figure 1. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-5 weighed 323 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 3/8 in, from 33 to 32 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 2.

5.1.2 30-ft drop Test for 325-5

The 30-ft drop was performed with the package oriented so that its axis was 10°, top down, at release. The angle of the drum at impact was 7º. 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 nearly uniform flattening of the side of the package, the flat region having a width of approximately 11 in. The inverted "J" rim of the drum lid was bent inward, forming a reverse curvature. The curl of the drum was flattened, with the clamp-ring remaining engaged with the curl. The distance from the inner edge of the clamp ring to the peak of the inward buckle of the J section was about 3/8 in, measured radially. The vertical distance between reference marks 1 and 5 (point of impact increased slightly, from 33 to 33 1/4 in. The other vertical dimensions were essentially unchanged. The drum top diameter through the impact point was reduced by ½ in., from 22 ½ to 22 in. The damage was typical of very shallow angle drops, with the deformation of the chime being comparable to that of the curl. The clamp-ring remained engaged with the drum and lid and the lid was securely retained. Upon disassembly, it was confirmed that no opening into the interior (i.e., the fiberboard region) was present. The results of this drop are shown in Figures 3 through 6.

5.2 Tests of Package 325-4 (20° Impact Angle)

The results of the drop testing of package 325-4, are shown in Figures 7 through 11.

5.2.1 NCT Preconditioning Test for 325-4

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 325-4 weighed 327 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 1/4 inch, from 33 to 32 3/4 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 7.

5.2.2 30-ft drop Test for 325-4

The 30-ft drop was performed with the package oriented so that its axis was 20°, top down, at release, Figure 8. 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 17.6º. 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 11-in wide, the center rolling hoop about10-in wide, the lower rolling hoop about 11-in wide, and that of the bottom chime was about 11-in wide. The outside diameter of the drum was reduced from 22 3/8 to 21 3/8 in measured through the point of impact. The width of the flattened region of the closure ring was 12 in. The axial distance between the reference marks on the impact side was not changed, remaining at 33 in. The damage was typical of low angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and lid in the damage region. The rim of the drum top was bent downward along a line parallel to the flattened side. This bending resulted in the curl 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 the curl became disengaged from the clamp-ring and the drum over most of its circumference (approximately 230°). The maximum opening between the lid and the curl of the drum, measured after the test, was approximately 3.5 in. The raised and curved (inverted “J”) rim on the lid of the drum was buckled inward and folded downward, almost touching 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 fiberboard disks, in the vicinity of the impact point. This, along with the clamp-

ring remaining engaged in this region, prevented the lid from falling completely away from the drum. The results of this drop are shown in Figures 9 through 11.

5.3 Tests of Package 325-3 (20° Impact Angle)

The test procedure directed that a repeat test be preformed following the first test which resulted in a failure. Accordingly, following the lid failure of package 325-4 at 20°, a duplicate test was performed using package 325-3. The results of the drop testing of package 325-3 are shown in Figures 12 through 16.

5.3.1 NCT Preconditioning Test for 325-3

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-3 weighed 329 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 1/4 in, from 33 to 32 3/4 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 12.

5.3.2 30-ft drop Test for 325-3

The 30-ft drop was performed with the package oriented so that its axis was 20°, top down, at release, Figure 13. 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 18.8º. As was expected, the results were almost identical with those of 325-4, which was also dropped at 20°. As in the case of 325-4, 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 11-in wide, the center rolling hoop about 10-in wide, the lower rolling hoop about 10-in wide, and that of the bottom chime was about 11-in wide. The outside diameter of the drum was reduced from 22 3/8 to 21 1/2 in. measured through the point of impact. The width of the flattened region of the closure ring was 12 in. The axial distance between the reference marks on the impact side was not changed, remaining at 33 in. As in the case of 325-4, the damage was typical of low angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and lid in the damage region. The rim of the lid was bent downward along a line parallel to the flattened side. This bending resulted in the curl

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 the curl became disengaged from the clamp-ring and the drum over approximately 190° of its circumference. The maximum opening between the lid and the curl of the drum, measured after the test, was approximately 2.5 in. The raised and curved (inverted "J") rim of the drum lid was buckled inward and folded downward, on to the horizontal, disk section of the lid, at the point of impact. As in the case of 325-4, the region where the raised rim was folded back was lightly pinched between the curl of the drum and the fiberboard disks, in the vicinity of the impact point. This, along with the clamp-ring remaining engaged in this region, prevented the drum lid from falling completely away from the drum. The results of this drop are shown in Figures 14 through 16.

5.4 Tests of Package 325-6 (Plywood Disk Enhanced Closure, 20° Impact Angle)

The test procedure directed that a test with the Plywood Disk Enhanced Closure be preformed following any event where a repeat test resulted in a second failure.[7] Accordingly, following the second failure in the 20° drop (package 325-3), a duplicate (20° drop) test of a package with a Plywood Disk Enhanced Closure was performed using package 325-6. As noted in Section 3.1 of this report, this enhancement consisted of replacing the top one-inch of fiberboard with a one-inch thick plywood disk. The results of the drop testing of package 325-6, are shown in Figures 17 through 20.

5.4.1 NCT Preconditioning Test for 325-6

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release, Figure 17. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. 325-6 weighed 329 lb. The preconditioning drop resulted in bending the drum lid, clamp-ring and rim assembly downward over a width of approximately 6 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 3/4 in, from 33 ¼ to 32 ½ in. Away from the small deformed region, the dimensions of the drum were essentially unaffected, with no change exceeding 1/8 in. The results of this drop are shown in Figure 18.

5.4.2 30-Ft Drop Test for 325-6

The 30-ft drop was performed with the package oriented so that its axis was 20°, top 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). Examination of the high speed video revealed that the drop orientation drifted following release, so that the angle of the drum

at impact was estimated to be 6.5º. The response of the package was sufficiently energetic that it rotated upright and came to rest standing on its bottom. The lid remained securely attached following the test. 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 9-in wide, the center rolling hoop about 7-in wide, the lower rolling hoop about 9-in wide, and that of the bottom chime was about 11-in wide. The outside diameter of the drum was reduced from 22 5/8 to 21 1/2 in. measured through the point of impact. The width of the flattened region of the closure ring was approximately 11 in. The axial distance between the reference marks on the impact side was reduced by ½ in, from 33 ¼ to 32 ¾ in. The damage was typical of low angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and lid in the damage region. Although the purpose of this test was to repeat the HAC tests using the enhanced closure, for comparison with packages 325-3 and 325-4, the result of this test is more representative of the HAC test of package 325-5, due to the drop-angle drift. The actual drop angles of 325-6 and 325-5 were within 1° of each other: 6.5° and 7° respectively. Therefore, the enhanced closure improved the package performance at a very shallow angle, but the results are inconclusive at angles greater than 7°. The clamp-ring remained engaged with the lid and the curl of the drum around the full circumference except for the region of reverse curvature of the rim at the point of impact. At this location, the raised and curved (inverted "J") rim of the drum lid was buckled inward against an upward bulge of the lid. This buckled region of the lid was parallel to the region flattened by the impact. The curl of the drum also assumed a reverse curvature, so that a gap (of approximately ½ in) was formed between the clamp ring and the curl and lid of the drum at the impact point, Figure 19. The clamp-ring remained engaged with the drum and lid and the lid was securely retained, with no opening into the interior (i.e., fiberboard region) present. The results of this drop are shown in Figures 19 and 20.

5.5 Tests of Package 325-2 (30° Impact Angle)

The results of the drop testing of package 325-2, are shown in Figures 21 through 24.

5.5.1 NCT Preconditioning Test for 325-2

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-2 weighed 325 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 1/4 in, from 33 to

32 3/4 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 21.

5.5.2 30-ft drop Test for 325-2

The 30-ft drop was performed with the package oriented so that its axis was 30°, top down, at release, Figure 22. 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 24º. 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 11 ¼-in wide, the center rolling hoop about 10 ½-in wide, the lower rolling hoop about 10 ½-in wide, and that of the bottom chime was about 10 ¼-in wide. The outside diameter of the drum was reduced by about 1 ½ in, from 22 1/2 to 21 in measured through the point of impact. The width of the flattened region of the closure ring was approximately 14 in. The axial distance between the reference marks on the impact side was reduced by ¼ in, from 33 to 32 ¾ in. The damage was typical of intermediate angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and lid in the damage region. The flattening of the side was less pronounced than in the shallow angle cases. As in the 20° test cases, the rim of the drum lid was bent downward along a line parallel to the flattened side. This bending was more pronounced than in the 20° cases, and resulted in the curl 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 the curl became disengaged from the clamp-ring and the drum over its most of its circumference (approximately 250°). The maximum opening between the lid and the curl of the drum, measured after the test, was approximately 4.5 in. The raised and curved (inverted "J") rim of the drum lid was buckled inward and folded downward, on to the horizontal, disk section of the lid, over a length of approximately 4 in at the point of impact. The region where the raised rim was folded back was pinched between the curl of the drum and the fiberboard disks, in the vicinity of the impact point. This, along with the clamp-ring remaining engaged in this region, prevented the lid from falling completely away from the drum. The results of this drop are shown in Figures 23 and 24.

5.6 Tests of Package 325-1 (CGOC Impact Angle)

The results of the drop testing of package 325-1, are shown in Figures 25 through 31.

5.6.1 NCT Preconditioning Test for 325-1

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release, Figure 25. The

circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-2 weighed 325 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 6 (point of impact) was reduced approximately 1/4 in, from 33 to 32 3/4 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 26.

5.6.2 30-ft drop Test for 325-1

The 30-ft drop was performed with the package oriented so that its axis was 55° (i.e., CGOC), top 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 53º. The drop resulted in separation of the lid and crushing of the "corner" of the package in the region of the point of contact. The maximum width of the flattened area of the drum top was approximately 20 in. The vertical distance between reference marks 1 and 5 (point of impact) was reduced by approximately 3 1/4 in, from 33 to 29 3/4 in. The vertical distance between marks 2 and 6, on the NCT damage side, was reduced by 1/2 in, from 33 to 32 ½-in in the sequential drops. The distance between reference marks 5 and 7 was reduced from 22 ½ to 22 in (the final dimension being measured at an angle to the drum axis due to the displacement of reference mark 5). Other dimensions between reference marks were little affected by the damage. The damage was typical of CGOC drops with extensive local buckling and folding of the drum and lid in the damage region. The crushing of the corner resulted in the curl pulling out from under the closure ring in the NCT damage region. The opening then propagated around the lid, so that the curl became disengaged from the clamp-ring and the drum over approximately 120°. A discharge of dust occurred when the lid began to separate from the drum, indicating that pressure caused by deformation of the drum was released by the opening of the lid. The maximum opening between the lid and the curl of the drum, measured after the test, was approximately 1.5 in. The lid and clamp-ring were crushed into the side of the drum and upper rolling ring in the impact region. This prevented the lid from falling completely away from the drum. The results of this drop are shown in Figures 27 through 30.

5.7 Tests of Package 325-7 (Plywood Disk Enhanced Closure, 30° Impact Angle)

Following the initial series of 325 lb tests, SRS was requested to test 6M packages with the plywood disk enhanced closure at 30° and 55° (CGOC) orientations. As noted in Section 3.1, this enhancement consisted of replacing the top 1 ½ in of fiberboard with a 1-in thick plywood disk. The results of the drop testing of package 325-7 at 30° are shown in Figures 31 through 34.

5.7.1 NCT Preconditioning Test for 325-7

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-7 weighed 326 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 slightly in the vicinity of the impact point. The vertical height between reference marks 2 and 10 (point of impact) was reduced approximately 1/2 in, from 32 1/2 to 32 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 31.

5.7.2 30-Ft Drop Test for 325-7

The 30-ft drop was performed with the package oriented so that its axis was 30°, top 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 about 27.5º. The lid remained attached with no opening, following the impact. The drop resulted in flattening of the rim and closure ring of the package at the point of contact, with associated flattening along the length of the drum. The flattened region of the upper rolling hoop was about 10 ½-in wide, the center rolling hoop about 6 ½- in wide, the lower rolling hoop about 11-in wide, and that of the bottom chime was about 12-in wide. The outside diameter of the drum was reduced by about 7/8 in, from 22 1/2 to 21 5/8 in, measured through the point of impact. The width of the flattened region of the closure ring was approximately 13 in. The axial distance between the reference marks on the impact side was reduced by 3/4 in, from 32 1/2 to 31 3/4 in. The damage was typical of intermediate angle drops, with a distinct triangular, flattened region surrounding the point of contact, and local buckling of the drum and lid in the damage region. At impact, the drum rebounded and rotated, so that the second impact was on the chime flattening it and the lower rolling ring. As a result of this rotation, the middle of the package was subjected to less force than the ends, resulting in flattening of the middle rolling ring of only 6 ½ in. As in the 20° test cases, the rim of the lid was bent downward along a line parallel to the flattened side. This bending was more pronounced than in the 20° cases. The lower edge of the clamp ring was displaced about 3/8-in in the vicinity of the NCT point of impact, exposing much of the bottom surface of the curl in this region. Although the engagement of the clamp ring with the curl of the drum was challenged, the drum lid was securely retained all around its circumference. The raised and curved (inverted “J”) rim of the lid was buckled inward and folded downward, against the buckled section of the lid at the point of impact, producing a reversed curvature. The closure ring was flattened in this region, and formed a chord across the reverse curvature section, resulting

in disengagement of the ring from the lid over a length of about 6 in with a maximum gap width of about 5/8 in. The results of this drop are shown in Figures 32 through 34.

5.8 Tests of Package 325-8 (Plywood Disk Enhanced Closure, CGOC Impact Angle)

Package 325-8 employed a plywood disk enhanced closure identical to that of 325-7. Both the NCT and HAC drop tests were performed at 55° (CGOC) orientation. The results of the drop testing of package 325-8, are shown in Figures 35 through 38

5.8.1 NCT Preconditioning Test for 325-8

The preconditioning drop was performed from an elevation of 4 ft, with the package oriented so that its axis was 55°, top down (CGOC), at release. The circumferential orientation for the preconditioning drop was 90° clockwise from the target contact point. Package 325-8 weighed 330 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 slightly in the vicinity of the impact point (i.e., the width of the rolling hoop, measured parallel to the axis of the drum, was slightly reduced). The vertical height between reference marks 2 and 10 (point of impact) was reduced approximately 1/4 in, from 32 1/2 to 32 1/4 in. Away from the small deformed region, the dimensions of the drum were essentially unaffected. The results of this drop are shown in Figure 35.

5.8.2 30-Ft Drop Test for 325-8

The 30-ft drop was performed with the package oriented so that its axis was 55° (i.e., CGOC), top 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 actual angle of the drum at impact was 54º. On the rebound, the package rotated to the vertical position and came to rest standing on its bottom. As a result, there was no flattening of the side of the package away from the crushed corner. The drop resulted in separation of the lid and crushing of the "corner" of the package in the region of the point of contact. The maximum width of the flattened area of the top was approximately 22 in. The vertical distance between reference marks 1 and 9 (point of impact) was reduced by approximately 2 7/8 in, from 32 1/2 to 29 5/8 in. The vertical distance between marks 2 and 10, on the NCT damage side, was reduced by 1/2 in, from 32 1/2 to 32-in in the sequential drops. The distance between reference marks 9 and 11 was reduced from 22 1/2 to 22 3/8 in (the final dimension being measured at an angle to the drum axis due to the displacement of point 9). 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 crushing of the corner resulted in the closure ring being pulled over the drum curl in the NCT damage region, exposing the plywood. The opening extended from the buckled region to within 40 degrees of reference mark 11, the point opposite the impact point. The resulting opening was approximately ½-in wide and 10-in long, corresponding to an angular width of about 60°. The lid and clamp-ring were crushed into the side of the drum and upper rolling ring in the impact region. The results of this drop are shown in Figures 36 through 38.

Figure 1 - Package 325-5 rigged for 10°, shallow angle drop test.

Figure 2 - Package 325-5 following NCT preconditioning drop.

Figure 3 - Package 325-5 following 30-ft drop test with 10° impact angle.

Figure 4 - Flattened side of 325-5 following 10°, shallow angle drop test.

Damage is typical of results for shallow angle impact.

Figure 5 - Reverse curvature of inverted "J" rim at the lid of 325-5 resulting from 10° drop test

Figure 6 - Disassembled closure of 325-5 showing that inward buckle of lid rim did not result in exposure of fiberboard. Even though the inverted "j" lid rim was buckled, the perimeter of the disk conformed to the side of the drum and was covered by the drum curl.

Figure 7 - Package 325-4 following NCT preconditioning drop.

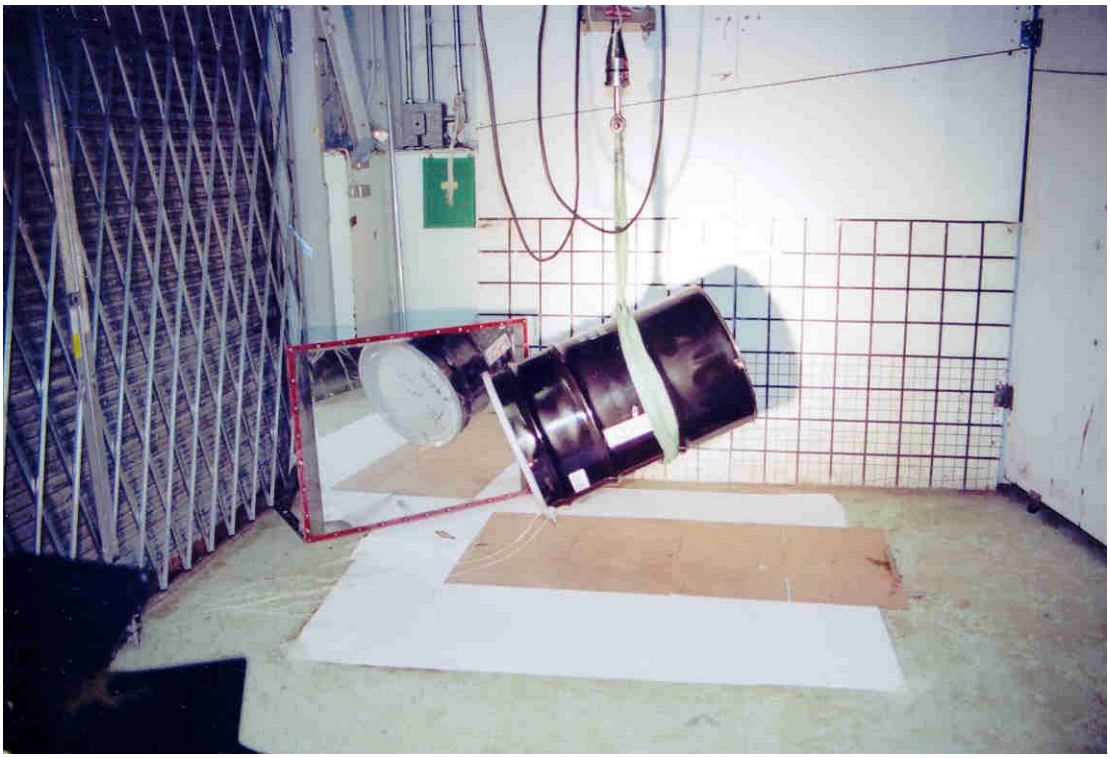

Figure 8 - Package 325-4 rigged for 20° impact angle drop test.

Figure 9 - Package 325-4 following 30-ft drop test with 20° impact angle.

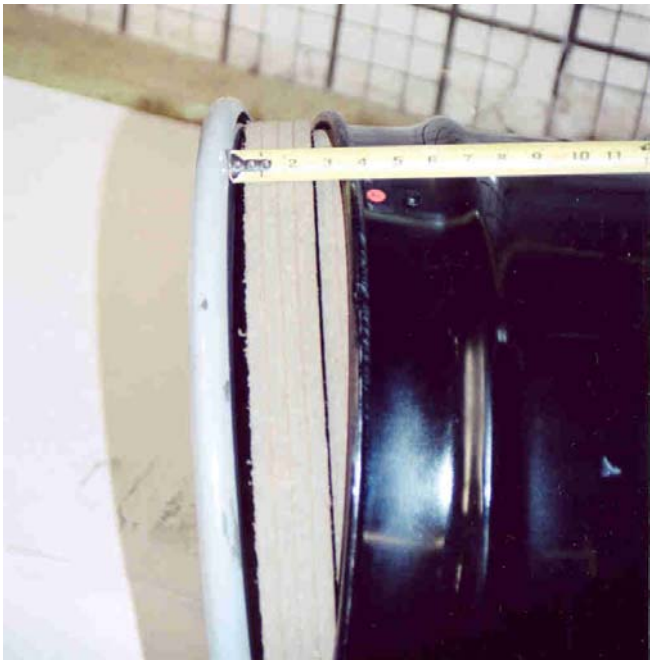

Figure 10 - The 20° impact resulted in an opening of about 3 ½ in.

Figure 11 - View of flattened impact region and lid separation of 325-4.

Figure 12 - Package 325-3 following NCT preconditioning drop.

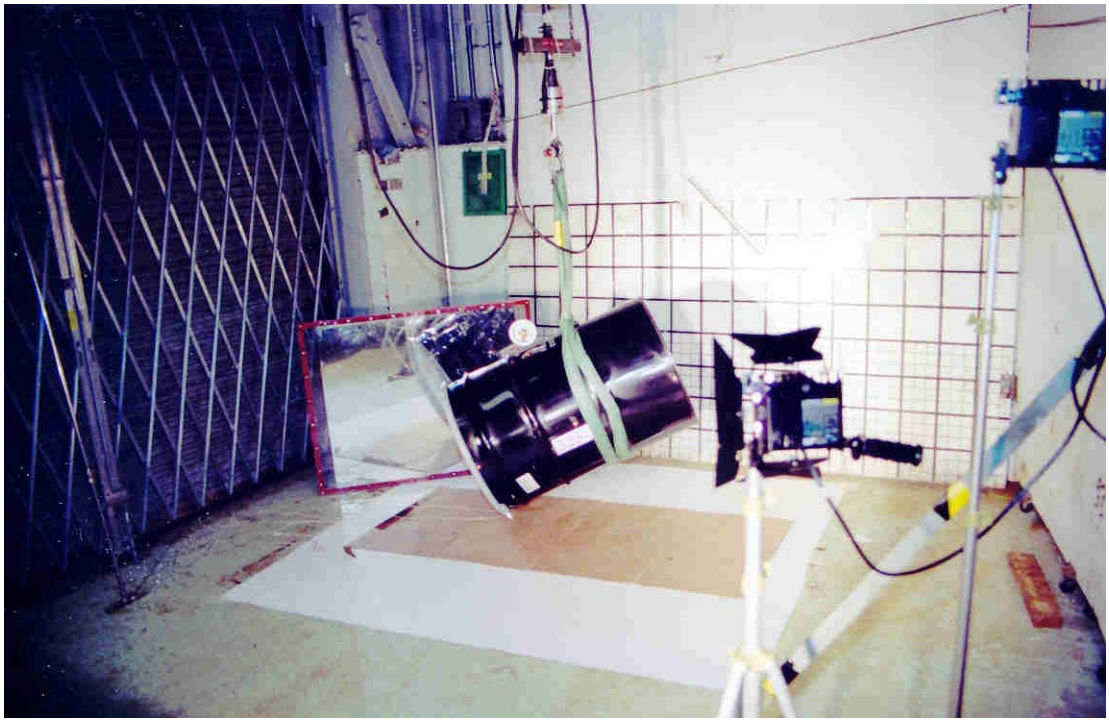

Figure 13 - Package 325-3 rigged for the repeat of the 20° drop test.

Figure 14 - Package 325-3 in mid-rebound following impact for 30 ft, 20° drop test. The opening of the package lid is visible at this time.

Figure 15 - Package 325-3 following 30-ft drop test with 20° impact angle.

Figure 16 - Impact region deformation and lid opening of 325-3 following repeat of 30 ft, 20° drop test.

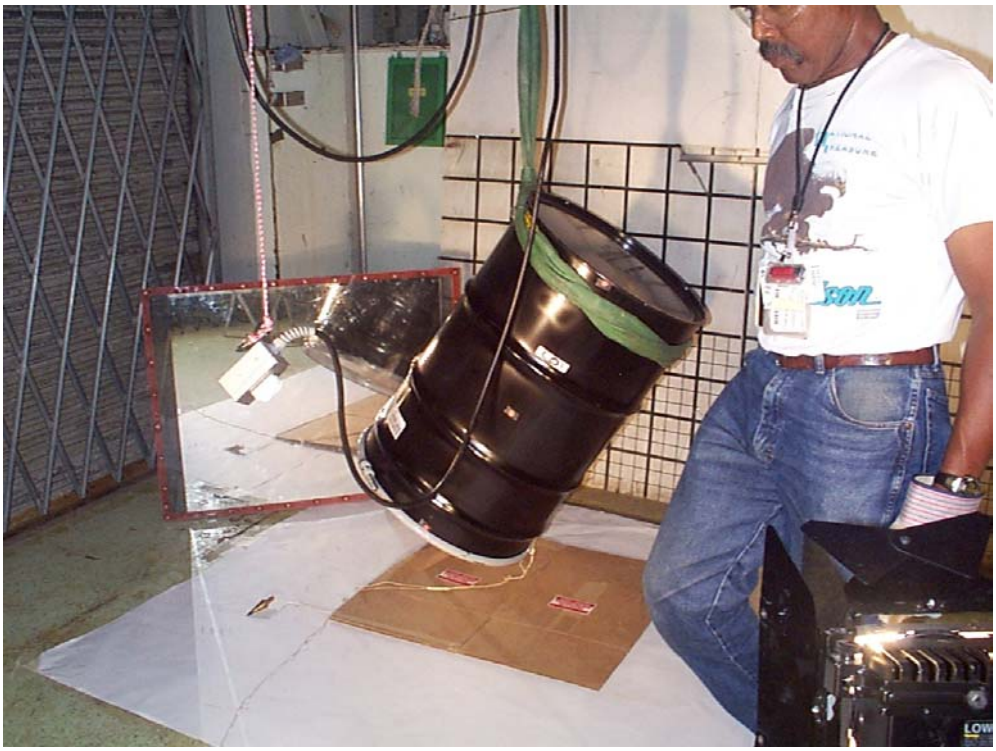

Figure 17 - Package 325-6, with plywood disk enhanced closure rigged for NCT CGOC preconditioning drop test.

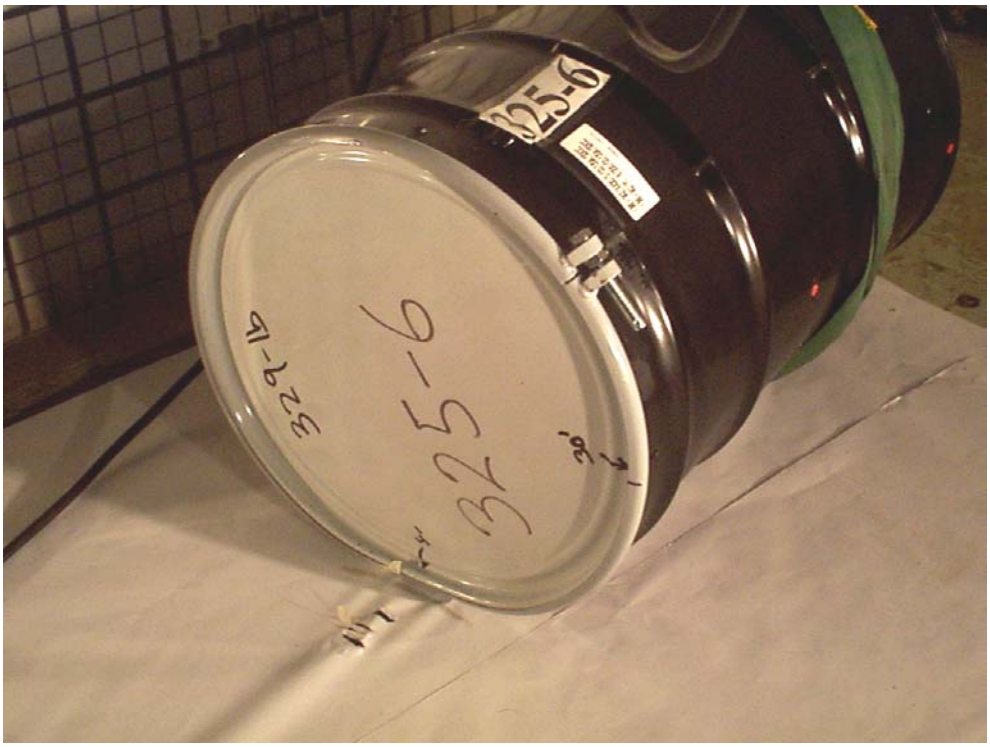

Figure 18 - Package 325-6 following NCT preconditioning drop.

Figure 19 - Package 325-6 with plywood disk enhanced closure struck the test surface at 6.5°. The damage was typical of that for other shallow angle tests. As discussed in the text, the intended impact angle was 20°.

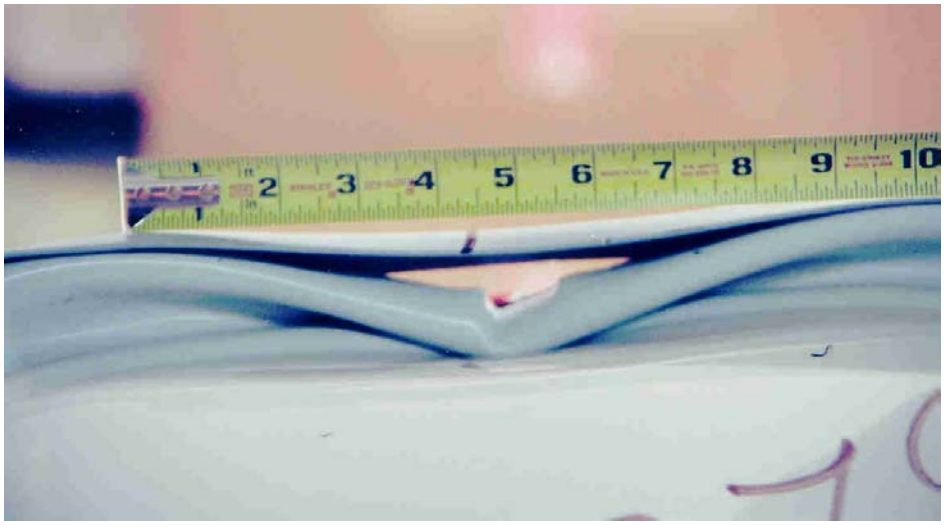

Figure 20 - The test of 325-6 resulted in reverse curvature of both the drum curl and the inverted "J" rim at the drum lid

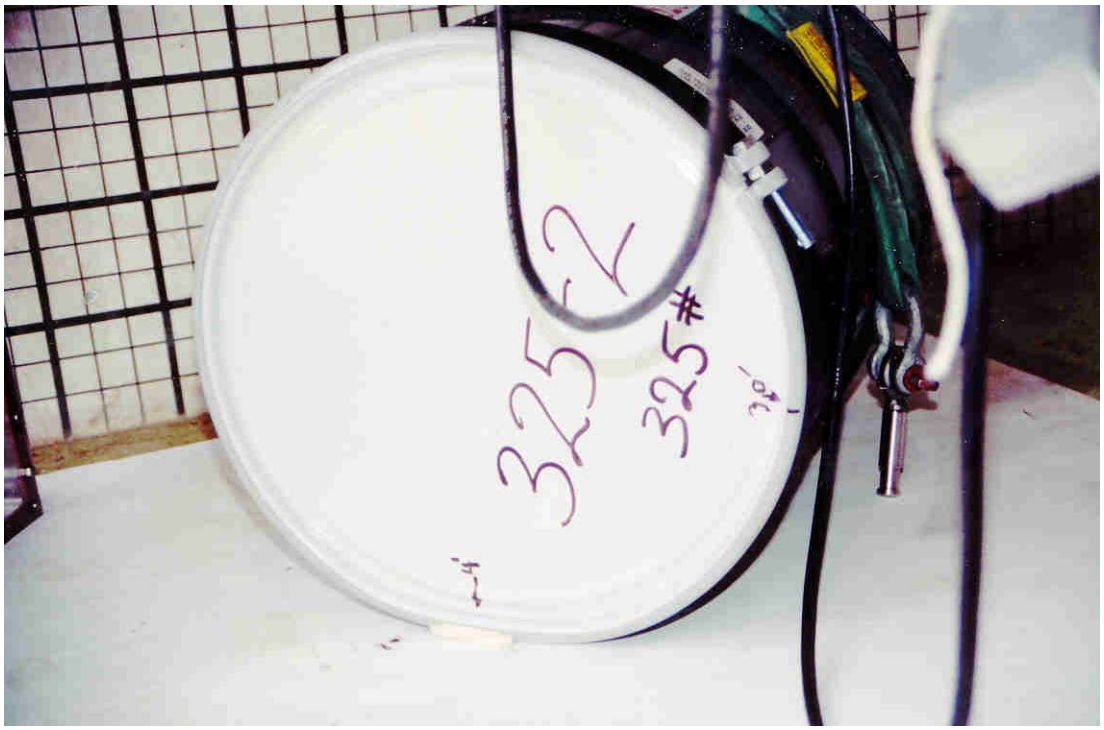

Figure 21 - Package 325-2 following NCT preconditioning drop.

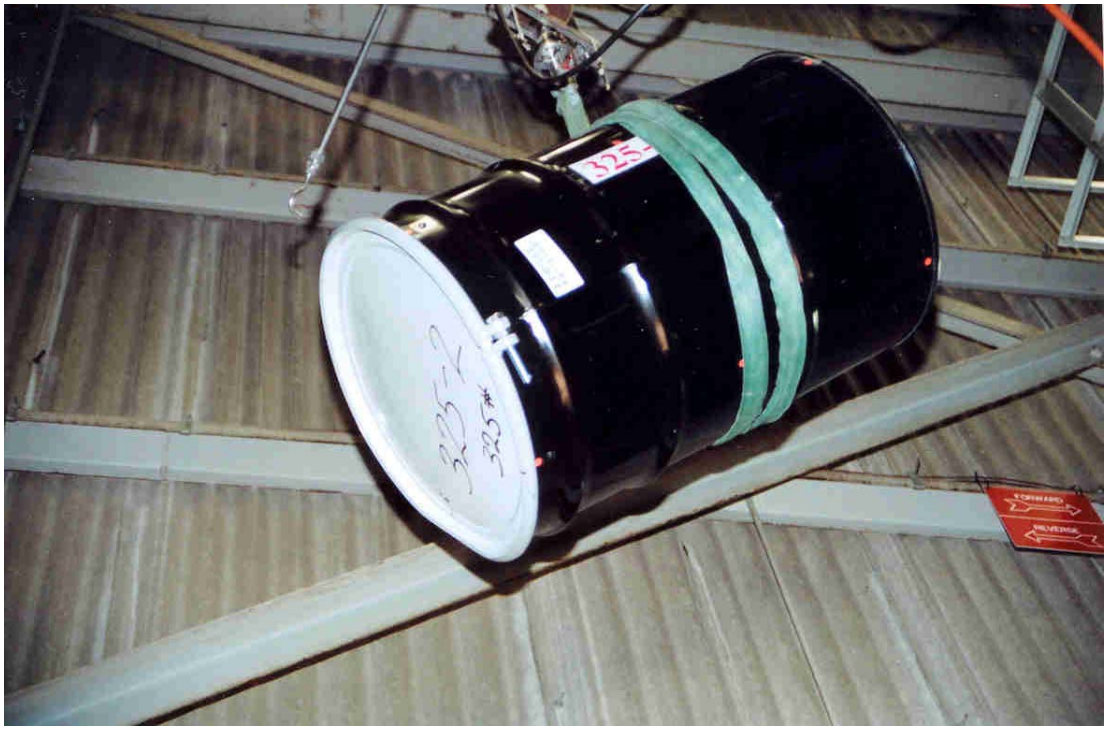

Figure 22 - Package 325-2 rigged for the 30° drop test.

Figure 23 - Package 325-2 following 30-ft drop with 30° impact angle. This test resulted in the largest opening of the lid.

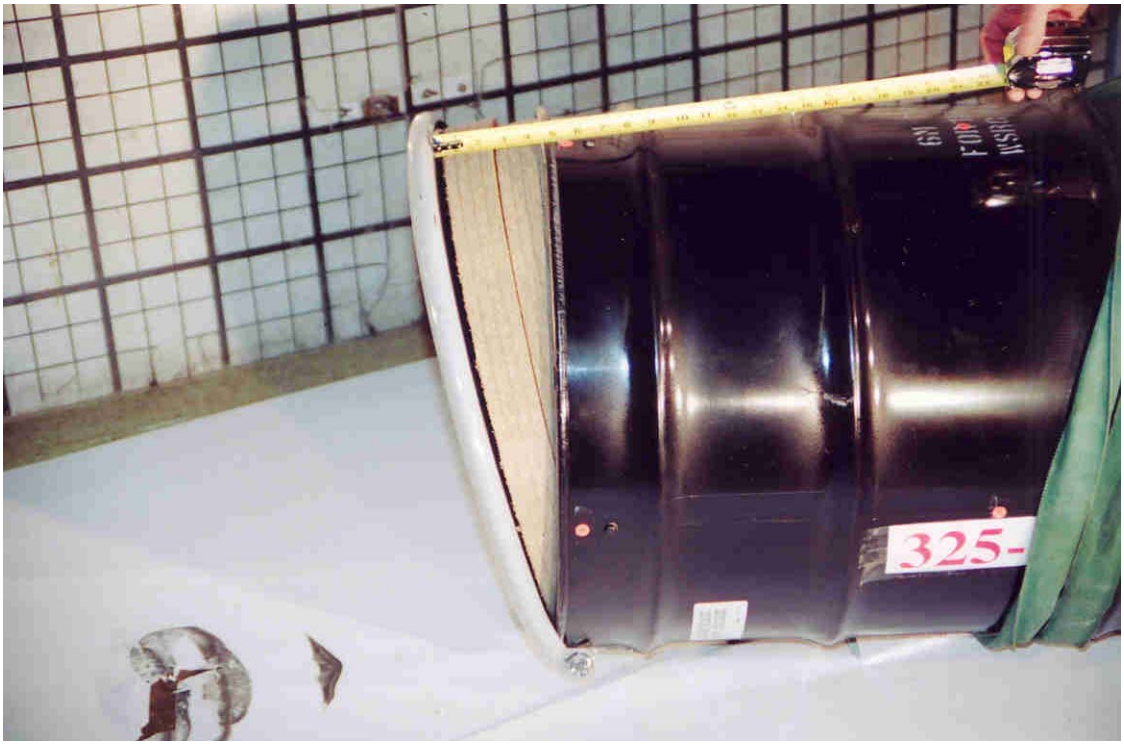

Figure 24 - The 30° impact angle test resulted in an opening of approximately 4.5 in.

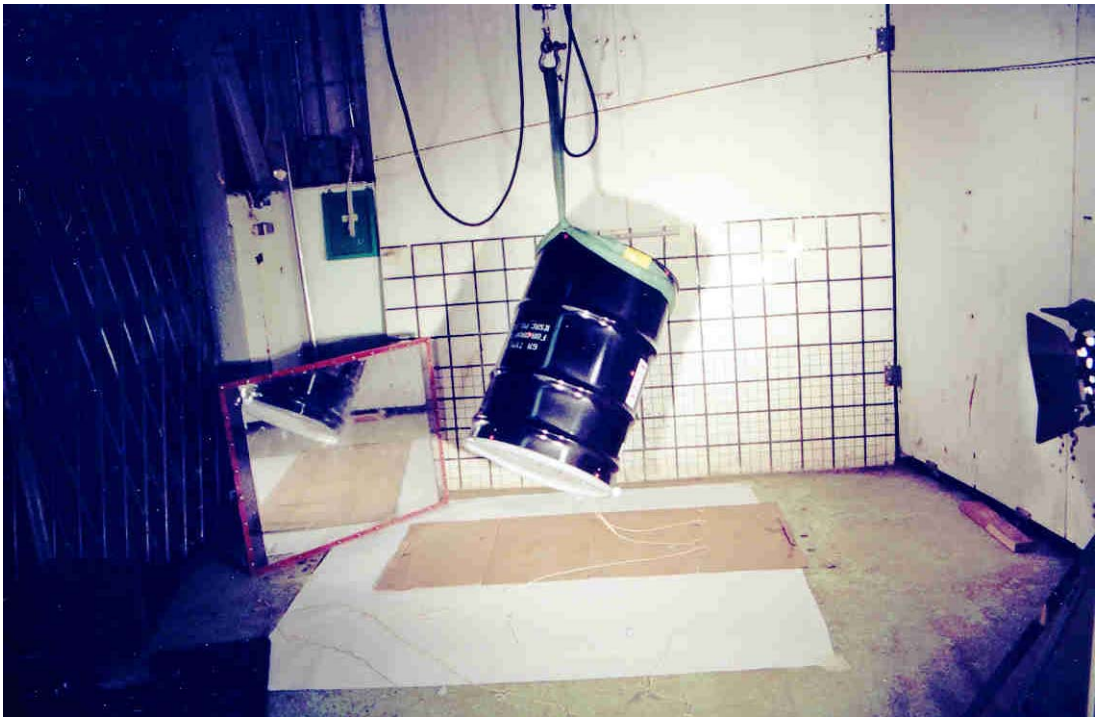

Figure 25 - Package 325-1 rigged for the 55°, Center of Gravity Over Corner drop test.

Figure 26 - Package 325-1 following NCT preconditioning drop.

Figure 27 - Package 325-1 in mid rebound following impact for 30 ft, 55° (CGOC) drop test.

Figure 28 - Package 325-1 following 30-ft drop with 55° impact angle. The resulting damage was typical of CGOC tests. The lid opening is not visible in this view.

Figure 29 - The 55°, CGOC test resulted in an opening of approximately 1.5 in.

Figure 30 - The lid opening extended for approximately 120° around the rim.

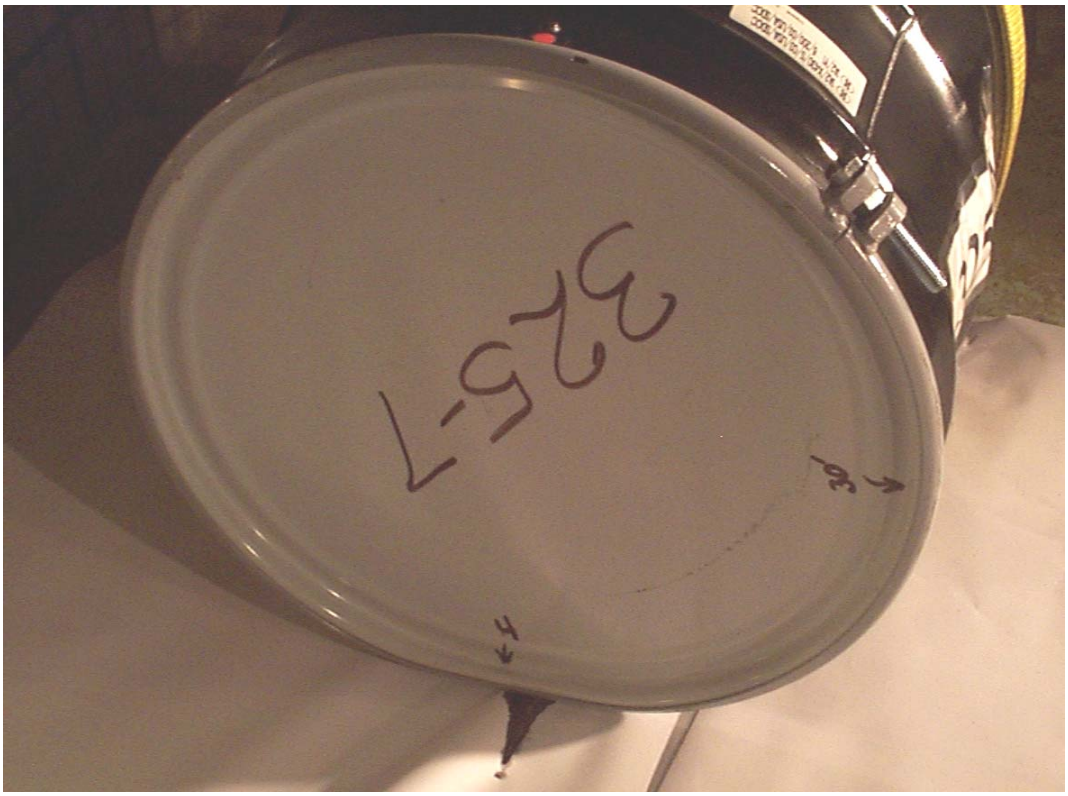

Figure 31 - Package 325-7 following NCT preconditioning drop.

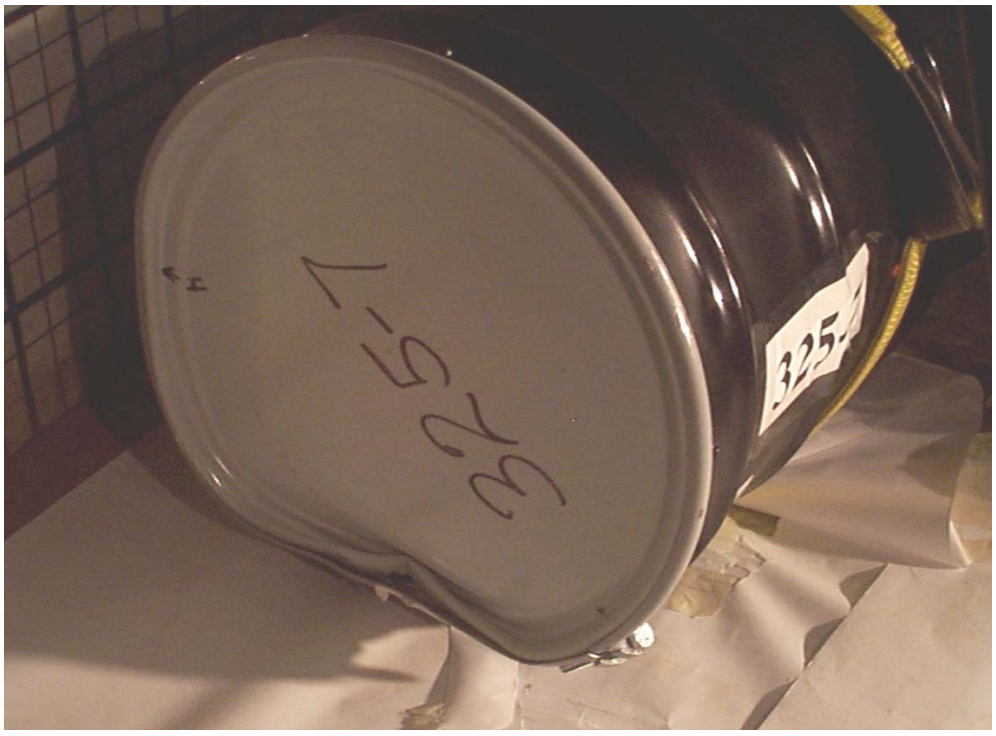

Figure 32 - Package 325-7 following 30-ft drop with 30° (27.5° actual) impact angle.

Figure 33 - Package 325-7 closure ring was flattened, but the lid was retained.

Figure 34 - Package 325-7 closure ring separation at the point of impact: 5/-8-in deep by 6-in length.

Figure 35 - Package 325-8 following NCT preconditioning drop.

Figure 36 - Package 325-7 following 30-ft drop with CGOC° (53° actual) impact angle

Figure 37 - Package 325-8 lid opened 90° from point of impact.

Figure 38 - Package 325-8 lid opening: approximately ½-in wide by 10-in length.

Figure 39 - The 325 pound 6M test specimens arranged in order of testing, from left to right. The 30° impact angle, specimen 325-2 (second from right) had the greatest opening.

Figure 40 - The 325 pound 6M test specimens arranged in order of testing, from left to right (Note: drum rotated 90º clockwise from photo in Figure 39). The 30° impact angle, specimen 325-2 (second from right) had the greatest opening.

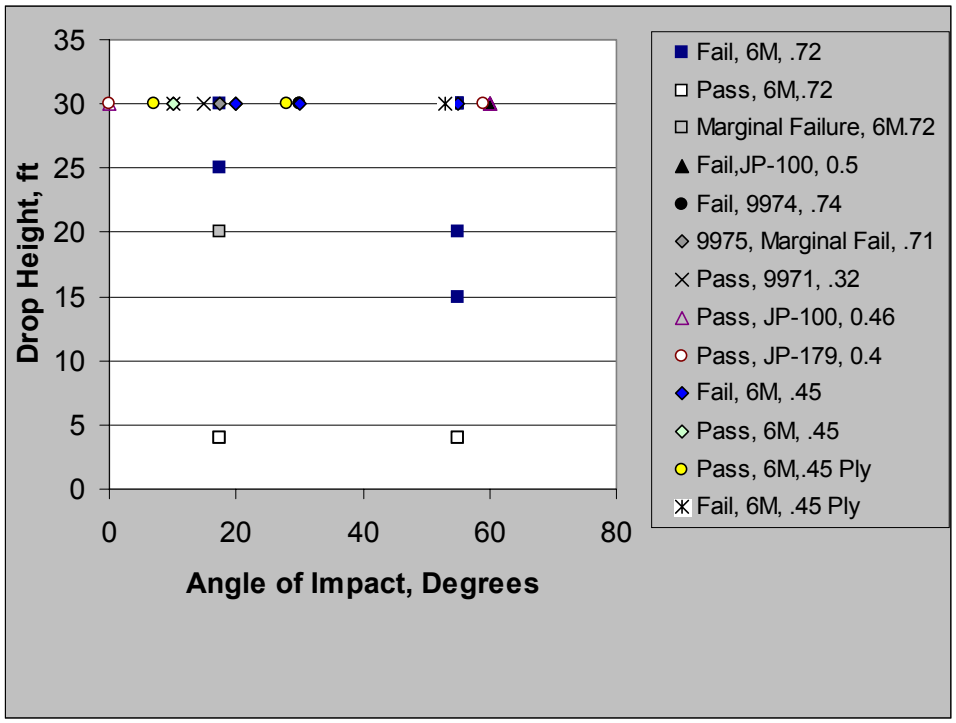

Figure 41 - Lid Retention in Clamp-Ring Closure Drop Tests

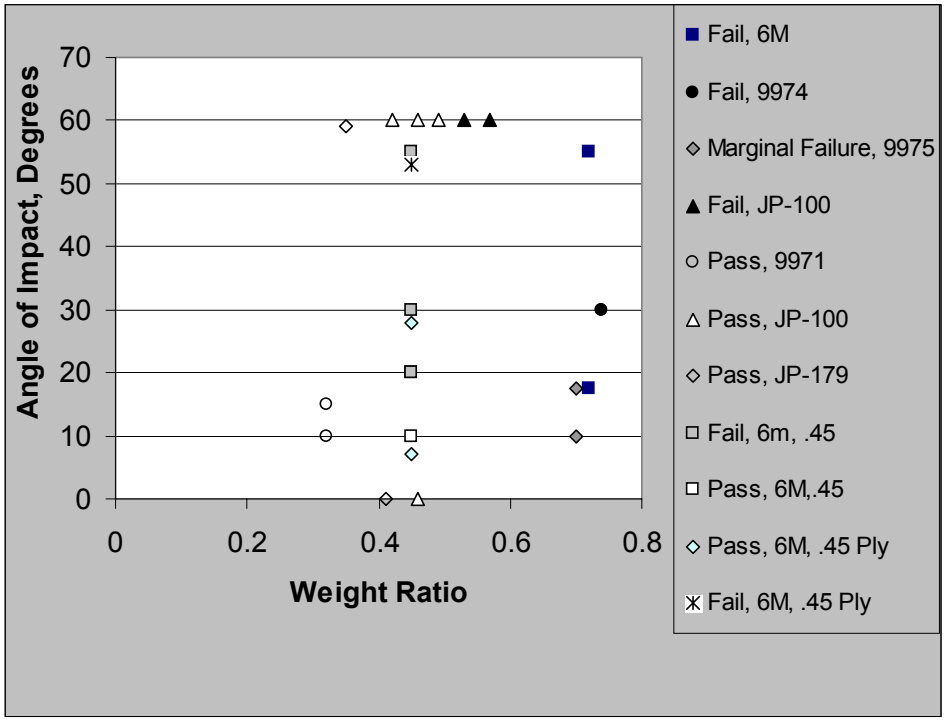

Figure 42 - Lid Retention in Clamp-Ring Closure Drop Tests from 30 ft. for Various Impact angles

6.0 Discussion

The objective of these tests was to determine if 6M packages loaded to the weight typical of DOE shipments were vulnerable to the same lid opening mechanism that was observed in tests of 6M packages loaded to the maximum weight allowed by the specification.

The 6M test packages tested on October 27-28, 2003 are shown for comparison in Figures 39 and 40.

Although no opening 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 ½-in long and 9/16-in high led to redesign and adoption of a bolted flange closure for the 9975. Development of a significant opening or complete loss of the lid would make contents vulnerable to fire event. Consequently, the presence of such an opening is deemed a failure of the closure.

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 angle of impact. 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., fiberboard), and configuration of closure (clamp-ring, bolted flange, etc.). For the clamp-ring closure configuration, like that employed by the 6M, a study of published drop test results has shown that packages having a weight ratio of less than 50% were typically able to retain their lids in HAC drop tests.[2] Those having weight ratios greater than 50% typically failed. The results of the earlier tests (i.e., maximum weight 6M and published results) are shown in Figures 33 and 34, for the principal test conditions: Weight Ratio, Angle of Impact, and Drop Height. The results of the present testing are also shown in these figures. The figures provide views of a three dimensional pass-fail threshold surface in Weight Ratio, Impact Angle, and Drop Height space.

For the present testing, the packages were tested at 325 lb ± 5 lb, resulting in a weight ratio of 45%. Despite these test packages being below the 50% guideline, the drop tests resulted in large lid openings for all cases except the 10°, shallow angle case. The two failures for the 20° case indicate that the failure threshold is closer to 10° than to 20°. Comparison of these results with the 9975 test results [8,9] suggests that the clamp-ring closure when employed on a 55 gal (drum size) package (22 ½-in diameter) is less secure than when applied to a 35 gal package (18 ¼ -in diameter).

In the tests reported here, the failure mechanism appears the same as in the earlier 6M tests. The opening of the lid is attributed to the combination of load applied by bending of the lid and closure ring with unloading of the ring due to deformation. The lid is first observed to pullout from beneath the clamp-ring, or the clamp-ring is observed to pull over the drum curl at one or both ends of the flattened region caused by the HAC drop.

The opening then grows progressively and rapidly from the initial openings. In the 20° and 30° cases the opening propagated completely around the circumference of the rim.

The fiberboard disks in the 325 lb test packages did not show indication of the crushing and breakup in the central region that was observed in the 640 lb test packages. This indicates that loading of the closure due to translation of the contents was less of a factor in the opening of the lid than in the 640 lb cases.

The pressurization of the interior of the package caused by volume change during impact is too low, to account for the opening of the lid. However, the ejection of fiberboard dust observed during the CGOC test of 325-1 confirms that the interior pressure is increased by the deformation of the package, and will contribute to the loading of the lid.

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 first of three Plywood Disk enhanced packages was dropped at 20° to determine if this simple enhancement would enable the package to retain its lid, following the failure of the closure in the two 20 ° cases. However, the package drifted during the drop so that the impact angle was 6.5°. Since closure performed successfully in the 10° test case, the successful performance of the plywood disk enhancement in this shallow angle impact was inconclusive. The two additional tests of plywood disk enhanced 6M's, at 30° and 55°, confirmed that the incorporation of the plywood disk improved the performance of the closure. The 30° case displayed reduced engagement of the clamp ring with the curl in the NCT damage region. The opening which occurred in the 55° case was in the same region and was the result of complete disengagement of the clamp ring with the curl of the drum. Comparison of the performance of the plywood disk enhanced packages with other drum packages, Figures 41 and 42, showed that the incorporation of the plywood disk raised the pass-fail threshold surface for HAC drop tests. That is, it provided improved performance against failure in the drop tests, even though it did not insure against lid opening.

Comparison of the packages for the cases tested here shows that the maximum opening was made in the 30° case. The results fell into three damage types, depending on impact angle. The shallow angle case resulted in flattening of the side of the package and reverse curvature of the rim at the point of impact. The mid angle cases resulted in large lid openings, with modest corner crushing. The CGOC case resulted in significant corner crushing with a significant lid opening.

7.0 Conclusions

The results of the testing showed that the standard clamp-ring closure was inadequate for 6M packages at weight typical of DOE shipments.

The 55 gallon, 6M packages with standard clamp-ring closures are more vulnerable to HAC drop tests than similar 30 or 35 gal size packages.

The 55 gallon, 6M package closure was typically most vulnerable to impact in the CGOC orientation.

The plywood disk enhancement provided lid-retention performance improvement at impact angles of 6.5°, 30°; and CGOC; nevertheless, this enhancement still resulted in a package test failure in the CGOC orientation.

8.0 References

1. Hafner, R. S. Mok, G. C., and Hagler, L. B., *Drop Test Results for the Combustion Engineering Model No. ABB-2901 Fuel Pellet Shipping Package*, UCRL-ID-149067, Appendix A, Lawrence Livermore National Laboratory, June, 2002
2. Blanton, P. S. and Smith, A. C., *Response of Conventional Ring Closures of Drum Type Packages to Regulatory Drop Tests with Application to the 9974/9975 Package*, 2002 ASME Pressure Vessels and Piping Conference Proceedings Volume 449, August, 2002.
3. Smith, A. C. and Gelder L. F., *Drop Tests for the 6M Specification Package Closure Investigation (U)*, M-TRT-A-00002, Revision 0, August 2003
4. "Specification 6M; Metal Packaging", United States Code of Federal Regulation, 49 CFR 178.354, 1999.
5. Lutz, R. N., *Drop Test Plan for the 6M Specification Closure Investigation*, M-TPL-A-00002, September, 2003.
6. Lewallen, E. E., *Drum and Board-Type Insulation Overpacks of Shipping Packages for Radioactive Materials*, Savannah River Site Report DP-1292, July 1972.
7. *Drop Testing of Radioactive Material Packages*, Savannah River Technology Procedure L9.5-9150, Rev. 1, October 2003.
8. Smith, A. C., *Drop Tests of the Closure Ring for the 9975 Package*, Westinghouse Savannah River Co., WSRC-TR-2000-00140, April 2000.
9. Smith, A. C., *Drop Tests of the Redesigned 9975 Package*, WSRC-TR-2000-00236, June, 2000.