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Early Accident-simulating Testing of Radioactive Material Packages in Road Vehicles

Ronald B. Pope, Consultant
11262 Weatherstone Drive
Waynesboro, PA 17268, USA

Lawrence B. Shappert
129 Cumberland View Drive
Oak Ridge, TN 37830, USA

Chris Taylor
The Pumping Station, Mill Lane
Sutton Courtenay, Abingdon, OX14 4BE
United Kingdom

Robert A. Vaughan
Croft Associates Ltd
B2 North Culham Estate
Culham, Abingdon, Oxfordshire, OX14 3GY
United Kingdom

ABSTRACT

Beginning as early as the 1960s, concerns were voiced as to the adequacy of the package test standards imposed by the Transport Regulations promulgated by the International Atomic Energy Agency. One concern that was frequently raised, and has continued to the present time, is that the test standards do not necessarily simulate real accidents. The purpose of the crash tests and the fire test described here, which were done with typical packages carried in full-scale vehicles, was to assess the IAEA standards, their adequacy, and to suggest changes that might be needed to them. They were also performed with a view to showing regulators, users of the regulations, and members of the public that current regulations already provide a very high level of safety for real-world accidents. The tests were performed in the United States of America and in the United Kingdom. With the passage of time, much of the original information regarding these tests and their results has been lost. The few documents that remain have been surveyed. This paper presents brief summaries from this survey of the tests and their results. A significantly expanded version of this paper has been published in Vol. 18, No. 2 of the international journal "*Packaging, Transport, Storage & Security of Radioactive Material*".

INTRODUCTION

Since the time package test requirements were first introduced in 1964 into the international Regulations for the Safe Transport of Radioactive Material [1], questions have been asked as to how well the prescriptive tests cover potential real accident situations, and whether the regulatory acceptance requirements are adequate. Tests simulating accidents involving Type B, Type A and excepted packages used for transport of radioactive material in road vehicles were first performed as early as the mid-1960s. This paper refers back to some of this very early work, with a view to summarizing in a single document the results of two sets of such tests. Little original information on these tests remains available in published form; therefore one purpose of this paper is to provide summary documentation of the tests for future reference.

The first set of tests addressed in this paper was performed in 1966 as a joint effort by the United States Atomic Energy Commission (US AEC) and the Department of the Army (US DOA) at the DOA's Aberdeen Proving Ground facilities. The authors have used documents dating from that period to provide the summary of this first set of tests including the test plan for this effort [2], a document summarizing the tests and their results [3], and handwritten and informal notes from that period of time. The second set of tests addressed in this paper was performed by Amersham International at a Motor Industries Research Association (MIRA) facility in the United Kingdom (UK) in the late 1970s. The authors have used a paper presented at PATRAM 80[4] to provide the summary of this second set of tests. The authors acknowledge the many researchers who were involved in both test programs.

HIGHWAY VEHICLE TESTS IN THE USA

Four highway vehicle impact tests were performed during 1966 at the Aberdeen Proving Grounds. The goal of these tests was to advance the ability to describe the dynamics of transport accidents. Three different combinations of truck tractors and semi-trailers and two types of cargo were used. The loaded vehicles, remotely operated, were impacted into a massive barrier. The impacts occurred at velocities ranging from 6.4 to 66 km/h. For these early tests, photographic measurements provided the most meaningful description of the dynamics of the impacts. Although the dynamic measurements and the mathematical modelling were not successful, "*sufficient structural and transportability data were gained to assure a positive approach for evaluating the dynamics involved*". [3]

Test Facility and Control of Tests

In all four tests, the vehicles were remotely driven down a 12 m wide paved roadway. The vehicles used their own motive power, and were controlled remotely using an instrumentation/control van connected by an umbilical cable. A barrier was located at the end of the paved roadway, and the test vehicle impact occurred with the instrument/control van trailing by approximately 27 m as is shown in Figure 1. The impact barrier was constructed of thick steel armour plate, braced with worn military gun tubes, having a total weight of approximately 317 t. The barrier was embedded in the roadway with a view to providing an immovable barricade.

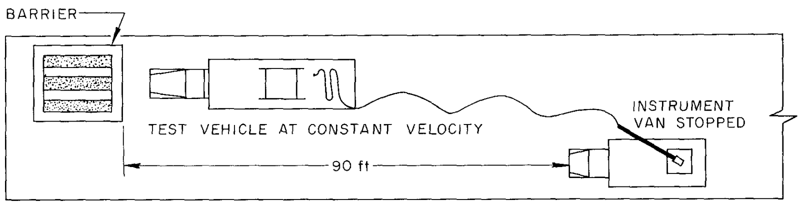


Fig.1. Schematic representation of the instrument/control vehicle used for remote operation of the test vehicle.

VehiclePackage Test Configurations and Results

A dry-run test was performed using a "cab-behind-motor commercial type tractor" pulling an empty van-type semi-trailer. The tractor trailer combination, with a total of three axles, had a gross weight of 8.1 t. This was an exploratory, non-destructive test with a low impact speed of 7.2 km/h, performed to evaluate the adequacy of vehicle control and the test set up and methods to be employed in the following three tests. Those three tests of truck-tractor vehicles loaded with packages, which are discussed here, were as follows:

Test 1 – The second test (identified here as Test 1) involved the same type of tractor/trailer as used in the dry-run test, except the roof of the trailer was removed to permit photographic coverage of the behaviour of the cargo during impact. With cargo, the test vehicle weight 20.4 t. This was a destructive test with an impact speed of 66 km/h. It involved loading the vehicle with 33 test packages of six different types used, at the time, for the transport of un-irradiated nuclear materials (nuclear materials are currently called "fissile materials" in the IAEA Transport Regulations [5, 6]). The six types of packages, the number of each included in the test, their locations on the vehicle, and the weight of the surrogate contents are summarized in Table 1. Two of the package designs were the so-called "birdcage containers"; one was a pipe located in a drum with metal spacers, and the other three designs were inner-containers placed in the centre of drums surrounded by solid material (Vermiculite or foamed boron-silicate glass) – see Table 1. The six package designs are depicted graphically in Figure 2.

The test packages were located longitudinally, in the centre portion of the trailer, on two levels. Since packages of nuclear material were frequently transported by common carrier and could be sandwiched between heavily loaded packages, 114- and 208-litre drums of crushed stone were placed in front of and behind the test packages. Each stone-filled drum weighed approximately 340 kg. In addition, the centre portion of the top level contained only empty 208-litre containers. The total cargo weight was 12.3 t. In the impact, the cab of the tractor was completely demolished and the fifth-wheel connection separated between the tractor and trailer, allowing the trailer to impact the barricade. Severe damage was inflicted on the forward section of the trailer. The impact was monitored with cameras, some of the results from which are shown in Figure 3. Figure 3a shows the tractor/trailer at a time just prior to impact (0 msec); while Figure 3b provides an overhead view of the test vehicle and its contents following the impact.

Because the top of the trailer had been removed for viewing during the impact, all of the test packages in the top rows (i.e. two of the ICC-6L packages, the five Union Carbide Y-12 Foamglass Shipping Containers, and the three Three-litre Class II Containers) were thrown from the trailer during the test. High-speed motion pictures taken during the event showed that these test packages moved forward in a crushing action, then laterally bowed outward and then suddenly burst upward and outward from the trailer to the ground.

Table 1. Six Types of Packages included in Test 1.

Package Designation	Number and Locations of Packages used in the Test	Approximate Weight of Simulated Contents
US DOT Specification Package ICC-6L (Combination of shipping container ICC-2R and ICC6J) [B of E Permit 1736]	5 in a bottom outer row; 2 in a top outer row	27.2 kg
Union Carbide "Birdcage" in Banded Plywood Box [B of E Permit 1685]	6 in a bottom inner row	22.7 kg
US AEC KKD-1 (or LLD-1)	7 in a bottom inner row	15.9
Eight-inch Schedule 40 Pipe inside a 55-gallon drum container	5 in a bottom outer row	61.2 kg
Union Carbide Y-12 Foamglass Shipping Container [B of E Permit 1561]	5 in a top outer row	22.7 kg
Three-litre Class II Container	3 in a top outer row (separated by ICC-6L packages)	9.1 kg

Detailed post-test measurements were taken of each package and are documented [3]. Many of the packages, depending upon their specific design, experienced significant dynamic crushing and were severely deformed. Table 2 lists each package design, and summarizes the effects the tests had on their integrity. The extent of axial compression (see footnote 1 to Table 2) was significantly greater for three of the package designs, whereas the extent of lateral bowing, or expansion, (see footnote 2 to Table 2) as shown in column three of Table 2 was much less significant than the axial compression.

The extent of axial compression of the different package designs varied significantly, from none to as much as 70 percent; while the extent of lateral expansion varied from none to as much as 25 percent. As a result, for those packages which experienced axial compression, the spacing necessary for ensuring proper criticality control of the nuclear material was reduced. In addition, three of the 7 US AEC KKD-1 may have lost containment, and all 5 of the containers in the Union Carbide Y-12 Foamglass Shipping Containers lost their containment.

<u>Test 2</u> – This test involved a "cab-over-motor tractor", which was pulling a flat-bed trailer with cargo; otherwise the configuration was the same as for the first two tests. For this test, and Test 3, the flat bed trailer was loaded with a single, carbon-steel/lead-shielded irradiated fuel cask, as depicted in Figure 4. The cask was 1.5-m high, and weighed 13.6 t. It is noted that this package design is no longer used for the transport of radioactive materials. The tractor/trailer/cargo combination, with a total of three axles, had a gross weight of 21.1 t. This was an exploratory test, intended to be non-destructive with a low impact speed of 6.4 km/h to evaluate the adequacy of vehicle control and the test setup and methods. However, the impact caused the frame of the tractor to buckle. As a result, the tractor for the next test (i.e. Test 3) was changed to a more robust tractor.

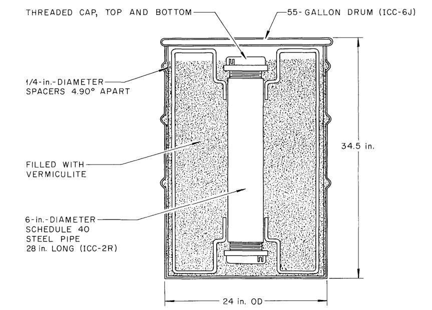
<u>Test 3</u> – This final test involved a military, three-axle "cab-behind-motor" heavy-duty military tractor, which was pulling the same trailer/cargo combination that was used in Test 2. This vehicle combination had a total of four axles (dual axles on the rear of the tractor), with a total gross weight of 22.3 t. This was a destructive test with an impact speed of 45.9 km/h.

As a result of the information obtained from Test 2, adjustments in test procedures allowed the tractor to impact the barrier squarely, but off centre to the extent that the left front wheel missed the barrier. The tractor was completely demolished during the test. The crushing of the tractor started to transmit significant force to the trailer at about 176 msec after initial impact, and the front end of the trailer impacted the barrier at about 340 msec after initial impact with an approximate speed of 41.9 km/h. The results of the impact at 780 msec are shown in Figure 5.

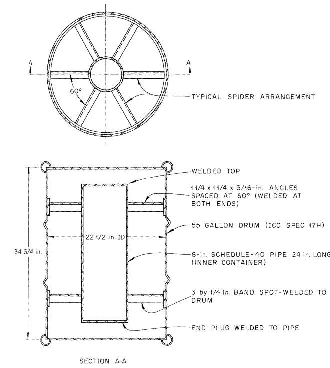
The frame of the trailer was permanently deformed from the impact. However, the cask remained attached to the trailer and no damage was detected to it. Deceleration of the cask was relatively low, estimated to be less than 4 g.

HIGHWAY VEHICLE TESTS IN THE UK

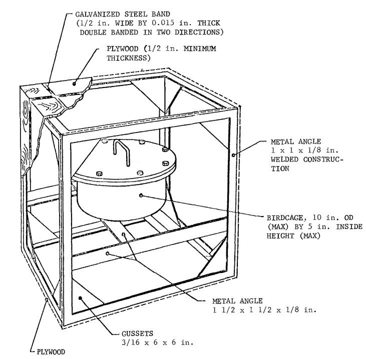
By the 1970s the packaging and transport of radioisotopes for everyday use – in medicine, research or industry – had become routine, with standard package designs regularly carried by all the ordinary means of public transport. Amersham International, alone, was shipping well over 300,000 radioisotope packages a year. By this time, standard “can-in-carton” Type A packages and fire-protected Type B drums were being used for most of these shipments. There were no known serious problems. Occasional damage to packages was being sustained during handling and transport but there had been only one case of serious radioactive leakage.



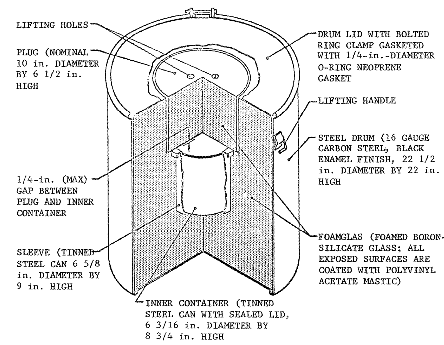
US DOT Specification Package ICC-6L



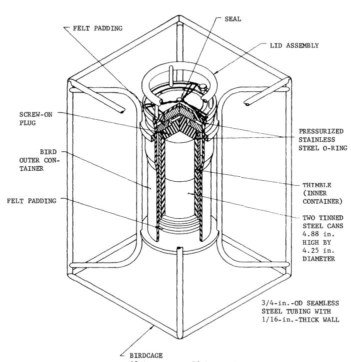
Eight-inch Schedule 40 Pipe inside a 55-gallon drum container



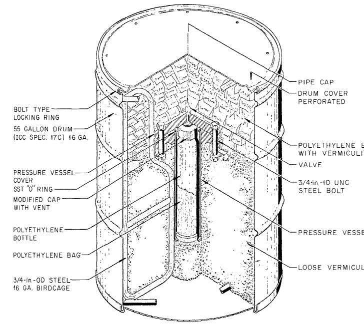
Union Carbide “Birdcage” in Banded Plywood Box



Union Carbide Y-12 Foamglass Shipping Container



US AEC KKD-1



Three-litre Class II Container

Figure 2. Graphical depiction of packages tested in the US.

All packages despatched by Amersham left the site by road in ordinary commercial vehicles. In order to address concerns about risks during this first stage of the journey, questions included what is the chance of severe impact or fire accident and what would the consequences be? Various organizations in the UK were contacted to assist in defining accident statistics and severities, including MIRA, but little information on these topics was available.

<u>Test Facility and Control of Tests</u>

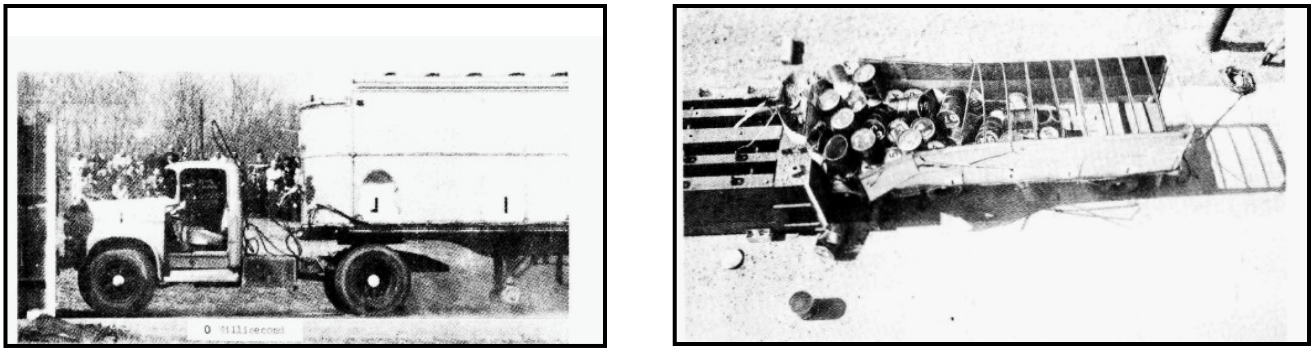
The tests were performed at a MIRA site on a disused airfield having an outdoor crash facility based on equipment used for launching gliders by winch & cable. Three written-off delivery vehicles happened to available at Amersham. It was decided to load them with typical radioisotope packages filled with surrogate materials and to subject them to crash tests under realistic conditions. The impact target was a 41 t concrete block. The driving force was an electric winch set up near the target. The cable from the winch, which passed through pulleys leading it under the concrete target, was attached to a small wheeled block running along a guide rail several hundred meters long. For each test the cable was pulled out along the guide rail and the vehicle to be crashed was linked to the block. A few meters before the end of the run a trigger released the cable from the block. The tests were performed with impact velocities ranging from 35 to 111 km/h. Afterwards a fire test was performed by pouring fuel on the ground underneath a crashed vehicle and igniting the fuel.

Table 2. Effects on Package Integrity of Test 1.

Package Designation	Extent of Axial Comp-ression[a]	Extent of Lateral Bowing[b]	Types of Damage Sustained	Remarks
US DOT Specification Package ICC-6L	0.44 – 0.68	1.10 – 1.21	5 packages on lower level: ▪ Two lost top covers and Vermiculite, ▪ Two had loose top covers, and ▪ One with top cover intact; where ▪ No visual damage observed to inner containers. 2 package on top level: ▪ Both were thrown from the trailer, ▪ One lost top cover and Vermiculite, and ▪ One with top cover intact.	Loss of top cover resulted in loss of Vermiculite spacing/shock absorbing material. No visual damage to inner containers. This design experienced the greatest extent of axial compression for drum-type package designs.
Union Carbide "Birdcage" in Banded Plywood Box	0.30 – 0.1.00	1.00	6 packages on lower level: ▪ Two with birdcages significantly crushed from 54.6 to 17.8 cm (21.5 to 7 in), spacing lost; and ▪ Four sustained negligible damage though some steel banding straps were broken	No apparent damage to nuclear material container (commonly known as "the Bird"). Some packages lost all spacing.
US AEC KKD-1 (or LLD-1)	0.44 – 1.00	1.00 – 1.25	7 packages on lower level: ▪ Forward 5 packages were crushed with all spacing lost, where 3 packages may have experienced loosening of threaded plugs in the containment vessels; and ▪ Back 2 packages experienced negligible crushing or damage	No apparent damage to nuclear material container. Threaded plugs that were loose following the test had not had tightness verified prior to the test.
Eight-inch Schedule 40 Pipe inside a 55-gallon drum container	0.80 – 0.89	1.00	5 packages on lower level: ▪ All 5 experienced slight crushing, and ▪ None experienced any apparent damage to the inner containers.	No loss of spacing. No apparent failure of nuclear material containment.
Union Carbide Y-12 Foamglass Shipping Container	0.86 – 0.96	1.00 – 1.02	5 packages on upper level: ▪ All 5 thrown from trailer, and ▪ All 5 retained top closure intact.	Four inner containers experienced "considerable indenting and some perforation of inner container". Containment lost on all inner containers.
Three-litre Class II Container	0.84 – 0.96	1.02 – 1.03	3 packages on upper level: ▪ All 3 thrown from trailer, but ▪ All 3 retained their integrity with their tops intact.	No damage sustained to nuclear material containment.

[a] The ratio of the final package dimension in the direction of travel (axial) to the original axial dimension.
[b] The ratio of the maximum lateral dimension following the test to the original lateral dimension.

The tests were monitored with still and motion photography. No instrumentation was used other than temperature-sensitive stickers attached to lead pots inside some of the Type B containers. Following the tests, the damaged packages were photographed after they had been transferred to the Atomic Energy Research Establishment (AERE), Harwell site. The negatives are preserved in Harwell's Photo Archives and can be accessed if needed [7].



(a) (b)

Fig. 3. Photographs of Test 1 (a) at 0 msec; and (b) post-test overhead view.

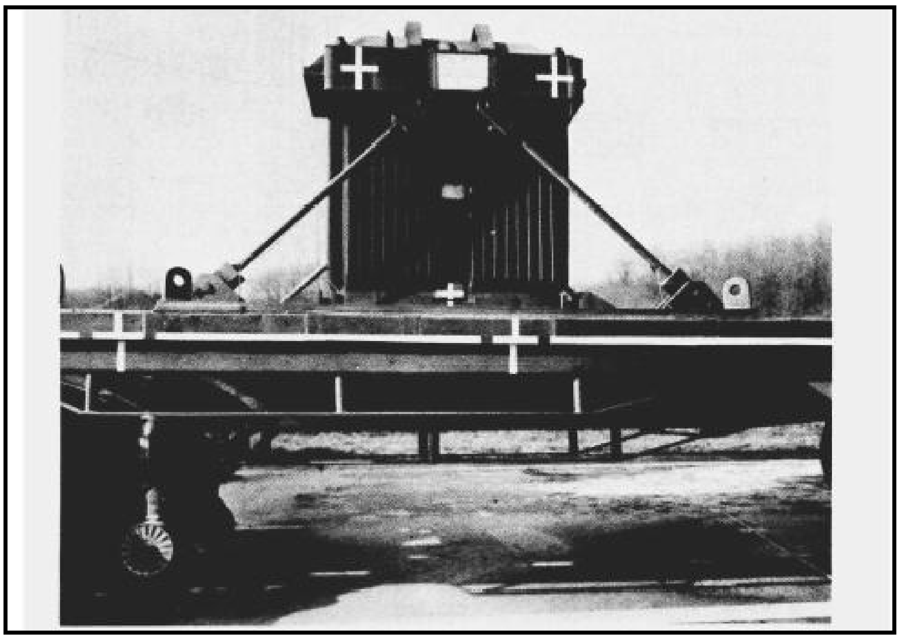


Fig. 4. Irradiated Fuel Cask used in Tests 2 and 3.

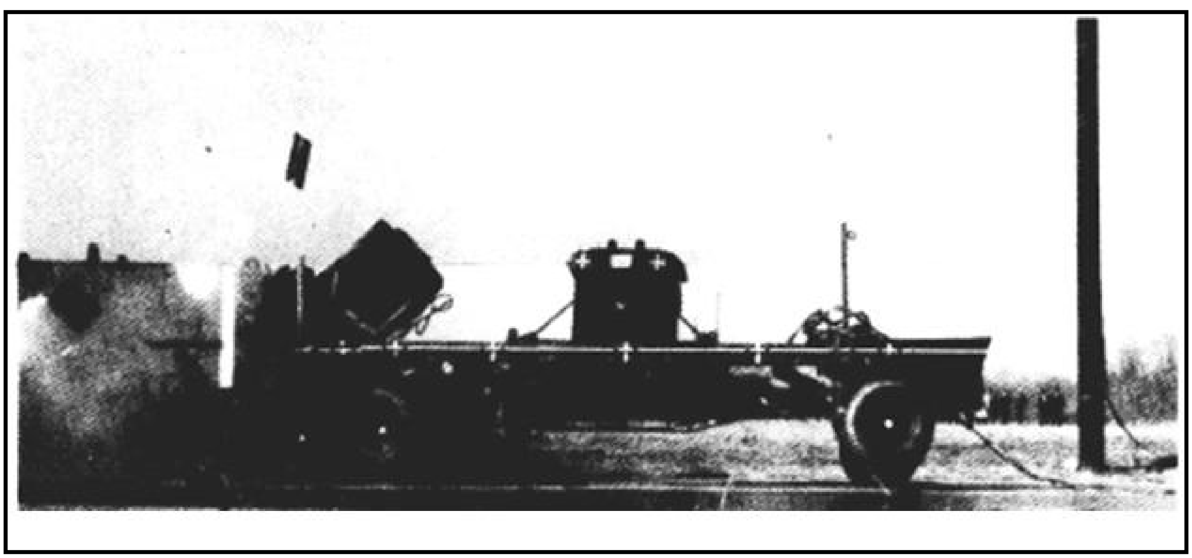


Fig. 5. Photograph of Test 3 impact at 780 msec after initial impact.

Vehicle and Package Test Configurations

Vehicle A was an open-backed truck, illustrated with its mixed load of packages in Figure 6(a). This open van was selected for the first test to allow visualization of the behaviour of the packages during impact. The figure shows the arrangement of the location of packages as loaded for testing, with many lightweight packages were stacked such that they would be targets for crushing by heavier packages loaded behind them. Vehicle B had the same chassis construction, dimensions and mixed package load as Vehicle A, but had a closed van back. Vehicles A and B were each loaded with 300 Type A packages of a kind then in common use, a metal can in an outer case of corrugated cardboard. In the trials, half the glass inner isotope containers were shielded with 3mm of lead; the other half were of moulded polystyrene. As surrogate for the liquid radioactive contents 10 ml of non-radioactive water was used.

In Vehicles A and B, 140 Type A packages were stacked loosely against the wooden partition behind the driver's seat. The remaining 160 Type A packages were placed in "overpacks", i.e. rigid cartons of corrugated cardboard. The Type B drums were of two types, 50 or 58 kg. Each held a 40 kg lead pot surrounded by a fire shield of bonded cork (i.e. granular cork bonded together with resin adhesive). The drums were arranged so that a column of four, and beside that a single drum, would impact overpacked packages; and a similar column of four and a single drum would impact those not in overpacks.

Vehicle C was a small conventional delivery van typical of those used to take partly finished radiopharmaceutical components between Amersham's production sites. This smaller van carried 72 Excepted Packages – radiopharmaceutical kits – stacked in front of six small Type A drums. Each kit was a moulding of expanded polystyrene containing 12 small glass bottles. The kits were stacked one above the other at the front of the load compartment. The drums were behind the kits in two parallel columns of three.

Results of the Tests

Tests of Vehicle A – Two impact tests were performed with Vehicle A. The first was at 35 km/h, the second at 111 km/h. During the first, low-speed impact, the drums moved forward among the cartons and then rebounded to near their original positions. In the second higher speed impact many of the cartons were severely damaged, the drums rebounded to the back of the vehicle, two were thrown out onto the road, and the upper layers of overpacks and free cartons were thrown violently upwards, some reaching a height of 5 m as shown in Figure 6(b). Some of the smaller drums were compressed to three quarters of their original diameter and their lids were buckled and forced off.

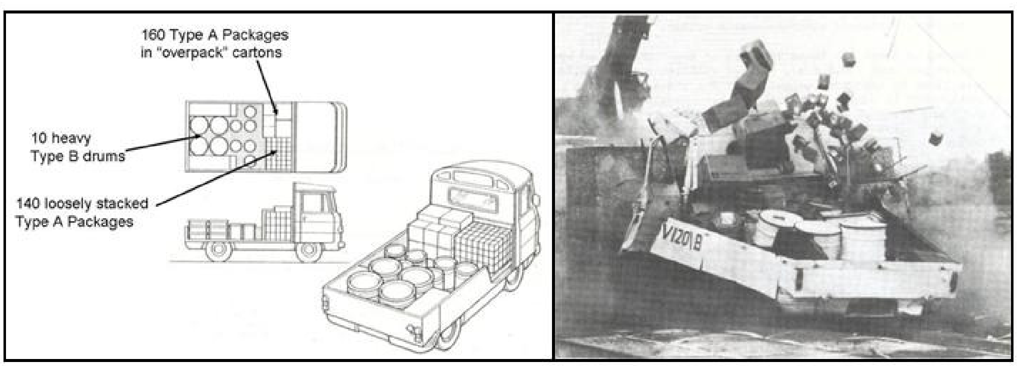


Fig. 6. (a) Graphical depiction of Vehicle A used in the UK tests; and (b) Impact of Vehicle A at 111 km/h.

Tests of Vehicle B – The impact of vehicle B at 71 km/h caused similar but milder damage than was experienced in the higher-speed impact of Vehicle A. As the Type B drums rebounded they burst open the doors at the back of the vehicle and one fell out. No drum lost its lid. A fire test of the damaged Vehicle B, with its packages still inside**,** was then performed. The fire test was started by igniting 40 litres of petrol poured onto the ground under the van. Flames took hold very quickly, setting fire to the tyres and rising into the driving compartment from which they streamed out through the broken windshield (Figure 7(a)). The cardboard of the cartons was set alight by heat rising through the metal floor and burned fiercely, air for combustion entering through the burst-open rear doors and broken windshield. Within 12 minutes loud reports were heard as air inside the cans expanded and forced lid seams to snap open. The van interior appeared to be filled with flames. Cork fire shields in the Type B drums contributed to the blaze, jets of flame bursting out as their lids bulged outwards and lid gaskets failed. Eventually all the cartons and overpacks were burnt away, leaving a disordered mass of charred cans and drums (Figure 7(b)).

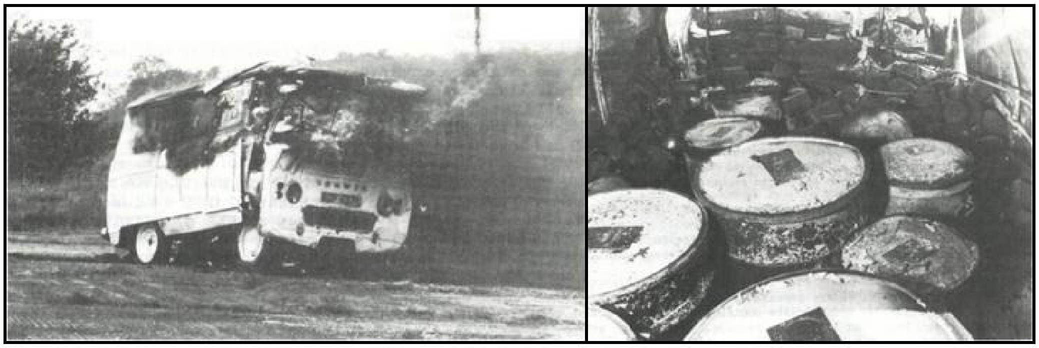


Fig. 7. (a) Vehicle B during the fire test; and (b) damaged packages after the fire test of Vehicle B.

Tests of Vehicle C – This vehicle was impacted at 111 km/h. During this impact, the drums demolished the two lower stacks of Exempt Packages, reducing the kits to broken pieces of polystyrene and scattered bottles. Details of the results of these tests are summarized in Reference [8]. The impact tests showed that Type A packages in overpacks were if anything damaged less than those that were stacked loosely. It was concluded that overpacks add to safety when large numbers of small items are transported**,** not only reducing damage in accidents but also by preventing loss of individual packages, reducing damage by cargo handling equipment, and making it easier to recover packages after an accident.

CONCLUSIONS

The two series of tests summarized in this paper provided early insight into the adequacies and inadequacies of the package test requirements, and their operational requirements, provided by the then existing Transport Regulations. The tests helped guide future actions in planning similar accident-simulating tests, and helped guide later efforts in assessing the need for changes in the regulatory requirements. An expanded version of this paper has been published in Vol. 18, No. 2 of the international journal "*Packaging, Transport, Storage & Security of Radioactive Material*"[8], which includes further details concerning the packages tested, the results of the test measurements, the basis of the conclusions and the impacts these tests had on guiding later changes to the Transport Regulations.

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