# Fire and explosions at an aerosol storage warehouse

5 November 2010

**Newton Aycliffe**

**United Kingdom**

**LPG / Aerosols**
**Flammable liquids**
**Explosive atmosphere / ATEX**
**Fire / Explosion**
**Lift truck**
**Organisation**

## THE FACILITIES INVOLVED

### The site:

The accident occurred at a Top Tier Seveso site operated by a well-established warehousing and transportation company. The only dangerous Seveso material stored was LPG as an aerosol propellant. One of the company's activities was to serve as a UK distribution centre for a major EU manufacturer of anti-perspirant aerosols, liquid hair dyes and shampoos.

### The involved unit:

The warehouse where the accident occurred contained approximately 4,000 pallets of aerosols with a typical composition LPG/Ethanol 60/40 %w/w. The warehouse also contained a similar number of pallets of liquid (aqueous) hair colourings and shampoos in plastic bottles.

Palletised products were stored on racks up to 6 levels high. Pallet handling involved 7.5 tonne electric flexi-trucks. Aerosol storage areas are not normally zoned under the ATEX Workplace Directive and the trucks at this site were not rated for use in a potentially flammable atmosphere. The warehouse was not sprinklered.

Site operator

Figure 1: Interior of the facility prior to the accident


Figure 2: Unprotected electric flexi-truck in use at the site

## THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

### The accident:

A fire started around midday on a week day when the warehouse and wider site was in full operation. The fire service attended a few minutes after the fire was discovered but the warehouse was already well alight and rapidly burned to the ground. Witnesses reports and CCTV records revealed that the warehouse became smoke logged extremely rapidly after the fire started and there were at least two larger explosions that blew off part of the roof and shook cameras on neighbouring buildings.


Figure 3: Damage to the warehouse and contents caused by the fire

The Fire Service used water to cool surrounding buildings and prevent fire spread but avoided putting water on the burning warehouse since the fire had progressed well beyond the point where extinguishment was a possibility. This controlled use of water avoided immediate large scale dispersal of potentially damaging detergent products into local rivers.

## The consequences of the accident:

The fire was discovered at an early stage and unsuccessful attempts were made to control it using a hand-held extinguisher. The fire alarm was sounded promptly and approximately 10 people who were working in the warehouse all successfully escaped within about 40 seconds. CCTV records suggest that the first mass explosion that triggered ultra-rapid fire spread and smoke logging of the building occurred about 80 seconds after the alarm was raised.

The fire service controlled use of water and found there was relatively little environmental damage but 200 fish were killed in a nearby river by detergents and hair dyes being washed from the site after the fire mainly by rain rather than fire water. The fire destroyed 30 per cent of the storage facilities leading to economic losses about 12 million €.

## 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 information available, this accident can be characterised by the four following indices:


The quantity of LPG burned during the fire is unknown. By default, parameter Q1 (Q1< 0.1%) of the "dangerous materials released" is thus 1. As the effects of the explosions had not been characterized, parameter Q2 was given a rating of 1. The overall "dangerous materials released" rating is thus 1. In the absence of any observed human and social consequences, the relevant index had to be assigned a "0" rating. About 200 fish were killed, leading to an index relative to environmental consequences equal to 1 (see parameter E10). Economic losses were about 12 million €, leading to an index relative to economic consequences equal to 4 (see parameter E15).

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

# THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

Excellent information on the location of the ignition is available from several witnesses who observed a small flame on a full pallet of aerosols at ground level. This pallet was not close to any lights or other fixed equipment that could have acted as potential ignition sources. Immediately prior to the discovery of fire, a 7.5 tonne electric "flexi" lift truck had been used to remove a pallet from racking across the aisle from the ignited pallet. The lift operation with this truck had involved: driving into the narrow aisle rack array; turning the front section of the truck into the rack; lifting a load at high level and reversing out with the load on the forks. This operation would necessarily have brought the back of the pallet truck close to the stored pallets at a time when the driver's attention was divided between safely extracting the pallet from the high level storage slot and controlling the truck body position within the aisle.

Fork lift trucks used in the warehouse were not suitable for use in areas where there was a risk of a flammable gas cloud. This is because motor brushes and other high-current electrical contactors would have regularly produced highly incendive sparks. These sparking components were not fully enclosed, which means that flammable gas around the truck could move into contact with the sparking components and the resulting gas ignition could propagate out of the truck body and spread to the rest of the gas cloud. The Fire Service investigating officer carefully reviewed evidence relating to all potential sources of ignition other than the lift truck (including arson and smoking). His conclusion was that there is no evidence for any such ignitions. All of the evidence is, however, consistent with ignition of flammable vapours from leaking aerosols being ignited by unprotected components in the lift truck.

There are several ways that a flammable gas cloud might be produced in an aerosol warehouse, many of which have caused major accidents in the past:

i. Loose cans on the floor can be run over, releasing a cloud of flammable gas and finely divided flammable vapour immediately under a lift truck. There are no reports of loose cans in this case and the fire became established on a pallet on the rack rather than the truck.

ii. A truck can collide with a stored pallet, crushing cans and releasing flammable gas and liquid. If this cloud of flammable vapour is immediately ignited by the lift truck, the vapour explosion will track back to the source of vapour and may cause ignition of spilled liquid or cardboard soaked in liquid. This then leads to a sustained, condensed-phase fire that can spread in the normal way. Given the fragility of cans and the mass of lift trucks it is possible for significant releases to occur without the truck driver's knowledge. There were no witness reports of crushed cans in this case but given the stressful circumstances during the accident it is possible that these could have been overlooked.

iii. Aerosols can leak because of manufacturing faults or can corrosion. Given the relatively long time period between manufacture of the aerosols and the accident it seems relatively unlikely that significant leakage would still be occurring.

iv. Aerosols can become damaged during handling by various types of impact or by inappropriate stacking of products (which stresses the caps and discharge mechanisms). This can lead to loss of gas and liquid contents. Full pallets are normally covered in a shrink-wrap cover which is tightly fitted around the pallet. Heavy gases released from cans may not immediately be able to drain downwards out of the load. Flammable liquids released within the pallet begin to vaporise quickly and this continues until all of the air enclosed by the plastic cover is saturated with vapour. Liquid vaporisation then stops and can only progress as saturated air leaks out of the wrapped pallet and is replaced by fresh air. Slow vaporisation of spilled liquid in this way could maintain a flammable vapour concentration within a wrapped pallet for a very long period (several days). A pallet in this condition requires only the lightest contact with a truck to pierce the plastic film and release the vapour cloud within. Again the cloud may be ignited by the truck and the explosion will then track back to ignite the remains of the liquid spill.

The ignition of plastic and cardboard observed by the witnesses tends to suggest that there was a liquid spill within the pallet. There is not enough information available from witnesses or from examination of the fire scene to be able to distinguish between these variations on the themes of leaking aerosols, truck impact and spark ignition.

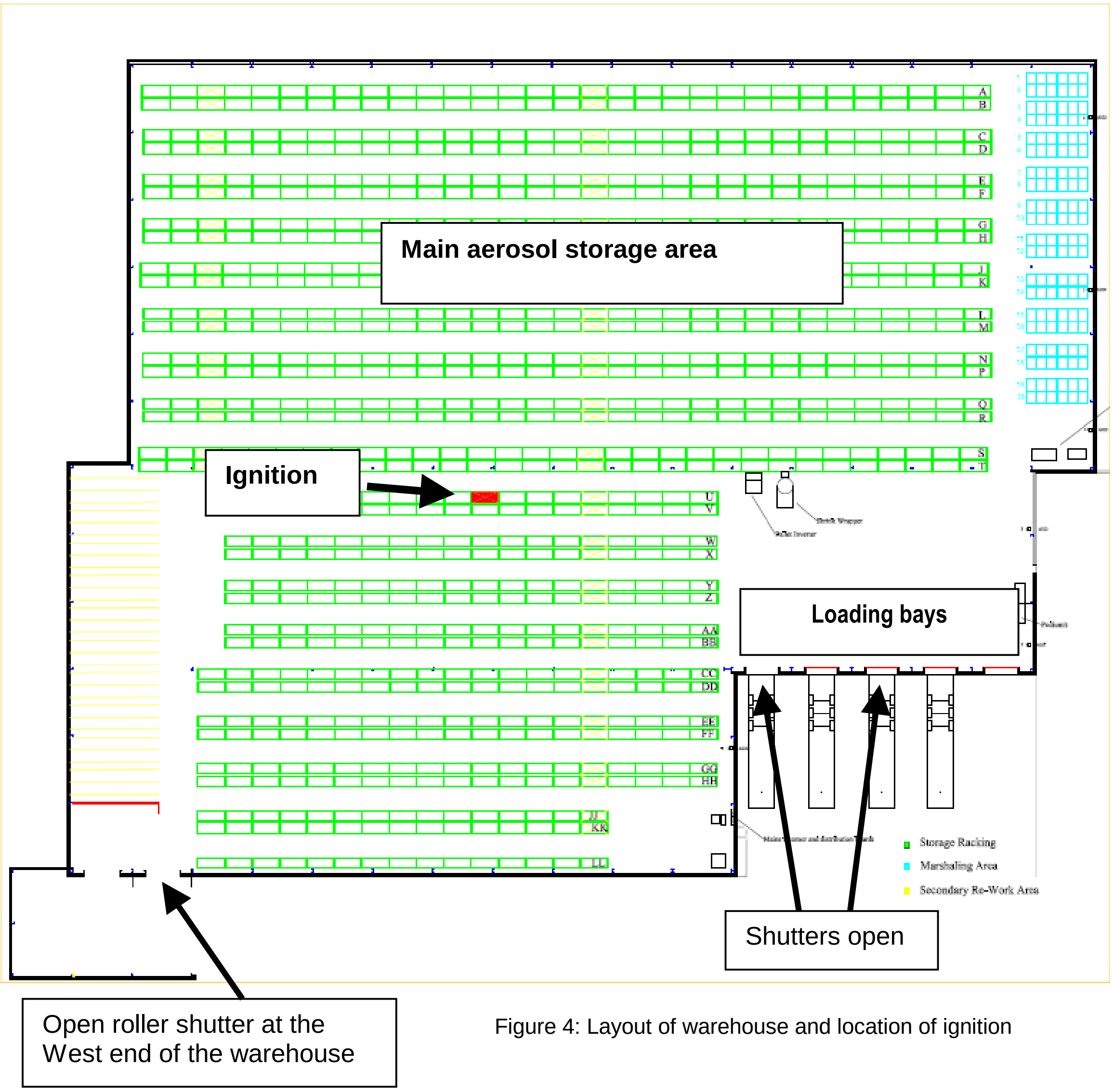


Figure 4: Layout of warehouse and location of ignition

When first spotted by the lift truck driver the flames were only 300mm high – towards the base of an aerosol pallet at ground level. A small foam extinguisher was used and initially the visible flame was knocked down but seconds later flames broke out again. Witnesses fighting the fire then heard a popping noise that they recognised as the failure of an aerosol can and started to run out of the building. The last worker to leave reported his final impressions of the fire:

"..the fire had started to spread to adjacent pallets on either side of it and above. It was spreading surprisingly quick and was beginning to spread towards pallets opposite. You could hear popping and rumbling. This all happened over seconds. There was thick dense black smoke which was spreading up and along the ceiling."

After evacuation was complete, information about the state of the fire comes only from external CCTV and the statements of witnesses who remained close to the aerosol warehouse. A fire development timeline developed from this evidence is shown in Table 1.

| Time | Fire condition |
|---|---|
| -60 (?) seconds | Fire start |
| 0 seconds | Operation of the fire alarm |
| 40 seconds | Last witnesses leave the warehouse |
| 80 seconds | First explosion – onset of rapid fire growth and smoke logging |
| 110 seconds | Building smoke-logged to low level |
| 150 seconds | Second explosion (portion of roof peeled off) |
| 1200 seconds | Uncontrolled yielding of structural columns around warehouse perimeter |

Table 1: Fire timeline focussing on the early stages of development

Some witness accounts of explosions early in the fire are reproduced below. The rumbling and cracking noises referred to are the failure of individual aerosol cans:

"I would have ran about 10m out of the gate when I heard the building go… As I ran from the building you heard rumbling and cracking building up, getting louder and louder. The rumbling and cracking did not stop for ages. However when I was running from the building there was one big boom."

"The noise got faster and faster until we heard a bigger bang. We saw a blast of air across the yard with smoke in it."

"There was loads of cardboard coming out through the roof, along with smoke and flames, this all again seeming to happen shortly after I left the building."

The later stages of the fire appeared reasonably typical of the progress of a (high fire load) warehouse fire. However, the complete destruction of steel cladding over areas containing a high density of aerosol pallets is unusual. This is probably due to the combined effect of high temperatures and millions of separate aerosol bursts. These bursts have a percussive local effect that dislodges the rust scale that builds up on steel sheet at high temperatures. The steel roof sheets can therefore rust away during the course of the fire at an unusually high rate.

## ACTION TAKEN

The fire destroyed 30 per cent of the storage facilities but, since then, the company has recovered and replaced the lost business with new storage and distribution contracts.

HSE have given presentations on the fire at a conference of the British Aerosol Manufacturers Association (BAMA) and at an NFPA Seminar on High Risk Storage Challenges (Paris, 27th June 2012).

In the future National and European Trade organisations as well as regulators have an important role to play in improving awareness of risks associated with large scale storage of aerosols. The UK BAMA guidance is widely used but this does not clearly identify unprotected lift trucks as an important cause of fires. Similarly the speed with which fires develop and the shortness of the time available for evacuation is not generally understood.

These issues are most important for warehouses that store very large numbers of pallets of aerosols (Seveso sites). Many shops have relatively small numbers of aerosols mixed in with much large quantities of other goods. In these cases the risk of ignition is much lower and the rate of fire growth not unusual. For these stores investment in protected trucks may not be justified.

## LESSONS LEARNT

### Important process safety lessons to be learned

i. Unprotected forklift trucks represent a serious risk of starting fires in aerosol stores. There are many scenarios in which small vapour clouds can be created and ignited by an unprotected lift truck.

ii. Fire growth in aerosol stores can be extremely high. Even in large buildings the time available for escape can be as low as 100 seconds. This means that emergency planning is of prime importance. Fire evacuation should be practised regularly with 100 seconds being the target evacuation time.

iii. Careful attention should be given to mezzanine levels (that are rapidly affected by smoke) and any separate compartments from which escape is only possible through the warehouse. Special risk assessments may be needed where people are working at elevation and cannot get down quickly (e.g. scissor lifts). For example, it may be necessary to suspend the use of unprotected lift trucks within high rack storage areas (where they can start ultra-rapid fires) if there are people working in locations where they cannot escape quickly in response to an alarm.


Figure 5: Smoke flow from the building 135 seconds after the fire alarm was sounded

## Potential for larger explosions at aerosol warehouses

This fire shows clearly that the release and combustion of flammable vapours from large numbers of aerosol pallets may not be a steady process. Aerosol cans may vent under conditions in which there is no immediate ignition; flammable gas and dispersed liquid then accumulates in the upper parts of the warehouse and there may be rainout of flammable liquid away from the established fire. Subsequent ignition can lead to an explosion and/or sustained burning of fuel rich volumes. The latter may generate a swelling fireball that could in principle engulf and ignite goods in a substantial fraction of the warehouse in a few seconds. Ignition of dispersed liquid may spread the fire to lower level over a wide area. This also has the effect of greatly increasing the subsequent rate of smoke logging.

The safety significance of such explosions depends on the circumstances. If the warehouse is very large and aerosols are stored (at high level) in one separate area there is potential for a large volume of gas to accumulate over a relatively long period of time (tens of minutes). Overpressure effects from explosion of such an accumulated cloud could be a significant threat to the Fire Service and any other people close to the burning warehouse. The risk is greatest if a fire starts in other goods remote from the aerosols and stabilises at a level corresponding to an upper layer temperature in the range 150 - 300°C. This type of explosion could be a Major Accident Hazard but is normally a possible but unlikely scenario. More likely is a fire that continues to develop rapidly. Upper layer temperatures > 300°C cause rapid can failure but there is insufficient residual air to support a premixed explosion.

If the warehouse contains a high proportion of aerosols and these are distributed throughout the warehouse, explosions are likely to occur more rapidly but to be of smaller size and intensity. The aerosol store destroyed by fire described in this note was of this sort. In this case the significance of explosions is in accelerating the spread of fire and restricting the time available for escape.

The extent and consequences of vapour accumulation and explosion are likely to be highly variable and difficult to predict. In some cases no significant explosions will occur but, on the other hand, much more severe blasts might occur in a warehouse with a similar size and stock mix to that at this warehouse.

There appears to be a lack of published information of the rate of failure of palletised aerosols cans exposed to temperatures in the range 150 - 300°C. Without this data it is impossible to attempt to determine when and where areas of unburned gas and liquid may form and in what concentration. Consequently, there is a need for research on the behaviour of aerosols in these circumstances.