DEFENSE WASTE PROCESSING FACILITY CANISTER IMPACT TESTING

K. M. Olson and J. M. Alzheimer
Materials Characterization Center
Pacific Northwest Laboratory*
Richland, Washington 99352

ABSTRACT

The Materials Characterization Center at Pacific Northwest Laboratory (PNL) has drop tested seven Defense Waste Processing Facility high-level waste canisters for Savannah River Laboratory (SRL) (1). The canisters were filled with simulated waste glass to ~ 85% capacity and sealed by SRL before being shipped to PNL. Each 304L stainless steel canister was approximately 300 cm (9 ft 10 in.) long, and 61 cm (2 ft) in diameter, and weighed approximately 2150 kg (4740 lb).

Each canister was dropped 7 m (23 ft) in two orientations. In the first drop, the canister was oriented vertically to hit the impact pad bottom-first with the canister bottom parallel to the pad. In the second drop, the canister was oriented with its center of gravity over the shoulder corner, and was dropped top-first, hitting the impact pad at an angle. Examinations were performed on the canisters before and after each drop to evaluate the results of each drop independently.

Procedures used to examine the canisters were the application and analysis of strain circles, helium leak testing, dye penetrant examination, and canister measurements. Little deformation was observed after the bottom drops. The top drops caused the greatest effect on canister dimensions and apparent strain. Height decreased by 14.0 to 16.4 cm or approximately 5%. The largest deformations occurred where the neck of the canister meets the body on the impact side and 180 away from this point. Strain circles showed strain ranging from 52% compressive to 8% tensile.

Helium leak testing and dye penetrant examination showed no breach of the canisters after either drop, meeting the drop test requirement of the Waste Acceptance Preliminary Specification.

INTRODUCTION

Over the next few years, the Defense Waste Processing Facility (DWPF) at Savannah River Laboratory (SRL) is expected to produce high-level radioactive glass that will eventually be placed in a geologic repository. The DWPF must meet the Waste Acceptance Preliminary Specification that canisters containing waste glass survive a drop of 7 m onto an unyielding surface and remain leak-tight (2). Seven canisters were filled with simulated waste glass, frit 165 (black frit), at SRL and were shipped to the Pacific Northwest Laboratory (PNL) in April 1988.

TESTING AND RESULTS

Upon their arrival, the seven canisters were visually inspected and weighed. The initial inspection revealed only minor dents and abrasions with some rusting where the surface had been abraded. The canisters were approximately 61 cm (24 in.) in diameter, 300 cm (9 ft 10 in.) long, and weighed approximately 2150 kg (4740 lb). Figure 1 shows the canister welds of interest.

In addition to the visual inspection, the top plug weld was helium leak tested. All the canisters showed helium leak rates of less than 10-7 atmcm3/s.

Impacts

The impact pad, as shown in Fig. 2, is a 21.6-cm (8.5-in.)-thick steel plate measuring 317 cm (10.4 ft) by 164.6 cm (5.4 ft) on top of a 176.8-cm (5.8-ft)-thick slab of reinforced concrete 563.9 cm (18.5 ft) by 411.5 cm (13.5 ft). Behind the impact pad are two checkerboard backdrops consisting of 0.3 m (1 ft) by 0.3 (1 ft) squares. The backdrops are oriented at right angles to each other so that the horizontal and vertical lines are at 0 and 90 with the horizon. In this way, high-speed movies taken in two directions during each drop can verify the exact angle of impact.

The first impact tests were 7-m (23-ft) vertical bottom drops. Each canister was lifted using cloth slings around the neck. The canister was held ~10 cm off the ground while the vertical orientation was determined using a bubble level. (See Fig. 2).

After a vertical orientation was verified, the canister was lifted by crane until the lowest point on the canister was 7 m (23-ft) off the ground. The height was determined with a calibrated sash chain taped to the bottom of the canister. At the correct height, the bottom of the chain just touched the impact pad. The chain was then pulled off the canister. The canister was steadied, if necessary, and released by means of a quick release mechanism attached to a rope. High-speed (100 frames/s) cameras photographed the drop.

All seven canisters bounced more than once after the first impact; the initial bounce was approximately 75 cm high. Two of the canisters remained upright; the others swayed before falling. Even though the canisters fell sideways after five of the bottom impacts, all of the canisters appeared to be in the correct vertical position upon impact.

Little deformation of the canisters was observed after the bottom drops. This amount of deformation was

---

* Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

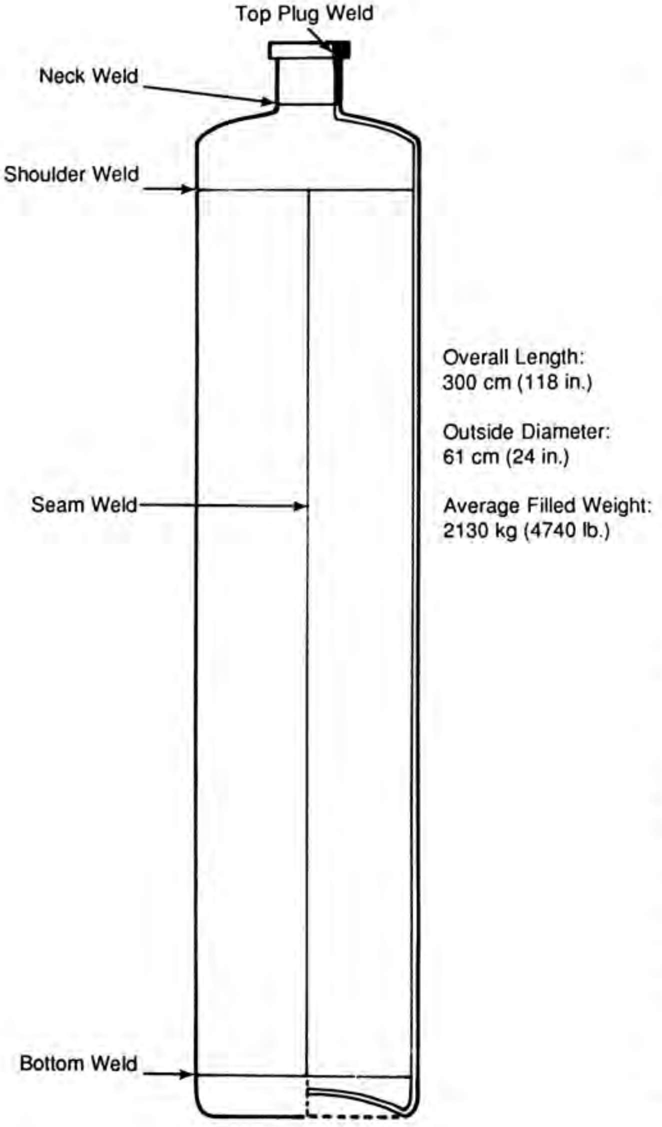


Fig. 1. Prototypical 304L Stainless Steel Canister.

Fig. 2. Determination of Vertical Orientation.

expected to be small because the glass in the containers prevented more extensive deformation.

During the top impact tests, canister center of gravity was over the shoulder corner of the canisters. The angle of inclination required for each impact was calculated using center-of-gravity determinations made after the bottom impact tests. At the impact pad, each canister was lifted approximately 10 cm off the ground, using an arrangement of chains. The inclination angle was measured with a bubble level and protractor. When proper orientation was achieved with the use of a ratchet on the shorter chain, the canister was lifted until the lowest point was 7 m off the ground as shown in Fig. 3.

All canisters, except A19, impacted on the top flange of the canister and fell to the side. A bounce of up to 15 cm was noted for these six canisters. The appearance of a typical canister after top impact is shown in Fig. 4. The canisters showed considerable deformation after a top impact because the top and neck were pushed back into the hollow portion of each canister. The area of highest deformation, where the neck buckled into the shoulder, was warm to the touch after impact.

Fig. 3. Canister Elevated and Ready for Top Impact.

Fig. 4. Appearance of Canister After Top Impacts.

The top of canister A19 bounced approximately 75 cm on impact, and a bottom corner hit unexpectedly. This unexpected impact is discussed below.

Actual impact angle was determined from prints of high-speed movies and is listed in Table I. The measured angle on the top drop was within 1.2 of the calculated angle for five of the canisters--A23, A28, A29, A31, and A39. Canister A38 hit at 9.4; i.e. 2.4 less (more vertical) than the 11.8 that was calculated. As discussed in a later section, the more vertical angle does not seem to have made any difference in the resulting canister height and diameter changes. However, Canister A19 impacted at 14.5, 2.6 greater (more horizontal) than the calculated impact angle; this did make a difference in canister height and diameter changes.

The impact energies, which are the product of the canister weights and the drop distances, are listed in Table I.

Strain Circle Application and Analysis

A grid of the strain circles was etched on the canister surface in regions expected to experience surface strain. During impact, the strain circles were deformed along with the canister surface. By superimposing a circle templet on the deformed circles, deformation could be measured with an accuracy of 2%.

Strain circles were applied on four equally spaced regions around the bottom of the canisters at the points indicated on Fig. 5(a) and (b). These regions extended from the side wall, around the bottom, and at least 5 cm (2 in.) inside the concave bottom of each. Additional strain circles were applied to the concave bottom of one canister, as shown in Fig. 5(c), in case the concave bottom of the canisters should flatten during the bottom impacts. The strain circles were nominally 0.51 cm (0.2 in.) in diameter arranged in a rectangular grid; they measured 0.64 cm (0.25 in.) from center to center, both vertically and horizontally. Grids of strain circles were applied using an electrochemical process. Figure 6 shows a grid of strain circles being applied to a canister top.

The quality of the strain circle application varied somewhat from region to region. For the most part, the circles were crisp and well defined. However, some regions had circles that were slightly blurred. Some of the circles were abraded during the impact and, therefore, unreadable. For each circle read, a longitudinal and a circumferential reading were taken.

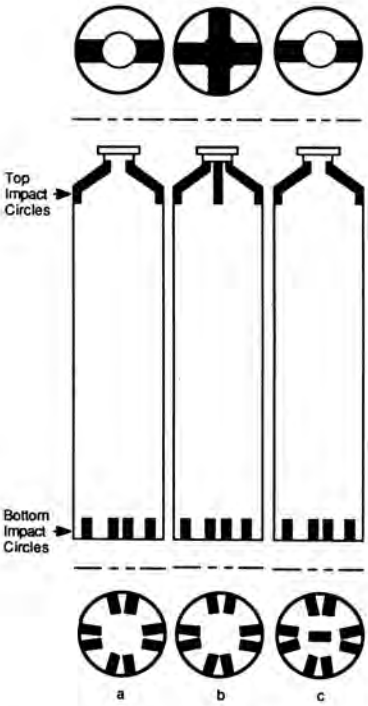
The changes in circle diameters were calculated by subtracting the undeformed diameter from the measured diameter. The scale developed for reading the diameters is on a transparent sheet that can be placed over the strain circle. The scale has increments of 0.005 cm, which corresponds to a one percent strain.

The change in diameter is divided by the original diameter and multiplied by 100 to obtain the percent strain:

TABLE I

Impact Orientation, Weights, and Impact Energies of Canisters

Canister	Calculated Impact Angle, °	Actual Impact Angle, °	Weight, kg (lb)	Impact Energy, kJ
A19	0 (bottom) 11.9 (top)	0 (bottom) 14.5 (top)	2113.7 (4660)	145.1
A23	0 (bottom) 12.0 (top)	0 (bottom) 10.8 (top)	2117.8 (4669)	145.38
A28	0 (bottom) 11.3 (top)	0 (bottom) 11.3 (top)	2152.7 (4746)	147.78
A29	0 (bottom) 12.3 (top)	0 (bottom) 12.4 (top)	2105.6 (4642)	144.54
A31	0 (bottom) 12.1 (top)	0 (bottom) 11.0 (top)	2221.2 (4642)	144.54
A38	0 (bottom) 11.8 (top)	0 (bottom) 9.4 (top)	2169.1 (4782)	148.90
A39	0 (bottom) 12.0 (top)	0 (bottom) 11.7 (top)	2160.9 (4764)	148.34



R8901064.001

Fig. 5. Placement of Strain Circle Grids.

Fig. 6. Application of Strain Circles.

$$\frac{(D_{orig} - D_{deformed})}{(D_{orig})} \times 100$$

The strains calculated from the strain circles are the average strains over the circle diameter.

After the bottom drops, several of the grids of strain circles were examined and representative circles measured. All strains were less than 2% and were therefore insignificant. This included the grid of strain circles in the concave bottom of canister A23. After the bottom impact tests, strain circles were placed on the top end of each canister. The strain circles were applied to all canisters in two regions as shown in Fig. 5(a) and 5(c). The regions of strain circles extended from the side wall, across the top weld, across the intersection of the cylindrical neck and thetop, and up the cylindrical neck. One region was in line with the planned initial impact point. The second was on the opposite side of the canister. Two canisters, A28 and A39, also had strain circle grids placed half way between these regions, as shown in Fig. 5(b). The strains in these auxiliary regions were not as severe as those in line with the impact point and, therefore, were not recorded. Strain circles were also placed on the cylindrical neck.

For each canister, the strain circle diameters were read for a single row of circles that were as close as possible to being in line with the initial impact point. The strain patterns for all canisters were very similar. The tops of the canisters act as energy absorbers; the canisters showed higher deformation and less bounce than during bottom impact.

The only area where significant strains were measured was on the shoulder near the neck weld. For canister A31, a longitudinal compressive strain of 52% was recorded on the shoulder, perpendicular to the neck weld. This was the largest strain measured for any canister.

Failure of the neck weld in the area of highest strain was improbable because all strains in the vicinity were compressive. The high compressive strains were due to severe bending of the canister wall. Tensile strains predicted to be present on the inside surface at the same location would be of lower magnitude because the radius of curvature would be increased by the approximate thickness of the canister wall. Compressive strains would prevent pre-existing flaws on the inside surface from propagating through the wall.

For all regions more than 1.7 cm (0.5 in.) from the neck weld, the magnitude of all strains was less than 20%. No tensile strains greater than 8% were measured.

Strain measurements were also made for circles on the cylindrical neck; these strains were also insignificant. For the strain circle on the neck immediately next to the weld with high axial strains reported above, the strains were approximately 8%.

Canister Dimensions

Before the bottom impact tests, canister height was determined at four locations. A vertical line was drawn through the welded canister label. This was labelled 0. Using the 0 line, further vertical lines were drawn at 90, 180, and 270, moving clockwise around the circle. The height was measured four times, at each of the four vertical lines.

The diameter of each canister was measured near the bottom before the bottom impact tests, as shown in Fig. 7. From the 0 vertical line, vertical lines were drawn at 45°, 90°, and 135°. The diameter of each canister was then measured at each angle at five distances from the bottom: 5.1 cm (2 in.), 10.2 cm (4 in.), 15.2 cm (6 in.), 25.4 cm (10 in.), and 45.7 cm (18 in.).

The canisters showed little visual deformation after the bottom drops. After the bottom drop tests, the height decreased by about 1 cm (-0.25% to -0.31%) on each canister, and the diameter increased to 1.5 cm (2.43%) in the area closest to the bottom. At 45.7 cm (18 in.) from the bottom, the diameter increased very slightly, less than 0.2 cm. The changes are small, as would be expected, because the filler glass keeps the canister surrounding it from being deformed. A summary of the dimensional change after the bottom drop tests is shown in Table II.

A summary of height and diameter changes after the top impacts is shown in Table III. All of the canisters except A19 decreased in height 14 to 16.4 cm (4.7 to 5.5%). In addition, all the canisters except A19 showed diameter increases of 0.41 to 0.46 cm (0.67 to 0.95%).

Canister A19, which bounced and unexpectedly impacted on the bottom corner after the top impact, showed a decrease in height of only 8.6 cm (2.9%) and an increase in diameter of 0.18 cm (0.3%). These dimensional changes are roughly half as great as those exhibited by the other six canisters during the top drops. Apparently, the energy was dissipated less in deformation and more in a harder bounce

Helium Leak Testing

Helium leak testing was performed to determine if any of the canisters had breached upon impact. The tests were performed in accordance with the hood method for helium leak testing. Two 1.3-cm (0.5-in.) holes were drilled into the canister wall near the top and bottom and 180° apart. A nozzle was attached to each hole and each canister was evacuated. After evacuation, helium was allowed to leak into the canister through one of the nozzles. Detection of a "standard leak rate" by a mass spectrometer at the other nozzle would indicate the presence of a passage for gas through the glass in the canister. It is generally assumed that such a passage is formed when the glass pulls away from the wall of the canister.

After evacuating the canister and checking for internal leaks, the test surface for each canister was enclosed within a plastic bag (or hood). The area between the plastic bag and the canister surface was then filled with helium, and the leak test was started. A leak in the canister test surface would be indicated if the leak detector detected the presence of helium in the canister. No helium was detected inside any of the canisters when a standard leak rate of 10^{-7} atmcm^3/s was used.

For the initial helium leak testing of the weld in the top plug, only one nozzle was necessary; it was placed near the

TABLE II

Summary: Dimensional Changes During Bottom Impact Tests

	Canister A19		Canister A23		Canister A28	
	Differ	%	Differ	%	Differ	%
Height, cm(a)	-0.89	-0.30	-0.75	-0.25	-0.98	-0.33
Bottom, Diameter, cm(b)						
5.1 cm from bottom	1.18	1.95	1.26	2.08	1.39	2.30
10.2 cm from bottom	0.77	1.26	0.84	1.38	0.95	1.56
15.2 cm from bottom	0.33	0.55	0.30	0.49	0.37	0.61
25.4 cm from bottom	0.11	0.18	0.12	0.19	0.06	0.10
45.7 cm from bottom	0.09	0.15	0.09	0.15	0.12	0.19

	Canister A29		Canister A31		Canister A38	
	Differ	%	Differ	%	Differ	%
Height, cm	-0.98	-0.33	-0.87	-0.29	-0.82	-0.27
Bottom, Diameter, cm						
5.1 cm from bottom	1.47	2.43	1.29	2.13	1.12	1.85
10.2 cm from bottom	0.80	1.32	0.81	1.33	0.77	1.27
15.2 cm from bottom	0.27	0.45	0.29	0.47	0.31	0.50
25.4 cm from bottom	0.11	0.18	0.11	0.19	0.07	0.12
45.7 cm from bottom	0.11	0.18	0.11	0.19	0.07	0.12
45.7 cm from bottom	0.05	0.08	0.12	0.19	0.06	0.11

	Canister A39	
	Differ	%
Height, cm	-0.92	-0.31
Bottom, Diameter, cm		
5.1 cm from bottom	1.01	1.67
10.2 cm from bottom	0.57	0.94
15.2 cm from bottom	0.20	0.32
25.4 cm from bottom	0.22	0.37
45.7 cm from bottom	0.10	0.17

(a) Average canister height before impact was 300.1 cm

(b) Average canister bottom diameter before impact was 60.6 cm.

Fig. 7. Measurement of Bottom Diameters.

TABLE III

Summary: Dimensional Changes During Top Impact Tests

	Canister A19		Canister A23		Canister A28	
	Differ	%	Differ	%	Differ	%
Height, cm[a]	-8.64	-2.88	-15.53	-5.19	-15.58	-5.21
Top Diameter, cm[b]						
1.27 cm above shoulder weld	0.18	0.30	0.46	0.76	0.41	0.67
2.54 cm below shoulder weld	0.05	0.08	0.22	0.35	0.21	0.34
45.7 cm below shoulder weld	-0.00	-0.00	0.00	0.00	-0.00	-0.00
76.2 cm below shoulder weld	-0.00	-0.00	-0.01	-0.01	0.01	0.01

	Canister A29		Canister A31		Canister A38	
	Differ	%	Differ	%	Differ	%
Height, cm	-15.58	-5.21	-16.42	-5.49	-14.09	-4.71
Top Diameter, cm						
1.27 cm above shoulder weld	0.41	0.67	0.45	0.75	0.40	0.67
2.54 cm below shoulder weld	0.21	0.34	0.22	0.36	0.18	0.30
45.7 cm below shoulder weld	-0.00	-0.00	0.01	0.02	0.07	0.11
76.2 cm below shoulder weld	0.01	0.01	0.00	0.00	0.00	0.00

	Canister A39	
	Differ	%
Height, cm	-16.10	-5.38
Top Diameter, cm		
1.27 cm above shoulder weld	0.58	0.96
2.54 cm below shoulder weld	0.23	0.38
45.7 cm below shoulder weld	0.01	0.01
76.2 cm below shoulder weld	0.01	0.01

(a) Average canister height before impact was 299.2 cm.

(b) Average canister top diameter before impact was 60.5 cm.

top of the canister. No helium was detected inside any of the canisters during leak testing of the top plug using a standard leak rate of 10^{-7} atmcm^3/s.

Dye Penetrant Examination

Dye penetrant examination was performed on the canister welds near the bottom and at the shoulder after each impact. There was no evidence of cracking or breaching on any of the canisters after each impact.

CONCLUSIONS

Seven DWPF canisters were impact tested by dropping them 7 m (23 ft) in two orientations. The first impact was a vertical bottom drop; the second was a top drop with the center of gravity oriented over the shoulder corner. Examinations were performed on the canisters before and after each drop so that results from each drop could be evaluated separately. Based on these examinations, the following conclusions have been drawn:

- The structural integrity of all seven canisters was not affected by either impact. Helium leak testing and dye penetrant examination of the welds did not reveal any evidence of cracking or breaching.
- The bottom drops resulted in the least amount of change in canister dimensions.
- The top drops resulted in the greatest change in canister dimensions and apparent strain; the canister neck was pushed into the hollow top.
- Canister 19 was unexpectedly impacted on a bottom corner when it bounced during the top drop. Deformation resulting from the top drop of Canister 19 was approximately half that of the other six canisters.

REFERENCES

1. K. M. OLSON and J. M. ALZHEIMER, "Defense Waste Processing Facility Canister Impact Testing," PNL-6812, Pacific Northwest Laboratory, (1989).
2. DOE/RW-0125, Waste Acceptance Preliminary Specification for the DWPF Waste Form, (OGR/B-8), U.S. Department of Energy, Washington, D.C.