

# Explosion of a gunpowder factory

8<sup>th</sup> December, 1972

Muiden

The Netherlands

Explosives

Hunting gunpowder

Human factor / operating error

Static electricity

Management of change

Degraded mode of operation

## THE FACILITIES INVOLVED

### The site:

This gunpowder factory had been located since 1702 in the municipality of Muiden, near Amsterdam (the Netherlands). Closed after World War I, the factory was reopened in 1922, then changed operator and corporate holding in 1972.

The site occupied a land area of 65 ha, on which 71 buildings had been set up. It was limited to the north by IJssel Lake, to the east by the town of Muiden and to the west by a parcel covered with wetland grasses. Moreover, the grounds were surrounded on all sides by railings and ditches. The only access was an entrance door adjacent to the site caretaker's lodge.



The gunpowder was produced and stored in the pyrotechnics zone, which was separated from the rest of the site by railings. This zone was divided into 3 sectors, each of which overseen by factory managers: 1) production of crude gunpowder, 2) processing stages, and 3) bagging and shipment. Employees were not normally asked to work in buildings located outside their assigned sector.

The pyrotechnic substances involved in this accident were porous "R80" and "R100" powders. The raw material introduced to manufacture the gunpowder was nitrocellulose, produced in a plant run by the same operator and located 90 km away, in Ouderkerk.

The nitrocellulose was "phlegmatized" with water to an extent of 30% by weight. Its nitrogen content amounted to between 12.1% and 13.4%, with an average of 13.1%. This material was being transported from Ouderkerk in 100-litre wooden crates fitted with a zinc lining on the inside.

### Gunpowder manufacturing steps:

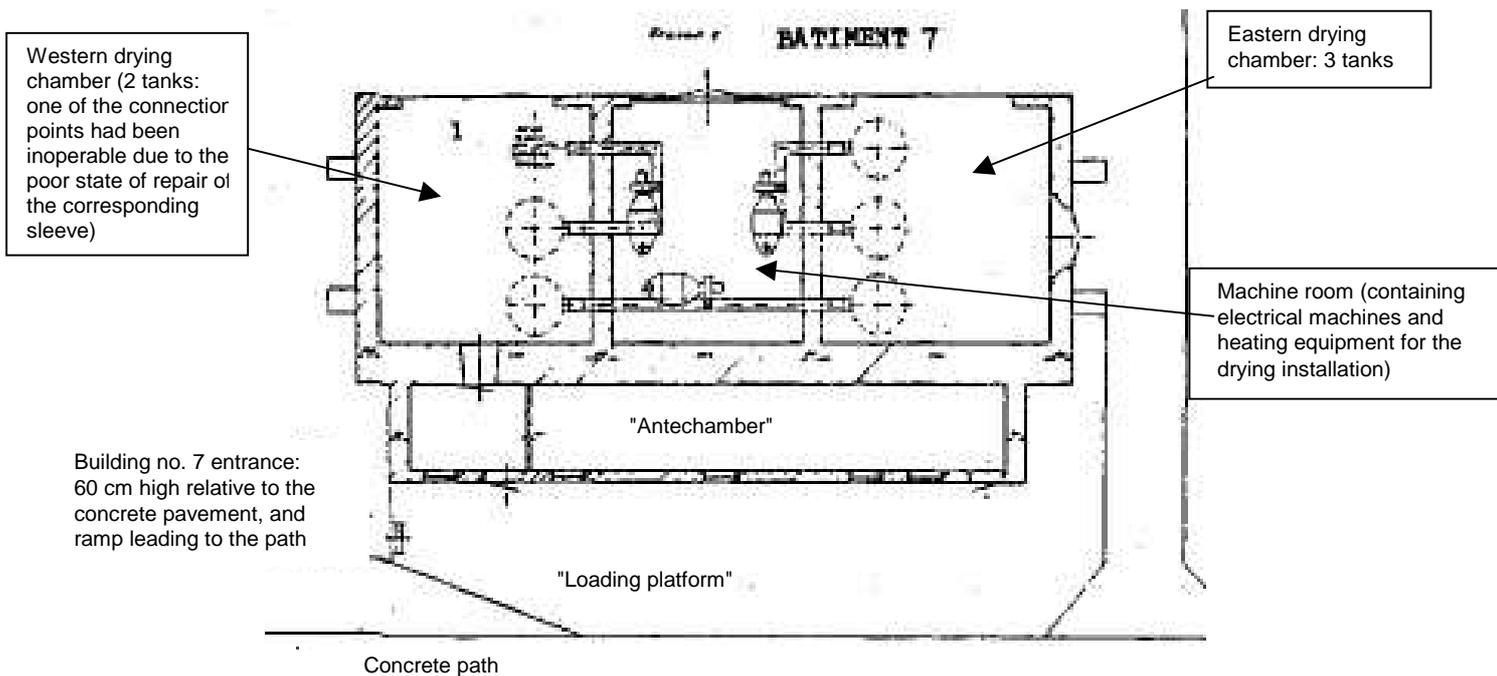
- Elimination of water in a centrifuge by means of sprinkling with ethyl alcohol (operation performed in Building no. 6).
- Transport of nitrocellulose imbibed with ethyl alcohol to Building no. 8, dedicated to the mixing and stirring section. This step was conducted using a forklift truck with wooden crates, each of which contained 7 cotton bags capable of holding 14 kg in dry weight.
- Mixing of the ethyl alcohol-impregnated nitrocellulose with ether, potassium nitrate and ethyl centralite, introduced as a stabiliser.
- Transport in aluminium boxes containing 8 kg of dry weight to Building 45, where the contents were pressed into ribbons with a (2 x 2-mm) square cross-section.
- Surface drying of the ribbons, followed by transport in flat wooden platform trucks to Buildings 9 and 7A to be cut into small 0.8-mm thick packets used for manufacturing tablets.
- Transport of these packets in aluminium tanks containing 300 kg of dry weight to Building 9-III, where they were screened and subjected in a mixer to the first surfacing stage by the addition of graphite so as to decrease their sensitivity to static electricity.
- Transport in these same tanks to Tunnel 9 for a 2-stage drying sequence (1<sup>st</sup> drying of 24 h at 25°C, 2<sup>nd</sup> drying of 24 h by means of blowing forced air at 45°C). All solvent vapours were recovered.
- "Cleaning": powder surface treatment (alternation of extraction and drying phases) in Buildings 11 and 12.
- "Cooking" for 1 or 4 days in boilers filled with water at 60°C.
- Transport of the water-imbibed powder to Building 7 in aluminium drying tanks, each with a capacity of 350 kg dry weight, using a forklift truck (2 drying tanks per forklift).
- Drying by hot-air blowing at 60°C for 8 h. Building 7 housed a total of 5 tanks.
- Transport to Buildings 11 and 12 to undergo final treatment.

### The specific unit involved:

Due to a partial reorganisation of factory operations, Building 7, located in the "crude gunpowder production" sector, was temporarily housing a portion of the drying activities, which depended on output from the "treatment" sector.

At the time of the accident, this building housed 5 tanks: 3 "dry" tanks containing hunting gunpowder of the "dirty" K 100 type, and the other 2 "wet" tanks storing "cleaned" hunting gunpowder of the same type imbibed with water. Both wet tanks had been placed online to replace 2 dry tanks, which remained nearby either on or adjacent to a forklift truck parked in front of the building entrance steps.

Built in breezeblock with a corrugated iron roof, the building was divided into 4 compartments by means of 55-cm thick walls:



An "antechamber" occupied nearly the entire building length (15 m long by 2 m wide). Separated from the remainder of the building by a 1-m thick wall, this antechamber had 2 points of access: an interior wood door from the western drying chamber, and an exterior door almost exactly opposite the first one, yet punctured into the building's southern facade.

The building's northern facade was open, with the exception of the part at the level of the machine room. A set of entrance steps circled both the western and northern sides of the building, which had been equipped with a ramp leading to the concrete path, providing access for a small transport vehicle.

The building was also equipped with a 4.10-m loading platform on its southern side, from where the tanks were loaded and unloaded using forklift trucks.



Another building (no. 7A) was close to Building 7, on the opposite side of the concrete path; built in breezeblock with a corrugated sheet metal roof, Building 7A comprised 2 workshops and 2 engine rooms. On the day of the accident, a worker was cutting 75 kg of gunpowder into ribbons inside one of the workshops.

### The drying installation and safety features:

The air in Building 7 was heated by a steam radiator, behind which a fan was blowing air at 60°C through a 0.33-m diameter duct. Between 1,700 and 2,000 m<sup>3</sup> of air were thus being injected per hour per tank.

A regulating thermostat stopped the supply of steam at temperatures exceeding 60°C; a second "high level" thermostat stopped the steam supply as well as the fan current.

The tanks were connected from underneath; blown air was escaping through an aluminium lid fitted with a very fine (i.e. 0.6-mm<sup>2</sup> mesh width) metal gauze. Drying time depended on the type of gunpowder being produced (8 h for "R100").

The cylindrical drying tanks (diameter: 1.40 m, height: 1.71 m) were made of 4-mm thick sheet aluminium. Their capacity was 1,500 litres for an unloaded weight of 150 kg, while a very fine metal gauze, cone-shaped screen with its top turned downward was placed in the lower part of each tank. The opening in the screen bottom was closed by a dense detachable rubber ball. Two aluminium rods were fastened onto the lower face of the drying tank so as to support the tank weight. These rods were designed so that the forks on the forklift could take their place exactly between two successive rods. During the drying process, the tanks were covered by a lid fitted with a very fine (0.6-mm<sup>2</sup> mesh width) metal cloth. During transport, the tanks were covered with a 20-mm thick plywood lid.

#### **Procedure used to exchange a "dry" tank for a "wet" tank**

Once the powder was dry (as validated by inspection), the technician was required to sweep the powder (dust) eventually found on the floor and then wash the floor with large quantities of water using a pipe connected to the water main. The air intake valve was then closed and the connecting sleeve as well as the ground wire (for earthing) were removed.

The lid fastening systems made of metal gauze were unscrewed, allowing to lift the lid 5 cm with the help of a rope attached on the one side to the tank lid and on the other to a lug on a grip fastened to the wall, while the rope passed on a pulley above the tank. The "dried" tank could be slightly lifted by hand in introducing a forklift, then moved and replaced by another tank filled with powder to be dried.

The drying tanks filled with gunpowder were transported between the various buildings by means of a platform truck running on solid tyres and drawn by a small tractor on tyres activated by a four-stroke, 16-horsepower diesel engine with air cooling (see opposite). The engine exhaust pipe and muffler were both turned upward, and moreover the exhaust was fitted with a fireguard. The forklifts were specially designed with features like: a smooth floor, shock-resistant edges, and dimensions for two tanks.



[1]



*Reconstitution of a tank trans-shipment operation using a small forklift truck [1]*

## THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

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### The accident:

Around 8:35 am, two explosions a few tenths of a second apart occurred inside Building 7, generating a huge smoke column. Several witnesses confirmed seeing a lightning bolt before hearing the sound of the explosions.

Fire-fighters, local gendarmes, elected officials, members of the military equipped to search through rubble, road emergency crews and local physicians all arrived on the scene to provide assistance to the victims.

### Consequences of this accident:

Two factory employees aged 25 and 29 working inside Building 7 or standing at the building entrance were killed on the spot. Another employee was found seriously injured 90 min after the explosion in Building 7A rubble. Many of the site's 140 workers were hurt to varying degrees by falling objects (ripped doors, tiles, etc.) or by broken window glass.

Building 7 was completely destroyed; the only part left was a small section of the concrete entrance steps. The locations of the 2 drying chambers were recognised by the presence of deep craters.



*Entrance to Building 7, viewed from the west (the damaged forest can be seen in the background) [1]*



*View of the eastern crater (foreground) and western crater (background), as seen from the east. Between the two craters are the remains of the reinforced concrete floor from the machine room [1].*

Building 7A, located about ten metres away, was blasted apart, collapsed and then buried under considerable rubble and debris from Building 7.



*Remnants of Building 7A (with debris and materials stemming from Building 7) [1]*

Many factory buildings were seriously damaged and all sustained broken windows. Several pipelines crossing the factory were also destroyed.

In the town of Muiden, 350 residences and buildings were slightly damaged with considerable broken glass (1,550 shattered panes). Total property damage caused by this explosion was appraised at 1 million Dutch guilders.



*Damaged pipeline [1]*



*Remains of the diesel tractor [1]*

**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:

|                                   |   |                               |
|-----------------------------------|---|-------------------------------|
| Matières dangereuses relâchées    |  <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>            | Hazardous materials released  |
| Conséquences humaines et sociales |  <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> | Human and social consequences |
| Conséquences environnementales    |  <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>   | Environmental consequences    |
| Conséquences économiques          |  <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>                       | Economic consequences         |

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

Nearly 2.45 tonnes (7 tanks of 350 kg) of gunpowder exploded; hence, the hazardous substances released index was scored a level "3".

Two employees died as a result of the accident, and at least one other was seriously hurt along with many more minor injuries (estimated for parameter H5 at half the factory personnel, i.e. 70), resulting in a human and social consequences index rated at "4".

Due to a lack of information on any environmental consequences, this parameter could not be rated.

The amount of property damage caused by this explosion was valued at 1 million guilders, i.e. the equivalent of €1.5 million in 2008. For this reason, the corresponding economic consequences index was assigned a "2".

## THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

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The evaluation of craters, debris and projections from buildings and machines (including the tractor, platform truck, forklift, etc.) enabled investigators to conclude that all 7 tanks inside or adjacent to Building 7 detonated and moreover that the explosion source was located inside Building 7. This first blast then caused 2 dry gunpowder tanks to explode on the platform truck parked outside the building.

Several hypotheses (eventually combined) were envisaged in order to explain the phenomenon, yet a 25-year-old technician considered relatively inexperienced and a sequence of incorrect manipulations (operating errors) were strongly suggested as exacerbating factors:

- The drying tank lid fitted with metal gauze could have been opened in an untimely manner and hoisted prior to closure of the air intake, thereby causing dispersion inside the room of a distinct amount of dry gunpowder. If the floor had not been previously watered, then this gunpowder could have ignited subsequent to a blow or shock, which in turn would have spread fire to the tank.
- Since the lid had been hoisted and the cable fastened to the grip lug (after removal of the drying tank), the cable might have become detached or slid off the lug, causing the lid to drop a height of more than 1.75 m onto the drying chamber floor. Combined with a floor that had not been swept and/or watered, traces of gunpowder on the floor could have ignited.
- The ignition of gunpowder on a floor that had not been swept and watered could also have arisen as a result of forklift wheel friction (less likely given the spot where the forklift was found after the accident).
- An electric motor on the drying installation's fan could have been heated, and in so doing generated sparks or flames that, when blasted through the pipelines, would have ignited gunpowder in the drying tank.
- Phenomenon of static electricity: the lid, which had not been grounded, could have become electrostatically charged, and an electrostatic discharge with sparking would then have triggered ignition.

Lastly, the hypothesis of a negligent smoker cannot be entirely discarded, even if this cause of ignition seems highly unlikely.

## ACTIONS TAKEN

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Several investigations were conducted (gendarmerie, labour inspection office, TNO<sup>1</sup> technical departments, etc.), complete with questioning of employees, testing on suspected pyrotechnic substances and reconstitutions.

The rebuilt factory would experience two other fatal accidents, on 30<sup>th</sup> May 1983 (storage depot explosion: 3 deaths) and 9<sup>th</sup> September 1983 (explosion: 1 death) [2, 3].

On 25<sup>th</sup> November 1986, the site closed a portion of its operations; then, on 10<sup>th</sup> December 1990, the company was declared bankrupt. It was purchased by a British company and activity resumed on 24<sup>th</sup> August 1991 [2].

## LESSONS LEARNT

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Given the quantities of substances simultaneously present in and near Building 7, as well as the protection systems in place in both this building and Building 7A, the accident highlights the importance of good installation design, including: location away from buildings, limitation of the rated values<sup>2</sup> inside buildings, decoupling of loads capable of reacting simultaneously, recognition of the relay effect (e.g. via internal transport) and domino effects.

<sup>1</sup> TNO (*Toegepast Natuurwetenschappelijk Onderzoek*, Dutch organisation for applied research): A Dutch expert appraisal committee, along the lines of France's INERIS Institute.

<sup>2</sup> Maximum authorised quantity.

The sources consulted did not explicitly mention the extent to which the partial reorganisation of factory operations (see page 2) might have affected circumstances surrounding this accident. Nonetheless, a study of the accident indicates the importance to be ascribed to managing such organisational modifications from a safety standpoint, e.g. risk analysis or closer executive oversight.

Along the same lines as the Pont-de-Buis gunpowder factory accident in 1975 (ARIA 14745<sup>3</sup>), the risks of gunpowder explosion were poorly identified and moreover the resources allocated were insufficient to provide protection against the effects or propagation of an explosion (safety distances, types of materials used, etc.). The quantities of materials present in the buildings were also much greater than those commonly used today; the risk at the source has since been reduced.

These two accidents helped give rise to noteworthy changes in French pyrotechnics regulations (Decree no. 79-846 enacted 28<sup>th</sup> September 1979, and the 26<sup>th</sup> September 1980 administrative order), stipulating among other things workplace safety reports for all pyrotechnic operations, along with a series of both technical and organisational prevention / protection measures still in effect today.



*Rubble that was once Building 7A [1]*

## SOURCES (INCLUDING PHOTO CREDITS)

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- [1] *Report issued by the Dutch Labour Inspection Office on the explosion of the Muiden gunpowder factory*, A. Balemans, J. Bezemer and B. Van Elburg, 1973
- [2] <http://www.muideninfo.nl/dePers/minfo-desluiz-0110.html>
- [3] <http://en.wikipedia.org/wiki/Muiden>

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<sup>3</sup> This accident was the subject of a detailed report, which can be consulted on the ARIA Website: <http://www.aria.developpement-durable.gouv.fr/Explosion-dans-une-usine-pyrotechnique-a-Pont-de-Buis-les-Quimerch-29-le-07-aout-1975--4904.html>