Explosion in a fireworks storage facility

3 November 2004

Kolding

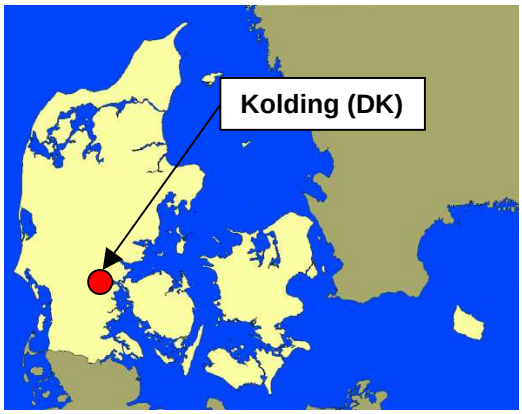
Denmark

Pyrotechnics/ Explosives
Fireworks
Domino effect
Urban environment
Explosion
Organisation
Risk assessment
Safety distances

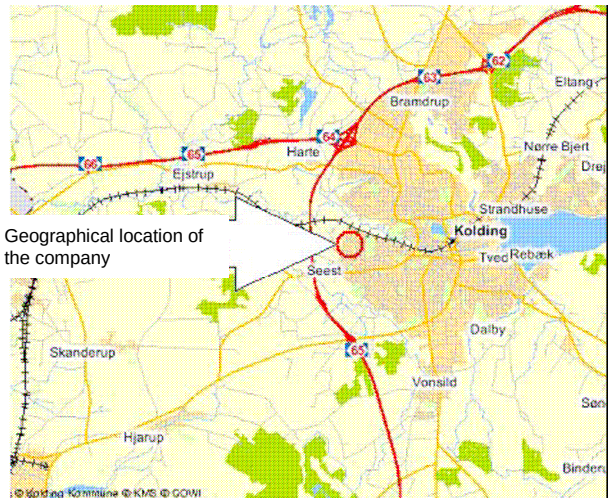
THE FACILITIES INVOLVED

The site:

The fireworks depot was located in a sparsely populated and small industrial zone at 2-3 km from the city centre of the town of Kolding and surrounded by individual houses. The company does not manufacture but imports fireworks. It solely accounts for 25% of the total Danish imports of fireworks for private citizens (non-professional users). The site was classified as a top-tier SEVESO site with a storage capacity of 300 tonnes expressed in terms of the net explosive mass. On the day of the accident, shortly before the peak season for fireworks, the depot was practically to its full capacity (282 tonnes).



The industrial zone was set up in 1963. It was initially isolated but "reached" by the expanding urbanisation in the 1970s.



Aerial view of the company before the accident

Operations started in 1974 and were expanded by acquiring existing buildings or constructing new ones. Some houses were as close as 10 meters from the warehouses to the north.

According to the Danish authorities, all safety requirements for storage were fulfilled. The facilities were less than 10 years old and were equipped with a sprinkling system. The emergency services were well aware of the prevailing fire risks.

20 employees including 16 casual employees were working onsite. [2]

The involved unit:

Fireworks were stored over 9,000 m^2 in 7 single-storey buildings and at least temporarily in outside containers.

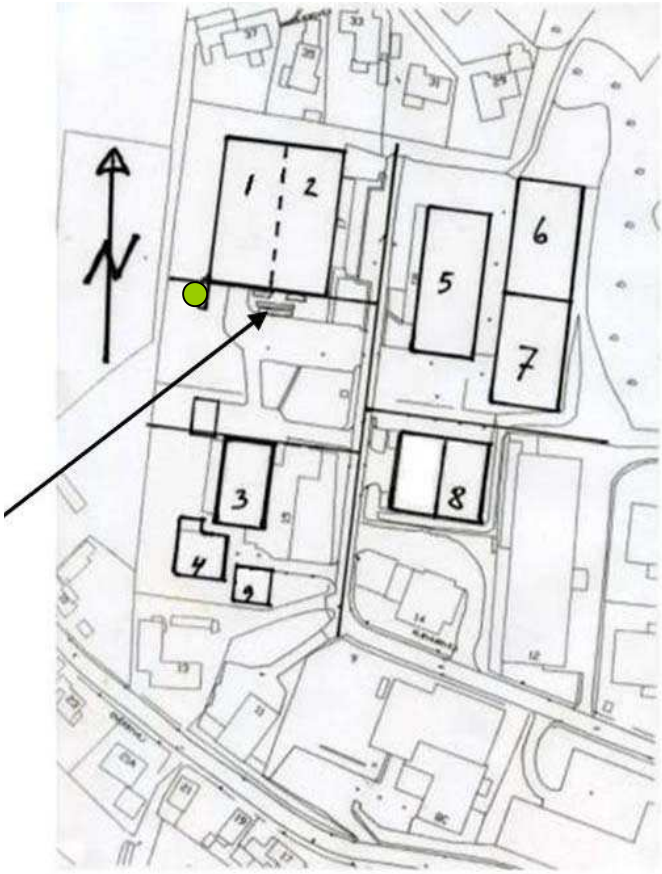
Two buildings were subdivided each into two warehouses by a fire wall (building 1+2 and 6/7). The buildings structures were in wood or steel, the walls in bricks or concrete and the roofs in fibre cement [4].

The two 40 feet containers 1 and 2, where the fire started, were 1 m apart and at 20 m from building 1+2.

In the text, container 2 refers to the one nearest to building 1+2.

Two 20 feet containers that were full and closed were located to the north of container 1 and 2.

On the day of the accident, several other 20 and 40 feet containers that are not shown in the drawing were also stored outside in between buildings 5 and 8 and (1+2) and 3.
A gas cylinder storage site (green dot) was also located in the vicinity.



The distribution of fireworks in the warehouses (two days before the explosion) is as follows [4]:

Warehouse No.	*Surface (m^2)*	*Quantity (net weight in tonnes)*
1+2	2,250	38
3	940	8.7
4	280	7.1
5	1,200	31
6	1,550	85
7	1,550	62
8	970	50
9	140	0.46
	Total	*282*

According to the above diagram, the dimensions of building 1+2 containing 38 tonnes of explosives were around 43 x 53 m. Building 6+7 that stored 147 tonnes was approximately 60 m from building 1+2 (with building 5 between the 2 !). For the sake of comparison, the French regulations in all likelihood would have considered that the facilities were uncoupled since the corresponding minimum distance was around 100 meters depending on the product type (and without building 5 between the two). In this configuration, it would be considered that the entire 282 t fireworks stock was likely to react simultaneously. The impact zones to be considered would be around 500 meters for thermal effects and 1 km for overpressure effects (considering the mass explosion of one-third of the net explosive weight). These

assumptions are partly supported by the damage observed in the accident. However, one must remain cautious with such superficial comparisons. Indeed, the mechanisms at play are not identical and the effects deserve to be studied specifically, while taking into account the kinetic influence of the phenomena.

At the time of the accident, the following items were stored in container 1 (where the fire started) [4]:

ID (no.)	Type of firework	Size (mm)	Net explosive mass per object (g)	No. Of objects per carton	No. of cartons	D.R.	Total number of objects	Total weight (kg)	Comments
03602	Rocket (wildfire triple break)	55	153	30	176	1.3G	5280	807,84	Rockets stored at the back of the container The rockets were being unloaded when the fire started.
03730	Rocket	27	42	80	100	1.3G	8000	336	Unloaded from the container.

The following items were stored in container 2 [4]:

ID (no.)	Type of firework	Size (mm)	Net explosive mass per object (g)	No. Of objects per carton	No. of cartons	D.R.	Total number of objects	Total weight (kg)	Comments
60240	Battery	29	998	2	122	1.3G	244	243,5	Batteries stored at the back of the container.
60709	Battery	29	495	2	330	1.3G	660	326,7	2 palettes were unloaded

It is to be noted that the palettes being unloaded from containers were temporarily stored in groups of 2 to 5 palettes at 4 different sites along the passageway going to buildings 1+2 and 3 before reaching their final storage site in the same buildings. It also appears that the palettes were directly unloaded from the containers onto trailers without an unloading dock.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The accident sequence started on 3 November 2004 just a little before 2.00 pm when three employees of the company were unloading containers 1 and 2 (see “involved unit”).

The containers were manually emptied. An employee took the stacked boxes in the container and handed them down to his co-worker who put them on palettes. The third employee operated a forklift truck and took the palettes away once completed.

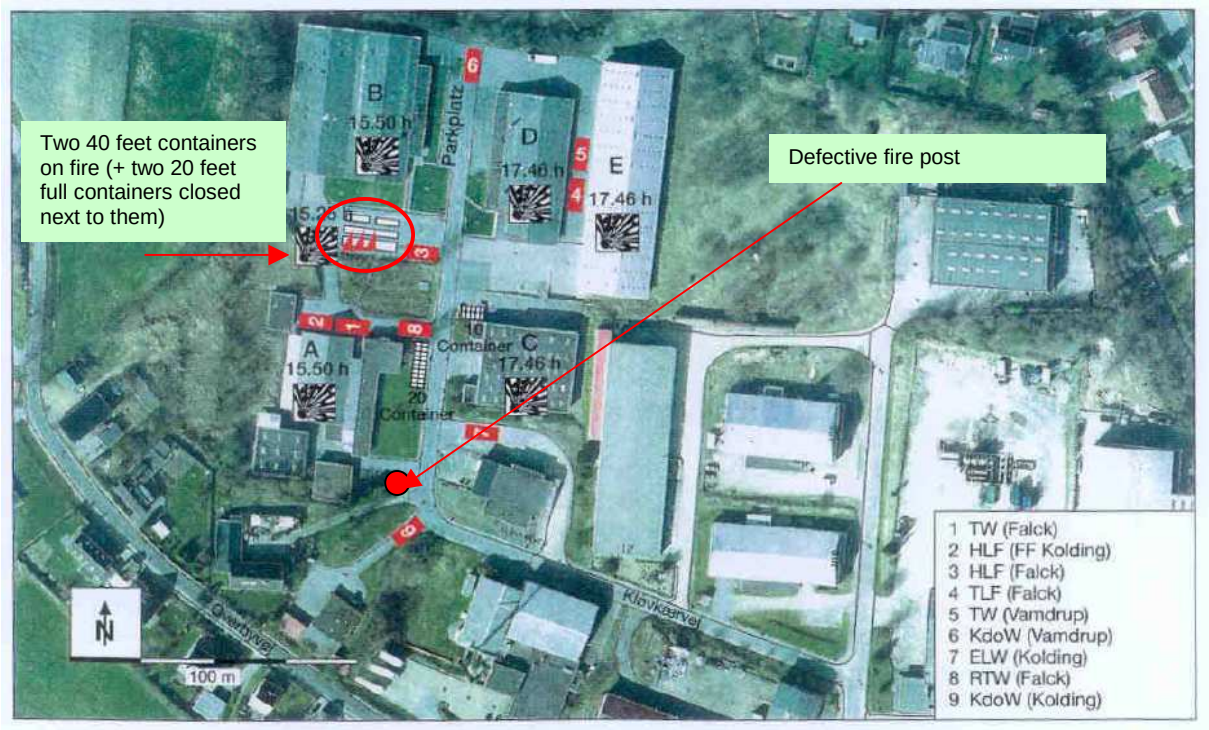
According to the police report [2], an employee accidentally dropped a carton of rockets (ref. 03602) that ignited in container 1. The fire rapidly spread to the fireworks in the container, in the palettes outside the containers and to container 2 as well.

The company triggered its internal emergency plan and evacuated the staff.

The alarm was received at 2.02 pm in an emergency call centre that informed the local police and the emergency services. A first unit of 8 fire-fighters arrived.

The emergency services focused their efforts on cooling the two containers on fire and protecting the nearest buildings to prevent the fire from spreading. The rescue squad requested additional human and water resources.

Fire in the 2 containers at 3 p.m. [2]



The emergency team faced difficulties in the rescue operations. The fire-fighters were unable to target the water nozzles directly at the entrance of the two containers due to the thick cloud of smoke and the explosion of fireworks. Moreover, the nearest fire post was out of order thus complicating water supply. The police decided to evacuate residents within a perimeter of 500 m.

At 3.25 pm a major explosion occurred[1] to the surprise of the rescue workers as there were no signs of increase in the intensity of fire.

During the explosion, 34 fire-fighters and 12 vehicles were present on site. One death and several cases of injuries were reported amongst the rescue workers (shock and/or burns).

The emergency equipment sustained substantial damage. 9 vehicles (7 fire vehicles, 1 ambulance and the Kolding command vehicle) were de-commissioned due to the explosion and fire.

The intervention with the 3 first vehicles. The situation seems to improve.

The 3.25 pm explosion

The explosion destroyed the doors and windows of warehouses 1+2 and 4. The ignited fireworks were projected into the buildings. At 3.33 pm, the fireworks exploded in the building 1+2.

The rescue operations were performed under difficult conditions: besides having lost a colleague to the fire, the fire-fighters were disoriented by the noise and the smoke released from the explosion of the fireworks. The situation was temporarily chaotic among the rescue workers as they had to take stock of the damage before resuming fire-fighting operations.

[1] The various sources revealed contradictory versions on the origin of the explosion. [1] and [3] stated that container 2 exploded. However, container 2 was 2/3 empty at the start of the accident and the remaining 1/3 was on fire for 90 minutes at the time of the explosion. It was hard to imagine that the low quantity of material still on fire at 3.25 pm in container 2 could have exploded so violently and caused such damage. A likely explanation would be that one of the 20 feet closed containers on the side exploded followed by the explosion of containers 1 and 2. This seems to fit in well with the descriptions of the sources [2/appendix 3] and [5].

The fire-fighter command requested for backup and a general control station was set up. Since a second explosion was feared, residents within a perimeter of 1000 m were evacuated (see map). The rescue workers also pulled back from within this perimeter [5, 2].

Three major explosions resulting in spectacular fire balls (cf. [8] [9]) of several meters occurred at 5.45 pm (explosions are presumed to have occurred in buildings 6 and 7 containing 150 tonnes of fireworks).

The company, most of the buildings in the industrial zone and a part of the residential buildings in the neighbourhood were destroyed or severely damaged.

Explosions at 5.45 pm

The residents in the city were informed by vehicles. Several municipalities requisitioned backup and accepted support from outside mainly fire-fighters from a nearby air base [1, 2].

Military resources were also used to assist the disaster control operations: military tanks were used to open fireworks containers damaged by the fire. Several containers were consumed over several days without exploding.

Military experts on explosives collected the fireworks during and after the fire-fighting operations (equivalent of the French mine clearing unit).

Consequences of the accident:

Among the fire-fighters, one death, 3 serious injuries and 13 minor injuries were reported. Around 60 people were treated for hearing problems or irritation due to the inhalation of smoke.

The fire-fighting operations that last untill the morning of 7 November required 332 people and 55 vehicles (both fire-fighting and rescue operations). Around 1,500 tonnes of fireworks (total weight of fireworks / 282 tonnes in net explosive weight) were destroyed.

The company, most of the buildings in the industrial zone and a part of the residential buildings in the neighbourhood were destroyed or severely damaged: 450 houses were damaged and some were made unfit for living. Debris of the buildings were found over 1,000 meters away from the disaster.

A 2 m^2 and 15 cm thick fragment of the concrete wall, weighing a tonne, was found at 150 m from building 6 [3, 4]. The houses to the south of the site were damaged to a lesser extent. They were located on the other side of the 5 to 10 m high hill to the north of the facility and were thus partly protected. The damage caused to the buildings was assessed at 100 million euros [1, 3].

The containers between the buildings burnt for several hours without exploding. Some of them were deformed by the heat and the possible rise in internal pressure.

The door and fragments of the lateral walls of the container that exploded at 3.25 pm were found at respectively 50, 120, 80 and 96 m. However, no crater was reported to the right of the container [4].

10 craters whose characteristics are indicated below were found in buildings 1, 4, 6, 7 and 8:

Crater number	Building	Surface (m^2)	Depth (m)	Thickness (cm) and type of coating	Location in the building
1	1	8	0.2	10 / concrete	East / centre
2	4	3	0.08		West
3	4	5	0.26		East
4	6	35	0.22	15 / shingle macadam	North-west
5	6	29	0.50	15 / shingle macadam	North-east
6	6	75	0.59	13 / shingle macadam	Centre / east
7	7	110	0.49	13 / shingle macadam	North-east
8	7	25	0.25	15 / shingle macadam	South-west
9	8	24	0.48	10 / concrete	Centre
10	8	70	0.52	10 / concrete	South

Apart from a ground fully covered with debris, pollution measurements carried out after the accident revealed no significant ground pollution attributable to the accident.

Aerial view of the sire after the accident (cf. photo on first page)

The European scale of industrial accidents:

By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the '*SEVESO*' directive on handling hazardous substances, and in light of the information available, this accident can be characterised by the four following indices:

The parameters composing these indices and their corresponding rating protocol are available from the following Website: http://www.aria.developpement-durable.gouv.fr

Two parameters come into play in determining the "dangerous materials released" index: Q1 and Q2.

- 300 tonnes of explosives (net weight) of class 1.3 representing 540% of the corresponding Seveso threshold (50 tonnes – explosive substances not classified in division 1.4 according to the ADR agreement (United Nations), whish is the equivalent of level 5 of the "dangerous materials released" index according to the Q1 parameter (Q1 between 1 and 10 times the threshold).
- the effects of the explosion were not characterised and shattered glass panes were observed over 1,000 m, the Q2 parameter was rated at 3.

Consequently, the overall rating for the "dangerous materials released" index reached 5.

Four parameters come into play in determining the "human and social consequences" index: H3, H4, H5 and H6.

- The H3 parameter reached level 2: 1 fire-fighter died after the first explosion.
- The H4 parameter reached level 2: 3 fire-fighters were seriously injured.
- The H5 parameter reached level 2: 63 people were treated for hearing problems or lung irritation (H5 between 50 et 199 people injured).
- The H6 parameter reached level 2 due to the number of third parties rendered homeless or unfit for work (around 200 people)

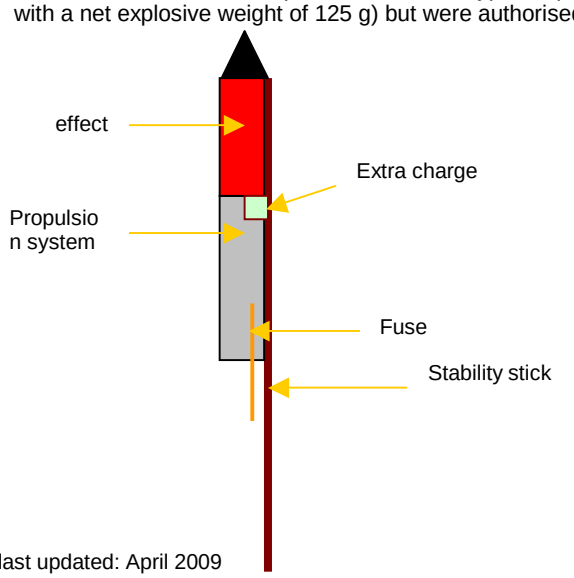
The overall rating for the "human and social consequences" index consequently stood at 5.

The €15 and €16 parameters of the "economic consequences" index was rated at 6 since the amount of material damage was assessed to be 100 M€.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

According to the police report based mainly on the audition of employees, the fire may have been sparked off by the fall of a box of rockets when being handed over by one employee to the other. The box fell from a height of around 50 cm and may have hit the palette. Three employees confirm having seen a 0.2 à 0.4 m flash and heard an explosion in the box. The spark would have ignited the other rockets and the fire in container 1.

The Danish authorities inspected the rocket type in question. The rockets (reference 3602) were rather heavy (380 g, with a net explosive weight of 125 g) but were authorised for sale in the Danish market at that time.



The rocket in question comprises a propulsion system and 3 bombs of 5 cm diameter (effect). An additional pyrotechnic charge between its stabilising stick and propulsion system separates the latter from the support when the rocket is at its peak height.

Danish regulations lay down limitations on the size of fireworks debris when the total weight of the fireworks item tops 200 g. In this case the motor and the support must be separated, which may require the addition of an extra charge.

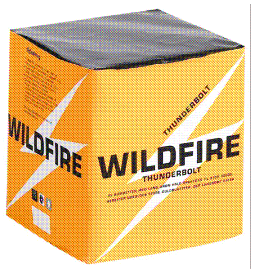
Initially, an assumption widely spread by the media considered that the extra charge may have been improperly attached and may have been triggered spontaneously by the shock. However, the police found 60 rockets of the same type in Danish shops and proceeded to testing them (chemical analysis, fall test involving a 9 kg load on the support, impact and friction tests. Even though the friction and impact tests conducted by the BAM[2] in Germany revealed that the flash composition of these rockets was more sensitive than other flash compositions, none of the rockets tested were triggered spontaneously during the tests. The assumption could thus not be validated.

The static electricity or possible ignition of the black powder present on the ground of the container was also considered. Static electricity was ruled out especially after the uniforms of the technicians were analysed by the Swedish Textile institute (IFP Research). A trace of black powder in the container was deemed rather unlikely. It was considered that the technicians would have noticed any powder lying on the ground. Lastly, an open flame or cigarette as the cause of the accident was also ruled out (deemed unlikely).

The initial cause of the start of the fire remains unknown. Some information was however gathered from observations made after the accident.

The police enquiry revealed 10 craters in buildings 1, 4, 6, 7 and 8, but strangely the various reports did not mention craters relating to the first explosion. Tying up with detailed information on storage guidelines before the accident (obtained from a detailed entry-exit register and saved outside the company), the enquiry revealed that the largest craters were formed at the sites where significant (over 500 kg of net weight) quantities of explosives of the same type, in this case, batteries (wildfire thunderbolt or space invader[3]) were stored[4]. Transport classification tests carried out later on the same type of fireworks confirmed their rating as DR 1.3G.

Other tests carried out by the Danish authorities on some rockets revealed the limits of the default classification of the dangerous goods classification. Some rockets that were classified 1.3G by default ought to have been placed in the 1.1G category even though they contained only 11% of the active weight (<25%). These rockets contributed to the accident but did not form craters, raising the question on the influence of quantities stored on the behaviour of fireworks.



In application of the SEVESO directive, the company was in possession of a safety report, emergency plan and provided training to its staff. However, the company only stored fireworks for private citizens ("maximum" transport classification 1.3 G), the risk of explosion had not been identified despite the major firework depot accident at Enschede in Holland on the 13 May 2000.

The company had implemented preventive measures at the storage site: ground markings to store boxes, regular inspection of electrical facilities, fire-fighting system, etc. However, loading and unloading that must be fully considered as pyrotechnical operations were probably underestimated along with the involved risks.

Limited information is available on the content of the safety report. Nevertheless, several key safety points can be questioned, including the following ones, which analysis is in France made compulsory since 1980 by the probabilistic assessment of phenomena in work safety reports (EST) and environmental safety reports (EDD) of all pyrotechnical sites :

- overall configuration of facilities that certainly contributed to the development of the fire and obstructed fire-fighting operations (location of buildings with respect to each other and outside, loaded containers located between buildings, absence of a loading dock etc.),
- configuration of storage sites (implantation and risks depending on the products stored, impact zones and uncoupling, presence of gas cylinders in the vicinity, etc.)
- the possible relay effect of palettes stored temporarily between the containers and buildings,
- risk analysis of various pyrotechnical operations with special care when they take place at the same time,
- effectiveness of fire protection. The facilities were equipped with a sprinkler system. However, no information was available on their possible triggering or their sizing or effectiveness. On the contrary, it has been established that fiery projections (fireworks) passed through the smoke vents and triggered fires in buildings and houses within a range of around 100 m (range of rockets).

[2] BAM: Bundesanstalt für Materialforschung und –prüfung: National German laboratory accredited to classify explosives.
[3] The "space invader" differs from the "wildfire thunderbolt" only in its commercial packing. It is a battery with 25 tubes of 20 cm in length with an ID number attributed by the Danish authorities of BRS-01-306-RC-01-341 and containing 575 g of explosives (net weight).
[4] The fireworks were present at the base of 6 craters and near 2 craters.

ACTIONS TAKEN

The police and the Danish labour and environment authorities decided to drop all charges incurring any liability in the accident. An enquiry carried out by international experts also concluded that the Danish authorities showed no signs of negligence in their actions relating to the circumstances of the accident.

Thirty major fireworks storage sites of the country were inspected especially to ensure their compatibility with their urban environment. Seven of the sites were moved to military zones.

More generally, Danish authorities amended the legislation on the manufacture and sale of fireworks to lay restrictions on their sale and use by the public. The European standards were retained as reference standards to assess fireworks.

For retail outlets, the authorised quantity of stored fireworks was brought down to 1 tonne in 20 feet containers that must be located at a minimum of 40 m from other buildings. The quantities and safety regulations in retail outlets were also reviewed. The authorised quantities in outlets open to the public must not exceed 50 kg. This quantity also constitutes the upper limit for retail outlets in France (2 x 25 kg, order issued by the Secretary of State for industry on 3 July 2000).

Denmark has also launched a set of coordinated initiatives between various government departments (police, income tax and fraud control, safety inspection, etc) to check the fireworks present in the territory. In all, 120 tonnes of illegal fireworks were confiscated between December 2004 and January 2005.

Denmark has also suggested to the European Commission to designate standardisation bodies to define methods and assess the sensitivity limits of these substances especially to friction.

In 2009, drafting of European standards in underway within the framework of the application of the European directive 2007/23/CE on the marketing (CE marking) of pyrotechnical items including fireworks.

LESSONS LEARNT

Safety distances:

It is important to look into the conditions that promoted the fire to spread so quickly: were sufficient safety distances between the containers and between the containers and buildings planned and respected? Was the relay effect of the spreading of fire from container 1 to container 2, and then to the adjacent buildings via palettes studied? Were the risks relating to the simultaneous unloading of two containers assessed?

With regard to French regulations, simultaneous loading/unloading stations make up two basic pyrotechnical facilities (a_0[5]) and would have required additional safety measures to separate them (distance between the work stations, protective elements, etc.). Similarly, given their respective distances, the storage sites could not be considered as separated. **The proper definition of a basic pyrotechnical facility and compliance with safety distances between the various pyrotechnical facilities are two fundamental provisions of pyrotechnical safety.**

Risk classification and division and storage risk

In light of the tests carried out after the accident on the same type of rockets (reference 3602), no final conclusion was reached with regards to the cause of the fire. In fact, in order to be transportable, a pyrotechnical package must not ignite during fall tests. It is only when the transportability tests are performed that a risk division classification can be attributed. Did other operations (regrouping or picking with open parcels for instance) take place at the same time? The question of compliance of products imported from countries where manufacturing accidents are numerous was also raised by some people. The EU member states carry out a pyrotechnical item market watch that include fireworks (in application of national legislations and directive 2007/23/CE in the future).

Moreover, researches on fireworks are carried out mainly at a European level (e.g. CHAF tests) with a view to characterise the risks of fire turning into an explosion. All identified risks must be dealt with in the safety report.

[5] a_o: "A basic pyrotechnical facility includes an outdoor or indoor work station that may be isolated or be part of a workshop, depot or storage site and contains explosive products. The basic facility with its access and annexes that must be located in its immediate surrounding is referred to as a0." (interministerial order dated 20 April 2007 laying down the regulations on assessing risks and preventing accidents in pyrotechnical facilities). In a work safety report the two a_0s were considered as a_2 with respect to each other that required separating them and/or not working at the same time.

The work risk division attributed to a product is not an intrinsic characteristic and may depend on its conditioning (and especially on the packaging mode used) as well as on the manufacturing configurations, implementation and disposal. Simply classifying the product in a risk division does not substitute a sound analysis of the risks relating to pyrotechnical products. The transport risk may differ from the work risk. Therefore, it is important that accident scenarios and their potential effects be studied depending on the site configurations.

Fire protection and feedback management

Failure of either of the fire posts raises a few questions on fire-fighting equipment: were they adapted (efficient)? Appropriately sized? tested?

Lastly, four years after the Enschede accident in Holland, the Kolding accident again raises the question of managing feedback as well as controlling urban development around pyrotechnical sites.

In France, the last question concerns above all small depots. Indeed, sites subject to permit are in general located relatively far away from residences as laid down by law since the 1970s[6].

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[7] Letter of the Danish authorities to the European Commission

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[9] Amateur videos of the accident http://video.google.com/videoplay?docid=4839817865249089909&hl=fr

[10] Detailed Enschede accident sheet (ARIA 17730), French Ministry of Sustainable Development, BARPI. Can be consulted at www.aria.developpement-durable.gouv.fr

[11] Detailed Culemborg accident sheet (ARIA 3098), French Ministry of Sustainable Development, BARPI. Can be consulted at www.aria.developpement-durable.gouv.fr

[6] Decree n°79-846 of 28 September 1979 on public auth ority regulations on protection of workers against specific risks faced by them in pyrotechnical sites. This text, along with the environmental code and other regulations defines stringent reference guidelines for pyrotechnical activities.