DROP TESTING AT THE OAK RIDGE NATIONAL LABORATORY

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Abstract

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Two full-scale packages designed to carry radioactive materials were drop tested at the Oak Ridge National Laboratory. The unique aspects of the tests are described. The first drop test series involved the 22 700 kg (50 000 lb) TRUPACT package. Because of the substantial thickness of foam insulation in the walls and the thin, outer steel shell, the rigging of the package for the series of seven drops was carefully designed not to cause damage to the package during the testing. Each impact had the potential to change the position of the waste containers inside the TRUPACT package. As a result, the centre of gravity (c.g.) of the package was determined between drops. The rigging was adjusted to ensure that the c.g. was in the proper location for the subsequent tests. Following the drop, the TRUPACT package was transferred to Sandia National Laboratories for further tests and evaluations. In the second series of tests, a full-size steel canister, constructed to transport spent Three Mile Island fuel, was dropped. These tests were designed to subject the package to the same shock environment it would experience if the cask carrying a similar canister were subjected to a 9 m drop as specified in the regulations. Energy absorbers were designed to provide the proper decelerations. One unique aspect of the tests involved the surrogate fuel, located inside the canister, which was frozen to ensure that the poison rods inside the canister would be subjected to a severe shock load. The package survived the tests as predicted.

1. INTRODUCTION

Recently two different types of packages were drop tested at the Drop Test Facility [1] located at the Oak Ridge National Laboratory (ORNL). The first involved the TRUPACT overpack, and the second involved a canister designed to carry pieces of spent fuel. This package weighs approximately 16 000 kg (35 000 lb) empty and 22 700 kg (50 000 lb) when full. While the test package was being fabricated, strain gauges and accelerometers were installed at predesignated points on structural members inside the 30 cm (1 ft) thick walls. The package was then transferred to Sandia National Laboratories (SNL), loaded with surrogate waste, placed on a flat-bed truck and transported to ORNL.

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Because the TRUPACT package is 7.6 m (25.1 ft) long, the impact surface had to be lengthened. Two 1.2 m by 2.4 m steel sheets were welded to the end of the armor plate impact surface to accommodate the long package.

Within the constraints stipulated in the regulations [2,3], the sequence of the tests and their specifications were developed by SNL staff members. Both normal operating, and accident test sequences, were carried out; a summary of tests performed on the cask is listed in Table I.

Table I. TRUPACT Drop Tests

Height of drop (m)	Type of drop	Point of impact
0.33	Impact	Flat bottom
9	Impact	Longitudinal edge
9	Impact	Corner
1	Punch	Flat bottom
1	Punch	Flat end
1	Punch	Corner
1	Punch	Door seal area

The package was instrumented with 7 accelerometers and 40 strain gauges; however, not all of these were utilized in every drop test. A microprocessor-controlled activation system was developed to maintain complete control over all phases of the tests.

The significant aspects, insofar as ORNL participation in the program was concerned, involved the rigging and handling of a thick-walled overpack, which has relatively soft sides. In addition, the penetrator used in the punch test was very long because of the package geometry and specified points of impact.

2. TRUPACT TESTS

The TRUPACT system [4] is a Type B package designed to transport TRU waste to the Waste Isolation Pilot Plant (WIPP) located in Carlsbad, New Mexico.

2.1 Rigging and Suspension System

The outer skin of the package is constructed of 0.31 mm (0.012 in) thick corrugated stainless steel, which functions primarily to protect the package from weather. Because this outer shell is thin, it was important to protect the package during handling. As a result, ORNL rejected the single-point release concept in which the package is held up by cables that come to a single common point, from which it can be released. Even though such a system is desirable from a safety point of view, the suspension hardware could damage the top surface of the TRUPACT. Therefore, it was necessary to suspend this package from 1.90 cm (0.75 in) diameter cables, adjusting them to achieve the proper drop attitude and cutting them as close to the package as possible. Two cable cutters were used on each of the suspension cables; this redundancy ensured that the failure of one cutter to actuate properly would not jeopardize the tests or the facility.

For most of the tests it was necessary that the center of gravity (c.g.) be over the point of impact. Since the payload of the TRUPACT was not symmetric with respect to the external dimensions, and since the c.g. changed as a result of each test, its approximate location had to be determined between each test. This was done by balancing the package on a beam on each of three undamaged faces. The technique proved to be highly successful.

The forged ISO corners designed as tie-down points for the package were utilized as points of suspension for the tests. The attitude of the package was varied by adjusting the length of the appropriate cables prior to each drop.

2.2 Impact tests

A microprocessor-controlled activation system was developed to maintain complete control over all phases of the drop tests. These phases included: (1) start of tape recorder, (2) start normal-speed cameras, (3) start high-speed video recorder, (4) start high-speed cameras, (5) start safety light and audio alarm, (6) check continuity of cable cutter firing circuit, (7) deliver 12 V DC to actuate cable cutters at a preset time, (8) shut down all systems and (9) reset. A system of feed-back signals was employed to ensure that each step in the sequence was initiated and that the equipment was operating properly before the cable cutters were activated. A signal light would indicate any malfunctioning subsystem; the malfunction must be corrected and the system reset before the test sequence can be restarted.

The TRUPACT was first dropped from a height of 30 cm (1 ft) on its flat bottom. The package was suspended from the four top ISO corners. All cables were the same length and rigging the package for a flat drop was straightforward. The sequencer worked as expected and all eight cable cutters were actuated. The package dropped and sustained only cosmetic damage.

The first 9 m drop was on a longitudinal edge of the package. A V-shaped support structure was fabricated to hold the package in the proper suspension and release attitude. Because the package was not square in cross section and the c.g. was not in the geometrical center of the package, the suspension cables had to be carefully adjusted. They were attached to the two ISO

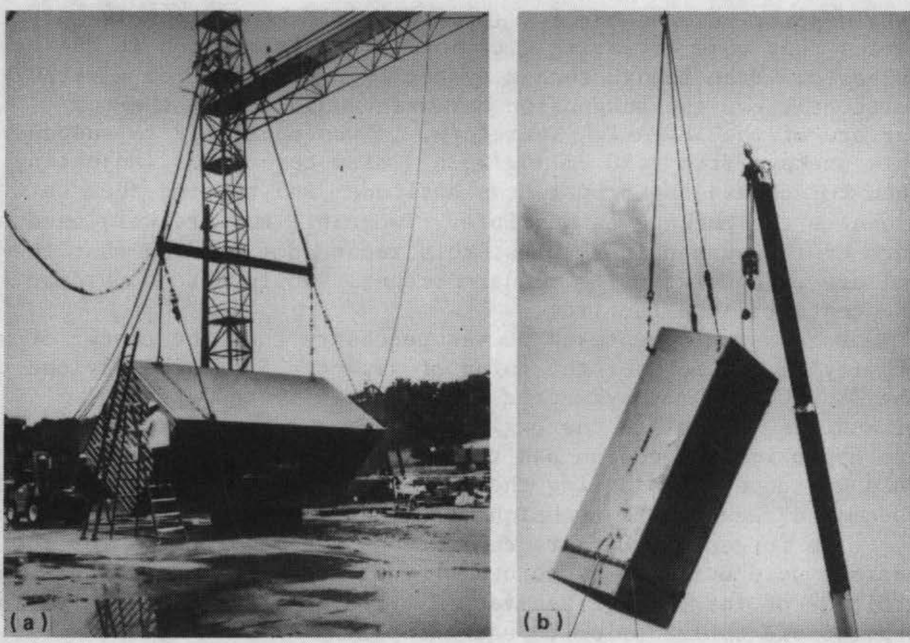

FIG. 1. TRUPACT rigging used for (a) the first 9 m (side) drop and (b) the second 9 m (end) drop.

corners diagonally opposite the impact edge and terminated at a longitudinal I beam which acted as a level support point (see Fig. 1(a)). Angle adjustments were made by connecting two cables between the I beam and the lower of the two nonimpact edges. These cables were shortened until the proper release and impact attitude were achieved. The sequencer worked properly and the package dropped, impacting at the correct angle; it rolled on its side, where it came to rest. The physical damage was slight, accelerometer and strain-gauge values were recorded. The package was checked and found to be leaktight.

The package was then prepared for the second 9 m drop. Since the impact point was to be a corner next to the closure, the support cables had to be attached to three ISO corners of the nonclosure end (see Fig. 1(b)). The package was raised to a height of 9 m and the sequencer was activated. All peripheral equipment started on time in accordance with the preprogrammed sequence and the package was released in the proper attitude. Following the initial contact with the pad, the package toppled over, impacting again on an edge. The initial impact crushed the corner, but the package received a significant amount of crush damage to its edge and side when it fell over. The closure seals were checked and found to be functioning properly.

2.3 Punch tests

Four punch tests were carried out on the TRUPACT. The punch was designed to be about 2 m (6.5 ft) long to ensure that the package sustained maximum damage from the penetrator. The punch was welded to the surface of the impact pad and was instrumented with strain gauges so the impact forces could be studied.

The TRUPACT wall is thick and composed of foam insulation, punch panels and other structural members. In each of the four punch tests, the punch penetrated from about 15 cm (6 in) to over 1 m (3 ft), depending upon the impact angle and the point of penetration. As the package fell off the penetrator, it frequently tore chunks of insulating material out of the wall. Further damage was inflicted each time the package fell over and struck the impact surface.

2.4 Results

Even though this package had to be handled carefully, the rigging and release systems worked well. The penetrator, as rugged as it was, still bent during two of the punch tests because of the package geometry and the angle at which it struck the internal steel shell.

3. DROP TESTS ON A TMI-2 DEFUELING CANISTER

Recently, another series of drop tests have been carried out to confirm the design analyses on a TMI-2 defueling canister. Three types of canisters have been designed for defueling the TMI-2 core. The three canisters function as receptacles for the core debris during the defueling operation and as long-term storage containers afterwards. The three canisters are identified as: (1) fuel, (2) knockout and (3) filter, but all have common external dimensions. Each of the canisters has a different upper head design in order to facilitate the various defueling techniques developed to accommodate the large range of fuel sizes found in the reactor. One of these, the knockout canister, has internal poison rods designed to maintain a critically safe mass even in the most reactive configuration (see Fig. 2). It is this canister that was physically tested to confirm that the nuclear poisons will remain in place even if the cask that transports the canister is subjected to the hypothetical accident conditions [2,3].

A full-scale prototype of the knockout canister was fabricated and sent to ORNL before being assembled. The canister is 3.81 m long with an OD of 35.56 cm and a wall thickness of 0.64 cm. It has a 0.95 cm thick reversed-dish lower head and a thick-plate upper head that features quick-disconnect fittings, a handling grapple connection and a protective skirt. Internally, there are four small and one large steel tubes that contain B_4C

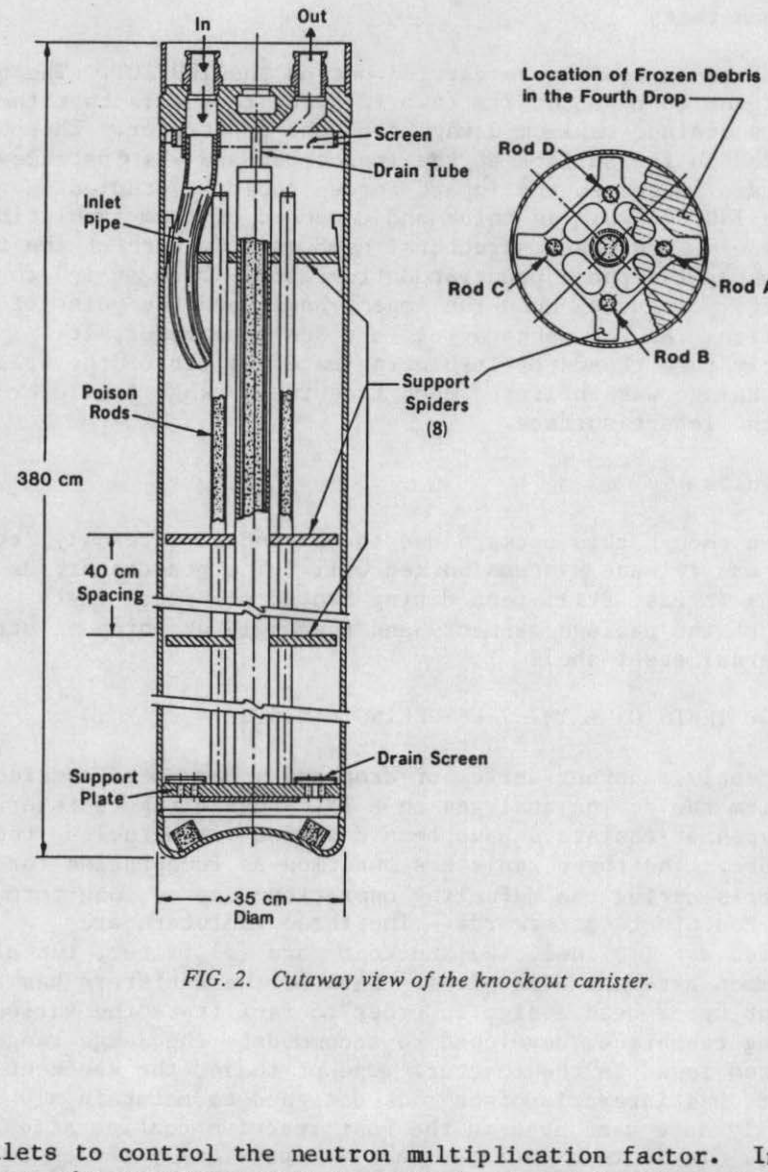

FIG. 2. Cutaway view of the knockout canister.

pellets to control the neutron multiplication factor. In actual usage, the canisters will be sealed, placed inside a shipping cask approved by the U.S. Nuclear Regulatory Commission (NRC) and transferred from the Three Mile Island reactor to the Idaho National Engineering Laboratory (INEL). At INEL they will be removed from the cask and transferred to a storage pool.

The knockout canister shell, head, lower head and internal poison rod assembly were sent to ORNL in separate pieces. The internal assembly was first taken to the metrology laboratory to measure the exact locations of the poison rods relative to their support spiders. These measurements became the base from which subsequent measurements, made after the drop tests, were compared. The canister was then assembled and welded together in accordance with the assembly drawings; it was then hydrostatically tested to 1550 kPa (225 psi) internal pressure. Following this, the canister was X-rayed from a number of predetermined angles to produce a base with which subsequent X-rays, taken after each test, could be compared.

The canister was filled with water. Surrogate fuel, in the form of 815 kg (1800 lb) of lead shot, was added through an inlet tube in the upper head. Excess water was removed and the gross weight of the canister was adjusted to approximately 1300 kg (2850 lb).

The unique aspect of these tests is the method used to create high forces on the canister internals. This effect was accomplished by placing the canister in a specific orientation in a refrigerator and freezing the lead shot water the package impacted; the weight of the frozen mixture would dynamically load the internal structure in a specific way. Details are discussed below.

3.1 The drop tests

A scale model of the cask in which these canisters will be placed was drop tested by SNL. Results of these tests indicated the expected decelerations that a full-scale canister would experience in a drop test of a full-scale package. As a result, ORNL designed an energy—absorbing system to be attached to a Cask Simulation Vessel (CSV) which would restrict the decelerations experienced by the canister to 60 to 80g axially and 90 to 110g density to desired levels. Densities of about 190 kg/m^3 (12 lb/ft^3) and crush strengths of approximately 193 000 kg/m^2 (275 psi) as measured by compression tests were found to provide the desired shock loadings.

The canister (see Fig. 2) was to be dropped on end (axially), having one of the internal poison rods loaded with the majority of the fuel weight at impact. In order to accomplish this, the canister was pressurized to 103.5 kPa (15 psig), placed horizontally in a specific orientation in a refrigerated truck and cooled to about -18°C (0°F). The lead-water surrogate fuel mixture froze around one of the poison rods. The canister was then removed and placed in the CSV which was equipped with an appropriately designed impact limiter bolted to its end. The pressure was readjusted to 103.5 kPa (15 psig). Two sets of triaxial accelerometers were attached to the top head of the package; signals were transmitted to signal conditioners and tape recorders via an umbilical cable. The canister (inside the CSV) was erected vertically, elevated to a height of 9 m and dropped. A system of cables prevented the CSV and its contained canister from falling over after the vertical impact.

The maximum vertical deceleration measured was 100g. The force of the impact drove the central poison rod down and bent a thin retainer plate on the internal bottom support plate. The internal pressure was measured to be 110.4 kPa (16 psig), this increase was due to the rise in temperature. The canister was transferred to the Inspection Department, where X-rays of the package were taken. No welds cracked and all poison pellets remained intact; the only damage incurred was to a retention plate that held the central poison rod in place. This damage was considered so slight as to be of no consequence.

The second test was intended to put high stresses on rod C. As in the first drop, the canister was placed in a refrigerated truck; this time, however, rod C was in the downward position. The surrogate fuel mixture was then frozen, and the canister was pressurized to 110.4 kPa (16 psig). The canister was slid into the CSV, with the surrogate fuel and rod C in the upper position relative to the direction of the drop and impact. The canister was held in position relative to the CSV with wooden wedges, and accelerometers were located on both its top and bottom.

The CSV was equipped with four energy absorbers arranged equidistant along its length so that the drop could be made with the canister and CSV in a horizontal attitude. The test piece was dropped from 9 m.

After impact, the canister pressure was found to be 110.4 kPa (16 psig), indicating that no leakage had occurred. Maximum accelerations of 160g and 120g were measured at the top and bottom ends of the package, respectively, the difference being caused because the bottom end impacted slightly in advance of the top end. The duration of the pulse was approximately 0.03 s. From a post-test inspection, there was no significant damage nor displacement to either the poison rods or support webs.

The third drop was conducted with the test piece in a vertical orientation but with the head down. The contents were not frozen, allowing the surrogate fuel to accumulate in the top section of the canister as it was erected in the upside-down position. The test piece, in the CSV, was then raised to 9 m and dropped. As before, a system of cables prevented the CSV and canister from falling over after the vertical impact.

Accelerometers attached to the canister bottom measured a maximum impact loading of 90g. The pressure was checked both before and after the drop and no leakage was detected. Post-test X-rays indicated that the upper two support plates bent slightly, approximately 1.5 cm (0.6 in).

To evaluate the effect of a torsional force applied to one of the poison rods by the fuel pieces, a fourth test was performed. The canister was placed in the refrigerated truck and positioned so that the surrogate fuel mixture would freeze around rod A (see Fig. 2). The canister was removed and placed in the CSV, which was equipped with four impact limiters to allow the test piece to be dropped in a horizontal attitude.

Accelerometers were attached to both the top and bottom heads. At the time of the 9 m drop, the canister temperature was 29°C and the internal pressure was 106.9 kPa (15.5 psig).

The test piece, including the CSV and its energy absorbers, was laid on its side. Because the large mass of surrogate fuel in the lower half of the canister was frozen around a poison rod, the canister was slid into the CSV with the frozen lead shot in a down position. The canister was then wedged tightly within the CSV and the test piece was rerighted to the normal drop orientation with the four impact limiters facing down. This arrangement resulted in the frozen fuel being located 90° from the direction of travel and would put a large torsional force on the canister upon impact.

Because the lead-ice mass in the canister was rotated relative to the (vertical) center plane of the test piece, its c.g. no longer lay in the center plane. The test piece, therefore, did not hang in a vertical attitude when suspended from lifting lugs located in the center plane of the test piece. When the CSV was released, it rotated slightly and impacted at about a 22° angle from vertical. At this angle the energy absorbers were only partially effective, crushing slightly before shearing the foam blocks at a 45° angle. With only part of the impact energy dissipated, the top heavy test piece rotated about 90° and struck the armor plate surface of the impact pad. The accelerometers on the canister bottom and top indicated initial vertical loadings of 63g and 94g, respectively. The second impact, as the CSV hit the armor plate, sent the accelerometers off-scale, above 250g. The second load was sustained over a 0.1 s time period. The internal pressure remained the same as before the test, indicating that no leakage had occurred.

3.2 Results

Following the fourth test, the canister was moved to the machine shop, where the top and bottom heads were cut off. A third cut, just above the bottom support plate, was made which allowed the internals to be slid out of the canister shell. The separation was made easily, even though two of the support webs had minor deformations. A visual inspection of the major subassemblies was made. All poison rods appeared to be straight, and all welds undamaged. No surrogate fuel had migrated below the bottom support plate.

Post-drop-test measurements were made and compared with those taken before the tests were carried out. In general, very little deformation was found. A maximum displacement of 0.45 cm was found on two of the four outer rods. The two support webs that bent had displacements of 1.40 and 0.75 cm, but this condition did not affect the position of the outer rods.

In summary, while a unique method was used to create high forces on the internals, no significant deformations occurred in the knockout canister as a consequence of the drop testing. Criticality calculations, based on the range of possible tube locations, have been found to be well within the assumptions used.

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