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Responses of Conventional Ring Closures of Drum Type Packages to Regulatory Drop Tests with Application to the 9974/9975 Package

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ABSTRACT

DOT, DOE and NRC Type A and Type B radioactive material (RAM) transport packages routinely use industrial or military specification drums with conventional clamp ring closures as an overpack. Considerable testing has been performed on these type packages over the past 30 years. Observations from test data have resulted in various design changes and recommendations to the standard drum specification and use, enhancing the reliability of the overpack. Recently, performance capability of the 9975 conventional clamp ring closure design was questioned by the Regulatory Authority. This paper highlights the observations of recent 9974 and 9975 package testing that led to redesign of the 9975, replacing the standard clamp ring closure with a bolted ring closure. In the course of this review and redesign effort, 18 package designs and approximately 100 Hypothetical Accident Condition (HAC) drops of various size and weight drum packages were evaluated. A trend was observed with respect to overpack lid failures for packages utilizing conventional ring closure. Based on this trend, a limit on the ratio of the content weight to total package weight was identified, beyond which clamp ring closure failure may be expected.

BACKGROUND

Drum type packages, conceptually similar to the DOT 6M specification package, are widely used in radioactive material packaging applications. These packages typically consist of a standard, commercial open head drum, enclosing an engineered, leak tight containment system and an annular region of overpack material which serves as both the impact absorber and thermal insulation for the containment vessel. Typically, the overpack is assembled by bonding disks, cut from sheets of cane fiberboard (Celotex®), together to form a thick walled annulus.

The top closure for the drum overpack has typically consisted of a standard formed drum lid, having a dished center and a raised rim of inverted "J" cross section. The channel of the "J" section contains a gasket and engages the curl or rolled rim of the drum when it is installed. The lid is retained by a "C" section clamp ring which is pulled tight, circumferentially, by a bolt, which passes through lugs located on either side of the gap in the ring, Figure 1. For RAM packages, the ring and lugs are typically of greater cross section than those used in standard commercial applications.

Packages of this general configuration, in a wide range of sizes, have been widely and successfully used for many years. However, experience in regulatory testing of the 9974 and 9975 led to recognition of deficiencies in the conventional closure arrangement. The identification of closure deficiencies initiated a review of 18, similar style, packagings and ultimately led to 9975 closure redesign. A trend was observed in the course of the review which indicated that drum packages, with a weight ratio exceeding 50% internal weight to package gross weight, may result in ring-closure failure.

Figure 1 Conventional Clamp Ring Closure

SHIPPING PACKAGE COMPONETS

Eighteen shipping package designs were reviewed to help identify the cause and a solution for the 9975 package lid failure. Package designs considered sufficiently similar for comparison included three major components as illustrated in Figure 2:

1) An inner shipping container assembly,
2) An outer container or drum, and
3) An annular insulation assembly.

Figure 3 (attached) illustrates a cross-sectioned view of the packages considered in this review. In each design, the inner container assembly is unrestrained relative to the drum. The insulating/crush resistive material provides positioning but does not necessarily prevent movement of the inner container relative to the drum or drum lid during HAC.

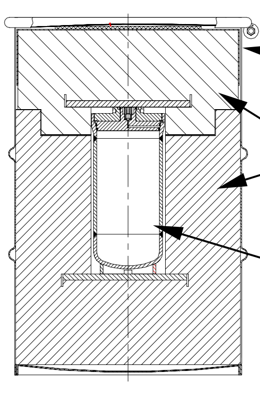

Figure 2 Primary Components of a RAM Drum Packaging

For the purposes of this paper the shipping containers inner assembly weight is defined as the gross package weight less the packaging insulation assembly weight.

HAC DROP TESTING OF DRUM PACKAGINGS

In past HAC drop testing of drum type packages, the tests have generally consisted of horizontal drop (drum axis parallel to impact surface), axial drop (drum axis perpendicular to impact surface), and Center of Gravity over Corner drop (CG of package directly above rim of package). Slap-down tests, where the package strikes, bottom first, at a shallow angle, are frequently performed for high aspect ratio (length to diameter) packages. The horizontal and axial drops typically impart maximum loads to the containment vessels, thereby challenging their integrity. The CG-over-Corner drop typically results in maximum crushing of the drum overpack and the overpack material. The slap-down test, for high aspect ration packages, results in rotation of the package and consequent acceleration of the top of the package, following contact of the bottom with the impact surface. The resulting lateral loads applied to the drum and containment vessel closures, may be greater than for the direct, horizontal drop.

INDICATIONS OF DEFICIENCIES IN CLAMP RING TYPE CLOSURES

Although a wide range of packages, employing the clamp ring type of closure, have been successfully tested over the years, there is evidence that this type of closure will not be appropriate for some applications. Early HAC testing of drum packagings at the Savannah River Site resulted in a number of recommended specifications and certain design features for drum shipping packages that are still in use today, Lewallen 1972. Of particular interest to this paper are Lewallens observations on the standard drum type closure. As early as 1972 HAC test results indicated that the standard industrial ring closure required strengthening to pass HAC testing. Lewallen also concluded from his observations that gasketed lids contribute to closure failures. Based on his tests Lewallen made five recommendations for RAM packaging that used a drum as its overpack.

- Use standard military or equivalent specified drums
- Do not use lid gaskets,
- Increase the strength of the locking ring closure,
- Minimum torque requirements on the locking ring bolt, and
- Use reinforced closures (flanged) for drum packages with gross weights greater than 500 lbs.

Lewallen concluded from his series of tests that heavy drum type packages with gross weight of more than 500 pounds required a reinforced closure. This paper builds on his observations and shows that drum failures using the ring closure may be characterized not only by gross drum weight (heavy packages) but failure is better characterized due to a relationship between the gross packaging weight and internal weights.

Similarly, following eight-drop test failures out of twenty drops for Oak Ridge's prototype DT series packaging the standard ring closure for the DT-22 was redesigned, Speaks 1993. All lid failures occurred when the packaging was dropped on the drum closure at an angle of approximating 47° from horizontal. The DT-22 gross weight is approximately 400 lbs. A bolted flange closure assembly was adopted to correct this deficiency. This DT series redesign ultimately was selected as the basis for the 9975 closure redesign. On test completion, Speaks concluded that difference in closure ring material, presence of a lid gasket, lid drum fit up, and or lighter payloads had no noticeable effect on lid failures. These conclusions are in general opposite to those presented by Lewallen and are not completely in line with data reported on in this paper.

In the course of development testing for the UC-609, the CG-over-Corner drop resulted in separation of the lid from the package with a maximum gap of around 3 inches, over an arc in excess of 180°, Sandberg 1998. The drop broke the ring-lug connection. After testing various modifications to the closure configuration, a ring of eight clamps was adopted. The J style clamp can be seen in Figure 4.

During the 9965-9975 prototype testing at Savannah River a similar loss-of-lid event occurred during testing of the 9974, as part of testing the 9965-9975 family of packages, Blanton 1997. The 9965 through 9968 packages were predecessors of the 9972-9975 design. The primary differences being the set of packaging designs were 1) the 65-68 drums were made of carbon steel versus the current use of stainless steel, and 2) the insulation assemblies were held together with bolts and threaded rods vs. the current use of adhesives for holding the assemblies together. At 675 lbs., the 9974 was the heaviest of the family of packaging. Testing prior to '97 of the 9974 resulted in a ring-lug breakage. The 9974 closure lug was strengthened to correct further failure. In the '97 tests the 9974 was dropped from 30 feet at an inclination of 30 degrees from horizontal. On impact the lid separated opposite the impact point similar to that experienced by Lewallens and Speaks drum tests, Figure 5.

Figure 5 9974 Test Partial Lid Failure

The 9974 closure ring was modified in an attempt to correct this mode of failure. The modification was an extension to the clip design that was already in use for the 9972-9975 packagings, which consisted of two clips welded to the ring closure directly above the ring closure extension lugs. The purpose of the clips was to prevent the lid closure from being weakened or completely snatched off in the event the lugs were directly impacted in the NCT puncture pin test. Repeated drops of 9972-9975 packaging with this ring modification had demonstrated that the clips enhance both strength and the retention of the drum closure during NCT tests. Additionally, the clips also appeared to help retain the lid during subsequent HAC 30 foot drops. The 9974 lid modification consisted of the addition of three clips positioned at 90-degree integrals from the lugs, providing a total of five clips around the drum circumference. On retest the design fix was ineffective and the lid completely detached on impact, Figure 6. It is believed the added clips increased the stiffness of the band. The increased stiffness between the drum body and the banded closure caused the closure failure.

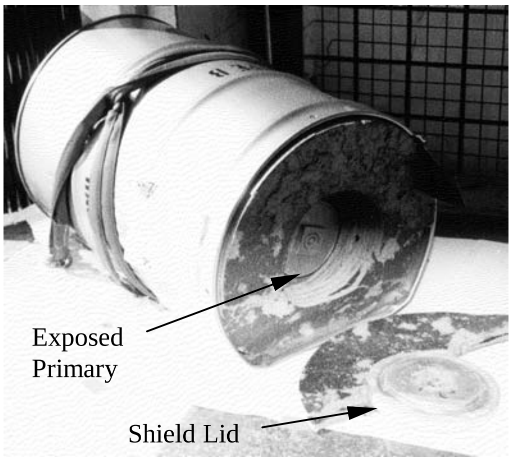

Figure 6 9974 Test Complete Lid Loss

Since the certification effort was primarily directed toward the 9975, further corrective action for the 9974 closure was deferred. During this series of tests five prototype 9975s were HAC drop tested; none of which failed, Blanton 1997.

9975 Closure Development

Testing of the 9975 resumed in September 1998 to demonstrate pressurized containment vessels were not susceptible to leakage following the HAC 30 foot drop, Smith 1998. The objective of these tests was resolution of issues associated with gas generation by proposed contents. While the performance of the containment vessels under pressurized conditions was demonstrated in these tests, the response of the clamp ring closure was unexpected and caused concern. The damaged package was dropped at an angle of 8° to 10° inclination from horizontal, shallow angle. The impact buckled the drum rim inward, causing a reversed curvature, over a small distance, at the center of impact, Figure 7. The clamp ring was deformed but not to the extent of the drum rim. Consequently, the clamp ring was not engaged with the drum rim and top, over much of the span of the deformed region. The concern that this could result in loss of the top, under some conditions (e.g., puncture test) led to additional testing, directed at the drum closure arrangement.

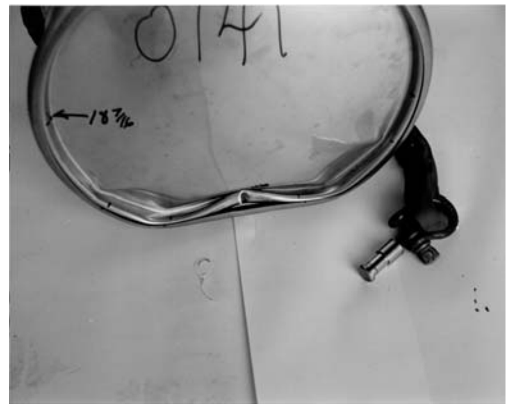

Figure 7 9975 Closure Deformation

This concern subsequently led to two series of closure ring tests. The first series involved replicating the previous pressurized containment vessel test and to determine if the closure was vulnerable to the regulatory puncture test in the "position for which maximum damage is expected" (Ref 2). Three 9-meter drop tests were planned and performed with impact with the package axis at 8°, 14° and a slap-down with bottom down impact at 10°, Smith 1999. The criterion for acceptable performance was based on damaged package configuration previously subjected to HAC testing. In order for the fire test results to remain applicable, the drop tests could not result in any opening larger in area than the existing vent holes. No gap was opened between the top and the drum rim over the course of this testing so that the ability of the package to withstand a subsequent fire test was not compromised.

The second series of closure ring tests again planned for three 30 foot drops but at different angles, two drops at 45°, approximately CG-over-corner, and one at 17.5°. However, in these tests the HAC drops were preceded by the NCT 1-meter drop. The first test, performed at 45°, indicated that the large angle drops would not challenge the ability of the closure ring to retain the top of the drum. The subsequent 17.5° test was preceded by a 1 m preconditioning drop with the package oriented top down, at 17.5°, and striking 90° from the point of impact for the subsequent 9 m drop. The closure ring lugs were located 45° from the point of contact (on the opposite side from the NCT test damage region) where they would likely be subjected to maximum bending. The resulting damage was typical of low angle drop tests. The drop resulted in a flattened region of the closure ring approximately 11 in. wide. The top of the drum buckled outward along a line parallel to the flattened side. This buckling resulted in the top pulling out from under the closure ring in the sector between the preconditioning drop damage region and the flattened side produced by the 9 m drop. This resulted in a opening approximately 12 cm (4.5 in.) long, with a maximum width of 0.4 cm (0.56 in.) at its mid point, Figure 8. This exceeded the test criterion of no opening larger than the vent hole openings.

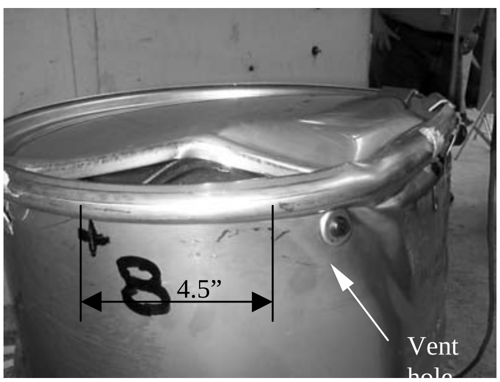

Figure 8 9975 Ring Closure Lid Failure

For the puncture test, the package was oriented so that the bar would strike the open edge of the top, in an attempt to further separate the lid from the drum. The top was too well retained for this to occur, however, and the impact flattened the buckled region against the package.

The opening produced in the 17.5° test failed the acceptance criterion which called into question the ability of the package to withstand a regulatory fire. Consequently, the 9975 top closure was redesigned. The new closure is a bolted flange design employing 24 bolts to retain the top.

To verify the performance of the new design, a series of three 9-m drop tests, with 1 m preconditioning tests and subsequent puncture pin tests, were performed. The bolted flange design successfully withstood the test sequence, Figure 9.

DISCUSSION

Study of the test results for the various drum type packages, Table 1 and review of video recordings of cases where loss of lid has occurred, indicates that the collective responses of the closure ring, lid, drum opening, and contents determine whether the top is retained. Consequently, the material properties and thicknesses for the drum closure are critical to the security of the closure. In addition, the properties of the impact absorbing material, which supports the drum, are also important in determining the response of the closure assembly.

Figure 9 9975 Drop Tested Redesigned Bolt Ring Closure

Table 1 lists test data and package characteristics for 45 drops of 17 different style drums. The tested drums range in weight from 130 to 880 lbs. and drum sizes from 30 to 140 gallons. Available test data was compiled in Table 1 to quantitatively determine a lid failure mechanism. On inspection of the test results a notable trend can be discerned for the various drum package failures. This trend reveals that conventional clamp ring closures are not suitable for packages where the weight ratio of the internals (containment vessels, contents, shielding, etc.) to the gross package weight is greater than 50%, Figure 10. It is clearly evident in this figure that the failure rate for packages exceeding this limit is nearly 100% for the packages evaluated. Additionally, the failure trend line superimposed on the data indicates that as the weight ratio increases so does package failures. Approximately 25% of the reported failures were similar to the damage shown in Figure 8. The remaining 75% of failures were of packages where the lid detachment was over 180 degrees or complete, Figures 5 and 6, respectively.

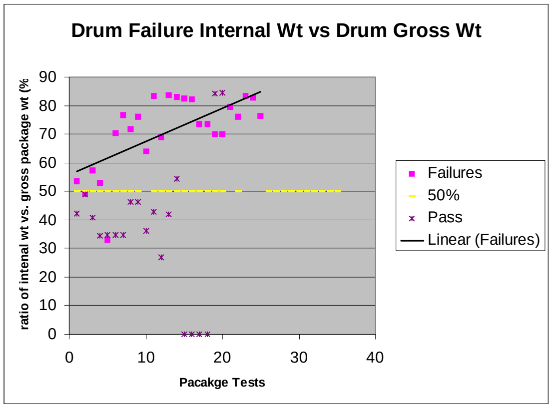

Figure 10 Drum Failure Trend

The failure limit can be used as a design rule for packaging. If in the course of design the limit is reached then a standard closure lid should not be used.

Based on the testing and observations discussed above, the parameters that are important in determining the response of a closure are:

- Weight of package
- Weight of package internals
- Drum diameter
- Angle of impact
- Mechanical stiffness of closure

Other conclusions can be drawn from the evaluation of the test results. Results indicated that larger diameter and heavy packages were more susceptible to lid loss than smaller diameter, lighter packages, Figure 11. Heavy packages are those with weights above 300 lbs, Figure 12. By inspection of Table 1, angle of impact data tends to indicate that packages dropped from CG are more prone to failure. Additionally calculations by Wu, indicate that a larger diameter drum opening is stiff compared to the more flexible smaller diameter drums. The stiffer closures are less adaptable to drum deformation and therefore more prone to lid failure.

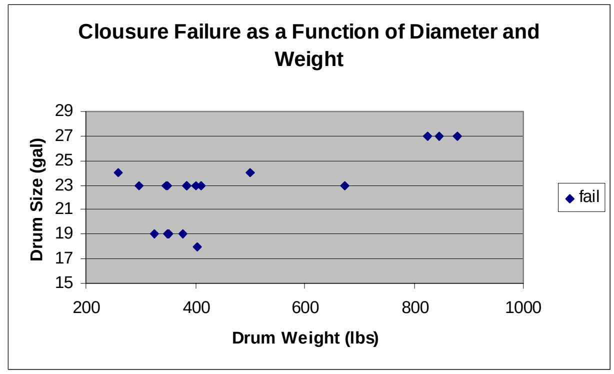

Figure 11 Drum Closure Failures

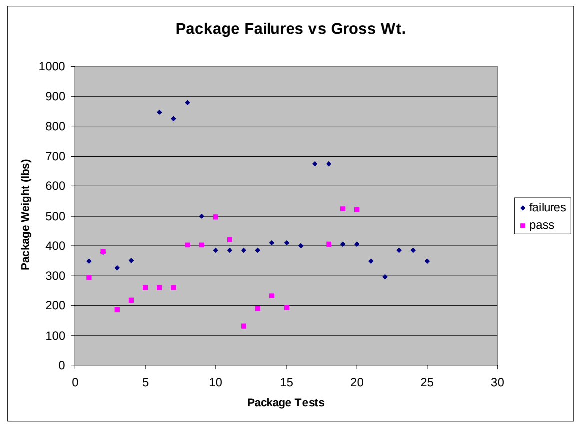

Figure 12 Package Tests Based on Weight

CONCLUSIONS

Savannah River Site testing of the 9974 and 9975 packages have resulted in a reinvestigation of drum closure failures. Based on this evaluation it is recognized that the 9975 clamp ring closure was marginal and redesign was warranted. Study of the test data also reveals a performance trend that could be used to develop a design "rule of thumb"; that conventional clamp ring closures are not suitable for packages where the weight ratio of the internals to the gross package weight is greater than 50%.

RECOMMENDATIONS

Other variables that have been considered to be failure mechanisms were closure ring torque, lug orientation, variations in closure ring materials and lids with and without gaskets. Even with the available test data there is no clear means of distinguishing the effects these variables had on lid failure.

The complex nature of the closure assembly and the importance of crush response of the impact absorbing material to the overall performance of the lid closure makes it difficult to determine the exact cause of failure through tests alone. Regulatory testing by an applicant is typically constrained by funding. Large test matrices to determine specific causes of failure of drum type packages have not been performed. The reported data is based on over 30 years of testing by multiple applicants.

Shipment of drum packages accounts for a significant amount of all radioactive material shipments. However, there is no national program in existence to qualify the specific causes of failures of drum type packaging. Given the significant number of radioactive material shipments utilizing this style of packaging, a program to determine the specific failure mechanisms of drum type packaging should be instituted.

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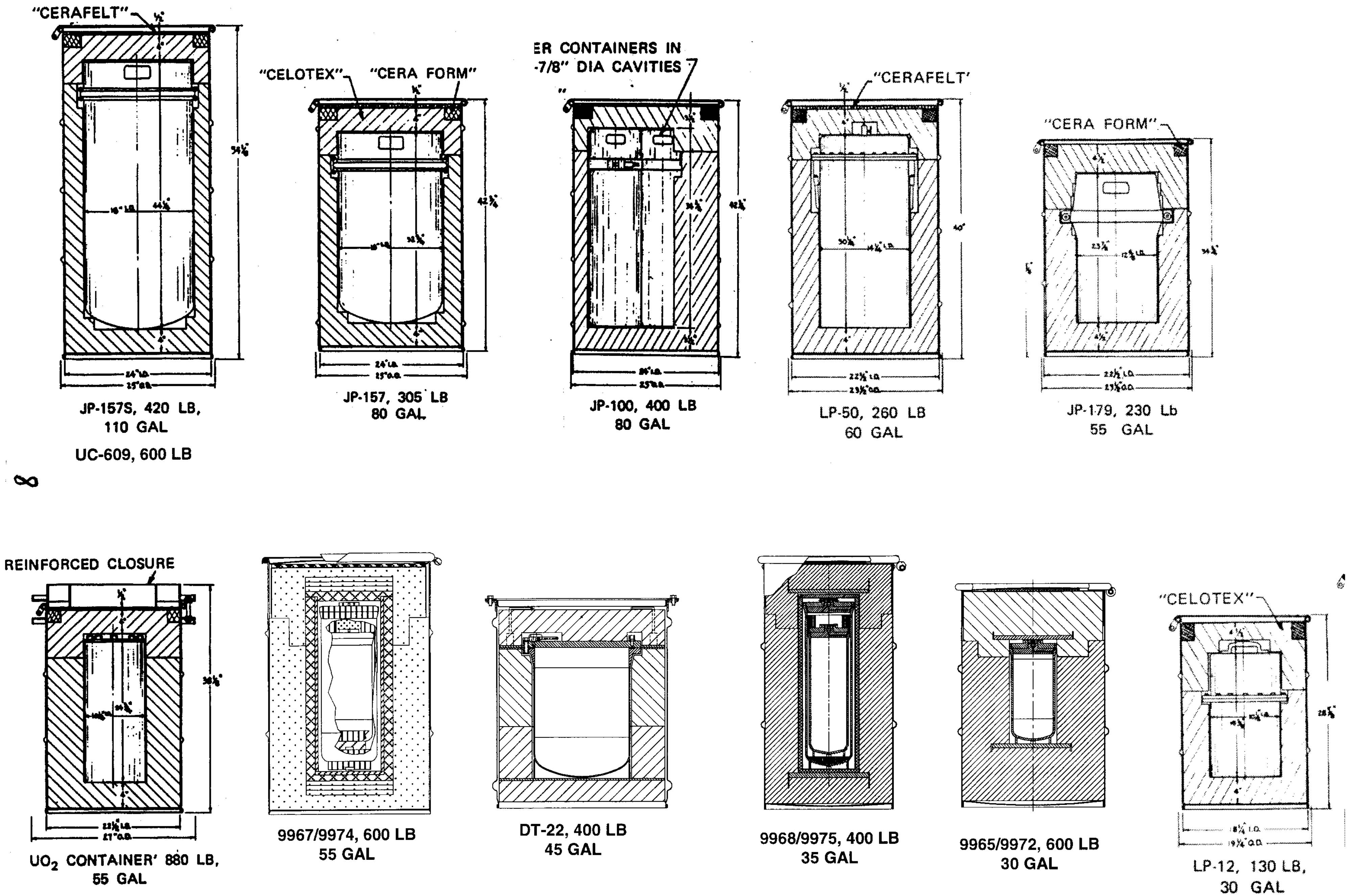

Figure 3 Shipping Package Cross Sections

No.	pkg	drum size	drum ga	drum zsize dia	drum zsize ht	Lid torque ft-lbs	drop orientat	P/F	gross wt (lb)	intern wt	inter/gros %	ref
1	JP-100	60	18	19	29	20	60	F	348	186	53	pn3, , [1],n3
2	JP-100	80	18	19	29	20	-	F	377	186	49	pn5, g, [1]
3	JP-100	80	18	19	29	20	60	F	325	186	57	pn1,Fesco Insulation, [1],n3
4	JP-100	80	18	19	29	20	-	F	351	186	53	pn2, Cera Form Insulation, [1]
5	LP-50	60	18	24	40		60	F	260	86	33	pn9, [1],n3
6	UO2	55	16	27	38		60		846	595	70	pn18, [1],n3
7	UO2	55	16	27	38		-		824	631	77	pn19, [1]
8	UO2	57	16	27	38		-		880	631	72	Pn20, [1], N1
9	UC-609	110	14	24	52		65	F	500	380	76	T1, n2
10	DT-22	45	18	23	27	40	47	F	384	246	64	5-1, [2]
11	DT-22	45	18	23	27	40	47	F	384	320	83	2a1, [2]
12	DT-22	45	18	23	27	40	47	F	384	265	69	5a1
13	DT-22	45	18	23	27	40	47	F	384	321	84	6a1
14	DT-22	45	18	23	27	40	47	F	410	340	83	1a1
15	DT-22	45	18	23	27	40	48	F	411	339	82	3a1
16	DT-22	45	18	23	27	40	46	F	401	329	82	4a1
17	9974	55	16	23	33	50	30	F	673	495	74	FP-734-9974-1,[3]
18	9974	55	16	23	33	50	27	F	673	495	74	FP-734-9974-1 redrop,[4]
20	9975	35	18	18	35	50	17.5	F	404	283	70	
21	9975	35	18	18	35	50	10	F	404	283	70	
22	dt-22	45	18	23	27	40	49.3	F	347	276	80	1-1b
23	dt-22	45	18	23	27	40	43.6	F	296	225	76	6-1c
24	dt-22	45	18	23	27	40	90	F	384	320	83	3-1,[2],n1
25	dt-22	45	18	23	27	40	10	F	385	319	83	4-1,[2],n1, slap down
26	dt-18	45	18	23	27	40	90	F	349	267	77	2b[3] n1, side drop
27	JP-100	60	18	19	29	20		P	294	124	42	pn4, [1]
28	JP-100	60	18	19	29	20		P	380	186	49	pn6, [1]
29	JP-179	55	18	24	35	20		P	184	75	41	pn7, [1]
30	JP-179	55	18	24	35	20		P	217	75	35	pn8, [1]
31	LP-50	60	18	24	40	20	60	P	260	90	35	pn10, [1],n3
32	LP-50	60	16	24	40	20		P	260	90	35	pn11-failed fire
33	LP-50	60	16	24	40	20		P	260	90	35	pn12, [1]
34	JP-100	80	16	19	29	20		P	402	186	46	pn13, [1]
35	JP-100	80	16	19	29	20		P	402	186	46	pn14, [1]

36	JP-157S	110	16	25	54	20		P	496	180	36	pn15, [1]
37	JP-157S	110	16	25	54	20		P	420	180	43	pn16, [1]
38	LP-12	30	18	19	29	20		P	130	35	27	pn17, [1]
39	9972	30	18	19.6	29.1	50		P	190	80	42	Calculated wt
40	9973	30	18	19.6	29.1	50		P	231	126	55	Calculated wt
41	65	30		19.6	29.1	50		P	193		0	
42	66	55				50		P			#DIV/0!	
43	67	55				50		P			#DIV/0!	Wt equivalent to 9974
44	68	35	18	19.6	35	50		P	406		0	Wt equivalent to 9975
45	dt-18	45	18	23	27	40	90	P	524	441	84	3b, [3]side drop
46	dt-18	45	18	23	27	40	90	P	521	441	85	4b,[3], side drop

n1 In report, this test was noted as a pass. There was a small opening above the closure lugs. (no information if this was burned.)
n2 First Drop at Rocky Flats. Nominal insulation wt was calculated to determine the internal contents wt.
n3 Drop angles were recorded at top corner. For purposes of this evaluation, top corner is assumbed to be CG and taken as ~60 from horiz

[1]
[2] locking ring failed in tennsion , SAR for Model UC-609 B(U) DOE Shiping Package, Oct 1998UCRL-ID-111494
[3] Procedure for the 9974/9975 Shipping Package Drum Closure Sequential 30 ft Drop and Puncture Tests, Procedure No FP-734, Rev 0, 10/1
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