Pneumatic explosion during an intervention on a pipe at a pyrotechnic plant

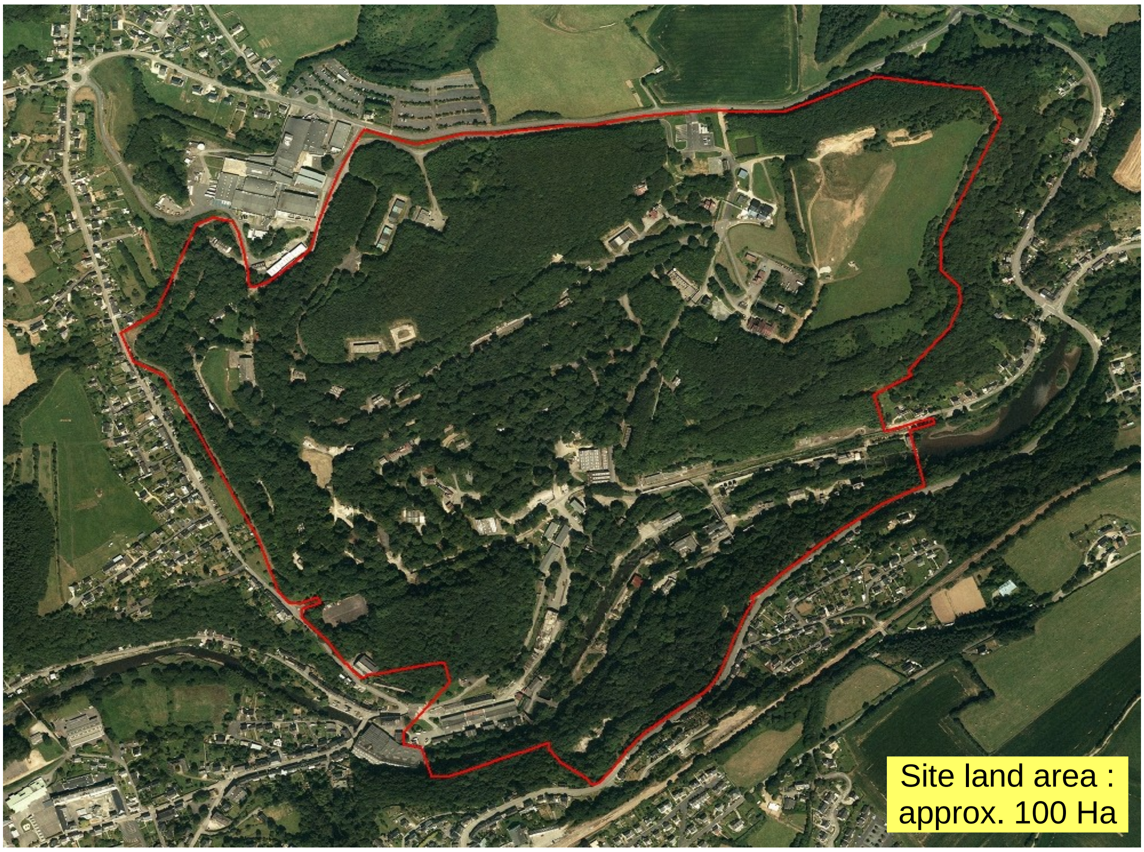
30 July 2014

Pont de Buis (Finistère)
FRANCE

Pyrotechnics
Pneumatic explosion
Organisation / Procedures

THE FACILITIES INVOLVED

The site:



The facility was producing:

- primarily powders for hunting and sport shooting;
- but also products for law enforcement (tear gas grenades, smoke grenades, explosive cartridges, etc.), plastic materials and composites.

On-site activity included the storage and shipment of finished products as well as the destruction of pyrotechnic waste.

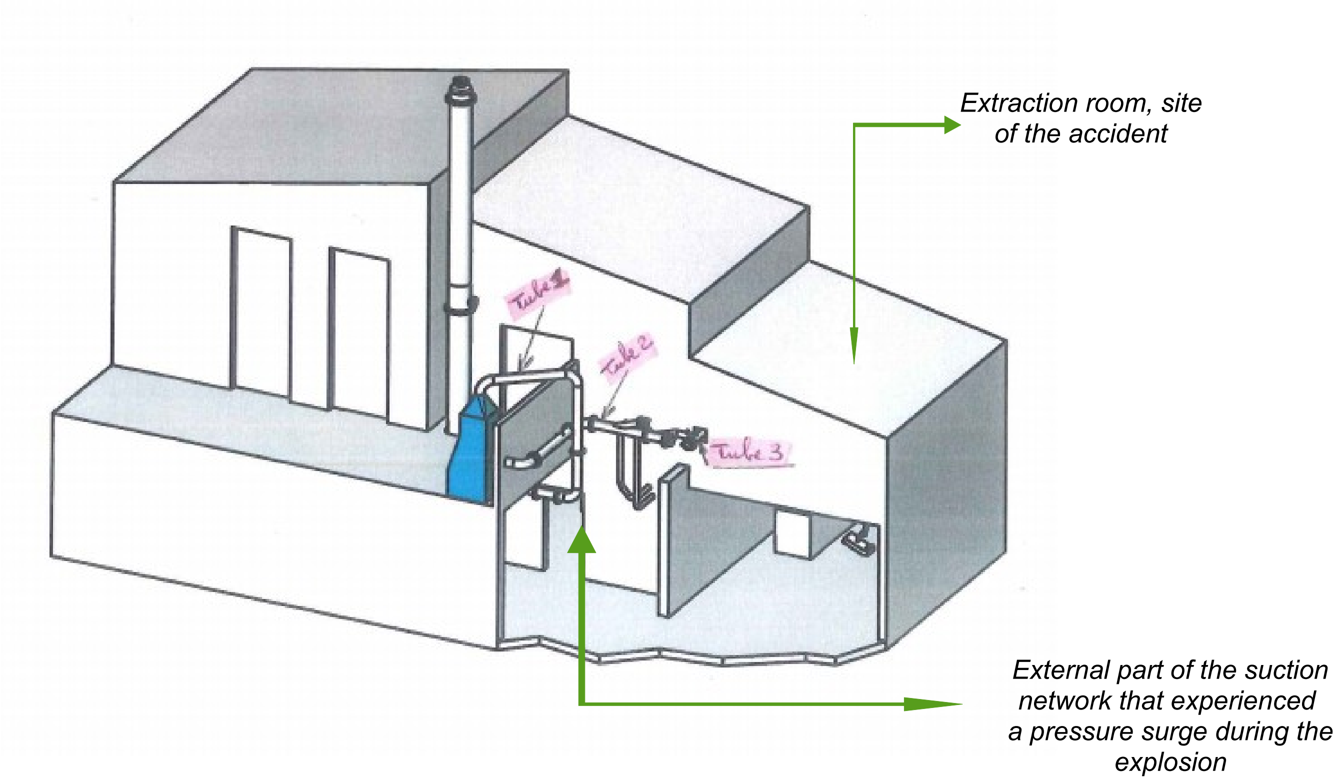
The facility was under the autorisation regime with easements, as prescribed under Book V of the Environmental Code, and moreover falling within the "upper tier" category of the Seveso II Directive.

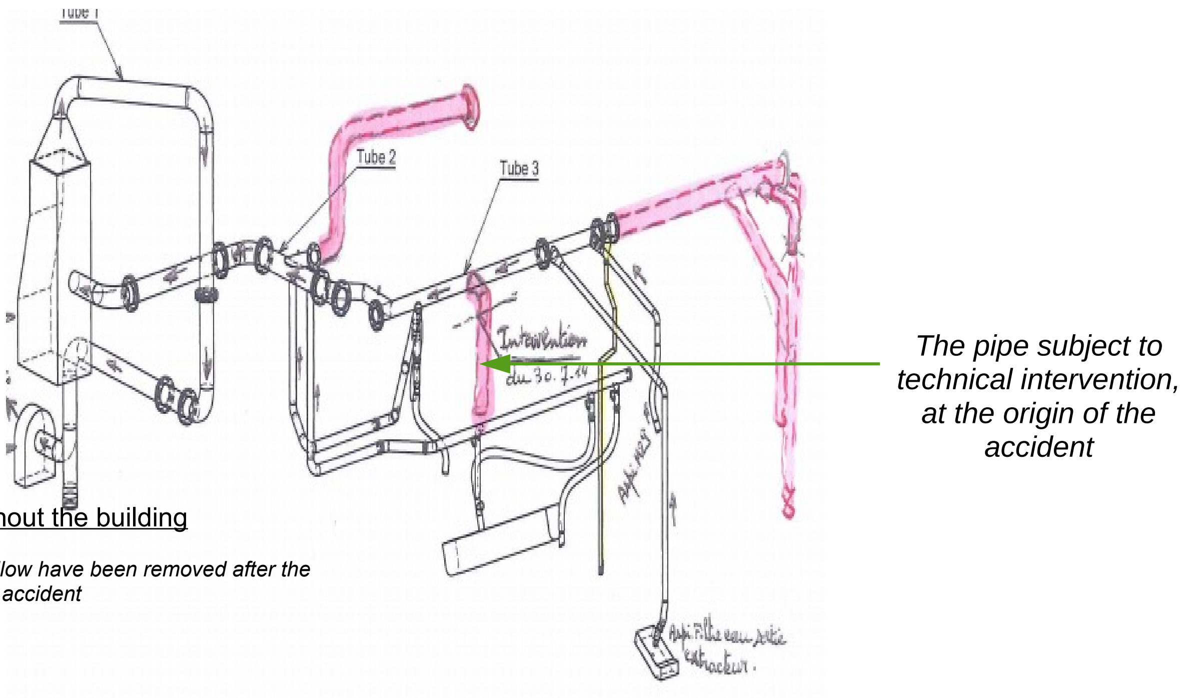
The involved unit:

The installation involved was one of the powder production units. A double-screw extruder, fitted with a double worm gear, made it possible to continuously perform in just a single operation:

- the assembly and mixing of raw materials;
- their extrusion via a dedicated line;
- the cut-out step to obtain powder.

The accident occurred inside the "extractor" room located on the ground floor of the production workshop. This room was equipped with machinery for extracting the solvents contained in the powders output by the double-screw extruder operating on the floor above. This extraction entailed washing with hot water circulating upstream in a worm gear. The solvent-laden water recovered was then channelled to a distillation unit for solvent regeneration. In conjunction with this step, the air filled with volatile organic compounds (VOC) was also collected by a suction network for distillation treatment prior to discharge. This network wound up at the origin of the accident.





View without the building

The pipes in red and yellow have been removed after the accident

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

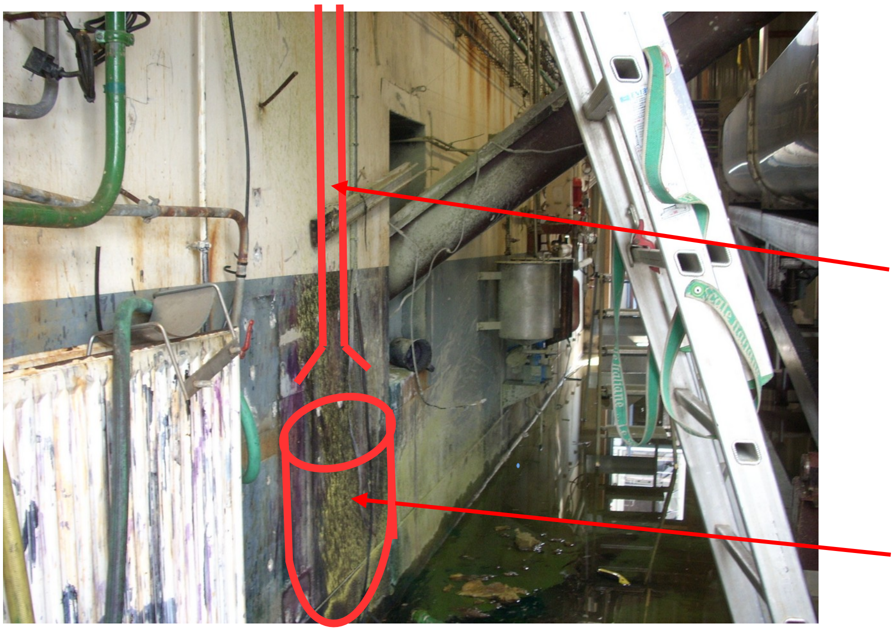
The accident:

The accident occurred during the 3 weeks annual maintenance period. This down period was dedicated to performing various maintenance operations and repairs.

The accident happened as an intervention was conducted with the purpose of modifying the powder dye installation: a dye tank was to be replaced and then disassembled.

Taking the former dye tank off-line rendered inoperable the air extraction network duct at the site of the tank. In order to definitively remove this ductwork, a technician assigned to the powder manufacturing workshop began to cut away with a metal saw the particular section of pipe (a vertical, 80 mm diameter stainless steel tube). During this operation, a second technician was tasked with flooding both the saw blade and pipe from the outside. These two technicians were positioned approx. 2 meters above ground on ladders placed on both sides of the pipe being sawed.

Around 4 pm, **this pipe experienced a pneumatic burst.**
The explosion did not spark a fire or trigger a secondary explosion. The building was cooled by deploying the company's water reserves.



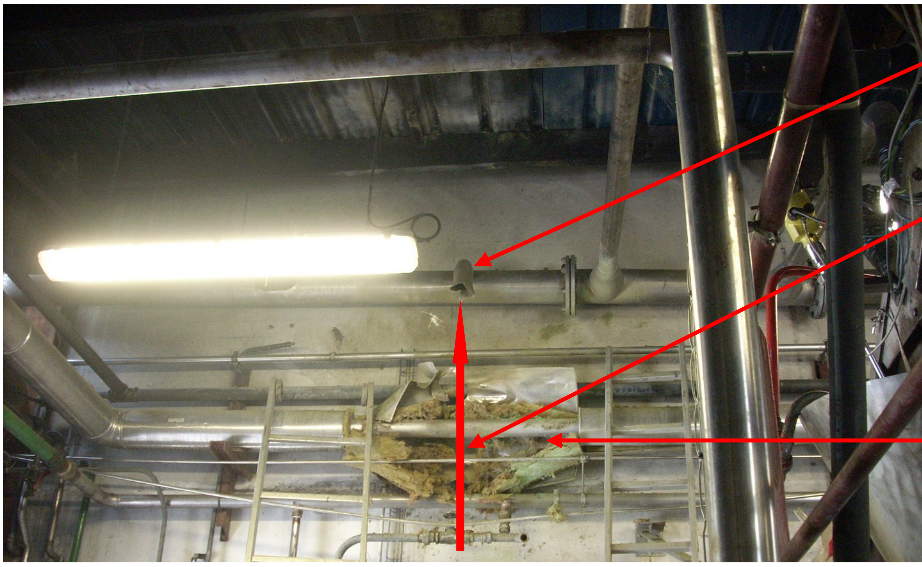
Location of the suction pipe that was rendered inoperable, i.e. the origin of this accident

Location of the former dye tank (under the pipe at the origin of the explosion)

The consequences of the accident:

Material consequences:

The powerful pressure surge associated with the explosion led to considerable metal debris being blasted within the room, as well as ruptures at several vulnerable parts of the suction network. In addition, metal foil installed on flanges was ripped open.
These material consequences were limited to the equipment involved in initiating the event and other machinery located immediately adjacent.



Remainder of the pipe torn off by the explosion

Location of the stripped "idle" pipe section

Damage caused by the explosion on heat insulation of a nearby pipe

The portion of pipe damaged by the explosion was an "empty" conduit from a larger network responsible for collecting VOC-laden air in various zones of the workshop.

Plugs and/or foil present on the suction network that had opened subsequent to the pressure surge generated by the explosion

Human consequences:

The three technicians present in the utility room at the time of the event (two employees, one temp worker) were seriously injured and had to be hospitalised. The two working on ladders sustained facial burns from the flash and pneumatic pipe burst. The third victim, standing on the floor, was struck on the arm by flying metal fragments and these injuries required amputation.

European scale of industrial accidents:

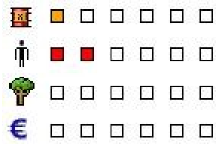
By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the 'SEVESO' Directive on handling hazardous substances and in light of available information, this accident can be characterised by the four following indexes:

Dangerous materials released

Human and social consequences

Environmental consequences

Economic consequences



The index corresponds to hazardous substances released. Level "1" was reached since the accident involved pyrotechnic substances (quantity of explosive substance contributing to the explosion < 0.1 tonne of TNT equivalent).

The index corresponds to human and social consequences; it was scored a "2" due to the fact the accident caused 3 serious injuries (level "2" definition: presence of 2 to 5 serious injuries).

The parameters composing these indexes and their rating methodology are available on the Web page: http://www.aria.developpement-durable.gouv.fr

THE ORIGIN, CAUSES AND CIRCUMSTANCES OF THE ACCIDENT

Primary cause of a technical nature

Pyrotechnic dust residue (a yellowish substance with powdery texture) was present on the metal debris of the stripped pipe (found on the floor of the workshop and outside the building, along the path of the foil that had been ripped apart). These observations indicated that **the pipe had not been adequately washed** during preliminary rinsing steps.

Metal debris, from the pipe blasted by the explosion, found on the floor. The picture on the left shows residue from pyrotechnic dust (yellowish) covering the inner pipe wall.

The fire most likely broke out due to ignition of this powder residue and/or pyrotechnic dust accumulated inside the pipe. This build-up was correlated with the **heating produced by friction of the metal saw blade on the stainless steel suction pipe (hotspot)**.

Root causes of human and organisational nature

A procedure carried out in violation of accepted protocol

According to the plant operator, the extraction pipe cut-out procedure had not been scheduled during the plant's annual closure. It was decided, on the spur of the moment, by manufacturing workshop technicians assigned to perform the dye installation modification. No hot work permit had been issued.

The applicable procedures for supervising works capable of creating hazards stipulated that:

- In the case of repair work on fouled hollow bodies:

  "When cutting out a hollow body that had contained pyrotechnic products (powder, dust, nitrocellulose, etc.) or solvents, or when suspecting their presence, the use of a pipe cutter or tools capable of generating a hotspot must systematically be specified in a hot work permit.";

- The hot work permit was to be signed by the job supervisor, the repair technician and at least one management representative.

When cutting the portion of pipe rendered inoperable, **several violations were committed by undertaking this procedure :**

- **Despite not having been scheduled;**
- **Lacking proper approvals or hot work permit;**
- **Without any preliminary validation of working conditions by a supervisor.**

The failure to procure a hot work permit was the root cause of this accident since it led to the absence of:

- A validation of operating conditions,
- The implementation of compensatory measures to mitigate the potential presence of pyrotechnic residue in the pipe.

It should be noted that the use of a metal saw had not been strictly prohibited. The dedicated procedure had simply stated that: "*Mechanical disassembly must systematically be favoured over any intended cutting operation.*" The objective behind issuance of a hot work permit that incorporates safety measures and special prescriptions is indeed to oversee situations in which the use of a tool capable of creating a hotspot, e.g. a metal saw, cannot be avoided. Such was the case here due to the vertical pipe configuration, placed against the wall: it was technically impossible to introduce a pipe cutter, which proceeds by rotating around the element to be cut.

The identifiable root cause at first glance: the human factor

According to the plant operator, the manufacturing workshop technicians, who took the initiative of removing the idle pipe section of the suction network, were indeed experienced and knew the building layout very well. Their seniority probably led to a **feeling of overconfidence** as regards their handling of the situation, prompting them to waive the rules in the aim of improving the results of their intervention.

Yet beyond these personal factors, procedural non-compliance can be traced to a series of organisational breakdowns.

An insufficient presence of supervisors during the annual maintenance period

On the day of the accident, the facility director, his deputy, the head of the safety department and the industrial director were all on holiday. Only the on-call manager was present at the site during a technical maintenance period that nonetheless featured a number of non-standard procedures. This **inadequate oversight** could have led technicians to act solo, without the possibility of a streamlined validation from superiors.

Inaccuracies in the official instructions and procedures

The presence of dust in the given pipe raises questions about the pyrotechnic decontamination protocol. The published **procedure outlining cleaning** (SE09: "Procedure for handling contaminated equipment") actually **remained quite qualitative**, simply noting that: *"Contaminated equipment must be decontaminated as much as possible."* The operating protocol should definitely have been explicit about guiding technicians in their tasks.
Article 8 of the Prefectoral order issued on 25 July 2003 relative to hot work permits also failed to define cleaning quality criteria. It merely prescribed: *"When works are carried out in a zone displaying major risks, the first step consists of completely shutting down and draining installations in the designated zone, along with cleaning and degassing the devices to be repaired plus a preliminary verification of a non-explosive atmosphere."*

In addition to the cleaning steps themselves, arises the question of the means for verifying cleaning efficiency. **No formalised procedure actually imposed verification prior to any works or addressed the state of cleanliness of pipes** that had contained pyrotechnic products. This shortcoming suggests insufficient recognition of the risks associated with such a configuration on the part of the company.

This failure to fully acknowledge risks was reflected by deficiencies found in other procedures. Such was the case as well regarding the sprinkling introduced during the cut-out operation. **No instructions had been written on the flooding methods or equipment to use.** This operation however is a vital compensatory measure as soon as a cut-out procedure needs to be performed with a tool capable of generating a hotspot and especially in the absence of any guarantees on the pipe's state of cleanliness.
In the present case, the technicians, who were probably aware that the cleaning might not be exemplary, set up a means for flooding. Yet in all likelihood, they had not been trained in this particular step, which had never been formalised. They performed sprinkling from the exterior as well as interior (via the upper portion of the pipe to be removed), while holding a simple sprinkler hose. This approach proved incapable of wetting and eliminating the powder residue that had dried inside the pipe (the installations had been idle for six days and the ambient temperature was around 23°C).

A non-efficient training process

A training programme must normally serve to transfer key knowledge required to carry out the various tasks technicians were assigned under optimal safety conditions. Formalised instruction is necessary to ensure course content is being transmitted to the entire workforce. The safety instructions associated with "cutting out a hollow body" were not specified in the hot work permit specific to each operation of this type. Consequently, the instructions were not incorporated into the general guidance procedures, which in turn hindered their recognition during the employee training process. The initiative taken by technicians was thus a manifestation of a flaw in the company's training strategy. It is therefore recommended to insert into the facility's safety management system some general safety principles applicable to hollow body cut-out operations.

Debatable choices regarding certain equipment

The selection of some equipment proved to be unwise. For instance, the suction network ducts were hard to inspect and access. This **ergonomic problem** relative to the installations obviously constituted an obstacle to a high-quality cleaning of the ducts. The remedial measures proposed by the site operator (as detailed in the "Actions taken" section below) demonstrated his awareness of this fact. As an example, it would have been possible to rely on flange couplings rather than welded couplings.
The sprinkling systems used during pipe cut-out also revealed that technical resources intended to guarantee safety during repairs conducted in the pyrotechnic zone had not been allocated. The absence of suitable instruments led technicians to use a simple sprinkler hose whose pressure was most likely insufficient to reach all zones of the internal faces of the pipe wall. An apparatus with a higher flow rate and pressure would certainly have been more efficient.

Inadequate attention paid to experience feedback

In December 2004, an accident (ARIA 28707) caused by a similar pipe cutting operation occurred at the same site. This event had prompted the operator to revise the work permits issuance procedure by adding a heading for "hollow body cut-outs". It had also led to systematically requiring a hot work permit for any works suspected of involving a hotspot or heating that were to be carried out in a contaminated environment. Implementation of these **corrective measures** fell short however of preventing the occurrence of this new event since the **operator failed to sustain their application over the long term**.

In sum, a substandard safety culture

On the whole, inappropriate or incomplete procedures, ineffective technician training or managerial lapses during down periods reflect a poor company-wide safety culture. **The operator did not deploy the full set of proper resources to ensure that staff could comply with procedures and that on-site maintenance operations could be successfully conducted.**

As pointed out by the Inspector of Classified Facilities, the operator failed to respect the prescriptions cited in Article 7 of the order adopted on 10 May 2000, and modified thereafter, relative to the safety management system applicable to installations capable of causing major accidents inside a SEVESO-designated facility. This article moreover stipulates that:

"*[…] The operator is to implement all procedures and actions outlined in the safety management system. […] The operator is also to allocate resources appropriate to this system and ensure its effective operations. […]*"

ACTIONS TAKEN

Subsequent to this accident, all subcontracted works and repairs were suspended and factory premises underwent clean-up and decontamination. Site activity was resumed on 20 August 2014, or three weeks after the accident had occurred.

The Inspection Authorities for Classified Facilities recorded the regulatory infractions and breaches at the origin of this accident. A formal notification and infringement statement were issued against the operator.

Several corrective measures were adopted by the operator, either of his own volition or imposed by the Classified Facilities Inspector.

Organisational measures:

- *Regarding the breaches in terms of workplace organisation and supervision:*

The Inspection Authorities requested that the operator consolidate the set of conditions relative to continuous supervision and management during holiday and maintenance periods. In response, the operator committed to reinforcing the existing organisation, notably by introducing a **daily gathering of all maintenance personnel with supervisors to discuss currently scheduled tasks**. Moreover, a policy was adopted to have at least two supervisors present instead of just one during all phases of down time for technical repairs.

- *Regarding technicians' failure to comply with procedures:*

The training courses offered to personnel were to include a **module relative to human behaviour** and the means employed to avoid "errors". Following the accident and before restarting the installations, a memorandum was circulated to the entire workforce on the importance of complying with procedures.

- *Regarding the inadequate cleaning of installations:*

The operator extended and consolidated its dedicated procedure. **The cleaning guideline would contain a checklist** detailing, workshop by workshop, the sequence of preliminary washing operations to be performed depending on the specific situation (index change, weekly cleaning, installation shutdown). A fact sheet recorded the successful execution of these operations and was submitted to a manager for final validation. These preliminary measures allowed the manager responsible for the validation step to authorise or reject subsequent works. This modified order, with a double validation required by both technician and management prior repairs, was tested during the winter 2014 closure.

- *Regarding deficient sprinkling systems:*

The operator anticipated that a **"fire guard" could be named to ensure sprinkling** of the target zone during repair works. The fire-fighting lorry available to the operator could be present at the zone with all its accessories. A variable flow hose could also be placed into service to secure the work site as needed.

Technical measures:

- The pipes damaged by the explosion were repaired. **Rupture discs were installed on hinged flanges**; they could be manually opened to observe the inside of piping and verify the degree of cleaning efficiency.
- Broadly speaking, in order to limit the risks of pyrotechnic residue being present inside hollow bodies, the operator preferred **replacing former single-piece ducts with split stainless steel pipes** easy to maintain and inspect.
- The operator installed **detection equipment** to improve the identification of pyrotechnic substances within hollow bodies. A camera was purchased to visualise pipe interiors, and nitrocellulose detection products were also envisaged.

At the request of inspectors, the various **measures adopted relative to experience feedback from the 30 July 2014 event were formalised in procedures included in the plant's safety management system**. These procedures were the subject of a memorandum circulated to all personnel concerned.

Moreover, **the risk analysis associated with the facility's safety report was complemented** by incorporating the hazardous phenomena stemming from the potential presence of pyrotechnic residue in hollow bodies.

LESSONS LEARNT

Any repair work performed on an installation that over the course of its life cycle had been in direct contact with an active pyrotechnic substance must be closely monitored and undergo special precautions before, during and after the mission.

Before the mission:

- validation by the operations scheduling manager of pertinent execution conditions;
- drainage and pyrotechnic decontamination of machinery used during the mission;
- visual inspection of cleaning efficiency and decontamination using appropriate tools (endoscopes, cameras, etc.);
- verification of both the organisational and technical conditions of the mission by a safety manager;
- verification of the successful application of these dedicated procedures;
- verification that all mandatory documents framing and authorising the mission have been completed and signed by the competent authority.

During the mission:

- verification of sprinkling efficiency throughout the zone targeted by the mission;
- use of suitable equipment, if possible not needing to be placed too close to the installation itself;
- wearing of adequate protective gear;
- a work site layout to ensure an adapted mission protocol (no requirement to climb a ladder, optimised position, etc.).

After the mission:

- verification that the installation has been restored to good working order;
- completion of a mission acceptance / end of mission inspection in the presence of a designated manager;
- dissemination of lessons learned, if applicable, through experience feedback from the mission (difficulties encountered, technical advice, unexpected events, etc.).

Over the course of mission efforts:

On the whole, in pyrotechnic installations, efforts are to be aimed at achieving:

- a good level of coordination between management and technical staff based on regular exchanges, during which applicable risks and procedures are recalled and any difficulties in implementing procedures are aired;
- a sufficient level of managerial oversight, especially when conducting works, to provide optimal guidance should any unusual situation arise;
- an in-depth analysis of the experience feedback lessons and a top-down flow of information reaching technicians with the greatest chance of being concerned;
- the execution of daily actions to create and nurture a vigilant attitude inside the factory;
- an installation design that facilitates monitoring and regular maintenance operations;
- frequent training sessions covering the full set of risks associated with pyrotechnics, including those more insidious and deeply ingrained in human behaviour. The contents of these training modules must also emphasise the mandatory general procedures addressing safety.
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Source of photographs on this document : DREAL Bretagne