Hazards Associated with the Storage of Fireworks

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ABSTRACT

Large quantities of a whole range of materials, including fireworks, are moved around the world in steel ISO containers. In recent years in the UK, manufacturers and retailers have used such containers to store fireworks. It has been long recognised that confinement can increase the hazard of energetic materials such as pyrotechnics and propellants. Recent incidents involving fireworks and large-scale fire engulfment trials on ISO containers filled with fireworks have raised concerns about the possible effects of confinement on the hazards presented by the more energetic fireworks. This paper presents information on one such fireworks incident in the UK and the action taken following this incident; together with a summary of the fire trials conducted to date by the UK's Health and Safety Executive (HSE) on packaged fireworks in ISO containers.

Keywords: fireworks storage, fire, explosion, hazard, explosive storage

Introduction

Under the UN Scheme for the Transport of Dangerous Goods,[1] substances and articles are assigned to one of nine classes according to the most predominant hazard they present. Some of these classes are subdivided into hazard divisions. Although fireworks fall into Class 1 (explosives), many of them are assigned to explosives hazard sub-divisions that are considered not to present either a mass fireball or a mass explosion hazard. Internationally a variety of arrangements exists for classifying fireworks. This ranges from self-classification by the importer to a formal application of the UN test scheme.[1]

In 1980[2] the Seattle Fire Department, USA, conducted a bonfire test on 2,540 kg (presumably gross weight) of unspecified confiscated Chinese fireworks held in a 6.1 m long steel ISO container. Just after 2 minutes the container burst violently, expelling the contents 45–60 m in the air, and up to 215 m horizontally, causing fire damage to 20,000 m^2 of land.

Because of the increasing use of ISO containers for the bulk storage of fireworks in the UK, the HSE's Health and Safety Laboratory was commissioned to undertake research into the potential effects of confinement on fireworks held in storage. Specifically, a limited number of fire trials have been carried out on fireworks held in steel ISO containers.[3] This work is against a background of several firework storage incidents such as those at Culemborg (The Netherlands, 2 Feb 1991), Stourbridge (The Midlands, UK, 14 Mar 1996), Uffculme (Devon, UK, 17 Nov 1998), and more recently at Enschede (The Netherlands, 13 May 2000), which raise further questions about the possible effects of confinement on the potential hazards presented by fires involving stored fireworks.

At any one time, large numbers of fireworks types and sizes are available on the market, and new types are continually being introduced. Because of this, some years ago the UK introduced a *default* classification system for fireworks. Also due to concerns about the possible effects of confinement on fireworks in bulk storage, the UK introduced a *hazard type* (HT) rather than hazard division (HD) concept (as used for transport) for the purposes of licensing manufacture and storage. Both the fireworks *default classification* and *hazard type* schemes have been discussed and agreed to by the UK fireworks industry.

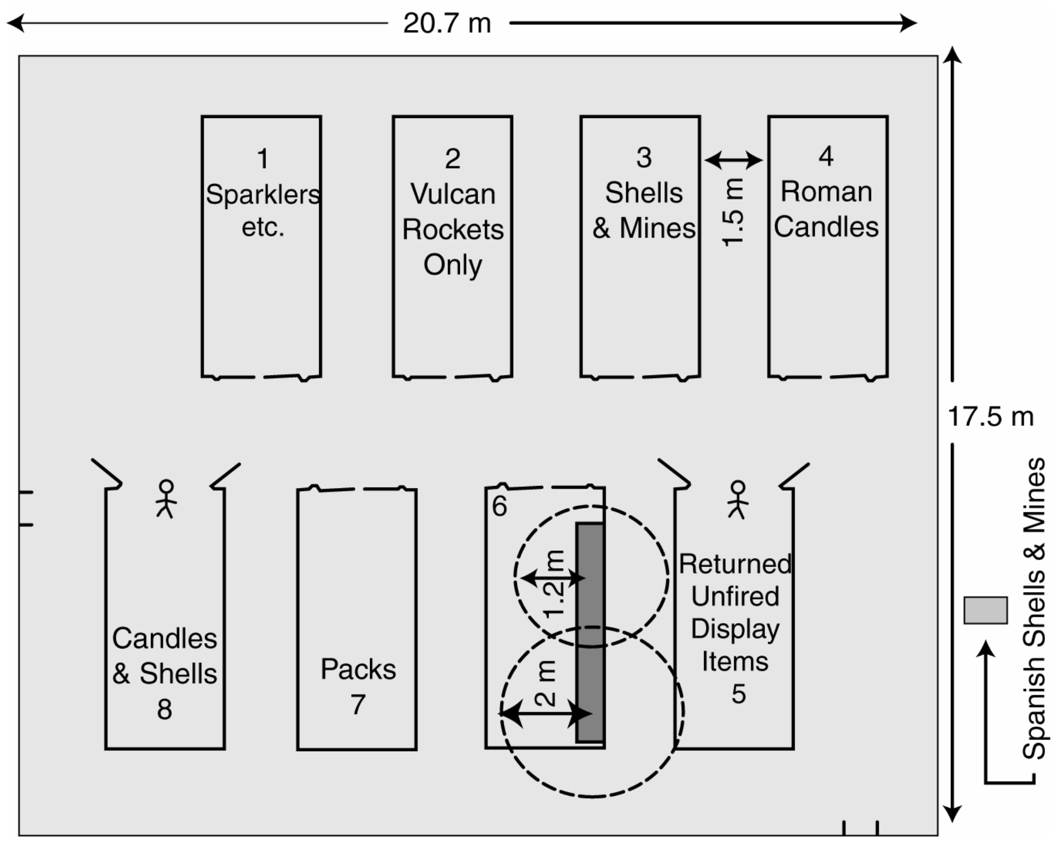

Figure 1. Approximate locations of ISO containers in the storage building before the explosion.

Fireworks Incident at Uffculme, Devon

On 17 November 1998 an explosion occurred at a licensed explosives factory in Uffculme, Devon. The explosion occurred in container number 6 of the eight fireworks-containing steel ISO containers (6.1×2.4×2.4 m), which were co-located inside a metal clad steel-framed building (see Figure 1). The centre of the explosion was marked by two depressions in the floor of the building as indicated. The explosion was preceded by an intense fire inside the building, which had been initiated by a prohibited operation in the entrance to container number 5. The building and containers were completely destroyed by the explosion, and fragments were scattered to a distance in excess of 200 m. Other buildings on and off site were damaged by blast, fragments and/or fires.

All records of the precise contents of each magazine were lost in the fire that followed the explosion. A combination of contact by the company with their fireworks suppliers and recollections by the magazine attendants has enabled a fairly reliable estimate to be made of the magazine contents (see Table 1 and Figure 2). The facility licence required that the fireworks be held in the packages as received from the supplier.

The explosion(s) resulted in the destruction of the building and destruction or movement of the other ISO containers (Figure 3). The centre of the explosion was marked by two depressions in the 163 mm thick concrete base of the building. The largest depression in the concrete floor was approximately 113 mm deep by 4 m in diameter. The second depression, centred some 3 m away, was approximately 50 mm deep by 3 m in diameter. A summary of the damage to other buildings in the immediate vicinity of the blast (see Figure 4) is presented in Table 2. Metal cladding from the steel portal building which housed the ISO containers, together with fragments from the ISO containers (primarily containers 5 and 6), were dispersed around the sur-

Table 1. Uffculme Incident: Contents of Container Number 6.

Supplier	Type	Size (mm)	Quantity (each)	NEC[(a)] per firework item (kg)	Total NEC (kg)
Arnal	Mine	50	240	0.09	21.6
Arnal	Mine	75	318	0.15	47.7
Arnal	Mine	100	222	0.3	66.6
Arnal	Star Shell	75	84	0.15	12.6
Arnal	Star Shell	100	80	0.3	24
Arnal	Star Shell	125	80	0.5	40
Arnal	Star Shell	150	41	0.75	30.75
Cabeller	Star Shell	75	55	0.15	8.25
Brunchu	Salute Shell	75	25	0.15	3.75
Brunchu	Star Shell	75	235	0.15	35.25
Brunchu	Star Shell	100	80	0.3	24
Brunchu	Star Shell	125	79	0.5	39.5
Brunchu	Star Shell	150	32	0.75	24
Vulcan	Roman Candle	30	50	0.3	15
Vulcan	Roman Candle	25	36	0.17	6.12
Cabeller	Mine	60	40	1.2	48
Pirofantasia	Roman Candle	30	720	0.26	187.2
Pirofantasia	Roman Candle	45	50	0.74	37
Brunchu	Wheel	Aerial	36	0.04	1.58
Arnal	Rocket	14	1,234	0.05	61.7
				NEC in Container	734.6

(a) NEC is the Net Explosives Content.

Note: some information regarding shells from certain manufacturers do not include the weight of any stars in the explosives NEC. The figures given above are taken from the manufacturers' literature.

rounding area (see Figure 5). Not all of the fragments are included in the top left hand quadrant of the plan since some of these had been removed from the yard of the factory premises before the fragment survey was conducted. Even so, one particular fragment, a steel corner of an ISO container weighing approximately 10 kg, fell through the roof of an extension some 140 m away, on the main street of the village.

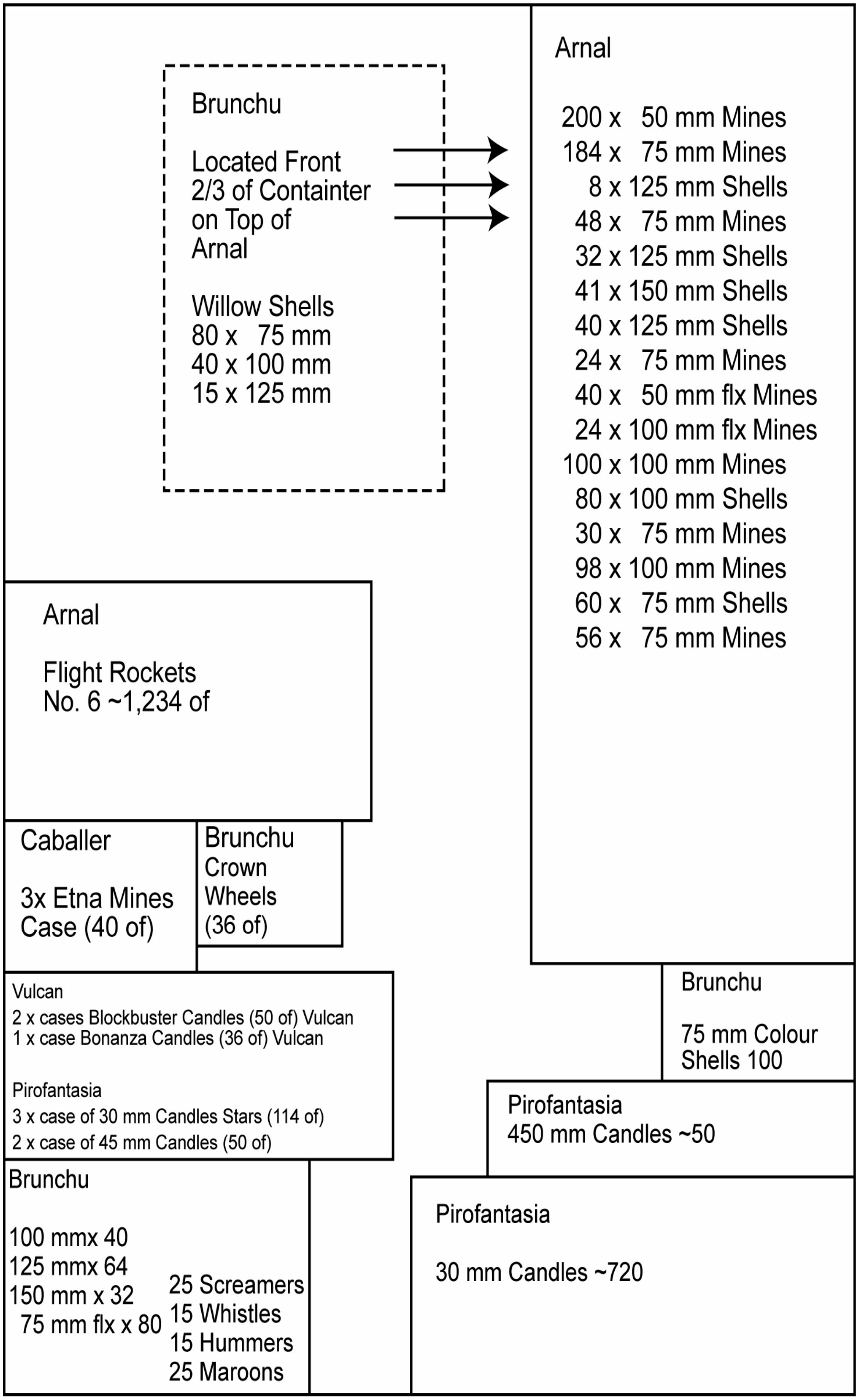

Figure 2. Contents and layout of magazine (container) number 6 before the explosion.

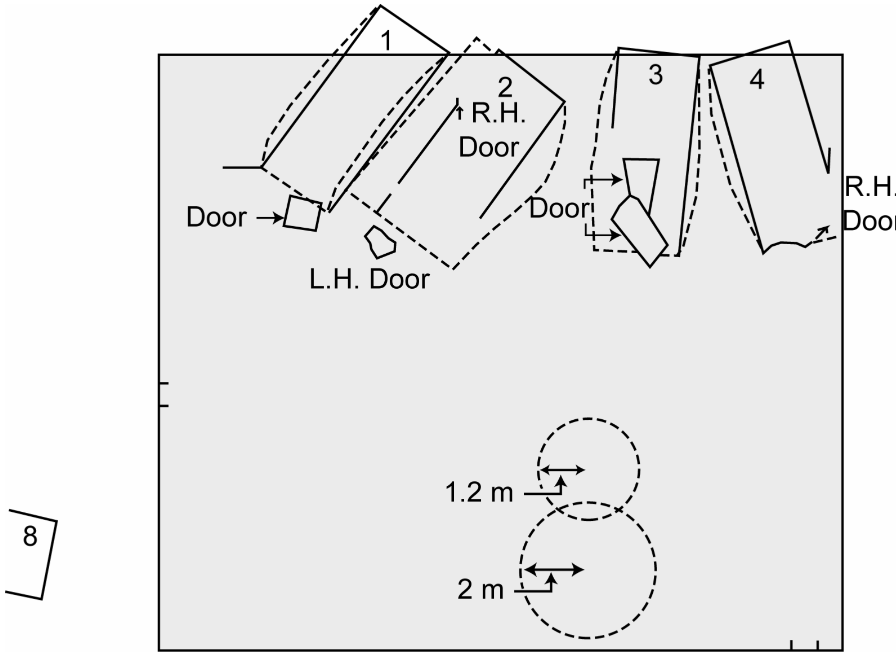

Figure 3. Location of ISO containers inside building after the explosion.

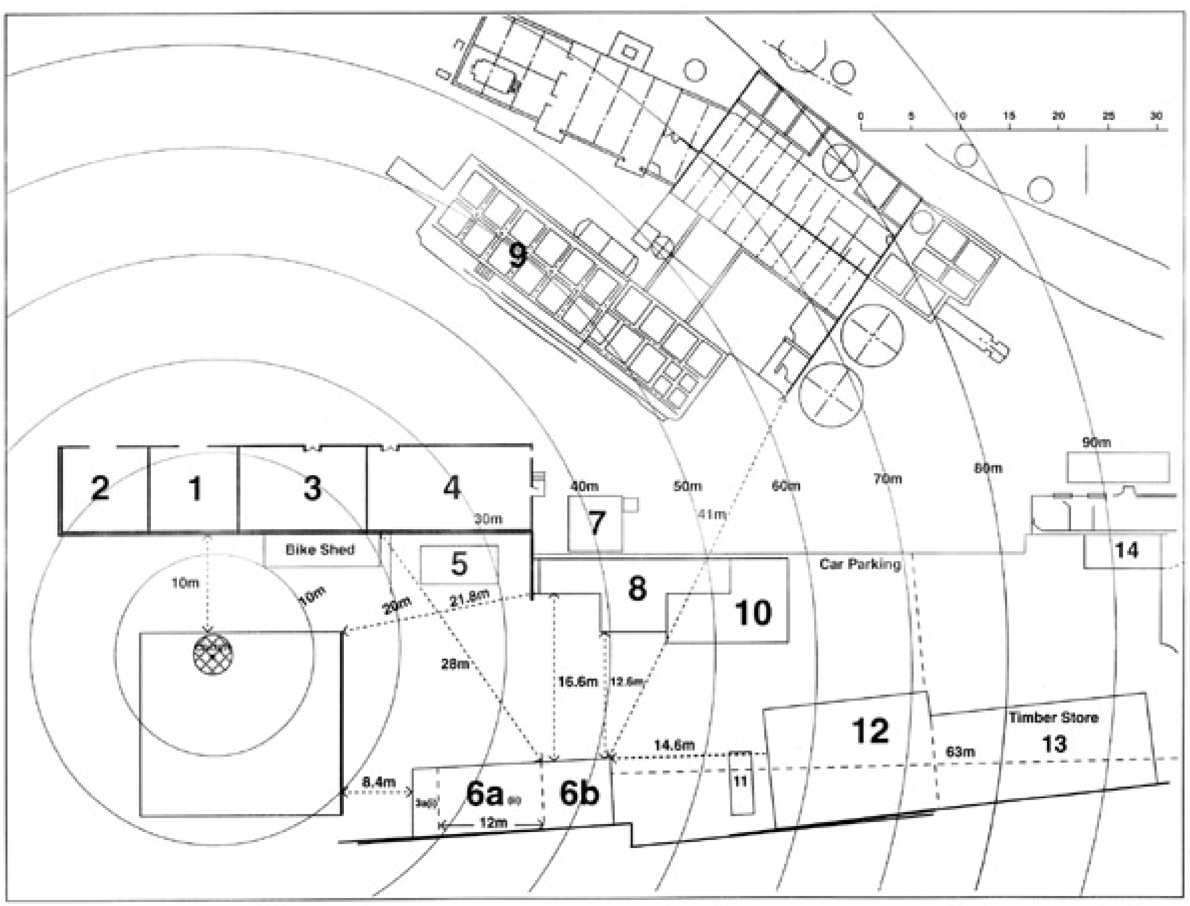

Figure 4. Buildings in immediate vicinity of fireworks explosion.

Table 2. Uffculme Incident: Damage to Adjacent Buildings.

Building number	Distance from blast centre (m)	Description of damage
1	13–22	Single story, solid double concrete block walled room. Wooden trussed roof with asbestos sheeting. Front wall demolished. All of asbestos roofing destroyed and half of the wooden trusses missing.
2	14–26	Construction as above. Front wall and top of gable end blown down. All of roof including wooden trusses missing. Rear wall leaning outwards at angle of 30 degrees to the vertical.
3	13–27	Front wall deflected inwards at centre by approx. 120 mm at top edge. Asbestos roof on front half of room missing. Wooden roof trusses intact.
4	20–38	Approx. 15% of asbestos roof (closest to blast source) missing.
5	22–31	Mobile home destroyed.
6	23–37	Wooden-framed single story building; corrugated iron clad, destroyed.
7	37–44	Single story brick building; flat roof. Little damage.
8	34–53	Steel-framed building, mobile home type construction, destroyed by fire.
9	47–60	Tall metal-framed mill building. Part clad in metal sheeting and part in asbestos sheeting. Asbestos cladding/sheeting facing the blast damaged out to approximately 50 m from the blast source.
10	46–58	Steel-framed building, mobile home type construction, destroyed by fire.
11	53–56	Portacabin destroyed.
12	56–74	Steel-framed building. Asbestos roof (undamaged) and corrugated iron clad. Some minor buckling of the steel cladding.
13	73–95	Minor missile damage to the corrugated asbestos roof.
14	88–100	Single story brick building. Windows broken.

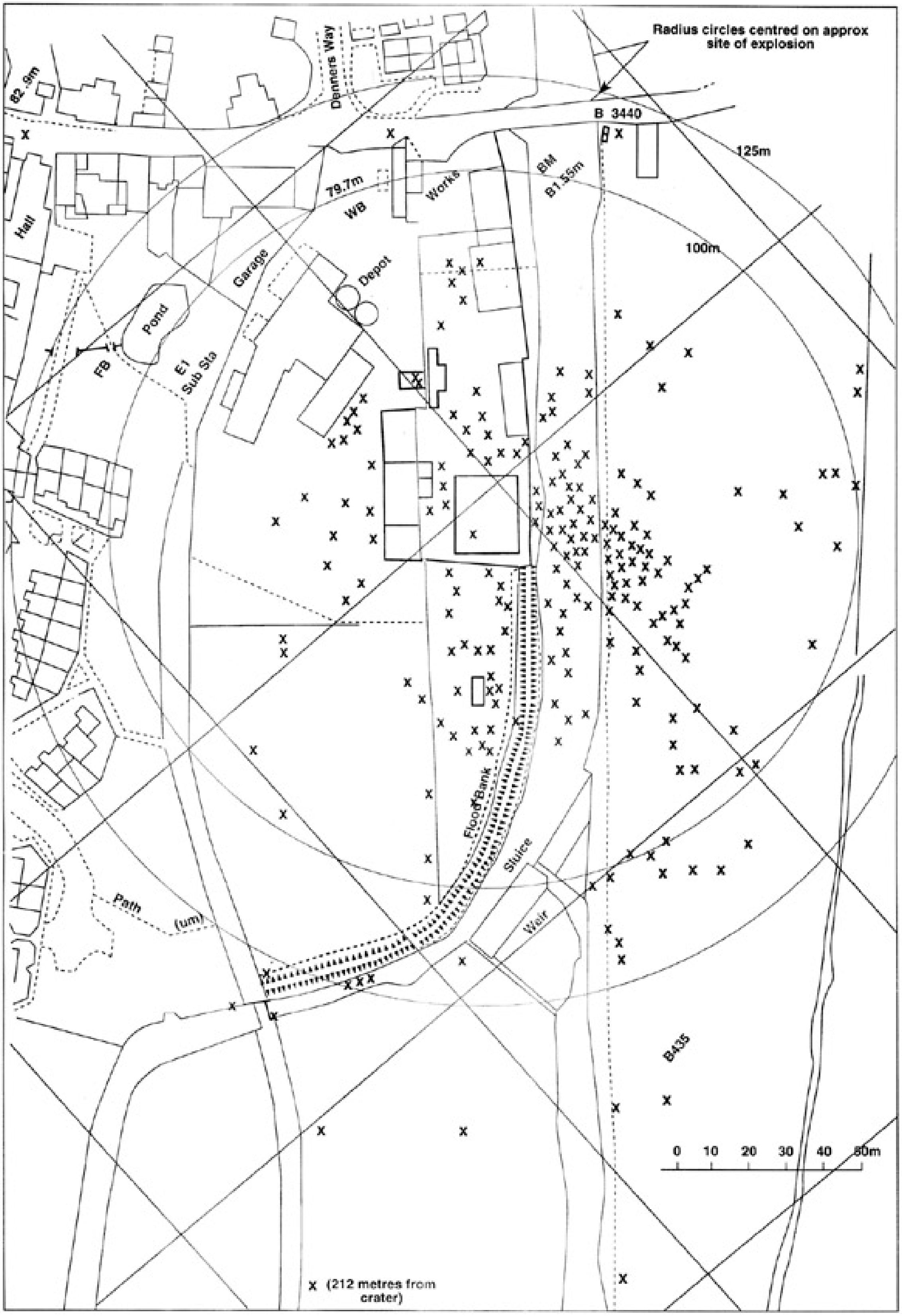

Figure 5. Debris plot.

Estimated TNT-Equivalence from Damage Survey

Crude estimates of the TNT-equivalence of the explosion were made from a simple examination[4] of some of the available damage and other diagnostic markers as follows:

- The double thickness concrete-blockwork buildings in the immediate vicinity of the explosion (numbers 1 and 2 in Figure 4; some 13–20 m away), suffered category B damage,[4] which equates to 50–70% of the walls being destroyed.
- The concrete floor of the building was cleared to a distance of approximately 9.5 m. In the Peterborough Explosion[5] the yard in which the 800 kg of blasting explosive exploded was cleared of all machinery, vehicles, etc. out to a distance (in metres) of 1.5×W0.333; where W is mass of TNT in kg.
- The two furthest missiles were thrown approximately 210 m.
- There was damage to asbestos roofs to 50 m and to metal cladding to 53 m.
- The furthest instance of ceiling damage was at 255 m.
- There was extensive glazing (window) damage: numerous examples were recorded, which are not easily summarised in this paper.

The estimates of TNT-equivalence from these markers surprisingly all fell in a narrow range between 200 and 250 kg. It is worth pointing out that although this explosion produced measurable and damaging blast effects, the greatest potential hazard was produced by fragments. In the future, any quantity-safety distance (QD) arrangement will need to be mindful of this since existing QD arrangements for HD1.1/HT1, HD1.2/HT2, or HD1.3/HT3 might not be appropriate for fireworks in ISO containers that can explode violently (not detonate).

Theoretical TNT-Equivalence of Event

Fireworks in general contain a large range of pyrotechnic compositions. Some shells, for instance, typically contain both gunpowder lifting charges and flash composition bursting charges. It is generally well recognised that for the more energetic pyrotechnics, their TNT-equivalence will depend upon a number of factors including mass, configuration, and distance from the charge. The latter is reflected in the following TNT-equivalences:

- The TNT-equivalence of 127 mm report shells[6] (as tested by subjecting a small number of unconfined, loosely-bound shells to a bonfire) based on pressure, varies from about 0.19 to 0.59 over the scaled distance range from 1 to 7.5 m/kg0.33. The 127 mm star shells are "30% less energetic" than the same size report shells (suggesting TNT-equivalence of 0.13 to 0.41 over the same range).
- The pressure TNT-equivalence of Black Powder (from trials[7] on weights from 227 to 2041 kg) increases from approx. 0.27 at a scaled distance of 0.71 m/kg0.33, to 0.42 at 3.17 m/kg0.33, thereafter decreasing to approx. 0.17 at 15.9 m/kg0.33. The maximum impulse TNT-equivalence was 0.46.

UK *Default* System for the Classification of Fireworks

The Classification and Labelling of Explosives Regulations 1983 (CLER)[8,9] in the UK require that an explosive be classified by the UK Competent Authority (CA) before it may be kept, supplied or conveyed. The CA for commercial explosives is the HSE, and for military explosives is the Ministry of Defence. The purpose of classification is to identify the hazard posed by explosive substances and articles as packaged for transport. Classification under CLER involves the assessment of an explosive to determine whether it is assigned to, or excluded from, Class 1 of the UN classification scheme[10] for the transport of dangerous goods. An explosive assigned to Class 1 is accorded an appropriate United Nations (UN) Serial Number, hazard code and compatibility group, having regard to its composition, type, and hazard.

A number of routes are recognised for the classification of explosives. Assignment may be on the basis of UN test series[10] results and other information supplied by the applicant, or by analogy with a similar explosive previously classified by HSE, or through documentary evidence of classification by the Competent Authority of another country. Additionally, in the UK, *for fireworks only*, a default classification may be claimed.

The default system (see Table 3) has been agreed upon by the HSE and the UK fireworks industry and provides a list of classifications of fireworks according to type. The classifications are those that the HSE would normally award

Table 3. UK Default Classification Scheme for Fireworks.

Description	Specification	UN Hazard Division if in UN Approved Package
Rockets (with or without sticks)	≤4 oz calibre or 25 mm motor inner diam.	1.4G
	>4 oz calibre or 25 mm motor inner diam.	1.3G
Roman candles: Type1 with bombettes or units containing only flash composition	≤30 mm inner diameter	1.4G
	>30 mm and ≤45 mm inner diameter	1.3G see note 1
	>45 mm inner diameter	1.1G see note 1
Roman candles: Type 2 with bombettes or units other than Type 1	≤30 mm inner diameter	1.4G
	>30 mm and ≤60 mm inner diameter	1.3G
	>60 mm inner diameter	1.1G
Gerbs	≤8 oz calibre or 26 mm inner diameter	1.4G
	>8 oz calibre or 26 mm inner diameter	1.3G
Wheels		1.4G
Set pieces/Batteries		See notes 2 and 3
Lancework on frames		1.4S
Lancework & effects	packaged	See note 4
Report Shells (not in mortars)	≤75 mm (see note 5)	1.3G
	>75 mm	1.1G
Star Shells (not in mortars)	≤125 mm	1.4G
	>125 mm	1.3G
Shells (in mortar)	All sizes and types (see also note 3)	1.1G
Mines	≤100 mm diameter	1.4G
	>100 mm diameter	1.3G
British Standard (BS) [11] Category 1		1.4S
BS Category 2 and 3 (other than types listed above)		1.4G
BS Category 4 (other than types listed above)		No default classification
Mixed Packs (Selection Boxes)		Highest individual type Hazard Division applies (i.e., 1.1>1.3>1.4>1.4S)

Note 1: These items contain bombettes or units containing only flash composition and no other composition such as stars.

Note 2: Default hazard depends on types of unit used in any set piece, combination or battery (e.g., batteries containing Roman Candles >30 and ≤45 mm inside diameter, with bombettes or units containing only flash composition default to 1.3G).

Note 3: Any combination, set piece or battery containing shell-in-mortar units default to 1.1G.

Note 4: Default hazard depends on effects (e.g., Lancework Battles with Roman Candles ≤30 mm inside diameter default to 1.4G).

Note 5: If only one report shell of this category is in a mixed box, the shell, provided it is individually packaged, can be regarded as 1.4G.

where information from specific UN tests or competent authority documents is not available. The publishing of the default list does not replace the requirement for HSE to classify all individual fireworks and should not be used as a basis for "self classification". Classification by the default route may be claimed where test results are not available or where no satisfactory documentary evidence of classification in the country of manufacture can be obtained. Classification on the basis of test results will take precedence over classifications derived by default. Classifications awarded by another competent authority may also be considered by HSE. Applicants may be asked to demonstrate that the fireworks as packaged are safe to convey by satisfactorily undergoing the UN Series 4(b) (ii) 12 metre drop test.[10] The default list may be reviewed from time to time in the light of further tests.

UK Hazard Type Scheme for Fireworks in Steel Containers

In recent years, UK licenses for explosives factories and magazines have referred to Hazard Types (HTs) and not Hazard Divisions (HDs). HTs have been defined in the terms of the licence by descriptions similar to those for the UN HDs employed in the classification of explosives (see Table 4). This move was prompted because there are certain conditions of manufacture and/or storage where a different hazard may be presented than that recognised and classified in accordance with the UN scheme. Such circumstances may occur for example, with the storage of fireworks in steel containers. Guidance on HTs for the storage of fireworks in steel containers has been generated and circulated to the industry[12] (see Table 4). This guidance is interim pending the results of further large-scale fire testing of fireworks in containers.

Bonfire Trials on Fireworks Stored in Steel ISO Containers

HSE has conducted three bonfire trials on fireworks held in 6.1 m long steel ISO containers and the results from this work will be reported in full in a separate paper.[3] Since one of the UK's recent fireworks incidents involved initiation of the fireworks inside an ISO container as a result of external heating by an adjacent burning car, stacks of wooden pallets, as high as the container, were positioned 0.5 m away from the container walls to simulate this external fire threat. The first two trials had relatively small quantities of fireworks stacked against one side of the container whereas the third trial was packed 70% full of fireworks, with the remaining space filled with boxes of wood shavings. The three trials were intended to be representative of the bulk storage of fireworks with low, medium and high Net Explosive Content (NEC). Tables 5 and 6 provide a summary and detailed breakdown of the fireworks used. The first two trials—arrangements with the containers only partly full—had limited confinement.

Table 4. UK Guidance on Hazard Types for Fireworks Stored in Steel Magazines.

Hazard Type 1 — having a mass explosion hazard:	
Shell in mortar	All sizes and types
Report shells/aerial maroons	Diameter >75 mm
Any items of UN HD 1.1	As classified by HSE under CLER
Hazard Type 3 — having a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard:	
Airbomb	Diameter >30 mm internal diameter
Battery	Gross mass >10 kg
Combination	Gross mass >10 kg
Fountain/gerb	>8 oz or 26 mm calibre
Lancework	Lancework containing fireworks of Hazard Type 3
Mine	Diameter >100 mm internal diameter
Report shell	Diameter ≤75 mm
Rocket	>4 oz calibre or 25 mm diameter
Roman candle	Diameter >30 mm internal diameter or including bombettes containing flash compositions
Wheel	Gross mass >1.5 kg (excluding any frame)
Selection boxes	Containing any items of Hazard Type 3
Shells	All types and sizes (see Note below)
Any items of UN HD 1.3	As classified by HSE under CLER, and not otherwise placed in Hazard Type 1
Hazard Type 4 — having a fire or slight explosion hazard or both, with only local effect:	
Airbomb	Diameter ≤ 30 mm internal diameter
Battery	Gross mass ≤10 kg
Combination	Gross mass ≤10 kg
Fountain/gerb	≤8 oz or 26 mm calibre
Lancework	Simple lancework or lancework containing fireworks of Hazard Type 4
Mine	Diameter ≤100 mm internal diameter
Rocket	≤4 oz calibre or 25 mm diameter
Roman candle	Diameter ≤30 mm internal diameter and not including bombettes containing flash compositions
Wheel	Gross mass ≤1.5 kg (excluding any frame)
Selection boxes	Containing only types of Hazard Type 4
Any items UN HD 1.4	As classified by HSE under CLER and not otherwise placed in Hazard Type 3 or Hazard Type 1

Note: All shells classified as UN HD 1.4 are considered to be Hazard Type 3 unless they are stored in accordance with the following conditions in which case they may be considered to be Hazard Type 4:

(a) They are kept in their closed transport packages.

(b) Within the container the storage of shells is limited to units or stacks holding a maximum number of 8 boxes of shells in each.

(c) Shell units/stacks shall be separated from each other in any direction by either:

- (i) a 1 m air gap or barrier of empty boxes or boxes containing low energy fireworks (i.e., relatively small items of low hazard such as those that may be sold to the general public under the Fireworks Safety Regulations 1997[13]).
- (ii) a 0.5 m barrier of boxes filled with sawdust or similar material.

Table 5: Summary of Firework Loads in ISO Container Bonfire Trials.

Trial No.	Summary of contents of load	% volume fill of container with fireworks.	Gross weight (kg)	NEC (kg)
1	BS Category 3,[11] 1.4G, small selection box fireworks (containing >85% Category 2 fireworks).	25	1,000	228
2	Mixture of UN 1.3G & UN 1.4G fireworks: (Chinese cakes, gerbs, 2 & 4oz rockets, mines, 30, 45 & 60 mm Roman candles, 75, 100, 125, 150 & 200 mm star shells).	32	1,684	823
3	BS Category 3, UN 1.4G, star shells (125 mm diameter).	70	4,050	2,600

Table 6. Details of Fireworks Loads in ISO Container Bonfire Trials.

Fireworks Trial 1					
Description	Gross mass of UN transport carton (kg)	NEC contained/ UN transport carton (kg)	Number of UN cartons	Total gross mass (kg)	Total NEC (kg)
British Bulldog Selection Boxes					
Saturn	15	3.26	18	270	58.7
Venus	15	3.26	31	455	101.1
Red Dragon Selection Boxes					
Jade	11.7	3	16	187.2	48
Ruby	12.6	3	7	88.2	21
Totals			72	1,000.4	228.8

Fireworks Trial 2				
Description	No. of UN packs	Total gross mass (kg)	Total NEC (kg)	Classification
Chinese cakes/crackle mines	15	345	90	1.4G
19 and 24 mm titanium gerbs	1	8	4	1.4G
2 oz sticked rockets (100)	1	30	10	1.4G
2 oz Rockets (100)	1	30	10	1.4G
4 oz Rockets (100)	1	60	20	1.4G
4 oz sticked rockets (100)	2	60	20	1.4G
30 mm comet candles (48)	1	50	23	1.4G
30 mm Bombette candles (48)	1	50	14.5	1.4G
45 mm comet candles (40)	2	56	29.6	1.3G
45 mm Bombette candles (40)	2	56	20	1.3G
60 mm candles (assorted) (30)	3	60	30	1.3G
Shell 75 mm diameter (288)	4	63.6	43.2	1.4G
Shell 100 mm diameter (216)	6	140.4	86.4	1.4G
Shell 125 mm diameter (198)	11	221.8	138.6	1.4G
Shell 150 mm diameter (117)	13	224.6	140.4	1.3G
Shell 200 mm diameter (40)	10	224	140	1.3G
Mines (colour) 75 mm (20)	1	4.4	3	1.4G
Totals		1683.8	822.7	

Table 6. Details of Fireworks Loads in ISO Container Bonfire Trials (continued).

Description	No. of UN packs	Total gross mass (kg)	Total NEC (kg)	Classification
Fireworks Trial 3				
Assorted 125 mm diameter chrysanthemum shells with perchlorate burst charges (18 shells per box, manufactured by Sunny)	270	4,050	2,600	1.4G

The results from Trials 1 and 2 indicated that the HD 1.4 fireworks tested presented only a limited hazard when the ISO storage container was exposed to an external fire source. There was no damage to the container in Trial 1 and, although the doors were blown open in Trial 2 and individual fireworks were ejected, there was no bulk effect.

For fireworks Trial 3 however, significant explosions were recorded and a large fireball 100 m in diameter was formed by the burning shells and ejected stars. Full details of the experimental configuration and the outcomes from the tests will be given in a future publication.[3]

Summary and Conclusions

- Large quantities of a whole range of materials, including fireworks, are moved around the world in steel ISO-containers, and in recent years UK manufacturers and retailers have used such containers to store fireworks. Recent incidents and trials have heightened concerns about the possible effects of confinement on the more energetic fireworks held in storage.
- The container of fireworks, which caused the most damage at Uffculme, is considered to have exploded violently rather than to have detonated. The packaging arrangements of boxed fireworks will generally suppress the rate of flame propagation through a mass of material, and the resultant pressure wave will initially be drawn out as the flame front propagates through the stack of fireworks. This long duration pressure wave, however, can quickly shock-up into a shock wave as it moves away from the source.
- A limited number of large-scale bonfire trials have been carried out on fireworks in steel ISO containers. The initial results suggest that:

a) A steel container approximately one-third full of very low hazard HD 1.4 fireworks presents no significant hazard outside of the container.

b) A steel container essentially full of a certain type of HD 1.4 125 mm star shells presents a significant fireball hazard.

- Concerns remain that

a) Other more energetic HD 1.4 fireworks might present either a HD 1.3 or a HD 1.1 type hazard when heavily confined.

b) Energetic HD 1.3 fireworks might present a HD 1.1 type hazard when heavily confined.

c) The presence of small quantities of very high-energy fireworks such as maroons or report shells might boost or drive adjacent energetic fireworks into an additive high-energy response.

- Further large-scale trials are required to fully investigate this matter. We are also beginning to develop a small-scale test method to rank fireworks in order of their confined mass burning rate.
- In the UK, the hazard division classifications, derived for transport via the UN scheme, have not been used automatically for defining the hazards of fireworks held in storage. The guidance currently followed by the industry for storage and li-

censing purposes will be revised as necessary following the results of further large-scale trials on fireworks held in confinement. Similarly, the UK default classification scheme used for fireworks will be reconsidered in the light of any new trials information.

- Questions arise concerning the adequacy of the existing tests in the UN Scheme for the classification of fireworks. In particular, there are questions regarding the proper characterisation of the hazards associated with fireworks held in steel ISO containers used for transport and, in some countries, for storage. In the longer term, there is need for the development of additional test methods for fireworks. For the latter, any consequential proposals will be submitted to the United Nations Committee of Experts on the Transport of Dangerous Goods (UNCOETDG).
- This work may also impact upon QD safety distances for existing and future stores.
- We intend to seek European collaboration regarding further research into this area.

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