THE RISKS ASSOCIATED WITH THE STORAGE OF SMALL QUANTITIES OF GUNPOWDER AND SHOOTERS POWDERS IN CONTAINERS AND BUILDINGS

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Summary:

For many years in the UK, significant quantities of both gunpowder and smokeless powders have been held in domestic premises. Extensive trials have recently been carried out to consider the risks presented by the storage of such materials in these situations. The work has demonstrated that the primary hazard from smokeless powders results from the fireball potential. With gunpowder there is an additional significant risk of damaging overpressure effects. Ignition and deflagration of 0.5kg of gunpowder inside a thin-walled tin, as supplied, can blow out the walls of a room. Increased confinement increases potential overpressure effects. The cladding of metal security/storage cabinets with wood (25mm) provides a significant increase in the delay between fire engulfment and ignition of the explosives they contain. Tests have also shown that tins of gunpowder can be ejected from an explosion intact, which suggests that a reduction in hazard might be achieved by packaging the material in smaller quantities. Further work is planned.

Introduction:

In the UK in 1875 under a simple registration scheme which had no power of refusal, the Explosives Act allowed for the storage of up to 50 lbs of gunpowder (in a suitable substantial receptacle) inside a dwelling house. At that same time a maximum of 25 lbs of smokeless powders could be held with gunpowder up to an overall balance of 50 lbs. From 1875 to 1911 the law was progressively relaxed to allow for the quantity of smokeless powders to be increased to the same as for gunpowder. In 1912 a Home Office departmental committee was set up to reconsider the quantities of explosives that could be kept, this led to an increase on the limit of smokeless powder from 50 lbs to 100 lbs. This paper will report on the results of trials performed on these materials and will re-consider the risks posed by the storage of quantities of such materials in the home situation.

Accident Records:

The 1912 committee of enquiry heard that between 1876 and 1910 (35 years) there had been 132 accidents at the 30-35,000 registered premises. This had resulted in 43 fatalities and 132 injuries. Of these 132 accidents, gunpowder was involved in 79, and had been responsible for killing 28 and injuring 102. In almost every case the resulting damage was said to be limited to the premises

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on which the accident occurred, and in congested neighbourhoods presenting a danger not substantially greater than presented in an isolated house in a country area. In one of the reported 'domestic' incidents which occurred during the night a woman in bed 'next door' was killed by a 'Mode B' gunpowder explosion. Presumably this was due to building collapse. (In a Mode B store, explosives can be kept almost anywhere on the premises provided they are held in a suitable substantial receptacle).

More recently in the UK, records of fires in the home situation are recorded by the Home Office through the fire brigade service. Unfortunately these incidents are not recorded in a category of their own, but are included with fireworks and other similar events. It is not possible therefore to analyse the data sensibly for this area of interest. One of the UK's Local Authority explosives liaison officers however recalls two such incidents in his area over the recent past. The first of these occurred in a garden shed and involved the conversion of medium grain gunpowder into fine grain powder for subsequent use in cartridge re-loading. After the incident 12kg of unburned gunpowder was found. The injured person survived the blast but sustained severe burns to head, arms and hands. The second incident involved the drying of 7kg of 're-claimed' smokeless powder inside an open metal box, on top of a cooker. The resultant 'explosion' blew out the windows of the kitchen, and blew down the stud-partition wall between the kitchen and the lounge.

1912 Trials Data:

Some of the experiments conducted in 1912 at the request of the committee are described in Table 1.

Table 1: Summary of 1912 tests

	Experiment	Result
1	The lid was removed from a 5 lb tin of smokeless powder; the tin was laid on its side; a little compound was spilled at the mouth and ignited by fuse.	The smokeless powder flared off without report.
2	As above but with gunpowder.	A violent explosion blew the tin to pieces.
3	A sealed 5 lb tin of smokeless powder was placed on an improvised brick stove filled with straw; the whole was piled up with brush wood; paraffin oil was poured on the heap and it was set on fire.	The smokeless powder flared off without exploding.
4	As for [3] but with gunpowder.	Explosion projecting a large gas cloud of considerable velocity.
5	Sealed tins containing a total of 50 lbs of different smokeless powders were bundled together by wire and placed on a bonfire.	The tins flared off separately. In three cases there were mild reports due to the lap joints of the tins parting.
6	As for [5] but for gunpowder in six tins.	After about a minute one tin exploded violently, followed by the remainder 15 seconds later. A large cloud of smoke was projected with great velocity.

Recent trials:

Recent research at the Health and Safety Laboratory in Buxton(1) has investigated the effect of ignition of smokeless powders and gunpowder in different types of storage container in the open and in a simple brick building. Some of the tests that were carried out in the open were repeated using a wood fire to engulf the containers of explosives to simulate a fire in a building. Tests used fast burning smokeless powders, and/or fine gunpowder.

The explosives were used in multiples of 500g or 1000g and were always stored in either plastic bottles or metal tins (Table 2). The effects of further confinement were investigated by placing the bottles/tins in steel ammunition boxes, steel gun cabinets or wooden boxes (Table 2). When gunpowder and smokeless powder were required for the same test an equal mass of each type of explosive was used. Where electric fuses were used to ignite a test, only one of the packs was fused and in cases where gunpowder and smokeless powder were used in the same trial, the gunpowder was initiated in preference to the smokeless powder. Fire engulfment tests used a wood fire which was 1.5m square and 1m high, constructed in a similar manner to a UN6c test(2).

The quantity of explosive used in the tests varied. Smokeless powder tests used 1,2,4 or 10 packs each containing 500g; Gunpowder tests used 1 pack of 500g, or 1or 2 packs with a mass of 1000g. The total mass of explosives in mixed powder tests was 1or 2kg.

Each trial was recorded using two normal speed cameras, a high speed video and a high speed cine camera. The normal speed video cameras viewed the explosion from different angles to allow the spatial position of some of the fragments to be established. Noise meters and blast gauges were positioned at known distances from the explosion point.

Where fire engulfment trials were carried out, the time from ignition of the fire to the time of explosion was recorded in order to assess the effectiveness of the different storage containers at delaying the ignition of the explosives.

For each trial the mass of the fragments and their positions in relation to the explosion point were measured. The velocities of some fragments were estimated from the video and cine film recordings using scale poles on the test pad as reference points. Parallax errors were not taken into account and therefore the velocities measured were expected to be lower than the actual fragment velocities.

Analysis of the blast data was undertaken using in-house developed automated blast analysis routines based on a modified Friedlander equation utilising the FAMOS data analysis and reporting system(3).

Table 2: Types of container used in recent trials

Type of container	Description
Plastic bottle	Retail pack for storing nominally 500g smokeless powder. Plastic bottle with plastic snap shut cap. (90mmx70mmx230mm high. Wall thickness 0.6mm).
Metal tin	Retail pack for storing nominally 2lbs (0.91kg) fine gunpowder. Metal tin with plastic lid insert and metal screw cap. (70mmx20mmx80mm high. Wall thickness 0.2mm)
Steel ammunition boxes	Type H83 Mk2 (14x27.5x17.5cm high) and Type L17A1 (14x31x35cm high). Main bodies made from 1.5±0.1mm thick steel. Clasps made of heavier gauge steel.
Gun cabinets	61cm high, 20.5cm deep and 36.5cm wide. Complied with BS7558 and were made from 2mm thick steel. An internal locker, which was as wide as the cabinet, extended 18cm down from the top.
Wooden boxes	Made from 25mm thick plywood. Joints were glued and screwed for additional strength. The hinged lid had a plastic foam strip to provide a weatherproof seal with the rest of the box and was fitted with a hasp and staple to allow a padlocked to be used.
Brick/block building with explosives in a steel ammunition box	2.4m square and 2.4m high. Representing a downstairs room in a modern two storey private dwelling. Single skin block construction on three sides, double skin brick and block on the fourth side. 1m^2 glazed window in double skin wall. Door positioned on one of the single skin walls and opened inwards. Ceiling joists at 600mm centres with plasterboard on the lower side, tongue and groove chipboard on the upper side to represent the floorboards of an upper storey.

Results:

Smokeless powder tests

Tests which only used smokeless powder, showed that fuse ignition did not reliably ignite the charge. In all cases incomplete combustion of the powder occurred which was sufficient to rupture the plastic bottle allowing unburnt powder to scatter on the floor. Noise measurements did not exceed those obtained as background wind noise (100-110dB(C)) and no measurable blast overpressures were recorded. Fire engulfment tests indicated that there was little hazard from fragments, blast, or noise when multiples of 500g of this type of gun propellant where stored in plastic bottles. The bottles flared-off before sufficient pressure could be generated inside the container to propel the bottles significant distances or at high velocity.

Gunpowder and mixed explosive tests

A summary of the fragmentation data is given in Tables 3 and 4.

In many of the mixed gun propellant trials (in which the gunpowder was initiated by fuse), smokeless powder bottles were ejected from rupturing steel containers by the primary explosion with unburnt composition emanating from them. The intensity of the heat from the primary explosion was sufficient to ignite the spilled powder which produced a secondary fireball. The distance of the secondary fireball from the primary explosion varied but in one case, when a mixed powder test of 2kg was fired in a steel gun cabinet, a burning bottle was projected 43m. A similar effect was observed with gunpowder in plastic bottles, although the bottles were only ejected 2-3m from the primary explosion site before ignition occurred. When multiple tins of gunpowder were put in wooden boxes, only one of the tins exploded, the other was ejected from the box intact, or shedding composition as it flew through the air. This type of event was observed for fuse and fire engulfment tests.

From the evidence that smokeless powder charges can be ejected from an explosion unburnt, and that the energy output is low (insufficient to produce hazardous fragments), it is reasonable to assume that most of the damage caused in the mixed explosive tests was due to the gunpowder charge alone. If it is assumed that this is true, the mean mass, velocity and projected distance of fragments generated by different charge masses of mixed explosive or gunpowder in different containers can be compared.

The data show that large fragments (1-4kg) could be projected up to 135m at velocities of up to 270ms^{-1} when gunpowder charges of 1kg are used. One steel fragment (a gun cabinet door) of mass 3670g was projected 125m at 123ms^{-1}, while another of mass 694g (ammunition box lid) travelled 127m at 271ms^{-1}. The mass of wooden fragments generated from 2x1kg tins of gunpowder ranged from 11-798g and were projected comparable distances (110m) at velocities of up to 104ms^{-1} (these 2x1kg tests had an effective charge mass of 1kg since one tin was ejected unburnt).

Comparison of the effect of explosion on the outer wooden containers used to hold the retail bottles and tins of gunpowder indicated that when the composition was contained in metal tins, wood panels were projected more than twice the distance that they were when the same material was stored in plastic bottles. This suggests that the confinement afforded by the tins is greater than by the plastic bottles and gives rise to a faster reaction and greater gas pressure to propel the fragments.

Ammunition box fragments were propelled to the same distance (90m) with either ignition system but the type of failure was different. Fuse ignition caused the ammunition box lid to be ripped from its hinges leaving the main body of the box intact whereas fire engulfment caused the main body of the box to be blown open at the welds and parts of it to become detached. The failure of welds may be due to softening of the weld metal or an increase in the rate of energy output of the explosive as a result of bulk heating.

Significant differences in projection of the wooden box fragments were observed depending on whether a fuse or fire engulfment ignition system was used. Wood panels were propelled over 5 times as far when plastic bottles or metal tins of gunpowder were ignited by fuse compared to fire engulfment. In the fire engulfment tests ignition occurred over 14 minutes after the fire was ignited, which allowed the thickness of the wood panels to be reduced considerably by the fire. This meant that the degree of confinement was significantly reduced in these tests compared to those ignited by a fuse. The effect of the reduction in confinement is also exhibited in the distance that the unexploded tins of gunpowder were projected (52m for fuse ignition, 23m for fire engulfment), and is supported by pressure measurements (Figure 1). These show that fire engulfment resulted in at least a 3-fold reduction in the pressures generated compared to fuse ignition. For gunpowder contained in plastic bottles a reduction to 1.6% of the pressure generated by fuse ignition was observed, probably due to the plastic bottle melting and allowing the gases from the burning gunpowder to expand into a larger volume.

Table 3: Summary of fragment data from smokeless powder and gunpowder tests ignited by fuse

Test Type	Type of fragment	Mass of fragments (g)		Maximum projected distance (m)	Maximum velocity (ms^{-1})
		Range	Mean		
500g gunpowder in plastic bottle	Plastic bottle	13-67	40	10	33
500g gunpowder in metal tin	Tin	17-98	37	25	77
500g gunpowder in metal tin in building	Glass	-	-	-	14
500g gunpowder in tin in ammo. box in building	Glass	-	-	-	25
500g gunpowder in tin in ammo. box	Tin	22-99	51	25	-
	Ammo. box	1251	n/a	90	38
*500g gunpowder in tin in ammo. box	Tin	13-66	32	36	-
	Ammo. box	267	n/a	-	103
*500g gunpowder in tin in gun cabinet	Tin	5-59	30.3	-	-
	Gun cabinet	1317-3571	2444	64	49
*1000g gunpowder in tin in ammo. box	Tin	13-49	35.2	75	-
	Ammo. box	11-1370	368	127	271
*1000g gunpowder in tin in gun cabinet	Tin	9-32	21.9	-	-
	Gun cabinet	132-3670	1055	135	123
2x1000g gunpowder in plastic bottles in wooden box	Plastic bottles	76-78	77	8	-
	Wood panels	305-798	581	50	40
	Hasp & staple	-	-	-	-
2x1000g gunpowder in metal tins in wooden box	Tin	18-74	37	80	-
	Full tin	475	n/a	52	7
	Wood panels	405-733	606	110	104
	Hasp & staple	-	-	-	-

* Mixed explosives tests (Gunpowder & smokeless powder)

Table 4: Summary of fragment data from gunpowder tests ignited by fire engulfment

Test Type	Type of fragment	Mass of fragments (g)		Maximum projected distance (m)	Maximum velocity (ms^{-1})
		Range	Mean		
500g gunpowder in plastic bottle	Plastic bottle	86	n/a	30	11
500g gunpowder in metal tin	Tin	31-56	40	23	13
500g gunpowder in tin in ammo. box	Tin	22-63	35	11	-
	Ammo. box	153-892	523	90	85
2x1000g gunpowder in plastic bottles in wooden box	Plastic bottles	14-77	76	9	-
	Wood panels		201	9	6
	Hasp & staple	200	n/a	-	-
2x1000g gunpowder in metal tins in wooden box	Tin	21-98	50	80	24
	Full tin	674-689	682	23	53
	Wood panels	11-235	125	20	24
	Hasp & staple	201	n/a	20	25

Overpressure measurements at 5m from the explosion for gunpowder tests using different types of storage container gave values of 170, 1030 & 5160Pa for 500g of gunpowder contained in a plastic bottle, a metal tin, and a metal tin in a steel ammunition box, respectively, which suggests that the degree of confinement of the explosive affects the overpressure generated. This is supported by tests carried out in buildings, one using 500g gunpowder in the manufacturers retail tin, and the other which used 500g each of smokeless powder and gunpowder in an ammunition box, resulted in different building damage. The latter test produced broken blocks and timbers whereas the former demolished the building by 'pushing' it apart without breaking blocks or timbers. Both tests can be considered to have the same amount of explosive in them (500g gunpowder) since the smokeless powder was ejected from the building in the ammunition box test. In both tests the masonry remained within 3m of its original position but glass fragments were ejected with considerable force.

Comparison of the elapsed time from lighting the fire to ignition (Table 5) shows that maximum protection is afforded by wood outer containers, which, due to their good thermal insulation properties, provided a delay of up to 23 minutes before ignition occurred. Metal containers, which do not provide good thermal insulation, resulted in ignition relatively quickly after the fire had been lit (<5 minutes).

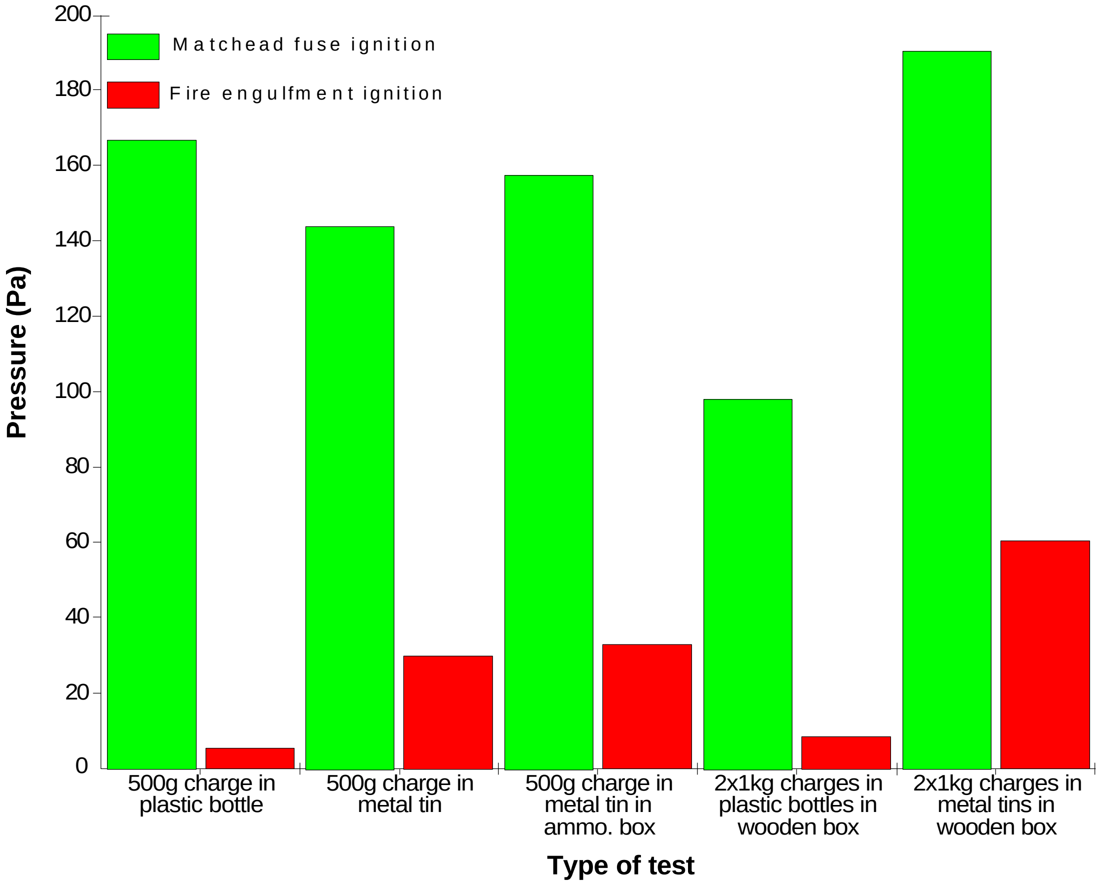

Figure 1: Overpressures generated at 50m from the explosion point when gunpowder charges in different containers are ignited by matchead fuse or by fire engulfment

Table 5: Elapsed time between a fire being lit and the ignition of the explosives

Description	Elapsed time (mins)
4x500g smokeless powder, stored in the manufacturers plastic bottles	1
4x500g smokeless powder, stored in a steel ammunition box in the manufacturers plastic bottles	1
4x500g smokeless powder, stored in the manufacturers plastic bottles in a wooden box	16
10x500g smokeless powder, stored in the manufacturers plastic bottles in a wooden box	14
500g gunpowder, in plastic smokeless powder bottle	1
500g gunpowder, in the manufacturers metal tin	3
500g gunpowder, stored in the manufacturers metal tin in a steel ammunition box	4
2x1000g gunpowder, stored in plastic smokeless powder bottles in a wooden box	20
2x1000g gunpowder, stored in the manufacturers metal tins in a wooden box	21
Repeat 2x1000g gunpowder, stored in the manufacturers metal tins in a wooden box	23

The tests have shown that, in general, the noise generated, fragment velocities, and projected distances are lower for tests carried out in a fire compared to similar tests ignited by a matchead fuse. These observations all suggest that the rate of energy release from the fire induced explosions was lower than in the case of fuse ignition. Confinement of explosives increases the rate of reaction causing more energy to be released over a very short period which suggests that the degree of confinement of the explosives is reduced in a fire.

Discussion of Hazards:

Smokeless powder

The main hazard from smokeless powders is likely to be from the flare-off of the composition which could produce a fireball capable of causing severe burns to anyone who is standing close by. These effects are likely to be more pronounced in a confined area such as a small room.

Gunpowder

Tests using gunpowder have shown that at 50m from an explosion, low order pressure waves of up to 200Pa can be produced from a charge of 1kg. The magnitude of the pressure is dependent on the degree of confinement. This effect was demonstrated in the building trials where more damage was observed when a more heavily confined charge was used. Literature values(4) suggest that an overpressure of approximately 50kPa is necessary to cause a 10% chance of rupturing the ear which suggests that such injuries are unlikely unless the person is in close proximity to the event (within 5m).

A more hazardous aspect of gunpowder explosions was the fragments produced from retail packaging and storage containers. Tins fragmented readily producing fragments with masses in the range 5-99g and velocities of up to 77ms^{-1}. More massive fragments (up to 3670g) have been shown to be capable of travelling at over 100ms^{-1} over distances of up to 135m. This indicates that fragment energies are considerable and would be sufficient to cause serious injury or death.

The tests have shown that tins of gunpowder can be ejected from an explosion intact or shedding composition as they fly through the air. This type of event was observed for fuse and fire engulfment tests. Clearly, the scattering of full gunpowder containers presents additional hazards to any occupants of a building or to the emergency services. Containers could be thrown over 50m, possibly into areas which appear to present little hazard. Fatal injuries could occur to people who are close by if these containers explode as a result of an external heat source such as flames from a burning building.

Quantitative analysis of fireball hazards has not been undertaken as part of this study. However, fireball diameters of approximately 3.5m, generated from the ignition of as little as 1kg of gunpowder, have previously been reported(5). It has been estimated that 3rd degree burns and spontaneous ignition of clothing could occur within 1.6m of the centre of such a fireball. This suggests that small quantities of gunpowder could have the potential to kill everyone in a small room.

Likelihood of an Accident:

Attempts to determine the frequency of recent accidents involving gunpowder and shooters powders in the home loaders situation is very difficult. A crude analysis of some of the powder incidents between 1876 and 1911 is given in Table 6.

Table 6: Main causes of gunpowder accidents 1876-1911

Type of Accident	Number of Incidents	Number of Fatalities	Numbers Injured
Ignition of powder in room by naked light	30	9	52
Ignition of powder in room by friction	8	4	20
Ignition of powder from undeclared source of ignition	11	12	20
Explosion during cartridge filling/handling	16	6	22

Expert opinion at the 1912 hearing was that the number of accidents was relatively small.

A crude estimate of the individual risk presented by the gunpowder 'handling' can be derived from the historical records if some very rough and ready assumptions are made:

(i) that over the 35 year period of study approx. 2/3rds of the premises held gunpowder;

(ii) that on average 4 people are exposed to the 'blast' on each occasion;

It follows that the gunpowder incident rate $= \frac{79}{20{,}000 x 35} = 1.13 \times 10^{-4}$ incidents/premises. year

and the individual risk of fatality approximates to $\frac{28}{79 x 4} \times 1.13 \times 10^{-4} = 1 \times 10^{-5}$.

From a tolerability of risk criterion(6) this equates to falling in the ALARP (As Low As Reasonably Practicable). To extrapolate this figure for current conditions is difficult. Approximately 40% of all the powder incidents were due to direct contact of powder with candles, matches etc. and it is reasonable to assume that the frequency of such accidents at the present time is likely to be much lower. Perhaps a reduction by half is reasonable. However, this could well now be countered by the new firearms legislation in the UK, which apparently has caused a significant increase in the number of people using gunpowder for muzzle loading etc in the home.

Conclusions:

- The smokeless powder tested appeared to be less sensitive to spark initiation than gunpowder and was able to withstand severe mechanical shock (e.g. an adjacent explosion) without deflagrating.
- In a domestic situation such as the home loading of ammunition, the primary hazard for the smokeless powders tested results from the fireball potential. Ignition of as little as 1 kg of material can give a fireball diameter of ~ 3.5 m; i.e engulfing and potentially killing everyone in a small room.

- Containers of unburnt smokeless powder that were ejected from adjacent gunpowder explosions caused a secondary fireball hazard which could be projected considerable distances from the initial explosion point. A distance of 43m was recorded.
- With gunpowder there is a significant risk of damaging overpressure effects. From the trials carried out to date we have seen that ignition of 0.5 kg of gunpowder inside a thin-walled tin as supplied, can blow out the walls of the room. If such an incident occurred on the ground floor of an ordinary 2 or 3 storey brick building, then this could result in building collapse. Further tests on actual buildings are planned. In a multi-storey block of flats the likelihood of progressive collapse of the structure is considered to be insignificant due to the Building Regulations requirement for continuous reinforcement.
- The greater the confinement of the gunpowder, the greater the potential overpressure effects.
- The fragmentation of the metal storage containers which housed mixed charges of smokeless powder and gunpowder, is thought to be as a result of the gunpowder only.
- Metal fragments of considerable mass (1-4kg) and initial velocities of hundreds of meters per second can be projected more than 100m from the gunpowder explosion point.
- Most fragments would have sufficient energy to penetrate bone or cause severe injury by blunt trauma.
- Tests have shown that tins of gunpowder can be ejected from an explosion intact, which suggests that a reduction in the hazards from gunpowder could be achieved by packaging the material in smaller quantities. This would also affect the quantities that could be safely stored in the domestic situation. Further work is planned.
- Due to lack of robust data both on recent incidents in the home-loaders situation and the numbers of people using gunpowder, it appears not possible to properly quantify the risks presented. Crude analysis of all the data suggests that the risks are neither intolerable nor trivial.
- The fragment and overpressure hazards associated with the explosion of gunpowder are reduced when ignition is caused by fire engulfment rather than fuse ignition. This is likely to be due to the weakening of the containers used which results in reduced confinement of the explosives.
- Wooden boxes with a wall thickness of 25mm provide a significant increase in the delay between fire engulfment and ignition of the explosives, compared to metal containers such as steel ammunition boxes. From a security and safety point of view, cladding of metal ammunition boxes or gun cabinets could provide a sensible compromise.

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