Incident

Series of mass explosions in a fireworks plant

Fausta Delli Quadri, ISPRA, Italy

Summary

In 2013 a series of explosions occurred in a fireworks facility. The first three explosions occurred in close sequence, near the depots no. 4 and 5, where fireworks were stored. The blast caused three fatalities. The depots exploded almost simultaneously, involving all the explosive content.

At the time of the accident, according to the results of a preliminary investigation, some operators (the victims) were probably loading the fireworks from the depots onto a small truck located close-by. The truck was used for the internal transport of the explosives. The fireworks had to be transferred to other trucks parked near the entrance of the plant. These trucks were found partially loaded containing some explosive materials after the accident.

The operators were extremely busy in preparing and transferring the fireworks, due to a large number of firework displays planned at festivals in the country at that time of the year. About 40 minutes after the first three explosions, a fourth explosion, caused by domino effect, occurred in the depot no. 8. The maximum authorised capacity of the depot was 9.6 t of explosive. It was first damaged by the pressure and blast wave of the previous explosions, and then was probably hit by fire debris thrown from the subsequent minor blasts and exploded later probably in bulk. This fourth explosion caused the death of a fourth operator (the owner's son) and a serious injury, which fatally injured a firefighter involved in emergency operations. In total the accident caused five fatalities and injured eight.

The accident caused also serious material damage, completely destroying all the depots of the plant, and damaging off-site buildings up to a kilometre away. Debris of different sizes was found at distances ranging up to one kilometre. Damage to the environment was caused by extensive fires ignited in the surrounding rural area, which were extinguished by the Fire Fighters and Forest Service using two helicopters.

The accident investigation highlighted deficiencies in the safety management system. These included: violation of safety regulations and infringement of safety procedures; failings in the on-site emergency procedures; inadequate siting of the residences; inadequate construction of the roofs of the depots.

Keywords: Fireworks, explosion

Location and installation

The accident happened in a fireworks facility. The plant which extended over an area of ca. 30.000 m², was located on a hill in a rural area in Italy. The plant area included eleven small buildings, used for storage or production, located at different elevations due to the location on a hill (Figure 1).

Two residential buildings (the house of the facility's operator and the house of the facility's watchman) stood close to the plant, at the top of the hill, together with other small buildings used as garages for trucks, offices and depots.

The plant produced and stored fireworks, following the process steps listed below:

- raw material reception and storage
- semi-finished products preparation
- inert crushing by millstone
- colorants mixing
- pressing
- finished products wrapping
- finished products storage.

The plant was classified as a "lower tier" establishment under the Seveso II Directive because of the presence of the dangerous substances above lower threshold limits.

The accident and its consequences

Description of the accident

On the day of the accident, at 10:15 am, a sequence of explosions occurred in the storage area of the fireworks plant. At the time of the accident, three workers (the operator himself and two technicians) were transferring fireworks from the buildings no. 4 and 5, used as fireworks storage, to a pick-up truck located in front of them. The pick-up was used for internal transfer. As a following step, the fireworks were to be loaded onto larger trucks located in the area outside the entrance of the plant. These trucks were found partially loaded with explosives products after the accident. The fireworks transfer operations probably triggered the explosions.

Three explosions occurred in buildings no. 4 and 5. The total amount of explosives stored inside these buildings exploded almost instantaneously in a phenomenon called "mass explosion". After 40 minutes, a fourth explosion occurred in building no. 8, also used as explosives storage. This fourth explosion was probably due to a delayed domino effect. The building, already damaged by the blast wave of the first explosions, was probably hit by debris and flying sparks generated by minor blasts that occurred after the main explosions. Building no. 8 exploded in mass too. In total, almost all the pyrotechnic substances stored

0260-9576/18/$17.63 + 0.00

1. Unclassified products storage (products that do not fall under the Italian regulation on explosives storage and production)
2. Black powder storage (max 500 kg)
3. Fireworks laboratory
4. Products storage (max 4 t)
5. Products storage (max 9.6 t)
6. Mixing
7. Colours and various material storage
8. Products storage (max 9.6 t)
9. Engines installation
10. Coal crushing
11. Semi-finished products storage under authorization process (max 7 t). This building was not yet authorised at the time of the accident.

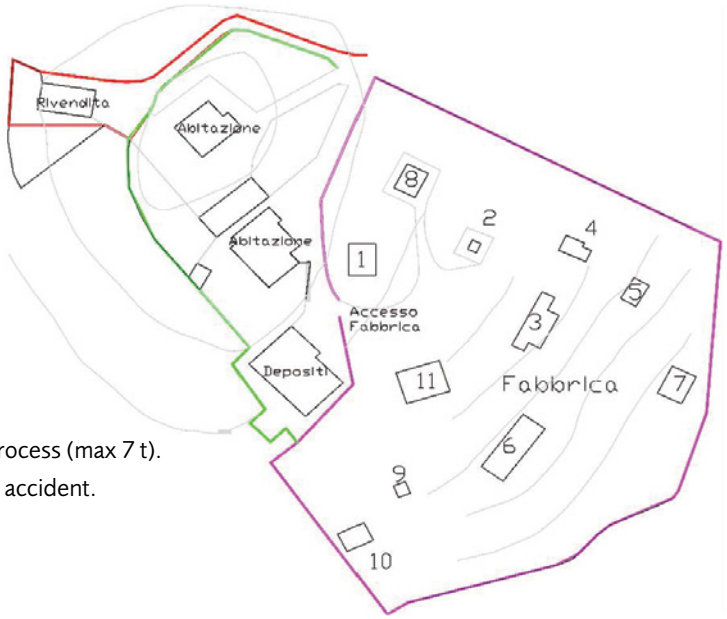


Figure 1 – Layout of the plant

in the plant was involved. Seven of the eleven buildings were destroyed (buildings no. 2, 3, 4, 5, 6, 7, 8). The other buildings were partly damaged (buildings 1, 9, 10 and 11). Figures 2 and 3 shows some of the damage.

Despite the scale of the accident, the company did not properly activate its internal emergency plan. Firefighters were alerted by the inhabitants of the dwellings nearby, who heard and saw the major effects of the explosions. Only after the firefighters had already received eight calls by alarmed residents did a call come from the company. In addition, after the first explosions, because of the high risk of further explosions, the workers were supposed to evacuate the area and to reach the assembly point located outside of the plant. However, the evacuation signal was not given and the employees remained on-site. One worker, the operator's son, went inside the damaged buildings to look for his missing father (the establishment operator) and was killed.

From 10:20 am to 7:30 pm, eight firefighter teams were involved in managing the emergency operations, using fire-trucks, water pumps, helicopters and fire-planes. Firefighters encountered difficulties in their intervention due to the layout of the access ways and of the plant itself. The area outside the entrance of the plant was too small for easy access of fire-trucks and equipment and there was only one access from where it was possible to manage the emergency. The set-up of the plant did not allow them to easily manoeuvre their fire trucks and to manage the fire systems. The emergency was considered concluded after nine hours, during which other local authorities arrived together with the prosecuting authority, which seized the whole area.

Accident consequences

The three persons that were occupied with the transfer operations, two technicians and the facility's operator, were instantly killed by the first series of explosions. A fourth person, the operator's son, was hit by a piece of the roof projected by the explosion of building no. 8 while he was searching for his missing father. A firefighter was also hit by a projectile triggered by the explosion of building no. 8. and died three months later in hospital. In addition, three workers and five firefighters were injured during the emergency operations.

Further to that, the explosions caused the total destruction of

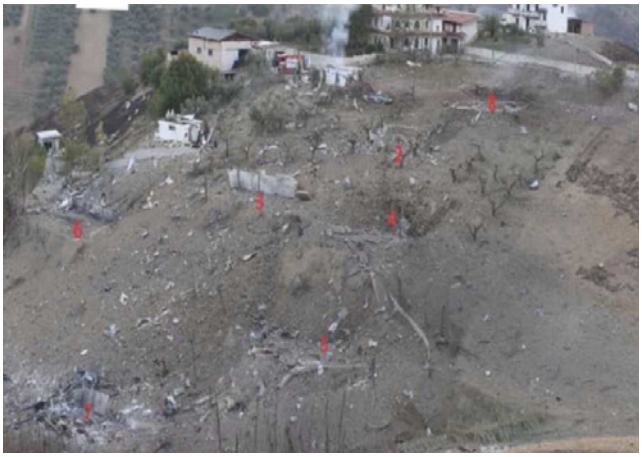


Figure 2 – The remains of the plant after the accident

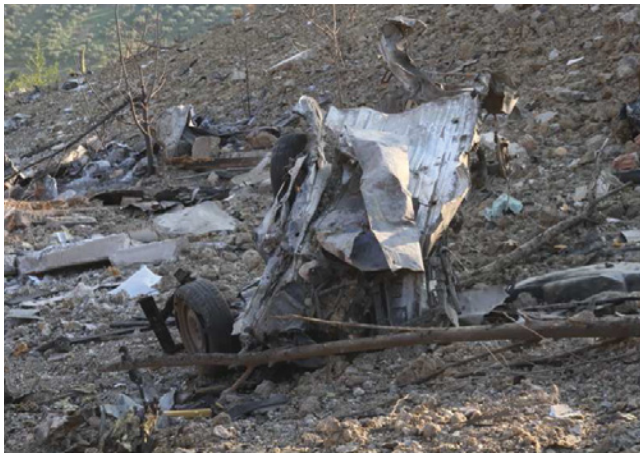


Figure 3 – The remains of the pick-up truck

0260-9576/18/$17.63 + 0.00

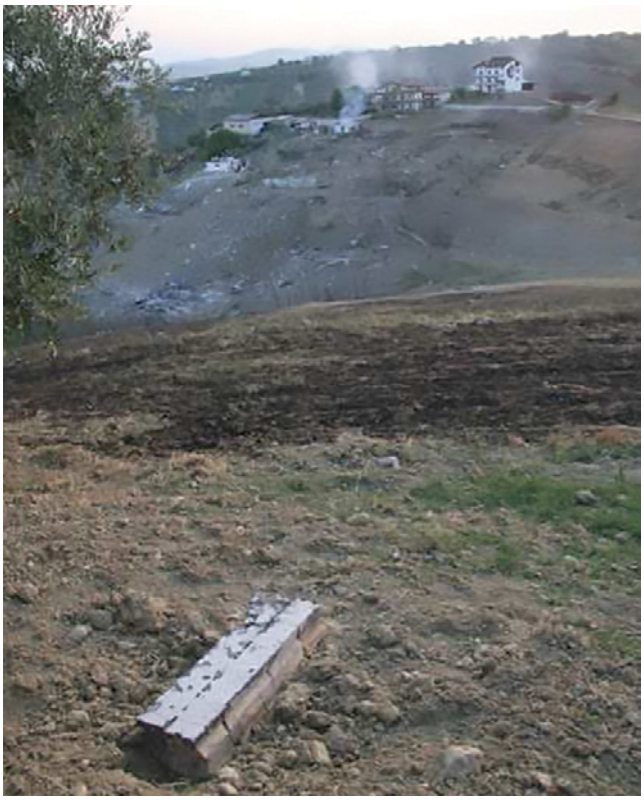


Figure 4 – Piece of concrete found more than 900 m away from the plant

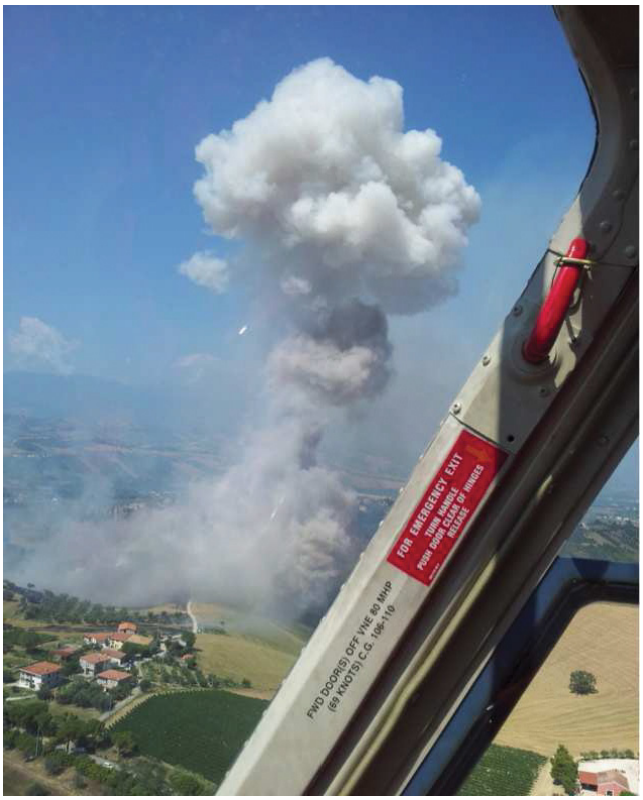


Figure 6 – Toxic cloud emitted to the atmosphere

almost the entire establishment. The blast waves caused damage to several buildings (houses, church, factories,...) within a 500 m radius. Debris was projected up to a radius of 1 km (Figure 4). In total, the accident caused an estimated financial loss of 1.5 million euros.

The accident generated a sequence of fires in the rural/natural area surrounding the plant (in a 500 m radius) (Figure 5), and a large cloud of gaseous products (including toxic substances) was observed after the explosions (Figure 6).

The accident was classified as a "major accident" in accordance with the Seveso Directive, due to the extent of the human, materials and environmental consequences.

Causes of the accident

The Major Accident Hazards Bureau of the European Commission conducted an investigation and also obtained some information about the dynamics of the accident from the company's technical investigator. On the basis of gathered elements, it is possible to identify some probable causes of the accident.

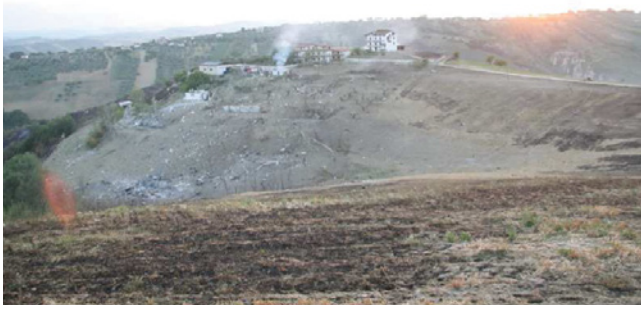


Figure 5 – Fires in the area around the plant

Presence of different dangerous products

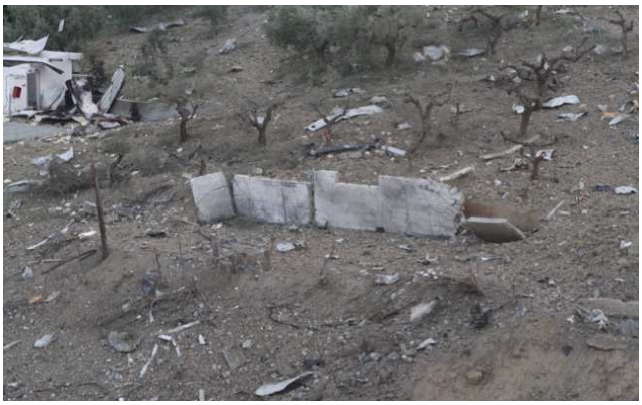
After the accident different explosive products, including fireworks probably already "armed" with a detonator were found in the remains of the plant and also in the trucks parked just outside the plant, near the operator's house. Operations such as transferring and loading of such pre-armed products are extremely risky and it is possible that the transfer operations conducted by the workers in front of buildings no. 4 and 5 triggered the explosions. The material damages observed in the storage buildings and their protection walls (Figures 7 and 8) show a possible disintegration effect, which is evidence of a "mass explosion" (the entire explosive amount exploded almost instantaneously). This phenomenon indicates that it is highly likely that dangerous pre-assembled explosive products were present at the moment of the accident.

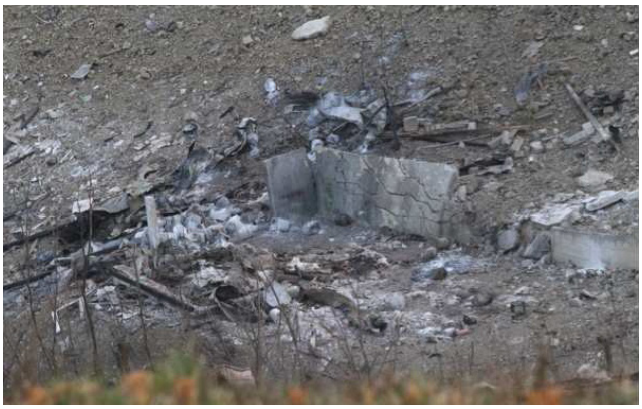
Storage of excessive quantities

After the accident, local firefighters carried out an approximate estimation of the effects of the explosion by applying the TNT equivalent method: the results were that the real accident effects (effects' distances in a range from 100 to 500 m from the plant) were probably greater than the possible estimated effects (that remained within a radius of 100 m from the plant).

Moreover, a domino effect occurred in building no.8 40 minutes after the first explosions. As shown in Figure 9, building no. 8 had already been damaged by the first blast wave. The

0260-9576/18/$17.63 + 0.00





Figures 7 and 8 – Damage caused to the buildings and their protection walls

occurrence of a domino effect leads to the conclusion that there might have been more quantities and different qualities of explosives stored in the plant. Furthermore, 20 days after the accident, an additional amount of black powder (0.2 t) was discovered in a small disused building located outside the establishment, next to the south part of the fence.

Productive pressure led to a lapse in safety procedures by the technicians

At the period of the year where the accident took place, summer time, the company was particularly busy in preparing fireworks that would be used for fireworks displays in the nearby town festivals. These circumstances probably placed time pressures on the technicians, who were in a rush to perform their tasks. These time constraints, associated with a possible excess of confidence of the technicians regarding their level of management of their tasks (the three workers had all longtime experience in managing explosives), could have led them to work in unsafe operative conditions.

Deficiencies in plant design and emergency procedures led to increased consequences

Important deficiencies could be observed during the execution of the internal emergency procedure. The company failed to call the firefighters immediately and failed to activate the evacuation plan after the first explosions, which considering the risks due to further explosions should have been a priority. In addition, inadequate layout of the plant in terms of emergency access

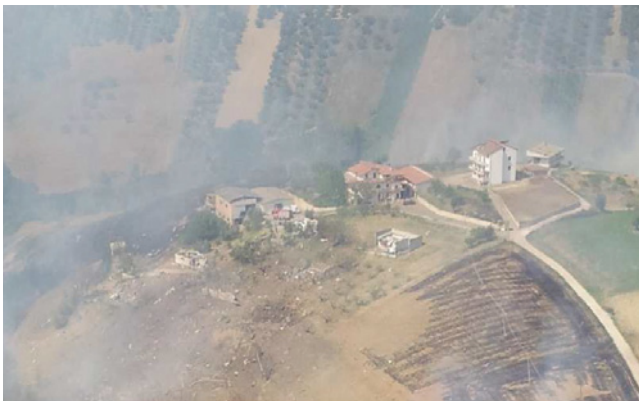


Figure 9 – View of the plant after the first series of explosions

hampered firefighters' efforts. The inappropriate location of the watchman's and operator's family houses in the immediate vicinity should also be noted (visible in Figures 2 and 9), with both buildings suffering substantial damage.

Last but not least, it would appear that the construction of the roofs of the depots was unsuitable, with debris from the roofs leading to a fatality.

All these problems in terms of conception, design and procedures reveal failures in the identification of risks by the operator.

Lessons learned

This accident, and the failures identified in the Safety Management System highlight some key lessons. These points are critical issues on which attention should be focused in fireworks plants:

- **Respect of safety regulation and safety procedures, in terms of quality (compatibility) and quantity of explosive products managed or stored inside a plant.** The operating practices employed by the company were unsafe and indicated negligence. In particular, primed explosive products fitted with electric fuses were found in the factory. Compliance with norms and standards for handling explosives should be an ongoing subject of audits, inspections and training on explosives production and storage sites.
- **Safe operating conditions and adequate behaviour/ competence of operators in working and preparing explosive products, especially during peak activity.** Stressful working conditions and pressure to complete jobs in a hurry can lead to violation of operational procedures and create hazardous situations. Dangerous processes require a stable time frame for handling the procedures properly and time schedules to delivery should be planned accordingly. Operators need to maintain a culture of constant vigilance and prevent any complacency in the handling of explosive substances. Typical strategies often include strict enforcement of safety procedures at all times, building awareness of accident potential through posting of near misses and accident lessons learned (from onsite or elsewhere), and frequent safety meetings where near misses or incidents of safe and unsafe behaviour can be discussed.
- **Adequate internal emergency procedures, especially**

0260-9576/18/$17.63 + 0.00

in terms of activation of the emergency plan (call to the firefighters), and evacuation of personnel. Due to the risks from further explosions, evacuation of personnel should have been a priority. The fire-brigade should have been notified immediately. The on-site emergency plan should have been practiced so that it was known and understood by all persons on-site

- **Adequate layout of the plant, in terms of emergency access for external firefighters, in order to allow easy access to the area for fire trucks and other equipment.** The layout of the plant and access to the site should be considered so that firefighters are able to respond at any time. Only having one access route is a severe limitation. Regular drills should be carried out between the site operator and the fire-brigade to ensure that access remains available and that any problems which could limit a response are identified early on and dealt with.
- **Use of adequate construction materials (for example for the roofs of the buildings), in order to avoid increased human consequences in case of an accident.** Construction of the roofs of depots for explosive materials should be such that to avoid any subsequent injuries or domino effects. Where the whole construction is not blast proof, it is common practice to have roofs made of light materials which are then anchored by chains. The roof is not permanently bonded with the walls and in the event of an explosion the lifting of the roof acts as a pressure relief.
- **Risk analysis is essential.** Without adequate systematic hazard identification and risk analysis appropriate measures to counter those risks cannot be adopted. This step, correctly applied, would have addressed all the above-mentioned issues.
- **Applying the principles of inherent safety**. This means that only the quantities required are made available at any one time; that fireworks are not fitted with ignition/detonation systems until they are required; that the storage units (depots) are constructed so that there is no propagation from one depot to another (this means in practice that the doors of one unit are not directed towards the doors of another unit. Only one set of doors should ever be open at any one time).

Conclusion

Fireworks manufacturing plants continue to be one of the most critical kind of establishments, and it does not appear easy to find a good and efficient Safety Management System (SMS). In spite of the simple processes carried out, and the small size of the plants, the highly hazardous nature of the substances (explosives) leads to the operations having a high level of risk which needs to be well managed, for example within the Seveso Directive regime. Cases still occur almost every year in Italy, often leading to very serious impacts, as in the accident presented in this article.

All the problems pointed out from this accident analysis, in terms of SMS deficiencies, reveal a substantial lack of risk identification by the operator. Seven months before the accident, a detailed SMS inspection had been conducted by the Regional Environmental Agency, which pointed out several serious failings in the plant's SMS, clearly related to the causes of the accident. This led to reflect on the importance of the inspection activities in the fireworks plants, which strategy should include a follow-up of the actions taken by an operator to correct the errors and defaults identified during a previous review.

From this point of view, the implementation of article 20 No. 7 of the Seveso III Directive 2012/18/EU, requiring the competent authority to communicate the results of inspection to the operator within a period of four months and following this that the authority shall ensure that operator takes appropriate action, could help Member States to enhance the safety of the inspected establishments.

References

1. *EMARS Accident #939 – ISPRA/INAIL/CNVVF – February 2014*
2. *IMPEL – French Ministry for Sustainable Development - DGPR / SRT / BARPI – ISPRA (Italian National Institute for Environmental Protection and Research) No. 46088 – March 2015*
3. *ARIA-BARPI No. 46088 ISPRA*
4. *Seveso III Directive: Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances, amending and subsequently repealing Council Directive 96/82/EC, OJ L 197, 24.7.2012, p. 1–37*

0260-9576/18/$17.63 + 0.00