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## Physical and Chemical Evidence Remaining After the Explosion of Large Improvised Bombs. Part 1: Firings of Ammonium Nitrate/Sugar and Urea Nitrate\*

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**ABSTRACT:** Recent criminal acts in the United Kingdom, United States and other countries have demonstrated the dangers to public safety from the criminal use of improvised explosives on a large scale. Four sets of trials were carried out over four years, partly in collaboration with the United States Federal Bureau of Investigation, involving the firing of large bombs, mostly fertilizer based. The principal objectives of the firings were to measure the physical effects of the explosions upon objects representative of those that would be found at a real bomb scene and to recover any chemical traces deposited on these objects. The results are intended for use as an aid in determining the approximate size and type of an explosive employed in a terrorist attack. This paper describes the background behind the trials, the procedures for preparation of witness materials and charges, and the collection and analysis of physical and chemical evidence.

**KEYWORDS:** forensic science, explosives, homemade explosives, improvised explosive devices, fertilizer, sugar, chemical residues, physical damage

In recent years the detonation of large improvised explosive devices (IEDs), such as those on the U.K. mainland, summarized in Table 1, and those in the United States of America at the World Trade Center in New York and the Alfred P. Murrah Federal Building in Oklahoma City, has caused grave concern. These events have demonstrated the danger to public safety and the substantial economic impact arising from the criminal use of improvised explosives on a large scale.

In addition to the incidents cited above, substantial quantities of homemade explosives of the fertilizer/sugar type have been discovered by the police on the U.K. mainland. These include both large quantities in storage and also those already made into large

IEDs ready for detonation. Table 2 shows quantities of fertilizer/sugar mixtures recovered from a variety of locations on the U.K. mainland.

Following the detonation of such devices, one of the primary tasks of the forensic scientist is to determine the type of explosive employed and to estimate the charge size. The physical evidence recorded from the scene, such as degrees of shattering and bending of objects close to the seat of the explosion, can be useful in determining the general nature of the explosive while chemical traces recovered from debris allow for a more precise identification. From both the physical and chemical evidence an estimation of the charge size can be made.

To optimize the collection of evidence following the detonation of a large IED and to aid in its interpretation, a number of controlled detonations of large IEDs were performed in New Mexico, beginning in November 1994. The physical and chemical signatures produced on witness materials placed around the charges were studied.

The first set of trials in 1994 was a collaborative project between the Forensic Explosives Laboratory (FEL) and the Federal Bureau of Investigation (FBI). Four firings were performed comprising one charge of 545 kg urea nitrate and three charges of 455 kg ammonium nitrate/sugar (ANS). Residues were only collected and analyzed for the three ANS firings. This paper describes the preparation of the sampling and witness materials, the collection of the chemical and physical evidence following detonation, and the analysis and interpretation of results.

### 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, NM. This site is at an altitude of approximately 1900 m above sea level.

#### Ammonium Nitrate/Sugar Charge Configurations

The ammonium nitrate was received in prill form from the manufacturers and was ground to the required particle size prior to mixing with confectioner's sugar. The ANS charges were prepared and loaded into open-top cylindrical steel containers (96.5 cm high by 96.5 cm diameter by 0.32 cm wall thickness) lined with polyeth-

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ylene sheeting. Two sets of four piezoelectric pins were placed radially at the top of the charge to measure detonation velocities. The charges were transported to the test site and positioned on wooden frames (height 1.07 m), simulating the height in the back of a vehicle, resting over a steel plate (7.6 cm thickness). The steel plates were placed under the charges to minimize the size of the crater produced, therefore making it easier to prepare the site for the fol-

TABLE 1—*The detonation of large IEDs on the U.K. Mainland and the U.S.*

Location	Date	Vehicle
St. Mary Axe, London	April 1992	Transit van
Staples Corner, London	April 1992	Van
Bishopsgate, London	April 1993	Van
South Quay, London	February 1996	Lorry
Manchester, City Center	June 1996	Van
World Trade Center	February 1993	Van
Oklahoma City	April 1995	Truck

TABLE 2—*Summary of finds of fertilizer/sugar mixtures on U.K. Mainland.*

Location	Date	Container	Quantity	Remarks
London	August 1992	Trailer	12.7 metric tons	Incl. fifteen partially prepared devices
London	August 1992	Van	1.5 tonnes	One device
London	November 1992	Van	1.6 tonnes	One device
London	December 1992	Van	1.45 tonnes	One device
London	November 1992	Cargo van	3.2 tonnes	One device
Lancashire	July 1994	Flatbed lorry	3.3 tonnes	One device
London	September 1996	Self storage unit	6.5 tonnes	Incl. four partially prepared devices

lowing firing. A suitable booster was placed in the charge and detonation initiated electrically. Figure 1 shows a diagram of the charge configuration. 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 corresponding author.

#### Urea Nitrate Charge Configuration

The urea nitrate was supplied by the FBI and the charge placed in the cargo compartment of a Ford F/350 Econoline van, resting over a steel plate similar to that used for the ANS firings. The 545 kg of urea nitrate was contained in cardboard boxes, each box containing approximately 9.1 kg of urea nitrate in plastic bags. The cardboard boxes were placed in a plywood box centered over the rear axle of the van and three full standard laboratory-size hydrogen cylinders placed directly beneath. A suitable booster was placed in the charge and detonation initiated electrically.

#### Measurement of Blast Pressures

Nine pressure gages (PCB type pressure transducers with built-in line amplifiers, Piezoelectronics Inc.) were located at ground level at distances of 15.2, 30.5, 45.7, and 61.0 m from the charge.

#### Witness Materials

The charges were surrounded by witness materials representative of those which would be found at a real bomb scene, Fig. 2. Eight U.S. metal road signs (30.5 cm × 45.7 cm) fixed to steel channeled posts (height 3.1 m) were placed at distances of 7.6, 15.2, 22.9, and 30.5 m from the charge, Fig. 2. Four medium-size sedan cars were placed side-on to the charge at distances of 2.1, 4.6, 15.2, and 22.9 m. Wooden witness frames were also used to which were attached pieces of material such as cloth, foam and rubber. The pieces were collected after firing and analyzed for explosive residues. The results obtained from these witness materials were very poor. The wooden frames were found to be very unstable during firing and the materials were, in most cases, deposited on the ground at some distance from the charge; many were not recovered. For this reason the frames were not used for subsequent trials and the results are not included in this paper.

#### Preparation of Materials for the Collection of Inorganic Residues

Witness materials were sampled by both the FEL and the FBI and the samples chemically analyzed using procedures and methods routinely used by each laboratory.

Sampling kits were prepared at the FEL suitable for inorganic residue collection. The sampling materials were contained in re-sealable polyethylene bags, each bag containing five snap-top glass vials (10.5 mL), a packet of five cotton wool swabs and five disposable plastic forceps. 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. All the kit components were quality assured to ensure that they were free from ammonium, nitrate and sugar. Swab samples were taken by placing a clean swab into one of the glass vials and adding approximately 5 mL of deionized

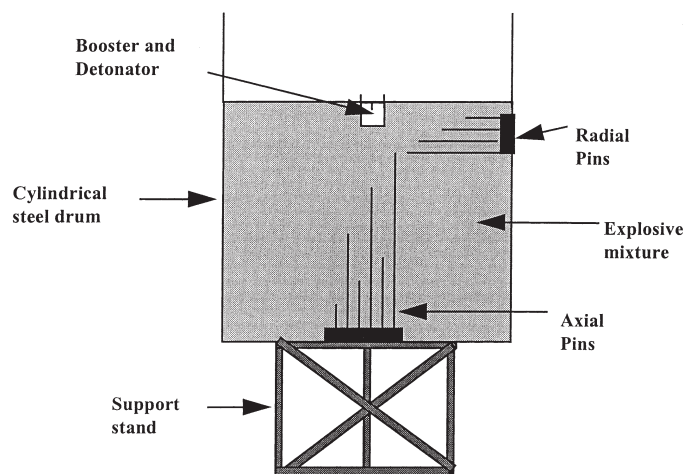


FIG. 1—*Diagram of charge configuration.*

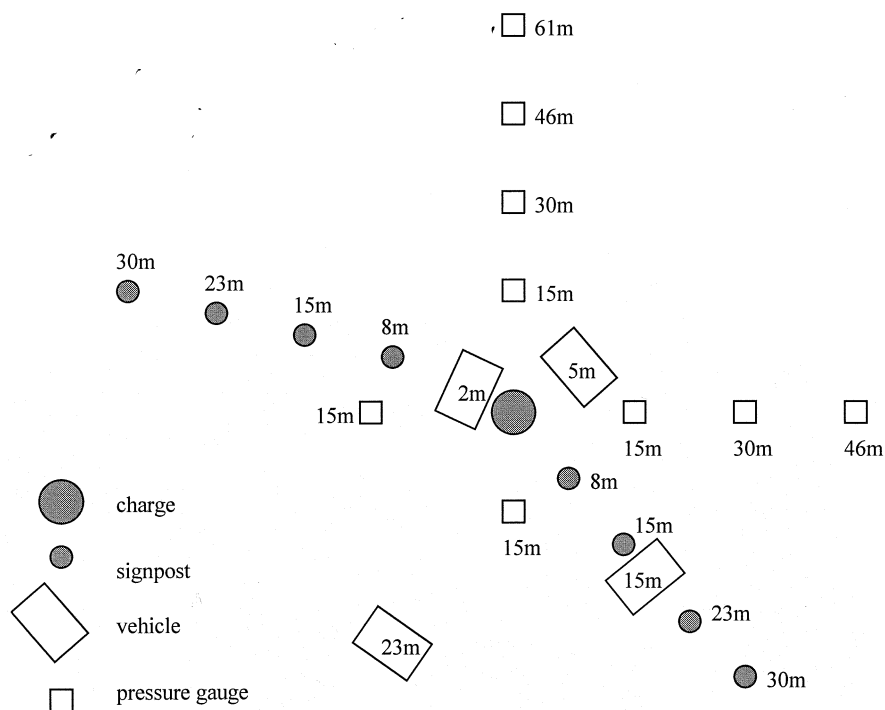


FIG. 2—Site plan for the urea nitrate and ANS firings.

water. Using the disposable forceps, the swab was gently squeezed against the inner surface of the vial to remove excess water and then wiped systematically over the surface to be sampled. If the swab became dirty it was returned to the vial, rinsed out, gently squeezed and the swabbing continued. Once the swabbing was completed the swab was returned to the vial with the residual solvent, the cap replaced and the vial sealed into a polyethylene bag.

Samples were collected by the FBI using individually packaged sterile 12-ply gauze pads (Johnson & Johnson Medical Inc.). Each swab was moistened with deionized water, systematically wiped over the surface to be sampled and sealed into a nylon bag.

#### Preparation of Witness Materials

Once each charge had been placed in position at the test site the road signs and cars were washed with deionized water. Control swabs were taken from each piece of witness material by both the FEL and the FBI immediately prior to firing. Swab samples were taken from the cars from an area approximately 60 cm × 50 cm on the side facing the charge. The facing sides of the road signs were marked into two halves, the FEL and the FBI each taking control swabs from one half.

#### 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 ANS) wearing disposable oversuits, boots and gloves. Swab samples were taken immediately from the cars from the same areas as the controls were taken. The road signs were detached from their posts (if not already so) and sealed into polyethylene bags. The signs were transported to the laboratory at NMT where half of each sign was swabbed by the FBI. The signs were heat sealed into nylon bags for transportation back to the FEL

for swabbing of their corresponding halves and for physical damage measurements.

The physical damage to the cars, signposts and the metal plates placed under each charge was recorded by photography and video. Each charge was detonated at the same position on the test site and the metal plates were placed under the charge to minimize cratering of the soil. The craters formed were deemed not to be representative of those which would be found in real life since they had been formed in sandy soil that had been repeatedly exploded and filled; therefore, crater size was not recorded.

#### FEL Chemical Residue Analysis Procedure

Each swab was transferred from its vial into a clean elution tube (glass centrifuge tube with a small hole in the bottom) and pushed firmly to the bottom with a clean Pasteur pipette. Any excess water remaining in the vial was transferred to the tube and allowed to pass through the swab, collecting the extract in a clean glass vial. The swab was extracted with a further 5 mL of deionized water added to the elution tube and excess water was squeezed from the swab by gently pressing with the wide end of a clean pipette. The extracts were stored in a refrigerator and, immediately prior to analysis, the volumes were adjusted to 10 mL in clean volumetric flasks.

The aqueous extracts were analyzed for ammonium, nitrate and sugar by ion chromatography, which was performed using series 4000i (cations and sugars) and series 2010i (anions) Dionex ion chromatography apparatus (Dionex U.K. Ltd., Camberly, Surrey, U.K.). Each analytical system consisted of an eluant degas module, a gradient pump (anions and cations), or an analytical pump (sugars) with a conductivity detector (anions and cations) or a pulsed amperometric detector (sugars).

Details of the chromatographic conditions for the analysis of anions, cations and sugars are given in Table 3. Samples were injected from disposable plastic syringes through 0.2 μm disposable

TABLE 3—Summary of the FEL ion chromatography conditions.

	Anions	Cations	Sugars
Column	Dionex IonPac AS9-SC (4 × 250 mm)	Dionex IonPac CS12 (4 × 250 mm)	Dionex CarboPac PA1 (4 × 250 mm)
Guard column	AG9-SC (4 × 50 mm)	CG12 (4 × 50 mm)	CarboPac PA1 (4 × 50 mm)
Eluant	1.8 mM sodium carbonate/1.7 mM sodium bicarbonate	20 mM methanesulphonic acid	0.15 mM sodium hydroxide
Flow rate	2 mL/min	1 mL/min	1 mL/min
Detection	Conductivity with an Anion Self-Regenerating Suppressor in the autosuppression mode	Conductivity with a Cation Self-Regenerating Suppressor in the autosuppression mode	Pulsed amperometric detection with an applied potential of 200 mV

TABLE 4—Composition of FEL ion chromatography standards.

Anions	Cations	Sugars
Fluoride 1 mg/L	Sodium 2 mg/L	Glucose 50 mg/L
Chloride 5 mg/L	Ammonium 5 mg/L	Fructose 50 mg/L
Nitrite 10 mg/L	Potassium 5 mg/L	Sucrose 100 mg/L
Bromide 10 mg/L	Magnesium 5 mg/L	
Chlorate 10 mg/L	Calcium 10 mg/L	
Nitrate 10 mg/L		
Phosphate 10 mg/L		
Sulfate 10 mg/L		

membrane filters into a 50 µL injection loop. The compositions of the mixed anion, cation and sugar standards are shown in Table 4. A mixed standard was injected followed by up to a maximum of six samples followed by a standard injection. Quantitation (approximate) was achieved by comparison of the sample peak area with that of the corresponding standard peak. The responses are linear for nitrate and sucrose but nonlinear for ammonium.

#### FBI Chemical Residue Analysis Procedure

Each swab was placed into a clean, sterile 20 mL plastic syringe. Increments of water, up to a maximum combined total of 15 mL, were added to the syringe and pressed through the swab. The extracts were transferred to clean 20 mL volumetric flasks and the volume adjusted to 20 mL with deionized water.

The aqueous extracts were analyzed for ammonium and nitrate by ion chromatography. Each system consisted of an eluant degas module, a pump (Waters Model 590) with a UV detector for nitrate (Waters Model 486) or a conductivity detector for ammonium (Waters Model 431). Sugars were analyzed by HPLC with refractive index detection (Waters 410 Differential Refractometer). Details of the chromatographic conditions are given in Table 5.

Samples were filtered through disposable 0.2 µm filters prior to analysis and each sample analyzed three times on each system. The peak areas were averaged and quantitation achieved from calibration curves run for each analyte (2 to 100 ppm).

## Results and Discussion

### Recovery of ANS Residues from the Witness Materials

The recoveries of ANS residues from the witness materials are shown in Tables 6–9. For the FEL results ammonium and nitrate detected below 0.3 ppm, corresponding to 3 µg per 10 mL sample, are marked as trace. For the FBI results all detectable concentrations below 0.2 ppm, corresponding to 4 µg in a 20 mL sample, are marked as trace.

In all firings the cars placed closest to the charge (2.1 m) were destroyed and no samples could be taken. No swab samples were taken from the vehicles of the first ANS firing due to bad weather conditions. The control swabs from the vehicles and road signs prior to firing were found, on the whole, to be free from ammonium, nitrate and sugar contamination. Those that did contain nitrate and ammonium did so at trace level (following the criteria outlined above).

Ammonium and nitrate were both detected in swab samples taken from the vehicles and the FEL recoveries were comparable to those of the FBI. The recoveries of ammonium and nitrate were found to increase with increasing vehicle distance from the charge. This result was unexpected but a similar result was obtained during the second set of trials. The recovery of ammonium and nitrate from the road signs was found, as expected, to decrease with increasing distance from the charge.

The recoveries of nitrate ranged from 12 µg to 5 mg for the vehicles and 3 µg to 5.5 mg for the signs. Similarly, the recoveries of ammonium ranged from 26 to 161 µg for the

TABLE 5—Summary of the FBI chromatography conditions.

	Anions	Cations	Sugars
Column	Vydac 300IC405 4.6 × 50 mm	Waters IC-Pak M/D 3.9 × 150 mm	Shodex Sugar SC1011
Eluant	1.2 mM isophthalic acid pH 4.6	3 mM nitric acid 0.1 mM EDTA	Water 80°C
Flow rate	2 mL/min	1 mL/min	1 mL/min
Detection	Indirect photometric 280 nm	Conductivity	Refractive index

TABLE 6—Recovery of ammonium from the vehicles.

Distance of Vehicle from Charge	Ammonium ( $\mu\text{g}$ ) Recovered from Vehicles					
	Firing 1		Firing 2		Firing 3	
	FEL	FBI	FEL	FBI	FEL	FBI
4.6 m	*	26	60	66	84	
15.2 m	*	46	30	161	128	
22.9 m	*	44	62	153	156	

\* No swab samples taken.

TABLE 7—Recovery of nitrate from the vehicles.

Distance of Vehicle from Charge	Nitrate ( $\mu\text{g}$ ) Recovered from Vehicles					
	Firing 1		Firing 2		Firing 3	
	FEL	FBI	FEL	FBI	FEL	FBI
4.6 m	*	141	130	461	370	
15.2 m	*	nd†	12	1299	1166	
22.9 m	*	685	2620	5062	4166	

\* No swab samples taken.

† Not detected.

TABLE 8—Recovery of ammonium from the road signs.

Distance of Sign from Charge	Ammonium ( $\mu\text{g}$ ) Recovered from Road Signs					
	Firing 1		Firing 2		Firing 3	
	FEL	FBI	FEL	FBI	FEL	FBI
7.6 m	trace	18	6	76	trace	22
15.2 m	5	32	5	52	nd*	trace
22.9 m	trace	trace	trace	16	nd	nd
30.5 m	3	trace	nd	nd	nd	nd
7.6 m	4	42	37	242	11	116
15.2 m	trace	36	44	366	15	122
22.9 m	trace	trace	nd	nd	nd	trace
30.5 m	trace	nd	nd	nd	nd	trace

\* Not detected.

TABLE 9—Recovery of nitrate from the road signs.

Distance of Sign from Charge	Nitrate ( $\mu\text{g}$ ) Recovered from Road Signs					
	Firing 1		Firing 2		Firing 3	
	FEL	FBI	FEL	FBI	FEL	FBI
7.6 m	195	304	1455	2512	210	1608
15.2 m	12	116	105	1168	5	366
22.9 m	nd*	nd	66	256	6	82
30.5 m	nd	nd	65	nd	nd	nd
7.6 m	635	430	5498	1552	1342	1318
15.2 m	5	74	188	850	582	184
22.9 m	nd	nd	3	68	4	126
30.5 m	nd	nd	4	224	nd	nd

\* Not detected.

vehicles and 3 to 366  $\mu\text{g}$  for the signs. An environmental survey carried out by the FEL in Great Britain in 1995/96 has shown that nitrate and ammonium ions are commonly recovered from road signs and cars. The recoveries of nitrate ions ranged from 3 to 124  $\mu\text{g}$  for vehicles and 5 to 35  $\mu\text{g}$  for road signs, and for ammonium ranged from 1 to 88  $\mu\text{g}$  for vehicles and 2 to 70  $\mu\text{g}$  for road signs. These results suggest that a 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 no detectable recovery of sugar from any of the cars or road signs. While this was not unexpected it was thought that due to the long delay between taking the samples and analysis (approximately two months) the sugar may have decomposed during storage. A study into the short-term stability of sucrose in solution showed that a pure solution of sucrose was stable at 26°C over a period of 29 days. However, when a sample of CAN/S (calcium ammonium nitrate/sugar) was stored in solution under similar conditions there was a decrease in the sucrose content after 29 days. Solutions which were stored frozen at -20°C were found to be stable over 29 days and it was recommended that samples from subsequent trials should be stored frozen.

The contribution of soil contamination to the levels of nitrate and ammonium recovered from the signs is unknown. Soil samples taken prior to the first firing showed the presence of ammonium and nitrate at approximate levels of 4  $\mu\text{g/g}$  soil and results from subsequent trials have shown that soil contamination does occur throughout the duration of the firings. The lower levels of ammonium and nitrate recovered from the witness materials may be due to soil contamination and indicates the usefulness of control samples taken from a scene.

While the FEL and the FBI recoveries were similar in their patterns on the whole, the FBI recoveries were greater than those of the FEL. Differences in the recovery may be due to differences in residue recovery methods and/or the greater accuracy of the FBI quantitation, but may also be due to time differences between sampling. The FBI swab samples were taken from the signs the day after firing and the signs then repackaged and sent to the FEL for sampling. The signs were stored in their bags for a period of approximately two months before being reswabbed and it is possible that some of the particulate matter was lost in the bags during this period. This may be an indication of the importance of sampling post-explosion debris in situ. The recoveries of residues from the road signs in the first ANS firing were lower than for subsequent firings. Collection of evidence after the first firing was hindered by bad weather, including rain, which enforces the importance of collecting residues as soon as possible after an explosion or at least protecting potential residue evidence from the elements.

#### Blast Pressure and Detonation Velocity Measurements

Blast pressures and detonation velocities for each firing are shown in Tables 10 and 11. Much of the data from the pressure gages placed at 15.2 m were lost due to damage of the signal cables during firing by fragments and debris. In subsequent trials the cables were buried to prevent damage.

*Physical Damage to Road Signs and Vehicles*

When acted upon by the blast wave the edges of the signs folded backwards around the post. Attempts to measure the angle of bend were possible only for the more moderate angles exhibited by signs farther from the charge. The signs closest to the charge, 7.6 m, were in most cases detached from the posts and severely crumpled so that meaningful bend

angles could not be measured, Fig. 3. The damage to the signs was consistent with increasing distance from the charge: signs closest to the charge were severely crumpled and bent while those farthest from the charge were relatively undamaged, Fig. 4. The signposts themselves exhibited a consistency of damage. Posts closest to the charge were sheared in two while those farthest from the charge remained unaffected, with the intermediate posts showing moderate to slight bending.

The distances that the signs were blown and the angle of bend of the signposts were not measured. Attempts were made to do this for subsequent trials but it was found that the physical damage to the posts was dependent on how rigidly they were set into the soil and would not be representative of that found at a real bomb scene.

Damage to the vehicles was recorded from the photographs and video. Features common to all vehicles, i.e., windscreen,

TABLE 10—*Velocity of detonation measurements.*

Mean Velocity of Detonation (m/s)		
Urea Nitrate Firing	2nd ANS Firing	3rd ANS Firing
3730	3560	3560

TABLE 11—*Blast pressure data from the urea nitrate and three ANS firings.\**

Gage No. and Distance (m) from Charge	Peak Pressure, kPa (psi)			
	Urea Nitrate	1st ANS	2nd ANS	3rd ANS
1. 15.2	...	...	...	...
2. 30.5	52.6 (7.63)	37.2 (5.4)	38.5 (5.58)	46.2 (6.70)
3. 45.7	29.6 (4.29)	21.5 (3.12)	22.2 (3.22)	22.8 (3.31)
4. 61.0	17.2 (2.49)	...	16.0 (2.32)	14.8 (2.14)
5. 15.2	252.4 (36.6)	...	...	170.4 (24.7)
6. 30.5	51.0 (7.39)	27.8 (4.03)	34.4 (4.99)	31.8 (4.61)
7. 45.7	15.0 (2.18)	...	13.2 (1.91)	15.0 (2.18)
8. 15.2	108.3 (15.7)	139.3 (20.2)	108.3 (15.7)	216.6 (31.4)
9. 15.2	...	...	...	...

\* Data not corrected for atmospheric pressure and temperature.



FIG. 3—*Post-blast damage to sign at 7.6 m.*

tires, headlamps, were assessed for damage in a systematic fashion, the results for which are summarized in Table 12 and shown in Figs. 5–8. The pattern of damage to the vehicles at a given distance to the charge was found to be consistent for the ANS firings and the urea nitrate firing despite a wide variation in the make and model of the vehicle. The distances that the vehicles had moved from the charge were not record-

ed and this was recommended for subsequent trials. These observations could provide valuable objective evidence of explosive charge size even in the very confused conditions often encountered at bomb scenes. It is envisaged that once all the trials are completed a set of data produced relating vehicle and road sign damage to blast pressure, this can be used together with the distance of the object from the seat of the explosion to estimate charge size.

### Conclusion

The first set of trials of large IEDs, apart from providing a set of useful data, proved a very useful learning experience and confirmed the enormous damage that can be caused by IEDs of this size. The vehicles and road signs were found to be good surfaces for the capture and recovery of explosives residues. Ammonium and nitrate were recovered from witness materials at levels significantly higher than would be expected to be found in the environment. There was no detectable recovery of sugar in any of the samples. Given the low percentage of sugar used in the charge and the low recoveries of ammonium and nitrate, this is not unexpected. Analysis of residues from past cases involving the detonation of large fertilizer sugar devices has shown that ammonium and nitrate are predominately detected. Sugar has only been detected when a partial detonation of the device was thought to occur.

When all the trials are completed a comprehensive body of data will be available on the detonation of large improvised IEDs—the velocities of detonation, blast pressures and how these relate to the physical and chemical signatures produced upon surrounding witness materials will be known. The trials will also serve as a valuable training program for junior forensic scientists who have never witnessed the detonation of devices of this size. If called upon in the future to investigate crimes of this nature their interpretation of bomb scene evidence will be based on experience and scientific data.



FIG. 4—Post-blast damage to sign at 22.9 m.

TABLE 12—Summary of physical damage to the vehicles for all four firings.

Vehicle Component	Distance of Vehicle from Charge, m		
	4.6	15.2	22.9
Windscreen	Shattered	Shattered, glass remaining in frame	Shattered, glass remaining in frame
Side windows (facing charge)	Shattered	Shattered	Shattered
Side windows (opposing charge)	Shattered	Shattered	Shattered
Rear windscreen	Shattered	Shattered	Shattered
Bonnet	Crumpled	Raised on side facing charge	Slightly raised on side facing charge
Side body panels (facing charge)	Severely dented/destroyed	Dented	Dented
Side body panels (opposing charge)	Severely dented/destroyed	Dented	Slightly dented
Wheels and tires	Wheels remain intact,	possibility of burst tires on sides facing and	opposing the charge
Headlamps	Shattered	Shattered	Possibility of remaining intact
Orientation	Flipped onto roof for three out of four firings	Upright	Upright

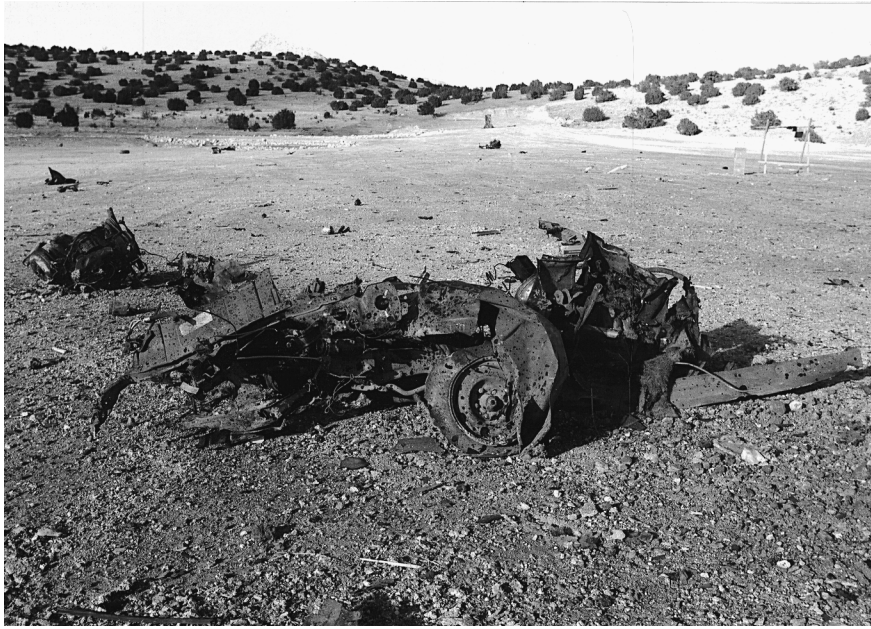


FIG. 5—Post-blast damage to vehicle at 2.1 m.



FIG. 6—Post-blast damage to vehicle at 4.6 m.

### Recommendations

There were many recommendations made for the improvement of subsequent trials. The use of wooden witness frames was halted due to their instability, and the numbers of road signs and vehicles, which were found to be ideal for residue capture, were increased. British road signs and posts were shipped to the test site for subsequent trials to be placed alongside the American signs. Problems were encountered

during these trials with the blast pressure measurements due to signal cable damage from the blast fragments, and it is recommended that cables be buried for future trials. Prior to these trials the test site had not been used for the detonation of large quantities of ammonium nitrate-based improvised explosives and the site soil was relatively free from ammonium and nitrate contamination. Future trials would need to monitor the background level of ANS in the soil to ensure that ANS residues recovered from the witness pieces





FIG. 7—Post-blast damage to vehicle at 15.2 m.



FIG. 8—Post-blast damage to vehicle at 22.9 m.

can be attributed to the charge and not to soil contamination.

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