Explosion of a fireworks warehouse

May 13, 2000

Enschede

The Netherlands

Pyrotechnics / Explosives
Recreational fireworks
Domino effect
Urban setting
Explosion
Organisation
Evaluation of risks (workplace / transport)
Safety distances

THE FACILITIES INVOLVED

The site:

The city of Enschede is located in the eastern part of the Netherlands, at a distance of roughly twenty kilometres from the German border, with a population of about 150,000.

The company operates a fireworks warehouse in the residential district of Roombeck, near the city centre, which is home to an estimated 2,500 residents.

Aerial photograph of the site. On the day of the accident, two containers 20 feet longer were found onsite (Topographical Unit [2])

The installation was created in 1976 within a less densely urbanised zone, with one cell (C2) serving as a workshop and another 13 storage cells (shown as C3 through C15 on the diagram on page 2). As of the end of the 1970's, the operator had set up MAVO boxes (lightweight concrete construction, along the lines of a prefabricated garage). Around 1990, the type of activities were evolving towards fireworks for professionals, a move that had triggered a "regulatory regularisation", which only got initiated in 1996 and then authorised in 1997 (with the 10 bunkers, numbered C3 through C11 + C13 capable of accommodating 7 tonnes each, and the 3 "small" bunkers[1] C12, C14 and C15 containing 5 tonnes each, 7 MAVO boxes each of a 2-tonne capacity, and 3 containers also holding 2 tonnes each). The maximum quantity of explosives at the facility therefore amounted to 105 tonnes.

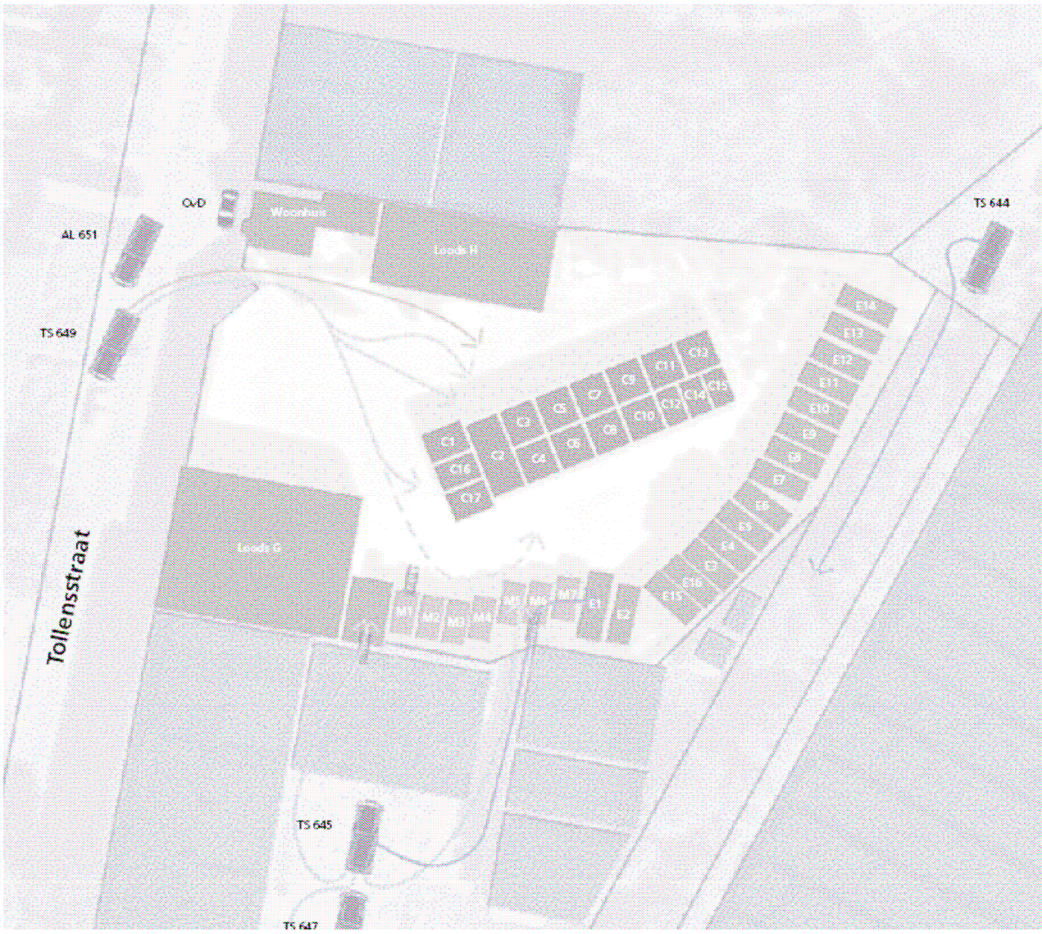
The operating company purchased the warehouse in 1998 and undertook its extension, with the addition of 11 containers (authorisation was granted in 1999); 2 non-authorised containers were subsequently introduced, bringing the total number of containers onsite to 16. Moreover, the quantity capable of being stored in the boxes and containers expands to 3.5 tonnes for each storage element. The maximum quantity of stored explosives thereby increased to reach nearly 159 tonnes. This authorisation was awarded for explosives classified in Division 1.4 and in accordance with various construction-related clauses. Given these theoretical quantities, the warehouse fell outside the scope of the Seveso 1 directive[2].

[1] Dimensions (l x L x h) of a "small bunker": 4 x 2.4 x 3 m. Dimensions of a regular bunker: 4 x 3.8 x 3 m.
[2] The hypothesis adopted in the Netherlands for fireworks is: net mass = 30% of gross mass, i.e. a net mass of 48 tonnes (for 159 tonnes in storage), which lies below the previous Seveso lower tier (i.e. "category 4" explosives / 50 tonnes).

At the time of events surrounding the accident, the company was storing and repackaging explosive products, for the most part recreational fireworks imported from China. This 3,600-m^2 site comprised:

- A "central island" composed of 17 "bunkers", numbered C1 through C17 on the diagram. The walls were made of reinforced concrete and the floor consisted of a concrete slab. The 4^{th} side of each bunker contained a wooden access door that opened from the middle (see photograph below).
  - Cell C1 contained fireworks used for indoor "special effects", although such use had not been stipulated in the authorisation.
  - Cell C2 was a workshop space, devoted in particular to "repairing" fireworks[3]. The electrical installation was apparently not compliant ("reconfigured" by the operator and, in particular, featured a bypass branch to allow feeding an electrical radio [2]).
  - Cell C16 covered both the locker area and lavatories.
  - C17 housed an old gas boiler used to heat cells C1, C2, C16 and C17.
  - Cells C3 through C15 constituted storage zones; this cluster of cells was sprinkled, albeit with manual activation (i.e. no integrated detector [2]). Extinguishers were placed at access doors to cells C4, C8, C12, C3, C7 and C11.
- 16 steel containers (type ISO 20 feet large), of which (E15 and E16) had been installed since 1999 without previous authorisation. No fire-fighting capabilities were available for these cells (detection, extinguisher, etc.).
- 7 structures built of lightweight concrete (50-mm thick walls, a 70-mm roof), of a type resembling a prefabricated garage (MAVO boxes, indicated by an "M" on the diagram). The boxes were laid out side-by-side, without a separating fire wall in between[4].
- 2 hangars (H and G) and a residence. A wood trailer parked next to Building H was used for discarding unusable fireworks and the "sweeping residue" from workshop C2 [2].

The diagram below allows locating these various structures (some of which never received nor complied with their corresponding building permit). A brewery is located just behind the row of containers E1 through E16.



M = MAVO box, E = container, C = "bunker" cell, Loods = hangar, Woonhuis = residence [1]

[3] Installations of new blasting fuses on fireworks that had not fired during previous shows.

[4] This point does not, in and of itself, represent an anomaly; yet it does influence the kinetics of the hazardous phenomenon to consider in both the work safety report and the safety/hazards study.

The central storage zone, as seen from the north-west (photo taken by the site operator [2])

The involved unit:

The warehouse, which had originally been built to accommodate 18 tonnes of fireworks for individuals, was at the time of these events storing nearly 180 tonnes of fireworks for professional use (with fewer than 150 tonnes actually authorised, as containers E15 and E16 had been added to the operations since 1999 without any authorisation).

At the time of the accident, the quantities in storage (broken down by their transport risk class D.R.[5]) were as follows:

	D.R. 1.1	D.R. 1.2	D.R. 1.3	D.R. 1.4
Quantity authorised (in tonnes)	0	0	2	136
Actual onsite quantity (in tonnes, estimated during enquiry [2])	1.6	5.3	153.7	16.3

Details on the fireworks contained in the warehouses are provided in the Appendix.

On the day of the accident, which was a Saturday, the company was not open for business. In theory, the presence of fireworks in workshop C2 is only authorised during business hours. However, this workshop contained, in addition to 2 wooden workbench, an electrical radio, a cabinet and approx. 900 kg of fireworks, including 2.5" to 5" bombs, fireworks batteries, Roman candles, fountains, fuses and other items. Some articles were lying in open cartons.

According to the previous layout, the distances between containers or between MAVO boxes were less than 1 m; moreover, the distances between C storage cells and the closest E containers were on the order of 15 m.

All storage openings exited towards the "free" space; however, the doors to cells C4 through C15 were actually positioned opposite the doors to containers E1 through E8, E15, E16 and M7.

Doors of a C-cell (central storage) (photo exploitant [2])

[5] After reclassifying some of the fireworks during the investigation into a D.R. category more "consistent" with their effects, in accordance with the U.N.'s default classification relative to transport [2].

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The accidental sequence was triggered on May 13, 2000 just before 3 pm, when a fire broke out in the C2 workshop.

Fire-fighters were called by neighbours at 3:03 pm to respond to a standard type of fire emergency. At 3:08, the fire brigade arrived on the scene, noted the pyrotechnic materials contained in the warehouse facility and requested back-up. No one was present at the site [1].

The emergency response strategy was established: several ignition sources were identified on the site, as the fire had already spread to the facade of Building H, the roofs of building G and to a few of the MAVO boxes and the plants and landscaping around the facility (at a distance of 60 m from C2). Response difficulties were caused by the geographic layout of these installations.

Rescue crews took up positions as shown on the diagram on page 2.

The fire quickly engulfed cell C4 via a hole drilled to run water pipes between cells C2 and C4. The blaze then spread to containers via the launchers; containers E2 and E15 were observed to have caught fire at 3:28 pm. Container E2 exploded at 3:34, and in so doing projected many of the warehoused fireworks.

Approximately 40 seconds after the explosion of container E2, the row of MAVO boxes began exploding in sequence. The first such explosion (MAVO M7) was particularly powerful. The explosion of MAVO boxes created a pressure wave whose TNT equivalent was estimated at 800 kg, in addition to a fireball 85 m in diameter [1-2].

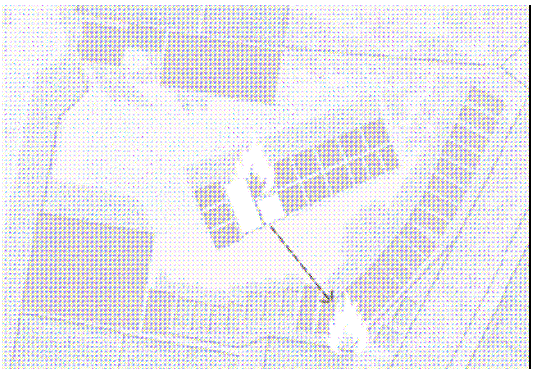
The explosions and their associated successive shockwaves destroyed the doors on a number of storage elements; the central bunker, once reached, exploded violently, generating a fireball 135 m across along with an enormous plume of smoke ([1-2], [9-10]). The remaining containers in turn also exploded, with the blast heard over a 15-km radius [3].

This last blast sounded like a massive explosion, centred at cell C11, assigned to store "powerful" fireworks (most likely classified under D.R 1.1). Experts[6] evaluated its force at between 4 and 5 tonnes of TNT equivalent [1].

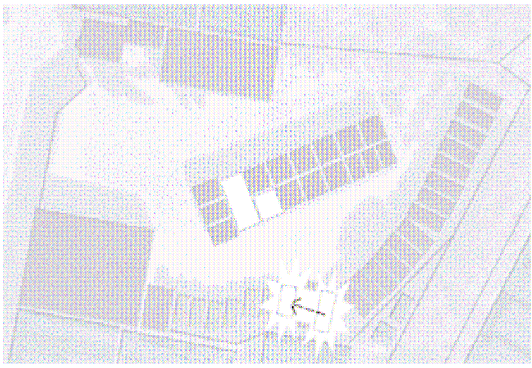
The fire-fighters had exhausted their resources to continue battling these blazes, as the series of explosions had destroyed the entire vicinity, especially the emergency vehicles. The various fires ignited by fireworks within the zone would not be extinguished until the end of the day, thanks in particular to the support received from German fire-fighters who crossed the nearby border.

The company, most buildings in the accident zone and a number of residential structures in the vicinity were either destroyed or severely damaged.

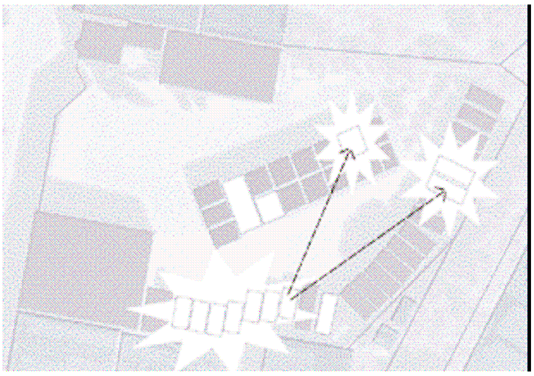
As the fire was spreading, many "curious onlookers" were able to approach the scene, since the safety perimeter set up by police and emergency services ran too close to the explosive zone (see video accounts in [9-10]). The explosions created panic and left many of the local witnesses injured.



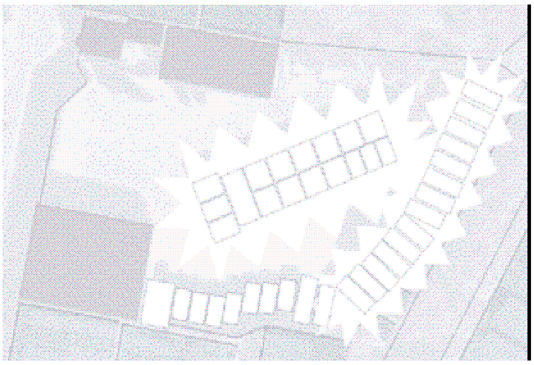
Fire broke out in cells C2 and C4, before spreading via the fireworks into a triangle-shaped blaze (complicating access for fire-fighters) formed by containers E2 and E15.



Container E2 caught fire and then exploded, in turn causing the first MAVO box, i.e. M7, to explode.



The explosion of M7 engendered the explosion sequence of all MAVO boxes and propagation of the fire to cell C11 and containers E8 through E11.



The central unit exploded simultaneously with all of the remaining containers [2].

[6] Expert appraisal conducted by the Dutch organisation TNO/PML, followed by a second evaluation by three different specialised organisations: HSE (U.K.), BAM (Germany), and ATF (U.S.) [2].

Consequences of this accident:

The outcome of this accident was disastrous: 22 deaths would ultimately be counted, with 4 fire-fighters among the casualties, along with 3 disappearances. A total of 974 individuals sustained some kind of injuries, including 50 in serious condition (i.e. requiring at least 5 days of hospitalisation).

The houses and other structures were razed within a 250-m radius around the site. Over the zone extending out to 750 m, buildings were heavily damaged. In all, 500 homes or businesses were destroyed or sustained considerable damage; the accident had rendered this zone unsafe for any human residence or activity.

The municipality of Enschede decided to evacuate and demolish whatever was still standing. For the time being, the district was considered to no longer exist.

Property damage was assessed at 1 billion florins, i.e. €500 million.

A 13-m diameter, 1.3-m deep crater could be observed at the location where concrete ground cells C9 and C11 to C15 once stood, thus confirming the massive explosion effect of the final blast, whose TNT equivalent was evaluated at between 4 and 5 tonnes[7] [1].

Crater above the C11 [2]

Remnants of fireworks found in workshop C2 [2]

Residue of containers [2]

[7] The TNO estimation, based on observed damage conditions, for a "comparison with known orders of magnitude". It should nonetheless be pointed out that the mechanisms involved and the subsequent effects are not identical.

Sanitary and environmental monitoring following the accident

Two to three weeks after the catastrophe, an epidemiological monitoring campaign of the post-accident sanitary consequences was launched in order to assess the potential exposure to harmful substances, in addition to recording physical or psychological trauma among victims and relief workers [5].

Regarding the evaluation of potential exposure to substances, 936 blood and urine samples were taken at random among the 2,905 victims included in the study conducted between May 31 and June 4, 2000 and analysed (to determine traces of Ba, Cd, Cr, Cu, Ni, Pb, Sb, Sr, Ti and Zn). No increase in the quantities of these heavy metals was reported among the study population, with respect to the "normal" levels exhibited by the general population.

A questionnaire served to assess the psychological consequences; the data were collected between May 30 and June 7, 2000. Initial results were announced 8 weeks after the accident. Two other reports followed, at intervals of 18 months and 4 years, respectively, following the accident.

The investigation revealed that that the disaster heavily influenced victims' state of health. Two to three weeks after the explosion, at least half of the victims reported experiencing emotional and psychosomatic disorders, such as insomnia, anxiety, difficulty coping with day-to-day life and lack of self-confidence. A number of parameters, including the age, gender, state of health prior to the accident, level of education and ethnic origin of the surveyed population, were taken into consideration in the investigation. Victims who had lost their homes, a loved one or who had sustained injuries turned out to be two to three times more affected by these emotional problems than "less serious" victims.

Eighteen months after the catastrophe, the questionnaire was again distributed; 2,851 responses, or 75% of the initial sample, were received. The emotional problems had attenuated over the intervening period for all victims, yet this sample group still displayed greater difficulties than a control group adopted as a reference. The study indicated that a large number of victims were still in need of care and psychological treatment a full 18 months after the accident. Some victims were continuing to suffer from chronic health problems 4 years later.

The RIVM Institute's Environmental Unit[8] conducted a sampling campaign in the area surrounding the site on the day of the accident and for several days afterwards in order to determine potential human exposure. Measurements performed in the smoke plume near the fire revealed high concentrations of particulate matter, carbon monoxide and heavy metals, especially lead, copper and zinc. The second series of measurements undertaken during the days following the accident indicated a slight increase in concentrations of particulates, heavy metals, volatile organic compounds and dioxins. The airborne concentration of asbestos did not exceed the "maximum risk threshold"[9]. The study concluded that direct deleterious health effects from the accident were not very likely, beyond short-term respiratory discomfort. The measurements of particulate matter outside the accident zone fell and did not reveal any additional environmental load compared with background concentrations in the soil [6].

[8] RIVM: Rijksinstituut voor Volksgezondheld en Milieu: National Institute for Public Health and the Environment.
[9] "Maximum risk threshold": Calculation method employed by the Dutch authorities for individual exposure. Potential human exposure is modelled, based on measurement recordings and exposure profiles, and then compared to a reference scenario.

European scale of industrial accidents

By applying the rating rules of the 18 parameters on the scale officially adopted in February 1994 by the Committee of Competent Authorities of the Member States, which oversees application of the 'SEVESO' directive, this accident can be characterised by the following 4 indices.

The parameters comprising these indices and the corresponding rating method are available at the following address: http://www.aria.ecologie.gouv.fr.

Two parameters are involved in determining the rating level of the "hazardous materials released" index: Q1 and Q2.

In adopting the Dutch hypothesis of a net mass of fireworks equal to 30% of the gross mass, the quantities of fireworks having contributed to an explosive reaction (according to the table on page 3) are respectively 5 tonnes of class 1.4 and 48 tonnes of class 1.1, 1.2 or 1.3.

- The 5 tonnes of class 1.4 explosives represent 2.5% of the corresponding Seveso threshold (200 tonnes – explosive substances classified in Division 1.4, as per the European Agreement concerning the International Carriage of Dangerous Goods (ADR) (United Nations)), which equals level 3 of the "quantities of hazardous substances" rating per parameter Q1 (with Q1 valued at between 1% and 10%).
- The 48 tonnes of 1.1, 1.2 or 1.3 class explosives represent 96% of the corresponding Seveso threshold (50 tonnes – explosive substances classified in a Division other than 1.4, as per the European Agreement concerning the International Carriage of Dangerous Goods (ADR) (United Nations)), which equals level 4 of the "quantities of hazardous substances" rating per parameter Q1 (with Q1 between 1 and 10 times the threshold).
- The explosion was estimated at a force of 5 tonnes of TNT equivalent, hence parameter Q2 is rated at a 4 level.

The overall "hazardous materials released" rating is thus equal to 4.

Four parameters are involved in determining the level of the "Human and social consequences" rating: H3, H4, H5 and H6.
- Parameter H3 reached level 5: 22 deaths, including 4 rescue team members (H3: between 20 and 49 deaths).
- Parameter H4 reached level 5: 50 people were seriously injured (H4: between 50 and 199 seriously injured).
- Parameter H5 reached level 5: 974 people injured (H5: between 200 and 999 injured).
- Parameter H5 reached level 5 due to the number of people who lost their homes or were unable to work (about 400 families concerned).

As a result, the overall "Human and social consequences" index rating is 5.

Parameters €15 and €16 of the "economic consequences" index are rated 6: The amount of property damage was estimated at €500 million (€15 and €16: ≥ €200 M).

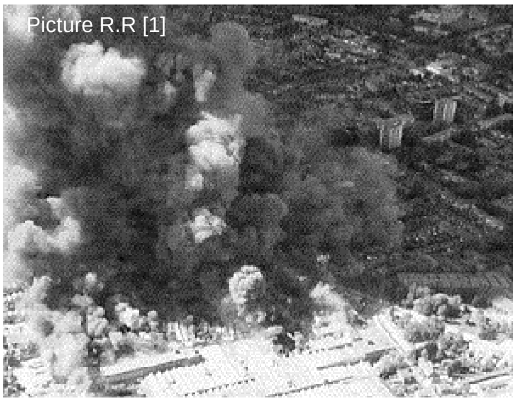

Picture R.R [3]

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The initial cause of the fire outbreak in workshop C2 remains a mystery. The investigation proved difficult to complete due in particular to the complete destruction of the premises. Several hypotheses have been proposed: arson (a pyromaniac had been setting fires in the area during the few weeks prior [3]), human error while handling fireworks (although no one was reported at the site at the time), a short circuit (nonconforming installation, radio, etc.) or self-combustion (following manipulations performed the day before?) [11].

Nonetheless, many aggravating factors are to be highlighted, namely:

- According to some aerial photographs taken a few days prior to the accident, it appears that the container doors were sometimes left open. Had this been the case on the day of the accident, then the initial fire would have easily spread and domino effects would have been enhanced [3].
- The workshop C2 had contained 900 kg of fireworks, even though no operation was underway.
- The quantities and types of fireworks stored did not correspond to what was authorised (see above section: "The involved unit"). Instead of 140 tonnes of fireworks being primarily classified as D.R. 1.4, 154 tonnes of D.R 1.3 and nearly 6 tonnes of fireworks assigned a D.R. 1.1 or 1.2 classification were stored together[10] (most likely therefore without applying storage rules relative to risk and accounting for group distinctions).
- The layout of containers and MAVO boxes on the site: no separation distance between containers, the unauthorised presence of 2 additional containers, a spatial layout that limited access to emergency services, etc. Moreover, the triangle formed by containers E2 and E15 constituted a restricted access zone that was also cluttered by the presence of various equipment (trailer, concrete mixer, etc.).
- The structures and boxes did not carry adequate guarantees relative to fire and explosion risks. Even the building permit's construction clauses, despite their lack of stringency (e.g. allowing for a distance between containers of at least 1 m), were still not respected. The MAVO boxes and containers had not undergone any kind of testing and were either not or only barely equipped with appropriate detection and fire extinction devices. It was also observed that the alarm system was inoperable or nonexistent. The automatic extinction network in the bunker had been poorly designed and was no doubt inoperable as well.



ACTIONS TAKEN

Just a short while after the accident and without waiting for the assigned investigation commission's conclusions to be announced (see below), the Dutch authorities undertook a series of measures of a general nature:

- Creation of a new regulatory framework for fireworks (June 2000); this step initially involved seeking the authority from several ministries yet has subsequently relied upon the Environment Ministry. Moreover, the authorisations to operate pyrotechnic installations are granted at the provincial level and not by municipalities.
- Strategies for establishing new regulations for high-risk situations, since one the motivations behind this project was the lack of information held by competent authorities in the area of regional planning / zoning. Informing the public on this type of high-risk situation would also be the focus of future development efforts.
- Generation of a national catalogue of fireworks storage facilities: 270 warehouses were inventoried, 50 of which were to undergo detailed inspection within the next few months by the Environment Ministry.
- From a technical perspective, several practical measures were implemented:
    - A single safety distance of 800 m was applied to all installations responsible for storing professional fireworks. This measure led to closing or moving over 50% of all such installations;
    - A single safety distance of 30 m was selected for installations storing fireworks intended for individual users, including for points of sale. Many of these outlets were required to close their operations or at least no longer sell fireworks.

[10] In using ADR's default classification to estimate these quantities (this explains why some fireworks were categorised by default in Class 1.2, which is not the case for example in France [14]).

The Oosting commission:

At the request of the public authorities, a Board of Inquiry was set up, called the Oosting Commission, for the purpose of conducting a large-scale investigation on the circumstances and responsibilities involved in this accident. The inquiry concentrated on the manner in which the various operators worked, although it also analysed the operating mechanisms of the various authorities, on both national and local levels, implicated in drafting texts or controlling fireworks. In this manner, it was sought to establish responsibility within the various organisations. The report, dated February 28, 2001, was quite extensive (2,000 pages). A few of the conclusions will be presented below:

Responsibility of the successive operators:

The successive operators, i.e. warehouse managers, were the focus of the following observations:

- They committed a number of serious offences in terms of: pyrotechnic materials management, equipment from various structures, and the use and location of inadequate structures.
- Over several years time, certain parts of the warehouse were unauthorised. In addition, the operators failed, within the scope of their obligations, by not sufficiently considering regulatory requirements in their filings, which were not presented on time to authorities.
- No risk assessment, rendered mandatory by labour legislation, was undertaken.
- They could not ignore the fact that the classifications of products imported from China were generally underestimated. During previous inspections by official organisations, this fact had already been established.

A passive attitude on the part of operators was discovered: no recourse to an external specialist, an interprofessional organisation or a local union was attempted. They limited their interaction solely to the public authorities, which is insufficient considering their level of responsibility. The commission indicated that this attitude led to a transfer of responsibility to the public authorities, which was not an acceptable course of action. In addition, it was indicated that a highly-limited inspection on the part of the administration in no way justifies the disregard for regulatory texts.

Responsibility of national public authorities:

The national public authorities were also the subject of the commission's observations, particularly in terms of organisation. It is clear that, in so doing, the commission was looking for ways to improve the system and not to blame the authorities, be they local or national. The various elements mentioned could have contributed, to widely varying extents, to preventing this accident from happening:

- No lessons were learned from the Culemborg accident of 1991. At that time, the problem of classification accuracy relative to production indications, was raised. The problem of proper fireworks classification had already been raised at the time, yet no progress was made on the topic (i.e. no fireworks re-classification obligation on the basis of national tests after importation). Moreover, it would seem that only the ADR default classification was being used in the Netherlands.
- The organisation of departments and the distribution of tasks among departments resulted in a complicated system: the RVI (the National Transport Inspectorate), the DMKL (Environmental Investigation Bureau, "Substances Office of the Royal Armed Forces, Department of Defence") and the VROM (Dutch Ministry of Housing, Spatial Planning and the Environment) are all involved in the area of fireworks with, for each, a different role or activity. In addition, following reorganisation, the traditionally competent branches have over the past 10 years been eliminated (KCGS – hazardous materials inspection agency) or withdrawn (Environmental Hygiene Inspectorate) or been denied sufficient manpower (drastic reductions in some departments since the 1990's).
- Regulations are complex and not very accessible due to partitioning of the various departments concerned.

- A lack of communication between the various departments is witnessed: this was particularly true within the framework of handling the aftermath of the Culemborg accident. The information held was not disseminated between the departments and withheld to nearly the same extent to municipalities, particularly Enschede.
- The process relative to regulations governing professional fireworks was handled slowly: for example, the sector was extensively consulted due to the possibility of engaging in certification for the profession. After several years of discussion, the process was finally abandoned. While the commission approved this decision, it still considered it as late. The VROM was in charge of this process; a lack of harmonisation was also detected on the subject of regulatory review between the various ministries (VROM and the Transport Division).
- A certain amount of ambiguity apparently exists in the role of DMKL, which acts as technical consultant for the authorities and operators.
- The inspections carried out by federal agencies appear to be theoretical. Recent inspections conducted by the police were essentially based on the end-users of fireworks.

Responsibility of local public authorities:

As far as local public authorities are concerned, remarks remained essentially in the following domain:

- No distinction was noted between the roles of consultant, appearing within the scope of application processing, and surveillance, introduced during inspection operations: the same official handles both aspects within the municipality. It should be recalled that, within the Dutch public-sector organisation, it is the municipality that controls the field level through its technical services, which are also responsible for granting operating permits.
- According to the commission, a "lack of perseverance" on the part of inspectors in enforcing environmental law led to the pure and simple discontinuation of applying regulatory texts: few inspections; inspectors not issuing fines even after having been informed of disregard for regulations; no reports sent to the authority (Mayor), and even informal relationships between inspectors and their technical support, i.e. DMKL. The municipality counted on the latter to offer opinions, yet the organisation did not provide a clear position on the subject. The relocation of the establishment was brought up.
- A lack of co-ordination between the city's Environmental Office, Building Permit Office and fire brigade led to a variety of malfunctions, one of them being the disregard for cities' own zoning plan, as well as for regulating the location distances for industrial activities. Another is the lack of consultation with fire brigades during attribution of permits granted by the "Environmental" Office. The commission recognised however that fire brigades are equipped with very limited resources.

Aerial view of the site following the accident [3]

Criminal charges were also brought. In April 2002, the two company heads were sentenced to 15 months in jail for both environmental and safety regulation violations and the illegal sale of fireworks. They were found guilty of explosion with fatal consequences due to negligence [7].

In May 2003, the Arnhem appellate court acquitted, due to a lack of proof, a presumed 36 year-old arsonist sentenced in first instance to 15 years in prison for arson [7].

Furthermore, the 3,519 victims of the accident, after filing a suit for damages, shared a compensation package worth € 8.5 million [7].

LESSONS LEARNT

Conception of the installation and safety distances:

As discussed above, the location and position of "buildings" relative both to one another and to other structures would explain the seriousness of this particular accident. Inadequate separation distances (that moreover were not respected) caused rapid propagation of the fire, followed by explosions and emergency response constraints.

With respect to French regulations, such a storage set-up with workstations and loading/unloading activities practically juxtaposed would be prohibited, except for the added safety measures introduced to separate them (significant reduction in quantities stored on a site of this size, isolation distances between the workstations, protective elements, etc.).

Given the limited information available on the content of an eventual initial safety report, several points merit question; such an exercise would in France be mandated for analysis by the regulation in effect since 1980 according to a probabilistic approach towards phenomena, as part of both the work / safety report and the safety study on any pyrotechnic site. Along these lines, the following points would need to be raised:

- the overall configuration of installations, which undoubtedly helped the fire spread and disturbed intervention efforts (location of buildings and containers with respect to one another and to the outside, fire propagation kinetics, potential cumulative or domino effects, etc.),
- storage space configuration (locations and risks depending on the products stored, effects and decoupling, best storage practices, etc.),
- risk analysis specific to the various pyrotechnic operations,
- safety study (with respect to the risk of intrusion),
- fire protection efficiency (sprinkling apparently proving to be ineffective on fireworks warehouse space, etc.),
- emergency plan (including information conveyed to emergency services on installation-related risks).

The appropriate definition of elementary pyrotechnic facilities (a_0[11]) and compliance with safety distances between the various pyrotechnic installations are two fundamental conditions in the area of pyrotechnic safety.

Classification into risk category and storage risk

Besides the improper product storage practices with respect to their authorisation, a combustion-to-explosion transition phenomenon was observed in Enschede for products that in theory should have been labelled D.R. 1.3 at most. Some products should have been reclassified into 1.1 given their characteristics and then treated as such when organising the installation (application of shared storage rules). This practice had not been requested in the Netherlands.

In France, all imported fireworks must undergo a reclassification based on tests, as validated by the body designated within the scope of ADR (INERIS); the INERIS organisation has established, in conjunction with IPE (see June 28, 2007 memorandum), a default classification table from the many tests conducted for the purpose of awarding transport certificates without test results [14].

Moreover, assignment to a workplace risk category for a given product does not constitute an intrinsic characteristic and might depend on its conditioning (particularly the packaging mode employed), manufacturing set-up, implementation and elimination. The simple classification into risk categories is not sufficient to ensure an effective analysis of risks generated by pyrotechnic products. The transport classification may differ from the workplace classification; it is thus essential that accident scenarios and their potential effects be studied relative to the actual site configuration.

Feedback management and control over urbanisation

Nine years after the Culemborg accident in the same country, no lessons had been drawn, especially by the public authorities; the Enschede town hall had received no information even though the risk classification issue had already been raised [12]. The question over managing feedback within a country or for that matter between countries (see Kolding accident in 2004 [13]) had still not been adequately answered.

In conclusion, this accident illustrates the problem associated with controlling urbanisation around pyrotechnic sites. In France, this issue is aimed in particular at small warehouses, as larger facilities that require authorisation are typically located quite far from residences, as mandated in a number of regulations since the 1970's[12].

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[11] a_o: "elementary pyrotechnic facility, more specifically each work location set up outdoors or in a room that is insulated and included inside a workshop, warehouse or storage depot, in addition to containing a charge of explosive products. This basic installation, with its access roads and outbuildings (which require placement in the immediate vicinity), is designated a0." (joint Ministerial decree adopted on April 20, 2007 establishing the set of rules relative to risk evaluation and accident prevention within pyrotechnic facilities). In a Work Safety Report, these two a_0 would be considered as an a_2, one with respect to the other, necessitating decoupling and/or simultaneous non-operations.

REFERENCES (INCLUDING PHOTO CREDITS)

[1] Report of the Oosting Commission: "De vuurwerkramp Einrapport", February 28, 2001, ISBN: 90-71082-67-9. The complete report and its appendices (in Dutch), along with an extract in English of the primary conclusions, are available on the site: http://www.nbdc.nl/cms/show/id=599252.

[2] Report of the Oosting Commission: Appendix A: « SE Fireworks / De overheid / De ramp », February 28, 2001, ISBN: 90-71082-68-7 (specifications in Dutch on the company's situation and in particular the accident chronology).

[3] NIMIC 0-59: Enschede, Chronicle of a Disaster. Presentation of NIMIC.

[4] Reports (in Dutch) of both the workplace inspection and transport inspection available on the site: http://www.nbdc.nl/cms/show/id=599252.

[5] Reports on the health-related consequences after the accident by RIVM and the Institute voor Psycho Trauma, the most recent of which dates from October 2004, 4-year post-accident evaluation. Gezondheid Getroffenen vier jaar na de Vuurwerkramp Enschede. Available (in Dutch) on the RIVM site: http://www.rivm.nl/bibliotheek/rapporten/630930005.html. The report written 18 months after the accident is available at the following Web address: http://www.rivm.nl/bibliotheek/rapporten/630930004.html, and the initial report can be found at: http://www.rivm.nl/bibliotheek/rapporten/630930002.html. The report on blood and urine samples is available on: http://www.rivm.nl/bibliotheek/rapporten/630830001.html.

[6] Report on the state of the environment after the accident: "Vuurwerkramp Enschede: Metingen van concentraties, verspreiding en depositie van schadelijke stoffen: rapportage van het milieuonderzoek", RIVM, April 2001. Available (in Dutch) on the RIVM site: http://www.rivm.nl/bibliotheek/rapporten/609022002.html.

[7] http://en.wikipedia.org/wiki/Enschede_fireworks_disaster

[8] http://www.independent.co.uk/news/world/europe/after-400-homes-and-15-streets-are-incinerated-by-firework-blast-the-dutch-ask-was-it-arson-716195.html.

[9] Videos of the accident: http://www.youtube.com/watch?v=S52p2AMISFk&feature=related.

[10] Videos of the accident: http://www.youtube.com/watch?v=mF3UplnCyhM&feature=related.

[11] Presentation of the accident at the IMPEL seminar by the Dutch authorities, and the IMPEL data sheet on the accident (available on the site: www.aria.developpement-durable.gouv.fr / heading: IMPEL 2001).

[12] Detailed data sheet on the Culemborg accident (ARIA 3098), Ministry of Sustainable Development, BARPI. Available on the site: www.aria.developpement-durable.gouv.fr.

[13] Detailed data sheet on the Kolding accident (ARIA 28480), Ministry of Sustainable Development, BARPI. Available on the site: www.aria.developpement-durable.gouv.fr.

[14] http://www.inerisfr/index.php?action=getContent&id_heading_object=169&module=cms - Database of fireworks certification in France (INERIS), and access to the joint INERIS / IPE memorandum, dated June 28, 2007, on the classification of recreational fireworks.

[12] Decree No. 79-846, dated September 28, 1979, specific to public administration regulations concerning the protection of workers against the special risks incurred within pyrotechnic facilities. These regulations, along with the Environmental Code and associated legal texts, serve to define a strict reference for pyrotechnic activities.

APPENDIX (DETAILS OF THE CONTENTS IN THE VARIOUS STORAGE DEPOTS [2])

Storage space	Type of firework	Quantity	Weight (kg)
Hangar G	Lettering (table on which firework components and cord are assembled to create texts (logos, portraits, etc.)	1 piece	-
Hangar H	Fireworks for individual use	3 to 5 pallets containing 25 to 30 boxes each	1,620
Semi-trailer	Empty reels	1,000 to 1,500 pieces	
Waste container	Compact		
C 1	Smoke grenades Fountains Airburst (firework capable of being used indoors / star effect) *Pot à feu* Brandpasta (pasta used for shows on a stage: burned with a crackling effect)	20 to 25 pieces 20 to 30 kg 25 boxes containing 12 tubes each 1 3-4 blikken	150
C 2	Roman candles Compact Launchers Fountains Bombs (diameter 5" - 6") Bombs (diameter 2.5", 3" and 4") IJ fountain Flashkoord: nitrated cotton cord used as a fuse in text tables (stored wet for safety / used dry) Table with fountains Lighters	6 to 8 boxes opened 8 to 10 compact components 20 to 25 boxes 20-30 boxes 13 3 boxes of 15 pieces each A few boxes 3 to 4 cords Several hundreds	900
C 3	IJ fountains Aansteekfakkels (newspaper filled with powder slowly burning on tables) Bengal lights Flashkoord	50 - 60 boxes 600 pieces 40 pots 50 small packages	1,500
C 4	Compact 2.5"	1/4 to 1/3 of total storage volume	2,840
C 5	Roman candles 1 - 2.5"	Approx. 3/4 of storage volume	7,344
C 6	Compact 2.5"	Approx. 3/4 of storage volume	7,344
C 7	Bombs 3"-5"	30 - 40 boxes, 24 pieces per box	525
C 8	Compact 2.5"	Approx. 3/4 of storage volume	7,344
C 9	Bombs 3" and 4" "Titanium Salutes" *marrons d'air* - 4"	Approx. 3/4 of storage volume	7,344
C10	Fireworks for individuals	Full storage volume	9,792
C 11	Bombs 3" - 8"	Half-full storage volume	4,896
C 12	Fireworks for individuals	Full storage volume	5,418
C 13	Bombs 8"	Half-full storage volume	4,896
C 14	Bombs 2.5" Mines 1.5" – 2.5" Fireworks for individuals	Storage volume exceeding 1/2	3,359
C 15	Bombs 8" and 10"	Half-full storage volume	2,709

M 1	Fountains Stars (sterretjes)	Half-full storage volume	3,395
M 2	Compact 1" – 1.5"	Full storage volume	6,790
M 3	Compact 1" – 1.5"	Full storage volume	6,790
M 4	Compact 1" – 1.5"	Full storage volume	6,790
M 5	Compact 1" – 1.5"	¾ full storage volume	5,092
M 6	Roman candles, 2" Waza lont (fuse for igniting professional fireworks shot at outdoor events) Cascades Compact, repaired Creates with small fireworks	Half-full storage volume	3,395
M 7	Bombs 6", 8" and 10"	1/3 full storage volume	2,447
E 1	Compact 2" – 2.5" Celebration crackers 100,000	Half-full storage volume	3,917
E 2	Bombs 5", 6", 8" and 12" Cylindrical bomb, 4"	Half-full storage volume	3,917
E 3	Compact 0.5" – 1.5"	Half-full storage volume	3,917
E 4	Compact 0.5" – 1.5"	1/2 to 3/4 full storage volume	4,935
E 5	Compact 0.5" – 1.5"	1/2 to full storage volume	5,875
E 6	Compact 0.5" – 1.5"	3/4 to full storage volume	6,815
E 7	Compact 0.5" – 1.5"	3/4 to full storage volume	6,815
E 8 *	Compact 1" – 4"	3/4 to full storage volume	6,815
E 9 *	Bombs 3" and 4"	1/2 to 3/4 full storage volume	4,935
E 10 *	Bombs 8" - 10"	1/4 to half-full storage volume	2,898
E 11 *	Compact 0.5" – 1.5"	1/2 to 3/4 full storage volume	4,935
E 12	Compact 2"	1/4 to 3/4 full storage volume	2,272
E 13	Compact 2"	1/4 to 3/4 full storage volume	2,272
E 14	Compact 2"	1/4 to 3/4 full storage volume	2,272
E 15	Compact 1.5"	3/4 full storage volume	5,875
E 16	Compact 1.5" Bombs	3/4 full storage volume	5,875
TOTAL			**177,020**

** The witnesses questioned had a had time recalling with precision the contents of containers E8 through E11. These containers are thus to be considered as a whole set.*

Moreover, the risk classification for some of these fireworks, nearly all of which were "tagged" 1.4, should have been classified D.R 1.1, 1.2 or 1.3 according to the default TMD classification, especially the Bombs, i.e. ≥ 12" (D.R. 1.1), the Roman candles, ≥ 2" (DR1.2), and the majority of professional fireworks (D.R. 1.3) [2].