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Testing of ORNL Radioisotope Shipping Packaging for Compliance with DOT Specification 7A and IAEA Type A and IATA Regulations

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OAK RIDGE NATIONAL LABORATORY
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OPERATIONS DIVISION

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ABSTRACT

Four types of ORNL shipping containers, designed for shipping Type A quantities of radioisotopes, were tested and found to be in compliance with the USA DOT-7A*, IAEA** Type A, and the IATA*** requirements.

INTRODUCTION

A notice of Proposed Rule Making by the Hazardous Materials Regulations Board, Department of Transportation (DOT), DOT No. HM-111, Notice No. 73-7 stated that the present listing of authorized DOT specifications in paragraphs 173.394 and 173.395 of the Code of Federal Regulations (CFR) DOT (Type A packages) would be deleted and that each shipper of Type A quantities of radioactive material would be required to test or analyze, certify and document that the packaging complies with DOT Specification 7A performance requirements. International shipments of Type A quantities must also conform to the International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition of Safety Series No. 6. and, to Section V, General Packaging Requirements of the International Air Transport Association (IATA), Restricted Articles, August 1, 1975 Edition. Domestic shipments must comply with DOT and IATA requirements. To determine compliance with these regulations, four types of shipping containers were tested and found to meet the DOT, IAEA, and IATA requirements for Type A shipments.

The shipping containers tested were the non-returnable combination cardboard box-steel can containers, returnable aluminum-clad wood box containers, returnable gas cylinders, and returnable cyclotron target containers. Each of these four types of containers are fabricated in one or more sizes, and comprise sets of containers identical in design but different in size and weight. Only the heaviest container in each set was tested since it is subjected to the greatest possible stress due to its weight. Lighter containers of the same series were not tested since the stress induced during testing would have been less than that occurring in the heaviest container (referred to in the report as the "test package").

*USA DOT Specification 7A CFR-49.

**Regulations for the Safe Transport of Radioactive Material, IAEA Safety Series No. 6, 1973, Revised Edition.

***International Air Transport Association, Restricted Articles, August 1, 1975. Section V, General Packaging Requirements.

Table 1. Summary of Container Test Results

	Test				
	Mechanical				
Container Type*	Water Spray	30-ft Free Drop	Penetration	Compression	Corner Drop
Cardboard Box Container	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT
Wood Box Container	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT
Gas Cylinder	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT
Cyclotron Container	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT	Passed IAEA and DOT

*All container types passed the vibration test required under IAEA regulations and the environmental tests required under both IAEA and DOT regulations.

The tests (Table 2) were the free drop, compression, penetration, and corner drop, preceded in each case by the water spray test. In most cases more than one of the above listed tests were performed on a single test package. For the IAEA tests, the water soaked into the package to the maximum extent without appreciable drying of the exterior of the test package. The packages were tested immediately following the water spray, which was applied to each corner consecutively over a period of one hour, which was equivalent to a rainfall of 2 in./hr at a 45° angle from the horizontal and directed so as to strike the sides and top of the test packages. The DOT water spray test was less demanding, requiring a water spray heavy enough to keep the entire exposed surface of the test package (except the bottom) continuously wet during a period of 30 minutes. Packages for which the outer layer consisted entirely of metal, wood, ceramic, plastic or combinations of these are exempt from the DOT water spray test.

In cases where the IAEA tests were equal to or more demanding than the corresponding DOT tests, only the IAEA tests were performed. However, the DOT regulations require that the "Packaging" shall be subjected to the consecutive application of at least two of the tests from which it is not specifically exempted." To meet this DOT requirement, two consecutive IAEA tests which were equal to or more demanding than the corresponding DOT tests were made on the test packages.

All of the test packages were examined before testing to identify and record divergence from specifications, defects in construction, and deterioration or distortion of features. After testing, the packages were examined to determine if the containment was breeched, or the shielding was damaged sufficiently to exceed the allowable radiation. Labels and other identification marks were examined to determine if they remained attached and legible. In some instances the labels were not visible on the photographs because the test packages were oriented to show areas where damage occurred as a result of a test. In most instances damage was minor and not visible on the photographs.

ORNL NON-RETURNABLE CARDBOARD BOX SHIPPING CONTAINERS FOR GASES, LIQUIDS, AND SOLIDS

Description of Container

Two sizes of cardboard box shipping containers are used (Table 3), (Fig. 1). The cardboard box used to enclose the inner package and to carry labels is procured as a DOT specification 12B.* The cardboard box is closed with coated metal staples and contains cardboard spacers used to center a 4 1/4-in.-diam by 6 7/8-in.-high steel can having a wall thickness of 0.01 in. There are three different packages contained within the steel can depending on the amount and type of material. These are shown in Figures 1 through 3. The package tested was the heaviest package and contained a 4-in.-diam lead shield having a height of 6 1/2-in. which was placed inside the steel can. The lead shield contains a highly absorbent material, Kimpak (or equal), which is wrapped around a heavy paper tube so as to fill the void space between the paper tube

Table 2. Comparison of IAEA, IATA, and DOT Type A Package Test Specifications

Test	IATA	IAEA Type A	DOT-7A
Water Spray	NR*	1 hr at 45°, 15 min each side	30 min total to all sides except bottom. metal, wood, ceramic, and plastic exempt
Free Drop	NR*	4 ft for 2L cylinder 30 ft for all others	Between 1.5-2.5 hr after spray test Free 4 ft drop to unyielding surface to strike surface of package for which most damage is expected
Corner Drop	NR*	NR*	From a height of 1 ft onto each corner or quarter of each rim. Applies only to wood or fiberboard and does not exceed 100 lb. Applies to fissile Class II
Penetration	NR*	13.23 lb wt, dropped 66.9 in. 1.26 in. diam hemispherical head	13 lb wt dropped 40 in. 1.25 in. diam bar
Compression	NR*	5 times package wt or 1.849 lb per square inch times projected vertical area, whichever is greatest	For packages weighing 10,000 lbs or less. 24 hr compressive load equal to 5 times package wt or 2 lb per square in. times maximum cross section, whichever is greatest
Vibration	0.2 in. amplitude at 7 cycles/sec (1 G acc.) to 0.002 in. amplitude at 200 cycles/sec (8 G)	NR*	NR*
High Temperature	+130°F	-40°F to +158°F	+130°F
Low Temperature	-40°F	-40°F	-40°F
Low Pressure	0.5 atm. abs.	0.5 atm. abs.	0.5 atm. abs.

*NR - Test not required.

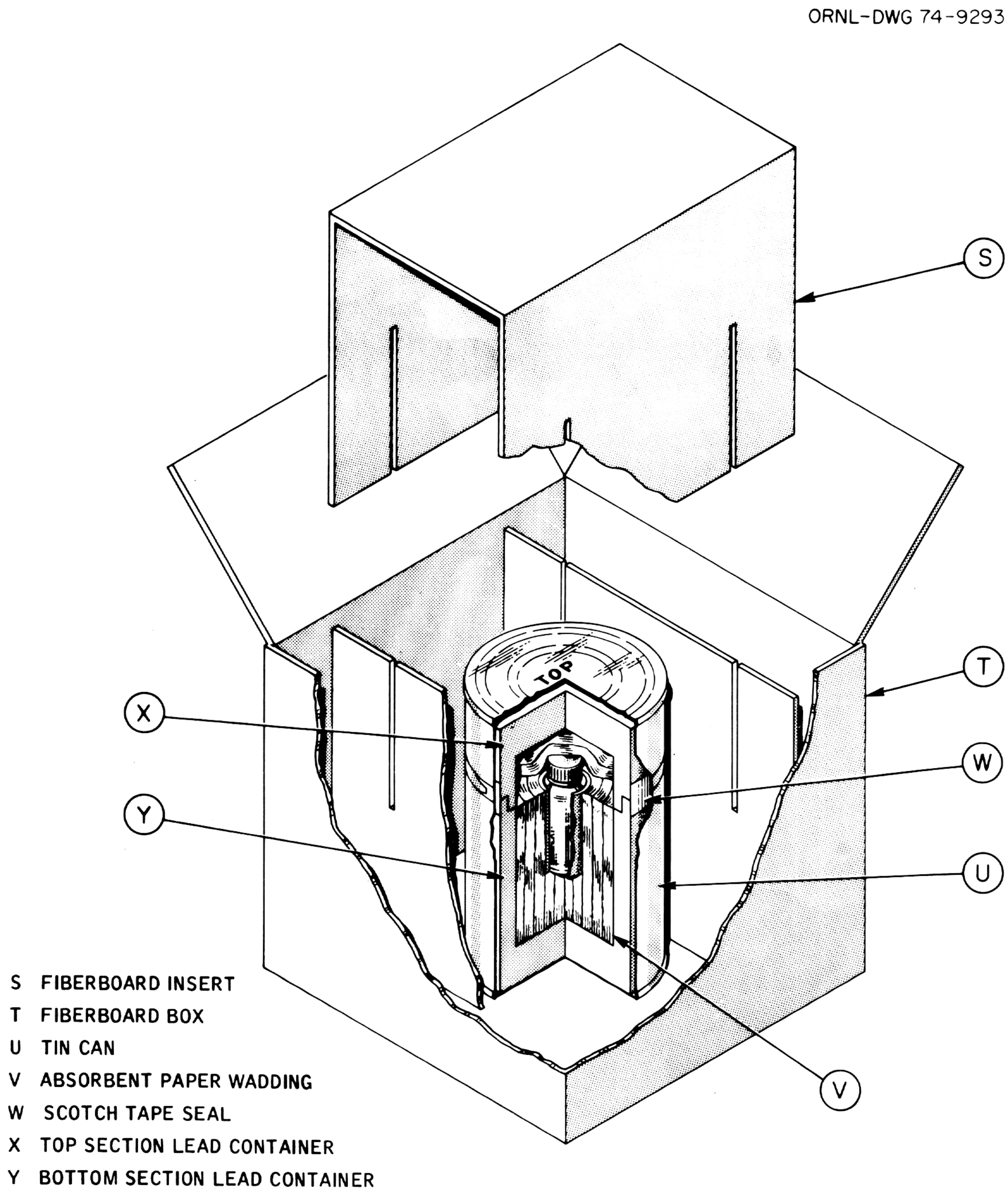

Figure 1. Cardboard Box Shipping Containers

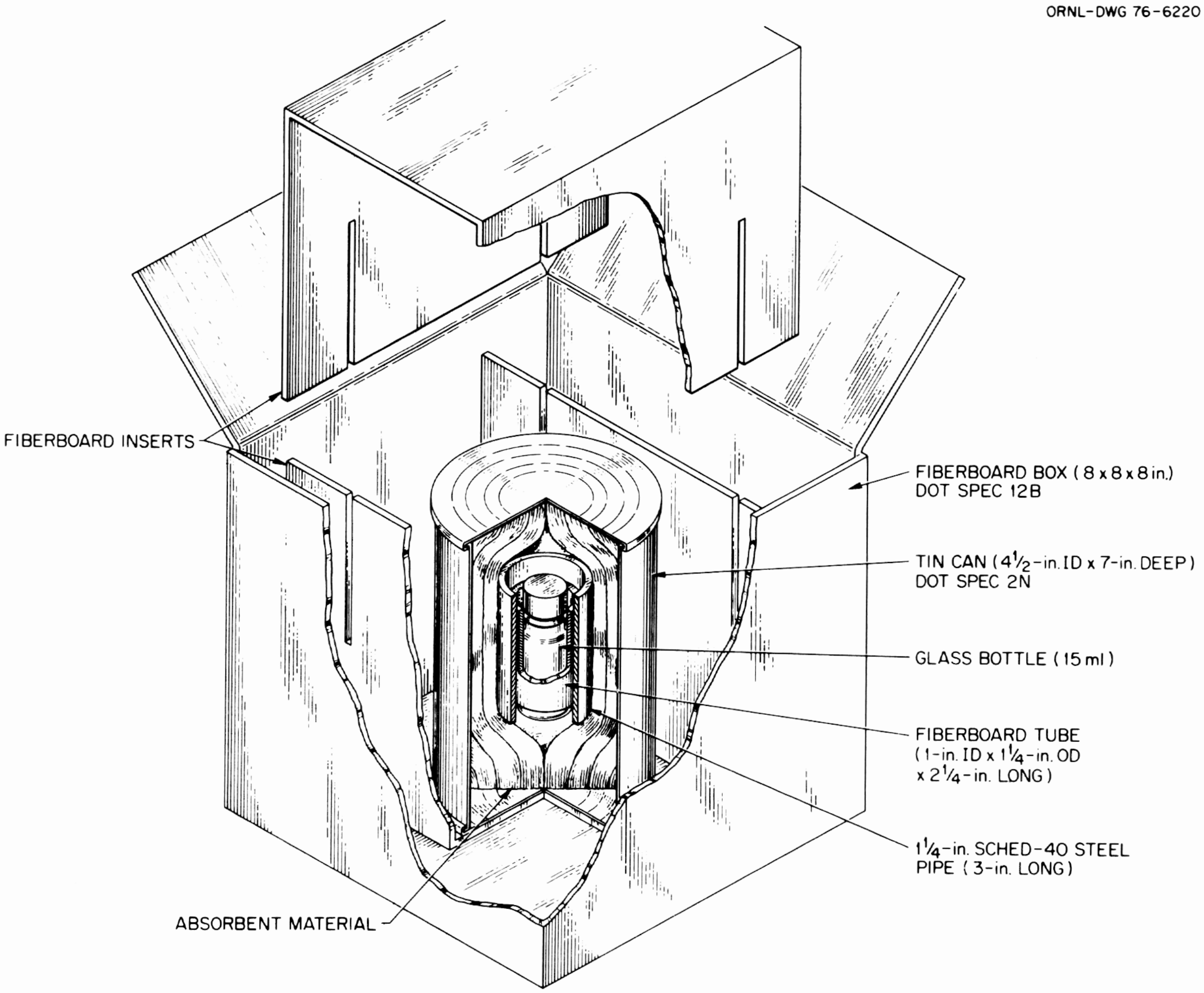

Figure 2. Disposable Container for Radioactive Liquid Shipments (Maximum Volume 10 ml)

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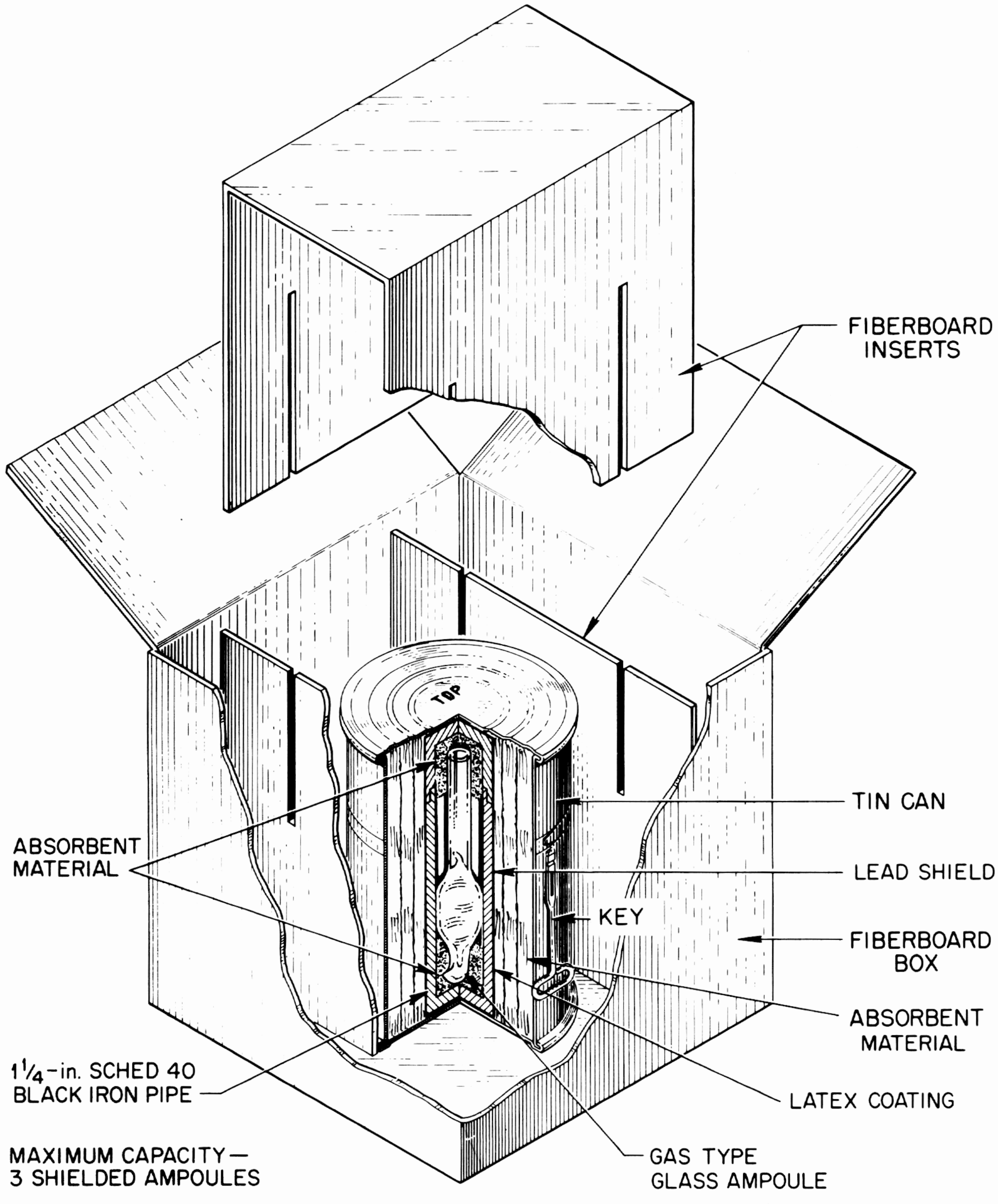

Figure 3. Disposable Container for Radioactive Gas Shipments

containing a bottle of radioactive material and the lead shield. The second package is used for shipment of radioactive gases and contains a glass ampule enclosed within a 1-in.-thick lead shield with an epoxy sealed cap. This is then dipped in polyvinyl acetate emulsion and dried. The glass ampule is cushioned on each end with 1/2-in.-thick pieces of foam rubber. The lead shield assembly is placed inside a 1 1/4-in. schedule 40 black iron pipe, and is wrapped in absorbent material and placed in the steel can. As many as three of these ampules so packaged may be shipped in one can.

The third package is used for quantities of radioactive materials shipped in liquid or solid form in which no lead shielding is required. It consists of a bottle into which the material to be shipped is placed into a fiberboard tube which in turn is placed in a 1 1/4-in. schedule 40 steel pipe and the assembly wrapped in absorbent material and placed in the can.

The steel can is effectively prevented from moving in the cardboard box under normal transport conditions by means of cardboard spacers which form a bracing system to the sides of the box. The lid of the lead shield is secured with a plastic tape seal and the steel can is sealed by mechanical crimping. The lead shield contains more than twice as much absorbent as is needed to absorb the liquid in the glass bottle.

Table 3. ORNL Non-returnable Cardboard Box Shipping Containers for Solids, Liquids, and Gases

Size (in.)	Weight (1 in. lead shielding) (lb)	Weight (no shielding) (lb)
12 1/4 cube	32	4
8 1/2 cube	30	3

IAEA Type A Tests on ORNL Non-Returnable Cardboard Box Shipping Containers

Penetration Test

Immediately following the water spray test, the penetration test was performed on the 12 1/4-in. test package No. 1, weighing 32 lb, using a 13.23-lb, 1.26-in.-diam steel bar with a hemispherical end, dropped perpendicularly to the test package surface from a height of 66.9 in. The bar was dropped onto the center of the test package because the center can be considered to be the weakest point, and with sufficient penetration the steel bar would strike the steel can. This resulted in a non-penetrating deformation of the wet cardboard box and a 1/16-in.-deep by 3/4-in.-diam non-penetrating indentation in the top lid of the steel can. To test for leakage, a glass bottle filled with potassium permanganate solution was used to simulate the radioisotope solution bottle. A broken bottle or leaking cap would be indicated by staining of the absorbent material located inside the lead shield next to the bottle. No leakage occurred as a result of this test as evidenced by the absence of permanganate coloring of the absorbent. The leak test was negative.*

Compression Test

Following the water spray test, test package No. 1 was immediately placed on a concrete pad and five test packages weighing a total of 150 lb were stacked on top of it for a period of 24 hours (Fig. 4). This resulted in deformation of the wet cardboard box of up to 1 in. on all four sides. The top and bottom surfaces were deformed less than 1/2 in. and remained intact. The bottle containing the permanganate did not leak as evidenced by no coloring of the absorbent. The leak test was negative.*

Corner Drop Test

Immediately following the water spray test, test package No. 1 was successively dropped from a height of 12 in. onto each of the four corners of the package, each time striking a flat unyielding horizontal surface. The only damage was 1/2-in. dents at the points of impact. The cardboard box and contents remained intact. The containment system was not breeched as evidenced by the fact that no potassium permanganate was found in the absorbent. The bottle containing permanganate was not broken. The leak test was negative.*

Free Drop Test

Immediately following the water spray test, test package No. 2 (identical to test package No. 1) was dropped from a height of 30 ft onto a thick concrete slab. This resulted in minor deformation (up to 1 in.) and some seam splitting of the cardboard box on all four sides (Fig. 5). The bottom of the carton was not damaged. The cardboard spacers used to position the steel can inside the box were deformed somewhat. The lead shield and the steel can were dented about 1/2 in. at the point of impact. The impact point was at the bottom edge of the cardboard box. The sample bottle did not leak as evidenced by the fact that none of the potassium permanganate was found in the absorbent. The leak test was negative.*

The steel can was found to leak in the soldered seam at the site of impact when tested by filling the can with water. The tape seal on the lead shield was undamaged.

*Observation for leakage was made at the end of the four tests listed.

USA DOT-7A Type A Container Tests on Non-Returnable Cardboard Box Shipping Containers

Free Drop Test

The DOT 4-ft free drop test was not performed since the IAEA 30-ft free drop test performed was much more stringent.

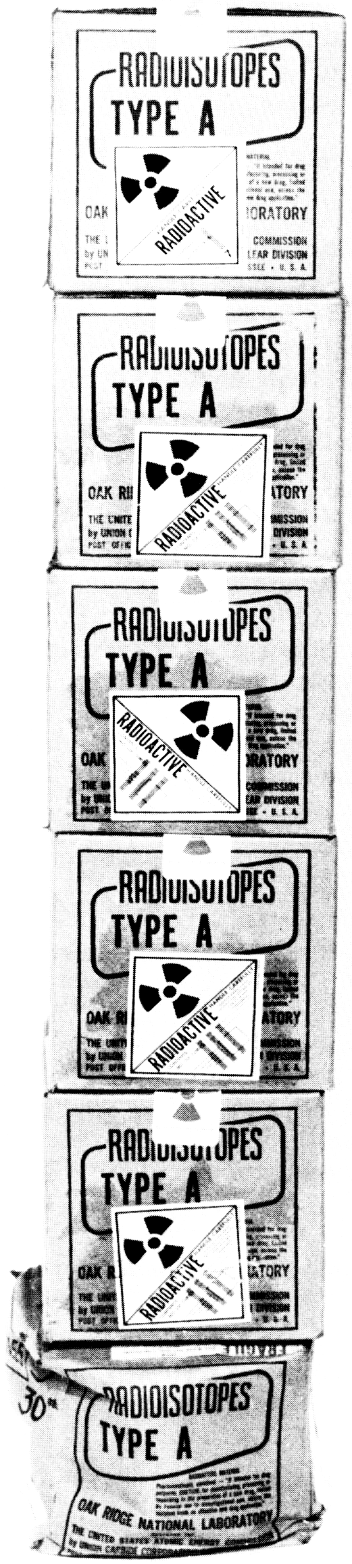

Figure 4. Front View of IAEA Compression Test on Test Package No. 1

Figure 5. Side View of IAEA 30-ft Free Drop Test on Test Package No. 2

Compression Test

The DOT compression test was not performed since the IAEA compression test performed was the same as the DOT test.

Penetration Test

The DOT penetration test in which a 13 lb, 1.25-in.-diam steel bar with a hemispherical end is dropped from a height of 40 in. onto the most vulnerable surface of the test package and perpendicular to the package surface, was not performed since the IAEA penetration test was more stringent in that the steel bar was dropped from a height of 66.9 in. and weighed 13.23 lb.

Corner Drop Test

It was not necessary to perform the corner drop test because the corresponding IAEA corner drop test performed utilizes the same test procedure as the DOT test.

Consecutive Application of Two of the Tests From Which the Test Package is Not Specifically Exempted

Since the No. 1 test package was subjected to three consecutive IAEA tests for penetration, compression, and corner drop, each of which was equal to or more stringent than the corresponding DOT tests, the requirement for the application of two consecutive DOT tests was satisfied.

ORNL RETURNABLE DOUBLE O-RING-SEAL ALUMINUM-CLAD WOOD BOX SHIPPING CONTAINERS FOR LIQUIDS AND SOLIDS

Description of Container

The double O-ring-seal wood box containers consist of a series of containers which are identical except for size and weight (Fig. 6). The boxes are constructed of 3/4 in. plywood and are completely covered with an 0.03-in.-thick protective aluminum cladding. The aluminum is held in place with an adhesive and is nailed at the corner posts. The carrying handles and a steel deck plate, which supports the carrier, are bolted through the plywood box and the cover is hinged for removal. During transport the cover is prevented from opening by a pinned hinge. The pin is 1/8 diam steel stock. A security seal is provided. The dimensions of the stainless steel containers placed inside the plywood box varies from 6-in.-diam by 9-in.-high to 14-in.-diam by 15-in.-high with 1 to 3.5 in. stainless steel clad lead shielding. This container has a flanged top held in place with six bolts and sealed with an O-ring. A removable stainless steel 2R type can with a screw top, sealed with an O-ring, is placed inside the stainless steel clad lead shield. This 2R can accommodates 25 to 100 ml bottles. The gross weight of the entire container varies from 87 to 208 lb (Table 4).

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NOTES:

(a) RETURNABLE SHIPPING CONTAINERS ARE IN THREE SIZES: 12 in. x 12 in., 17 in. x 17 in., 21 in. x 21 in.

(b) THICKNESS OF LEAD SHIELDING VARIES FROM 1½ in. TO 3 in.

(c) VOLUME SIZE OF SHIPMENT FROM 15 ml TO 200 ml

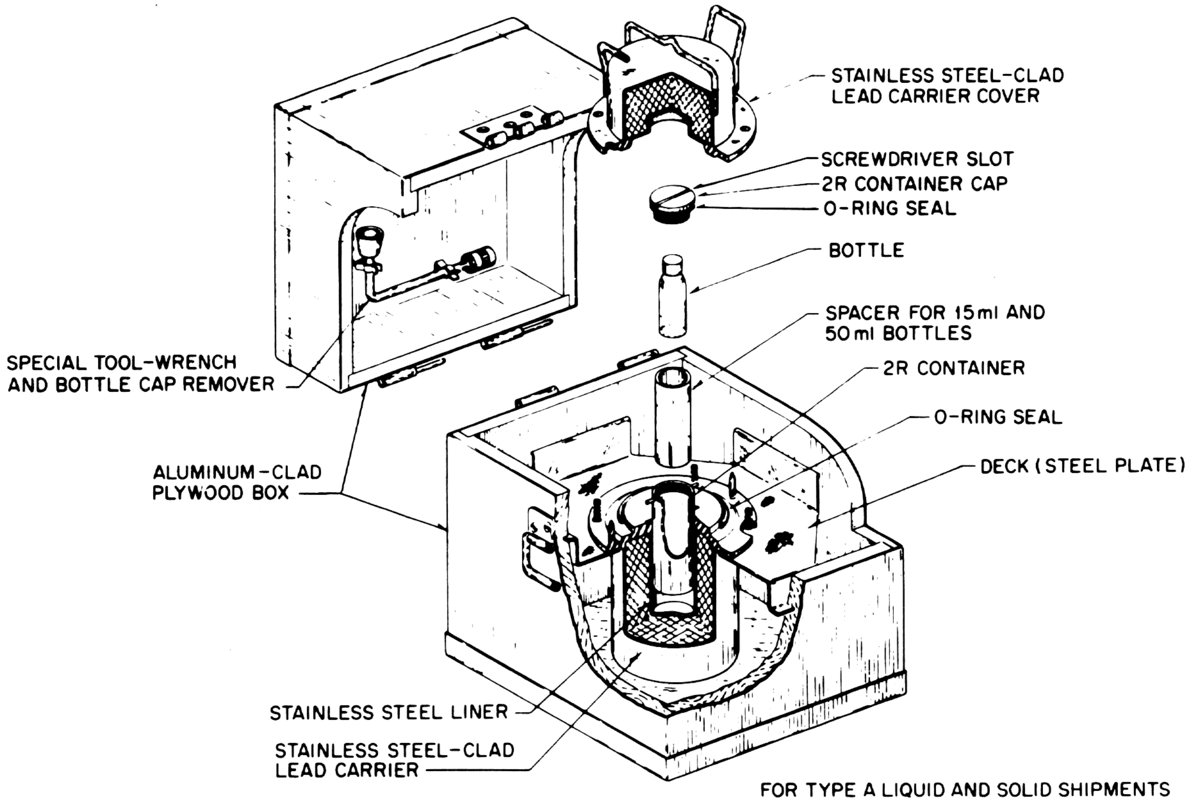

Figure 6. ORNL Returnable Shielded Shipping Container USA DOT-7A Type A

Table 4. ORNL Returnable Shipping Containers For Solids and Liquids Sizes and Weight of Wood Box Shipping Containers

Container	Gross wt. (lb)	Size (in.)	Capacity (ml)
3ABP-7	208	20 × 20 × 16	25
52CDP	205	21 × 21 × 16	100
25ABP	194	17 × 17 × 16	25
2ABP	136	17 × 17 × 16	25
32ABP	87	17 × 17 × 16	25

IAEA Type A Tests on ORNL Returnable Wood Box Shipping Containers

The shipping container tested (3ABP-7 test package) was selected because it was the heaviest (208 lb) of this series of containers and, therefore, represents the most severe stress situation for the series with respect to containment. (There was one exception; a 32ABP container was subjected to a corner drop test (see below). For leak test purposes the glass bottle was filled with a water solution of potassium permangante.

Compression Test

Immediately after the water spray test, a uniformly distributed weight of 1040 lb was applied to the top surface of the 3ABP-7 test package for 24 hr. There was no damage to the package as a result of this test. The leak test was negative.

Penetration Test

Immediately following the water spray test a 13.23 lb, 1.26-in.-diam steel bar with a hemispherical end was dropped perpendicularly from a height of 66.9 in. onto the center of the top of the 3ABP-7 test package which is the weakest point since with sufficient penetration the steel bar would strike the containment system. This test resulted in a minor non-penetrating dent in the center of the top of the 3ABP-7 test package. The leak test was negative.

Corner Drop Test

All of the wood box containers were exempt from the corner drop test because they weighed more than 110 lb, except the 32ABP test package which weighed 87 lb. Immediately following the water spray test the 32ABP test package was successively dropped from a height of 12 in. onto each corner of the package, each time striking a flat, unyielding, horizontal concrete surface.

The only damages were minor dents at the points of impact. The leak test was negative.

Free Drop Test

Immediately following the water spray test, the test package was dropped from a height of 30 ft onto a thick, horizontal concrete slab in such a way as to cause the maximum damage with respect to containment. About half of the nails were pulled out of the box, the top and bottom plywood sheets were jarred loose, the aluminum cladding remained largely intact, although much of it was torn as a result of the impact (Fig. 7). A steel plate used to position and support the stainless steel clad lead shield in the plywood box remained secured to the walls of the plywood box and were undamaged. The steel hinges and wire seals were not damaged. The leak test was negative. Most of the damage to the top of the box occurred by accident when a heavy angle iron brace attached to the drop mechanism struck the top of the box.

The stainless steel shielded 3ABP-7 test package was removed from the wood box. An examination of all the parts indicated that no damage had occurred to this container. The stainless steel clad lead shield, containing the 2R can and bottle of permanganate solution, was removed from the plywood box and dropped from a height of 30 ft onto the horizontal concrete pad. The only damage to the shield was a 1-in. dent on the bottom edge (Fig. 8). The leak test was negative, indicating that the shield and 2R container alone, without the wood box and steel support plate, was sufficient to maintain containment. The glass bottle containing the potassium permanganate solution did not leak or break.

USA DOT-7A Type A Tests on ORNL Returnable Plywood Box Shipping Containers

Free Drop Test

The DOT 4 ft drop test was not performed since the IAEA 30-ft drop test of the 3ABP-7 test package was much more stringent.

Compression Test

The DOT compression test was not performed since the IAEA compression test was the same as the DOT test.

Penetration Test

The DOT penetration test was not performed since the IAEA penetration test was more stringent.

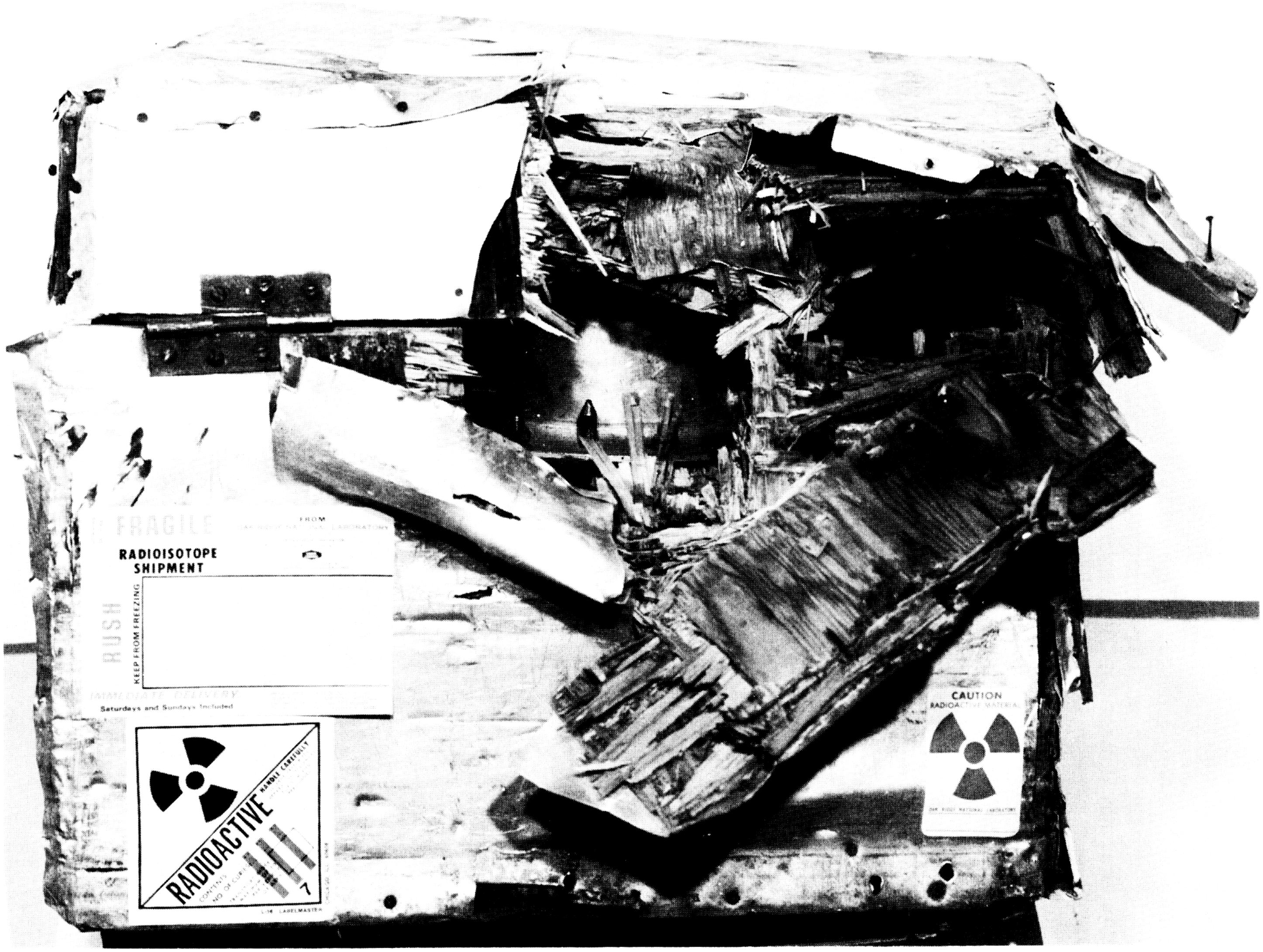

Figure 7. IAEA Penetration and 30-ft Free Drop Tests on 3ABP-7 Test Package

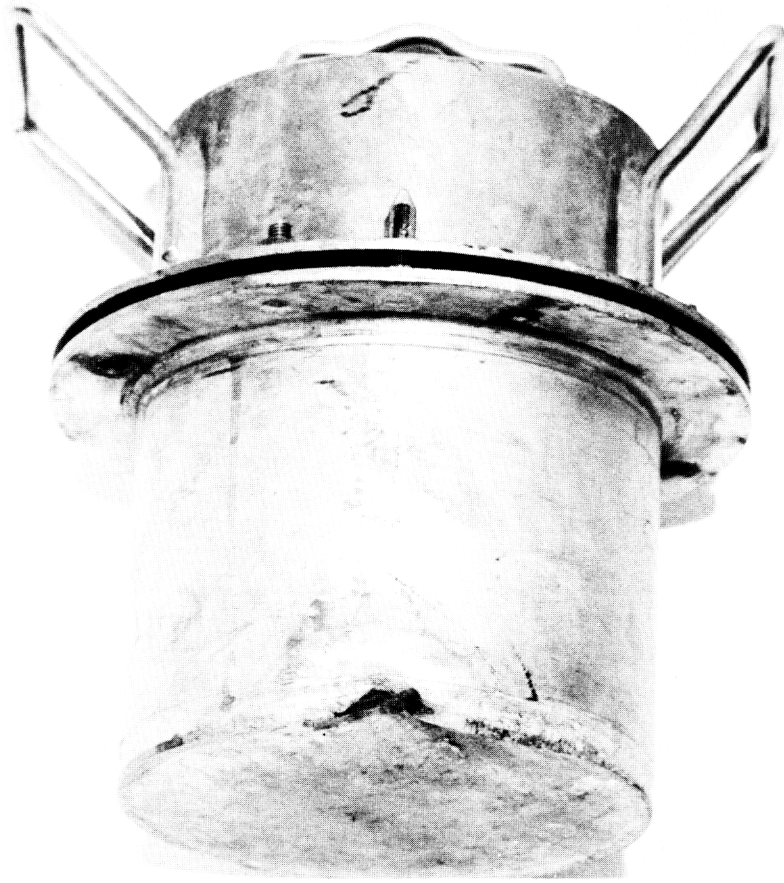

Figure 8. 30-ft Drop (Container only) 3ABP-7

Corner Drop Test

The DOT corner drop test was not performed since the 3ABP-7 test package weighs more than 110 lb and is, therefore, exempt from this test. It was not necessary to test the 32ABP test package since the DOT corner drop test is the same as the IAEA test.

Consecutive Application of Two of the Tests From Which the Package is Not Specifically Exempted

Since the 3ABP-7 test package was subjected consecutively to the three IAEA tests for compression, penetration, and free drop it meets the test requirements for the application of two consecutive tests, each of which were equal to or more stringent than the corresponding DOT tests.

RETURNABLE SHIPPING CONTAINERS FOR GASES

Description of Containers

The returnable shipping containers for gases consist of a series of cylinders which are identical except for size and weight. The containers (Table 5) consist of a valved inner stainless steel cylinder jacketed with a larger stainless steel case. The intervening space may be void or lead-filled for shielding. An O-ring sealed threaded valve cap is screwed onto the shoulder of the cylinder during transport. A wire and lead seal is attached to the valve handle and is secured with a wire seal after filling the cylinder and closing the valve. Wax seals are placed on the valve tension nut and at the valve outlet cover to indicate tampering during transport. A 1/8-in. pipe plug on top of the valve cap provides a sensing port for probing to determine valve leakage prior to removing the valve cap (Fig. 9).

The 1000 ml and greater capacity gas containers have four verticle stainless steel lugs which are welded to the container walls and are equally spaced to protrude above the container valve caps to prevent damage to the valve and valve cap. Containers with capacities less than 1000 ml do not have protective lugs.

Two different sized gas cylinders were subjected to the IAEA tests; the HOKR-500-9, test package, having a weight of 47 lbs, and the HOKR-1000-22 test package, having a weight of 116 lbs. Since the heaviest container of a container series represents the worst possible case with respect to possible stress, all of the gas cylinders having verticle lugs to protect the containment system and not weighing more than 116 lbs are assumed to also pass the tests of the type which were performed on container HOKR-1000-22. Also, those containers which rely on the heavy duty valve cap for protection of the containment system, weighing 47 lb or less, are assumed to also pass the tests performed on container HOKR-500-9 test package.

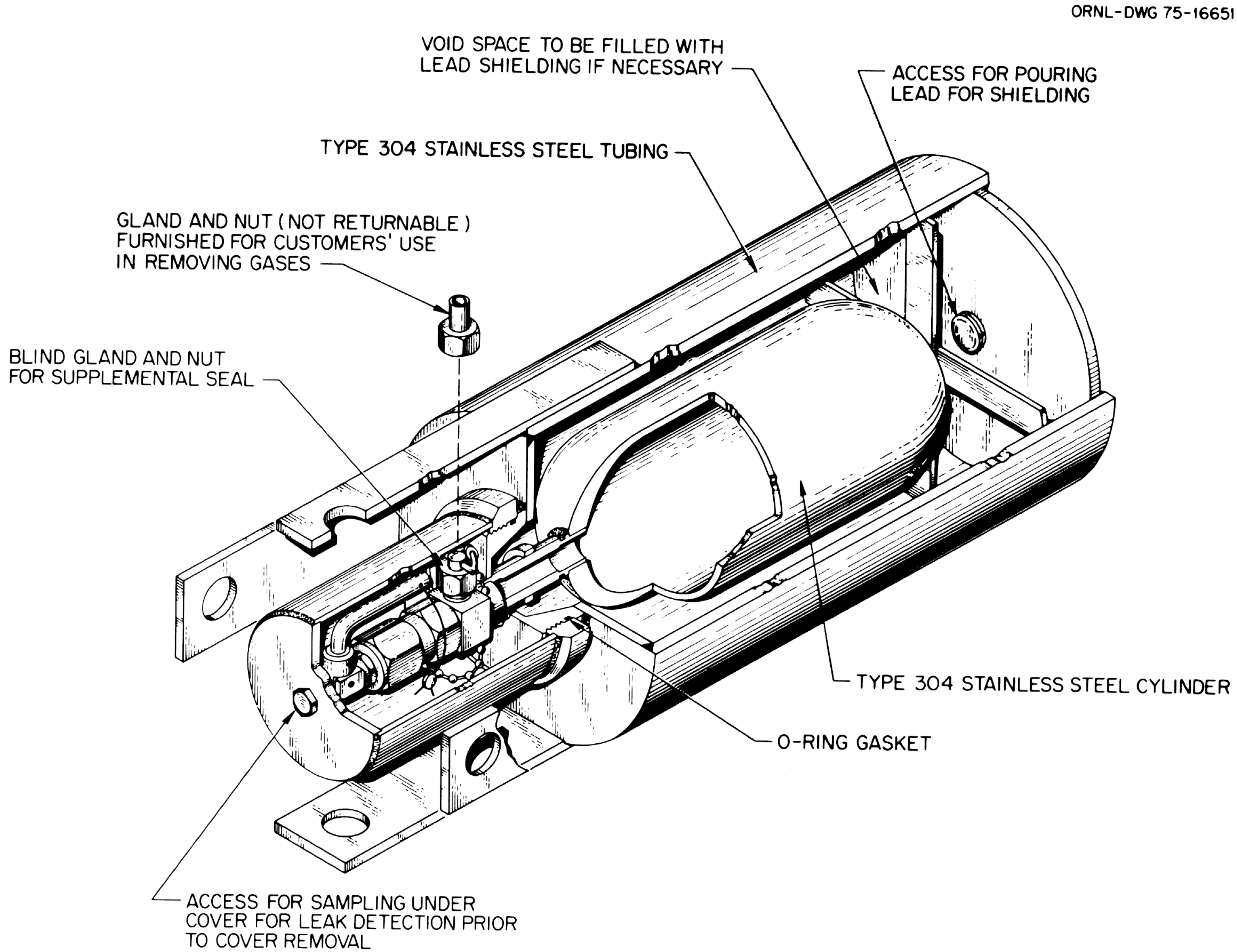

Figure 9. ORNL Returnable Gas Cylinder; USA DOT 7A Type A

Table 5. ORNL Shipping Containers for Radioactive Gases

Container	Capacity (ml)	Overall Length (in.)	Largest Diameter (in.)	Weight (lb)
		Tritium Cylinders		
HOH-10	10	7.5	3.5	6-8
HOH-50	50	12.5	3.5	15-17
HOH-150	150	15.5	3.5	11-13
HOH-300	300	15.5	3.5	13-15
HOH-500	500	21	3.5	15-17
HOH-1000	1000	17	6	35-37
HOH-2000	2000	24	6	50-52
		Xenon Cylinders		
HOXE-10	10	7.5	3.5	9-10
HOXE-50	50	12.5	3.5	15-17
		Krypton Cylinders		
HOKR-10	10	7.5	3.5	9-10
HOKR-50	50	12.5	3.5	15-17
HOKR-150	150	15.5	3.5	37-39
HOKR-300	300	15.5	3.5	36-39
HOKR-500	500	21	3.5	45-47
HOKR-1000	1000	17	6	116-120

Leak tests of the gas cylinders consisted of evacuating the cylinders to -28 in. Hg ($\sim$2 in. Hg absolute) before the tests and measuring the pressure after 7 days. An increase in pressure is a positive leak test.

IAEA Type A Tests on ORNL Returnable Gas Shipping Containers

IAEA Tests Performed on 1000 ml Gas Shipping Cylinder

Free Drop Test

Immediately following the water spray test, the test package was dropped from a height of 30 ft with the valve cover facing down onto a flat, essentially unyielding, horizontal concrete surface, striking the surface in a position for which maximum damage was expected. In this test three of the protective ears were bent about 1 in. and a weld in the valve cap was cracked, but remained intact (Fig. 10). The leak test was negative.

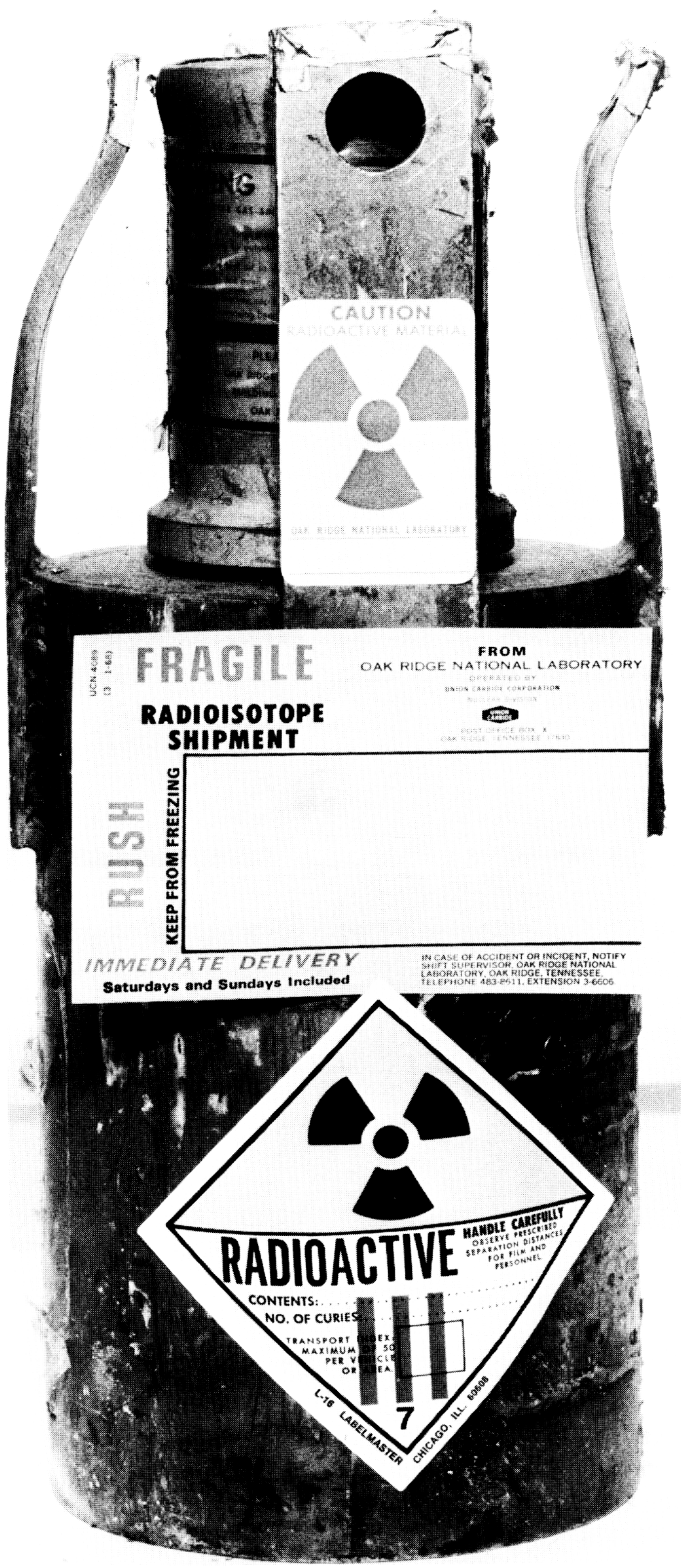

Figure 10. IAEA Free Drop and Penetration Tests on 1000 ml Test Package

Corner Drop Test

This test was not required for metal containers.

Penetration Test

Immediately following the water spray test, the penetration test was performed on the test package using a 13.23 lb, 1.26-in.-diam steel bar with a hemispherical end dropped from a height of 66.9 in. onto the center of the top of the protective valve cap, which is considered to be the weakest point since with sufficient penetration the bar would hit the containment system. There was no damage as a result of this test except a minor non-penetrating surface mark. The leak test was negative.

Compression Test

Immediately after the water spray test the test package was subjected to a uniform compressive load of 580 lbs for a period of 24 hours which is the greater of the two compression test methods required by the regulations. There was no damage as a result of this test (Fig. 11). The leak test was negative.

IAEA Tests Performed on 500 ml Capacity Gas Shipping Cylinder

Free Drop Test

Immediately following the water spray test, the test package was dropped from a height of 30 ft onto a flat, essentially unyielding, horizontal concrete surface, striking the surface with the valve cap facing down, a position for which maximum damage was expected. Impact was on the protective valve cap. The only damage was a 1/2-in. dent on the valve cap (Fig. 12). The leak test was negative.

Corner Drop Test

This test is not required for metal containers.

Penetration Test

Immediately following the water spray test, the penetration test was performed on the test package, using a 13.23 lb, 1.26-in.-diam steel bar with a hemispherical end dropped from a height of 66.9 in. onto the center of the top of the protective valve cap, which is considered to be the weakest point since with sufficient penetration the bar would hit the containment system. The only damage was a minor non-penetrating surface mar on the valve cap. The leak test was negative.

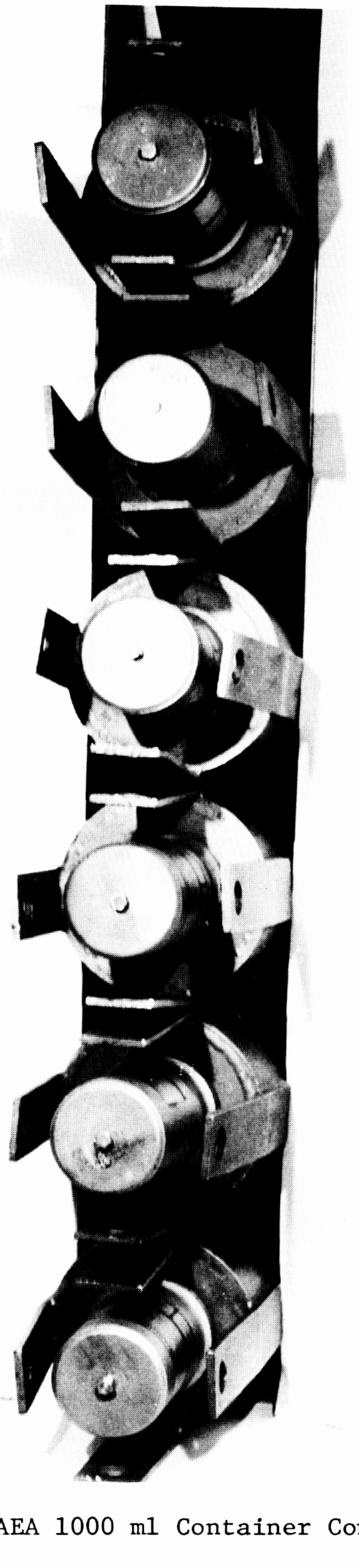

Figure 11. IAEA 1000 ml Container Compression Test

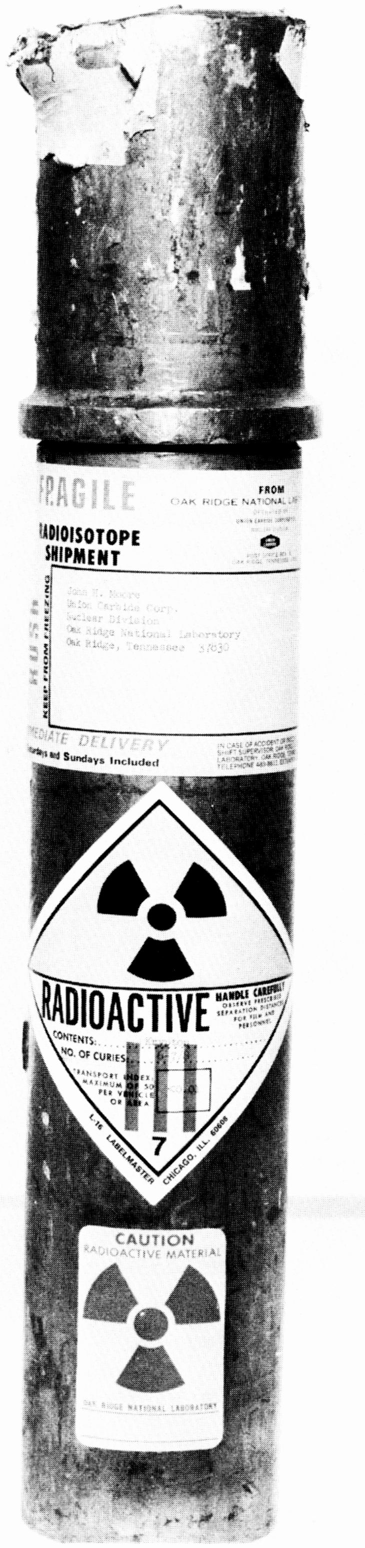

Figure 12. Free Drop, Penetration and Compression Test on 500 ml Container

Compression Test

Immediately following the water spray test the test package was subjected for a period of 24 hours to a uniform compressive load of 235 lbs which is the greater of the two compression test methods given in the regulations. There was no damage as a result of this test. The leak test was negative.

DOT-7A Type A Tests

DOT Tests on 1000 ml Container

Free Drop Test

The DOT 4-ft free drop test was not performed on the 1000 ml container since the IAEA 30-ft free drop test performed was much more stringent.

Compression Test

The DOT compression test was not performed since the IAEA compression test performed was the same as the DOT test.

Penetration Test

The DOT penetration test was not performed since the IAEA test performed was more stringent.

Corner Drop Test

This test is not required for metal containers.

Consecutive Application of Two of the Tests From Which the Test Package Was Not Specifically Exempted

Since the 1000 ml package was subjected to three consecutive IAEA tests for free drop, penetration, and compression, it met the DOT test requirements for the application of two consecutive tests.

DOT Tests on 500 ml Container

Free Drop Test

The DOT 4-ft free drop test was not performed on the 500 ml container since the IAEA 30-ft free drop performed was much more stringent.

Compression Test

The DOT compression test was not performed since the IAEA compression test performed was essentially the same as the DOT test.

Penetration Test

The DOT penetration test was not performed since the IAEA penetration test performed was more stringent.

Corner Drop Test

This test is not required for metal containers.

Consecutive Application of Two of the Tests From Which the Test Package Was Not Specifically Exempted

Since the 500 ml package was subjected consecutively to three IAEA tests for free drop, penetration, and compression, it therefore met the DOT test requirement for the application of two consecutive tests.

ORNL RETURNABLE SHIPPING CONTAINERS FOR 86-INCH CYCLOTRON FLAT-PLATE TARGET SHIPPING CONTAINERS

Description of Container

The oblong-shaped cyclotron flat-plate target shipping containers (Table 6) are of stainless steel construction (Fig. 13). Flanges are welded to both top and bottom of the containers. The containers are sealed by means of a neoprene gasket which is compressed between the flanged lid and the top flange of the container by means of bolts. The radioactive material is produced in a 6-in. by 5 5/8-in. by 1/2-in. copper flat plate target. After cyclotron bombardment the target is put into a plastic bag and placed in a cavity inside the shielded container. One to two inches of lead is used as a radiation shield. The cyclotron flat plate target containers were leak tested by filling their cavities with potassium permanganate solution prior to testing and placing them upside down for seven days and right side up for an additional seven days after testing. A leak would have been indicated by potassium permanganate on the outside surface of the test package or on the blotter paper which was placed underneath the test package during leak testing.

Table 6. Size and Weight of Cyclotron Containers

Container	Gross wt (lb)	Size (in.)
CYC-7	249	12 × 8 × 12
CYC-3	825	12 × 8 × 12
CYC-1FP-4	129	12 × 6 × 11

ORNL-DWG 76-12825R

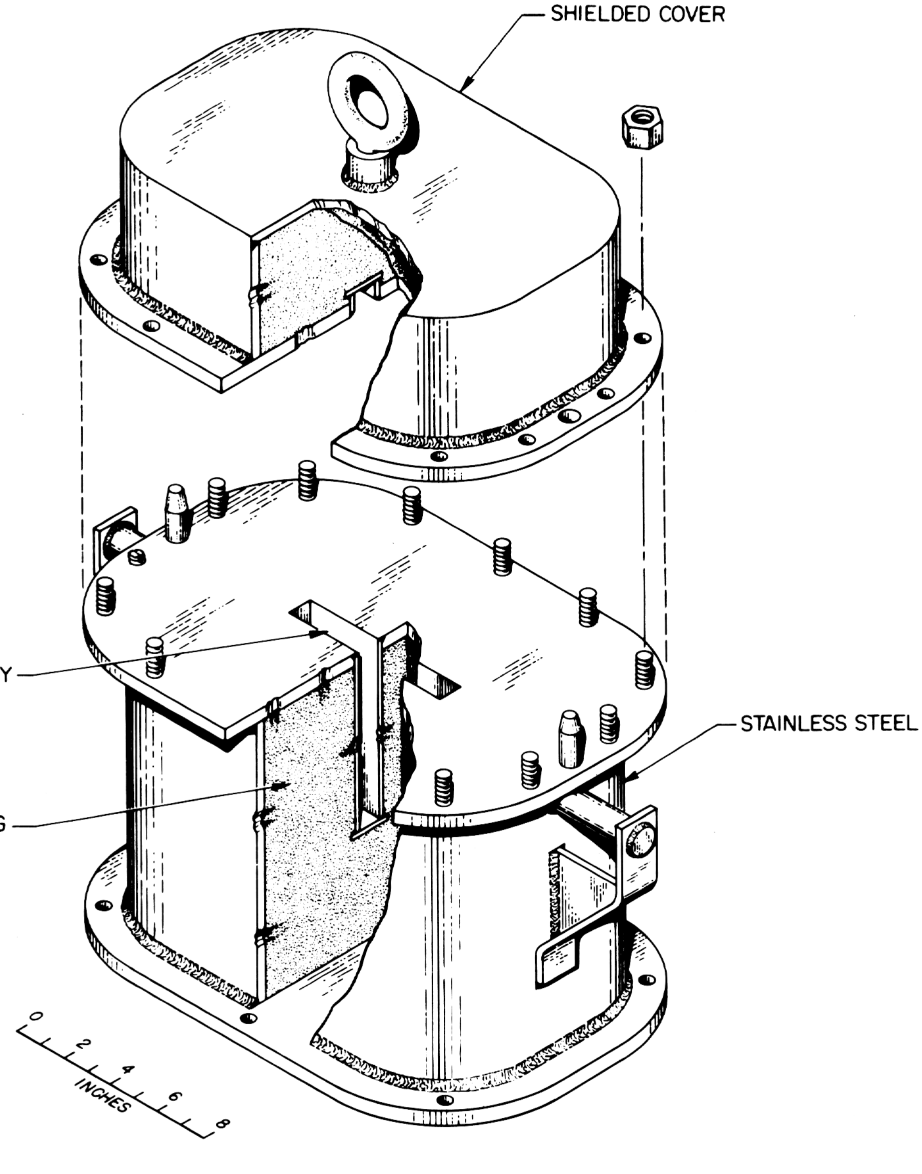

Figure 13. Typical ORNL Returnable Cyclotron Target Shipping Package

DOT-7A Type A Tests

Tests of 249 lb and 825 lb Cyclotron Target Shipping Containers

Water Spray Test

The test package is exempt because it is made of metal and neoprene plastic.

Free Drop Test

The test packages were both dropped from a height of 4 ft onto a flat, unyielding horizontal surface striking the surface on the side of the container so that the force of the impact was absorbed by the flanges. The only damage was a minor non-penetrating abrasion on the top edge of the lid (Fig. 14) of the smaller container. The leak test was negative. The larger sustained essentially the same damage. The leak test on it was also negative.

Corner Drop Test

This package is exempt because it is made of metal and neoprene plastic and weighs more than 110 lbs.

Penetration Test

A 13.23 lb, 1.26-in.-diam steel bar with a hemispherical end was dropped vertically from a height of 40 inches onto the center of the lid of the test packages. This is considered to be the weakest point in both packages since sufficient penetration would strike the containment system. The leak tests were negative.

Compression Test

The 249 lb test package was placed on it's side and a 1245-lb gas cylinder was placed on the lid flanges which support the container lid during transport. The gas cylinder remained on the flanges for a period of 24 hours. The container lid is considered to be the weakest point since failure of the flanges, flange bolts, or the neoprene gasket would, with sufficient penetration, breech the containment system. The leak test was negative. The compression test performed on the 825 lb package consisted of placing a 5000 lb weight on its top in the same manner as with the 249 lb package. No leaks were detected as a result of this test.

Consecutive Application of Two of the Tests From Which the Test Package is Not Specifically Exempted

Since the test package was subjected consecutively to three DOT tests for free drop, penetration, and compression, it meets the consecutive application requirements.

Figure 14. DOT 4-ft Drop and Penetration Tests
on 249 lb CYC-7 Container

Tests of 129 lb Containers

Water Spray Test

This package is exempt because it is made of metal and neoprene plastic.

Free Drop Test

The package was dropped from a height of 4 ft onto a flat unyielding horizontal surface striking the surface with the lid facing down and absorbing the impact. The package handles were bent slightly. No other damage to the package occurred (Fig. 15). The leak test was negative.

Corner Drop Test

Exempt because the package has metal construction.

Penetration Test

A 13.23 lb, 1.26-in.-diam steel bar with a hemispherical end was dropped vertically onto the center of the lid of the package, considered to be the weakest point since sufficient penetration would strike the containment system. The only damage was a minor surface dent where the steel rod hit the top of the test package. The leak test was negative.

Compression Test

The test package was placed on it's side and a 645-lb gas cylinder was placed on the flanges which support the package during transport. The gas cylinder remained on the flanges for 24 hours (Fig. 16). The package lid was considered to be the weakest point since failure of the flanges, flange bolts, or the neoprene gasket would, with sufficient penetration, breech the containment system.

Consecutive Application of Two of the Tests From Which the Test Package is Not Specifically Exempted

Since the test package was subjected consecutively to three DOT tests for free drop, penetration, and compression, it met the consecutive application requirement.

Since none of the test packages leaked as a result of either the IAEA or DOT tests performed on them, radioactivity would not have been released under the test conditions. In addition to the test packages passing the test requirements for the IAEA and DOT, the test packages also passed the test requirements for the IATA (Table 2).

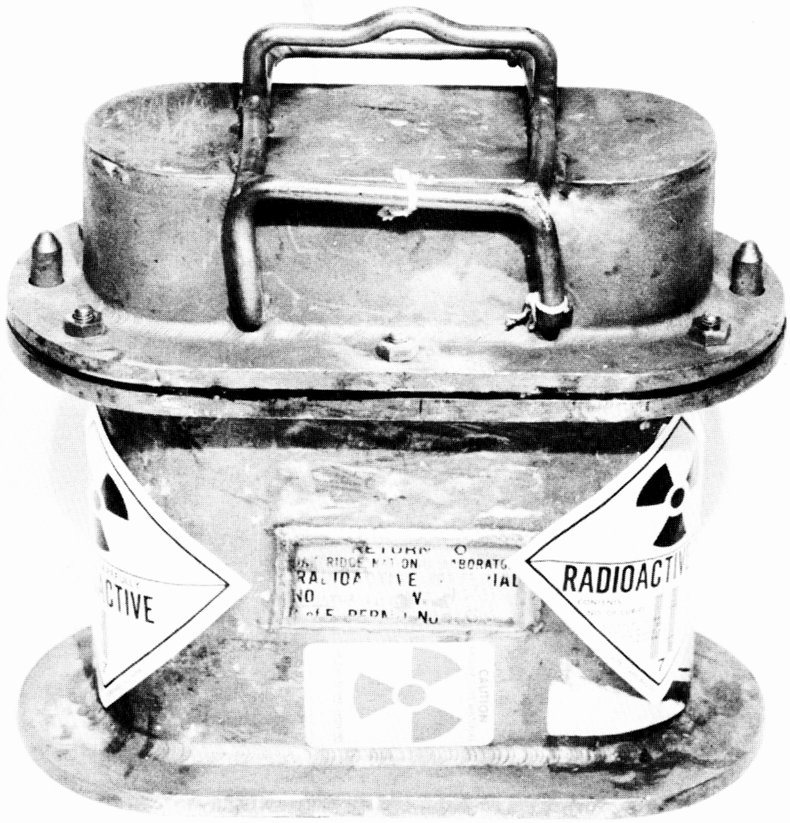

Figure 15. DOT 4-ft Drop and Penetration Tests on 129 lb CYC-1FP-4 Container

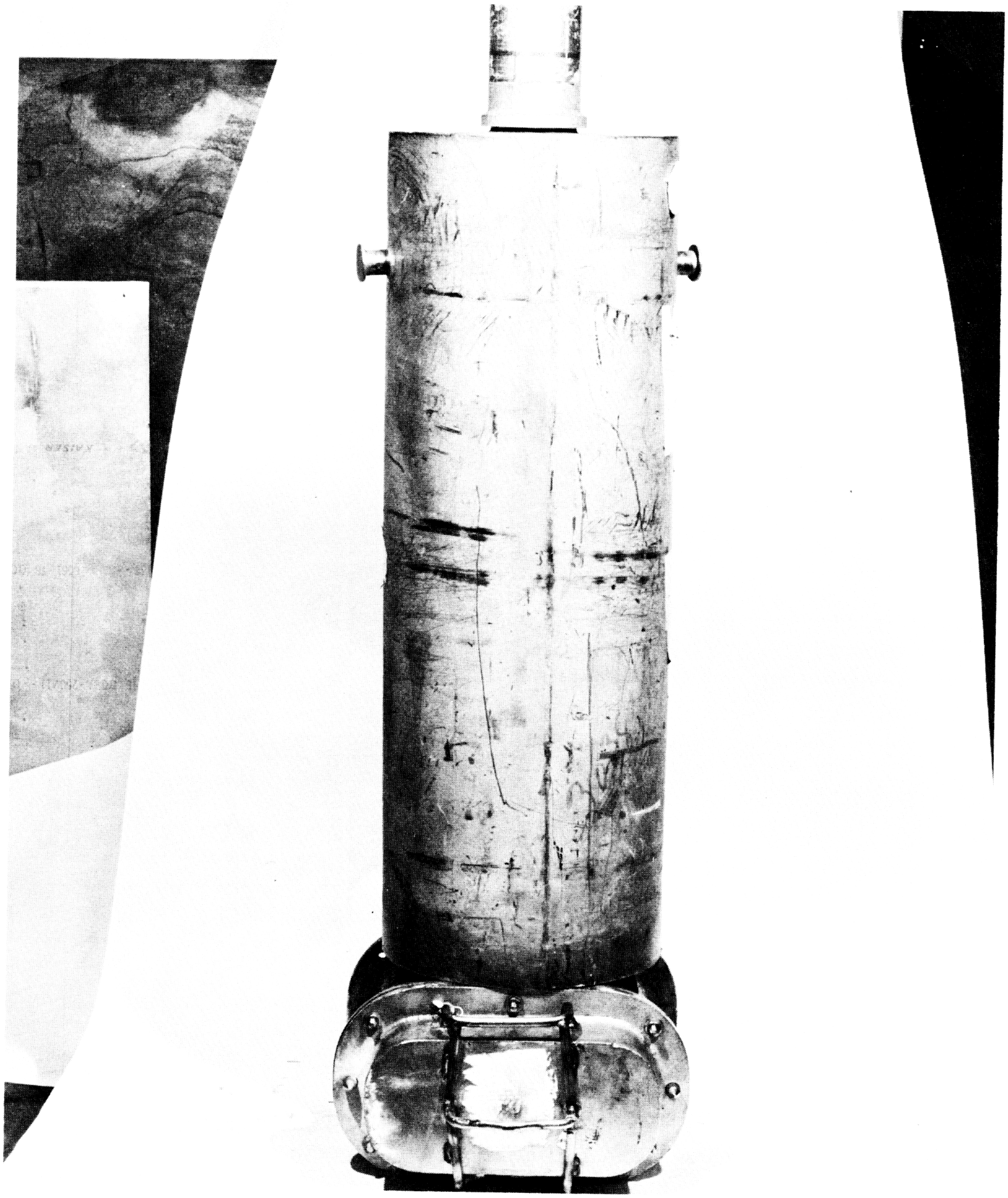

Figure 16. DOT Compression Test on 249 lb CYC-7 Container

ENVIRONMENTAL EFFECTS

Temperature and Pressure

The temperature range of -40°F to 158°F specified in the IAEA test procedures and -40°F to 130°F specified in the IATA and DOT test procedures fall within temperature ranges in which no damage can occur to any of the materials of construction used in the ORNL shipping containers. Testing was therefore confined to those components of the package that could be affected by temperature or pressure extremes specified in the procedures. The components tested were the glass bottles used to contain liquids and thus subject to freezing, the valves on gas shipping containers, and the lead ampule shield used for radioactive gas shipments made in glass ampules. The test procedure was as follows:

Ten 20 ml glass sample bottles were 50% filled with $KMnO_4$ solution and sealed in the normal manner as used for radioisotope shipments. The sample bottles were then subjected to the following tests.

1. Heating in an oven for 30 min to a temperature of 140°F.
2. Cooling to -40°F for 30 min.
3. Exposing to a 1/2 atmosphere pressure for 30 min with bottle inverted to expose cap seal to total immersion in solution.

One hundred percent of the bottles tested passed with no solution leakage or bottle breakage.

One complete ORNL type A cardboard shipping package component consisting of a 20 ml bottle 50% filled with $KMnO_4$ solution, wrapped in Kimpak and placed in the standard metal isotope "key strip" opening can, was subjected to

1. Heating in an oven at 140°F for 30 min.
2. Cooling to -40°F for 30 min.
3. Exposing to 1/2 atmosphere pressure for 30 min in the inverted position to expose the bottle cap seal to 100% immersion.

Examination after all three tests had been completed showed no leakage had occurred.

In all cases the low temperature caused the contents of the bottle to freeze solid.

One gas shipping package consisting of a 10 cc sealed glass ampule placed inside a lead shield with an epoxy sealed cap that had been dipped in polyvinyl acetate emulsion and dried at 200°F for approximately 30 min, was subjected to the following tests.

1. Heating to 140°F for 30 min.
2. Cooling to -40°F for 30 min.
3. Exposing to 1/2 atmosphere pressure at ambient temperature for 30 min.

The objective of these tests was to determine leakage at the lead cap seal as a consequence of the environmental conditions imposed. The leak test consisted of immersion of the lead shield in ethylene glycol at 1/2 atmospheric pressure over the glycol. No leakage in the form of bubbles of gas released from inside of the lead shield was observed and the test was negative.

A 150 ml tritium gas shipping container of the type described under Returnable Shipping Containers for Gases, Description of Containers, was evacuated to a vacuum of -28 in. Hg (∿2 in. Hg absolute), the valve closed, and the cylinder shelf tested for 24 hours. The pressure was again measured. Any increase in pressure was considered to be an indication of valve leakage.

Following the evaluation of valve condition, the cylinder was subjected to the following tests.

1. Evacuation to -28 in. Hg (∿2 in. Hg absolute).
2. Heating in an oven to 140°F for 30 min.
3. Cooling to -40°F for 30 min.
4. Exposing to 1/2 atmosphere pressure for 30 min.

Following these tests the pressure in the cylinder was measured. No increase in pressure was noted, indicating no valve leakage had occurred as a consequence of the environmental tests administered.

Since all cylinders used for ORNL shipments of radioactive gas have the same valve design the test was considered valid for cylinders of the various capacities shown in Table 5.

Vibration Tests

The cardboard Type A package, the gas shipping cylinders, the cyclotron target shipping container, and the returnable plywood box shipping container were subjected to vibration tests. The criteria for failure of the package when exposed to vibration of 0.2 in. amplitude at 7 cycles per second (1 G acceleration) to 0.002 in. amplitude at 200 cycles per second (8 G acceleration) was any leakage of liquid or gas from the container as a consequence of the vibration test. In no case did the package sustain any damage as a result of the vibration testing. The data from these tests concerning resonant frequencies, amplitude, g-forces and test times are presented in the Appendix.

General

The packages tested, with exception of the ampule lead shield, have been used for many years under conditions of normal air and surface transport, without failure of the containment system or occurrence of other than normal wear and tear due to vibration, dock handling, and exposure of temperature pressures and acceleration. The epoxy sealed lead shield for ampules was of recent design and was added to maintain shielded containment of gaseous radionuclides in case of glass ampule failure, as absorbent material is used to contain liquids in a shielded condition in case of glass bottle failure. While not specified in the testing procedures for IAEA or DOT, we have considered the effect of severe crush type accidents to the type A cardboard box package and as a consequence have protected the glass bottle by inserting a section of 2-in. diam pipe between the cardboard tube that holds the glass bottle and the Kimpak absorbent. With this addition the glass bottle survived without leakage when the package was crushed under the wheel of a 2-ton truck. This should simulate most highway or airport accidents involving wheeled vehicles.

APPENDIX A

Tables A1 through A5 contain the resonant frequency data for the IATA vibration test conducted on ORNL radioisotope shipping containers discussed in this report.

The test procedure followed in each case was to secure the container to the vibration test equipment table and scan through the frequencies and amplitude range specified in the test. During this scan the resonant frequencies, amplitudes, and g-forces were noted. After determination of resonant frequencies the container was tested at each resonant frequency for a period of 10 minutes. The total time required for scanning, plus the time the package was subjected to individual resonance frequency testing is shown.

Table A1. Vibration Test Data for Cardboard Box Container (Resonant Frequencies)

Amplitude (inches)	Frequency (cycles/sec)	G-Force (lb_m-ft/lb_f-sec^2)
0.015	178.0	3.7
0.02	36.8	1.4
0.02	58.5	1.7
0.02	148.0	1.9
0.02	168.0	6.2
0.02	196.0	3.3
0.03	18.6	1.0
0.03	19.4	1.1
0.03	152.0	7.5
0.04	16.4	1.7
0.04	17.0	1.6
0.04	178.0	3.7
0.04	186.0	3.8
0.05	41.3	2.0
0.05	16.3	2.1
0.05	19.0	1.3
0.05	40.0	1.5
0.05	40.8	1.1
0.05	42.0	1.3
0.05	58.3	1.4
0.05	146.0	2.1
0.05	172.0	5.2
0.06	15.1	5.0
0.06	15.2	2.2
0.06	15.8	1.1
0.06	17.0	1.5
0.06	34.8	2.1
0.07	8.9	3.0
0.07	15.0	2.9
0.07	15.0	2.4
0.07	76.6	5.3
0.08	11.2	1.8
0.08	13.3	1.25
0.09	12.8	1.25
0.09	14.8	3.8
0.09	33.4	2.5
0.10	7.8	2.2
0.13	13.7	4.2
0.13	15.7	5.0
0.14	15.3	3.8

Scan Time	265 min
Resonant Frequency Tests	400 min
Total Test Time	665 min (11 hr 5 min)

Table A2. Vibration Test Data for Wood Box Container (Resonant Frequencies)

Amplitude (inches)	Frequency (cycles/sec)	G-Force (lb_m-ft/lb_f-sec^2)
0.07	16.0	1.0
0.10	16.0	1.2
0.10	16.2	1.25
0.115	16.0	1.4
0.125	16.3	1.4
0.13	15.8	1.6
0.13	15.9	1.6
0.135	16.3	1.7
0.16	16.1	1.95
0.16	16.3	1.9
0.175	11.0	1.05
0.185	11.0	1.1
0.19	15.4	2.2
0.20	15.4	2.2

Scan Time	125 min
Resonant Frequency Tests	140 min
Total Test Time	265 min (4 hr 25 min)

Table A3. Vibration Test Data for 1000 ml Gas Shipping Cylinder (Resonant Frequencies)

Amplitude (inches)	Frequency (cycles/sec)	G-Force (lb_m-ft/lb_f-sec^2)
0.09	15.3	1.0
0.11	14.8	1.2
0.11	15.3	1.25
0.115	14.6	1.2
0.13	14.9	1.3
0.13	15.0	1.5
0.13	15.2	1.5
0.155	14.7	1.7
0.16	15.1	1.8
0.16	15.3	1.8
0.18	14.5	1.9
0.19	11.0	1.3
0.20	14.6	2.3
0.20	14.8	2.2
0.20	14.8	2.3
0.20	14.9	2.8
0.21	9.4	0.95

Scan Time	195 min
Resonant Frequency Test	170 min
Total Test Time	365 min (6 hr 5 min)

Table A4. Vibration Test Data for 500 ml Gas Shipping Cylinder (Resonant Frequencies)

Amplitude (inches)	Frequency (cycles/sec)	G-Force (lb_m-ft/lb_f-sec^2)
0.05	19.5	1.6
0.05	20.7	1.0
0.06	19.7	1.3
0.08	20.3	1.5
0.085	19.4	1.9
0.09	20.0	2.2
0.10	19.7	2.8
0.10	20.0	1.6
0.10	20.3	2.0
0.11	18.1	1.5
0.11	18.5	1.7
0.11	19.2	1.8
0.11	20.2	1.85
0.12	19.2	2.6
0.13	18.0	2.3
0.13	19.2	3.0
0.14	18.2	3.5
0.15	17.4	2.2
0.17	17.8	2.9
0.18	11.2	1.05
0.18	17.4	4.0
0.195	11.2	1.2

Scan Time	145 min
Resonant Frequency Tests	220 min
Total Test Time	365 min (6 hr 5 min)

Table A5. Vibration Test Data for Cyclotron Container (Resonant Frequencies)

Amplitude (inches)	Frequency (cycles/sec)	G-Force (lb_m-ft/lb_f-sec^2)
0.005	170.0	1.3
0.008	151.0	3.2
0.015	161.0	1.8
0.02	110.0	1.3
0.02	173.0	2.2
0.02	167.0	1.6
0.03	37.8	1.4
0.03	148.0	4.5
0.03	152.0	1.3
0.035	148.0	6.0
0.04	37.9	1.4
0.04	150.0	2.9
0.05	37.0	2.0
0.05	151.0	4.4
0.05	153.0	1.7
0.07	19.2	1.25
0.07	36.0	3.0
0.14	12.7	1.1
0.15	12.8	1.3
0.17	12.9	1.4
0.19	12.0	1.4
0.20	12.6	1.5

Scan Time	105 min
Resonant Frequency Tests	220 min
Total Test Time	325 min (5 hr 25 min)

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