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Physical and Chemical Evidence Remaining After the Explosion of Large Improvised Bombs. Part 3: Firings of Calcium Carbonate Ammonium Nitrate/Sugar

REFERENCE: Lowe AM, Marshall M, Walker CL, Hubbard P. Physical and chemical evidence remaining after the explosion of large improvised bombs. Part 3: Firings of calcium carbonate ammonium nitrate/sugar. J Forensic Sci 2001;46(3):535–548.

ABSTRACT: The collection of both physical and chemical evidence from the scene of a large bomb can be useful in determining the type of explosive charge used and also its approximate size. A shortage of practical experience of such explosives on a large scale can hinder the collection and interpretation of such evidence. Six charges of calcium carbonate (limestone) ammonium nitrate/sugar (LAN/S) improvised explosive devices were fired (three at 454 kg and three at 2268 kg) together with one charge of 2,4,6-trinitrotoluene (TNT, 454 kg) and one charge of ammonium nitrate fuel oil (ANFO, 2268 kg). The charges were surrounded by vehicles, roadsigns, and lampposts that acted as witness material to provide both physical and chemical evidence. Analyses showed that ammonium, higher levels of nitrate, and some sugars were recovered from the LAN/S firings; low levels of nitrate from the ANFO firing; significant levels of TNT from the TNT firing. Levels of recovery generally decreased with increasing distance from the charge. The pattern of physical damage to the witness pieces at given distances from the charge was recorded. The velocities of detonations were measured and the corresponding TNT equivalence calculated.

KEYWORDS: forensic science, improvised explosive device, fertilizer, ammonium nitrate, sugar, witness materials, chemical residues, physical damage, velocity of detonation, TNT equivalence

Following detonation of a terrorist bomb, one main task is to identify the explosive charge type and its approximate size. Both physical and chemical evidence can be used. The physical evidence recovered from the scene can be useful in determining the general nature of the explosive, while the chemical traces recovered from nearby debris and witness pieces can provide an identification of the explosive type and composition. The collection of physical evidence immediately following a large terrorist bombing is hindered by a shortage of practical experience of such explosives on a large scale. Four sets of trials were performed over a three-year period. This paper describes the third in the series of trials. The experimental methods used are detailed in a previous publication (1).

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Eight firings were performed comprised of three charges of 454 kg and three charges of 2268 kg of calcium carbonate ammonium nitrate (21% calcium carbonate)/icing sugar (LAN/S), one charge of 454 kg 2,4,6-trinitrotoluene (TNT) and one charge of 2268 kg ammonium nitrate fuel oil (ANFO). The charges were surrounded by 4 vehicles and 10 or 19 UK roadsigns and 5 or 9 US roadsigns. Two lampposts were used to provide bend angle and damage information for two 2268 kg and one 454 kg LAN/S charges.

The experimental methods used are described in previous publications (1,2). In the interests of public safety, precise details of the charge preparation have been omitted; however, bona fide enquirers may apply for more detailed information by writing to the authors.

Materials, Preparations, and Procedures

Test Site Location

All firings were performed at the High Performance Magazine (HPM) Site, New Mexico Institute of Mining and Technology (NMT), Socorro, New Mexico 87801, USA. This site is at an altitude of approximately 1900 m above sea level.

Calcium Carbonate Ammonium Nitrate/Sugar Charge Configuration

The calcium carbonate ammonium nitrate (LAN) fertilizer, 21% calcium carbonate, was received in prill form from the manufacturers and ground to the required particle size prior to mixing with confectioners sugar. Samples of the prepared charges were taken at the beginning, middle, and end of the preparation of each charge and returned to the FEL for composition analysis. The particle sizes present in the charges were checked by sieving, and the sugar content was checked by polarimetry. The components present in the charges were adequately characterized and the correct composition determined. The LAN/S charges were prepared and loaded into open top cylindrical containers. Two smaller charges, 454 kg, were placed in steel containers (96.5 cm high by 96.5 cm diameter, 0.34 cm wall thickness) and a third 454 kg charge placed in a cylindrical plastic container with a lid (129.5 cm high by 91.4 cm diameter). The plastic container was made from high-density polyethylene (HDPE) and had a capacity of 757 L. The three 2268 kg charges were placed in steel containers (152.4 cm high by 152.4 cm diameter, 0.34 cm wall thickness). Detonation velocities were measured using six piezoelectric pins placed vertically at the base of the charge and four piezoelectric pins placed radially at the top of the charge (Fig. 1). The charges were transported to the test site and positioned on frames (height 0.76 m), simulating the height in the back of a vehicle. Steel frames were used for the steel charge containers, and a wooden frame was used for the plastic container. A suitable booster was placed in the charge and detonation initiated electrically.

TNT Charge Configuration

The charge was prepared by NMT staff prior to the trial. 454 kg of TNT was cast in an open top cylindrical steel container (81.3 cm high by 81.3 cm diameter, 0.34 cm wall thickness). The charge was transported to the test site and positioned on a steel frame (height 0.76 m), simulating the height in the back of a vehicle. A suitable booster was placed in the charge and detonation initiated electrically.

ANFO Charge Configuration

The ANFO used was commercially available from ICI Explosives USA Inc. The ANFO was supplied in pellite (prill) form in 22.7 kg plastic bags. 2268 kg of pellite ANFO was placed in an open top cylindrical steel container (182.9 cm high by 182.9 cm diameter, 0.34 cm wall thickness). The charge was transported to the test site and positioned on a steel frame (height 0.76 m), simulating the height in the back of a vehicle. A suitable booster was placed in the charge and detonation initiated electrically.

Measurement of Blast Pressures

Ten pressure gages (PCB type pressure transducers with built in line amplifiers, Piezoelectronics Inc.) were located at ground level at distances of 5, 15, 30, 46, and 60 m from the charge. Four pencil pressure gages were also used. These were located at distances of 30, 46, and 60 m from the charge. The pencil gages were approximately 1 m above the ground and protected with a fragment protector positioned 2.44 m in front of the gage.

Velocity of Detonation Measurements

Six piezoelectric pins were placed axially at the base of the charge, and four were placed radially at the top of the charge in order to determine the velocity of detonation (VOD).

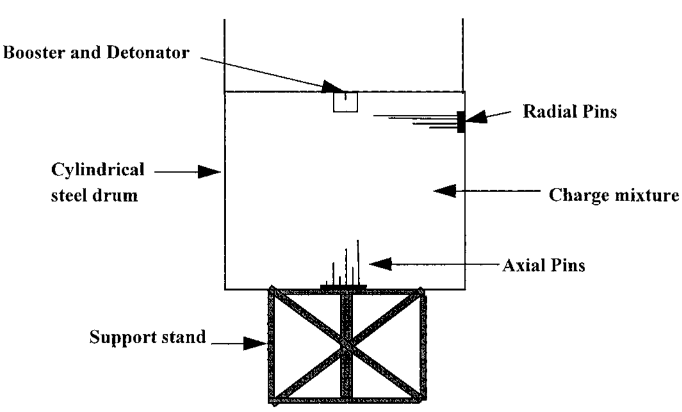

FIG. 1—*Diagram of charge.*

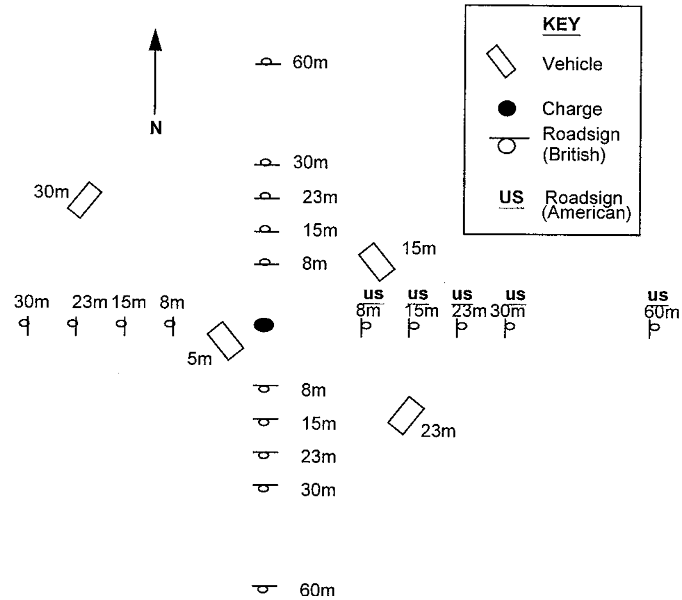

FIG. 2—*Site plan for 454 kg charges.*

Witness Materials

Vehicles and roadsigns were used as witness pieces in all eight firings as they are representative of those that would be found at a real scene. The UK roadsigns were aluminum with dimensions 460 by 300 by 2.7 mm thick with a class 2 PVC reflective face, gray back, and fixing rails supplied with posts and attachment clips. The signs were mounted on hollow steel posts (3.7 m length) that were buried 0.6 m beneath the ground surface, which was tamped to provide support. The signs were mounted with the lower edge 1.8 m above the ground surface with the longest side horizontal and the front facing the charge. The US roadsigns were also aluminum with dimensions 460 by 310 by 1.7 mm thick. The signs were mounted on channeled steel posts (3 m length), which were also buried 0.6 m beneath the surface of the ground, which was tamped to provide support. The signs were mounted with the lower edge 1.8 m above the ground surface with the longest side vertical and the front facing the charge. Between 9 and 19 UK roadsigns were used together with between 5 and 9 US roadsigns for each firing. Four vehicles, mostly medium size saloon cars, were placed side on to the charge at distances that varied with the size of the charge. Locations of the witness materials can be seen in Figs. 2 and 3. Lampposts were positioned 23 m north west of the charge for the three firings concerned.

Preparation of Materials for the Collection of Inorganic Residues

Sampling kits were prepared at the FEL suitable for inorganic residue collection. The sampling materials were contained in resealable plastic "Securitainer" pots, each pot containing five snap top glass vials (10.5 mL), a packet of five cotton wool swabs, five disposable plastic forceps, five pairs of disposable gloves, labels, notepaper, and pen. The cotton wool swabs were prepared by soxhlet extraction with water followed by two extractions with acetone and vacuum drying. The dry swabs were sealed into nylon bags, five per bag. A number of swabs and one complete kit were quality assured (1,2) to ensure that they were free from ammonium, magnesium, calcium, nitrate, and sugar. The swabs were found to

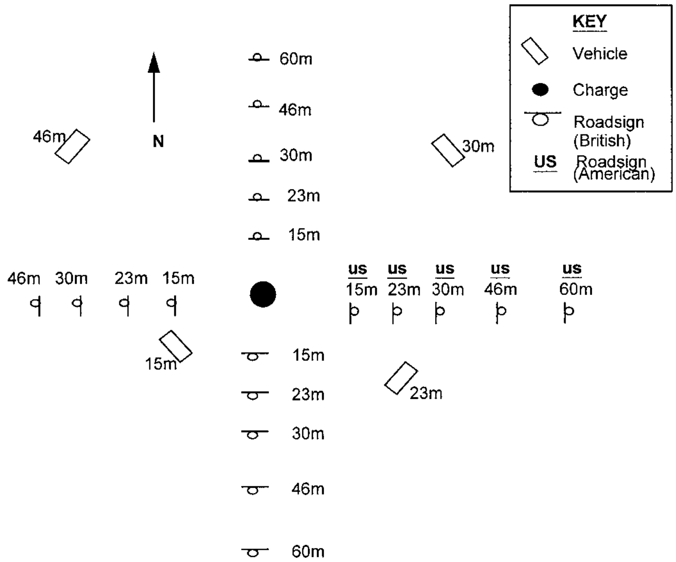

FIG. 3—*Site plan for 2268 kg charges.*

contain only very small amounts of calcium (less than 2 μg per five swabs) and nitrate (less than 0.5 μg per five swabs). Some calcium was found to be present in the kit at a level of 0.4 μg.

Preparation of Materials for the Collection of Organic Residues

The organic sampling kits were taken from a supply in the FEL that had previously been prepared and quality assured in the trace laboratory. The kits were similar to those used for the inorganic sampling. Each kit was contained in a resealable plastic "Securitainer" pot, containing ten snap top glass vials (10.5 mL), twenty cotton wool swabs, five disposable plastic forceps, two pairs of disposable gloves, notepaper, pen, self-seal polythene bags, and a bottle of ethanol solvent. All the quality assured kits were found to be free of explosive contamination.

Preparation of Witness Materials

Before the trial the UK roadsigns, fixing clips, screws, bolts, and washers were washed with deionized water, allowed to dry, and wrapped in clean nylon bags (2). Several washed signs and clips were quality assured to ensure that they were free from ammonium, magnesium, calcium, nitrate, and sugar.

The preparation of the witness materials and the layout of the site were similar to previous trial work (2). Once at the site, the UK signs were removed from the outer bag and mounted onto the posts keeping the inner bag as intact as possible. These bags were removed immediately before firing after the placement of the booster in the charge. The US signs were assembled into position and the side facing the charge was washed with deionized water, provided by NMT. Control swabs were taken from the US signs prior to the firing. The reverse of all signs were marked in each corner for identification.

Once each charge had been placed in position at the test site, the sample areas of the cars were washed with deionized water. The sample areas were marked on the doors by drawing around an A4 card frame (area approximately 0.06 m^2). Control swabs were taken from each marked area of the vehicles immediately prior to firing. The control samples were taken using deionized water for the LAN/S and ANFO firings, while the ethanol from the organic recovery kits was used for the TNT firing. Kit controls of swabs and solvent were also prepared.

Soil samples were taken from two randomly selected areas of the test site before each firing.

Collection of Chemical and Physical Evidence

Following detonation, chemical and physical evidence was collected by "clean" personnel (those who were not involved in the grinding and mixing of the LANS) wearing disposable oversuits, boots, and gloves (1,2). Swab samples were taken immediately from the cars from the same areas as the controls. The UK roadsigns were detached from their posts and sealed into clean, pre-labeled polythene bags for residue analysis back at the FEL. The US signs that remained on their posts were swabbed to recover the residues, the analyses of which would be carried out at the FEL. Any signs that had fallen to the ground were bagged and retained for physical damage reports only.

Recovery of Residues from UK Roadsigns

The sampling of the signs was carried out at the FEL using the above mentioned inorganic sampling kits. Only UK signs that remained on their posts after the firings were sampled. Those signs that were recovered from the ground were inspected for physical damage only. The signs were sampled both front and back with separate swabs giving two samples per sign (2). The bags containing the signs were opened, and the front of the sign and the area of the bag that had been in contact with the sign were sampled together. The sign was then turned over and the reverse and corresponding area of the bag were similarly sampled.

Inorganic Swab Extraction and Analysis Procedure

The extraction was carried out at the FEL using the method described previously (1). The extracts were stored in a freezer and defrosted when required with the volumes adjusted to 10 mL in clean volumetric flasks immediately prior to analysis.

The aqueous extracts were analyzed for ammonium, magnesium, calcium, nitrate, and sugar by ion chromatography (1).

Organic Swab Extraction and Analysis Procedure

The swabs were extracted in the FEL trace laboratory area. The ethanol was removed from the swab and an equal volume of water added to the ethanol. The extract was then cleaned up using Chromosorb 104 to reject unwanted co-extractives while retaining as far as possible any explosives present. The extracts were then concentrated under dry nitrogen.

The extracts were analyzed using gas chromatography systems with chemiluminescence detection (GC/TEA). The GC ovens used were Carlo Erba Mega Series types HRGC 5300, HRGC 5300-HT, and 8000 series with split/splitless injection ports lined with glass liners that were plugged at the middle with deactivated silica wool. Samples were injected with SGE 1BR-7 1 μL syringe with plunger-in-needle with a needle 70 mm in length. The carrier gas was high-purity helium. Three columns were used for the analyses with any positive samples being analyzed on each column type. The column details are given in Table 1. The detectors used were modified Thermedics (Thermo Electron) TEA Model 610 detectors.

TABLE 1—*Gas chromatography column details.*

Column	Oven Program	Carrier Pressure
SGE type 12QC2/BP1 0.25. 12 m polyimide clad silica, 0.22 mm i.d., 0.33 m o.d., coated with bonded dimethylsiloxane 0.25 μm film thickness.	80°C/1 min + 20°C/min to 200°C/2 min.	250 kPa (36 psi)
SGE type 12QC2/BP5 0.25. 12 m polyimide clad silica, 0.22 mm i.d., 0.33 m o.d., coated with bonded dimethylsiloxane 0.25 μm film thickness.	80°C/1 min + 20°C/min to 200°C/2 min.	250 kPa (36 psi)
Chrompack CP-Sil-19CB, 4 meters cut from 25 m polyimide clad silica, 0.25 mm i.d., 0.39 mm o.d., coated with bonded 7% cyanpropyl-7% phenyl-1% vinyl-dimethylsiloxane, 0.21 μm film thickness.	70°C/1 min + 20°C/min to 250°C/2 min.	70 kPa (10 psi)

TABLE 2—*Explosives standard solution for GC/TEA analysis.*

Explosive	Concentration (ng/μL)
Nitrobenzene (NB)	0.5
Ethylene glycol dinitrate (EGDN)	0.1
2-nitrotoluene (2-NT)	0.6
3-nitrotoluene (3-NT)	0.6
2-nitrotoluene (4-NT)	0.6
Nitro-glycerine (NG)	0.2
2,4-dinitrotoluene (2,4-DNT)	0.4
2,6-dinitrotoluene (2,6-DNT)	0.3
3,4-dinitrotoluene (3,4-DNT)	0.2
2,4,6-trinitrotoluene (TNT)	0.4
Pentaerythritol tetranitrate (PETN)	0.75
Cyclotrimethylene trinitramine (RDX)	0.5

A standard explosives solution, containing twelve common explosives, was used during the analysis for comparison with the samples. A second solution containing 2-fluoro-5-nitrotoluene (FNT) and Musk Tibetine (2,6-dinitro-3,4,5-tri-methyl-*tert*-butylbenzene, MT), both at concentrations of 5 ng/μL, was used as a retention time reference. The components of the explosives standard are given in Table 2.

Soil Sample Extraction and Analysis Procedure

For the inorganic firings, 10 mL of deionized water was added to a glass vial containing 0.5 g of soil. The sample was shaken and after the soil had settled the water extract was carefully removed from the top for ion chromatographic analysis as described for the inorganic swab samples above.

The samples taken prior to the TNT firing were extracted with 10 mL of ethanol/water (50:50) and then cleaned up as described for the organic swab samples above. These samples were analyzed on the GCTEA systems.

Results and Discussion

Recovery of LAN/S Residues from the Witness Materials

The results of the residues recovered from the witness materials are shown in Figs. 4 to 7 and Tables 3, 4, and 5. The roadsigns and vehicles showed a greater recovery of nitrate than ammonium and a greater recovery of calcium than magnesium. Recovery generally decreased with distance in any given direction, but quantities recovered at the same distance in different directions were not comparable indicating the influence of some directional factor. Recoveries were generally lower on the side opposing the charge and more unpredictable than recoveries from the side facing the charge. The recovery from the front of the roadsigns was generally greater than that from the back. The low proportion of magnesium reco-

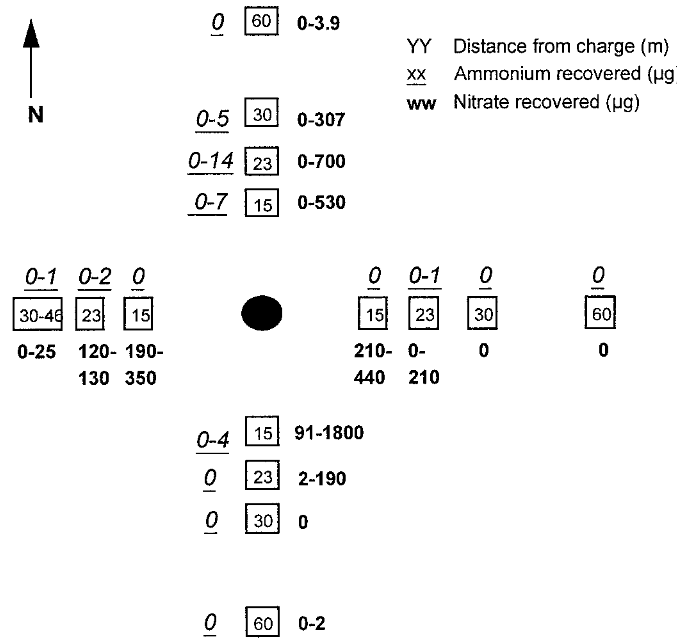

FIG. 4—*Recoveries from fronts of signs for the 454 kg LAN/S charges.*

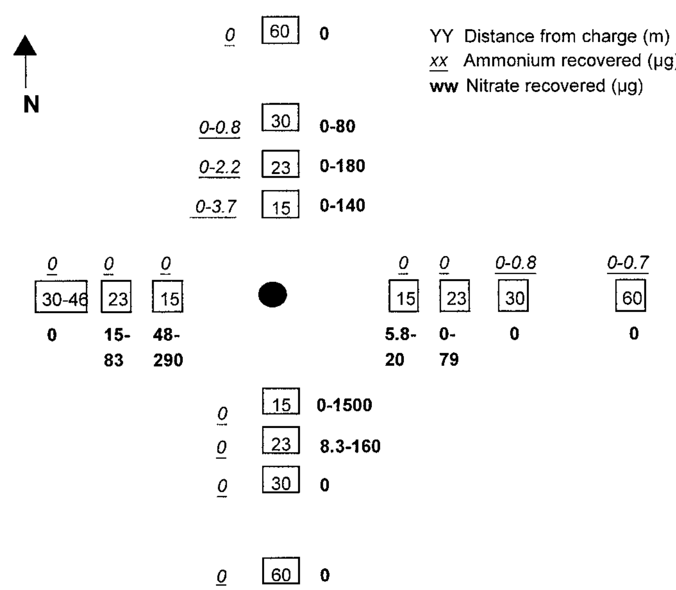

FIG. 5—*Recoveries from backs of signs for the 454 kg LAN/S charges.*

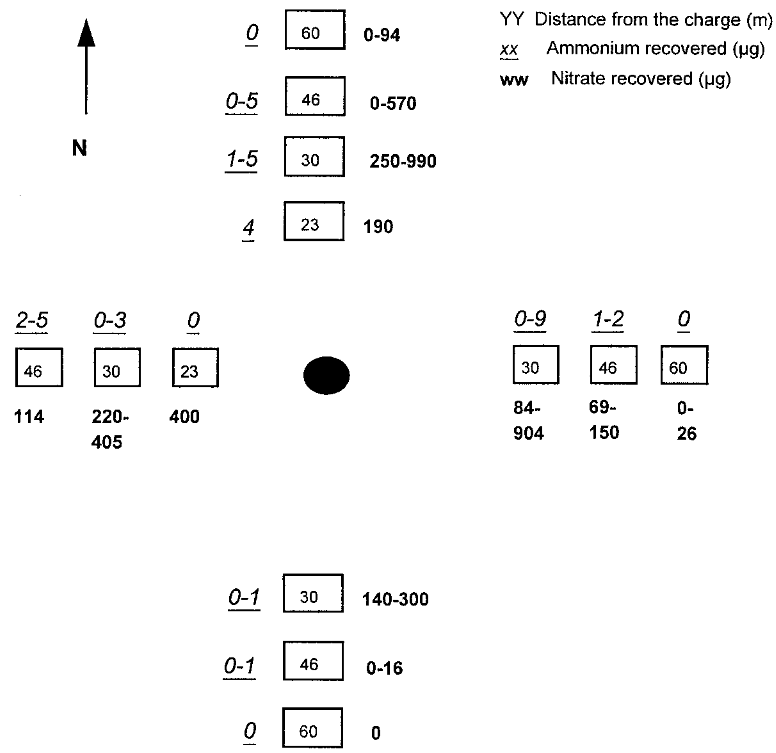

FIG. 6—*Recoveries from fronts of signs for the 2268 kg LAN/S charges.*

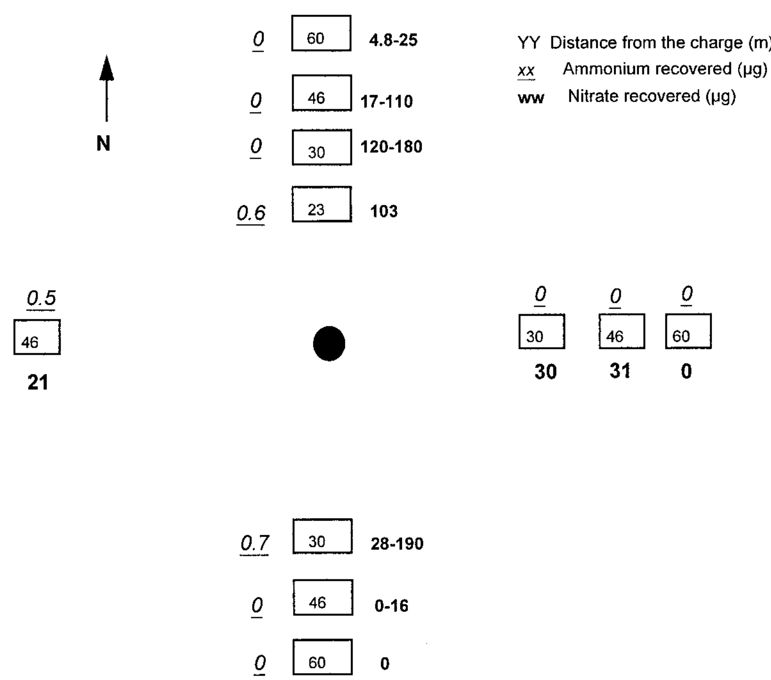

FIG. 7—*Recoveries from backs of signs for the 2268 kg LAN/S charges.*

vered demonstrates that the residue came from the explosive rather than being due to soil contamination.

An environmental survey carried out by the FEL in Great Britain in 1995/1996 has shown that nitrate and ammonium ions are commonly recovered from roadsigns and cars. The recoveries of nitrate ions ranged from 3 to 124 μg for vehicles and 5 to 35 μg for roadsigns and for ammonium ranged from 1 to 88 μg for vehicles and 2 to 70 μg for roadsigns. The results of the survey suggest that a

TABLE 3—*Recovery of sugars from witness pieces.*

Firing Number and Details	Sample Area	Sugars Recovered (μg)
LAN/S 454 kg Firing 1	46 m West sign back	Fructose 18
LAN/S 454 kg Firing 3	30 m vehicle facing charge	Glucose 19
LAN/S 2268 kg Firing 1	30 m vehicle Opposite charge before firing	Glucose 440

TABLE 4—*Mean recoveries from vehicles in the 454 kg LAN/S firings.*

Distance from Charge	Mean Recoveries (μg)							
	Ammonium		Nitrate		Calcium		Magnesium	
	Facing	Opposing	Facing	Opposing	Facing	Opposing	Facing	Opposing
5 m	*	*	*	*	*	*	*	*
15 m	55	3.7	1360	60	1004	650	0.16	16
23 m	16.7	0	307	0	640	533	9.3	21.7
30 m	6.7	0	118	0	590	517	14.7	18.7

* Swab sample not taken.

TABLE 5—*Mean recoveries from vehicles in the 2268 kg LAN/S firings.*

Distance from Charge	Mean Recoveries (μg)							
	Ammonium		Nitrate		Calcium		Magnesium	
	Facing	Opposing	Facing	Opposing	Facing	Opposing	Facing	Opposing
15 m	*	*	*	*	*	*	*	*
23 m	6.4	6	410	34	833	527	0.05	11.3
30 m	28.2	2.3	440	62.7	1010	883	0	6.7
46 m	4.9	1.5	404	126.7	883	737	0	6

* Swab sample not taken.

recovery of hundreds of micrograms or milligram quantities of ammonium and nitrate from post-blast debris is a significant indication of the use of an ammonium nitrate-based improvised explosive.

There was 18 μg of fructose recovered from the back of one roadsign and 19 μg of glucose recovered from the facing side of one vehicle placed at 30 m from a 454 kg charge. There was no detectable recovery of sucrose from the vehicles.

Recovery of ANFO Residues from the Witness Materials

The results of the residues recovered from the witness materials are shown in Figs. 8 and 9 and Table 6. Low levels of nitrate were recovered from the signs with no other recoveries of nitrate or ammonium detected. In general, the levels recovered from the front of the signs was greater than those recovered from the back of the signs. The recoveries from the side of the vehicle facing the charge and the side opposing the charge were comparable. As no ammonium or nitrate was recovered, the levels of calcium and magnesium recovered were probably due to the soil contamination rather than from the explosive.

Recovery of TNT Residues from the Witness Materials

The results of the residues recovered from the witness materials are shown in Figs. 10 and 11 and Table 7. Significant levels of TNT were recovered from both the front and back of the roadsigns, although the levels did not decrease with increasing distance from the charge. High levels of TNT were recovered from those vehicles not destroyed by the blast. The levels on the side facing the charge were higher than those opposing the charge. High levels of TNT were also detected in the soil sample prior to firing, therefore it is possible that some contamination occurred, more so for the vehicles than signs due to their closer proximity to the ground. However, organic analysis of roadsign samples taken from the LAN/S firing after the TNT charge shows only trace levels of TNT to be present. This suggests that the recoveries from roadsigns in the TNT firing are significant and not due to soil thrown up in the explosion.

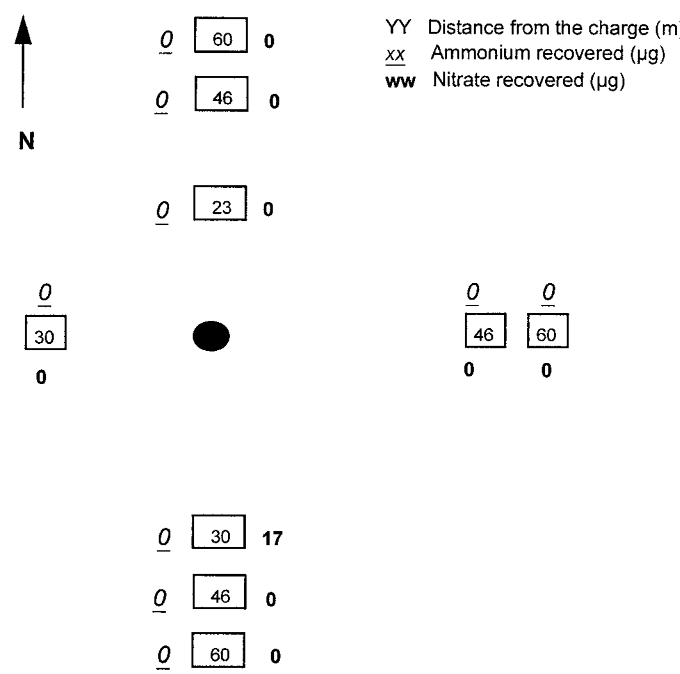

FIG. 8—*Recoveries from fronts of signs for the 2268 kg ANFO charge.*

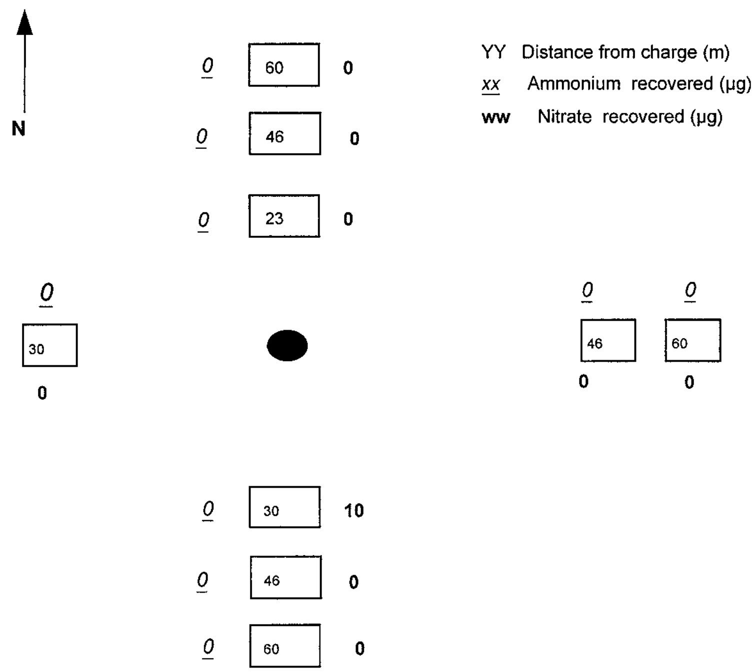

FIG. 9—*Recoveries from backs of signs for the 2268 kg ANFO charge.*

TABLE 6—*Mean recoveries from vehicles in the 2268 kg ANFO firings.*

	Mean Recoveries (µg)							
	Ammonium		Nitrate		Calcium		Magnesium	
Distance from Charge	Facing	Opposing	Facing	Opposing	Facing	Opposing	Facing	Opposing
15 m	*	*	*	*	*	*	*	*
23 m	*	0	*	0	*	680	*	89
30 m	0	0	0	0	760	730	34	32
46 m	0	0	0	0	460	710	207	20

* Swab sample not taken.

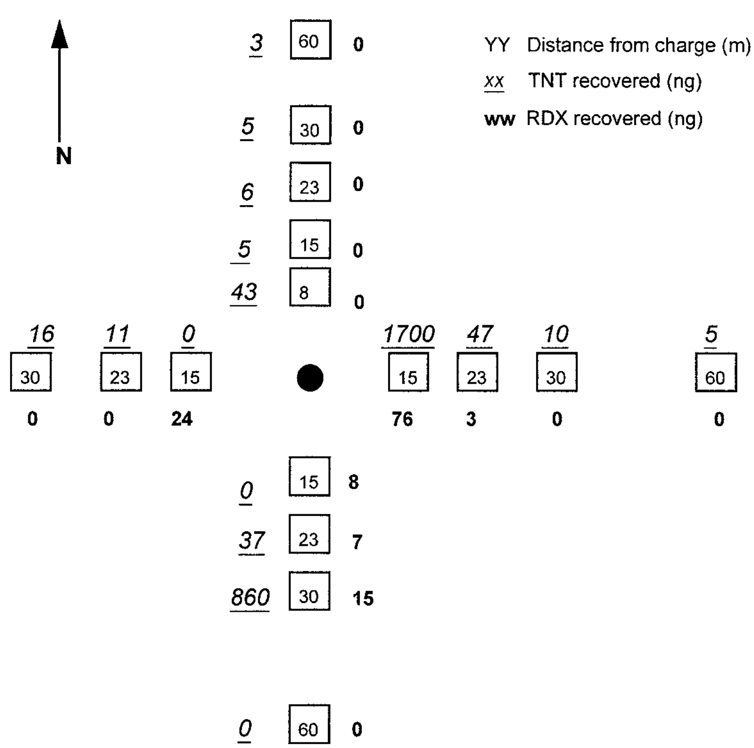

FIG. 10—*Recoveries from fronts of signs for the 454 kg TNT charge.*

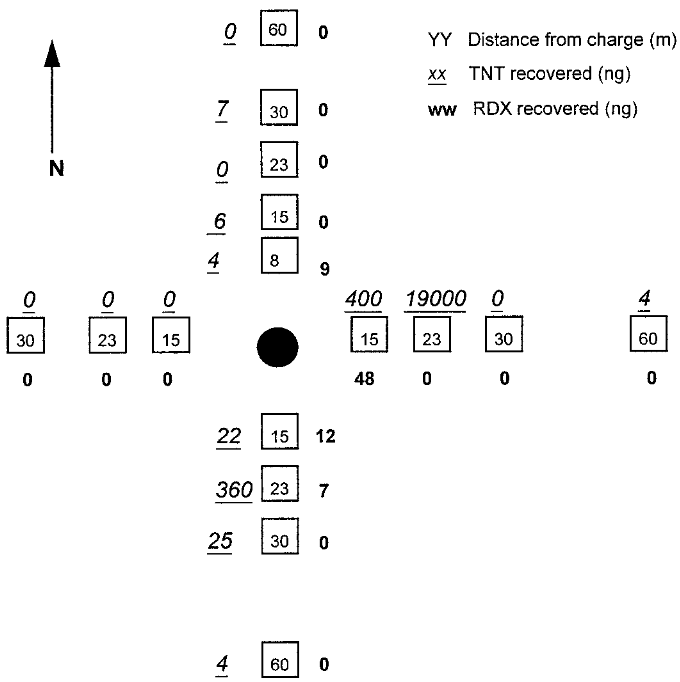

FIG. 11—*Recoveries from backs of signs for the 454 kg TNT charge.*

TABLE 7—*Recovery of explosives from the vehicles after 454 kg TNT firing.*

Distance from Charge	TNT		RDX	
	Facing	Opposing	Facing	Opposing
5 m	*	*	*	*
15 m	*	*	*	*
23 m	83 μg	1.2 ng	120 ng	76 ng
30 m	0	0	0	0

* No swab samples taken.

Soil Sample Analysis

The results of the analyses are shown in Tables 8 and 9. The results of the analyses show that the soil was contaminated with the analytes of interest, both organic and inorganic. The inorganic contamination increased during the trial period.

Blast Pressure Measurements

The blast pressure measurements and positive impulse readings are given in Tables 10 and 11. No adjustments were made for the high altitude of the test site. In some instances data were not obtained from certain pressure gages due to fragment damage of the lines, but this loss was minimal. As expected, as the distance of the pressure gage from the charge increased, the blast pressure recorded decreased. The blast pressure was higher for 2268 kg LAN/S charges than the 454 kg LAN/S charges. The blast pressure readings for TNT were greater than for the equivalent weight of LAN/S. Also, the blast pressure readings for 2268 kg of ANFO were higher than the similar weight of LAN/S.

Velocity of Detonation Measurements

The detonation velocities for each firing are given in Table 12 as the mean of the axial pin readings only. This is due to ambiguous results from the radial pins produced from a curved shock wave at the position of the radial pins, whereas the shock wave at the position of the axial pins is close to linear. The results show that there is no noticeable difference between the plastic and steel containers, so the results are not being distorted by the effect of the charge confinement. Measurement of explosive performance, such as VOD, is of forensic significance because it allows conclusions to be drawn about the effects of different explosives.

TABLE 9—*Soil sample analyses for TNT firing.*

Charge Size	Sample	TNT	RDX	Other
454 kg	15 m south	59 μg	2.6 μg	91 ng 2,4-DNT
454 kg	23 m north	140 ng	260 ng	none

TABLE 8—*Soil sample analyses (inorganic).*

Charge Size and Type	Sample	Nitrate (μg/g)	Ammonium (μg/g)	Magnesium (μg/g)	Calcium (μg/g)	Calcium/Magnesium Ratio
454 kg LAN/S 1	30 m North	23	0	64	330	5.2
454 kg LAN/S 1	8 m East	60	6.2	33	260	7.9
454 kg LAN/S 2	23 m South	140	10	51	330	6.5
454 kg LAN/S 2	30 m East	34	0	27	200	7.4
2268 kg LAN/S 1	15 m West	120	15	37	230	6.2
2268 kg LAN/S 1	60 m South	58	0	37	240	6.5
454 kg LAN/S 3	15 m West	26	4.6	22	150	6.8
454 kg LAN/S 3	15 m East	62	6.2	25	190	7.6
2268 kg LAN/S 2	15 m North	220	26	44	290	6.6
2268 kg LAN/S 2	30 m South	190	14	49	340	6.9
2268 kg LAN/S 3	46 m South	24	3.6	14	150	10.7
2268 kg LAN/S 3	60 m South	18	0	30	180	6.0
2268 kg ANFO	46 m East	25	5	35	160	4.6
2268 kg ANFO	15 m West	190	35	41	240	5.9

TABLE 10—*Maximum blast pressure for the LAN/S firings.*

	Maximum Pressure, kPa (psi)					
Gage Position	454 kg LAN/S 1	454 kg LAN/S 2	454 kg LAN/S 3	2268 kg LAN/S 1	2268 kg LAN/S 2	2268 kg LAN/S 3
4.6 m North	3098 (449)	2751 (399)	4277† (620)	11661 (1691)	10041 (1456)	–
15.2 m North	113 (16)	148 (21)	90† (13)	372 (54)	657 (95)	696 (101)
15.2 m East	160† (23)	146† (21)	55† (8)	546† (79)	569† (83)	725† (105)
15.2 m South	–	67† (10)	33† (5)	388† (56)	289† (42)	405† (59)
15.2 m West	92† (13)	44† (6)	61† (9)	217† (31)	–	710 (103)
30.5 m North*	40 (6)	41 (6)	25† (4)	96 (14)	127 (18)	–
30.5 m East	39† (6)	31† (5)	22† (3)	98† (14)	45† (7)	19† (3)
30.5 m South	33† (5)	40† (6)	37† (5)	146† (21)	210† (30)	146† (21)
30.5 m West*	47 (7)	39 (6)	22 (3)	155 (22)	135 (20)	165 (24)
45.7 m East	32† (5)	31 (5)	25† (4)	67† (10)	73† (11)	67† (10)
45.7 m South	10† (2)	8† (1)	9† (1)	42† (6)	28† (4)	46† (7)
45.7 m South*	24† (3)	21† (3)	19 (3)	59 (9)	52 (8)	55 (8)
61.0 m South	16† (2)	13† (2)	11† (2)	34† (5)	29 (4)	34† (5)
61.0 m South*	17 (2)	13 (2)	13 (2)	31 (5)	30 (4)	28 (4)

* Pencil gages.
† Data suspect or indeterminate.
– No reading/not used.

TABLE 11—*Maximum pressure data for the TNT and ANFO firings.*

	Maximum Pressure, kPa (psi)	
Gage Position	454 kg TNT	2268 kg ANFO
4.6 m North	7943 (1152)	12483 (1810)
15.2 m North	396 (57)	696† (101)
15.2 m East	476 (69)	725 (105)
15.2 m South	258† (37)	657† (95)
15.2 m West	110† (16)	710 (103)
30.5 m North*	58 (8)	202 (29)
30.5 m East	65 (9)	105 (15)
30.5 m South	45† (7)	311 (45)
30.5 m West*	73† (11)	–
45.7 m East	41† (6)	91 (13)
45.7 m South	25† (4)	48 (7)
45.7 m South*	33† (5)	83 (12)
61.0 m South	19† (3)	47 (7)
61.0 m South*	–	48 (7)

* Pencil gages.
† Data suspect or indeterminate.
– No reading/not used.

TNT Equivalence Calculations

The detonation velocities given in Table 12 were used to calculate the %TNT equivalence using the equation taken from Cooper (3).

$$\%\text{TNT equivalence} = \frac{\text{Velocity of detonation}^2_{(\text{sample})}}{\text{Velocity of detonation}^2_{(\text{TNT})}} \times 100$$

The results show that the calculated %TNT equivalence for the 454 kg TNT firing was less than 100% (91.66%). This was due to a difference in the theoretical maximum charge density (1.64 g/cm^3) and the actual charge density (1.47 g/cm^3). The theoretical value for velocity of detonation was also calculated under ideal experimental conditions, which naturally vary from the experimental conditions encountered during the trials.

Physical Damage to the Vehicles

The pattern of damage to the vehicles at a given distance from the charge was reasonably consistent despite wide variations in the make and model of vehicles. Features common to all vehicles e.g.,

TABLE 12—*Velocity of detonation and TNT equivalence calculations.*

Charge Description	Charge Size (kg)	Ullage (m)	Charge Density (kgm^{-3})	Mean Velocity of Detonation (m/s)	% TNT Equivalence
TNT	454	0.203	1474.30	6654	91.7
LAN/S 1	454	0.330	1000.88	3224	21.5
LAN/S 2	454	0.603	1003.08	3235	21.7
		Plastic Container			
LAN/S 3	454	0.381	1088.30	3162	20.7
LAN/S 1	2268	0.343	1070.82	3454	24.7
LAN/S 2	2268	0.381	1106.63	3382	23.7
LAN/S 3	2268	0.318	1048.23	3348	23.2
ANFO	2268	0.838	885.82	3892	31.4

windscreen, tyres, headlamps, bonnet were assessed for damage in a very systematic fashion.

For the 454 kg TNT firing, the vehicle placed at 5 m from the charge was completely destroyed with the chassis remaining in two separate pieces. The vehicle at 15 m was severely mangled by the blast, flipped onto its side, and caught fire, see Fig. 12. The vehicle at 23 m had all windows shattered, the bonnet removed, and all tires deflated. The body panels facing the charge were severely crumpled and exhibited major fragment damage, while the body panels opposing the charge were generally intact with some fragment damage. The vehicles placed at 30 m suffered less damage. All windows were shattered but partially remained in the frame and one tire remained inflated. The body panels exhibited some denting and minor fragmentation damage. The vehicles placed at 23 and 30 m from the charge remained upright with a clearly visible difference between the effect on the body panels facing the charge and those opposing the explosive charge.

For the 2268 kg ANFO firing, the vehicle placed at 15 m from the charge was completely destroyed with only the chassis remaining, see Fig. 13. The vehicle placed at 23 m from the charge was severely mangled by the blast and was flipped onto the driver's side. The vehicle placed at 30 m suffered overall denting and all the windows were shattered. There was a clearly visible difference between the effect on the body panels facing the charge compared with those opposing the charge. The vehicle was turned upside-down. The vehicle placed at 46 m did not exhibit much damage. All windows remained intact and there was no denting or fragment damage to any body panels. The vehicle remained upright.

The damage to vehicles in the three 454 kg LAN/S firings and three 2268 kg LAN/S firings is summarized in Tables 13 and 14. An example of the damage to vehicles placed at 15 m from a 454 kg LAN/S charge and 15 m from a 2268 kg LAN/S charge is shown in Figs. 14 and 15 respectively. Figures 16 shows the distance the vehicles move from their original position for all firings. Figure 17 is a summary of expected damage to vehicles at different distances from different size charges. In order to normalize the effect "reduced distance" is employed. Reduced distance is, in effect, the distance in meters from a 1 kg charge at which the same result would be observed. The use of such a diagram should enable more meaningful assessments at real scenes.

Physical Damage to UK Roadsigns

For the 454 kg LAN/S firings, the blastwave caused the roadsigns closest to the charge (8 m) to produce a rounded shape as they folded around their posts. The roadsigns placed at 15 m from the charge exhibited only slight bending/folding and the roadsigns at 23, 30, and 60 m were flat and generally unscathed.

For the 454 kg TNT firing, the roadsign at 8 m from the charge fragmented and not all fragments were recovered. The roadsigns at 15 m produced rounded shapes as they folded around the post and exhibited major fragment damage. The roadsigns at 23 m from the charge exhibited slight bending/folding and the roadsigns at 30 and 60 m were flat with little or no fragment damage.

For the 2268 kg LAN/S firing, the roadsign at 15 m from the charge fragmented and not all fragments were recovered. The roadsigns at 23 m produced rounded shapes as they folded around the post and exhibited major fragment damage. The roadsigns at 30 m from the charge exhibited slight bending/folding with some minor fragment damage and the roadsigns at 46 and 60 m were flat with little or no fragment damage.

FIG. 12—*Photograph of a vehicle placed at 15 m from a 454 kg TNT charge.*

FIG. 13—*Photograph of a vehicle placed at 15 m from a 2268 kg ANFO charge.*

TABLE 13—*Summary of expected damage to vehicles from a 454 kg LAN/S firing.*

Distance from Charge	5 m	15 m	23 m	30 m
Windscreen	Not found	Completely shattered	Shattered with the glass remaining in the frame	
Side windows	Not found	Shattered		Possibly intact
Rear windscreen	Not found	Shattered		Possibly intact
Bonnet	Not found	Indentations raised on side facing the charge		Undamaged
Side body panels	Not found	Severely dented	Minor dents	Negligible indentations
Roof	Not found	Dented and raised on side facing the charge	Negligible indentations	Intact
Wheels	Not found	Wheels generally intact and tires inflated. Possibility at least one tire deflated on side facing the charge		
Headlamps	Not found	Front and rear lamps on side facing the charge generally shattered and intact on side opposing the charge		
Orientation	Not found	Upright	Upright	Upright
Comments	Vehicle completely destroyed	Bodyshell severely mangled/dented	Some denting with minor fragment damage	Bodyshell intact and undistorted

TABLE 14—*Summary of expected damage to vehicles from a 2268 kg LAN/S firing.*

Distance from Charge	15 m	23 m	30 m	46 m
Windscreen	Not found		Shattered	Shattered with the glass remaining in frame
Side windows	Not found		Shattered	
Rear windows	Not found		Shattered	
Bonnet	Not found	Severely mangled. Possibly removed	Crumpled; raised on side facing the charge	
Side body panels	Not found	Severely crumpled	Dented	Minor indentations and abrasions
Roof	Not found	Severely distorted	Dented	Minimal change
Wheels	Not found	Wheels generally intact and tires deflated on side facing the charge Possibility of at least one tire intact on side opposing the charge		
Headlamps	Not found	Front and rear lamps shattered		Intact
Orientation	Not found	Upside-down	Generally upright but a possibility of being upside-down	Upright
Comments	Completely dismembered	Bodyshell intact but severely distorted	Bodyshell distorted with some fragment damage	Bodyshell intact with minor fragment damage

FIG. 14—*Photograph of a vehicle placed at 15 m from a 454 kg LAN/S charge.*

FIG. 15—*Photograph of a vehicle placed at 15 m from a 2268 kg LAN/S charge.*

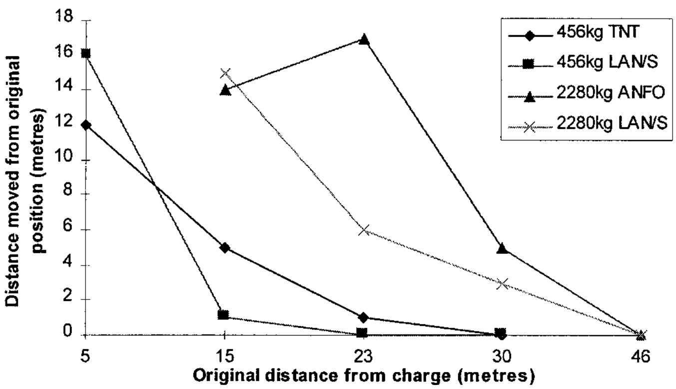

FIG. 16—*Graph to show the trend between charge size and distance vehicles moved.*

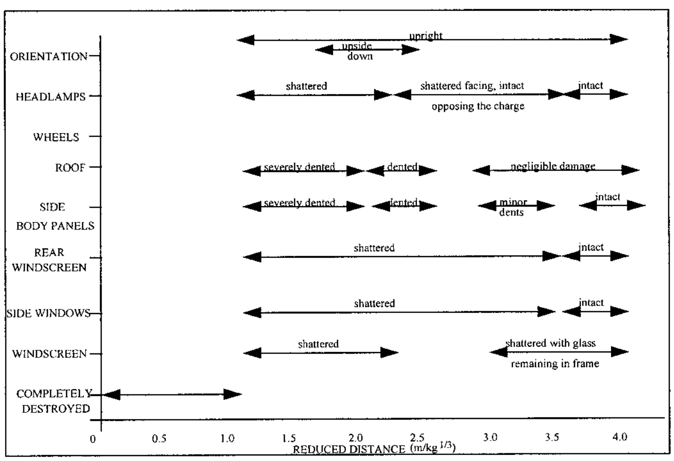

FIG. 17—*Summary of damage to vehicles for all firings and charge types.*

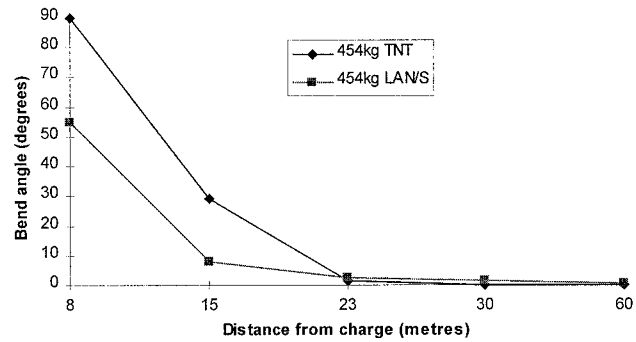

FIG. 18—*Graph to show the trend between bend angle and distance from 454 kg charges.*

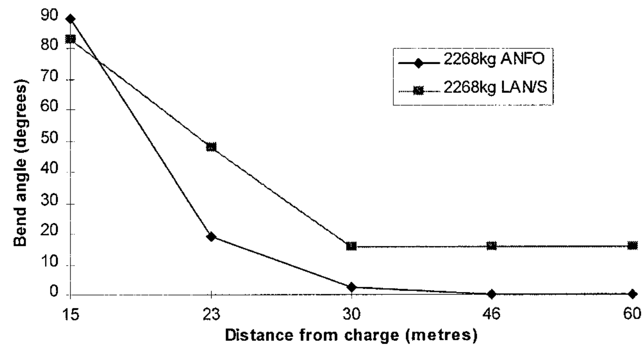

FIG. 19—*Graph to show the trend between bend angle and distance from 2268 kg charges.*

Physical Damage to US Roadsigns

For the 454 kg LAN/S firings, the blastwave caused the roadsigns closest to the charge (8 m) to fragment and not all fragments were recovered. The roadsigns placed at 15 m from the charge exhibited slight bending and a considerable amount of fragment damage. The roadsigns at 23, 30, and 60 m were flat and generally unscathed.

For the 454 kg TNT firing, the roadsign at 8 m from the charge fragmented and not all fragments were recovered. The roadsigns at 15 m folded around the post but not much fragment damage occurred. The roadsigns at 23 m from the charge exhibited slight bending and considerable fragment damage, the roadsigns at 30 and 60 m were flat with little or no fragment damage.

For the 2268 kg LAN/S firing, the roadsign at 15 and 23 m from the charge fragmented and not all fragments were recovered. The roadsigns at 30 m folded around the post and exhibited some fragment damage. The roadsigns at 46 m from the charge exhibited slight bending with considerable fragment damage. The roadsigns at 60 m were flat no fragment damage.

Bend Angles of Posts

For the 454 kg charges, the posts placed nearest to the charge were generally broken or lying on the ground. The posts at 15 m from the explosive were at a slight incline to the vertical and the posts at 23, 30, and 60 m from the blast remained upright.

For the 2268 kg charges, the posts placed nearest to the charge were broken or lying on the ground. The posts at 23 m were at a severe incline to the vertical and the posts at 30, 46, and 60 m from the charge remained upright.

The lampposts placed at 23 m from the 454 kg charge was unaffected by the blast and remained upright. The lampposts placed at 23 m from the 2268 kg LAN/S charges were inclined slightly from the vertical and bent near the top of the post.

Figures 18 and 19 show the trend in bend angles against distance from the charge for all firings performed.

Soil Sample Analysis

The results of the analyses are shown in Tables 3 and 4. The results of the analyses show that the soil was contaminated with the analytes of interest, both organic and inorganic. The inorganic contamination increased during the trial period. Since the soil contained magnesium, and the charges contained very little or no magnesium, this element can be used as an indication of the significance of any contamination of witness materials by the soil.

Conclusions

Roadsigns and vehicles both proved to be useful materials for the recovery of post blast explosions residues.

Nitrate was generally recovered in greater quantities than ammonium, and calcium was recovered in greater quantities than magnesium. Since during the explosion ammonium is oxidized to a mixture of nitrogen and nitrogen oxides, the recovery of an excess of nitrate over ammonium is to be expected.

There was no detectable recovery of sucrose from any of the witness pieces in any firing. A small quantity of fructose was detected on one roadsign and a higher level of glucose was detected in one vehicle sample. It is highly probable that any sucrose present in swab samples taken at the test site would have degraded to some extent during transportation back to the FEL. The samples were stored and transported in aqueous solution at ambient temperature for a period of approximately eight to ten weeks. The samples probably contain micro-organisms and acids, the presence of which would promote degradation of the sugar.

Residue recovery generally decreased with increasing distance of the witness material from the charge. Quantities of residues recovered from the roadsigns at the same distance in different directions were not comparable indicating the influence of some directional factor. The directional variation of the residue collection indicates that deposition of residue occurs primarily from the dust cloud and not the initial explosive shock wave.

Areas sampled on the roadsigns were twice that sampled on the vehicles, yet recovery from vehicles was generally greater than from roadsigns. This may be related to the fact that vehicles were swabbed on site and the roadsigns swabbed much later at the FEL. Also, the areas sampled on the vehicles were closer to the ground than the roadsigns and air currents around two witness pieces will also differ due to the differences in size of the witness piece.

The damage to vehicles varies with the type of explosive material used. TNT has a higher explosive performance than ANFO and LAN/S. The results obtained from all firings, as expected, showed that the damage to vehicles decreased as the explosive performance of the test material decreased taking into account the differences in charge size.

The pattern of damage to the vehicles at a given distance from the charge was reasonably consistent despite wide variations in the make and model of vehicle. This suggests that such an observation could provide valuable objective evidence of explosive charge size even in the very confused conditions often encountered at bomb scenes.

From the roadsign data obtained from all eight firings it is clear that the damage to the signs decreased with increasing distance from the charge and, as expected, the extent of damage increases with increasing charge size and increasing explosive performance of the charge. The American roadsigns suffered more damage than the British roadsigns at corresponding distances from the charge. This is as expected due to the difference in thickness of the signs and the form of mounting on the posts.

The angle of deflection of the posts from the vertical decreases with increasing distance from the charge, and the degree of inclination increased with increasing charge size. However, the posts deflected from the vertical without bending. This indicates that the angle of bend is related to the strength of the soil, and therefore the results are of limited use.

The lamppost placed at 23 m from a 454 kg LAN/S charge was unaffected by the blast and remained upright, but the lamppost placed at 23 m from a 2268 kg LAN/S charge deflected from the vertical.

Recommendations

The charges could be confined differently or placed inside vehicles (one such test was carried out previously (1)). This would give a more accurate comparison to real terrorist activity.

The techniques and equipment used for the collection of blast pressure data should be investigated in order to produce more meaningful results.

The effect of wind speed and direction on the deposition of residues should be examined.

More detailed investigation into the degradation of sucrose in aqueous solutions is required in order to determine the most appropriate way to store and transport swab samples from the test site to the laboratory.

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