Explosion of a fireworks storage

14 February 1991

Culemborg

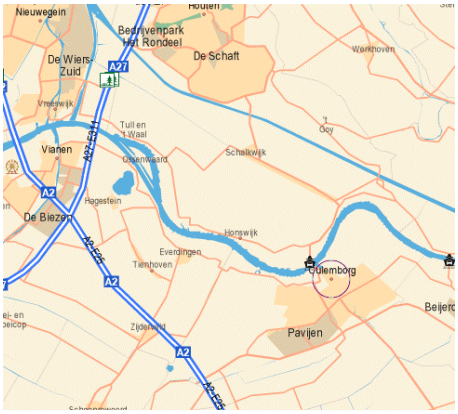
The Netherlands

Pyrotechnics / Explosives
Fireworks
Domino effect
Explosion
Organisation
Storage risk assessment
Safety distances

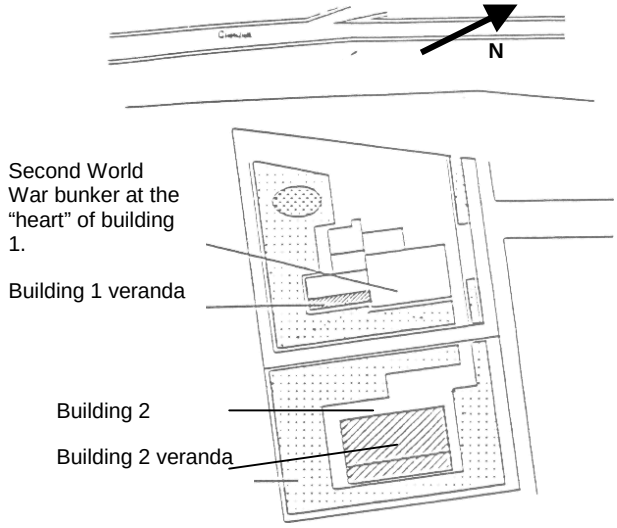
THE FACILITIES INVOLVED

The site:

The fireworks storage depot was located 5 km south west of the town of Culemborg at 15 km to the south of Utrecht in the centre of the country.



The facility comprising two buildings was at 50 metres from a 5.8m high dike. The Farmhouses and homes were mainly built along the other side of the dike. There were two farmhouses on the same side of the dike at 200 m from the facilities. The dike was the only elevated point of this rather flat landscape.



Factory implantation

The first building (building 1) comprised a bunker that dated back to the Second World War, 5 small storage rooms and one 25x16 m meeting room.

20 m further down stood the 2nd building (building 2) built in 1990 and commissioned two months back. It included 4 storage depots, 2 workshops and a 20x12 m meeting room (see building plan page 4).

The walls of the storage building 2 comprised two 0.2 m thick plain concrete blocks while the ceiling was made up of hollow concrete slabs.

The inner wall was also made up of concrete blocks whereas the outer wall of bricks. The veranda of building 2 comprised steel beams covered with asbestos-cement boards.

The safety distance from the outside was calculated taking into account a risk category of 1.3 (significant thermal effects).

Around 10 tonnes of fireworks classified under the transport risk category of 1.3 or 1.4 were authorised for storage in the site. Items classified under the category 1.1 or 1.2 (mass explosion hazard) were explicitly excluded except for 200 kg of black powder that was still stored in the Second World War bunker.

The involved unit:

The unit involved was located in the building built in 1990 (building 2).

Excluding the weight of wooden crates, a gross weight of 1,000 kg of fireworks was permitted in each of the four depots of the impacted buildings. The fireworks had to be stored in their packaging.

A maximum gross weight of 200 kg was allowed in each of the workshops. Thus the total maximum gross weight allowed in building 2 was 4400 kg, i.e. a net weight of 1,500 to 2,000 kg of explosives.

On the day of the accident, 8 to 9 tonnes of products (including building 1) were stored onsite.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

On 14 February 1991 at around 11.50 am, farmers heard a violent explosion. A second explosion that was far greater in intensity followed 20 seconds later along with fall of metal and concrete debris on the ground.

Building 2 was destroyed leaving behind a 10 m x 5 m crater more than 2 m deep. Building 1 caught fire and minor explosions occurred during the rest of the day in its warehouses.

The consequences:

Two people lost their lives and six sustained serious injuries.

Even though none of the houses were destroyed completely significant damage was reported as far as 500m behind the walls of the dike: damaged roofs, wide cracks on walls, most window panes shattered, window and door frames broken.

On the side of the dike housing the facility, the extent of damage was as far as 900 metres: brick walls of residences cracked, frames of double glazing smashed, roofs of big barns ripped out and their wooden framings slit. At 500 m from the site of explosion, huge wooden doors (3 m x 4 m) were ripped out and smashed.

The projection of debris also resulted in damage: 10 to 20 kg concrete blocks as wells as 4m long beam fragments were found as far as 650 m to the east of the facility (on the side of the facility). Most of the other debris comprised bricks, brick pieces and concrete.

Significant damage was reported in the city of Culemborg: smashed panes, damaged chimneys, roofs of exhibition rooms ripped out damaging the ceiling and items stored inside

The explosion was detected by seismographs at over 100 km.

By analysing the information on damage (shattered panes / distance from explosion / size and orientation of panes) and on the observed craters on the plant, the intensity of the explosion was assessed to be the equivalent of 1,800 kg of TNT.

According to insurance companies, the total cost of damage was as high as 50 to 60 million guilders, i.e. approximately 25 million euros.

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 rating the "dangerous materials released" index: Q1 and Q2.

- Since the exact quantities released were unknown but lower than the Seveso threshold; the Q1 parameter is rated at 1 by default.
- Since the effects of the explosion were deemed equivalent to two tonnes of TNT, the Q2 parameter is rated at 3.

The overall "dangerous materials released" index thus stands at 3.

Two parameters come into play in rating the "human and social consequences" index: H3 and H4.

- The H3 parameter was rated at 4 since two people lost their lives including one common man who happened to be in the company.
- The H4 parameter was rated at level 3 as six people sustained serious injuries

The overall "human and social consequences" index thus stands at 4.

In absence of any additional information on the distribution of the total cost of damage worth 25M€, and assuming that the damage is equally divided (12,5M€) within (parameters €15 and €16, rated at 4) and outside the facility (parameter €17, rated at 6), the overall "economic consequences" index stands at 6.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE FLOODING

Given the quantities involved in the explosion and their impact, all fireworks stored in the new building exploded in mass. Such an explosion was not planned for fireworks under the 1.3 risk category. The safety distances between the buildings and the outside was moreover calculated taking into account a significant thermal risk and not a blast effect. These distances were not large enough to counter the effects of a mass explosion.

To identify the possible causes of the accident, the authorities looked for material elements and clues within a radius of 20 m around the crater to bear out or refute the passage from deflagration to detonation. The focus was especially on:

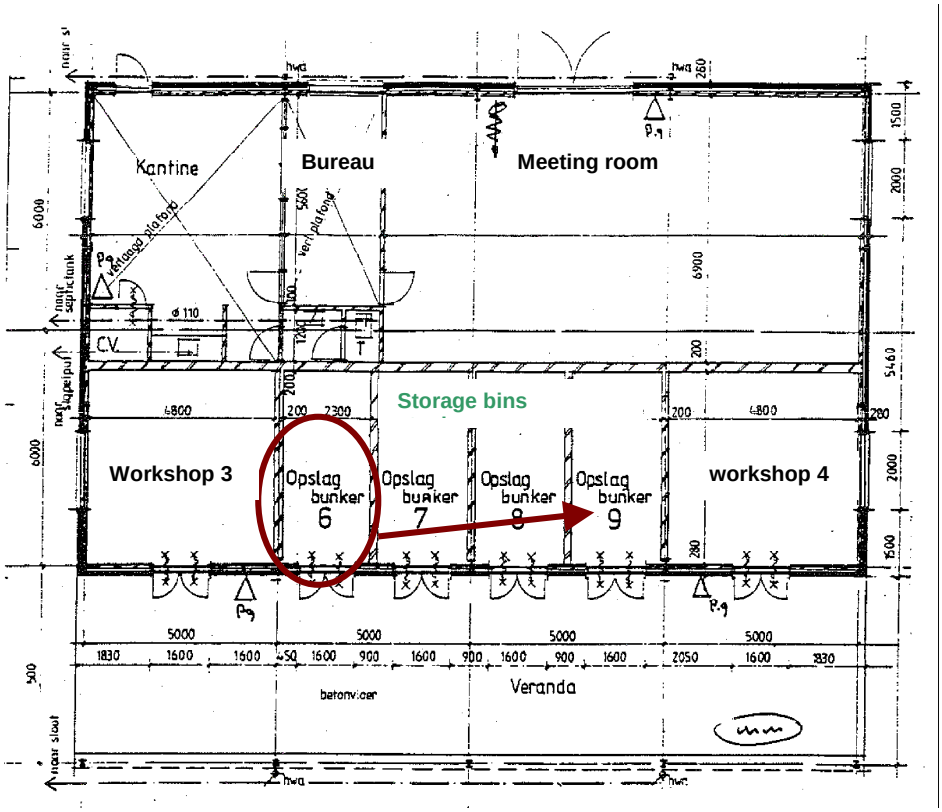
- parts of fireworks or whole structures that were not in the 1.3 risk category
- other elements besides fireworks present in theory and likely to have caused a mass explosion: fine grained black powder, special pyrotechnical formulations or even high explosives, etc.
- packaging in material other than cartons, fibreboard or wood
- fragments of the wooden doors of warehouses

Several types of fireworks had been recovered:

- **5 to 8 cm diameter cardboard shells**. Around hundred were recovered in their original state. A chemical analysis of the pyrotechnical composition revealed the presence of an aluminium / perchlorate mixture capable of mass explosion (point checked by fire tests conducted by the TNO[1]).
- **25 cm high "Knätter volcanoes" with a floor diameter of 8 cm.** None of the volcanoes were found in their original state. These fireworks articles were correctly classified in the 1.3 risk category.
- **Silver** "**gerbs**" **"Le Maître GB".** Only fragments of pertinax ranging from a few cm^2 to hundreds of cm^2 were found. These fragments helped reach the conclusion that the "gerbs" were 8 cm in diameter, 40 cm long and 0.6 cm thick. The explosive charge close to 3 kg comprised a mixture of black powder and titanium. Fire tests carried out on 14 May 1991 (UN test, 6C series) did not reveal any mass explosion.
- **Bombs manufactured in JAPAN.** Cardboard shells with an 18 cm diameter were found in their original state but broken into two parts due to impact on the ground. Their explosive matter comprised only black powder, sawdust and seeds. These fireworks articles did not deviate from the 1.3 risk category.
- **Roman candles manufactured in RUSSIA**. 5% were found intact and with their electric squibs. The rest had exploded (exploded carton cases, wooden boxes containing fireworks article fragments were found). Their behaviour was thus different from what was expected according to their 1.3 risk category classification.

The analysis of craters and fissures in the concrete slabs revealed that the explosion probably occurred in the warehouse of room 6 and was immediately followed by another explosion in rooms 7, 8 and 9.

[1] TNO : Dutch national research organisation. It is also the laboratory accredited to classify explosives in the Netherlands.



Plan of the «new building » levelled by the explosion. It most likely started in bin 6 and spread on to the other bins.

ACTIONS TAKEN

The investigation and the various material findings support the theory of two consecutive explosions in a very short time span. There was no deflagration before detonation as no large pieces of wooden crate were found.

The “cleaning of storage units” was probably underway at the time of the accident. There was no fire before the explosions. The origin of the accident is still unknown (It could have been a cigarette, static electricity, product instability, even product lying on the ground that reacted during cleaning, etc.).

LESSONS LEARNT

The explosion caused damage similar to the one caused by an explosion of 1,800 kg of TNT. The first explosion occurred in either of the warehouses of the new building triggering a second explosion in the three adjoining warehouses.

The products (classified under the 1.3 transport risk category) reacted in mass as if they belonged to the 1.1 risk category. Such a reaction can be expected when the products are stored with explosives belonging to the 1.1 risk category, even in limited quantities and when the storage conditions differ from the transport conditions (confinement?). It is also possible that the fireworks together may have had reactions different from the standard ones of each fireworks article taken separately.

All these conditions were met in all likelihood on the day of the accident. In fact, even though the owner confirmed the presence of 200 kg of black powder, this was not found in the old bunker where it was theoretically supposed to be stored. The black powder was only to be found in the recovered products. The tests performed by the TNO on the fireworks showed an increasing mass behaviour of certain fireworks articles (wrong labelling? Assembled fireworks?).

To recollect, such an explosion was not planned for fireworks articles under the 1.3 risk category. The safety distances between the buildings and the outside was moreover calculated taking into account a significant thermal risk and not a blast effect. These distances were not large enough to counter the effects of a mass explosion.

Further to this accident, the Dutch authorities issued the following recommendation: “Fireworks must be classified not only on the basis of their transport conditions but also manufacturing, assembly and storage conditions. The results of the classification on the basis of transport conditions may not be applied to other conditions, as is currently the case.”

Even though the transport risk classification need not be completely discarded, it is advisable to bear in mind that the risk categories may result from a default classification whose effects are only known in the case of a standard tests (stack of crates valid for transport under standard open air conditions). This is why storage risk analysis must be performed since the transport risk classification is only one aspect of the study.

This recommendation is still valid and ever more so in light of the Enschede and Kolding accidents in 2000 (ARIA 17730) and 2004 (ARIA 28480) respectively that unfortunately failed to draw lessons from the Culemborg explosion.

REFERENCES (INCLUDING CREDIT LINES)

- Presentation at the NATO sub-group meeting, AC/258 from 22 to 14 May 1991 in BRUSSELS by Ir. W.P.M. Mercx and Ing. H.H. Kadde.
- Full report (NL): W.P.M. Mercx et al. "Verslag van net Prins Maurits Laboratorium betreffende de explosie van de vuurwerkfavriek "MS Vuurwerk" te Culemborg op donderdag 14 februari 1991". PML 1991 - C35. TNO prins Maurits Laboratory, May 1991, Rijswijk, The Netherlands.
- Detailed sheet of the Enschede accident (ARIA 17730), French Ministry of Sustainable Development, BARPI. Available on the site www.aria.developpement-durable.gouv.fr
- Detailed sheet of the Kolding accident (ARIA 28480), French Ministry of Sustainable Development, BARPI. Available on the site www.aria.developpement-durable.gouv.fr