02F

MCC

Materials Characterization Center

**Defense Waste Processing
Facility Canister Impact
Testing**

K. M. Olson
J. M. Alzheimer

September 1989

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

DISCLAIMER

This program was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government of any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401. FTS 626-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

NTIS Price Codes, Microfiche A01

Printed Copy

<u>Pages</u>	<u>Price Codes</u>
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A10
226-250	A11
251-275	A12
276-300	A13

3 3679 00056 4205

DEFENSE WASTE PROCESSING FACILITY
CANISTER IMPACT TESTING

K. M. Olson
J. M. Alzheimer

September 1989

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

This report summarizes impact testing of seven Defense Waste Processing Facility (DWPF) high level waste canisters during FY 1988. Impact testing was conducted to demonstrate compliance of DWPF canisters with the drop test specification of the Waste Acceptance Preliminary Specification. The prototypical stainless steel canisters were filled with simulated waste to about 85% capacity at Savannah River Laboratory (SRL). They were received from SRL in April 1988. Each canister was approximately 300 cm (9 ft 10 in.) long, and 61 cm (2 ft) in diameter, and weighed about 2150 kg (4740 lb).

Each canister was dropped twice from a height of 7 m (23 ft). The first drop was a vertical bottom impact where the bottom of the canister was oriented parallel to the impact pad. The second was a center-of-gravity-over-the-corner top impact. Procedures used to examine the canisters were the application and analysis of strain circles, helium leak testing, dye penetrant examination, and canister dimensional measurements.

After the 7-m (23-ft) vertical bottom drops, there was little visual deformation. Strain circles deformed 2% or less. The average canister height decreased by approximately 0.3% (0.75 to 1.0 cm), and the average diameter increased by approximately 2.5% (1.0 to 1.5 cm) in the area close to the impact at the bottom of each canister. Both helium leak testing and dye penetrant examination of each weld showed no breach.

Each canister was oriented during the second 7-m (23-ft) drops so that the top of the canister was impacted and the center of gravity was over the shoulder corner. Deformation after the top drops was obvious; the neck of each canister was pushed back into the hollow canister top. Height of the canisters was reduced approximately 5% (14 to 16.4 cm). In the areas near the top of the canister body, diameters increased approximately 1% (1.7 to 2.4 cm). Helium leak testing and dye penetrant analysis, however, indicated no breach of the canisters.

Strain circle analysis indicated strain ranging from 52% compressive to 8% tensile. The highest compressive strain was localized at the intersection

of the canister's neck and shoulders at the neck weld. At regions more than 1.3 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.

During one of the top impacts, the canister unexpectedly bounced and impacted and flattened a bottom corner. Strain circle analysis showed less than 2% strain in this deformed area.

All results from post-impact testing of seven DWPF prototypical canisters indicate that the canisters survived two 7-m drops unbreached. This meets the drop test specification of the Waste Acceptance Preliminary Specification.

CONTENTS

SUMMARY	ii
INTRODUCTION	1
CONCLUSIONS	2
TESTING AND RESULTS	3
INITIAL EXAMINATION	3
IMPACTS	3
STRAIN CIRCLE APPLICATION AND ANALYSIS	16
CANISTER DIMENSIONS	37
HELIUM LEAK TESTING	40
DYE PENETRANT EXAMINATION	43
CANISTER A19	44
APPENDIX	A.1

FIGURES

1	Prototypical DWPF Stainless Steel Canisters	4
2	Weighing of Canister	6
3	Determination of Vertical Orientation	7
4	Canister Elevated and Ready for Bottom Vertical Impact	8
5	Quick Release Lifting Hook.	9
6	Canister Falling to Bottom Impact	10
7	Bottom Impact of Canister A19	12
8	Bottom Impact of Canister A23	12
9	Bottom Impact of Canister A28	13
10	Bottom Impact of Canister A29	13
11	Bottom Impact of Canister A31	14
12	Bottom Impact of Canister A38	14
13	Bottom Impact of Canister A39	15
14	Calculation of Canister Orientation for Top Impacts	16
15	Canister Elevated and Ready for Top Impact	17
16	Canister Falling to Top Impact	18
17	Top Impact of Canister	19
18	Appearance of Canister After Top Impact	20
19	Appearance of Canister After Top Impact	21
20	Calculation of Actual Top Impact Angle	22
21	Top Impact of Canister A19	22
22	Top Impact of Canister A23	23
23	Top Impact of Canister A28	23
24	Top Impact of Canister A29	24

25	Top Impact of Canister A31	24
26	Top Impact of Canister A38	25
27	Top Impact of Canister A39	25
28	Placement of Strain Circle Grids	27
29	Application of Strain Circles	29
30	Observed Strain of Canister A19	30
31	Observed Strain of Canister A23	31
32	Observed Strain of Canister A28	32
33	Observed Strain of Canister A29	33
34	Observed Strain of Canister A31	34
35	Observed Strain of Canister A38	35
36	Observed Strain of Canister A39	36
37	Measurement of Bottom Diameters	38
38	Helium Leak Testing	42
39	Metal Separation on Bottom Canister A19 After Unexpected Impact	45

TABLES

1	Weights and Impact Energies of Canisters	5
2	Impact Orientation of Impact Canisters	11
3	Summary: Dimensional Changes During Bottom Impacts	39
4	Summary: Dimensional Changes During Top Impacts	41
A.1	Canister A19: Dimensional Changes During Impact Tests	A.1
A.2	Canister A23: Dimensional Changes During Impact Tests	A.2
A.3	Canister A28: Dimensional Changes During Impact Tests	A.3
A.4	Canister A29: Dimensional Changes During Impact Tests	A.4
A.5	Canister A31: Dimensional Changes During Impact Tests	A.5
A.6	Canister A38: Dimensional Changes During Impact Tests	A.6
A.7	Canister A39: Dimensional Changes During Impact Tests	A.7

INTRODUCTION

Over the next few years, the Defense Waste Processing Facility (DWPF) at Savannah River Laboratory (SRL) is expected to produce high-level radioactive waste glass to be placed eventually in a geologic repository. The glass will be poured into stainless steel canisters that must meet the Waste Acceptance Preliminary Specification to survive a drop of 7 m onto an unyielding surface and remain leak-tight.^(a)

Seven stainless steel canisters were filled at SRL with simulated waste glass, frit 165 (black frit). These canisters were shipped to Pacific Northwest Laboratory (PNL)^(b) in April 1988 for canister impact testing. On their arrival, the canisters were unloaded into indoor storage in the Mechanical Development Laboratory (MDL) and visually inspected. Only minor scratches and dents were observed on the canisters.

Each canister was impacted by 7-m (23-ft) drops in two orientations. The first drop was a vertical bottom drop where the bottom of the canister was oriented parallel to the impact pad; 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.

In this document, the bottom and top impact testing is described and the results of post-test examinations are reported.

(a) DOE/RW-0125, Waste Acceptance Preliminary Specification for the DWPF Waste Form, (OGR/B-8).

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

CONCLUSIONS

Based on examination of each canister after each drop, the following conclusions have been drawn:

- The structural integrity of all seven canisters was not affected by either impact, as measured by helium leak testing and dye penetrant examination of the welds.
- The vertical bottom drops resulted in the least change in canister dimensions. Strain circles deformed 2% or less, height decreased by approximately 0.3% (0.3 to 1.14 cm), and canister diameters increased approximately 2.1% (0.9 to 1.7 cm) at 5.1 cm from the bottom.
- The top drops caused the greatest effect on canister dimensions and apparent strain. Strain circles deformation ranged from 52% compressive to 8% tensile. The average height decreased by approximately 5.2% (19.0 cm on the impact side and 12.0 cm 180° away), as the canister neck was pushed into the hollow top. Diameters increased approximately 0.75% (0.18 to 0.7 cm) at 1.3 cm above the shoulder weld.
- The greatest amount of deformation from the top drops occurred where the neck of the canister meets the shoulder on the impact side and 180° away.

TESTING AND RESULTS

This section describes the impacts and tests performed on each canister along with the test results.

INITIAL EXAMINATION

Upon their arrival, the seven canisters were visually inspected. The canisters were approximately 61 cm (24 in.) in diameter and 300 cm (9 ft 10 in.) long. The initial inspection of the canisters revealed only minor dents and abrasions with some rusting where the surface had been abraded. Figure 1 is a drawing of the canister, showing the dimensions and the locations of the welds of interest.

In addition to the visual inspection, the weld of the top plug was helium leak-tested. The procedure for helium leak testing follows later in the section "Helium Leak Testing." The weld on the top plug of all the canisters showed a helium leak rate of less than 10^{-7} atm·cm³/s.

IMPACTS

The impact pad 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. Each checkerboard is made up of 0.3 m (1 ft) by 0.3 m (1 ft) squares. The backdrops are oriented so that the horizontal and vertical lines are at 0° and 90° with the horizon. The second of these checkerboards was installed so that each drop could be recorded by high-speed cameras aimed at each of the backdrops, 90° apart. In this way, the impact angle could be verified exactly, rather than taking pictures in only one direction and assuming that the canister orientation was measurable in the single plane.

The weight of each canister and energy of each impact is listed on Table 1, SRL Canister Impact Information. The impact energy is equal to the product of the weight of the canister and the distance it was dropped. The weighing of a canister is shown in Figure 2.

FIGURE 1. Prototypical DWPF Stainless Steel Canister

TABLE 1. Weights and Impact Energies of Canisters

<u>Canister</u>	<u>Weight, kg (lb)</u>	<u>Impact Energy, kJ</u>
A19	2113.7 (4660)	145.1
A23	2117.8 (4669)	145.4
A28	2152.7 (4746)	147.8
A29	2105.6 (4642)	144.6
A31	2221.2 (4897)	152.5
A38	2169.1 (4782)	148.9
A39	2160.9 (4764)	148.4

The first impacts were 7-m (23-ft) vertical bottom drops. Each canister was lifted by using cloth slings around the neck. The canister was held about 10 cm off the ground while the vertical orientation was determined using a bubble level. Figure 3 shows the vertical orientation being measured, as well as the slings used for lifting, the impact pad, and the checkerboard backdrops. 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, as shown in Figure 4. The quick release device is shown in Figure 5. The canister was released (Figure 6) immediately after the high-speed cameras were turned on. The film speed was 100 frames/second; this was verified by timing marks on the edge of the film.

The actual angle at impact was recorded by the two high-speed cameras, and is listed in Table 2. The actual angles just before the bottom impacts are shown in Figures 7 to 13.

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 finally falling. Even though the canisters fell sideways after five of the bottom impacts, all of the canisters appeared

FIGURE 2. Weighing of Canister

FIGURE 3. Determination of Vertical Orientation

FIGURE 4. Canister Elevated and Ready for Bottom Vertical Impact

FIGURE 5. Quick Release Lifting Hook

to be in the correct vertical position upon impact, judging by the black ring left on the impact pad after impact and the actual impact angles of 0° recorded in Figures 7 to 13.

Little deformation of the canisters was observed after the bottom drops. The amount of deformation was expected to be small because the glass in the containers prevented more extensive deformation.

For the top impacts, the angle of inclination required for each impact was calculated. For these drops, calculations were made with the center of gravity over the shoulder rather than over the impact point, which would be at the top corner of the neck. This is illustrated in Figure 14.

The center of gravity was determined as distance from the bottom by physically locating the fulcrum on the opposite sides of the canister. The center of gravity used to calculate impact angles was an average of the two centers of gravity listed on Appendix Tables A.1 to A.7. The canister radius used in calculation of impact angles was an average of canister diameters before impact divided by 2, or average preimpact diameter.

FIGURE 6. Canister Falling to Bottom Impact

TABLE 2. Impact Orientation of Impact Canisters

Canister	Axial Center of Gravity, cm (in.)	Calculated Impact Angle, °	Orientation at Impact, °
A19	125.83 (49.54)	0 (bottom) 11.9 (top)	0 (bottom) 14.5 (top)
A23	125.43 (49.38)	0 (bottom) 12.0 (top)	0 (bottom) 10.8 (top)
A28	124.31 (48.94)	0 (bottom) 11.3 (top)	0 (bottom) 11.3 (top)
A29	128.90 (50.75)	0 (bottom) 12.3 (top)	0 (bottom) 12.4 (top)
A31	126.70 (49.88)	0 (bottom) 12.1 (top)	0 (bottom) 11.0 (top)
A38	123.83 (48.75)	0 (bottom) 11.8 (top)	0 (bottom) 9.4 (top)
A39	125.43 (49.38)	0 (bottom) 12.0 (top)	0 (bottom) 11.7 (top)

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 to the correct height and released as shown in Figures 15 to 17. Figure 15 also shows the rigging of chains for an angled drop.

All canisters, except A19, impacted on the top flange of the canister and fell to the side. A bounce of up to 15 cm high was noted on six of the canisters. The appearance of a typical canister after top impact is shown in Figures 18 and 19. Canister A19 bounced approximately 75 cm on impact, and a bottom corner impacted unexpectedly. This unexpected impact is discussed in the last section, "Canister A19."

FIGURE 7. Bottom Impact of Canister A19

FIGURE 8. Bottom Impact of Canister A23

FIGURE 9. Bottom Impact of Canister A28

FIGURE 10. Bottom Impact of Canister A29

FIGURE 11. Bottom Impact of Canister A31

FIGURE 12. Bottom Impact of Canister A38

FIGURE 13. Bottom Impact of Canister A39

The canisters showed considerable deformation after the top drops; the top and neck of each canister 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.

The method of calculation of actual top impact angle is shown in Figure 20. Actual impact angle is shown in Figure 21 to 27 and listed in Table 2. The measured angle on the top drops was within 1.2° of the calculated impact angle for five of the canisters--A23, A28, A29, A31, and A39. Canister A38 impacted at 9.4° rather than 11.8° . This does not seem to have made any difference with regard to height and diameter changes, as discussed in the section, "Canister Dimensions." However, Canister A19 impacted at 14.5° , 2.6° greater than the calculated impact angle. This is discussed more fully in the section "Canister A19."

The time of contact between the canister and impact pad was approximately 0.02 seconds for both top and bottom impacts. This was determined

$$\tan \alpha = \frac{y}{x} \text{ where } x = 269 \text{ cm (106 in.)} - z$$

FIGURE 14. Calculation of Canister Orientation for Top Impacts

from the fact that contact appeared in 2 frames of the high-speed movie film, which was moving at 100 frames/second. This speed was verified from timing marks on the edge of the film.

STRAIN CIRCLE APPLICATION AND ANALYSIS

Strain circles were used to measure surface strain. A grid of the strain circles was etched on the canister surface in regions expected to

FIGURE 15. Canister Elevated and Ready for Top Impact

FIGURE 16. Canister Falling to Top Impact

FIGURE 18. Vertical Use of Canister with Top Impact

FIGURE 17. Top Impact of Canister

FIGURE 18. Appearance of Canister After Top Impact

FIGURE 19. Appearance of Canister After Top Impact

$$\tan \alpha = \frac{c}{d}$$

$$\text{or } \sqrt{\frac{a^2 + b^2}{d}}$$

FIGURE 20. Calculation of Actual Top Impact Angle

FIGURE 21. Top Impact of Canister A19

FIGURE 22. Top Impact of Canister A23

FIGURE 23. Top Impact of Canister A28

FIGURE 24. Top Impact of Canister A29

FIGURE 25. Top Impact of Canister A31

FIGURE 26. Top Impact of Canister A38

FIGURE 27. Top Impact of Canister A39

experience strain. During impact, the strain circles were deformed along with the canister surface. By superimposing a circle templet on the now-deformed circles, deformation could be measured with an accuracy of $\pm 2\%$.

Strain circles were applied on four equally-spaced regions around the bottom of the canisters at the points indicated on Figure 28a. 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 Figure 28c, 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 and 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. After cleaning the surface, a stencil with the strain circle pattern was taped in the desired location on the canister. One lead from an electrical power supply was grounded to the canister. A special pad with a metal backing was attached to the other power supply lead. The electrolyte^(a) was applied to the pad and the pad rolled over the stencil surface. The electrolyte and the electric current combined to selectively oxidize the surface of the metal wherever the stencil permitted current flow. A neutralizing solution^(b) was applied to the surface immediately to prevent further oxidation. After drying, the surface was sprayed with a clear coating^(c) for protection.

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. Also, some of the circles were abraded during the impact and, therefore, unreadable. The reported strains based on the strain circle data were accurate to $\pm 2\%$. For each circle read, a longitudinal (parallel to canister axis) and a circumferential reading were taken.

-
- (a) Electrolyte #SC 44 from Electro Mark Co. Utica, New York.
 - (b) Neutralyte from Electro Mark Co., Utica, New York.
 - (c) Krylon, matte finish.

FIGURE 28. Placement of Strain Circle Grids

The changes in circle diameters were calculated by subtracting the undeformed diameter from the measured diameter ($D_{\text{deformed}} - D_{\text{original}}$). 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 0.002 in., which corresponds to a 1% strain. The change in diameter is divided by the original diameter and multiplied by 100 to obtain the percent strain $\frac{(D_{\text{orig}} - D_{\text{deformed}})}{(D_{\text{orig}})} \times 100$. The strains calculated from the strain 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 impacts, strain circles were placed on the top ends of each canister, as shown in Figure 29. The strain circles were applied to all canisters in two regions as shown in Figure 28a and 28c. 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 Figure 28b. 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 results are presented in Figures 30 to 36. The top figure on each page contains data for the region on the same side of the initial impact point. The bottom figure contains data for the region on the opposite side from the initial impact point. Observed strain is shown in the longitudinal direction (parallel to the vertical axis) and the circumferential direction.

The strain patterns for all canisters were very similar. Impact energy is dissipated in deformation of the canister top, causing less bounce than during the bottom impacts.

The only area where significant strains were measured was very near the intersection of the cylindrical neck and the top of the canister body. For canister A31, a compressive strain of 52% was recorded perpendicular to the weld (Figure 1) at the intersection of the cylindrical neck and the top. This was the largest strain measured for any canister. Failure of the neck weld in the area of highest strain is not considered likely since all strains in the vicinity were compressive. Tensile strains undoubtedly were present on the inside surface but were probably of a lower magnitude. A pre-existing

FIGURE 29. Application of Strain Circles

FIGURE 30. Observed Strain of Canister A19

FIGURE 31. Observed Strain of Canister A23

FIGURE 32. Observed Strain of Canister A28

FIGURE 33. Observed Strain of Canister A29

FIGURE 34. Observed Strain of Canister A31

FIGURE 35. Observed Strain of Canister A38

FIGURE 36. Observed Strain of Canister A39

flaw on the inside surface could start a crack, but the compressive strains would prevent such a crack from propagating through the wall.

For all regions more than 0.5 in. from this weld, the magnitude of all strains was less than 20% and no tensile strains greater than 10% were measured.

Strain measurements were also made for circles on the cylindrical neck; these strains were also determined to be insignificant. For the strain circle on the neck immediately next to the weld with high axial strains reported above, the strains were less than 10%.

CANISTER DIMENSIONS

Before the bottom impacts, canister height was determined at four places on the canister. First, a vertical line was drawn through the approximate center of the welded numbers and labelled 0°. Using the 0° line, further vertical lines were drawn at 90° (approximate location of longitudinal seam weld), 180°, and 270°. The height was measured at each of the four vertical lines.

The diameter of each canister was measured near the bottom before the bottom impacts as shown in Figure 37. From the arbitrary 0° vertical line, vertical lines were drawn at 45°, 90°, and 135°. The diameter of each canister was then measured at 0°, 45°, 90°, and 135° 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.).

After the bottom impacts, the heights and diameters were remeasured. All dimensions are listed in Appendix Tables A.1 to A.7.

The canisters showed little obvious deformation after the bottom drops. A summary of the dimensional change after the bottom drops is shown in Table 3. After the bottom drops, the height decreased by about 1 cm (-0.25% to -0.307%) on each canister. After the bottom drops, 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 (0.05%). The changes are small, as would be expected, because the filler glass would be expected to absorb the impact energy.

FIGURE 37. Measurement of Bottom Diameters

Before the top drops, canister diameters were measured at the top end below the neck. In addition, location of the center of gravity was determined as distance from bottom by physically locating the fulcrum on opposite sides of the canister. The location of the center of gravity is necessary to calculate the proper angle of inclination for the top drops. These diameters and center of gravity information are also listed in Appendix Tables A.1 to A.7.

A summary of height and diameter changes after the top impacts is shown in Table 4. 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%). The changes in Canister A19 are discussed in the last Section, "Canister A19."

In addition, an informal observation is that the concave bottom of the canisters, which was approximately 4.6 cm deep before the bottom impacts, decreased by about 0.81 cm during the bottom impacts.

HELIUM LEAK TESTING

Helium leak testing of the canisters was performed initially to check the leak-tightness of the plug weld and after each impact to test the leak tightness of the plug weld, neck weld, shoulder weld, and bottom weld (as shown in Figure 1). These tests were performed in accordance with the hood method for helium leak testing (ASME, Section V, Article 10, Appendix V, 1986). Performance of a leak test after impact is shown in Figure 38.

For the initial helium leak-testing of the weld in the top plug, only one nozzle near the top of the canister was necessary. A 1.3-cm (0.5-in.) hole was drilled into the canister wall near the top of the canister. A nozzle was attached to this hole and the hollow top of the canister was evacuated through it. A plastic bag (or hood) was placed around the weld area and the area between the bag and canister filled with helium. No helium was detected inside any of the evacuated canisters by the mass spectrometer, while a standard leak rate of 10^{-7} atm·cm³/s of helium released through

TABLE 4. Summary: Dimensional Changes During Top Impacts

	Canister A19				Canister A23				Canister A28			
	Before	After	Difference		%	Before	After		Difference	%	Before	
Height, cm	299.47	290.83	-8.64	-2.88	299.31	283.78	-15.53	-5.19	298.95	283.36	-15.58	-5.21
Top Diameter, cm	60.45	60.63	0.18	0.30	60.41	60.87	0.46	0.76	60.50	60.91	0.41	0.67
1.27 cm above shoulder weld	60.70	60.75	0.05	0.08	60.88	61.10	0.22	0.35	60.86	61.06	0.21	0.34
2.54 cm below shoulder weld	60.78	60.78	-0.00	-0.00	60.98	60.98	0.00	0.00	60.96	60.96	-0.00	-0.00
45.7 cm below shoulder weld	60.80	60.80	-0.00	-0.00	60.98	60.97	-0.01	-0.01	61.02	61.02	0.01	0.01
76.2 cm below shoulder weld												
	Canister A29				Canister A31				Canister A38			
	Before	After	Difference		%	Before	After		Difference	%	Before	
Height, cm	298.95	283.36	-15.58	-5.21	299.16	282.74	-16.42	-5.49	299.36	285.27	-14.09	-4.71
Top Diameter, cm	60.50	60.91	0.41	0.67	60.51	60.96	0.45	0.75	60.52	60.93	0.40	0.67
1.27 cm above shoulder weld	60.86	61.06	0.21	0.34	60.84	61.06	0.22	0.36	60.91	61.09	0.18	0.30
2.54 cm below shoulder weld	60.96	60.96	-0.00	-0.00	60.96	60.97	0.01	0.02	60.98	61.05	0.07	0.11
45.7 cm below shoulder weld	61.02	61.02	0.01	0.01	61.02	61.02	0.00	0.00	61.01	61.01	0.00	0.00
76.2 cm below shoulder weld												
	Canister A39											
	Before	After	Difference		%							
Height, cm	299.31	283.21	-16.10	-5.38								
Top Diameter, cm	60.51	61.09	0.58	0.96								
1.27 cm above shoulder weld	60.86	61.09	0.23	0.38								
2.54 cm below shoulder weld	60.98	60.99	0.01	0.01								
45.7 cm below shoulder weld	61.03	61.03	0.01	0.01								
76.2 cm below shoulder weld

FIGURE 38. Helium Leak Testing

another port into the mass spectrometer was detected. Therefore, the top plug weld of these canisters met the specification for leak tightness of 10^{-7} atm·cm³/s.(a)

Helium leak testing was performed on all four welds (the top plug weld and welds 1, 2, and 3) after each impact to determine if any of the canisters had breached upon impact. An additional 1.3-cm (0.5-in.) hole was drilled into each canister wall, near the bottom and 180° away from the top nozzle. A nozzle was attached to each bottom hole and each canister was evacuated using the roughing pump in the mass spectrometer attached to the nozzle nearest impact and an auxiliary roughing pump attached to the nozzle furthest from impact.

After canister evacuation, the top and bottom of each canister were enclosed within a plastic bag. The top test area on each canister included the top plug weld, weld 1, and weld 2 and the bottom test area of the canister included weld 3. The area between the plastic bag and the canister surface was then filled with helium, and the leak test started. A leak in the canister test surface is indicated if the mass spectrometer detects the presence of helium in the canister. No helium was detected inside any of the canisters at or above 10^{-7} atm·cm³/s. This was confirmed in all cases because a standard leak rate of 10^{-7} atm·cm³/s released into the evacuated canister through the opposite end of the canister (with the auxiliary roughing pump sealed off) was detected.

DYE PENETRANT EXAMINATION

Dye penetrant examination was performed on the canister welds near the bottom and at the shoulder after each impact. A special dye is painted onto each weld and allowed to penetrate, if possible, and dry. Visible dye is then removed with a specially formulated solvent. A developer is then painted on the canister in the area of interest. If dye then becomes

(a) DOE/RW-0125, Waste Acceptance Preliminary Specification for the DWPF Waste Form (OGR/B-8).

visible, it has "penetrated" the canister wall, which has cracked or breached in some way. There was no evidence of cracking or breaching of any of the canisters after the impacts.

CANISTER A19

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%). This is roughly half the extent of the dimensional changes exhibited by the other six canisters during the top drops. Apparently, less energy was dissipated in deformation resulting in a higher bounce. It seems likely that the higher bounce occurred because the impact angle was 2° higher than calculated (the canister was slightly more horizontal than planned).

In addition, the canister showed what appeared to be the beginning of metal separation in the bottom corner impact area, as shown in Figure 39. Because of the possibility of an unexpected weld in that area, special attention was given to this area during helium leak testing and dye penetrant examination. No breach had occurred. Strain circle analysis was not conclusive, but the strain was estimated at no greater than 2%.

Acid etching of the area showed clearly that the metal on the canister at that point was different from the canister metal. However, the foreign material was a thin strip of metal that could easily be filed off.

The foreign material was magnetic, as were all of the weld areas. No other areas of magnetic material could be found on the bottom of any of the canisters. Further work is being performed to identify this foreign material.

FIGURE 39. Metal Separation on Bottom Canister A19 After Unexpected Impact

APPENDIX

TABLE A.1. Canister A19: Dimensional Changes During Impact Tests

	Height, cm (in.)			
	at 0°	at 90°	at 180°	at 270°
Before Bottom Impact				
After Bottom Impact	300.36 (118.25)	300.35 (118.25)	300.35 (118.25)	300.35 (118.25)
Center of Gravity	299.72 (118.00)	299.47 (117.90)	299.46 (117.90)	299.21 (117.80)
(Distance from Bottom)				
After Top Impact	287.02 (113.00)	125.73 (49.50)	294.64 (116.00)	125.42 (49.38)
	Diameter, cm (in.)			
	at 0°	at 45°	at 90°	at 135°
Before Bottom Impact				
5.1 cm (2 in.) from bottom	60.516 (23.825)	60.632 (23.871)	60.587 (23.853)	60.546 (23.837)
10.2 cm (4 in.) from bottom	60.653 (23.879)	60.749 (23.917)	60.724 (23.907)	60.594 (23.856)
15.2 cm (6 in.) from bottom	60.780 (23.929)	60.846 (23.955)	60.823 (23.946)	60.663 (23.883)
15.4 cm (10 in.) from bottom	60.884 (23.970)	60.894 (23.974)	60.863 (23.962)	60.663 (23.883)
45.7 cm (18 in.) from bottom	60.808 (23.940)	60.909 (23.980)	60.909 (23.980)	60.592 (23.855)
After Bottom Impact				
5.1 cm (2 in.) from bottom	61.623 (24.261)	62.050 (24.429)	61.788 (24.326)	61.537 (24.227)
10.2 cm (4 in.) from bottom	61.483 (24.206)	61.620 (24.260)	61.415 (24.179)	61.265 (24.120)
15.2 cm (6 in.) from bottom	61.176 (24.085)	61.145 (24.073)	61.097 (24.054)	61.029 (24.027)
25.4 cm (10 in.) from bottom	61.026 (24.026)	60.988 (24.011)	60.960 (24.000)	60.757 (23.920)
45.7 cm (18 in.) from bottom	60.922 (23.985)	61.008 (24.019)	61.003 (24.017)	60.660 (23.882)
Before Top Impact				
1.27 cm (1/2 in.) above shoulder weld	60.414 (23.785)	60.533 (23.832)	60.422 (23.788)	60.434 (23.793)
2.54 cm (1 in.) below shoulder weld	60.640 (23.874)	60.762 (23.922)	60.670 (23.886)	60.734 (23.911)
45.7 cm (18 in.) from top	60.792 (23.934)	60.858 (23.960)	60.782 (23.930)	60.693 (23.895)
75.2 cm (30 in.) from top	60.843 (23.954)	60.930 (23.988)	60.757 (23.920)	60.668 (23.885)
After Top Impact				
1.27 cm (1/2 in.) above shoulder weld	60.640 (23.874)	60.584 (23.852)	60.561 (23.843)	60.744 (23.915)
2.54 cm (1 in.) below shoulder weld	60.706 (23.900)	60.701 (23.898)	60.716 (23.904)	60.866 (23.963)
45.7 cm (18 in.) from top	60.810 (23.941)	60.820 (23.945)	60.772 (23.926)	60.719 (23.905)
76.2 cm (30 in.) from top	60.848 (23.956)	60.909 (23.980)	60.759 (23.921)	60.670 (23.886)

TABLE A.2. Canister A23: Dimensional Changes During Impact Tests

	Height, cm (in.)		
	at 0°	at 90°	at 270°
Before Bottom Impact	300.08 (118.14)	300.02 (118.12)	300.10 (118.15)
After Bottom Impact	299.47 (117.90)	298.96 (117.70)	299.09 (117.75)
Center of Gravity			
(Distance from Bottom)		122.88 (48.38)	
After Top Impact	286.38 (112.75)		281.18 (110.70)
			127.96 50.38)

	Diameter, cm (in.)		
	at 0°	at 45°	at 135°
Before Bottom Impact:			
5.1 cm (2 in.) from bottom	60.538 (23.834)	60.587 (23.853)	60.533 (23.832)
10.2 cm (4 in.) from bottom	60.866 (23.963)	60.871 (23.965)	61.011 (24.020)
15.2 cm (6 in.) from bottom	60.904 (23.978)	60.965 (24.002)	61.001 (24.016)
25.4 cm (10 in.) from bottom	61.026 (24.026)	60.963 (24.001)	61.090 (24.051)
45.7 cm (18 in.) from Bottom	61.107 (24.058)	61.006 (24.018)	61.084 (24.049)
After Bottom Impact			
5.1 cm (2 in.) from bottom	61.686 (24.286)	61.722 (24.300)	61.709 (24.295)
10.2 cm (4 in.) from bottom	61.669 (24.279)	61.636 (24.266)	61.745 (24.309)
15.2 cm (6 in.) from bottom	61.194 (24.092)	61.303 (24.135)	61.204 (24.096)
25.4 cm (10 in.) from bottom	61.117 (24.062)	61.059 (24.039)	61.201 (24.095)
45.7 cm (18 in.) from bottom	61.163 (24.080)	61.090 (24.051)	61.209 (24.098)
Before Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.449 (23.799)	60.404 (23.781)	60.335 (23.754)
2.54 cm (1 in.) below shoulder weld	60.797 (23.936)	60.947 (23.995)	60.871 (23.965)
45.7 cm (18 in.) from top	61.024 (24.025)	60.973 (24.005)	60.922 (23.985)
76.2 cm (30 in.) from top	61.036 (24.030)	60.980 (24.008)	60.917 (23.983)
After Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.993 (24.013)	61.024 (24.025)	60.701 (23.898)
2.54 cm (1 in.) below shoulder weld	61.074 (24.045)	61.260 (24.118)	61.062 (24.040)
45.7 cm (18 in.) from top	61.024 (24.025)	61.013 (24.021)	60.930 (23.988)
76.2 cm (30 in.) from top	61.029 (24.027)	60.993 (24.013)	60.897 (23.975)

TABLE A.3. Canister A29: Dimensional Changes During Impact Tests

	Height, cm (in.)			
	at 0°	at 90°	at 180°	at 270°
Before Bottom Impact	299.97 (118.10)	299.87 (118.06)	299.92 (118.08)	299.92 (118.08)
After Bottom Impact	298.96 (117.70)	299.08 (117.75)	298.96 (117.70)	298.78 (117.63)
Center of Gravity				
(Distance from Bottom)		128.90 (50.75)		128.90 (50.75)
After Top Impact	286.05 (112.62)		280.67 (110.50)	

	Diameter, cm (in.)			
	at 0°	at 45°	at 90°	at 135°
Before Bottom Impact				
5.1 cm (2 in.) from bottom	60.556 (23.841)	60.609 (23.862)	60.564 (23.844)	60.561 (23.843)
10.2 cm (4 in.) from bottom	60.808 (23.940)	60.820 (23.945)	61.044 (24.033)	61.054 (24.037)
15.2 cm (6 in.) from bottom	60.960 (24.000)	60.950 (23.996)	61.041 (24.032)	61.120 (24.063)
25.4 cm (10 in.) from bottom	60.935 (23.990)	60.897 (23.975)	60.996 (24.014)	61.049 (24.035)
45.7 cm (18 in.) from bottom	61.018 (24.023)	61.003 (24.017)	61.044 (24.033)	61.095 (24.053)
After Bottom Impact				
5.1 cm (2 in.) from bottom	62.278 (24.519)	61.783 (24.324)	61.953 (24.391)	61.854 (24.352)
10.2 cm (4 in.) from bottom	61.981 (24.402)	61.389 (24.169)	62.139 (24.464)	62.027 (24.420)
15.2 cm (6 in.) from bottom	61.488 (24.208)	61.110 (24.059)	61.432 (24.186)	61.532 (24.225)
25.4 cm (10 in.) from bottom	60.965 (24.002)	60.968 (24.003)	61.059 (24.039)	61.120 (24.063)
45.7 cm (18 in.) from bottom	61.130 (24.067)	61.125 (24.065)	61.181 (24.087)	61.194 (24.092)
Before Top Impact				
1.27 cm (1/2 in.) above shoulder weld	60.477 (23.810)	60.452 (23.800)	60.508 (23.822)	60.554 (23.840)
2.54 cm (1 in.) below shoulder weld	60.803 (23.938)	60.841 (23.953)	60.871 (23.965)	60.907 (23.979)
45.7 cm (18 in.) from top	61.021 (24.024)	60.980 (24.008)	60.950 (23.996)	60.897 (23.975)
76.2 cm (30 in.) from top	61.112 (24.060)	61.054 (24.037)	60.983 (24.009)	60.912 (23.981)
After Top Impact:				
1.27 cm (1/2 in.) above shoulder weld	61.011 (24.020)	61.092 (24.052)	60.785 (23.931)	60.734 (23.911)
2.54 cm (1 in.) below shoulder weld	61.087 (24.050)	61.222 (24.103)	60.996 (24.014)	60.952 (23.997)
45.7 cm (18 in.) from top	60.996 (24.014)	61.069 (24.043)	60.963 (24.001)	60.810 (23.941)
76.2 cm (30 in.) from top	61.074 (24.045)	61.138 (24.070)	61.039 (24.031)	60.830 (23.949)

TABLE A.4. Canister A29: Dimensional Changes During Impact Tests

	Height, cm (in.)		
	at 0°	at 90°	at 270°
Before Bottom Impact	299.97 (118.10)	299.87 (118.06)	299.92 (118.08)
After Bottom Impact	298.96 (117.70)	299.08 (117.75)	298.78 (117.63)
Center of Gravity			
(Distance from Bottom)			
After Top Impact	286.05 (112.62)	128.90 (50.75)	128.90 (50.75)
		280.67 (110.50)	

	Diameter, cm (in.)		
	at 0°	at 45°	at 135°
Before Bottom Impact	60.622 (23.867)	60.592 (23.855)	60.551 (23.839)
5.1 cm (2 in.) from bottom	60.787 (23.932)	60.963 (24.001)	60.909 (23.980)
10.2 cm (4 in.) from bottom	60.968 (24.003)	61.039 (24.031)	60.930 (23.988)
15.2 cm (6 in.) from bottom	61.036 (24.030)	61.029 (24.027)	61.062 (24.040)
25.4 cm (10 in.) from bottom	61.074 (24.045)	61.107 (24.058)	61.041 (24.032)
After Bottom Impact			
5.1 cm (2 in.) from bottom	62.090 (24.445)	61.951 (24.390)	61.956 (24.392)
10.2 cm (4 in.) from bottom	61.623 (24.261)	61.684 (24.285)	61.620 (24.260)
15.2 cm (6 in.) from bottom	61.298 (24.133)	61.278 (24.125)	61.158 (24.078)
25.4 cm (10 in.) from bottom	61.151 (24.075)	61.115 (24.061)	61.201 (24.095)
45.7 cm (18 in.) from bottom	61.112 (24.060)	61.135 (24.069)	61.100 (24.055)
Before Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.477 (23.810)	60.452 (23.800)	60.508 (23.822)
2.54 cm (1 in.) below shoulder weld	60.803 (23.938)	60.841 (23.953)	60.871 (23.965)
45.7 cm (18 in.) from top	61.021 (24.024)	60.980 (24.008)	60.950 (23.996)
76.2 cm (30 in.) from top	61.112 (24.060)	61.054 (24.037)	60.983 (24.009)
After Top Impact			
1.27 cm (1/2 in.) above shoulder weld	61.011 (24.020)	61.092 (24.052)	60.785 (23.931)
2.54 cm (1 in.) below shoulder weld	61.087 (24.050)	61.222 (24.103)	60.996 (24.014)
45.7 cm (18 in.) from top	60.996 (24.014)	61.069 (24.043)	60.963 (24.001)
76.2 cm (30 in.) from top	61.074 (24.045)	61.138 (24.070)	61.039 (24.031)

TABLE A.5. Canister A31: Dimensional Changes During Impact Tests

	Height, cm (in.)		
	at 0°	at 90°	at 180°
Before Bottom Impact	300.02 (118.12)	300.02 (118.12)	300.02 (118.12)
After Bottom Impact	298.96 (117.70)	299.39 (117.87)	299.21 (117.80)
Center of Gravity			
(Distance from Bottom)		127.00 (50.00)	
After Top Impact	285.11 (112.25)		280.36 (110.38)

	Diameter, cm (in.)		
	at 0°	at 45°	at 90°
Before Bottom Impact	60.622 (23.867)	60.643 (23.875)	60.586 (23.892)
5.1 cm (2 in.) from bottom			
10.2 cm (4 in.) from bottom	60.894 (23.974)	60.830 (23.949)	60.846 (23.955)
15.2 cm (6 in.) from bottom	60.955 (23.998)	60.960 (24.000)	60.881 (23.969)
25.4 cm (10 in.) from bottom	61.029 (24.027)	60.968 (24.003)	60.980 (24.008)
45.7 cm (18 in.) from bottom	61.100 (24.055)	61.016 (24.022)	61.064 (24.041)
After Bottom Impact			
5.1 cm (2 in.) from bottom	61.905 (24.372)	62.085 (24.443)	61.968 (24.397)
10.2 cm (4 in.) from bottom	61.633 (24.265)	61.684 (24.285)	61.646 (24.270)
15.2 cm (6 in.) from bottom	61.224 (24.104)	61.255 (24.116)	61.161 (24.079)
25.4 cm (10 in.) from bottom	61.181 (24.087)	61.057 (24.038)	61.090 (24.051)
45.7 cm (18 in.) from bottom	61.222 (24.103)	61.069 (24.043)	61.219 (24.102)
Before Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.513 (23.824)	60.523 (23.828)	60.477 (23.810)
2.54 cm (1 in.) below shoulder weld	60.808 (23.940)	60.846 (23.955)	60.820 (23.945)
45.7 cm (18 in.) from top	60.980 (24.008)	60.955 (23.998)	60.922 (23.985)
76.2 cm (30 in.) from top	61.059 (24.039)	61.074 (24.045)	60.927 (23.987)
After Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.975 (24.006)	61.130 (24.067)	60.907 (23.979)
2.54 cm (1 in.) below shoulder weld	61.049 (24.035)	61.161 (24.079)	61.059 (24.039)
45.7 cm (18 in.) from top	61.008 (24.019)	60.990 (24.012)	60.963 (24.001)
76.2 cm (30 in.) from top	61.067 (24.042)	61.092 (24.052)	60.935 (23.990)

TABLE A.6. Canister A38: Dimensional Changes During Impact Tests

	Height, cm (in.)		
	at 0°	at 90°	at 180°
Before Bottom Impact	300.18 (118.18)	300.18 (118.18)	300.18 (118.18)
After Bottom Impact	299.39 (117.87)	299.39 (117.87)	299.44 (117.89)
Center of Gravity			
(Distance from Bottom)		123.82 (48.75)	123.825 (48.75)
After Top Impact	287.32 (113.12)	283.21 (111.50)	

	Diameter, cm (in.)		
	at 0°	at 45°	at 90°
Before Bottom Impact			
5.1 cm (2 in.) from bottom	60.724 (23.907)	60.701 (23.898)	60.721 (23.906)
10.2 cm (4 in.) from bottom	60.907 (23.979)	60.848 (23.956)	61.067 (24.042)
15.2 cm (6 in.) from bottom	60.973 (24.005)	60.922 (23.985)	61.036 (24.030)
25.4 cm (10 in.) from bottom	61.016 (24.022)	60.942 (23.993)	61.115 (24.061)
45.7 cm (18 in.) from bottom	61.013 (24.021)	61.021 (24.024)	61.049 (24.035)
After Bottom Impact			
5.1 cm (2 in.) from bottom	61.707 (24.294)	61.796 (24.329)	62.184 (24.482)
10.2 cm (4 in.) from bottom	61.547 (24.231)	61.592 (24.249)	62.106 (24.451)
15.2 cm (6 in.) from bottom	61.206 (24.097)	61.191 (24.091)	61.448 (24.192)
25.4 cm (10 in.) from bottom	61.079 (24.047)	60.993 (24.013)	61.229 (24.106)
45.7 cm (18 in.) from bottom	61.064 (24.041)	61.051 (24.036)	61.153 (24.076)
Before Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.533 (23.832)	60.528 (23.830)	60.503 (23.820)
2.54 cm (1 in.) below shoulder weld	60.846 (23.955)	60.968 (24.003)	60.846 (23.955)
45.7 cm (18 in.) from top	60.978 (24.007)	60.935 (23.990)	61.072 (24.044)
76.2 cm (30 in.) from top	60.983 (24.009)	60.952 (23.997)	61.143 (24.072)
After Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.818 (23.944)	60.889 (23.972)	60.990 (24.012)
2.54 cm (1 in.) below shoulder weld	60.932 (23.989)	61.123 (24.064)	61.102 (24.056)
45.7 cm (18 in.) from top	60.930 (23.988)	60.917 (23.983)	61.115 (24.061)
76.2 cm (30 in.) from top	60.945 (23.994)	60.947 (23.995)	61.153 (24.076)

TABLE A.7. Canister A39: Dimensional Changes During Impact Tests

	Height, cm (in.)		
	at 0°	at 90°	at 180°
Before Bottom Impact	25.91 (10.20)	25.86 (10.18)	26.03 (10.25)
After Bottom Impact	24.76 (9.75)	25.07 (9.87)	25.07 (9.87)
Center of Gravity			
(Distance from Bottom)			
After Top Impact	11.73 (4.62)	3.50 (1.38)	6.04 (2.38)
			3.50 (1.38)

	Diameter, cm (in.)		
	at 0°	at 45°	at 90°
Before Bottom Impact			
5.1 cm (2 in.) from bottom	60.597 (23.857)	60.604 (23.860)	60.592 (23.855)
10.2 cm (4 in.) from bottom	60.853 (23.958)	60.973 (24.005)	60.950 (23.996)
15.2 cm (6 in.) from bottom	60.998 (24.015)	61.057 (24.038)	61.006 (24.018)
25.4 cm (10 in.) from bottom	60.983 (24.009)	61.013 (24.021)	61.059 (24.039)
45.7 cm (18 in.) from bottom	60.985 (24.010)	61.069 (24.043)	61.117 (24.062)
After Bottom Impact			
5.1 cm (2 in.) from bottom	61.719 (24.299)	61.514 (24.218)	61.498 (24.212)
10.2 cm (4 in.) from bottom	61.397 (24.172)	61.529 (24.224)	61.453 (24.194)
15.2 cm (6 in.) from bottom	61.125 (24.065)	61.321 (24.142)	61.201 (24.095)
25.4 cm (10 in.) from bottom	61.194 (24.092)	61.229 (24.106)	61.290 (24.130)
45.7 cm (18 in.) from bottom	61.084 (24.049)	61.171 (24.083)	61.242 (24.111)
Before Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.541 (23.835)	60.477 (23.810)	60.528 (23.830)
2.54 cm (1 in.) below shoulder weld	60.729 (23.909)	60.897 (23.975)	60.891 (23.973)
45.7 cm (18 in.) from top	60.919 (23.984)	60.985 (24.010)	61.125 (24.065)
76.2 cm (30 in.) from top	60.947 (23.995)	61.044 (24.033)	61.224 (24.104)
After Top Impact			
1.27 cm (1/2 in.) above shoulder weld	60.935 (23.990)	61.227 (24.105)	61.293 (24.131)
2.54 cm (1 in.) below shoulder weld	60.876 (23.967)	61.051 (24.036)	61.344 (24.151)
45.7 cm (18 in.) from top	60.881 (23.969)	61.016 (24.022)	61.186 (24.089)
76.2 cm (30 in.) from top	60.937 (23.991)	61.062 (24.040)	61.242 (24.111)

DISTRIBUTION

<u>No. of Copies</u>		<u>No. of Copies</u>	
	<u>OFFSITE</u>		R. G. Baxter Westinghouse Savannah River Company Aiken, SC 29802
12	DOE Office of Scientific and Information		M. J. Bell Nuclear Regulatory Commission Washington, DC 29555
	J. A. Coleman DOE Headquarters NE-24 Washington, DC 20545		J. R. Berreth Westinghouse Idaho Nuclear Co. P.O. Box 4000 Idaho Falls, ID 83403
	W. A. Stringfield DOE Headquarters RW-222 Washington, DC 20545		H. Birnbaum 308 Metallurgy University of Illinois Urbana, IL 61801
	K. Chasey DOE Headquarters DP-123 Washington, DC 20545		W. J. Brumley DOE Savannah River Operations Office P.O. Box A Aiken, SC 29801
	J. Doenges 955 L'Enfant Plaza SW Suite 108 Washington, DC 20024		L. Brush Sandia National Laboratory P.O. Box 5800 Albuquerque, NM 87107
	M. W. Frei DOE Headquarters RW-23 Washington, DC 20545		J. E. Burke 33 Forest Road Burnt Hills, NY 12027
	T. W. McIntosh DOE Headquarters NE-24 Washington, DC 20545		R. Clayton Enrico Fermi Institute 5640 S. Ellis Chicago, IL 60647
	L. Jardine Lawrence Livermore National Laboratory University of California P.O. Box 808 Livermore, CA 94550		S. Clayton National Energy Information Center 3500 Center Avenue S.E. Albuquerque, NM 87131
	H. Barnes Pennsylvania State University University Park, PA 16802		

No. of
Copies

R. L. Coble
Massachusetts Institute of
Technology
Bldg. 13, RM 4062
77 Massachusetts Avenue
Cambridge, MA 01239

R. Edwards
Westinghouse Savannah River Co.
Aiken, SC 29802

A. C. Fracker
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

H. P. R. Frederikse
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

W. W. Gerberich
Department of Chemical Engineering
and Materials Science
151 Amundson Hall
University of Minnesota
Minneapolis, MN 55455

J. W. Godbee
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37830

K. Golliher
DOE Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115

S. L. Goudelock
Westinghouse Savannah River Co.
Aiken, SC 29802

J. Harbour
Westinghouse Savannah River Co.
Aiken, SC 29802

No. of
Copies

J. E. Harrar
Lawrence Livermore National
Laboratory
University of California
P.O. Box 808
Livermore, CA 94550

J. C. Haughen
DOE Chicago Operations Office
9800 South Cass Avenue
Argonne, IL 60439

C. G. Interrante
Corrosion Group, Metallurgy
Division
National Bureau of Standards
MATLS B-254
Gaithersburg, MD 20899

D. Isherwood
Lawrence Livermore National
Laboratory
University of California
P.O. Box 808
Livermore, CA 94550

C. M. Jantzen
Westinghouse Savannah River Co.
Aiken, SC 29802

A. Lerman
Department of Geologic Science
Northwestern University
Evanston, IL 60201

P. B. Macedo
Vitreous State Laboratory
Keane Hall
Catholic University of America
Washington, DC 20064

G. MacZura
Alcoa Laboratories
Alcoa Technical Center
Alcoa Center, PA 15069

No. of
Copies

M. M. Madsen
Division 6323
Sandia National Laboratory
P.O. Box 5800
Albuquerque, NM 87815

M. Magnani
Sandia National Laboratory
P.O. Box 5800
Albuquerque, NM 87107

R. D. McCright
Lawrence Livermore National
Laboratory
University of California
P.O. Box 808
Livermore, CA 94550

M. McFadden
DOE Albuquerque Operations
Office
P.O. Box 5400
Albuquerque, NM 87115

D. P. Moak
Office of Nuclear Waste
Isolation
Battelle Project Management
Division
1303 West First Street
Hereford, TX 79045

M. A. Molecke
Sandia National Laboratory
P.O. Box 5800
Albuquerque, NM 87107

J. O. Neff
U.S. Department of Energy
Salt Repository Project Office
110 North 25 Mile Avenue
Hereford, TX 79045

R. M. Neilson, Jr.
EG&G
P.O. Box 1625
Idaho Falls, ID 83415

No. of
Copies

5 M. J. Plodinec
Westinghouse Savannah River
Company
Aiken, SC 29802

J. M. Pope
West Valley Nuclear Services,
Co., Inc.
P.O. Box 191
West Valley, NY 14171-0191

BMI Library
505 King Avenue
Columbus, OH 43201

Dr. W. P. Reed
Office of Measurements for
Nuclear Technology
National Bureau of Standards
Physics Building, Room B320
Washington, DC 20234

University of Florida
Department of Material Science
and Engineering
College of Engineering
Gainesville, FL 32611

M. O. Cloniges
DOE Nevada Operations Office
P.O. Box 1400
Las Vegas, NV 89114

J. Van Cleve
DOE Oak Ridge Operations Office
P.O. Box X
Oak Ridge, TN 37830

S. Vogler
Argonne National Laboratory
9700 South Cass Avenue
Argonne, IL 60439

E. Wicks
Nuclear Regulatory Commission
Washington, DC 20555

No. of
Copies

G. G. Wicks
E.I. duPont deNemours & Co.
Savannah River Laboratory
Aiken, SC 29808-001

R. Yoshimura
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185

A. Zimmer
General Atomics
P.O. Box 85608
San Diego, CA 92138

ONSITE

5 DOE Richland Operations Office

R. W. Brown
M. J. Furman
R. E. Gerton
J. M. Peterson
D. C. Langstaff

6 Westinghouse Hanford Company

M. H. Campbell
G. H. Harper
R. L. Knecht
A. G. Pines
P. S. Schaus
W. W. Shultz

No. of
Copies

42 Pacific Northwest Laboratory

J. M. Alzheimer (3)
W. F. Bonner
D. L. Burk (2)
R. E. Einziger
R. K. Farnsworth
D. K. Hilliard
M. R. Kreiter
J. L. McElroy
B. P. McGrail
G. B. Mellinger
J. Mishima
B. L. Neth (10)
R. M. Olson (10)
W. A. Ross
S. C. Slate
Publishing Coordination
Technical Information (5)