

**REPORT ON THE
PETERBOROUGH EXPLOSION**

Peterborough, UK; 22 March 1989

BLAST DAMAGE AND INJURIES

by

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SUMMARY

- 1** At 09.45 on 22 March 1989 a vehicle carrying approximately 800 kg of mixed explosives exploded at the premises of Vibroplant Ltd on an industrial estate in Peterborough. The main bulk of the load was blasting explosives. The explosion caused the death of a fireman and injured well in excess of 100 people, 87 of whom received hospital treatment. Two of the injured were admitted to intensive care.
- 2** The vehicle was specially modified to carry explosives and operated by Nobels Explosives Company (NEC), a subsidiary of ICI. Shortly after it entered the Vibroplant yard a minor explosion occurred inside the load carrying compartment, causing a fire. The fire continued for some 12 minutes, during which time the fire brigade was called and took up position. After the 12 minutes the entire load, apart from a small number of detonators, detonated en masse.

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- 3 The investigations have concluded that the source of the fire and hence the cause of the ensuing explosion was a box of cerium fusehead combs which were destined for a fireworks manufacturer. The combs were in an unauthorised and unsafe packaging. NEC were subsequently fined £250,000 for breaching Section 3 of the Health and Safety at Work Act 1974.

DESCRIPTION OF SITE

- 4 The Vibroplant yard where the explosion occurred is on the edge of an industrial estate mainly comprising small to medium size commercial and industrial properties, consisting principally of large steel and pre-cast concrete framed buildings. These were clad with metal sheeting or, for the offices parts of the buildings, cavity brickwork. The estate is situated on the south side of Peterborough, see Figure 1.
- 5 The entrance to the yard of Vibroplant is set back and separated from the road by a pavement and grass verge some 24m wide: the yard is about 90 by 60 m, bounded on the south side by a 2 m high, 9" brick wall, and on the other sides by a chain link fence. The surface of the yard was asphalt over hard core. There was a 'sleeping policeman' speed ramp just inside the main gate.

DESCRIPTION OF VEHICLE

- 6 The vehicle was a Ford D series 11.5 tonne box van, specially modified to carry up to 5 tonnes of explosives. The sheet aluminium box load compartment was fitted with a roller shutter door at the rear, and was separated from the cab of the vehicle by a fire resistant screen.

EXPLOSIVES CONTENTS

- 7 At the time of the incident the vehicle contained:

High Explosives	- Powergel 800,	150 kg (6 by 25 kg cases)
	- Powergel E800,	500 kg (20 by 25 kg cases)
	- Magna Primers	56 kg
	- Ammon Gelit	75 kg
Detonators	- No 8 Star,	500 in number
	- Magnadet,	250 in number
Fuseheads	- Vulcan,	10,000 in 1 box
	- Cerium,	2,400 in 3 boxes
	(uncut combs)	

EVENTS LEADING TO THE EXPLOSION

- 8** The high explosives and detonators were typical of those used in quarrying and other blasting work. Powergels are relatively insensitive and are initiated by detonator and booster such as Magna Primer or other more sensitive explosives such as Ammon Gelit. The fuseheads were to be used at a fireworks factory as electrical igniters in pyrotechnic devices. The Cerium fuseheads were supplied uncut on combs with 20 fuseheads per comb -see Figure 2. The Vulcan fuseheads were supplied already cut into single devices.
- 9** It was a matter of chance that the explosives vehicle missed its way while heading for a nearby explosives factory, and used the yard belonging to Vibroplant as a turning place.
- 10** As the vehicle entered the yard of Vibroplant it passed over the concrete speed ramp whereupon there was a minor explosion inside the load compartment which blew the rear roller shutter door outwards. As the driver continued in a clockwise circle around the yard he noticed in his rear mirror, blue smoke behind the lorry. He stopped the vehicle near the middle of the yard facing the exit. Both the driver and mate went to the rear of the vehicle to investigate and subsequently to arrange contact with the emergency services.
- 11** The roller shutter door was hanging out of its guides on the passenger side and only partially in the guides on the drivers side. The door was secure both top and bottom. Through the gaps at the sides of the door could be seen smoke and flames inside the compartment. Initially the fire produced only a small amount of black smoke. As it progressed however, minor "pops" and bangs were heard with increasing frequency. As the fire progressed further, thick yellow smoke was observed and immediately before the explosion the sides of the vehicle were seen to bulge. The vehicle exploded at approximately 09.45, 12 minutes after the start of the fire.
- 12** At the time of the explosion 2 fire tenders and a fire rescue vehicle were in attendance. Two firemen took a branch(nozzle) just beyond the edge of the wall on the south side and at the entrance to the yard and stood ready to receive water. This was some 15 metres away from the burning vehicle. When the vehicle exploded one of these two firemen was killed.

INVESTIGATION

Examination of High Explosives and Detonators

- 13** Subsequent tests on samples of both high explosives and detonators involved in this incident showed normal behaviour. Their packagings

fully met the requirements laid down. Examination of production records revealed no anomalies. All were found to be safe to transport.

Examination of Fuseheads

- 14 The Vulcan fuseheads were found to be in a satisfactory condition and properly packed. The Cerium fusehead combs however were found to be packed in unauthorised and unsafe packagings. The type of packaging used was both illegal and dangerous in that there were excessive numbers of fuseheads per box, the packaging was loose resulting in presence of loose composition inside metal boxes, and presence of rust. Fusehead composition was examined and found to be extremely sensitive both to impact and friction. Mixtures with rust (1%) had a 10 fold increase in impact sensitivity. Boxes of combs dropped from a height of 1.2 metres exploded in some tests but not others. Ignition trials on one box of cerium combs produced a fireball approximately 2.5 m in diameter, and lasting 0.3 seconds.

CAUSE OF THE EXPLOSION

- 15 The sequence of events that led to the explosion began when a minor explosion inside the vehicle started a fire. After about 12 minutes the main bulk of the cargo, blasting explosives, detonated.
- 16 The initial minor explosion was probably caused by ignition of the Cerium fusehead combs when the vehicle jolted over the speed ramp control. The likely mechanism for ignition being impact or friction of the fusehead debris or loose composition against the metal box packaging. The fusehead composition was probably sensitised by the presence of rust. The fireball which followed threw burning debris around the load compartment, starting a number of fires.
- 17 The mechanism for detonation of the whole cargo cannot be firmly established. One possibility is the presence of detonators which were scattered about during the fire and landing on or near heated and perhaps sensitised explosives. Another possible mechanism is the burning to detonation of the Pentolite boosters or the Ammon-Gelit.

BLAST DAMAGE AND INJURIES

Damage Caused by Explosion

- 18 Appended are aerial photographs both of the Vibroplant yard some time before the explosion, and the general area after the explosion (Figures 3 and 4).
- 19 The epicentre of the explosion is marked by a depression (dimensions 46 cm deep, 3.5 m radius) in the tarmac surface of the yard. The floor of the explosives vehicle was approx. 1 meter off the floor.

- 20 Approximately 130 cars were damaged to varying degrees, i.e approx. 60 beyond viable repair, 13 badly damaged, 51 slightly damaged, and the remainder superficially damaged.
- 21 Blast damage to the two buildings on either side of the explosion, i.e to Vibroplant and City Electrical Factors, was considerable -see Figures 5 and 6. Damage to the Vibroplant building was such that it had to be demolished at the earliest opportunity. Damage to buildings further afield consists of large doors blown in, metal cladding removed, asbestos roofs collapsed, metal cladding damaged, window frames blown in,extensive window damage etc. The number of buildings significantly damaged was of the order of 150.
- 22 Window damage was extensive reaching as far out as an archaeological site (Flag Fen) some 1260m away.

Discussion on Blast Damage

- 23 Historically there have been relatively few explosives incidents not associated with the immediate act of explosives manufacturing, i.e few incidents off-site. This incident has presented a unique opportunity to study the explosion effects of a relatively small quantity of commercial blasting explosive, upon a modern industrial estate. Additionally, by comparing actual damage with what we would have predicted for this situation allows us to confirm or refine as appropriate,damage/injury predictive techniques.
- 24 It is common to relate structural damage simply to blast overpressure, as shown in Table 1 (reference 1), when attempting either to predict the damage which is likely to be caused by an accidental explosion, or, in any post accident investigation of an explosion to estimate the equivalent quantity of TNT involved in the same. This, however, ignores the considerable effects of impulse, i.e the duration of the positive phase of the blast wave. With the relatively small quantity of explosive involved in this incident this is an important factor. A compilation of blast overpressure / damage criteria which includes a consideration of impulse is given at Table 2 (reference 2). This procedure has developed over many years, with much useful information gathered largely from World War II bomb attacks, the A bomb attacks on Japan, and American trials with nuclear weapons. From Tables 1 and 2 it can be seen that many of the blast damage 'markers' are construction elements of traditional British brick/tiled roof houses. In this incident the types and quantities of explosives are known with certainty. The premises, however, both surrounding the explosion and affected by it are principally not houses, but steel clad and/or brick fronted, steel and concrete framed industrial buildings. In view of the limited amount of published information on the blast

overpressure effects from approx. 800 kg of known explosive to these industrial buildings, it is worthwhile therefore, to record here, the main explosion effects in terms of 'new' industrial type markers.

- 25 A summary of damage versus distance 'contours' are given in Table 3. In column [4] (of Table 3) are listed the distances at which the various levels of damage occurred. Column [6] gives the corresponding overpressures predicted from 800 kg of TNT. Column [5] lists the distances (using information from Table 2 and other sources) at which these levels of damage are expected to occur.
- 26 Window damage in this incident was very variable and generally in excess of what might have been predicted. The extremity of window damage at the Flag Fen archaeological site some 1260m away was due to flexing of the flimsy wooden structure. Other reasons for much reported damage was the fact that in some buildings, long sections of windows have been blown out from the sides of steel framed/metal clad buildings without many of the panes breaking, even when the frames landed on the ground. Other reasons for variability include that the windows range from small to very large, thin to thick, single and double glazed, glazing held by putty/ beading/ rubber, frames of wood/plastic/metal, frames retained weakly/strongly etc. Another fundamental problem in assessing window damage with the large buildings here was that distances to that building, for the purposes of damage assessment, are normally taken from the rear of the same to the blast source. When using a simple Table 2 type approach this will clearly introduce increasing inaccuracy with increasing length of building. On the same line, a particular record of percentage window damage for a long face of a building which is in line with the direction of travel of the blast wave is again subject to much error due to the considerable variation in overpressure along its length.
- 27 Fragments were thrown over a wide area - see Figure 7. The prime requirement in the immediate post accident situation was to collect all live pyrotechnic items from the surrounding area. Recognisable pieces of vehicle (except the many small pieces of aluminium from the body) were also collected. The extremity of fragment throw was not accurately determined, but within a licensed fireworks site some 380-400 m away, a number of small items in the weight range 100-3000 grammes were found. Also at approx 470 m a number of cars were allegedly damaged by falling gravel.
- 28 In general, the steel and concrete framed building withstood the effects of the blast very well. The steel framed buildings, being able to flex, performed better than the concrete framed buildings. A few concrete purlins failed and collapsed, but these resulted in no injuries.

- 29 Overall, the blast damage appears to be consistent with a high order detonation of a quantity of explosives equivalent to 800kg of TNT.

INJURIES

- 30 The number of persons injured in this explosion was well in excess of 100. Of these, 80 were admitted to hospital; i.e 2 in intensive care (1 punctured lung, 1 burns), 12 as in-patients with other blast related injuries (head, spine, eardrums), and the remainder with superficial injuries (cuts, shock).
- 31 The fireman killed in the incident was approximately 15 or so metres away from the centre of the explosion and was killed by a fragment (see Figure 8). One of the badly injured persons (burned) was a fireman who had been standing close to the fatality. The other badly injured person was outdoors approx. 40 metres away, and was hit by a fragment. The injury 'contours' are summarised in Table 4.
- 32 Persons outdoors and close to the explosion sustained perforated eardrums (see Figure 9), cuts and bruises from flying debris, and were thrown to the ground (see Figure 10). Persons indoors sustained the greatest numbers of injuries from flying glass. Other injuries indoors were due to collapsed ceilings.

Discussion of Injuries

- 33 During World War II the V1 bomb attacks on London caused the greatest number of injuries and fatalities to persons indoors by partial or complete demolition of the houses. i.e people were crushed and asphyxiated respectively by falling debris and dust. In this incident there were no instances of complete building collapse and consequently no related serious crushing injuries. Any housing at the sorts of distances from the explosion that both Vibroplant and City Electrical Factors were, would have been expected to have suffered considerable damage with corresponding numbers of serious injuries /fatalities (for 800 kg TNT, radii of A and B damages respectively are 22.1 and 32.2 metre). Against this background these two closest 'industrial' type buildings survived well.
- 34 In the 12 minute period between the onset of fire and the final explosion, numbers of people congregated both outdoors in close proximity to the van, and against windows which overlooked the Vibroplant yard (see Figure 8). This had the effects of causing persons outdoors to be blown off their feet, sustain hearing damage, and for some to be injured by fragments. Persons indoors sustained serious cuts from flying glass, translational injuries, and injuries from falling

ceilings/debris. Cuts injuries accounted for the majority of hospitalised persons. Previous expectations for an incident such as this might have been that the delay between the onset of the fire and the final explosion would have caused persons in the vicinity to move well away. This of course did not happen.

CONCLUSIONS

- (i) Overall, the the blast damage appears to be consistent with a high order detonation of approximately 800 kg of high explosives.
- (ii) A pre warning of the fire before the explosion, coupled with inadequate evacuation of the area, caused persons to congregate both in the open, close to the vehicle, and inside buildings adjacent to glazing. This resulted in many injuries from flying glass, fragments, and damaged eardrums.
- (iii) In general, the steel and concrete framed building withstood the effects of the explosion very well. The steelframed buildings being able to flex, performed better than the concrete- framed buildings. A few concrete purlins failed and collapsed, but these resulted in no injuries. The same explosion in the centre of an housing estate would have produced more serious injuries.
- (iv) Information gathered in this tragic incident, on the explosion effects of a fairly small quantity of commercial blasting explosive upon a modern industrial estate is very valuable and can be used for refinement, if necessary, of damage assessments techniques.

REFERENCES

- 1 CLANCEY V J S, Diagnostic features of explosion damage. Sixth Int. Mtg of Forensic Sciences, Edinburgh (1972).
- 2 SCILLY N F and HIGH W G, The Blast Effects of Explosions, 5th Int. Symp. Loss Prevention in the Process Industries, Cannes 15-19 September 1986, vol. 1, paper 39.

TABLE 1: DAMAGE PRODUCED BY BLAST OVERPRESSURE

Pressure (psig)	Damage
0.02	Annoying noise (137 dB), if of low frequency
0.03	Occasional breakage of large glass windows already under strain.
0.04	Loud Noise (143 dB). Sonic boom glass failure.
0.1	Breakage of small windows under strain.
0.15	Typical pressure for glass failure.
0.3	Some damage to ceilings, limit of missiles.
0.4	Limited minor structural damage.
0.5-1.0	Large and small windows usually shattered, occasional damage to window frames.
0.75	Minor damage to house structures 20-50% tiles displaced.
0.9	Roof damage to oil storage tanks
1.0	Partial demolition of houses, made uninhabitable
1.0-2.0	Asbestos cladding shattered Fastenings of corrugated steel and aluminium panels fail and panels distort Tiled roof lifted and replaced
1.3	Steel frame of clad buildings slightly distorted
1.5	Slight damage to window frames and doors
2.0	Partial collapse of walls and roofs of houses Loadbearing brickwork unaffected 30% trees blown down
2.0-2.5	Some frame distortion of steel framed buildings
2.0-3.0	Concrete or cinder brick walls 8-12", not reinforced shattered
3.0	90% trees blown down Steel framed buildings distorted and pulled away from foundations. Frameless, self-framing, steel panel buildings demolished
3.0-4.0	Rupture of oil storage tanks
3.5	Oil storage tanks distorted
4.0	Cladding of light industrial buildings ruptured
4.0-5.0	Severe displacement of motor vehicles
4.5	Severe distortion to frames of steel girder framed buildings
5.0	Wooden utility poles snapped
7.0	Rail cars overturned
7.0-8.0	Brick panels (8-12"), not reinforced, fail by flexure
7-9	Collapse of steel girder framed buildings
7-10	Cars severely crushed
8-10	Brick walls completely demolished
9	Collapse of steel truss type bridges Loaded train wagons completely demolished
>10	Complete destruction of all unreinforced buildings
13	18" brick walls completely destroyed
70	Collapse of heavy masonry or concrete bridges
280	Lip of crater

TABLE 2: DAMAGE PRODUCED BY BLAST OVERPRESSURE.

Structural Element	Failure Mode	Approximate Peak Side on overpressure (psig) from different quantities of TNT		
		1 Te	10 Te	100Te
Window Panes	5% broken	0.15	0.10	0.10
	50% broken	0.36	0.24	0.21
	90% broken	0.90	0.60	0.54
Primary missiles	Limit of travel	0.20	0.14	0.12
Houses	Tiles displaced	0.64	0.42	0.38
	Doors / window frames blown in	1.30	0.86	0.77
see notes at end of Table	Category D damage	0.71	0.44	0.42
	Category Ca damage	1.8	1.15	1.10
	Category Cb damage	4.0	2.4	2.3
	Category B damage	11.5	5.2	5.0
	Category A damage	26.5	11.5	11.0
Rail wagons	Superficial damage	4.6	2.6	2.5
	Damaged but repairable	11.5	5.7	5.5
	Bodywork crushed	20	8.7	8.4
	Limit of derailment	26.5	1.5	11.0
Telegraph poles	Snapped	52	26	24
Large trees	Destroyed	57	26	24
Railway line	Limit of destruction	205	97	93

Note:

B Damage:

relates to a category of house damage caused by bomb damage in World War II viz, houses so badly damaged that they are beyond repair and must be demolished when opportunity arises. Property is included in this category if 50-75% of the external brickwork is destroyed, or in the case of less severe destruction the remaining walls have gaping cracks rendering them unsafe.

A Damage:

Houses completely demolished, i.e, with over 75% of the external brickwork demolished.

Ca Damage:

Houses that are rendered uninhabitable, but can be repaired reasonably quickly under war time conditions, the damage sustained not exceeding minor structural damage, and partitions and joinery wrenched from fixings.

Cb Damage:

Houses which are rendered uninhabitable by serious damage, and need repairs so extensive that they must be postponed until after the war. Examples of damage resulting in such conditions include partial or total collapse of roof structure, partial demolition of one or two external walls up to 25% of the whole, and severe damage to load bearing partitions necessitating demolition and replacement.

D Damage:

Houses requiring repairs to remedy serious inconveniences, but remaining inhabitable. Houses in this category may have sustained damage to ceilings and tilings, battens and roof coverings and minor fragmentation effects on walls and window glazing. Cases in which the only damage amounts to broken glass in less than 10% of the windows are not included.

TABLE 3:DAMAGE DISTANCE CONTOURS

1]	[2]	Damage/Other [3]	Distance [m]		O.P (psi) [6]
			Obs. [4]	Expect. [5]	
a.	Clean Area:	Area of yard near to explosion cleared of cars etc.	14	n.a	78
b.	Fireball:	Vehicles set on fire, and fireman was engulfed in flames.	18	17.5	44
c.	Frames:	Serious damage to concrete frames of building	110		1.7
		Steel frame moved.	120		1.5
d.	Walls:	Cavity brick/block walls of steel framed building belonging to Vibroplant and City Electrical Factors, totally destroyed.	30	< 35	14
		-next nearest facing wall damaged only along top edge where meets with steel roof beams.	70	n.a	3.2
		Metal cladding; fastenings fail, and followed by buckling.	115	68-113	1.6
e.	Roofs:	Metal roof cladding on steel frames removed.	30	n.a	14
		Asbestos cement type roof panels badly damaged /removed.	90	70-110	2.2
		GRP roof lights all destroyed.	140	n.a	1.25
f.	Windows:	Windows were broken as far out as the Flag Fen archeological site. The flimsy wooden structure there (at ca. 1260 m.) flexed considerably causing the distant damage.	1260	n.a	0.06
		90% window damage (small,single-glazed ca. and well retained units)	225	182	0.69
		50% window damage	ca.360	360	0.37
		5% window damage	ca.580	695	0.19
		Damage to window frames.	160	110-195	1.06
continued					

TABLE 3 continued: DAMAGE DISTANCE CONTOURS

1]	[2]	Damage/Other [3]	Distance [m]		O.P (psi) [6]
			Obs. [4]	Expect. [5]	
g. Missiles:		Fragments were thrown over a very large area - see Figure 7 appended. The prime requirement in this instance was to collect all pyrotechnic items from the surrounding area and dispose them. Recognisable pieces of the vehicle (except for the many small pieces of aluminium from the body of the vehicle) were also collected. The extremity of fragment throw has not been pursued rigorously, but certainly within an HSE licensed fireworks site, some 380-400 m away were found a number of small items in the weight range 100 - 3,000 gramme. Also, further out still at approx 470 m a number of cars were allegedly damaged by falling gravel.	400	-	0.32
			470	560	0.26

TABLE 4: INJURY CONTOURS

1]	[2]	Injuries. [3]	Distance [m]		O.P (psi) [6]
			Obs. [4]	Expect. [5]	
a. Burns:		Fireman 'engulfed in flames at.....	18	17.5	44
		Fireman slight burns at.....	25	na	21
b. Perforated eardrums:		100% within a distance of.....	28	na	17
		50% at a distance of.....	30	29	15
		Furthest reported instance.....	45	54	6.6
c. Fragments:		Serious injuries experienced up to this distance (excluding flying glass injuries). * - clearly there was potential for more injuries much further out-see Figure 7.	40	*	
d. Blown off feet:		Persons outdoors blown over up to....	70	93	3.2
		50% " " " " " " ...	55	45	4.7
e. Cuts from glass.		Cuts to all persons indoors.	0-50	n.a	>5.5
		Cuts to many	70-100	"	3.2-1.9
		Cuts to few.....	100-150	"	1.9-1.15
		Furthest instance of cuts...	ca. 200	"	0.80

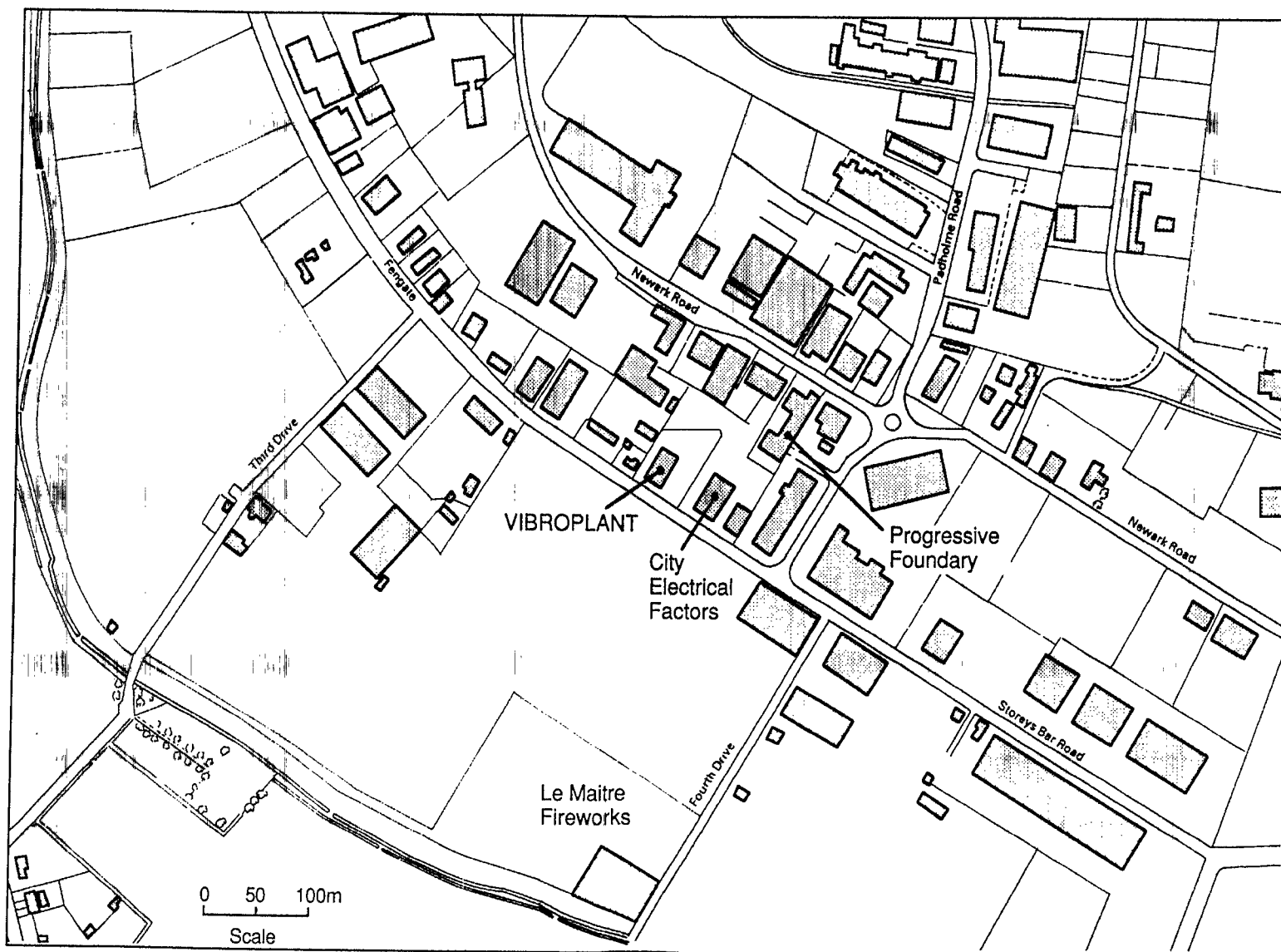


Fig 1 Plan of area around Vibroplant, Peterborough.

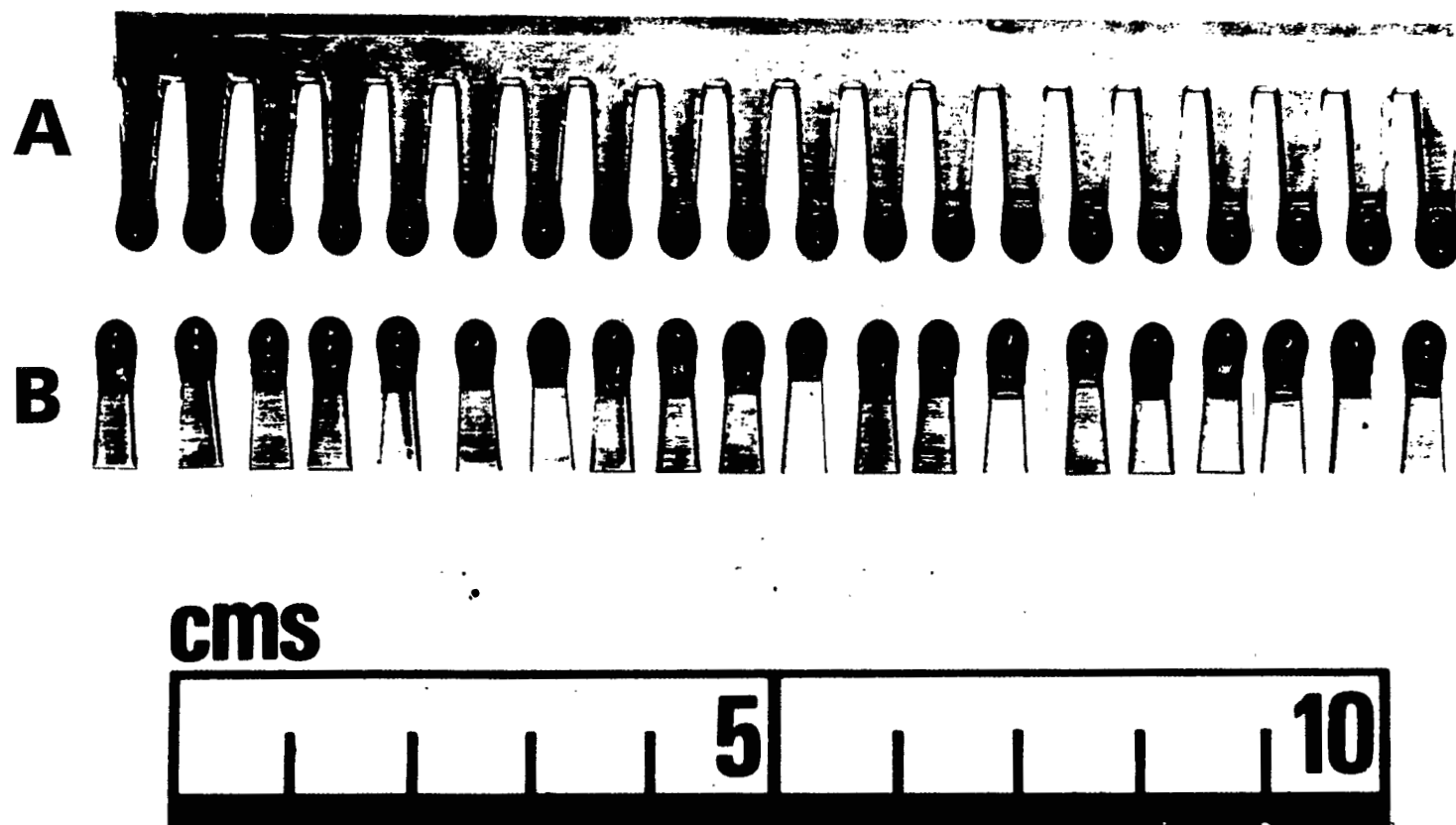


Fig 2 A - Cerium Fusehead Comb. B - Cut Fuseheads.

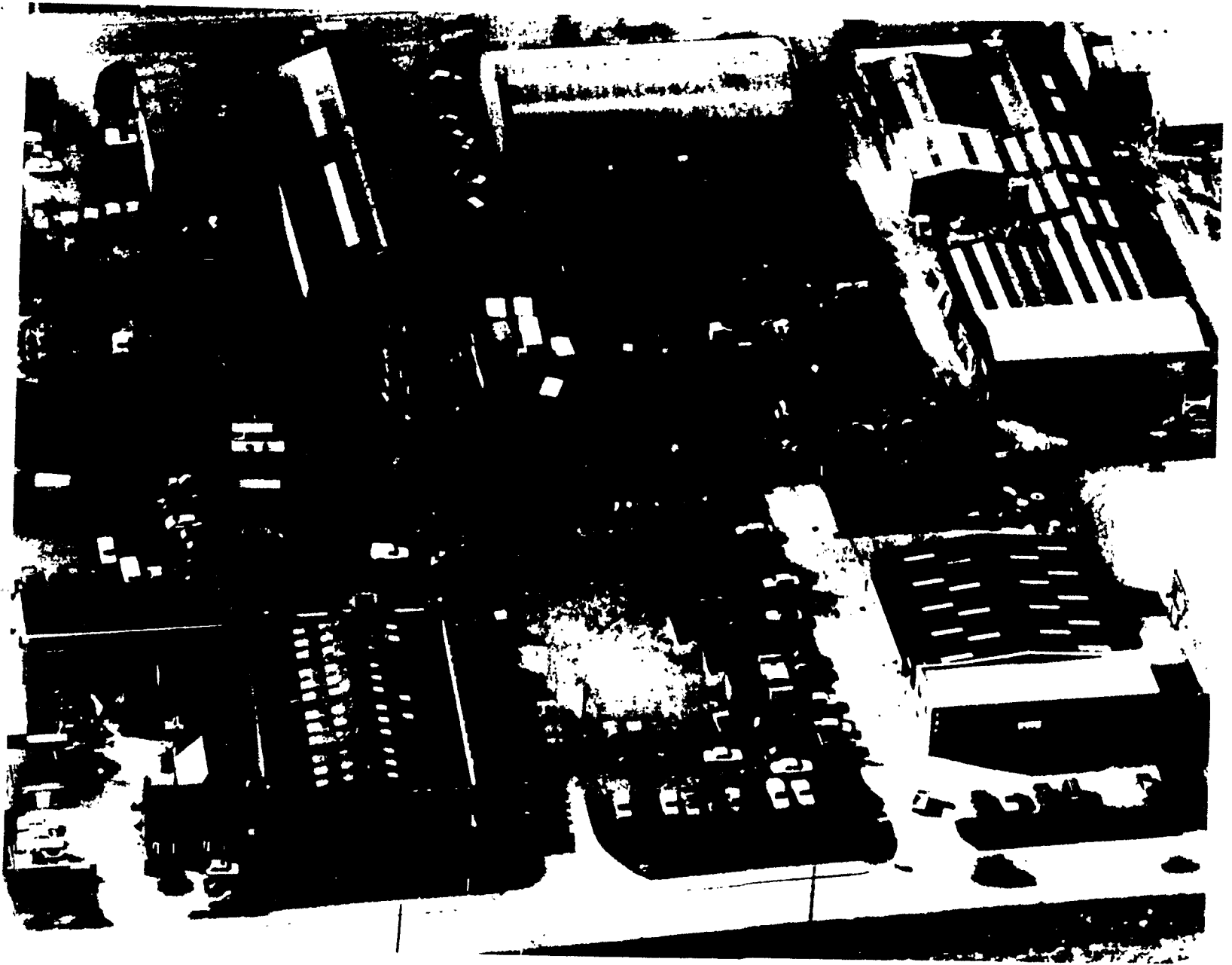


Fig 3 Scene of explosion - before

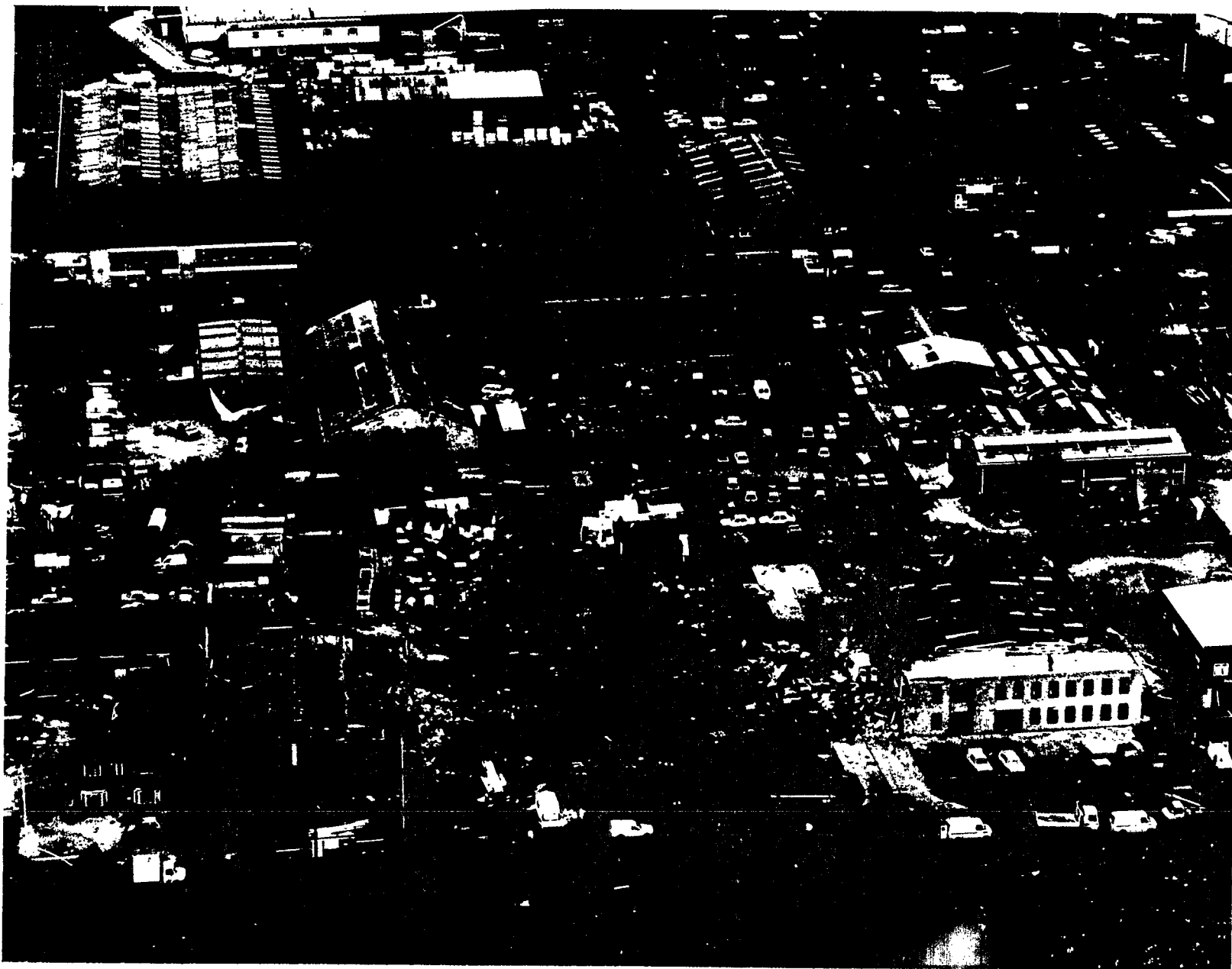


Fig 4 Scene of explosion - *after*



Fig 5 Damage to City Electrical Factors



Fig 6 Damage to Vibroplant Ltd.

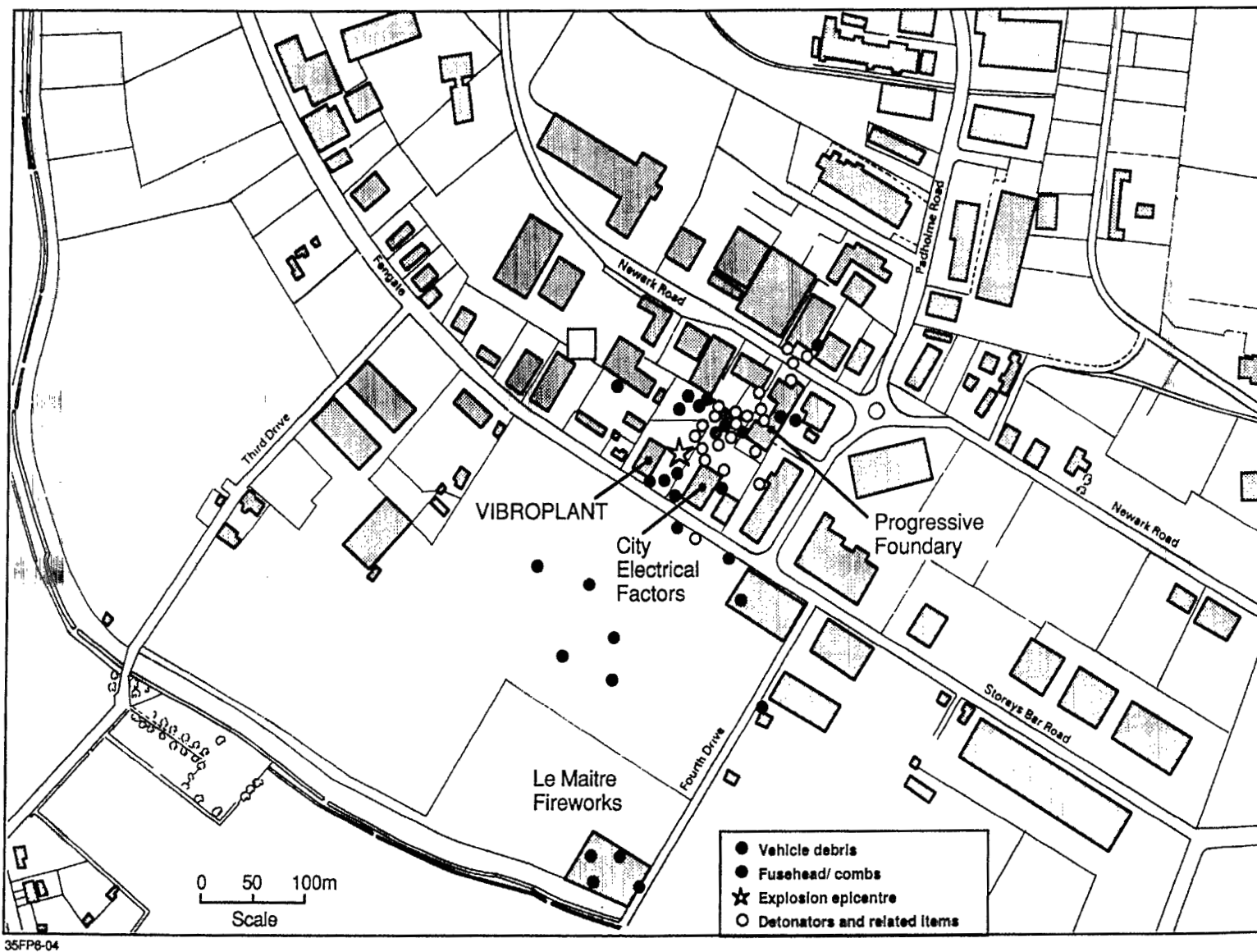


Fig 7 Explosion at premises of Vibroplant, Peterborough. Debris plan

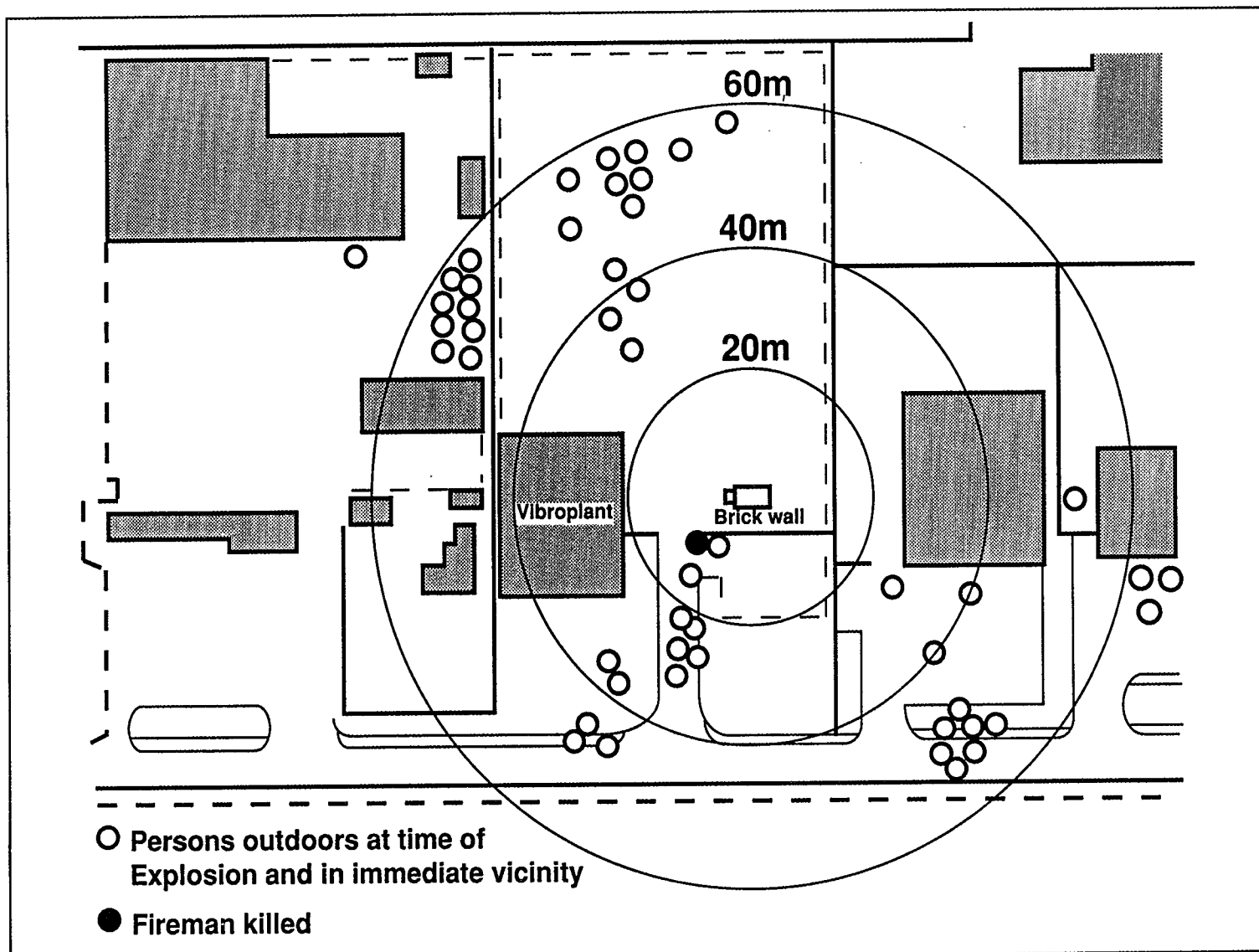
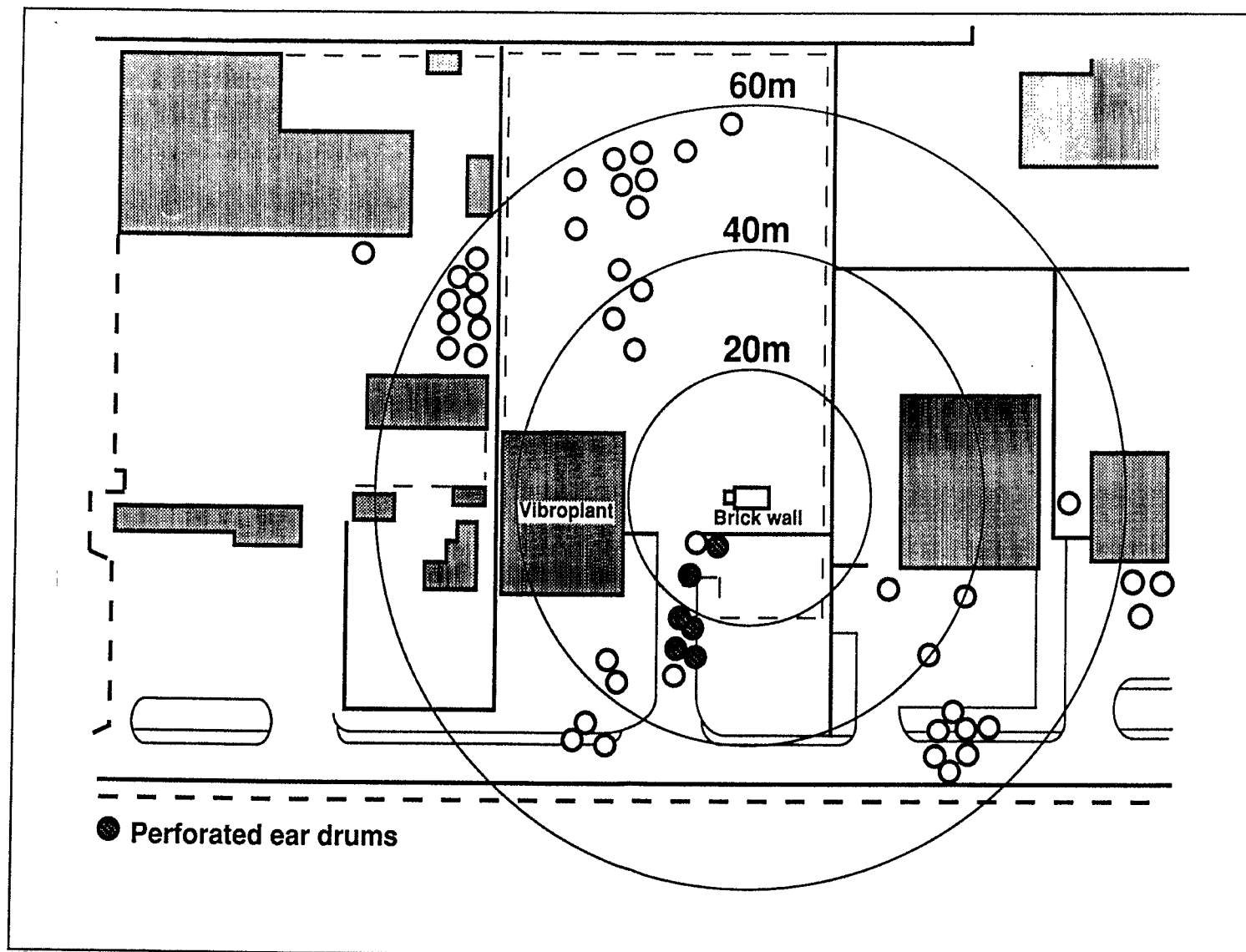


Fig 8



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Fig 9 Injuries sustained to persons outdoors

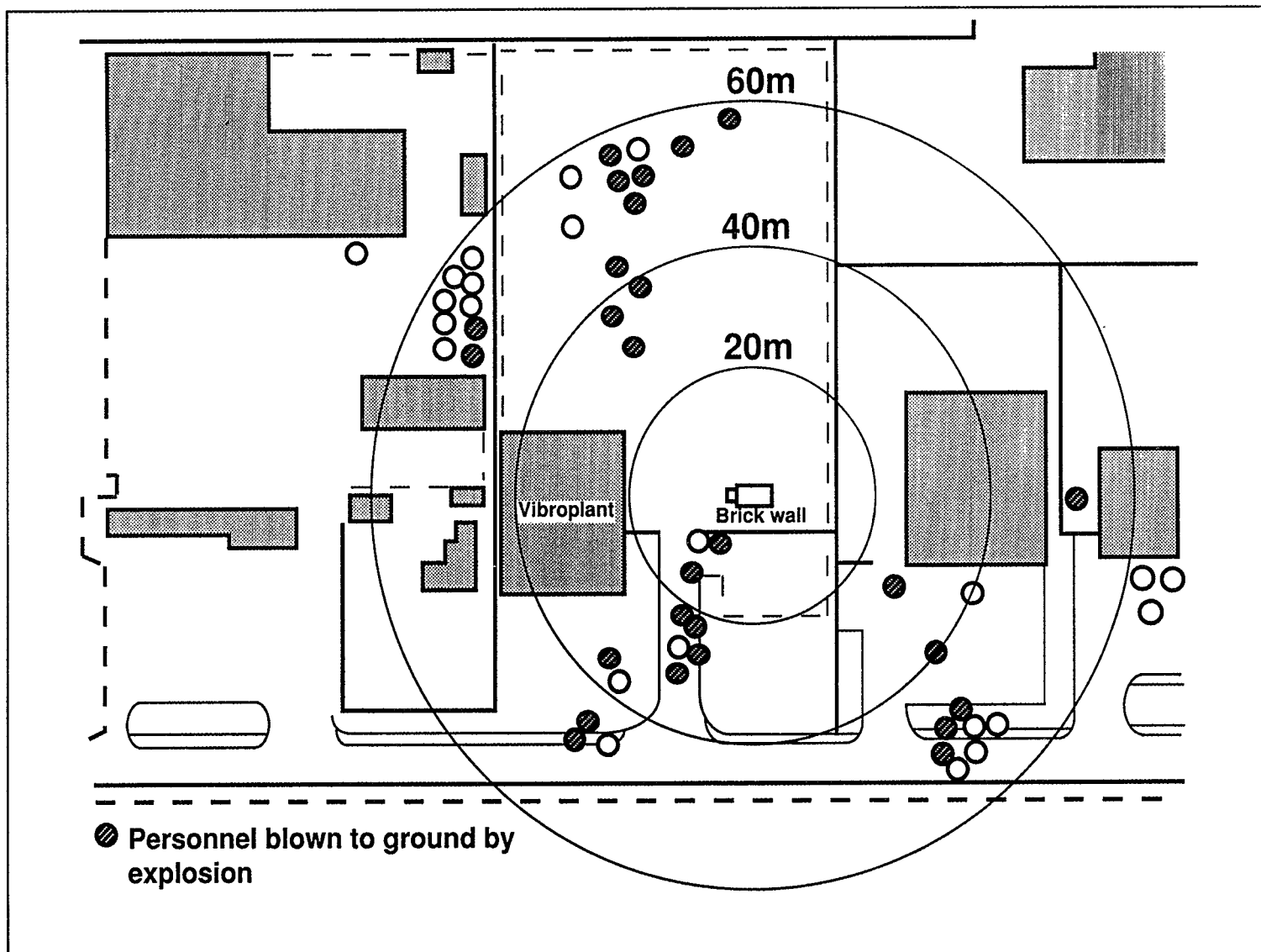


Fig 10 Blown to ground

