

FIREWORKS ACCIDENT ANALYSIS



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As an expression of festivities, fireworks must however not be perceived as inoffensive or devoid of risks. Fired for hundreds of years, some fireworks today can be directly used by the general public, which has given rise to the need for both intrinsically safe products and a minimum level of user precaution.

The commercial appeal of this type of activity draws many individuals into this field, yet for some of them, without possessing sufficient knowledge of both the risks incurred when using such products and the regulatory framework.

The present summary relies on an analysis of 316 accidents (102 in France, 214 elsewhere), as extracted from the ARIA¹ accident database and primarily involving classified facilities or potentially classified sites, in addition to a few selected cases, whose lessons are easily transposable (e.g. accidents involving black powder). In light of the available data and specificities of some of the events related to the fireworks themselves (e.g. accidents during use by the general public) but not necessarily input into the database, this summary is not intended to provide statistical analyses, but instead the basis for drawing lessons on risks inherent in these products during manufacturing, storage, use and disposal.



¹ Information collection has been practiced since January 1st, 1992, upon the creation of the ARIA database; nonetheless, some 30 prior events could also be recorded thanks to information gathered over many years by France's Armament Inspectorate for Powders and Explosives (IPE). [1]

The ARIA reference numbers included in the text of this synthesis correspond to a non-exhaustive selection of accidents illustrating this document's central themes. The summaries of accidents with an underlined ARIA number are either provided in the final section or discussed in a more abridged manner in the inserts. The complete list of summaries of all 316 events, occurring through December 31st, 2011, used to base this study is available on www.aria.developpement-durable.gouv.fr under the heading: «Analyses and feedback».

I. ACCIDENT STATISTICS AT A GLANCE

Accident statistics related to fireworks encompass 102 events occurring in France and 214 abroad. **Except when otherwise indicated, the data presented herein pertain exclusively to the French accidents.**

As opposed to other sectors of activity¹, the typology of events recorded comprises 77% fires, 51% explosions and 30% projections vs. just 8% accidental discharges of hazardous substances or pollutants, with several typologies being possible for each individual event. The higher proportion of explosions and projections is directly correlated with the composition of the products under consideration, whose inherent reactive nature is searched as such.

Given the volumes manufactured, transported, sold and shot off each year (see insert), the number of accidents occurring in France may seem relatively low. Yet, it must be pointed out that the ARIA database does not compile systematically, except for special cases, accidents involving the firing of fireworks and as a general fact, few accidents occurring abroad.

Taking knowledge of these limits, the fireworks-related events identified from the database are thus not quantitatively representative of the numerous events related in the international press, especially occurring in the producing countries.

Since the 1990's, a large share of fireworks production has been outsourced first to India then China, countries where high numbers of accidents are recorded, sometimes with very heavy human tolls. Although this firework activity seems traditional in those countries -and maybe partly because of that-, the accidents highlight serious lacks in safety conditions and worker protections, illegal workshops or installations not even complying with good practices standards. The lack of detailed information on these cases rarely allows drawing any constructive feedback.

The pyrotechnics industry dates back a long time, as the utilisation of powder resources was already commonplace a few centuries ago. Since the lessons learnt from explosions in Paris in 1794 (the Grenelle gunpowder factory, 1,000 deaths) and in 1866 (ARIA 39303, fireworks shop, 23 deaths), France's pyrotechnic sites known to the authorities remain relatively isolated from dwellings or other businesses, due in particular to strict regulatory requirements. This yields a positive consequence, in that accidental damage remains limited in most cases nowadays to the facility itself: with respect to classified facilities, 3 cases of broken windows outside the site boundary have been reported from among the 102 total accidents for the country; 5 other cases have involved depots failing to comply with current regulations.

Technical trends, along with the regular incorporation of feedback within organisations, has led to mitigating the human consequences and undoubtedly internal property damage as well, since property loss seems to be more consistently confined to the workstation, or eventually the building, but rarely beyond.

The fireworks market

In Europe, the fireworks market has been evaluated at €1.4 billion [4]. For France as a whole, turnover in the sector (that is production and wholesale, without the organisation of firework shows) was estimated in 2008 equal to €100 million. More than 90% of sector products are imported (for the most part from China, but also from Spain or Italy). Production and wholesale activities create well into the hundreds of jobs. The preparation of fireworks shows and firings is performed by a cadre of several hundred «regular» explosives technicians plus several thousand «occasional» technicians hired just for these shows.

In neglecting the activities of companies solely dedicated to organising the shows, the fireworks market is split 35% for the general public vs. 65% for professionals and firing exhibitions [2].

Over 15,000 fireworks shows are held in France each year, nearly half of which feature so-called «K4»-fireworks² requiring qualification. Depending on its duration, a fireworks display consists of between 200 and 1,000 individual explosives, hence over 1.5 million units of fireworks would be consumed annually in France [2].



Explosion and fire at a Paris fireworks factory in 1866
ARIA 39303 - Source : MEDDTL / C.S. (R.R.)

¹ See «Inventory of technological accidents, 2011». For the entire series of catalogued accidents, the division of phenomena is broken down as follows: 64% fire, 40% discharges of hazardous substances, and 8% explosions. [11]

² In application of European directives, the classifications of fireworks evolve. The French classification of K1 to K4 gradually disappears in favour of classes C1 to C4/T2, the latter requiring special skills. [2, 7]

I. ACCIDENT STATISTICS AT A GLANCE

The characteristic elements of accident causes will be detailed in the following chapters; however, a few statistics help serve as an introduction:

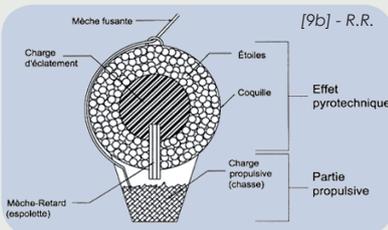
- Equipment deficiencies account for 37% of the database accidents.
- The works / maintenance set of circumstances represent 10% of accidents (i.e. 10 cases); this category often refers to insufficient cleaning prior to performing works, in some instances associated with either a lack of subcontractor supervision (ARIA [4936](#), 5843, 22852) or the ignition of accumulated dust during cleaning phases (ARIA 15029, [21310](#), 37039).
- Human and organisational breakdowns have appeared in nearly 65% of the studied accidents, namely: individual handling error or inappropriate action, loss of vigilance, overzealousness, in addition to inaccurate guidelines or nonexistent protocols, lack of adequate ergonomics, missing verifications.
- External aggressions (lightning, wind, extremely high temperatures) were either fully or partially responsible for 2 of the inventoried 102 accidents: ARIA [39303](#) and 29548. The presence of rodents caused another accident (ARIA [4534](#): package dropped due to rodents).
- Fireworks are capable of generating domino effects (fires) due to burning fallout to spreading distances beyond what corresponds to the thermal effects associated with an accidental situation (ARIA 384, [4534](#), [7181](#), [28480](#), 32509, [36014](#), [38267](#)...).

Some key operating terms [3]

STAR: a firework element consisting of a generally compacted pyrotechnic composition that produces a lighting effect during its operating sequence.

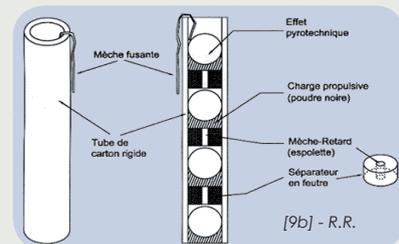


BATTERY: an assembly of identical elemental fireworks for which there is a single ignition point. [Note: The term COMPACT is used when the battery contains varied fireworks types.]



SHELL: firework, fired from a mortar, which scatters and ignites firework components (e.g. stars) to produce a visual and/or audible effect.

ROMAN CANDLE: a pyrotechnic product composed of a tube in which a series of small propulsion charges (black powder) and stars have been sequentially placed. When launched, the stars on a Roman candle are projected into the air in successive waves. These effects may be varied, i.e. noise, colour, gold, silver, a whirlpool, blinking.



BENGAL FIRE: a firework producing a coloured flame.

ROCKET: Self-propelled firework used to scatter and ignite elements at altitude to produce a visual or audible effect.

The rocket is propelled by a powder-powered engine throughout its ascension. Its trajectory is stabilised by means of a rod fastened to the body of the assembly; the rod falls back to the ground once the rocket's charge has exploded at its flight apex.

Their usage varies strongly between countries; in France, rockets are rarely used because of their sensitivity to lateral winds and the problem posed by the falling rods.

MORTAR: a short tube made of high-density polyethylene, cardboard or resin with glass fibres closed at one end and allowing for a curved projectile trajectory. Mortar is used as a cannon device for shooting fireworks.

They can be assembled in a battery if their diameter is below 150 mm. Mortars over 300 mm in diameter are forbidden in France. The use of mortars in a show requires prefectural agreement, of which professional firework makers are exempted.





Working table
Photo : DREAL Aquitaine (R.R.)

In France, the number of fireworks production incidents has tended to decrease, due in part to the outsourcing of a major proportion of activity to China, as well as to a decline in incident reporting whenever consequences proved to be limited. Only 44 production-related events were recorded in the database, given that the entry of accidents occurring prior to 1989 had been less systematic. The severity of accidents has also been decreasing thanks to developments since the 1980's of risk prevention methods and enhanced worker protection. The most recent fatality in a classified fireworks production facility dates back to 2004 (ARIA [27249](#)), and to 1999 for the one before that (ARIA [15658](#)). On the other hand, several fatal accidents were recorded in facilities not having been granted the requisite authorisations and failing to comply with minimum safety rules, notably the ban on loading fireworks adjacent to their stockpile (ARIA [11736](#), [13371](#), [20825](#)...).

The manufacturing steps, especially assembly (compression, etc.) or connection, constitute a critical phase and one that is difficult to automate. Technicians thus come into contact with hazardous substances, which increases the risk of eventual human consequences. The appropriate design of workstations, through application of a work safety study approach, the presence of protection elements (e.g. screens) and the wearing of individual protective gear, has become essential.

It would be useful to provide an optimal characterisation of all product-related risks encompassing all configurations (manufacturing, storage, transport), with special attention paid to the intermediate products generated during the manufacturing process. A knowledge of material characteristics includes its sensitivity to aggressions such as shock, friction, static electricity, chemical incompatibilities (ARIA [22843](#), [36509](#), [37097](#), [37060](#)), alongside an evaluation of potential effects (ARIA [37058](#), [37097](#), [38267](#)). An exhaustive risk analysis should serve to identify those aggressions capable of being encountered during normal operating situations, as well as in degraded situations, in order to adapt workstations, their tooling and protection, in addition to managing eventual joint activities, notably through limiting the risk of transmission from one workstation to the next and facilitating personnel evacuation (ARIA [383](#), [521](#)...).

Tooling is to be adapted to the greatest extent possible by acknowledging preventive or remedial maintenance efforts as distinct from production activities (ARIA [22851](#), [37084](#)). It is important for all equipment to be designed so as to facilitate regular maintenance operations, including: cleaning (using adapted materials, without hidden corners where dust can accumulate, etc.), adjustments (accessibility, adequate tools for making adjustments), inspections, and lubrication. Ideally speaking, the tools implemented should be dedicated to just a single product (or family of products) so as to avoid introducing impurities or chemical contamination (ARIA [6819](#), [7181](#)). Building design and location on a given site and relative to adjacent land uses plays a predominant role in limiting the consequences due to an accident (ARIA [36014](#), [37949](#)). In contrast, premises that are poorly designed, shoddily built or located in populated areas all constitute aggravating factors: ARIA [4936](#), [5118](#), [20825](#)...

Both the operating conditions and quantities of hazardous products present in manufacturing plants and warehouses need to be managed rigorously. Several accidents have been exacerbated by exceeding the quantity thresholds authorised for the workstation and in intermediate or final storage (ARIA [22845](#), [24429](#), [36014](#), [37473](#), [38267](#), [39223](#)), due to a lack of cleanliness or unclean state of the workstation or machines (ARIA [993](#), [21310](#), [36820](#), [37066](#)), as well as by imprecise, missing or incomplete safety guidelines (ARIA [4936](#), [22845](#), [24545](#), [37114](#))...

The proper protocol to follow when encountering a degraded situation, which must not be left up to technicians' sole initiative, is to strictly apply the procedure (ARIA [5118](#), [36876](#)). The same course of action is called for in cases of cleaning or maintenance work, whether run by technicians or subcontractors (ARIA [4936](#), [5843](#), [15029](#), [20825](#), [22852](#)...).

Regarding facility cleaning phases, pyrotechnic experts recall the utility of systematically soaking in water or an appropriate solvent any device requiring aggressive intervention; it is also preferable for all devices that cannot be entirely disassembled for inspection and cleaning to be designed without containing any confinements capable of trapping explosives. Otherwise, it is recommended to fill in all hollow parts with an inert product (polymer).

Vigilance regarding these various points tends to wane over time and when activity peaks; for this reason, a regular reminder of risks intended for technicians is necessary (ARIA [383](#), [7879](#), [37089](#)...).

In Monteux (84), in 1988, a fire broke out during the assembly of a batch of fireworks. [...] The operation consisted of closing the firework by a cardboard disc and then compressing it by means of a manual press. The fire spread to a portion of the elements present at the workstation. In following the protocol, the technician immediately left the premises and alerted emergency response teams; he was unharmed. The machinery on the premises was degraded. The station's cleanliness and organisation helped limit the extent of damage and speed of fire spreading. The operator decided to widen the screens in order to improve their efficiency. (ARIA [37066](#))

III. STORAGE

The ARIA database comprises 34 events involving fireworks storage facilities in France, of which only 13 pertain to classified facilities, plus another 40 or so accidents abroad, which have generated some degree of feedback depending on the type of information available.

A large and unrecognised proportion of accidents relate to fireworks storage in small depots or still in the mixed state placed amidst other products inside warehouses, party item stores, supermarket inventories, town hall basements, etc. (ARIA 13371, 14448, 17751, 19122, 29067, 31562). The recommendations issued in the **ARIA news flash entitled «Accidents in small fireworks depots»** [11] remain entirely valid in light of the May 2011 Coullons accident (ARIA 40398).

Storage facilities, whether they be temporary while awaiting the show, intermediate during the manufacturing stage or for finished products, must be assigned to well-adapted spaces designed for this very purpose, in addition to being clean, neat and free of all combustibles and any other hazardous substances. Moreover, no competing activity should be permitted without a preliminary safety study (ARIA 11736, 19122).

Much like with the manufacturing stages, strong knowledge of the products and risks is critical to implementing suitable and effective prevention measures relative to storage (ARIA 3098, 18408). The risk division classification¹ of products enables an initial selection, notably with respect to storage incompatibilities, yet such a selection does not always prove sufficient: the risk of ignited projectiles, mass fire, or even an explosion under certain confinement conditions (e.g. maritime containers) might enter into consideration; the spectacular accidents of fireworks depot containers at Enschede in 2000 (ARIA 17730) and Kolding in 2004 (ARIA 28480) serve as sobering illustrations.

Accidents with ignited projectiles causing fires to spread (ARIA 17730, 18408, 28480, 32509, 36014) and/or facilitating the fire-to-explosion transition (ARIA 17730, 18408, 22018, 23996, 28480) are not all that rare. In the event of product importation, extreme vigilance must be practiced on their quality and actual classification relative to transport or storage (underestimated classification: ARIA 17730, 22018, 28480... there has even been an incident of fireworks listed under the heading plastic toys: ARIA 23996!).



Destroyed neighbourhood in Enschede
ARIA 17730 ([11] R.R.)

As a general rule, it is recommended to handle fireworks with extreme precaution, especially in instances where assembly operations have been conducted as well, since assembly manipulations are indeed able to significantly modify initial product characteristics, especially their sensitivity (ARIA 8233, 27249). The same level of precaution is required for "ageing" products (ARIA 18408, 22832) or misfired products (ARIA 13371, 17751, 27575). These items, particularly if they are found to be defective (i.e. «duds»), should not be reused but rather destroyed or at least returned to the manufacturer for disposal (ARIA 35168).

It is also recommended to plan any building works taking place in pyrotechnic storage facilities and, if necessary, remove products, any potential source of ignition and packaging materials (paper, cardboard, wooden pallets, etc.) with strong heat-releasing capacities (ARIA 31562). Extinction resources are to be adapted to the inherent risks and kinetics of the phenomena at hand; keep in mind that large quantities of water may be necessary to battle several fire outbreaks caused by ignited projectiles (ARIA 7181, 17730, 36014...).

In the Netherlands, in 2000, a fire broke out at around 3 pm in the C2 workshop (used for manufacturing fireworks) at a fireworks depot. Rockets spread the fire to containers located just opposite the blaze. [...] A very intense deflagration accompanied by a fireball 85 m in diameter then rocked the zone. [...] the central bunker violently burst, generating a 135-m diameter fireball along with a tremendous plume of smoke. The fire spread to a brewery adjoining the warehouse and nearby homes. A supermarket was razed, with a 3 to 4-ha zone resembling a bombarded landscape, and the site of the warehouse was replaced by a crater 13 m in diameter and 1.3 m deep. The force of the main explosion was evaluated at between 4 and 5 tonnes of TNT equivalent. The smoke column was visible 40 km away; glass panes and store windows were blown out over a radius in the hundreds of metres. In all, 22 deaths were reported, including 4 fire-fighters, with 974 people hurt, 50 of whom suffered serious injuries. Over 2,000 local residents had to be evacuated, 500 houses were destroyed or heavily damaged. Hundreds of rescue workers were needed to extract the injured. A health monitoring effort was required in the area for several years hence.

An investigation was conducted, but the cause of the accident could not be determined (malicious act? handling error? short-circuit? self-ignition?). Neither the structures nor containers appeared to offer sufficient protections relative to the fire and explosion risk; moreover, they were not or inadequately equipped with fire detection and extinction resources. Their layout did not respect regulatory distances. The risk classifications among stored products had most likely been underestimated or the products poorly classified (fireworks imported from China). [...] (ARIA 17730 [11])

¹ The risk division nomenclature consists of a numerical symbol (1.1 to 1.6) designating the primary hazard associated with a given material or object belonging to Classification 1 regarding the transport of hazardous substances (i.e. presence of an explosion risk). The compatibility group is identified by a letter designating groups of substances that can be stored together. [3]

The transport of fireworks may give rise to accidents, whether due to a traffic accident (ARIA [4252](#) - explosion of a lorry hauling 3 tonnes of fireworks), a mechanical problem with the transport vehicle (brake overheating, sparks - ARIA [37689](#), [39295](#)) or a product reaction, which is more prevalent during loading and unloading.

Prior to transporting fireworks, it is recommended to adequately secure the individual items contained in the boxes, with their fuses protected and/or short-circuited. Lastly, it is advised to regularly remind technicians to handle these boxes with utmost caution, as a dropped box can actually cause a fire outbreak (ARIA [22516](#), [22517](#), [28480](#), [36670](#), [37120](#), [38295](#)).



ARIA 36593 - Fire aboard a container ship
 Note: Though the transported fireworks did react, they were not the cause of fire outbreak (non-declared chemical products).

By applying the rules for transporting hazardous substances¹, all fireworks being transported in France must receive classification certificates². The awarding of these certificates indicates successful trial outcomes and the adoption of appropriate safety measures. These rules are also valid for any firework imported into the country; it would be advised to run a product quality control and verify that the firework had been correctly classified during both the storage and transport phases (i.e. presence of the appropriate tags and certificates), in order to avoid «bad surprises» or eventual risks tied to poor-quality products or products whose risk has been underestimated due to an unverified «seat-of-the-pants» classification (ARIA [22516](#), [22517](#)). This issue has also been raised in the storage chapter of the present study.

The location of the loading platform, much like the storage building location, needs to be further examined in order to account for the risk of spreading that exists especially when the ignited product is capable of being projected (ARIA [37120](#), refer to the chapter on storage).

In Etoile-sur-Rhône ([26](#)), in 1993, a Spanish lorry, travelling on France's A7 motorway, transporting 3 tonnes of recreational fireworks hit the road's guardrail, ignited and exploded. The explosion, heard up to several kilometres away, ejected the driver's cab into a field some 100 metres from the point of impact. The driver had fallen asleep at the wheel; his body was found a few metres further in the field. Limited traffic on the road at the late hour of this accident occurred avoided a greater number of casualties. The motorway remained closed throughout the emergency response. Sparks generated by friction from the vehicle's trailer when slamming into the guardrail would have caused the fireworks being hauled to ignite. (ARIA [4959](#))

In Denmark, in 2004, around 2 pm, inside a company storing fireworks (net weight: 300 tonnes / gross weight: 2,000 tonnes), a fire broke out during an unloading operation on a 40-foot container subsequent to the mishandling of a box filled with fireworks rockets. The fire quickly spread within the container and to fireworks stored on pallets placed outside. [...] Despite a few intervention difficulties (caused by smoke, noise, water supply interruptions, a defective nearby hydrant), fire-fighters were able to cool the closed fireworks containers stored adjacent to the ignited containers. An explosion occurred at 3:25 pm, killing one of the fire-fighters and injuring 7 others. Three additional explosions occurred at 5:45 pm. The nearly nonstop explosions of fireworks lit the sky until the evening. The fire, which had been releasing a thick smoke, was only contained 2 days later. [...] Offsite property damage was estimated at €100 million. The violent explosions of fireworks were surprising in that the containers were only filled with fireworks imported from China and therefore theoretically classified as 1.3G (i.e. without any risk of explosion).[...] (ARIA [28480](#) [11])

¹ Fireworks are pyrotechnic products that belong to the Class 1 of United Nations recommendations relative to the transport of hazardous substances. Their transport by road, rail or water is regulated. Compliance with these rules, as well as with the minimum set of safety precautions, would serve to avoid explosion accidents involving coaches filled with fireworks, e.g. ARIA [22884](#), [31127](#).

² These certificates are delivered by the INERIS Institute, which is the competent authority in France –by delegation of the Transport of Dangerous Goods (TDG) office- with regards to the UN recommendations on TDG.

Nota 1: in France, the transport classification (risk division + compatibility group) can be used as storing classification in an industrial facility as long as products are stored within their closed transport packaging.

Nota 2: the INERIS is also the accrediting body with respect to both Directive 93/15/EEC and Directive 2007/23/EC for the certification of pyrotechnic articles and explosives approved for civilian use.

As is the case with all pyrotechnic products, the destruction of fireworks (whether they be duds, manufacturing rejects, ageing unsold products, etc.) can prove complicated, especially when collecting these items from individuals. The channels available to destroy fireworks, which remain relatively undeveloped, will need to progress as proper disposal of these objects can only be performed by professionals holding the requisite credentials (classified facilities).

With regards to accident analysis in this field, the reader is referred to the study entitled «**Destruction of pyrotechnic wastes: Accident analysis**», published by BARPI in 2010 [11]. Many lessons and recommendations can be directly transposed to destruction steps involving fireworks, notably a more comprehensive knowledge of the wastes to be destroyed and their associated risks (ARIA [14565](#), [19145](#) - unfamiliarity with the risks and mixing of incompatible products, causing fire during the unloading of fireworks scheduled for disposal; 22518 - reaction of a photogenic compound in storage for 20 years), a limitation of the quantities suitable for simultaneous destruction (ARIA [14565](#), [19132](#) and [36349](#) - deflagration during fireworks destruction), and technician protection (ARIA [19145](#), [24915](#) - flash experienced during the destruction of firework shells).



Destruction de Firework shells [9] - R.R.

In **Méré (89)**, in 2002, a flash occurred while disposing of fireworks (class 1.3.G, containing 20-mm candles, shells, full 30-mm strikes) in a firm dedicated to destroying pyrotechnic products at the end of their useful life. With the oven loaded, technicians perceived a white lightning bolt and felt intense heat. All products present operated successfully. A technician was burned on his hands, face and torso despite wearing protective gear (gloves, goggles, fire-retardant suit) and another was slightly injured. Several hypotheses were forwarded, the most plausible of which points to friction created on the floor with a friction-sensitive pyrotechnic product.

As for feedback from this accident, experts underlined the attention to be paid to operations involving the destruction of pyrotechnic products (which, by definition, have become degraded and more sensitive). In the case of this incident, the nearby presence of a water tank allowed one of the injured technicians to immerse himself, thus limiting the extent of his burns. Yet the technician was not wearing the anti-static gear and safety shoes recommended in the draft safety report (not yet approved). (ARIA **24915**)

In **Monteux (84)**, in 1995, fireworks candles exploded at the time of their destruction. The candles to be destroyed, measuring 30 mm, were composed of 8 «salute» displays with sound effects. [...]

Previous destruction operations allowed disposing of 22, then 80, candles of this type. On the day of the accident, 360 candles were placed in the nozzle. After ignition, 4 or 5 volleys were fired, followed by the deflagration of the entire set, through a triggered activation of the «salute» displays, most likely due to the confinement created inside the nozzle. The quantity of material released by the blast was estimated at 25 kg, i.e. approximately half the initial charge.

This accident resulted in no injuries. The nozzle was destroyed, leaving in its place a crater 1 m deep by 1.5 m in diameter. Concrete pieces were projected in all directions, including outside the designated destruction zone.

The operator limited the quantities of candles for simultaneous destruction to 100 candles of 30-mm dimension, or 50 candles of 45-mm dimension, or 50 candles of the 65-mm dimension per operation. The noise effect candles will be buried directly into sand or else in ground devoid of materials capable of generating hazardous projections. (ARIA **36349**)

In the **United Kingdom**, in 1998, a fire and series of explosions erupted in one of the country's largest fireworks plants. Nearby houses and local businesses, including a flour mill, had to be evacuated. Several small explosions were spaced over a 15-minute interval, followed by a violent blast causing an abundance of sheet metal projections in the vicinity (container pieces strewn 150 m around). Window panes were shattered up to 10 miles (16 km) away. A total of 8,200 kg of fireworks had reacted, for a TNT equivalent estimated at 200-250 kg, given both of the craters found at the site of one of the eight 6.1-m metal containers placed inside the building (made of a concrete slab and brick walls). Despite intervention difficulties (relative to access and a thick black smoke), 35 fire-fighters were on the scene battling the blaze and several hours later had control over the incident. They found the 13 workers, who were all safe and sound, despite the intensity of the explosions and fire.

An investigation conducted by Britain's Safety Authorities (HSE Office) revealed that the company's safety management system was deficient: lack of employee protection, inability to communicate information to the proper authorities regarding explosives-related risks, inappropriate use of buildings (including storage errors, most notably exceeding the quantity authorised inside a building), and the dismantling of fireworks (which was the operation responsible for the accident: a firework returned from a show was poorly disassembled, triggering its ignition). In noncompliance with the guideline that stipulated using a sharp knife and wood cutting board in a dedicated spot, the technician cut the fuses connected to the shells with a pair of scissors inside the storage container itself. (ARIA **14565**)

According to the European Commission, the number of accidents involving fireworks within the EU can reach upwards of 45,000 cases a year. These statistics also reveal a high number of injured children by fireworks subsequent to inappropriate use or malfunction [4].

No official statistic is kept in France regarding this specific category; however for information purposes, a parallel can be drawn with the situation in Belgium [5] or Canada [6]. In these two countries, whose regulations are somewhat comparable to those applicable in France, it would appear that more than half of all accidents cause burns to the body, with injuries (burns or trauma) being most frequently sustained to the fingers (32%), arm (25%), eyes (15%) and face (13%). Some accidents cause auditory impairment, as blasts from fireworks can reach 160 decibels, which is 20 decibels above the maximum pain threshold. Moreover, in 80% of accident cases, the victim is male with nearly half of them aged between 10 and 20.

These shooting accidents tend not to enter into the ARIA database field of observation; for this reason, only some 30 cases (10 in France) have been extracted for illustration purposes in this study. These fires have been caused by a live firework falling back to the ground (ARIA 6229, 14230, 30643) or occurred during pyrotechnic shows in injuring spectators and technicians (ARIA 23033, 27553, 27557, 28290, 40621). Such accidents, whose consequences can sometimes reach dramatic proportions, underscore the importance of observing required precautions when handling these products (safety distances, see insert).



Advisories for consumers [5, 7]

- Purchase only authorised fireworks from a specialist well known in the trade, with a serious reputation and able to justify, if asked, his knowledge and compliance with regulations (e.g. the «ICPE» regime for classified facilities, technical credentials). It is noted that: «The possession of a certificate of competency in shooting off fireworks from the C4/T2 group (formerly K4) implies a sufficient level of knowledge to ensure a completely safe use of even the most hazardous fireworks, yet in no way authorises the certificate holder to store said fireworks» (NB: neither to assemble or connect firework pieces outside of the launch site) [10].
- Be sure to purchase fireworks whose charges do not exceed the authorised maximum or that are exclusively reserved for professionals (e.g. large calibre).
- Prohibit the firing of any suspicious device due to its appearance or faulty packaging (e.g. without an EC marking or certification number, missing labelling).
- Request packaging for the transport of these items. Store the fireworks in a cool and dry spot, away from all children's activity, in its original packaging or as delivered without being opened, far from any inflammable product or heat source.
- Read attentively and strictly follow the instruction manual prior to launching the fireworks.
- Prepare the launch site and proceed with the shoot from a zone without any surrounding vegetation or clutter, far from the show's guests, dwellings, vehicles and any areas with significant plant growth, by very meticulously arranging the devices in a space where no one will enter before all fireworks have been launched. Be sure to keep water on hand in sufficient quantity, or perhaps a fire extinguisher.
- Extinguish sparks and incandescent residues on the ground.
- Only ignite one rocket at a time and, if possible, using a long match, a torch or else a special fuse, without placing any part of the body directly above the device. It is also recommended to wear glasses and earplugs when manually shooting off fireworks.
- Wait for the firework to be completely launched before proceeding to fire the next one.
- Step back immediately and maintain a good distance as soon as a fuse has been lit, never aim this kind of product at another person.
- Never relight a defective device that malfunctioned upon initial lighting or that fell back to the ground without having successfully fired. In the event of a firework that did not ignite (i.e. a dud), be sure to wait at least 30 minutes without taking action (never lean over the product), then drown it in water and wait another 30 minutes minimum before collecting it and placing it in safe storage. Do not discard these devices in the rubbish! They must be returned to the supplier for proper elimination.
- Keep animals in safe areas: dogs and horses in particular become very frightened and agitated around fireworks.

In Cébazat (63), in 2011, a fireworks show started around 11 pm in the city park in the presence of some 1,000 spectators. Shortly after the first rockets were fired, between 5 and 10 projectiles were propelled horizontally and exploded adjacent to where the public had congregated in back of the barricades just tens of metres away, creating crowd panic and jostling. Nine spectators, including four children, were slightly injured; [...] The origin of these defective firings remains unknown. [...] (ARIA 40621)

Without detailing the set of regulations applicable to all pyrotechnic activities, it goes without saying that regulatory compliance is fundamental to ensuring safety in this sector of activity. Given its extensive practice in history, fireworks offer the unique situation of imposing tailored prescriptions that incorporate a considerable body of feedback from accidents with relatively severe consequences: limitation of the number of individuals manning a workstation, safety distances between installations, systematic completion of safety studies, procedures, training.

Regulations applying to fireworks have recently been modified, given among other things the publication of Decrees 2010-580 (31st May, 2010), relative to the acquisition, possession and use of fireworks and pyrotechnic articles intended for the theatre, and 2010-455 (4th May, 2010) relative to the marketing and control of explosives with the adoption of associated legislative text. Depending on their quantities, the storage of fireworks may be governed by a specific classified facility protocol (DC, E, A, AS).

A circular dated 15th June, 2010 issued by the Ministry of the Interior, Overseas Territories and Local Authorities summarised the latest applicable texts for fireworks shows (and associated temporary storage) and moreover stipulated a number of conditions. This circular also recalled the set of best practices for staging a pyrotechnic launch that a professional would need to strictly respect (or for any use of fire requiring preliminary declaration); these practices are to serve as guidance for "consumer's firings" without any declaration requirements (i.e. total mass less than 35 kg of active material, or the absence of products classified «C4/T2») [7].

The risks tied to the manufacturing, storage and transport of fireworks necessitate a management system designed for the specific risks associated with each stage of the process. Such a system supposes implementing a rigorous organisation that allows for controls of the actual application, along with the heavy involvement of senior facility executives. Otherwise, history has already shown that accidents tend to severely penalise breakdowns in human organisation.

In conclusion, both retailers and individuals should be more vigilant of the best practices to adopt and precautions to follow when making use of these products, in order to limit bodily injuries - potentially very serious - when shooting off fireworks.

1 FRANCE'S ARMAMENT INSPECTORATE FOR POWDERS AND EXPLOSIVES (IPE)

http://www.defense.gouv.fr/dga/votre_espace/liens/poudres_et_explosifs

2 SFEPA (Syndicat des fabricants d'explosifs, de pyrotechnie et d'artifices) http://www.sfepa.com/note_sur_la_qualification_des_artificiers (2011) et **Guide de bonnes pratiques en pyrotechnie** (2009)

3 GTPS

Pyrotechnics Dictionnaire de pyrotechnie, 6th edition, Pyrotechnical Working Group (GTPS), Published by the French Association on Pyrotechnics, ISBN2-9521621-3-1

4 EUROSTAT : européen statistics

http://epp.eurostat.ec.europa.eu/portal/page/portal/external_trade/data/database
et pour les accidents <http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+IM-PRESS+20061129IPR00713+0+DOC+XML+V0//FR>

5 Accident statistics in Belgium

http://economie.fgov.be/fr/entreprises/securite_produits_et_services/Springstoffen_feestvuurwerk/artifices_joie/Securite_artifices_joie/

6 Accident statistics in canada

http://www.phac-aspc.gc.ca/injury-bles/chirpp/pdf/CHIRPP_INJURY_BRIEF_Fireworks_FR.pdf

7 Ministry of the interior / informations for firework consumers http://www.interieur.gouv.fr/sections/a_votre_service/vos_demarches/armes-munitions/spectacle-pyrotechnique/

8 INERIS

<http://www.ineris.fr/en/prestations/certification-ineris/produits-explosifs-et-pyrotechniques>

9 Photos of fireworks : <http://www.pyrotechnie.org/>

9b Diagram : <http://www.pyrotechnix.be/page2.html>

10 Parliamentary question n° 75498 <http://www.nosdeputes.fr/question/QE/75498>

11 BARPI

- www.aria.developpement-durable.gouv.fr
- Explosion of a fireworks storage in Culemborg (The Netherlands), february 14th, 1991 - ARIA 3098
- Explosion in a warehouse in Mazères (09), june 27th, 1993 - ARIA 4534
- Explosion of a fireworks storage in Enschede (The Netherlands), mai 13th, 2000 - ARIA 17730
- Fire and explosion of a fireworks storage in Carmel (Australia), march 6th, 2002 - ARIA 22018
- Explosion of a fireworks production and storage facility in Villeneuve sur Lot (47), june 1st, 2004 - ARIA 27249
- Explosion of a fireworks storage in Kolding (Denmark), novembre 3rd, 2004 ARIA 28480
- Explosion of an truck carrying explosives in Peterborough (United Kingdom), march 22nd, 1989 - ARIA 36670
- ARIA News flash : accidents in small fireworks depots (2009) - http://www.aria.developpement-durable.gouv.fr/ressources/flash_aria_ad_low_resol_gb1.pdf
- FLASH ARIA : accidents linked to fireworks shows (2012) http://www.aria.developpement-durable.gouv.fr/ressources/flash_aria_ad_2012_vfinal_gb.pdf
- SYNTHESIS : Destruction of pyrotechnic waste : accident analysis (2010) - <http://www.aria.developpement-durable.gouv.fr/Destruction-of-pyrotechnic-waste-accident-analysis--5110.html>
- Inventory of technological accident 2011

SELECTION OF FRENCH ACCIDENTS QUOTED IN THE TEXT



Wikipedia (colourful fireworks - Creative Commons)

European scale of industrial accidents :

The quotation of the four criteria of the European scale is shown for each accident. It provides an indication of the seriousness of the accidents, following their detailed analysis. The scale is based on 18 parameters that are grouped into four indices, namely:

Dangerous material released	 <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	(2 parameters)
Human and social consequences	 <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	(7 parameters)
Environmental consequences	 <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input type="checkbox"/> <input type="checkbox"/>	(5 parameters)
Economic consequences	 <input checked="" type="checkbox"/> <input type="checkbox"/>	(4 parameters)

The information used to determine the elementary level of each parameter is available on the site :

www.aria.developpement-durable.gouv.fr

on the « Information Tools / European scale of industrial accidents » page. For a given accident, the value of each index corresponds to the highest level of the parameters that it contains. Only some of these 18 parameters, which are designed to cover a broad variety of the possible consequences of diverse incidents, are usually of relevance when characterising an accident.

ACCIDENTS



ARIA 383 - 22/03/1988 - 16 - LE GOND-PONTOUVRE

20.51 - Manufacturing of explosive products

A technician was producing red comets by applying a compressive force with a mallet in a mould containing a chlorate pyrotechnic composition (featuring potassium chlorate, strontium oxalate, aluminium, magnesium and black powder). Two other employees were performing different operations on the same work table.

Excessive compression, combined with either abnormal friction or the presence of a foreign object, caused an explosion at the compression station, in turn leading to the death of the technician and serious burns to the other two workshop employees. The building was also damaged. Experts in the field point out that:

- the compression of chlorate compositions is in fact hazardous and must be performed in a protected zone;
- the sensitivity and behaviour of the products implemented must be well understood;
- to the greatest extent possible, it is necessary to substitute hazardous compositions with less sensitive ones;
- the execution of various activities on the same premises must not be undertaken without first adopting special measures;
- an individual apparatus must be used to complement the technician's protective gear;
- technicians must be made aware on a regular basis of the risks they incur through a well-designed training programme.



ARIA 4534 - 27/06/1993 - 09 - MAZERES

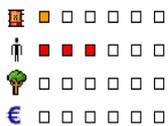
20.51 - Manufacturing of explosive products

A series of explosions occurred on a Sunday afternoon inside a pyrotechnic facility, when only the guardian was onsite. He sounded the alarm.

The fire would have been ignited in warehouse D22 by the fall (most likely caused by rodents, whose presence had been noted in this depot) followed by the untimely triggering of firecracker igniters and flares. During several minutes, the fire spread to other igniters as well as to cardboard boxes. After some time, the blaze reached the detonation fuses, which wound up exploding and forming a small crater (0.5 m diameter over a 0.25-m depth). The products dispersed by this low-intensity explosion in turn caught on fire (anti-hail rocket launchers and a Class 1.1F nitrate explosive): they partially detonated, also forming a crater, 1.6 m in diameter by 0.25 m deep. Some 20 seconds later, nitrate explosives plus other explosives containing trinitrotoluene / pentolite detonated by domino effect, forming yet another crater, this one 5.4 m in diameter with a depth of 1.5 m. Such a violent explosion, whose power was estimated at 1.77 tonnes of TNT, blew out the metal frame of building D22. The blast effect severely damaged both neighbouring warehouses (D13 and D19, separated from D22 by 60 m) and deformed the structure of the D19 building. Flying hot metal particles reached building D19, which had already lost its cladding, and triggered the powder stored inside along with the successive explosions of black powder crates. Depot D13 burned rather slowly, triggering an explosion of the signal flares. The combustion of smoke-producing substances released a thick black plume of smoke and formed a column that could be seen from Pamiers.

The explosion, felt up to 30 km away, also damaged the site's workshops, storage depots and offices. After extinguishing the dry grass fire in order to protect the remaining facilities, fire-fighters were able to bring the blaze under control around 9 pm. The next day, the burned warehouses were quenched to avoid any renewed risk of explosion, and the damaged depots were covered with a tarp. Since the accident took place on a weekend, no casualties were involved. Property damage was extensive (3 warehouses completely destroyed, damaged cladding and roofs on the other depots, broken glass panes). The plates used for roofs or walls became detached like petals on a rose, while inside the buildings all machinery remained in its place.

The plant's 145 employees were furloughed and resumed their posts at the beginning of August. The extent of property damage amounted to 14.6 M francs (equivalent of €2.22 M). The operator modified onsite storage conditions to avoid incompatibilities between substances while improving management controls on stored quantities (rated value). The operator also reviewed building construction techniques and protections against rodent intrusion. The reconstruction of destroyed installations had to be submitted for a new approval procedure.



ARIA 4936 - 15/05/1993 - 24 - BERGERAC

20.51 - Manufacturing of explosive products

In a gunpowder factory, a very intense combustion with a pressure surge effect occurred within a hopper containing powder. Maintenance work was ongoing: 2 workers were connecting by means of a copper cable the recently-installed metal sentry boxes around the loading hoppers of a cartridge production line («grounding» of the equipment). The line was shut, but sizeable quantities of powder remained both inside the hoppers (which had not been drained prior to the maintenance intervention) and in nearby plastic cans. The perforation (by an employee using a «standard» electric drill) of the wall of the third sentry box caused the heating that initiated the fire. The employee was killed on the spot due to burns. The fire spread throughout the corridor and to both of the juxtaposed platforms, on which cardboard boxes, lead bags and barrels of powder had been stored. The second employee, who was working in the room adjacent to the powder corridor, was severely burned and succumbed the next day. The third technician was thrown from the first floor and slightly burned; he was off work for a full month. Two fire-fighters also sustained burns. The cartridge-filling shop and machines were partially destroyed.

The operator stated having given a verbal order to empty the powder before starting these works, which however were not written up in a workplace safety report. Regular ongoing safety training was not being performed onsite. The construction measures adopted by the workshop proved ineffectual (missing or incorrect calculations): the roof designed to serve as an unloading surface resisted the pressure surge, which in fact contributed to spreading the fire to nearby powder cans.



ARIA 7181 - 19/07/1995 - 09 - MAZERES

20.51 - Manufacturing of explosive products

In a pyrotechnic plant, an explosion followed by fire destroyed an 8-tonne capacity depot storing recreational fireworks, smoke grenades, flares and simulation fireworks. According to employees working nearby, a white smoke was released first, with the explosion occurring 20 to 30 seconds later. Coloured stars were then projected. The alarm was triggered and the internal emergency plan activated. A safety perimeter was established. Areas of fire outbreak were ignited by projectiles over a widespread area extending more than 1 km around the premises, reaching zones beyond the site boundary and causing grass fires, which were fanned by the drought exacerbated by heat wave temperatures. The other depots were protected by fire-fighters, and the fire was brought under control within about 90 minutes. An aerial reconnaissance mission flew in a helicopter over the affected zone. Fire-fighting units monitored the situation through the night for any eventual resumption of fire. The intervention of emergency responders was complicated by the risk of potential explosion as well as by a limitation of access to gasoline-powered vehicles (compliance with safety rules). The fire extinction network, which had been appropriately designed, proved to be operable. The accident caused no injuries, but the storage depot was entirely destroyed.

The initial findings of the subsequent investigation revealed a breakdown in the manufacturing process adopted for some of the fireworks: an uncontrolled modification in raw materials (due to pollution) would have altered product behaviour. A chemical incompatibility stemming from these anomalies wound up causing heating and ignition of the materials present onsite.

- As a general consideration, pyrotechnic experts advise the following:
- compliance with basic manufacturing rules, in order to avoid pollution, e.g. dedicated equipment to specific product families;
 - for manufacturing purposes, only the use of products certified by the inspection department;
 - adoption of clear and comprehensible operating protocols;
 - systematic labelling of products, especially after any operation involving product splitting.

Moreover, the local Prefect enacted an emergency measure order upon the proposal of the facilities inspection unit, requesting a detailed report on the incident, with submission of an assessment on monitoring and detection instrumentation to be implemented, and requiring additional measures throughout renovation works on the destroyed premises.

ACCIDENTS



ARIA 19145 - 01/04/1999 - 84 - MONTEUX

20.51 - Manufacturing of explosive products

In a pyrotechnic plant, a fire broke out in the material destruction zone while unloading a lorry containing boxes of pyrotechnic products (fireworks and other chemical products). «Mad peas» firework products or chemical materials caught on fire and triggered a violent blaze consuming those products already placed on the slab and in the lorry. One employee was seriously burned and another sustained more minor injuries. The lorry, which had been parked near the slab and not in back of the fire resistant wall, was destroyed.

Initial investigation findings included the following observations: the types of products being transported were poorly known and poorly catalogued. Incompatible products, like for example chemical materials and pyrotechnic devices, were able to make contact with one another. Similarly, products sensitive to friction or shock could have been spread on the ground, thereby increasing the risk of ignition by stepping on one. Moreover, the employee severely injured was not wearing any safety clothing.

Pyrotechnic specialists have stressed the following recommendations:

- the need to reduce the quantity of material to be destroyed as well as the quantity located within proximity of the destruction zone;
- the benefit of keeping destruction zones cleared of materials in order to facilitate emergency exit paths;
- the importance of training provided to destruction technicians (wearing of protection equipments, knowledge of specific risks, etc.);
- the emphasis on efficient emergency response and communication resources.



ARIA 21310 - 21/06/1996 - 09 - MAZERES

20.51 - Manufacturing of explosive products

At a pyrotechnic plant, a violent explosion erupted inside a production unit due to compression in the triggering delay on recreational fireworks (delay referred to as «espolette»). The explosion took place at the level of the loading machine housing, during a black powder compression phase, and was followed by 2 less intense bursts. The spread of debris and shattered material were noticeable. The technician sustained multiple injuries (thorax, forearm, face, including an eye and neck). Property loss was considerable: the machine was damaged (broken protection screens, inoperable black powder flow system, a portion of which had been projected through the back partition on the box embedded within the aluminium frame on the blast-proof wall, a compression piston split into several pieces strewn over a 6-m radius), deterioration as well to the adjacent workstation (broken side screen, ruptured piston, burned hopper contents).

The accumulation of explosive product, combined with poor positioning of the socket and trajectory of the piston through the delay mechanism, would have caused this accident (punching, thus causing a friction-rubbing contact). The violence of the explosion, along with an analysis of the projection paths, suggests that the black powder had gradually accumulated inside a cavity at the level of the clearance hole on the power feed system inside the machine housing (with a free air volume of 67.2 cm³). This cavity had not been identified as a dust trap and, as such, no guideline was issued calling for its periodic disassembly for cleaning. The disassembly of devices on other workstations led to observing a case where powder was effectively present.

Before restarting the unit, the operator eliminated tube confinement and pyrotechnic powder trapping in the openings; moreover, the operator established a general machine cleaning instruction sheet and revised the screen protection procedure by avoiding the use of metal elements as much as possible. It was also proposed to modify the pneumatic casings (through the use of programmable automatons?). Experts have emphasized the risks of dust accumulation and underscored the importance of implementing appropriate cleaning guidelines.



ARIA 22516 - 13/06/2001 - 69 - RILLIEUX-LA-PAPE

20.51 - Manufacturing of explosive products

In a storage facility dedicated to recreational fireworks, a package containing firecrackers (1.4G category, originating in an Asian country) fell during unloading. A firecracker exploded and then, one by one, the remaining firecrackers wrapped in the same package popped, yet without causing any splattering capable of spreading fire. The alarm was sounded and the personnel reacted according to the posted procedure. The burning package was neutralised by the site's fire prevention unit using multi-purpose powder extinguishers. External fire-fighters called to the scene did not need to intervene. Based on an investigation, the products were found to be defective. A poor seal of the fireworks envelope led to the release of a large quantity of pyrotechnics composition, which then ignited subsequent to mechanical aggression during handling.

Experts in this field have suggested strengthening quality controls as part of the product acceptance protocol.



ARIA 22843 - 10/05/1994 - 09 - MAZERES

20.51 - Manufacturing of explosive products

In a pyrotechnic plant, the onset of fire followed by a localised blaze happened during the manufacturing of fireworks. Following a black powder coating operation, performed remotely, the products were laid out on a tray positioned on a cart for subsequent transfer into a drying oven. The accident occurred as the technician was setting a 5th tray onto the cart; he left the premises upon hearing the crackling sound of fire, which was followed by the actual outbreak, completed with the spraying of pieces of burning material. The technician suffered 1st-degree burns on 20% to 25% of his body, with some 2nd-degree burns as well. The shop room and machinery were also damaged.

The pyrotechnic composition treated and used to manufacture flexible stars was made from barium nitrate, magnesium and the chemical lucovyl. The exothermic reaction was due to an incompatibility, in the presence of humidity, between the pyrotechnic composition and sulphur contained in the black powder. Electrostatic discharge was another possible cause.

The lessons drawn from this accident basically relate to prevention efforts focused on both static electricity (design of a conducting can system to enable the flow of charges during the coating operation, plus the systematic use of metal trays for drying) and chemical incompatibility (use of a colour code for trays and other tools to distinguish their application; tray storage exclusively inside closed premises in order to avoid the presence of atmospheric humidity). The guidelines and operating protocols would be modified accordingly.



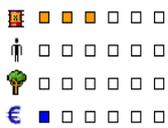
ARIA 27249 - 01/06/2004 - 47 - VILLENEUVE-SUR-LOT

20.51 - Manufacturing of explosive products

Around 11:20 am, an explosion ripped through a building of a Seveso classified facility used to manufacture fireworks. Extended by an awning, the building in question contained 2 parts separated by a reinforced wall. According to the facility manager, 2 employees beneath the awning began assembling 60-mm fireworks shells (powder + stars in a plastic shell) in order to subsequently produce several candles. These stored materials, following assembly in the first part of the building, were considered as belonging to Division 1.3 (normally not leading to detonation). The building's second part was where the filling step took place on shafts (composed of an alternation of shells and active material used for their ejection), which were then transported to another building. According to witness testimony, the accident occurred in two stages: an initial explosion followed shortly thereafter with a second, more violent explosion accompanied by thick white smoke. Both employees working in this building at the shell filling / assembly stations were killed; their bodies would be found at distances of 20 m and 25 m from their station. Two other employees were slightly injured (hearing disorders) in nearby buildings. The extent of property damage attests to the violence of this explosion; 14 of the facility's 27 pyrotechnic buildings were either totally or partially destroyed, 9 others damaged, and 5 others had to be razed. The building where detonation struck was totally obliterated, with a crater 3 m x 1.5 m x 0.5 m deep visible in the concrete foundation plate. A 50-kg cart was projected a distance of 150 m, chunks of the wall littered over a 50-m radius. The blockhouses storing the explosive substances were slightly penetrated. No domino effect was observed. Only a few impacts were noticeable outside the facility, with the exception of the nearest residence (broken windows). 2 employees had to be made redundant due to the ensuing shutdown. A judicial and administrative investigation was conducted in order to determine the causes. Upon proposal of the inspection authorities, the Prefect issued an emergency order requesting: shutdown of the site's manufacturing activities, disposal of finished products, restoration of the premises in order to ensure the storage of pyrotechnic substances in accordance with their certification stamping, and the separation of storage spaces between end use and intermediate products.

Given the effects observed, this pyrotechnic material wound up detonating; the TNT equivalent was estimated at 15-30 kg. While the origin of the fire outbreak remained unknown, it could have been exacerbated by configurations prohibited inside the building (the door separating the two premises being left open with a relay effect due to the handling cart?). The risk introduced by products typically stored on these premises had been poorly evaluated (with the risk of detonation being overlooked, despite the presence of «bulk» storage within a confined space).

ACCIDENTS



ARIA 36014 - 08/08/1983 - 84 - LORLIOL-DU-COMTAT

20.51 - Manufacturing of explosive products

In a fireworks production plant, a handling error (dropped material) inside a packaging workshop caused a («revolving sun») fireworks display to ignite around 2 pm.

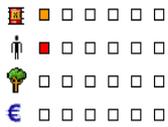
The technician was unable to extinguish the fire using the extinguishers at his disposal; he escaped the building and sounded the alarm, while incandescent projections were reaching the neighbouring containers.

All hangars and buildings on the site were one-story metal frame structures with walls and a roof made of sheet metal profile section (movable roof), all of which was supported on a concrete slab. The fire, which quickly gained in intensity, spread within 20 minutes in all directions, by means of rockets and ignited debris, reaching pallets of fireworks awaiting shipment nearby, then anti-hail rockets stored 20 m away. The successive explosions of anti-hail rockets in turn caused fire outbreaks inside other buildings, in addition to igniting onsite vegetation (cypress hedges) and a field 800 m offsite. Backup was called to help contain new fire outbreaks in the vicinity of the depot.

The fire was contained around 3:15 pm through a deployment of major fire-fighting resources: two 1-tonne capacity pump trucks and 12 tanker lorries used for fighting forest fires. This equipment was fuelled via suction points set up along a canal crossing the area of intervention and constituting a 1,200-m³ water reservoir. All individual fire sources were extinguished by 6 pm. Fire-fighters' effective knowledge of the site and of fire-related risks, thanks to joint drills performed with the company's safety unit, led to a successful intervention. No injuries were reported; property damage consisted of 7 collapsed buildings and a few vehicles (trailers, handling devices).

Powder storage areas were split into small distant structures located in a wooded zone that was not reached by the blaze. The high-quality site design made it possible to mitigate fire development and thereby avoided a more widespread accident. Nonetheless, due to the extreme heat, employees had opened building doors for ventilation, which in turn allowed flaming projections to enter into these premises and thus spread the fire to 2.8 tonnes of fireworks. The operator wound up adopting the following measures:

- Reinforcement of the protective features on the part most sensitive to the revolving fireworks ignition device, i.e. of the «hawthorn» type: a plastic design was to replace the brown wrapping paper;
- Closure in the packaging centre where anti-hail rockets were being stored; this zone was directly responsible for the fire spreading and moreover gave rise to many secondary fire sources;
- Protection of building openings by means of a grating;
- Construction of fire walls across from buildings whenever the building orientation so dictated;
- A 25-m spacing for all buildings used to store fireworks, with this distance being reduced should screens be installed to resist both projections and heat radiation;
- Strengthening of operating rules in order to ensure continuous compliance with maximum allowable quantities in the various storage locations (even for short periods on intermediate storage facilities, given the risk of a relay effect);
- The doors to intermediate storage depots were to be kept closed in the absence of employees.



ARIA 36876 - 01/06/1990 - NC - NC

20.51 - Manufacturing of explosive products

A technician was preparing 250 g of an explosive mixture to produce firecrackers used as alerts by divers. The technician noticed at the end of the mixing process the presence of lumps in the composition and decided to run it through a sieve. In order to streamline the operation, he added a porcelain bead into the composition. Turning on the sieve triggered the blast (due to friction), which ejected the technician 1.5 m; he suffered from noise-induced hearing loss. The door to the shop room was blown 10 m off its hinges, a partition wall and the suspended ceiling both collapsed. The technician's decision to initiate an additional work step not included in the protocol was the cause of this accident. The operator recalled to staff the need to strictly apply and not deviate from the protocol.



ARIA 37060 - 10/03/1988 - 40 - SAINT-PAUL-LES-DAX

20.51 - Manufacturing of explosive products

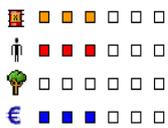
A fire broke out in an oven for drying fireworks stars at the time a technician remotely opened the oven doors to cool the contents. The 30 kg of composition made from barium chlorate, accroides gum, fine coal and sulphur were consumed by the fire, accompanied by projections of ignited stars. The oven was completely destroyed. This incident was the second in two months (see ARIA 37058) following a process modification that called for the reintroduction of manufacturing rejects into the normal cycle. Further testing on the composition revealed that this step of reintegrating manufacturing rejects into the normal cycle served to drop the spontaneous ignition point of the composition to 75°C, which was a temperature potentially reached during oven heating phase. Rejects would no longer be added back into the production cycle, but instead directly destroyed. Also, an additional safety device would be installed on the oven heating unit.



ARIA 37084 - 20/10/1988 - 84 - MONTEUX

20.51 - Manufacturing of explosive products

In a pyrotechnic facility, a technician was producing fireworks (jets with coloured grains). After compression of the pyrotechnic composition, one of the («sticks») used as a punch was still stuck in the matrix. The technician used a bronze sledgehammer to loosen it, and in so doing triggered the composition. The fire was confined to the products on the particular workstation. Excessive machinery wear was found to be the cause. The operator produced a new set of machines and instituted a periodic equipment control procedure.



ARIA 38267 - 12/04/1977 - 84 - MONTEUX

20.51 - Manufacturing of explosive products

In a fireworks manufacturing facility, a succession of explosions (perhaps 5 in all), 3 of which were more violent, destroyed a coating workshop (where black powder was being coated) and spread fire to neighbouring workshops (through the domino effect). The building (cement floor, cladding and fibre cement roof, without any doors) was completely demolished. The technician inside was killed on the spot; another, located 180 m from a building, was seriously burned and died at the hospital. A total of 19 employees were injured by flying glass, 2 of whom in critical condition. Windows were shattered within a 800-m radius. Beyond the site boundary, broken glass panes were recorded on homes as well as in a secondary school 200 m further away. The site's other buildings were damaged, with doors ripped out and windows smashed, etc.

The fall of a tray or star triggered the reaction, which was then exacerbated by an accumulation of chlorate products with great sensitivity inside the coating workshop. The rated value of the building was set at 40 kg; according to experts, the quantity present would have reached near 260 kg. Moreover, the safety organisation was shaped around the fire hazard, as the explosion risk had not been identified.

Experts recalled the importance of detailed workplace safety reports that take into account the risks presented by chlorate products; they also emphasised the need to conduct operations on sensitive substances and split loads (decoupling) within a protected environment. The authorised workstation quantities must be closely respected and the schedule set to ensure avoiding all product accumulation.



ARIA 39303 - 29/05/1866 - 75 - PARIS

20.51 - Manufacturing of explosive products

An explosion occurred around 5 pm inside the production workshop operated by a pyrotechnician. Fire spread to the charger workshop, which was adjacent to the production shop, as a consequence of changes introduced by the manufacturer following expropriation of a portion of the facility. The fire also spread to the composition workshop, located 7 m from the workshop where the explosion first erupted. However, 65 kg of powder, along with the entire inventory of fireworks, the fireworks colour room and other lightweight buildings were all spared. Fire-fighters counted 23 dead and 12 seriously injured, all of whom were transported to the nearest hospice facility. The press announced a total of 40 victims. The Public Health & Hygiene Council made a site inspection. The suddenness of the explosion, coupled with the fact that the most heavily damaged wall was the one with the lightning rod attached, suggested that lightning may have been at the origin of this catastrophe. The pyrotechnician moved his set-up to Prés Saint-Gervais and introduced prevention measures, namely: safety distance between the fireworks depot and the charger workshop and then between the charger workshop and the colour warehouse; separation of production facilities from storage areas; buildings designed for rapid evacuation; heating by the circulation of hot water; lighting by lamps with reflectors positioned outside the workshops; and protection of window surfaces (using blinds) in order to avoid materials heating up and prevent malicious intent.

TECHNOLOGICAL ACCIDENTS ONLINE

Safety and transparency are two legitimate requirements of our society. Therefore, since June 2001 the website www.aria.developpement-durable.gouv.fr of the Ministry of ecology, energy, sustainable development and the sea has been putting lessons learnt from the analysis of technological accidents at the disposal of professionals as well as the general public. The main sections of the website are presented both in French and English.

Under the general sections, the Internet user can, for example : inquire for the state's action, access to wide extracts of the ARIA database, discover the presentation of the European scale of industrial accidents, inquire for the "dangerous substances parameter" used to complete the "communication on the spot" in case of accident or incident.

Accidents description, which is the raw material of any method of feedback, constitutes an important part of the website : when known, events, consequences, origins, circumstances, established or presumed causes, actions taken and lessons learnt are compiled.

Over two hundred detailed and illustrated technical reports present accidents selected for their particular interest. Numerous analyses sorted by technical subjects or activities are also available. The section dedicated to technical recommendations develops various topics : chemistry, explosives, surface treatment, silos, tyre storage, hot work permit, waste treatment, handling ... A multicriteria research engine enables getting information about accidents arisen in France or abroad.

The website www.aria.developpement-durable.gouv.fr develops constantly. Currently, more than 40 000 accidents are online and new topics will be regularly added.

The summaries of the accidents presented in this document are available in French at:

www.aria.developpement-durable.gouv.fr

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