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Safety practices related to the storage of fireworks in the context of land use planning

Issue paper

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Contents

Summary

This issue paper discusses quantity-distance schemes for use in land use planning decisions of locating fireworks storages. It includes reviews of:
- a few major fireworks storage incidents that typify the hazard of such storages
- fireworks safety practises, particularly quantity-distance (QD) regulations in several countries
- how countries assign hazard type to fireworks held in storage arrangements

Summary is given of output from EU fireworks project entitled 'Quantification and control of the hazards associated with the transport and bulk storage of fireworks (CHAF)' and examples of country regulations in relation to CHAF findings are depicted.

One of the main problems of analysing the issue of fireworks storage accidents is that data on quantities, qualities and some other crucial factors are difficult to establish accurately. In the majority of incidents, either, the quantity of stored fireworks has exceeded the licensed quantity, the fireworks were of higher hazard, or both. Problems also include incorrect classification of fireworks, product quality matters and various other factors.

National regulations on safety distances as well as other safety factors vary widely as shown in this issue paper. The reason can be different practises of sale, use and distribution of the fireworks besides different regulation. To prepare a common approach to the QD issue, some variables have to be taken into account such as national and market conditions, sizes and types of storages, the neighbourhood they are located in, time of sale etc.

There are probably no best national practices; every country seems to have some rationale for their QD schemes, whether they are of cultural, practical or scientific origins. However, some countries have lately made an effort to better quantify the hazards.

Further work could include a more detailed study of the fireworks market and products, their classification, better study of some of the more recent national practises for QD schemes and better information of the explosive hazards of fireworks types (and mix) from research projects. Synchronisation with ongoing activity should improve the chances of success of this further work to find a common approach.

1 Introduction

Recent severe accidents in fireworks storages indicate that their location should be a bigger concern for urban planners. Damages to neighbouring areas as well as injuries and fatalities caused by these accidents have been extensive and unexpected. After the Enschede accident, the JRC (Joint Research Centre) in the EU identified several problems and found safety distances to vary between countries [11]. They recently issued LUP roadmaps [17] and guidelines [14] for Seveso establishments. In October 2008, OECD´s Working Group on Chemical Accidents decided to study the issue,

The main purpose of this report is to review the issue of safety distances from fireworks storages to neighbouring areas when determining their location in the context is land use planning [1][2].

Lessons learned from accidents of damages inflicted on neighbouring areas are discussed as are the safety distance regulations and practises in selected countries in order to establish principles and reasoning, and to seek common approaches. The question as to whether there are some best existing country practises for QD-schemes, based on scientific knowledge and experience, is discussed.

National approaches to LUP issues are touched upon in the country chapters. Risk assessments are discussed. Judging from the exemplified accidents here, large storages of fireworks could be incompatible with some sensitive infrastructure in its vicinity.

The review is limited to a number of sample countries. Focus will mainly be on the storage of consumer fireworks, classes 1.3 and 1.4. Both large and small scale storages are discussed to some extent when quantity distance values are referred to, including wholesalers/distributors and retail/outlet storages.

Concluding remarks and an outline of aspects for a potential follow-on study are given at the end of the report.

2 Recent accidents

Accidents with fireworks are common [9], [11]. Below are accounts of a few that have occurred recently in larger storage sites and at a fireworks factory and which demonstrate and typify the most serious hazards that storing large quantities of fireworks poses to the neighbouring areas.

2.1 Uffculme in UK

On 17 November 1998 an explosion occurred at a licensed explosives factory in Uffculme, Devon. The explosion occurred in one of several fireworks-containing steel ISO containers (6.1x2.4x2.4 m), which were co-located inside a metal clad steel-framed building [13]. The building and containers were completely destroyed by the explosion, and fragments were thrown both on and off site to a distance in excess of 200 m. Considerable damage was experienced to an adjacent factory, and a steel corner of one of the ISO containers (weighing approx. 10 kg) fell through the roof of an extension to a building on the main street of the town. The part of the site affected was only licensed for H.D 1.4 explosives/fireworks.

The fireworks involved in this incident were not solely consumer fireworks, and in the interim since the incident, the classifications of a significant proportion of these fireworks have changed from HD 1.4 to HD 1.3 and some from HD 1.4 to HD 1.1. Consequently for a similar store today, greater separation distances would apply.

2.2 Kolding in Denmark

The fire and subsequent explosions in Kolding (2004) killed 1 fireman and injured 90 and did extensive damage to the neighbourhood. The N.P. Johnsen Fireworks Factory had no actual production of fireworks but was an importer. At the time of the incident, N.P. Johnsen had about 25% market share of the total Danish import of consumer fireworks (Class 1.3G). The factory was located in a small light industrial area, surrounded on all sides by an estate of detached houses. The factory is classified according to the Seveso Directive as Column 3 premises. The accident occurred at a time immediately before the main fireworks season, so the permitted maximum storage of 300 tonnes of Net Explosive Quantity (NEQ) was almost fully utilised.

The main features of the fire in the firework stores in Kolding on November 3rd were:

- 332 fire-fighters and 55 vehicles took part in the fire control and rescue operations
- One fire-fighter was killed, three were seriously injured and 13 received minor injuries
- The fire control operation lasted four days
- Some 1500 tonnes of fireworks (gross weight) were destroyed
- Debris from buildings was found more than 1000 metres from the explosions
- 100 houses were made uninhabitable due to damage
- 350 houses were damaged
- Building damage amounted to € 100 million (≈ DKK 750 million)

In the period following the accident, several political and administrative initiatives were taken, investigations were implemented and various reports and evaluations were prepared. A ten-point plan for improving firework safety was presented by the government two weeks after the incident. As part of the plan and in order to ensure the prevention of any larger accidents related to fireworks operations in the future, a committee was established to review the whole complex of regulations relevant to fireworks operations.

The emergency response to the course of events at the Kolding accident has been divided into three phases:

- Phase 1, characterised as an incident that Danish emergency services experience regularly: a larger fire, with danger of fire spread and requiring comprehensive water supplies. The special features of this phase were that the burning materials were fireworks and that it was impossible to attack the initial fire directly.
- Phase 2, characterised by a series of explosions that killed a fire-fighter and injured several others. At the same time, there was a severe and substantial spread of fire, forcing the fire services to withdraw and reorganise. A number of fire-fighting vehicles were lost at the start of this phase.
- Phase 3, characterised by the widespread incident area, necessitating a comprehensive and lengthy emergency action. There was also uncertainty as regards to the security of the response units. [12]

In the technical regulations of November 1999 which were current at the time of the accident in Seest, there were not any safety distances for greater storage of fireworks to neighbouring plots or residential areas. If the warehouse was over 2000 kg (gross weight), it had to have a sprinkler system, however if it were over 5000 kg (gross weight), the Emergency Management Agency had to set the safety distances. Storage under these amounts should simply “keep the distances” to neighbouring plots etc. as indicated in the building regulations. (References: BEK nr. 778 of 14. October 1999[8], the changes which came with Seest are in BEK nr. 1068 09/11/2005)

2.3 Enschede, Holland

A fire broke out within the SE Fireworks depot in the eastern Dutch city of Enschede on 13 May 2000. The fire caused a massive explosion, killing 22 people (including 2 firemen) and injuring over 900. An area within a radius of 750 m around the depot was in effect demolished. Around 600 homes were destroyed and additionally about 900 were damaged which left 1250 people homeless, 40 shops and 60 small businesses were destroyed [9]. The cost of the damage was estimated to be more than half-a billion euros.

The Oosting Committee, charged with investigating the incident noted that not only had the company stored more fireworks at the depot than they had permits for, but also that most of these fireworks were wrongly classified as presenting no significant hazard [1.4G] or fire hazard [1.3G] rather than as a mass explosion hazard [1.1G]. The explosives storage permits allowed only 1.3G fireworks and the lower hazard, 1.4G fireworks. Again the fireworks involved in this incident were not solely consumer fireworks. The Committee was also critical of the role played by local and national government. The administration system in place was criticized for insufficiently inspecting the company and for not taking action against the company for a detected violation of the environmental permit in force. It was also criticised over planning issues new development monitoring issues.

2.4 Reasons for off-site effects

It is evident that in many of the fireworks storage accidents, the quantity of fireworks was far more than conditions at the storage houses and surrounding areas should have permitted and even the fireworks classes that were stored more dangerous than the storages were licensed for.

The physical damages to the neighbourhood in the accidents referred were mainly of fourfold cause:
1-Blast shock waves which damage buildings in the neighbourhood. In particularly the Enschede and also the Kolding case it seems that blasts that came some time after the storages caught fire were very powerful and caused demolitions of many houses and serious damages to others. These should not have taken place if the classification of the fireworks, quantities and other factors were right.
2-Flying igniters spread the fire, a special feature of firework storage fires; burning pieces of pyrotechnic articles, distributed by both the explosions as well as own powder and even fire updraft spread. In both Enschede and Kolding, the fire spread to large areas by flying fireworks pieces. Quantification of this cause, in relation to other damage causes, is difficult based on the information at hand. It is, however, evident by the fire fighting effort in the typified accidents above that this is one of the main causes of material damage to neighbourhoods. In synergy with blast and projectile damage of broken windows, flying fire has easy access to combustible material in the neighbouring houses.
3-Heat radiation from the fires ignites combustible materials which are close enough. This is also synergic with blasts and projectiles that rupture structure and reduce shielding of combustible material against the heat.
4-Projectiles and debris from exploded equipment and buildings. In typified cases, heavy pieces of e.g. storage buildings and fireworks containers were found at large distances from the explosions, more than a kilometre in case of Kolding.

In the Enschede case, where extensive damage stretched 3/4 of a kilometre out from the epicentre, particularly the residential areas were obviously far too close to the fireworks storage. The NEQ is not known so the quantity-distance relation can not be deducted easily. Lessons from Kolding, where the quantity of fireworks is estimated to have been 300 t NEQ, indicate that the spread of debris (over one kilometre) could create a worst-case-scenario of buildings being damaged, and even in worst cases catching fire, at a large distance because of projectiles or flying debris, beyond the fire and blast damaged residential area closer to the storage. This could have LUP implications for location of other industrial activity which store or handle dangerous substances. Also in Kolding, the residential area was too close to the fireworks storage.
Lessons from the typified accidents make rather clear that the blasts were more powerful than expected and the fires more difficult to take out than emergency services had planned for.

3 Existing LUP arrangements around fireworks storage sites

In this chapter, regulations of particularly safety distances for fireworks storages are summarised for several countries for the sake of comparison.

3.1 France

Regulation in France

The French regulation contains safety distance schemes for all explosives (1.1 to 1.6) and takes into account the type of the effects (overpressure or thermal principally). All storages containing more than 750 kg NEQ of 1.3 fireworks (and more than 250 kg NEQ of 1.1 explosives) are submitted to the assessment of these effects. Almost all storages will be submitted to this risk assessment in 2010 with the new regulation.

Five or four risk zones are defined (Z1 to Z5):

- Z1 and Z2: these zones have to be included in the limits of the site (it means that all buildings, dwellings, roads, etc. are forbidden in these areas if they are not linked to the storage)
- Z3 to Z5: some buildings and infrastructures forbidden (high buildings, important sites, big town, big magazines, etc.)

For each zone, depending on the probability of the dangerous phenomena, a number of persons exposed is defined and has to be respected if the permit of the storage is to be issued.

For 1.3 and 1.4 fireworks, the French regulation considers that these fireworks will engender thermal effects. The risk zones defined for these effects are for example for 1.3 :

Quantity, ton (NEQ)	Z1 (m)	Z2 (m)	Z3 (m)	Z4 (m)
1	24	34	48	63
10	52	73	104	135
100	112	156	223	290

The loading density is taken into account for the assessment of these risk zones. For example, if the loading density is over 170 kg/m^3, the fireworks have to be considered as 1.1 products. Then, the risk zones are defined by others formulas (formulas for overpressure effects), se table below:

Quantity, ton (0,8 eq TNT)	Z1 (m)	Z2 (m)	Z3 (m)	Z4 (m)	Z5 (m)
1	45	72	135	198	396
10	97	155	291	427	853
100	207	332	622	913	1826

Assessment of the hazard in storage in France

In France, the fireworks have to be considered as 1.1 products if they are stored with such explosives. Fireworks which are stored without their transport's packages (UN classification) have to be classified as 1.1 products.

About the issue of the loading density, the French industry tries to define some criteria to assess it and the densities associated for explosives and fireworks and proposed a grid to assess this concept. The grid classifies in four types the products depending on their storages conditions and characteristics. Then depending on the loading density and the type found, the overpressure effects have to be considered or not. The French industry is now trying to take into account the results of CHAF to define these densities but it represents some difficulties as, among others, the tests seemed to be not representatives of what is usually done or authorized.

3.2 Germany

Regulation in Germany

According to the German Explosives Law a license is necessary for the storage of explosives except for specified "small amounts".

Explosives are assigned to the storage groups 1.1, 1.2, 1.3 and 1.4 by the competent authority. Hazard definition of the storage groups and the assignment procedure is comparable to the transport classification (ADR, UN Recommendations on the Transport of Dangerous Goods).

Storage group SG	Hazard definition
1.1	substances, mixtures and articles which have a mass explosion hazard
1.2	substances, mixtures and articles which have a projection hazard but not a mass explosion hazard
1.3	substances, mixtures and articles which have a fire hazard and either a minor blast hazard or a minor projection hazard or both, but not a mass explosion hazard
1.4	substances, mixtures and articles which present no significant hazard; This division comprises substances and articles which present only a small hazard in the event of ignition or initiation

Only pyrotechnic articles classified as 1.4G/S can be used as consumer fireworks.

The German regulation is based on a combination of quantity-distance (QD) schemes, minimum distances and construction principles for the magazines.

For the storage of explosives SG 1.3 and 1.4 a fire-resistant structure is usually required. Earth-covered magazines are mandatory for the storage of explosives SG 1.1 for amounts > 1000 kg (NEM net explosive mass).

The regulation contains quantity-distance (QD) principles and minimum distances for the protection of the general public (protection distances) and for the safety inside the storage facilities (safety distances) following the NATO safety principles.

The protection distances are calculated by the equation $D = k \cdot NEM^{1/3}$ for SG 1.1 and 1.3 (D- distance [m]; k – scaled factor; NEM – net explosive mass [kg]). For the storage of explosives SG 1.4 > 100 kg NEM a distance of 25 m to the general public is necessary.

SG	Scaled factors $[m/kg^{1/3}]$ and minimum distances [m]		
	Inhabited buildings	Public traffic routes	
1.1	k = 22 (min. 275 m concerning heavy fragments)	k = 15 (min. 180 m concerning heavy fragments)	Distances to important objects (hospitals, schools etc.) or to permanent crowded areas should be increased (e.g. up to k = 40 for SG 1.1). Distances could be decreased, if there are advantageous conditions or measures to reduce blast overpressure and fragment effects.
1.3	k = 6,4 (min. 60 m)	k = 4,3 (min. 40 m)	

For example, in Germany the following protection distances are necessary for the storage of 100 t NEM of pyrotechnic articles:

SG 1.1G inhabited building distance = 1020 m
Public traffic routes distance = 700 m

SG 1.3G inhabited building distance = 300 m
Public traffic routes distance = 200 m

SG 1.4G/S 25 m

In Germany the storage of specified “small amounts” of explosives is possible without licensing and distance rules.
The storage of “small amounts” is specified for professional and non-professional users, the different storage groups and different storage rooms.
A few examples are given here:
It is allowed to store pyrotechnic articles SG 1.4G/S up to 70 kg NEW in a sale room and up to 350 kg NEW in a container outside a building.
The storage of pyrotechnic articles classified as 1.3G in a sale room is not permitted. But storage up to 25 kg NEW is possible in a container outside a building.

3.3 Iceland

Regulation in Iceland

Icelandic regulation does not contain safety distance (QD) schemes for fireworks storages, only for class 1.1 explosives. The fireworks regulation [5] divides fireworks into 4 classes each having from 3 to 12 subdivisions, class 4 is for professionals. It prescribes the application, area where they are allowed to be used, who is allowed both to use them and sell them. The regulation thus limits sale of certain larger and more hazardous pyrotechnic articles to the public even though they are classified as 1.3G or 1.4G which hitherto has made Icelandic storages for consumer fireworks less hazardous than e.g. in Sweden and Denmark. Regulations of fire protection and the building code specify certain design criteria and emergency systems of storages for explosive goods. The Seveso [1] [2] regulation (Icelandic nr. 160/2007) stipulates hazard analysis, which in effect means a risk assessment for storages over 10 ton NEQ.

LUP for larger storages (Seveso) in Iceland

Risk assessments are expected to take all pertinent factors into consideration, including building and emergency system design and also take aim of international experience. The results can be confusing as shown by the most recent risk assessment for a new store where the safety distance requirements for dwellings from a 350 t (gross) storage ranged from about 60 to more than 300 m in different countries.

Comparative study in Iceland

The main fireworks importer in Iceland compared, in their risk analysis for a new storage building, safety distances in several countries [6] [9] and found large discrepancies both in values and approach, se table below.

Table of Safety distances for 350 t gross / 70 t* NEQ fireworks 1.3 and 1.4 [6]

Country	Risk zone***	Safety distance**
Sweden,	separate buildings	316 m
	roads	95 m
Norway,	roads and dwellings	264 m
	magazines	58 m
(Denmark) & Germany,	dwellings	264 m
	roads	177 m
USA, Colorado,	roads	114 m
	other activities	76 m
USA (NFPA),	dwellings and magazines	61 m
	roads and storages	30 m
Canada,	process building	77 m
	magazine	34 m

***** NEQ is assumed to be 20 % of total weight

******The values are based on different assumptions in different countries. Only Sweden, Norway and Iceland allow 1.3G as consumer fireworks. Denmark does not allow storage of more than 50 t NEQ. States in the USA have different rules. Canada and France consider confinement in the store.

***Risk zone definitions vary; same words can be defined differently and different criteria apply in different countries.

This particular storage subsequently declared a Seveso quantity of 42 tons NEQ to be stored, i.e. 12% of total weight of the fireworks. According to Swedish regulation this calls for a safety distance of 267 m [7] which could however be halved with maximum protective measures such as earth walls. The storage was located to an old quarry so the cliffs provide a certain shield for the surrounding area.

3.4 Norway

Regulation in Norway

The Norwegian regulation contains safety distance schemes for explosives (1.1 to 1.3). The Norwegian legislation concerning handling of explosives including permanent storage of fireworks classified 1.3G follows the NATO schemes. The minimum safety distance for fireworks classified 1.3G in amounts less than 25 kg NEC is 60 metres to domestic buildings and public roads and 240 meters to schools, kindergartens, hospitals etc. Norway allows fireworks classified 1.3G to be sold to consumers but certain larger and more hazardous pyrotechnic articles are forbidden for the public, hence in 2008 all kinds of rockets where forbidden for public along with fireworks disguised as toys.

There are no permanent storage of fireworks containing solely fireworks classified 1.4G in Norway. Class 1.3G and 1.4G stored together are classified 1.3G.

When the safety distances are not fulfilled the Norwegian legislation can accept a thorough risk assessment of the storage facilities and surroundings, composed by the companies, instead of the safety distances given in the schemes.

Firework legislation for retail shops in Norway

In Norway the shops are only allowed to sell fireworks between 27th December and New Years Eve. In that period the shops can store up to 100 kg NEQ (classified 1.3G and 1.4G) in a fire safe room in the shop (or in a container outside the shop). It is only allowed to keep the fireworks in the shop in daytime and maximum 100 kg NEQ in total. The fireworks must be moved to a fire safe room connected to the shop in the night time. It is only allowed to keep 10 kg NEQ in the store at night time.

If the retail shop does not have a fire safe room the shop can store the fireworks in a special approved container outside. The container must fulfil the safety distances to other buildings and facilities. The safety distances for retail shops are shorter than for permanent storage due to the limited time. The shop can only store fireworks in the container outside the shop from 1st December until 31st January the year after. The permission for selling fireworks is given for one year at the time. Each year an evaluation of the shop is done before the permission is given (control of the safety distance/zone, building facilities etc). It is not allowed to sell fireworks from retail shops in buildings with apartments.

LUP legislation in Norway

New legislation in Norway adapted 30th June 2009 concerning impact study regarding development and regulation of areas also comprises storage of explosives and fireworks over 50 ton (Seveso companies). The process works approximately the same as in the UK. Where a site development would fall within a safety distance/zone which precludes such developments, the right authority advises against the planning permission. If however, permission is subsequently granted and the incompatible development goes ahead, the company must reduce their amount to ensure the new building remains outside the relevant distance/zone.

3.5 UK

Arrangements in the UK for licensing of fireworks sites and associated LUP

The UK legislation controlling the manufacture and storage of fireworks is the 'Manufacture and Storage of Explosives Regulations 2005' (SI 2005/1082) – known as MSER [8].

Quantity-distance (QD) prescriptions have long been used to control hazards at installations where explosives are manufactured or stored. The prescriptions limit the quantities of explosives that may be present in licensed areas within the installations according to the proximity of nearby population, both on and off site. The aim is to provide a reasonable degree of protection for the workforce and an even higher level of protection for the public should an accident occur. Complete immunity against the effects of accidental explosions would require impracticably large separation distances.

Historically the UK's QD's for explosives which can detonate en masse are empirical, having been derived in the late 1940s from an analysis of wartime bombing damage and a number of incidents of major accidental explosion; and were formulated both on the understanding that the likelihood of a major accident is low, and that a limited amount of damage off site (e.g. broken windows, dislodged roof tiles) can be tolerated in the event of an accident. The efficacy of these QD prescriptions has been proved by experience: since 1950 there have been almost 100 major accidents within licensed explosives installations in the UK, and not one has resulted in fatalities off site.

In the 1990s an analysis of some new magazine trials indicated that the principal hazard posed by buildings containing relatively small quantities of explosives is not blast but rather flying debris. This finding led to a review of current licensing arrangements and new prescriptions were introduced when the Manufacture and Storage of Explosives Regulations (MSER) come into force in 2005. These prescriptions are designed to ensure that (a) people living near to explosives storehouses are not exposed to an individual risk of fatality greater than 10^{-6} per year, and (b) an accident in an explosives storehouse would not result in an unacceptable number of fatalities amongst members of the public.

Of the three large scale CHAF trials resulting in mass explosion, only that involving the stickless rockets gave sufficient information for analysis of the associated fragment/debris effects[19]. This showed that the UK's existing MSER Inhabited Building Distance prescription is more than adequate to ensure a high level of safety for persons living, working or travelling near an area where an ISO container packed with mass-exploding fireworks of the type described in this paper is located.

In determining the safety distances for fireworks sites, the UK uses a TNT equivalence of 100% of the net explosives quantity (NEQ). When accurate information of the NEQ is not available, calculations are made on the basis of an assumed 25% of the gross weight.

UK Hazard Types

The basis of the licensing system for manufacture and storage of explosives in the UK is Hazard Type (HT) which categorises the hazards presented by the explosives under the conditions they are being processed or stored as follows:-

Hazard Type 1	an explosive which has a mass explosion hazard (a mass explosion is one in which the entire body of explosives explodes as one);
Hazard Type 2	an explosive which has a serious projectile hazard but does not have a mass explosion hazard;
Hazard Type 3	an explosive which has a fire hazard and either a minor blast hazard or a minor projection hazard, or both, but does not have a mass explosion hazard (i.e. those explosives which give rise to considerable radiant heat or which burn to produce a minor blast or projection hazard); and
Hazard Type 4	an explosive which has a fire or slight explosion hazard, or both, with only local effect (i.e. those explosives which present only a low hazard in the event of ignition or initiation, where no significant blast or projection of fragments of appreciable size or range is expected).

The reason for using this approach, rather than the UN Hazard Division (the international system for categorising explosives hazards when packaged for transport), is that hazards presented by fireworks and explosives in general, can be affected by confinement [see note 2 to 2.1.3.2.3 of orange book], and also by ‘boostering’ from higher energy explosives. Where explosives are being kept in their transport packaging, a direct read across from HD to HT (e.g. HD 1.1 to HT 1) may be appropriate, but in other circumstances this read across cannot necessarily be made.

Whilst this “hazard type” scheme is unique to the UK, other major explosives-producing countries either use, or are considering, similar approaches, e.g. Canada has recently introduced the concept of “explosives potential (PE)” to define hazards in manufacturing and storage (chapter 3.10- Canada).

LUP in the UK

The licensing process requires a separation to be maintained to off-site population, and for sites with quantities greater than 2 tonnes requires the licensee to define a safeguarding distance (or separation zone) for land use planning based on the quantity and hazard of fireworks being manufactured or stored. For those sites with a defined safeguarding zone the Local Planning Authority are required to consult HSE on any proposed developments within the “safeguarding plan”. Where a development would fall within a zone which precludes such developments, HSE advises against the planning permission. If however, permission is subsequently granted and the incompatible development goes ahead, HSE reduces the licence limits to ensure the new building remains outside the relevant zone. For those storage sites with less than 2 tonnes, which are generally not licensed by HSE, there is no safeguarding zone specified and hence no Land Use Planning consultation, however, the licence limits are set to ensure the new development is at the requisite distance.

3.6 Denmark

After the Kolding accident, Denmark stipulated that storage of quantities over 10 ton NEQ required a subdivision of the storage by fire safe screens and storage quantity over 50 ton was banned. Class 1.3G and 1.4G stored together are classed as 1.3G. The QD formulas of class 1.3G fireworks were for dwellings $D=6,4xQ^{1/3}$ and for transport routes $D=4,3xQ^{1/3}$. For class 1.4 fireworks explosive quantity was weighed as 25% of same quantity of 1.3G. Following table gives QD examples:

Table of Danish safety distances for consumer fireworks class 1.3G

Quantity, ton	Dwellings	Transport routes
1	64	43
10	134	26
100*	297	200

*Exceeds allowed quantity, 50t.

A new regulation was issued in Denmark 4.7.2008 with slight changes on e.g. the conversion formulas for 1.4G explosive power [8].

3.7 Sweden

New Swedish regulation is from 2006 (SRVFS 2006:10). Swedish Rescue Services Agency's Handbook gives quantity distance schemes. Explosives in class 1.3 are listed in the QD-table and a formula provided to convert class 1.4 to 1.3-equivalents; 1.4G quantity is weighed as 25% (same as in Denmark) and 1.4S as 10% of 1.3-explosive quantity. Three types of risk zones are defined.

I	More than 10 persons usually present or large economic risks
II	Less than 10 people usually present or important cultural sites
III	Roads with moderate traffic

Following table gives QD examples.

Table of Swedish safety distances for class 1.3 explosives

Quantity, ton	I	II	III
1	75	47	23
10	162	150	49
100	348	348	105

Swedish regulation allows safety distances to be reduced to up to 50% with preventive measures such as earthen walls around storages [7].

3.8 Holland

Dutch regulation was changed after the Enschede accident, now only 1.4G fireworks are considered consumer fireworks. Safety distances for storage of less than 0,75 ton is 400 meters but 800 meters above that quantity up to 6 tons. Professional 1.3G are regarded as 1.1G because of wrong classification in the past. The new regulation have led most larger storages to move out of Holland to neighbouring countries [6][9].

3.9 USA

NFPA provides a “Code for manufacture, Transportation, Storage and Retail Sales of Fireworks and Pyrotechnical Articles” [15] where a QD table for gross weight of fireworks indicates:

Table of safety distances in USA according to NFPA 1124 [6].

Gross weight, ton		Dwellings, magazines	Transport routes, storages
5*	(4,5-9,1)	41	20
50*	(over 45)	61	30

*Assuming 20% EQ-content of gross weight, these values correspond to 1 respectively 10 ton NEQ

Different states in the US have different regulations, exemplified in the following table:

Table of safety distances according to regulation in Colorado [10]* [6].

NEQ, ton		Dwellings	Roads	Other activities
1	(0,5-2,3)	35	35	23
10	(9,1-13,6)	66	66	44
100	(91- 136)	137	137	91

*Low explosives

3.10 Canada

Arrangements in Canada for the Licensing of fireworks sites

The Canadian definitions of PE are almost identical to the UK hazard types, as follows:-

"The possible potential effects are:

- PE1 - mass explosion hazard i.e. the entire body of explosives explodes as one;
- PE2 - serious projectile hazard but not a mass explosion hazard;
- PE3 - fire hazard and either a minor blast or minor projection hazard, or both, but not a mass explosion hazard;
- PE4 - fire hazard or slight explosion hazard, or both, with only local effect"

..... and "used as guidelines for determining which Potential Effect level is to be applied for Quantity/Distance (Q/D) principles for the issuance of Licences and Certificates".

High Hazard & Display Fireworks in Canada

For bulk stored HD/HT/PE 1 fireworks, Canada first calculates the NEQ based on 75% of the Gross mass. Thereafter this NEQ is factored down by 70% for those containing flash powder, and 50% to those to those which do not.

PE3 fireworks are only treated as PE3 if >40% free space is in the magazine, and the magazine is unconfined, otherwise PE1

Examples of NEQ, TNT-Equivalence and QD calculations in Canada

Fireworks Type	PE Type	Gross Mass (kg)	NEQ	NEEQ (TNT Equiv.)	Outside QD (m)
High Hazard (contains flash powder) (e.g sound/report shells)	PE1	15,000	75% of 15,000 = 11,250 kg	**70%** of NEQ = 7875 kg	445 m
Display (e.g 250 mm star shell)	PE1	15,000	75% of 15,000 = 11,250 kg	**50%** of NEQ = 5625 kg	405 m
Display (e.g 125 mm star shells)	PE3	15,000	75% of 15,000 = 11,250 kg	0	98 m

Low Hazard & Consumer Fireworks in Canada

-Low Hazard fireworks properly classified as HD 1.4 have PE4 up to 25,000 kg NEQ (= 50,000 kg gross); i.e default NEQ = 50% of gross weight.

-Consumer fireworks properly classified as HD 1.4 have PE4 up to 25,000 kg NEQ (= 100,000 kg gross); i.e default NEQ = 25% of gross weight.

Above 25,000 kg NEQ, PE4 applies if: the store is sprinkled and there is ample aisle space between stacks; otherwise, PE3.

Examples of Canadian QD schemes

Only fireworks that are classified as 1.4 are considered to be consumer fireworks. For both 1.3 and 1.4 classes there are 4 different activities defined that might be at risk and which have different safety distances.

For 1.3 goods are:

- D1 – Distance to magazine
- D2 – Distance to process building/distance to light traffic route
- D3 – Distance to medium traffic route
- D4 – Distance to inhabited building/distance to heavy traffic route

For 1.4 goods are:

- D1 – Distance to magazine
- D2 – Distance to process building
- D3 – Distance to public traffic route
- D4 – Distance to an inhabited building

Below are samples from the Canadian distance tables for the goods classified as 1.3 and 1.4.

Table of examples of quantity-distances (m) in Canada for the storage of 1.3G goods [6] [16]

NEQ, ton	D1	D2	D3	D4
50	50	120	160	240
100	70	150	200	300

Table of examples of quantity-distances (m) in Canada for the storage of 1.4G goods [6] [16]

NEQ, ton	D1	D2	D3	D4
50	27	27	30	60
100 (max)	27	27	33	70

The Canadian regulations, as the French regulations, take the loading density of the stored goods into account when determining safety distance. This means that when fireworks are tightly packed the safety distances increase.

Table of Canadian correction factor of safety distances as a function of the loading density [6] [16]

Loading Density (kg NEQ/m3)	Correction factor
10	0.57
100	0.86
1000	1.30

4 Basis of existing LUP arrangements

4.1 Quantity-distance schemes

This issue paper shows that the QD schemes vary vastly between countries, i.e. the distance versus quantity values are different in different countries. There are many reasons for this country difference, too lengthy a history to account for here but include practical, traditional and even cultural matters.

The QD schemes generally specify safety distances from explosives storages to neighbouring areas based on a few parameters:

a-explosives class
b-net explosive quantity
c-zone definitions for neighbouring areas

The explosive classification is in most instances similar to the known UN classification (often called ADR) although some countries, such as UK and Canada, have their own classification but reminiscent of the UN classification. Canada has introduced PE, potential effects concept to the hazard classification.
Net explosive quantity is generally possible to establish from product specifications or shipment invoices but countries have their estimates of NEQ as a percentage of gross product weight which are used (typically 20 % for the consumer fireworks) if net explosive weight data is not at hand. Countries, for example Sweden and Denmark, provide formulas to convert the explosive quantity of 1.4 to 1.3 class fireworks.
Some, e.g. Sweden, Denmark, Iceland and Norway, allow sale to the public of 1.3G-fireworks, although sometimes restricted when comes to type of products. Many, such as Germany and Canada, only allow sale of 1.4 to the public.

Some countries have been seeking to incorporate more variables into the safety distance values as exemplified by Canada and France who take the stacking densities into account.
Some countries have special rules, such as distance requirements or time of sale for the small fireworks storages for consumer fireworks at retail outlets. Germany stipulates more than 25 m to the public if quantity exceeds 100 kg NEM, Norway limits the sale period to Dec. 27th to New Years Eve.
Holland stipulates a general 400 m safety distance for quantity up to 750 kg and 800 m for 750-6000 kg.
The zones classification also varies between countries, sometimes in the number of zones and also their associated descriptions, e.g. Canada has 4, Sweden 3 and the description is very different.

4.2 Permits, emergency and mitigation measures

In most cases, some form of hazard or risk analysis is stipulated for at least the bigger storages when authorities give licences for storing of fireworks. The issuing authority takes safety-distance regulation into account when issuing permits. Some countries foresee that local authorities do not follow the recommendations of the national authorities and can require from the permit holder that he reduce his quantity to comply with QD regulation concerning buildings that have come within the distances stipulated there.

Seveso establishments have to prepare an emergency plan in the EU and EEA countries [17]. This means that worst-case scenario assumptions are made for at least the upper-tier of these storages but judging from the accidents described in this report; these scenarios have been grossly underestimated. Smaller storages come under varying country regulations and practises that stipulate various measures as exemplified by Norway (limited period) and Germany (limited distances to the public) in chapter 3. For example in Iceland, retail outlets are required to have adequately large extra escape doors for the customers and certain fire fighting automation in the storages.

5 The CHAF Project

5.1 Reason for CHAF

A number of serious accidents in European Union countries involving explosions in the large-scale storage of fireworks indicated that there was not an adequate understanding of the hazards posed by fireworks (especially display fireworks) during transport and bulk storage. To address this problem an EU research programme was initiated entitled 'Quantification and control of the hazards associated with the transport and bulk storage of fireworks (CHAF)'. The work was undertaken by three partners: The Health and Safety Laboratory (United Kingdom), TNO Prins Maurits Laboratory (The Netherlands) and Bundesanstalt für Materialforschung und - prüfung (Germany) and coordinated by the former.

The CHAF project aims to provide a better understanding of critical conditions that give rise to explosions in packaged fireworks, and improve methods of predicting performance in large scale storage. Indeed, there is a lack of knowledge about the mechanisms of flame spread and pressure build-up in packaged pyrotechnic articles under conditions of confinement.

5.2- CHAF tests

To gain a better understanding of the hazards posed by fireworks in transport and storage, the CHAF project involved testing at different scales including full-scale testing in 20 ft steel ISO containers. One of the principal considerations was to focus on fireworks at the boundaries between HD 1.4 and HD 1.3 and HD1.3 and HD 1.1. Nine large scale trials were carried out and in three cases a mass explosion effect was observed. The trials producing a mass explosion involved (1) stickless rockets, (2) waterfalls and (3) 150 mm coloured shells. In the latter trial an extra degree of confinement was achieved by placing the ISO container in the ground to a depth of around 1.5 m and covering it with at least one metre of sand in all directions.

5.3 CHAF findings

The results of five of the ‘CHAF’ large scale ISO container trials on fireworks (EC Framework 5 ‘CHAF’ Project ‘Quantification & Control of the Hazards Associated with the Transport & Bulk Storage of Fireworks’) were as follows (following table):

CHAF Large Scale Test	**Firework**	**Storage/Transport Conditions**	Net **Explosive Mass (kg)**	**UN Transport Classification**	**Full-scale Behaviour**
A1	150 mm colour shells	Full Container	5789	1.3G	Fireball Effects
A2	75 mm colour shells	Full Container	5288	1.3G	Fireball Effects
A5	Bag mines	Part-full Container	4680	1.3G	Fireball Effects
A6	Waterfalls	Full Container	8661	1.3G	Mass Explosion [1]
B7	Stickless Rockets	Full Container	5011	1.1G	Mass Explosion

Of the large scale tests carried out, the results were all consistent with the UN Classification Scheme (Series 6 tests) except the mass explosion of the waterfalls which was totally unexpected.

The CHAF project gives a number of observations and results which were not expected and which could only be partly explained, for example:

- Articles selected to represent the most energetic 1.3 articles which were classified as 1.3 according to the default list (i.e. 150 mm shells and 60 gram rockets without stick) turned out to be mass explosive when tested according to Series 6 tests. The formulation of these pyrotechnic compositions may have contributed to these unexpected classifications.

- For 150 mm shells, propagation velocity between the firework packages as measured in the large-scale tests was 2 to 5 times larger (12 and 35 m/s) than measured in the medium scale test (7 m/s).The causes of the higher propagation velocity (or higher conversion rate of the pyrotechnic material) in the large-scale situation are not fully understood.

  What mechanisms lead to such a fast initiation of a very large number of articles in the container? What circumstances should be avoided in order to assure much lower conversion velocities?

- For one article (waterfalls) the reaction velocity was found to increase with increasing amounts, both in small-scale tests and in large-scale tests. Although all UN Series 6 tests resulted in a 1.3 classification, a container full with waterfalls mass exploded very violently.

  A container full of waterfalls might not be a situation that occurs in practice but it can certainly not be excluded that other articles or combinations of different articles show the same phenomenon.

5.4 CHAF II

The reasons for the unexpected mass explosion of the waterfalls are still unclear, and trying to understand this result is one of the principal aims of a proposed follow-up CHAF II project.

The above listed examples of unexpected reactions and results justify a more in depth study of the behaviour of fireworks in order to avoid accidents and incidents with consequences more severe than can be expected on the basis of the classification. It’s the aim of CHAF II, whose defined outputs are among others:

- To increase confidence in the classification system for fireworks, both based on test methods and on default classification. This may lead to an optimum test or tests for classification with regards to time, costs and scale ;
- To exclude the possibility of mass explosions from (properly classified) 1.3G fireworks ;
- To give results to support the regulations based on the gross mass of fireworks or arguments to change to regulations based on net explosive mass ;
- To assess the possibility of predicting the TNT equivalences of different fireworks types ;
- To specify this influence of the confinement of articles ;
- To validate separation distances of storage facilities to (public) buildings and infrastructure or to propose new criteria derived from the results, if necessary.

6 Core problems

6.1 Storage without permissions

The causes of the incidents exemplified in this paper varied from site to site, but the main failings with regards to minimising damage and injuries to neighbours lay with non-compliance with the explosives licences or permits. Incidents at Uffculme, Enschede and elsewhere have shown this clearly. For the majority of serious fireworks incidents with off-site effects, the licensed ‘safety distances’ were prescribed for either smaller quantities of fireworks than were actually being stored at the time of the incident, or, had been set for lower hazard fireworks.
The European CE labelling conditions are in the making which could improve the situation in Europe when comes to coherent and transparent classification and labelling and identification of hazard in storage.

6.2 Quality issues

Generally, the manufacture of fireworks is undertaken in the Far East and Indian sub continent and is a small scale industry, often with sub-contracting arrangements where ingredients are weighed by hand and substitute components are not unusual leading to variability in finished articles. Consequently, consistent classification and potential hazard remains a significant concern.

6.3 Assessment of the hazard in storage

A classification system used by all does not quite exist as yet although the UN-classification is the closest candidate. Some countries, e.g. Sweden, classify all consumer fireworks by routine in class 1.3G, Holland and USA seem to classify them as 1.4G [9]. There seems still to be a need to coordinate or at least interrelate the classes if multinational guidelines are to be set for the fireworks storages. More recent approaches, such as Canada’s, seem to be an attempt at putting a more quantified or scientific base under the classes.

As seen by for example CHAF, the main classes do not tell the whole story when comes to hazard. Within each class whilst the nature of the hazard is the same (e.g. thermal radiation for HD1.3) the magnitude of this is different for different fireworks in that class. Additionally, in a real storage situation there are a number of other factors which may also effect the magnitude of the output. Clearly any classification system will be unable to quantify the effects of these variables. To address this any QD approach needs to be cautious / conservative.

Also the stacking density is an important factor which for example Canada and France now take into account. Size of empty storage spaces is also a factor as exemplified by the Canadian requirements. The design of the storage as well as emergency system is important both to counter incidents and provide efficient initial emergency measures.

Mitigation measures, including fire fighting systems, sectioned buildings, earthen walls (or quarry cliffs) are important measures to reduce the injurious effects of an incident. Their effects are not quantified or reflected in the QD schemes in general.

6.4 Firework effects at distance from store

The debris effects from fireworks explosions will be functions of a number of factors, including the nature and mass of material in the store in which the fireworks are held, and the violence of the explosion.

Of the three large scale CHAF trials resulting in mass explosion, only that involving the stickless rockets gave sufficient information for analysis of the associated fragment/debris effects [19]

In the Enschede disaster, flying fireworks landed on and ignited the roofs of houses which had already been damaged by one or more of the explosions. For example in the UK, the derivation of existing quantity-safety distances do not include this mechanism, but do provide some protection against it.

As shown by the CHAF tests, the effects explosions of fireworks in the same class are vastly different depending on what type they are. What is also interesting is to note the very different safety distances the exploded quantities would require in different countries (se table of CHAF large scale ISO container trial).

7 Discussion of key issues

A review of the countries' licensing approaches to the storage of 'energetic' fireworks has shown that approx half of these countries are quite conservative; i.e France, Holland, USA and Canada generally treat HD 1.3 fireworks as HD/HT/PE 1 whereas the UK, Germany, Sweden and Denmark treat them as HD/HT/PE 3.

There is a also considerable variation between these countries in the QD's applied to HD 1.1 / HT1 fireworks (e.g for 4.7 t NEM of bag mines, Canada requires 290 m whilst Holland requires 800 m as can be seen in the following Table:

CHAF Firework		**FRANCE [1]**	**HOLLAND [2]**	**USA [3]**	**CANADA [4]**	**UK [5]**	**GERMANY [6]**	**SWEDEN [7]**	**DENMARK [8]**		**CHAF result**	**UN TDG**
150 mm Colour Shells **NEM 5789 kg**	**Hazard**	explosion	explosion	explosion	explosion	fireball	1.3G	fireball	1.3G		fireball	1.3G
	QD to houses (m)	395	800	270 or 539	320	136	115	116 or 136	115			n/a
75 mm **Colour Shells** **NEM 5288 kg**	**Hazard**	explosion	explosion	explosion	explosion	fireball	1.3G	fireball	1.3G		fireball	1.3G
	QD to houses (m)	383	800	267 or 533	311	136	111	116 or 136	112			n/a
Bag Mines **NEM 4680 kg**	**Hazard**	explosion	explosion	explosion	explosion	fireball	1.3G	fireball	1.3G		fireball	1.3G
	QD to houses (m)	360	800	267 or 533	299	107	107	106 or 128	107			n/a
Waterfalls **NEM 8661 kg**	**Hazard**	explosion	explosion	explosion	explosion	fireball	1.3G	fireball	1.3G		explosion	1.3G
	QD to houses (m)	452	800	297 or 594	367	136	136	142 or 156	131			n/a
Stickless Rockets **NEM 5011 kg**	**Hazard**	explosion	explosion	explosion	explosion	explosion	1.1G	explosion	1.1G		explosion	1.1G
	QD to houses (m)	376	800	267 or 533	306	475	376	424 or 513	380			n/a

Notes to Table:

1- The French approach is based on ‘boxed fireworks’ explosives density.
2- In Holland all “professional” display fireworks are “explosion hazard” & each facility limited to 6000 kg gross with a minimum separation of 800 m to houses.

3- All display fireworks in the USA are “explosion hazard” - QDs relate to mounded or unmounded magazines.

4- All display fireworks in Canada are “explosion hazard unless magazine contains < 50,000 kg (100,000 kg gross) fireworks; > 40% free space; & magazine is unconfined.

5- In the UK the explosives Hazard Type is determined by licensee & enforced by regulator.
6-Germany uses UN Transport Classification to assign storage hazard.
7-In Sweden the QDs relate to buildings where constantly < 10 people or > 10 people.
8-Denmark appears to have no requirement for mounding.

8 Concluding remarks

The issue at stake is whether it is possible to make common guidelines or recommendations when dealing with land use planning for the location of fireworks storages, particularly if the quantity distance schemes could be generally applied in all countries.

Existing studies of accidents in firework storages have not established clear safety-distance relationship with the stored quantity and quality of the fireworks for many reasons. The UK's experience of fireworks incidents exemplifies this:

> (i) records of precisely what was in the store prior to the incident are often unavailable, and
>
> (ii) where records exist, it usually shows that a variety of fireworks of different 'energies' were present in the store, making it extremely difficult to relate the damage to any one particular firework type.

Both the accidents reviewed in this report, as well as findings from tests, show the complexity of defining and computing QD schemes with high accuracy. Given that the classification is known and correct, labelling correct and permitted quantities kept, there still are important variables to be taken into account if accurate computation of QD values is to be made:

1-Product types within each class

2-Packaging of the fireworks

3-Stacking densities

4-Product mix in the store

5-Storage design including confinement, subdivision, fireproof screens and empty spaces

6-Safety and mitigation: fire fighting systems, earthen walls

In order for common guidelines to be developed, certain simplifications would have to be made which means that safety margins in the distance values have to be increased. Alternatively, the QD schemes would have to build upon a detailed prescription of what was in the store, size and type of store, stacking densities, emergency systems etc. And then the requirements of consistent qualities, labelling and other crucial factors are still in the picture.

Guidelines for storages of fireworks could therefore become far too complex and the guidelines difficult to use in case a very precise quantification was the aim. A more simplified approach could be easier to apply and could be used more widely. In such an approach the most important factors are taken into account and experience from accidents as well as tests put into use. Plus some amount of contingency for non compliance, overstocking and faulty products, labelling etc if history is to be taken into account.

Research projects (such as CHAF) could shed light on some important factors making it more feasible to prepare common guidelines.

There is no best country practise to judge from data in here. Some countries are more cautious than others. Competence in this area seems to be growing in connection to the CHAF-project. There have been interesting developments, e.g. has one of the larger explosives producing countries, Canada, modified their approach. There are countries which have good competencies in this field and could be worth taking a closer look at.

Outline of scope and further study plan/strategy

A continued project, with the ultimate goal of developing guidelines or common approach to preparing QD-schemes, could consist of the following ingredients:

1-Further study of some key country practices regarding approaches, rules, implementation and success.

2- A comparison of lessons from the larger recent accidents could provide some insight into the hazard although it is doubtful if such a comparison would give reliable quantification of damage versus distance for future use.

3-Further results when they become available from a continued CHAF project, as well as other research projects, could also shed light on some of the important outstanding questions of product differences and behaviour in fire.

The optimal strategy would be to synchronise these steps with other ongoing studies, research, classification and activities concerning fireworks hazards.

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