Explosion inside a pyrotechnic plant

August 7, 1975

Pont de buis les Quimerch [29]

France

Pyrotechnics
Organisation / operating guidelines
Domino effect
Risk evaluation
Critical height
Decoupling / safety distances
Relay effect

THE FACILITIES INVOLVED

The site:

Created towards the end of the 17th century, the site is France's oldest blasting powder factory. The site encompasses 53 ha within the narrow Douphine Valley and is surrounded on three sides by a fairly dense urban zone. An isolation perimeter had since 1934 established a conservation easement to prohibit construction around the powder factory. This perimeter, which remained limited in land area, still included a few dwellings, given that these structures were built before building permit requirements.

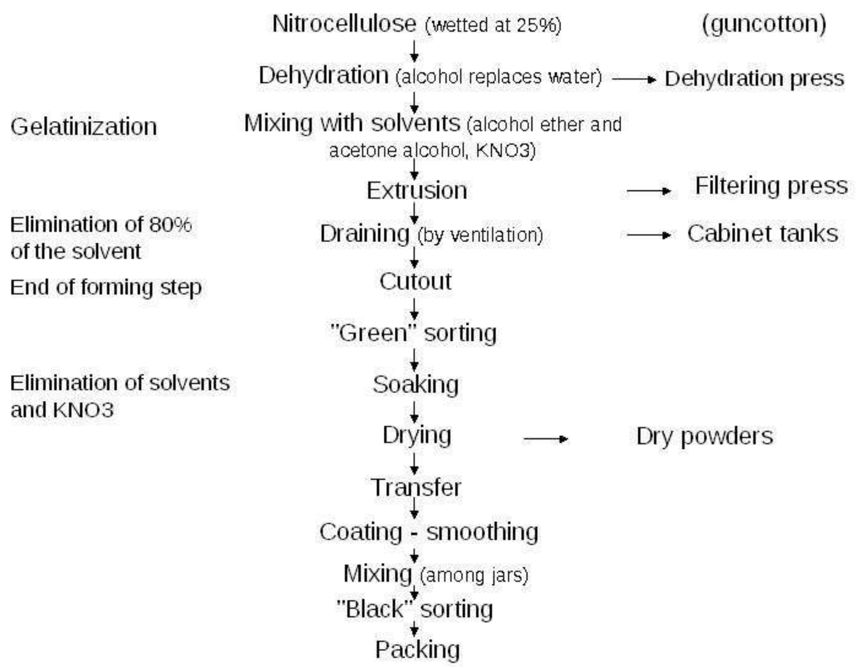
In 1974, the factory workforce had reached 530 for an annual production capacity of 1,400 tonnes, composed of 80% hunting powders and civil explosives and the other 20% ammunition explosives for light firearms. Production was increasing rapidly, and it was forecast that output would reach 2,000 tonnes in 1975 (with an expected 615 plant staff size).

The site included its own safety unit, which was able to operate effectively despite a lack of resources; the unit had a team of fire-fighters under its command. Drills were conducted and, overall, factory personnel were well versed in site safety aspects. Safety guidelines were distributed to every new hire, in addition to being posted, yet they were not always complete or regularly updated. For example, the amount of powder tonnage to be packed into a box was not indicated anywhere. Also, the intermediate storage quantities were not clearly associated with a given workshop, which added an element of "randomness" to the inventory management task.

Given that some of the installations were in derelict condition, an assessment was underway on how to improve safety: purchase of additional land, relocation of certain buildings, etc.

The involved unit:

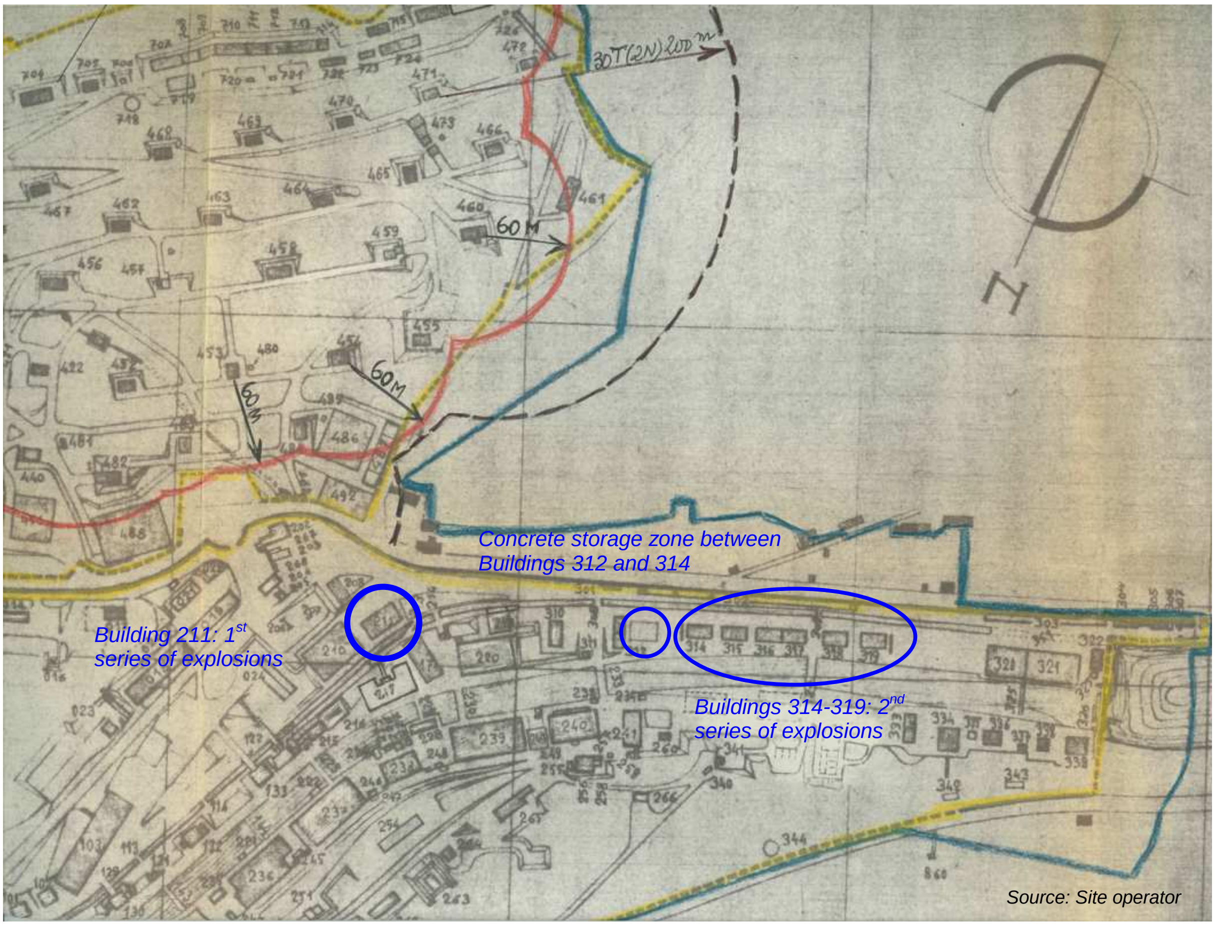
The manufacturing process for blasting powders made of nitrocellulose entails the following sequence of steps:



The particular sector of the factory where the successive explosions occurred spanned a distance of approximately 300 m, from Building 211 to Building 319.

Building 211 was used as a buffer storage facility for dry powder boxes between the drying and transfer operations. This old building had undergone refurbishment, and was not equipped with any fire prevention safety features. The handling of boxes inside Building 211 was not streamlined: presence of columns in the middle of storage spaces, strewn boxes, etc.

Buildings 314 through 319 housed the dryers and were located between the river crossing the site and an outdoor storage zone built on a concrete slab that extended between buildings 312 and 314 (see picture below). The dryers were of a conventional type with 4 shield units per building; each unit received 1 box, and the heating installation was shared by 2 units.



The boxes were transported to and from the dryers in Buildings 314 through 319 by an "Armax" forklift truck. These diesel trucks were fitted with accessories intended to make them explosion-proof when in contact with vapours of diethyl ether or alcohol; they were used in the so-called "green" powder zone.

In Building 211, boxes were handled by means of "Clark" forklift trucks, which offered greater power yet no protection against the risk of solvent vapour inflammation, given that the building was not exposed to this inflammable vapour risk.

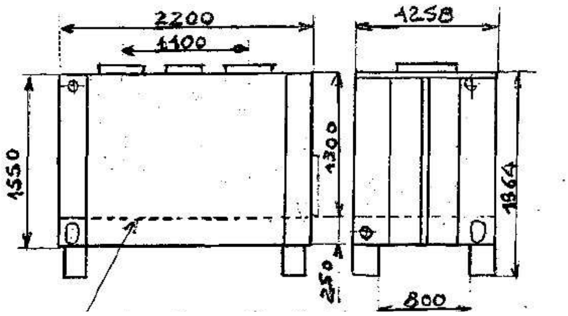
The "Clark" forklift / box pair was not optimal; moreover, forklift operations encountered a few obstacles:

1. Once the forks on the forklift were loaded, the driver lost all visibility and was forced to manoeuvre in reverse.
2. The forklift driver was also not able to see the sides of the box being transported, thus creating a risk of damaging the side door's clamping handles.
3. The driver placed boxes inside the building based on sounds heard, by "hitting" the box already in place to determine how close the manoeuvre was to completion.
4. The boxes were not tied onto the forks of the forklift, thereby increasing the risk of falling.
5. The lack of a flexible suspension system made for a bumpy and vibrating ride in the forklift, which in turn could have caused the crate door to break or the woven fabric to tear, leading to a loss of powder.

Boxes leaving the soaking stage were allowed to drain on the concrete zone while waiting to be dried. In some cases, boxes exiting drying were also stored on the concrete zone before being transported to Building 211. On the day of the accident, the premises of Building 211 contained some twenty powder boxes[1]. Three other containers were being stored outside the building, for the equivalent of approx. 12 tonnes of powder. Boxes of A1 powder[2], originating from the moisture removal stage and heading into the drying stage, along with two Zenon dry powder boxes, were warehoused in Buildings 314 through 319. Another four containers of dry A1 powder were lying along a wall near the dryer in Building 314.

On the day of the accident, the weather was nice and warm: 25℃, relative humidity of 57%, and a cloud cover ratio of 1/8. These conditions were somewhat exceptional (given that "typical" relative humidity for August was around 80%). This factor could have made the powder more sensitive.

The boxes contained a thin fabric on which the powder was laid in place. The most heavily used boxes often revealed the telltale signs of handling incidents: indentations on the sheet metal; impacts on the side door closing handles, making it necessary to shim the door; torn fabric, etc. Despite having washed the boxes after each operation, the presence of powder (up to 3 kg) in the double bottom was regularly noticed during repair work.



Bottom: Perforated metal sheet, with two perforated surfaces, for 30% of the total surface area. Slot: 3 x 20

Source: Site operator

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The epicentre of the initial explosion was located at the level of Building 211.

On August 7, 1975, a forklift operator began his shift at 12:30 pm. Around 1 pm, he removed a first box of A1 powder from Building 211. While he was placing the box and disengaging his forklift, fire broke out below and in back of the box (as confirmed by four witnesses 25 m from the scene). Detonation of the first box caused a chain of detonations of the other boxes contained in Building 211, due to flash-over (i.e. transmission by flying sparks and shock waves). This explosion lasted all of 2 seconds.

Hot sparks ignited boxes placed in the outdoor storage zone and 4 adjacent buildings. The "wet" powders were burning "normally" on the outdoor concrete slab. Fire-fighters quickly controlled the blazes burning in the nearby buildings (219, 220, 217 and 484), thanks to well-adapted fire-fighting equipment and the effective coordination established with local community fire services (by activating the ORSEC emergency response plan).

Seventy seconds later, spark projections originating from boxes burning on the concrete slab ignited 4 dry powder boxes temporarily stored near the dryer of Building 314. Five seconds afterwards, these boxes deflagrated and led to a series of blasts (deflagration to detonation transition). The same process was then repeated from box to box, within a span of 8 or 9 seconds, reaching the boxes that were either dry or being dried both inside and in front of Buildings 314 through 319.

Source : gendarmerie

Crater where Building 211 once stood

[1] Each box of A1 powder contained approx. 1,100 kg of "green" powder (i.e. with a solvent), reduced to 600 kg after drying.
[2] The "A" category powder is a porous hunting powder.

Consequences of the accident:

The forklift truck operator in Building 211 was killed on the spot. His body, like the forklift, was blown apart. Two other technicians also died in the vicinity of Building 211, after being hit by projectiles. The two other employees in this group were knocked to the ground by the force of the blast, yet they both managed to get up and find shelter.

Besides the three deaths, a total of 81 injured were counted (60 members of plant personnel and 21 residents of Pont-de-Buis): 38 of them required hospitalisation, 2 in very serious condition. The first of the two seriously inured, who was working in Building 219, had an arm ripped out, the second sustained a skull fracture as a result of falling stones and debris while passing close to Building 237.

Property damage was extensive. All factory buildings sustained damage to varying degrees: window panes, roofs, suspended ceilings, etc. The buildings near 211 were practically all destroyed, as were the powder dryers, with the exception of number 318 (which collapsed but did not explode). This particular dryer contained 2 Zenon powder boxes, neither of which detonated. Cracks ran along the enclosure wall opposite each destroyed building.

Large numbers of projectiles and flying objects were found: pieces of reinforced concrete, forklift truck debris, strewn boxes, etc. A 30-kg chunk of the forklift was recovered at more than 200 m from its original spot; the forks would never be found. The site's building layout was replaced by craters; 2/3 of the workforce had to be made redundant.

Outside the site, 90 houses were destroyed (collapsed walls and roofs), and another 300 to 400 were damaged to an extent of between 50% and 80%.

Lower left: Crater at the site of Building 211

Centre: Craters where Buildings 314 - 319 stood

The European scale of industrial accidents:

By applying the rating rules of the 18 parameters on the scale officially adopted in February 1994 by the Member States' Competent Authority Committee, which oversees application of the "*SEVESO*" directive on handling hazardous substances and in light of available information, this accident can be characterised by the following 4 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 are used to determine the rating level of the "hazardous materials released" index: Q1 and Q2.

- The 12 tonnes of explosives classified in Divisions 1.1, 1.2 and 1.3 represent 24% of the corresponding *Seveso* threshold (50 tonnes - explosives substances classified in a Division other than 1.4, according to the (United Nations) ADR agreement), which translates into a level 4 on the "quantity of hazardous materials released" index, as defined by parameter Q1 (with Q1 lying between 10% and 100% of the threshold value).
- Since each tonne that entered into reaction acted like 600 kg of TNT, i.e. for a total TNT equivalent of 7.2 tonnes, parameter Q2 is rated at a level of 4.

The composite level of the "hazardous materials released" index therefore stands at 4.

Four parameters are involved in determining the rating level of the "human and social consequences" index, namely: H3, H4, H5 and H6.

- Parameter H3 is rated at a 3: three deaths resulted from the accident among factory employees.
- Parameter H4 is rated at a 2: two employees were seriously injured.
- Parameter H5 is rated at a 4: 81 injuries were reported (60 employees and 21 members of the public).
- Parameter H6 is rated at a 5 due to the number of third parties left homeless or unable to work (approx. 400 households were affected).

The overall level of the "human and social consequences" index rises therefore to 5.

Since no information was available regarding environmental consequences, the corresponding parameter could not be rated.

Damage sustained inside the plant (as estimated by the cost of reconstruction) amounted to roughly 100 million francs (MF). Damage outside the site could be estimated separately at 40 MF, bringing the "economic consequences" index reading to 6.

Concrete block in a field 450 m from Building 211

Damaged residences

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

Some amount of powder must have spread on the floor of workshop 211, as well as on the outdoor concrete storage zone located in front of the building. A powder leak was likely, given the elements in place leading up to the accident (a poorly-matched forklift-box combination, inadequate safety distances, etc.). By manoeuvring in reverse, the forklift operator had very little chance of detecting such a powder streak.

During handling of the container, spontaneous ignition would have been caused by shock/friction as the container was placed in the outdoor storage zone and the forks of the forklift were removed. Dry A1 powder is quite sensitive to impact.

The fire then spread to the box, whose deflagration served to ignite the other boxes, which subsequently (given the confinement conditions created by the boxes present) triggered detonation of the 20 powder boxes (16 of which contained A1).

Two hypotheses can be forwarded to explain the presence of powder on the ground:

1. opening of the container's double-bottom door, coupled with the presence of powder in this double bottom due to tearing of the internal separation grating;
2. a break in the seal on the joint of the container discharge plug.

Poor site organisation was also highlighted as an aggravating factor: the use of intermediate "haphazard" storage, without any authorisation, safety guidelines or risk analysis, certainly created a situation stimulating the relay effect relative to detonation transmission.

The guidelines for Building 211 did not indicate the maximum load for boxes, nor did they specify whether the "20" listed actually corresponded to the number of tonnes or boxes; moreover, no mention was made of the type of powder contained in the boxes.

No guideline addressed the outdoor storage of Building 211 contents, either on the concrete slab or near Building 314.

In addition, safety rule infractions were noted, chief among them the temporary storage of boxes outside designated zones and in front of the dryers.

ACTIONS TAKEN

The factory was demolished and all production suspended. A different layout plan was adopted for site reconstruction in order to make better use of the space. A reorganisation of factory operations was established, calling for both additional land purchases and modified manufacturing processes.

A safety diagram was implemented for each production unit, stipulating for each phase of the process: fabrication stage, intermediate storage, warehousing of raw materials and finished products, manufacturing and transport operations, active material quantities, the number of onsite personnel, the type of risks present along with their corresponding prevention and protection measures, and the foreseen consequences of an accident with appropriate measures adopted. These improvements would subsequently be made mandatory as the regulatory framework evolved.

Additional testing was performed to understand the detonation mechanism observed during this accident. The test consisted of initiating charges inside tubes open at one end using an igniter containing 10 g of powder. Increasingly higher charges of A1 powder were tested and identified by their height in the tube.

The first series of tests were not conducted beyond 40 cm. During these complementary tests, the following phenomena were observed as a function of powder height:

- H < 40 cm: normal combustion,
- H > 40 cm: deflagration,
- H > 90 cm: detonation.

Similar experiments were carried out with various types of powders both in the laboratory and at the Landes Testing Centre, in the town of CAPTIEUX, for the dual purpose of the post-accident investigation and the two permitting procedures on behalf of ICPE (Environmental Protection of Classified Facilities), i.e. partial plant start-up in 1976, and complete resumption of operations in 1977.

It was recorded that the height H varied considerably from one type of powder to the next (between 20 cm and 30 cm for ballistic powders, to several metres for canon powders). This height depended principally on the level of powder dryness, its temperature and porosity. The "confinement" parameter also played a significant role, as witnessed when a detonation occurred inside a dryer with a closed fluidised bed at the same site in 1982.

These tests therefore helped define, for each type of powder, "a safe zone" by means of introducing several parameters beyond just the Critical Explosion Height; these included: chemical composition, dryness, porosity, self-ignition temperature, Critical Explosion Height (for both the deflagration and detonation stages), and confinement, with the focus on resuming factory operations.

To streamline oversight of the reconstruction plan, the local Prefect denied all building permit applications within the accident zone while awaiting quick revision of the municipality's land use plan. An initial draft outlining planning constraints around the company site was proposed just two weeks after the accident.

The plant director was sentenced guilty of homicide and involuntary injury on the 9 of July 1979 by the Quimper Court ; the sentence was granted an amnesty in 1981.

LESSONS LEARNT

Before this accident, the phenomenon of a powder detonation subsequent to combustion had never been experienced. Fire was considered to be the facility's major risk, and only deflagration-related phenomena had been identified between 1965 and 1967.

It had been presumed that preventing a fire from spreading entailed isolating buildings from one another and installing fixed fire-fighting devices (remote-controlled sprinkler systems) in shop areas the most exposed to this risk. Such measures however proved insufficient in containing the propagation of an explosion.

Research and testing conducted after the accident served to define the notion of critical explosion height (CEH) for powders. This CEH value corresponds to the height of product loaded into a half-closed container, beyond which an explosion occurs following ignition at the container base. Determination of this parameter is crucial for finely-divided products (like powders): in case of confinement, powders become capable of transitioning from combustion to detonation (i.e. the so-called "deflagration-to-detonation transition", or DDT, phenomenon).

It was observed that the circulation of feedback from other accidents (MUIDEN 1972, RIOTINTO 1974) was of limited effectiveness within the pyrotechnics industry. The powders and explosives inspection authorities (IPE) have, since this accident, been disseminating pyrotechnics-related feedback to all actors involved.

The increase in sensitive hunting powder production should have raised concerns not only over the quantities of powder to be packed into boxes, but also over the number of boxes to be stored and the storage conditions themselves. More in-depth studies could have focused on the specific characteristics of these powders.

In conclusion, this accident gave rise to a significant modification in pyrotechnics regulations (Decree No. 79-846, adopted on September 28, 1979, followed by administrative order issued on September 26, 1980[3]), calling in particular for workplace safety reports covering all pyrotechnics operations and an entire series of measures covering technical prevention and protection as well as organisational aspects, which are still in application today.

[3] *Today replaced by the modified Interministerial Decree, enacted on April 20, 2007, which establishes the set of rules relative to risk evaluation and accident prevention within pyrotechnics facilities.*