LESSONS LEARNT from INDUSTRIAL ACCIDENTS

10th SEMINAR

29 and 30 May 2013 – Strasbourg

European Union Network for the Implementation and Enforcement of Environmental Law

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

Ministère de l'Écologie, du Développement durable et de l'Énergie

Ministry of Ecology, Sustainable Development and Energy

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ENRICH THE DEBATE

The European Union Network for the **IMP**lementation and Enforcement of **E**nvironmental **L**aw (commonly known as the IMPEL network) was created in 1992 to promote the exchange of information and experience between the environmental authorities. Its purpose is to help building a more consistent approach regarding the implementation and enforcement of environmental legislation.

Since 1999, this network has been supporting the French project on lessons learnt from industrial accidents. In order to promote the exchanges, which are crucial for the improvement of the prevention of industrial accidents and the control of risks management, France regularly organizes a seminar for European inspectors, where about twelve recent accidents are presented. The analysis of established and supposed causes is rigorous and distinguishes technical, human and organizational levels.

The active participation of inspectors from numerous European states enables to cross views and to enliven the debate, which explains the success of these seminars.

Reports of all the events presented since 1999 are available on the Barpi website:

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LESSONS LEARNT from industrial accidents

IMPEL Seminar
Strasbourg, 29 and 30 May 2013

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Fact sheet

Sensor malfunction

By virtue of transmitting the information required to conduct a situation analysis and the ensuing action plan, sensors are critical components in ensuring the good working order of automated control and safety systems. As such, the role of sensors has become increasingly important in providing for the safety of industrial sites and the quality of their production. This greater emphasis placed on sensors in the field of industrial safety has naturally been accompanied by a higher frequency of accidents involving sensor malfunctions. A study[1] focusing on 345 accidents occurring at French classified facilities through 2011 has revealed a doubling in the average number of "sensor accidents" per year over the periods 1992-1999 and 2000-2008 for the 4 most highly automated sectors of activity (see Fig. 1).

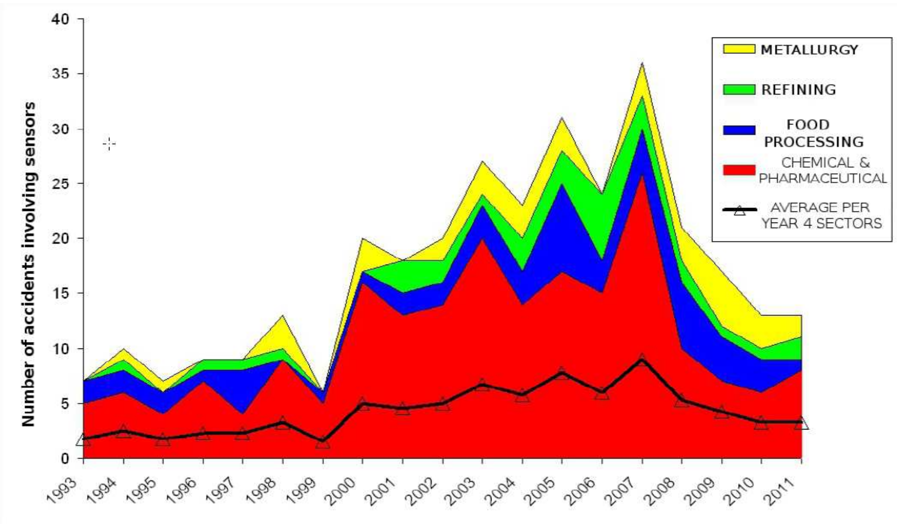


Fig. 1 : Annual number of accidents involving sensors for the most highly automated industrial sectors (ARIA base - 345 accidents)

1. Phenomena caused by accidents involving sensors

Industrial sensors offer the potential to remotely monitor facilities that operate with hazardous substances or processes, thus making it possible to remove technicians from these sources of danger. The accidents recorded as resulting from sensor malfunctions reveal the benefits offered by sensor use through a reduction in the most serious accident types, e.g. explosions and fires, since the majority of these accident records indicate a loss of hazardous materials, and in many instances remaining confined within the given unit or site (Fig. 2).

[1] « Sensors, compliant with safety ? », BARPI, 2012, 30 pages, free download on www.aria.developpement-durable.gouv.fr.

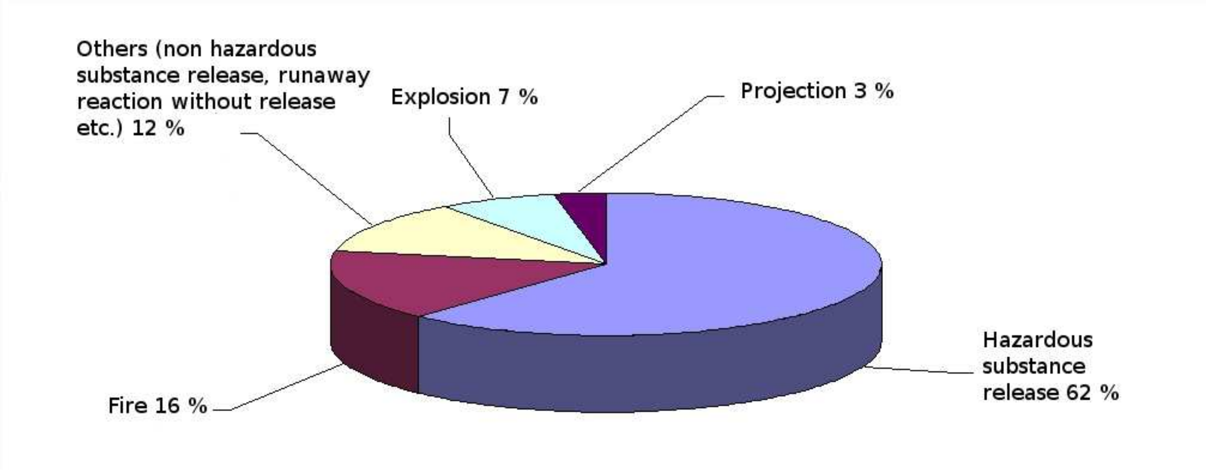
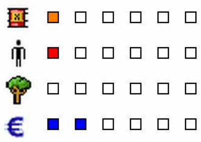


Fig. 2 : Breakdown of phenomena caused by accidents involving sensors (ARIA base)

The violent explosion that occurred on 8 June 2007 at a steel mill provides an effective illustration of the potential seriousness resulting from inadequate sensor equipment for process monitoring and safety functions:



ARIA 33059 - 08/06/2007 - 78 - PORCHEVILLE
24.10 - Manufacture of basic iron and steel and of ferro-alloys
In an electrical steel mill around 7:10 pm, the (70-tonne) melting furnace control operator noticed blue flames on the surveillance camera feed, which was an indication of the presence of water in the furnace. He proceeded by closing the safety guard in front of the window separating the control booth from the furnace wall and then ordered personnel to evacuate. A violent explosion occurred shortly thereafter, once water had come into contact with molten metal. During that afternoon, a water leak had been detected on 2 coolant return hoses at the furnace roof. One was replaced, and then it was decided to start the backup return circuit in order to compensate for the deficient second hose. Since the circuit water valve had not been opened, the cooling system malfunction caused a tube to be perforated and water to enter the furnace [...] The investigation exposed a substandard organisation of maintenance works performed on water supply hoses at the furnace roof (procedures, task management, supervision, etc.), in addition to **instruments incapable of controlling furnace roof cooling efficiency or water circuit integrity (i.e. no measurement of temperature and pressure variation) and a lack of instrumentation on the backup cooling circuit**. The mill operator commissioned an independent body to identify the causes of this accident and establish a set of technical and organisational measures to adopt so as to avoid recurrence. **The operator also specified: the backup circuit instrumentation to be introduced, installation of a hydrogen detector**, revision to the overall maintenance organisation, and a design study devoted to cooling circuit instrumentation for improved efficiency monitoring.

2. Functions performed by sensors involved in accidents

Some types of sensors involved in accidents stand out from the rest (Fig. 3). Depending on the extent of their use in industrial processes, especially chemical processes, temperature and pressure sensors are implicated in nearly half of all studied accidents. Sensors responsible for detecting an abnormal phenomenon (e.g. fire, toxic gas) were cited in the 2nd highest number of accidents, as a result of their role in exacerbating conditions in the event of malfunction. Lastly, level sensors are involved, on average, in over 20 % of all accidents inventoried and in up to 80 % of accidents recorded in the refining sector, where their operability is essential to ensuring process control.

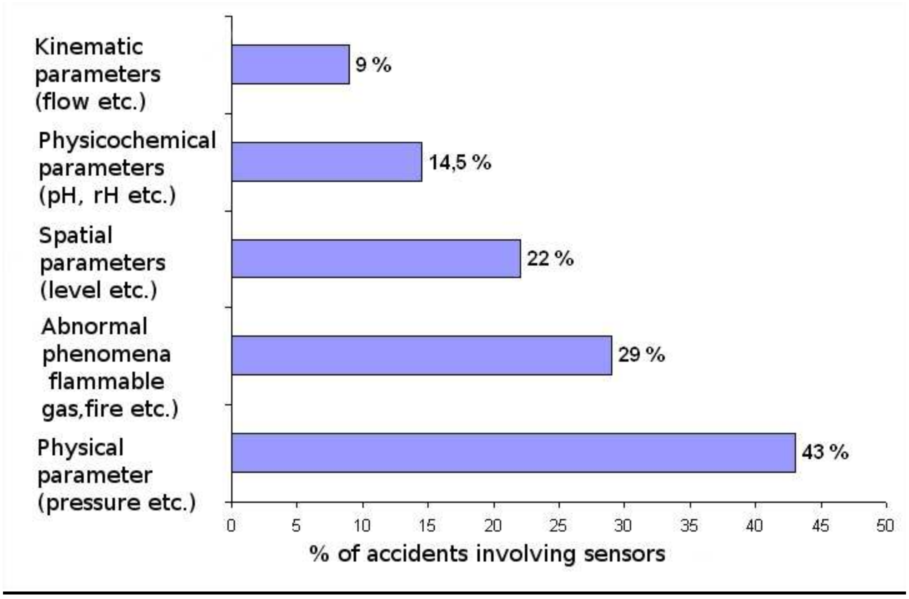
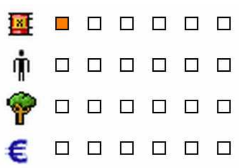


Fig. 3 : Breakdown of the functions performed by sensors involved in the analysed sample of accidents (ARIA base)

The accident that occurred in May 2005 in a French refinery clearly demonstrates the importance of level sensors for processes carried out in this sector :



ARIA 29903 - 26/05/2005 - 77 - GRANDPUITS-BAILLY-CARROIS

19.20 - Manufacture of refined petroleum products

Fire broke out in a refinery on an atmospheric distillation unit. The blaze was triggered by an ignited leak on the exhaust of a safety valve associated with a gasoline stabilisation column (i.e. a debutaniser) whose function was to separate gasoline from gas. The internal emergency plan was activated at 6:56 pm and the unit was shut down as per an emergency procedure. The refinery's internal responders extinguished the fire at 7:49 pm. Smoke from the blaze was dissipated by the south-easterly winds. The extinction water was channelled towards the refinery's treatment plant [...] The atmospheric distillation unit had been restarted a few days prior and its operations had not yet stabilised. Just a few hours before the incident, console operators and technicians had experienced difficulties on a vacuum distillation pump. **The stabilisation column was re-boiled at its base by an exchanger fitted with a column base level setting device. As of 3:30 that afternoon, a drift appeared on the corresponding measurement, leading to the partial, then complete, closure of the bottom valve and hence to the column filling with gasoline.** A mix of gasoline and gas spilled out via the overhead valve, formed a stream and ignited at a hotspot at the column base. The flame front rose to the outfall, thus sending a flame above the main atmospheric distillation column. The pressure sensor had been servo-controlled to allow turning off the heat, thus avoiding insufficient condensation at the top, which constitutes the typical cause of pressure surges. **This incident underscored the need for a new sensor locked loop on the column bypass, in order for the safety diagram to incorporate the risk of column overfilling.**

3. Accident circumstances

Installation shutdown or start-up constitutes a transitional phase capable of causing malfunction of the sensors, which often operate under atypical conditions not given full consideration at the time of sensor selection, installation or adjustment. This observation is also applicable to system maintenance phases when it is more frequent, for example, to overlook connections or encounter shunts, damage and sensor fouling. The accident that occurred at a Paris Region chemical site in August 2009 illustrates this concern :

ARIA 36660 - 13/08/2009 – 77 - GRANDPUITS-BAILLY-CARROIS

20.15 - Manufacture of fertilisers and nitrogen compounds

Ammonia (NH_3) was released around 10:50 am through a vent in the carbon dioxide (CO_2) liquefaction workshop at a chemical plant. A watchman observed the discharge and sounded the alarm. The shop was shut down and the internal emergency plan triggered […] The workshop was liquefying CO_2 by means of a refrigeration circuit using 5 tonnes of ammonia. **Since the workshop was idle, a pressure transmitter had been disassembled the day before to perform maintenance on the high-pressure ammonia compression circuit. This transmitter was providing a double function: regulating refrigeration circuit pressure at a recommended value of 13 bar, and ensuring installation safety by setting a 14-bar threshold. The workshop reopened the next morning while the transmitter was still undergoing repairs. Without any regulation or safety, the system diverged and the ammonia circuit experienced a temperature and pressure rise.** The circuit valve was tripped and 200 kg of ammonia were discharged via a 17-m high vent.

4. Focus on a few recurrent accident causes

Among the causes giving rise to sensor malfunctions, two are easily distinguished by their frequency in accidents catalogued for the 4 sectors of activity examined herein. The leading cause occurs early on and is tied to incorrect sensor installation. In many cases, the sensor is poorly connected or its location not suited to its assigned function. A survey[2] conducted among 119 French industrial sites equipped with 2,000 sensors on average has shown that 52 % of observed causes of malfunction stem from assembly or cabling errors. A recent accident at a chemical facility in the Isère department directly relates to this issue :

ARIA 43042 - 16/11/2012 - 38 - SALAISE-SUR-SANNE

20.14 - Manufacture of other organic basic chemicals

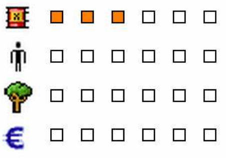
On an upper-tier Seveso petrochemical platform, a temperature rise vacuum test of a new reactor was underway when an explosion occurred at 9:15 am. The explosion took place on a heat-insulated tank used to melt salt by exposing it to water vapour at 180℃ and electrical resistances, before injecting it into the reactor's double containment as a heat transfer fluid [...] The investigation conducted by the site operator and an expert body confirmed ignition during the gaseous phase of an organic fuel, along with the presence of a combustible (NO_x) originating from the thermal decomposition of the heating salts, given that the tank vapour space was voluminous due to a low filling level (10 m³ of melted salt). This fuel contained as an ingredient either an anti-caking agent (organic product) in the salts, a foreign substance, or else a component stemming from a degradation reaction involving both these substances. This ingredient accumulated in the confined atmosphere of the tank until reaching its lower explosive limit and then burned once in contact with an ignition source (product temperature > 370℃?) [...] **The probe measuring temperature of the salt mix in the tank had been positioned too high relative to the low operating level and was insufficiently immersed in the liquid at the time of the accident, which led technicians running the test to underestimate the actual temperature of the mix.** The operator adopted several remedial measures, including **repositioning the temperature probe to ensure its immersion at the lower level** [...].

Fig. 4: The fouling of vibrating fork level probes caused a runaway reaction (ARIA 19339, Source: DREAL)

During the phase of normal facility use and operations, a 2nd very frequent cause of sensor malfunction pertains to deficient maintenance and cleaning. Since sensors are often in contact with the product(s) being monitored, the physicochemical characteristics of such products could on occasion quickly foul the main sensor parts (Fig. 4), or lock/clog/seize its operating mechanism, or even degrade its component materials (mechanical or electronic components).

[2] "Industries and their process instruments", MESURE magazine, issue no. 744, April 2002.

The July 2005 accident[3] at a chemical facility in France's Lorraine Region illustrates the consequences of improper sensor cleaning:



ARIA 30920 - 21/07/2005 - 57 - SAINT-AVOLD

20.16 - Manufacture of plastics in primary forms

In a plastics plant, a rupture disc burst on the medium-pressure circuit of a compressor; 3.2 tonnes of ethylene were released into the atmosphere. The incident occurred following a pressure rise at the primary compressor discharge. On 10 July, a leak was detected at the bleed valve of a grease bottle on the medium-pressure return line of the polyethylene unit. The bottle was refrigerated while awaiting its repair; the line was subsequently shut down on 20th July at 4 am for maintenance works and then started back up at 6 pm the same day. The technician turned on the primary compressor according to normal procedure, with the pressure rise being monitored in automatic mode. The pressure measurement at the secondary compressor inlet indicated a value above 300 bar, even though a discharge valve on the primary compressor should have opened at 284 bar. Moreover, the automatic mode switch on the primary compressor, designed to activate as of 270 bar, did not engage. The technician recorded an abnormal pressure increase and entered manual mode; this delayed action was unable to avoid a pressure rise to 310 bar, causing the disc to rupture**. The failure of the primary compressor to switch modes resulted from partial clogging of the pressure increase regulator gauge (i.e. measurement < actual pressure)**, and the valve did not open due to faulty maintenance; a noncompliant valve (calibration pressure > 310 bar) had been installed during a replacement step. Furthermore, fouling of the medium-pressure return section, correlated with several days of operations without bleeding the grease, only enhanced the pressure rise kinetics. After this accident, the check valve obstructed by polymers was cleaned and inspected, plus **a test enabled verifying the good working order of the automated safety mechanisms and automatic switching sequence for the primary compressor** [...] Both the rupture disc and check valve were replaced. Several remedial measures were adopted: mode-switching function installed on the compressor whether in automatic or manual mode, pressure measurement activating the backup function, revision to rules for using grease bottles in order to avoid fouling on the medium-pressure return lines, additional personnel training, and inclusion of this fouling phenomenon in the site's safety report.

An analysis of accidents caused or exacerbated by sensor malfunction has revealed that the problems of fouling, seizing and corrosion account for nearly half of all sensor-related accidents in the chemical - pharmaceutical sector, with almost one-third of those occurring in the food processing sector. Food processing also stands out by the frequency of causes related to sensor installation and connection, no doubt reflecting less rigorous supervision of instruments here than in the chemicals sector (Fig. 5).

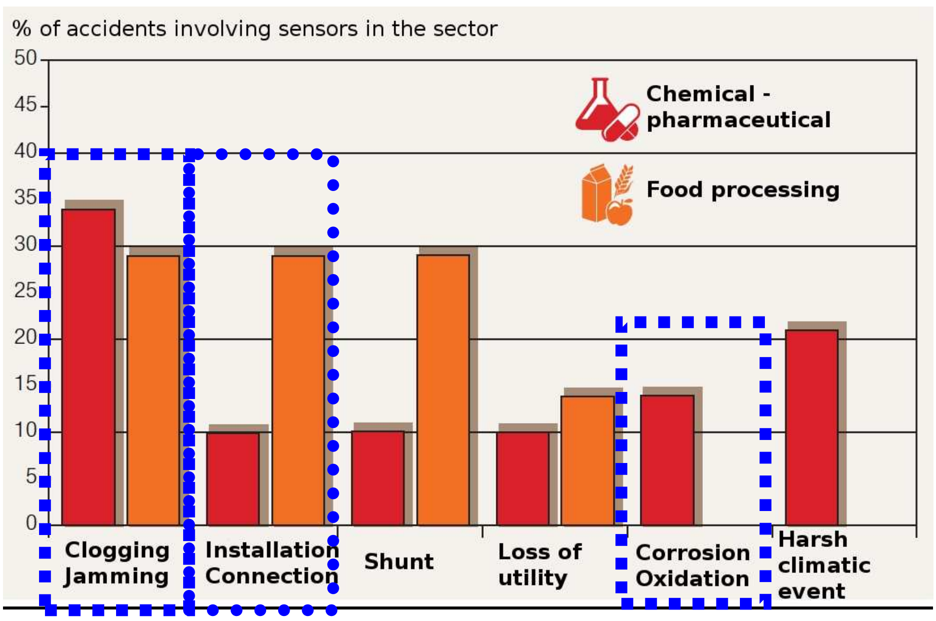
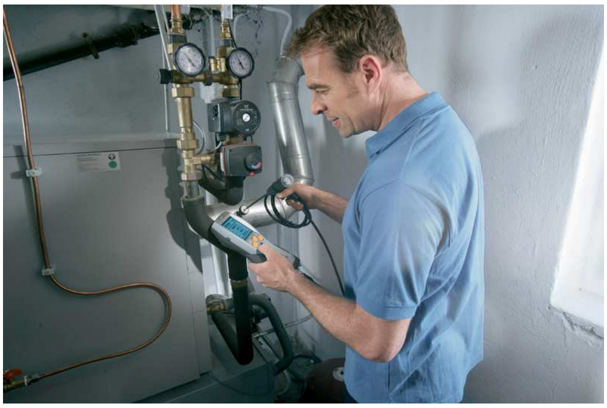


Fig. 5 : Primary causes of sensor malfunction for the chemical and food processing sector (ARIA base)

[3] Accident presented during the IMPEL seminar on feedback from industrial accidents, 30th and 31st May 2007 (Paris).

5. Conclusion and recommendations



A procedure of regularly calibrating sensors is mandatory !

The purchase of an "off the shelf" sensor does not necessarily mean that it can be forgotten once installed ! The efficiency of a sensor as a means of mitigating risks is not solely dependent on its performance, since use conditions also prove to be determinant. If these conditions are unsuitable, they may undermine efficiency and even raise the possibility of an accident should the sensor malfunction be difficult for technicians to detect.

During the preliminary phase, special attention needs to be paid to the chosen sensor location, in accounting for the various process steps or product states to be monitored, including infrequent or exceptional operating phases (e.g. extended down periods, emergency shutdowns, and scheduled maintenance).

During the operating phase and as is the case for any so-called "active" equipment, the good working order of a sensor over time depends on the efficiency of on-site control and maintenance measures, in order to avoid:

- malfunctions tied to operating errors committed by personnel or subcontractors (damage, absent or poor-quality connections at the time of initial installation or during the maintenance phase) : availability and compliance with supplier documentation, respected works schedule, awareness of sensor importance amongst maintenance teams, physical protection of sensors, consignment labelling, system of authorisation and traceability for all bypasses introduced;
- malfunctions tied to sensor operations under normal working conditions: calibration procedure in accordance with supplier recommendations for the purpose of guaranteeing measurement accuracy; and regular inspection and cleaning procedure whenever the sensor enters into contact with the product or an aggressive environment.

Overflow of a gasoline tank inside a refinery
22 October 2011
Reichstett (Bas-Rhin)
France

Oil depot
Hydrocarbons
Automatism
Sensor
Test periodicity
Material failure

THE FACILITIES INVOLVED

The site:

The refinery is located north of Strasbourg on a site covering more than 160 hectares. Refining activities started up in 1963 and until 2011 effectively supplied fuels throughout eastern France, along with liquefied petroleum gas to a filling centre set up in the vicinity (see Fig. 1).

The refinery contained a number of classified facilities subject to administrative authorisation with easements. The site was in fact classified "upper-tier" Seveso due to the quantities of flammable and/or toxic substances being manufactured and handled. Since 2011, the refinery part of the site has been idle. All sensitive facilities were gradually placed in safe operating mode according to a predetermined schedule. The refining units were taken offline. The shift crew consisted of 6 staff members: 1 control operator acting remotely (working from console displays) and 5 fire-fighters, including one safety team leader.

The site's oil depot however continued to operate, albeit at a reduced level of activity.

Figure 1: Aerial view of the refinery
(source: P. BANTZHAFF)

The specific unit involved in this accident:

Figure 2: View of the storage tanks
(source: DREAL Environmental Agency, Alsace)

Tank T 495 - 17 m in diameter and 18 m high - had been fitted with a floating roof, a radar-based operating level measurement installed in a vertical shaft, and a safety high-level measurement system (independent of the operating level and also performed in a vertical shaft, Fig. 2).

The radar-based level measurement system was equipped with three alarm levels: operating level, high level, and high-high level.

The high-high level safety measurement relied upon a system called MIP (for Marine Instrument Petroleum) that operates according to a different principle than the radar-based level measurement (Fig. 3). This system comprised a plunger hooked up to a hose connector and a spring, plus a vertical shaft connected to both the spring and a mercury bulb switch. With this set-up, the switch activation triggered a high-high level signal visible in the control room, thus initiating immediate shutdown of the transfer operation.

The tank was configured as a retention basin; it featured an outer ring to collect stormwater, including water stemming from the floating roof via a drain. The water accumulating in the tank was then recovered by a collector pipe running along the outer ring.

Hydrocarbon detectors, coupled with the site alarm, were installed on the collector pipe for water recovered by the outer ring as well as on the collector pipe for water recovered around the pumping station used to transfer hydrocarbons from one tank to another.

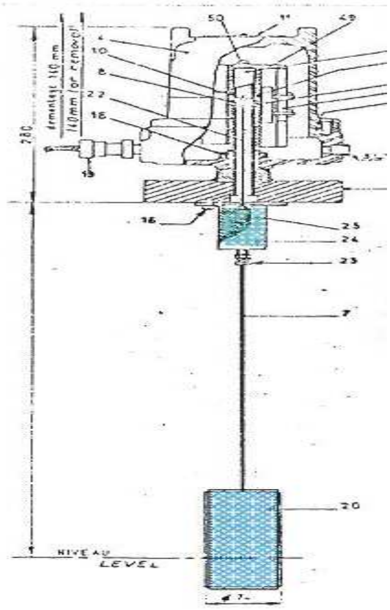


Figure 3: MIP operating diagram (source: Site operator)

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

Hydrocarbon fuel was being transferred in the refinery's depot in compliance with operating instructions. Tank-to-tank transfer of gasoline is a standard procedure that involves incorporating into an automated system (i.e. a calculator) the operating height of the recipient tank upon completion of the transfer step.

A 3,750-m^3 transfer of 95-octane rated gasoline from tank T 488 to tank T 495 was undertaken at the end of the afternoon. At 8:01 pm, the "hydrocarbon vapour" detection was triggered in the analyser room at the pumping station. A technician entered the room and smelled the gasoline. With his radio, he informed the control operator, who deduced that this detection was most likely related to the only ongoing transfer, i.e. between tanks T488 and T495. This transfer was immediately halted; the control operator then initiated the programmed alert procedure.

On the scene, the local monitoring team reported:

- the presence of gasoline in the outer ring of tank T495;
- a gasoline flow in the oily water sewer system via the drain line, which had remained open;
- the absence of gasoline in the retention basin due to the fact that the oily water purge valve had been left open;
- the floating roof, thrust by the gasoline, had bumped the upper edge of the tank structure.

From indications displayed on the monitoring screen, the control room operator determined that this tank overflow had caused the loss of 200 m^3 of gasoline. This initial estimate was subsequently revised downward upon learning the findings of investigations conducted by both the depot operator and fire-fighters.

The internal emergency plan was activated around 8:15 pm. In recognition of the inherent explosion and fire risks, the operator notified the fire department. The local authority (Prefecture) was also informed of the incident.

Fire-fighters arrived onsite near 9 pm, followed by police forces and a local authority representative. The Classified Facilities Inspectorate, alerted around 9:20 that evening, reached the scene at about 10:30 pm.

Consequences:

No victims were reported from this accident. Property damage was limited to the floating roof, which remained stuck to the upper edge of the tank shell. After several hours of investigation, the gasoline loss could be evaluated at approx. 20 m³. The gasoline was eventually recovered and routed to a slop tank (i.e. containing liquid residue) for treatment.

This event generated no impact outside of the site boundary; none of the areas of interest cited in Article L. 511-1 of the French Environmental regulation had been adversely affected.

European scale of industrial accidents:

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

Dangerous materials released	■	□	□	□	□	□
Human and social consequences	□	□	□	□	□	□
Environmental consequences	□	□	□	□	□	□
Economic consequences	□	□	□	□	□	□

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

The "hazardous substances released" index received a "1" rating due to the spill of gasoline in a quantity between 22 m³ and 30 m³, amounting to some 20 tonnes.

The "human and social consequences" index was not scored given the absence of victims.

The "environmental consequences" index was also unrated as no environmental impacts could be observed.

Moreover, the "economic consequences" index was not scored since the amount of property damage on the tank roof, when added to the loss caused by immobilisation of both the damaged tank and other tanks during the investigation, product losses and the cost of treating recovered product, were less than €100,000.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

The suspected faulty operation was intended to prepare a product for shipment to the Strasbourg oil port prior to loading onto a barge. The instruction submitted by the unit manager to the control operator sought to ensure that the gasoline transfer from tank T 488 to tank T 495 reached a point of filling to the "high operating height" level, so as to avoid tripping the alarm during gasoline transfer. This product movement was entered into a calculator in the control room, with automatic shutoff programmed by the system at the height recorded upon completion of the high operations phase.

The ullage of tank T 495 (i.e. gasoline height in the tank) was relayed to the control room console by a radar-type, high-level sensor indicating gasoline height in the vertical shaft (see Fig. 5).

The control operator, stationed in the control room, could visualise on a screen the gasoline level inside the tank. Relayed by radar, the reading displayed on his screen provided a measured gasoline level in the vertical shaft but not the actual gasoline level inside the tank. Water present at the bottom of the tank could rise into the vertical shaft as a result of the thrust generated by gasoline movement in the tank during this transfer process. Therefore, a height difference could occur between the gasoline level in the tank and its corresponding level in the vertical shaft.

The radar-based control system appeared to be operating normally with no preliminary indication observable by the control operator that the height being read by the radar was lower than the actual gasoline level in the tank (Fig. 6). During tank overflow, the height difference between the radar reading and the actual gasoline level in the tank was 3.3 m: the level reached inside the vertical shaft from the radar reading, as displayed on the control room screen, was however 12.7 m, just below the operating height set at 13.75 m for an actual 16-m tank level.

Due to its malfunction, the second "MIP" system failed to sound the high-high level alarm. The tank overflowed and gasoline spread towards the tank's outer ring, eventually reaching the oily water network, since the purge valve had remained open. This open valve position was a measure practiced during periods of heavy rainfall in order to avoid clogging the outer ring and to ensure good working order of the drain on tanks fitted with a floating roof.

The personnel on duty responded quickly after detecting hydrocarbons around the oily water network pumping station, located over 300 m from the tank. Using explosimeters, depot personnel recorded the presence of hydrocarbon vapours: at the pumping station, in the gutter running around the periphery of tank T 495, and leading to the underground oily water network. Concentrations measured at these points remained below the lower flammability limit (LFL).

Figure 4: View of the tank's floating roof after the overflow (source: Site operator)

Depot employees, assisted by fire-fighters, proceeded by covering all gasoline vapour emission sources (top of the tank, the tank's outer ring and around the pumping station zone) with foam. A safety perimeter was set up and moved as the situation evolved for responders; this perimeter was gradually reduced as individual areas were verified one by one to be free of gasoline vapours at the oily water network.

From drawings furnished by the operator, fire-fighters were able to identify gasoline at retention basin manholes. It was then attempted, though unsuccessfully, to recover the gasoline with a tanker truck whose cistern had been depressurised. Around 2 am, the operator placed a call to a specialised subcontractor equipped with an "ATEX" lorry for explosive atmospheres, but the company's certified personnel could not be reached.

Given the unfavourable weather conditions, responders' fatigue and the overall absence of adequate resources, the crisis response unit decided to postpone gasoline recovery until the next day. An onsite monitoring strategy was implemented; all sensitive zones were covered with foam and controlled with an explosimeter.

According to operator investigations, this overflow was caused by the two following conditions:

- The vertical shaft on the radar-based system for verifying operating levels (Fig. 6) was not equipped over its height with orifices to allow for unrestricted flow of gasoline into the tube. This shortcoming led to a false reading of gasoline level in the tank due to the presence of heavier water; the level read by the control operator in the control room was therefore actually lower;

- The high-high level barrier (MIP system) was inoperable despite recent verification. The vertical measurement shaft on this sensor contained orifices over the longitudinal generatrix, allowing gasoline to pass and thereby eliminating any risk of false reading due to the presence of water heavier than the product.

Figure 5: View of the radar device on tank T 495
(source: DREAL-ALSACE)

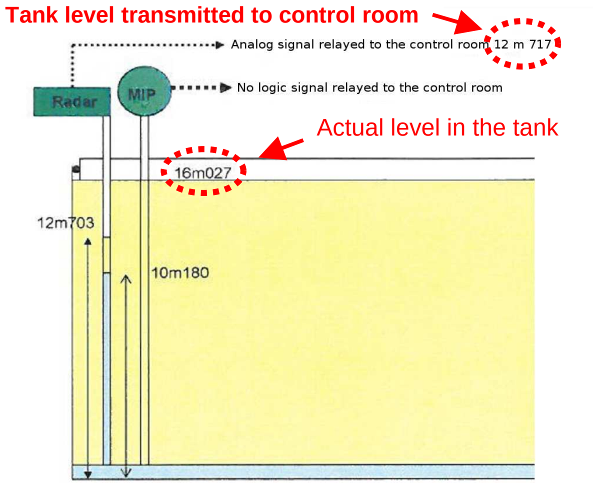


Figure 6: Presence of water in the control shaft of tank T495, observed after lowering the floating roof (source: Site operator)

ACTIONS TAKEN

The Classified Facilities Inspectorate visited the site around 10:30 pm. The situation had not yet been brought under control. The actual quantity of gasoline spilled from the tank was disputed. Investigations undertaken by fire-fighters on the one hand and an analysis of information output by the computerised monitoring of transfers on the other yielded a range of 22 to 30 m^3. This quantity interval was explained and justified by the operator in the accident report submitted.

An accident report explaining the causes of this overflow and proposing remedial measures was requested from the site operator. Regarding specific elements identified to be defective, the operator proceeded by:

- looking for similar configurations elsewhere on the site. 34 tanks were verified (with both floating and stationary roofs). These investigations also revealed the existence of 3 different MIP technologies installed on the tanks: use of a plunger for 7 tanks (including the T 495), a floater fitted on 14 tanks, and a mechanical scale on another 13 tanks;
- assessing the causes of malfunction experienced with the mechanical device for the high-high level (MIP) control. The site's MIP systems were tested: all activated normally, except for one installed on a crude tank, as the plunger system was unable to return to the rest position on its own and needed to be pulled down mechanically. Some slight seizing could be observed;
- ensuring that the protocol of relying on a subcontractor to resolve accidental situations was effectively in place under all circumstances, in terms of both human and technical resources.

LESSONS LEARNT

This accident prompted the depot operator to:

- improve the quality of information available on the control operator's console, including a more refined representation of ongoing transfer processes capable of alerting the technician of a deteriorating situation. Given the change in tank use patterns, operating conditions needed to be modified: no more tank-to-tank pouring and regularly scheduled purges due to the use of vapour (as was the case when the depot had been jointly run within the refinery complex);
- replace the 7 distinct MIP mechanical systems using a plunger to control operating levels by MIP systems based on a floater or mechanical scale device, deemed more reliable and easier to test. Moreover, the plunger model was no longer being manufactured and its replacement had already been planned prior to closure of the refinery installations;

- revise MIP test conditions to include floater or scale type mechanical systems in order to ensure no defects under actual operating conditions. More specifically, testing of the floater-based MIP entails disassembly and an external test protocol. The device spring, subject to wear, is a known weakness of this level measurement technology;

- change the control device test periodicity within the operating range by using an environment more representative of actual conditions: *in situ* testing of the MIP in a liquid medium (gasoline or crude);

- consolidate the instructions related to the handling of purges and purge valves placed along the tanks' outer rings. While such handling techniques during periods of heavy rainfall count among the best practices adopted by the profession, these steps had not been strictly enforced;

- review the assistance contract signed with subcontractors so as to ensure the availability of ATEX-rated equipment (appropriate lorries and accessories) and personnel certified to use such equipment in high-risk zones, when faced with emergency situations and under all circumstances.

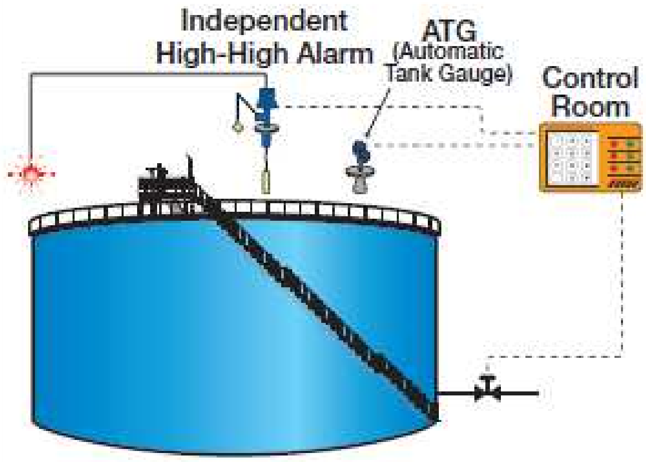


Figure 7: The American API 2350 Standard classes as Category III any storage tanks managed remotely; moreover, it recommends use of a high-high level safety sensor that is independent of the operating level (ATG) sensor and, preferably, offers self-diagnostic capacities relative to its malfunctions and defects.

Uncontrolled emissions subsequent to a decomposition reaction inside a dryer
19 November 2011
Lanester (Morbihan)
France

Fine chemistry
Drying
Toxic emissions
Temperature regulation
Risk analysis
Crisis management
Safety measures – automatism
Common defect mode

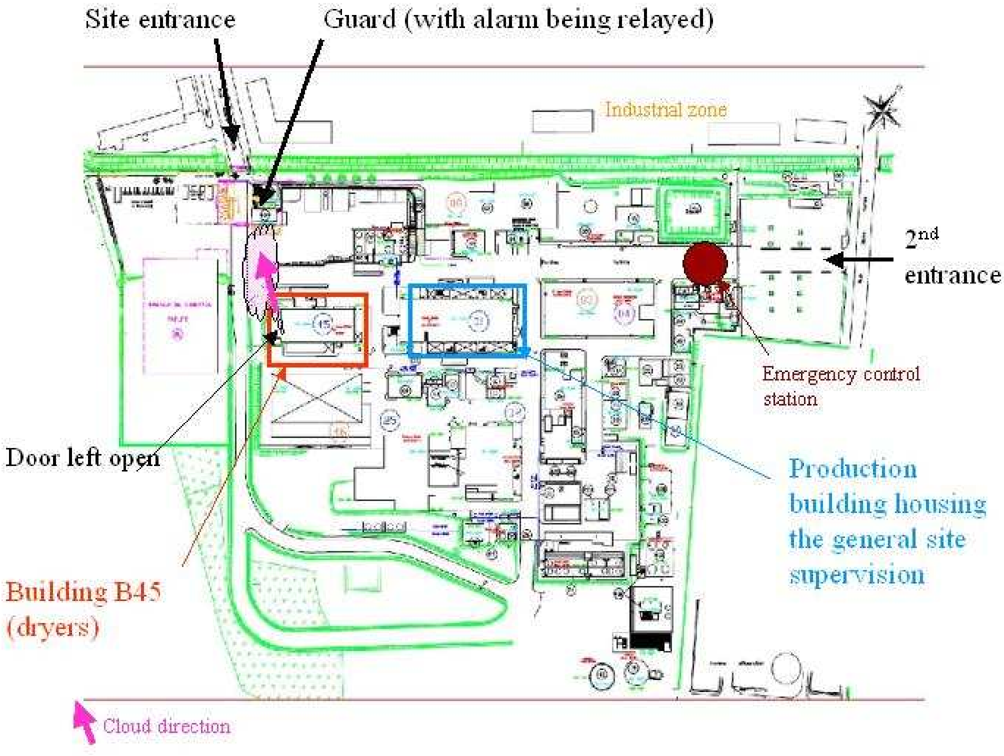
THE FACILITIES INVOLVED

The site:

This fine chemistry plant is situated in an industrial park within the Lorient metropolitan area; it is producing organic iodized products for pharmaceutical uses (medical imaging). This Upper-Tier Seveso site employs a workforce of approx. 220.

The closest dwellings are located about 150 metres from the building where this accident occurred.

Both the intermediate and final products involved are powdery. The batch-type (discontinuous) process includes drying steps for these various products. The B45 building, scene of this accident, is exclusively devoted to the drying of intermediate products.



The involved unit:

The B45 building housed five enamelled steel dryers with capacities ranging from 4 m³ to 6 m³: three so-called "rotary double cone" dryers (whereby rotational movement activates stirring); and two "screw" dryers (with stirring motion generated by rotation of an internal screw). The dryers were heated by circulating a heat transfer fluid inside their dual lining.

The drying operations were staged as follows:

- dryer loading with wet powder;
- vacuum pumping and gradual heating (temperature thresholds). A drying-cooling cycle could last more than 1 day (system managed by a programmable controller);
- cooling, followed by a gravity transfer.

Installed safety devices allowed halting the drying step and cooling the dryers upon detecting either a stirring malfunction, excessive temperature or a pressure surge. Cooling system availability was verified prior to initiating each drying operation. Both screw dryers had been equipped with a rupture disc, thus serving to channel discharge in the event of a pressure surge, as opposed to the 3 double cone dryers, none of which featured the same system.

The monitoring of drying operations had not been separately assigned to a full-time technician but instead was included among the tasks performed each shift by the production team, which conducted periodic verifications inside building B45. During periods with fewer onsite staff (nights, weekends, etc.), monitoring activity fell under general site supervision, centralised in the production building adjoining B45, and merely consisted of detecting an eventual triggering of an alarm or emergency shutdown. All alarms were relayed to the site's security office (Guard).

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

During the night of 19th to 20th November 2011, several dryers were running in building B45. The production of "DICOA" (an organic iodized substance with molecular formula C16H14Cl2I3NO5) had been drying for a few hours in a rotary double cone type dryer with a capacity of 4 m³.

At 10:02 pm, a bursting sound rang out and an alarm was simultaneously activated in building B45, which was unstaffed at the time. This bursting was followed by the appearance of a pinkish cloud that spread outside the building via ventilation fans as well as a door that had been left open. The plume of smoke headed north and north-westerly, extending several tens of metres along the site's frontage road. According to witness accounts, this cloud was visible for around 30 min. The eventual DICOA decomposition gases were composed of diiode (I2), hydrogen chloride (HCl), hydrogen iodide (HI), carbon oxides and nitrogen oxides. The cloud's pinkish colour was due to the presence of diiode.

The 18 employees operating the site at the time of this release were requested to assemble at the meeting point. The operator installed a water curtain in an attempt to attenuate emissions outside the plant.

The on-call manager arrived at the site by 10:20 pm. Fire-fighters, notified by neighbouring residents, showed up at 10:25. The decision to activate the external emergency plan was made at 10:58, at the behest of both first responders and the site operator.

Photograph of the cloud before its dispersion

Fire-fighter intervention wearing diving suits

Though it appeared at the outset that these emissions were due to product decomposition, a precise diagnostic of the accident (targeted installations, plus their possible evolution) was not immediately forthcoming since building access had been obstructed by the substances being released. Responders had to wear diving suits to survey the premises, during which they determined that the emissions had originated from a burst glass tube connected to the DICOA dryer, which was still being heated and whose contents had begun decomposing.

After an initial "blast" due to the burst tube, which was quite concentrated and visible, emissions were fed by further product degradation over the next three hours, i.e. the time required to identify the type of accident and organise emergency intervention with diving suits to shut down and cool the dryer. This mission was successfully completed near

1 am, and equipment cooling was periodically verified until 5 that morning. Around 5:30 am, the situation was deemed under control (i.e. emissions stopped, temperature in the dryer at 10°-12°C); the emergency plan was t hen lifted.

Airborne hydrochloric acid measurements at the site outlet did not reveal any abnormal concentration levels.

Consequences of the accident:

The initial mass of wet DICOA (solvent = water + ethanol) present in the dryer amounted to approx. 1.8 tonnes, i.e. on the order of 1.4 tonnes of dry DICOA. A portion of the decomposed product remained in the dryer (about one-third of the initial mass was found inside) and in building B45, whose walls, floors and ceilings had been covered by a pinkish deposit. The quantity released outside the site could not be accurately determined.

- Human consequences

No irreversible effect on human health was identified. Moreover, no personnel had been present inside the building when the accident occurred. The on-duty employee at the entrance and security office, located along the path of the plume, felt ill and was taken to hospital for medical clearance before resuming his shift.

Residents living within the emergency plan boundary were advised to remain indoors should the alarm be sounded; in reality, the alarm period lasted nearly seven hours.

Neighbours complained of eye and throat irritations. Foul odours were noticeable more than 1 km away.

Ioduria measurements taken among company personnel as part of an employee medical screening programme did not indicate the presence of any impact.

- Environmental consequences

At the facility site, the ground was contaminated (by iodine) over an area of approx. 250 m2 opposite the door left open. The contaminated soil was excavated and transported to an authorised dumpsite.

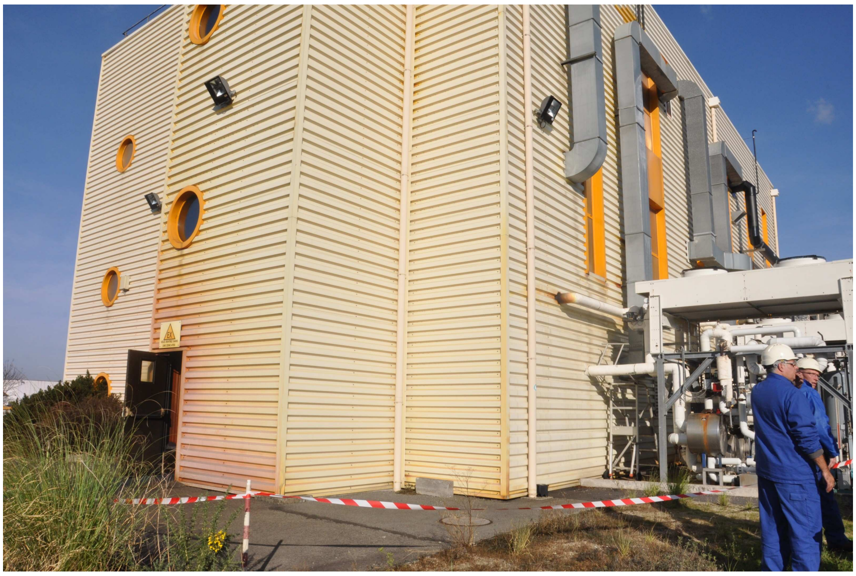
The soil analyses (for iodine and pH) conducted on 21st November beyond the site along the plume path suggested no presence of anomalies.

- Property damage

The effects of a pressure surge relative to the burst tube only caused localised damage: deformation of partition walls in the dryer room (positioned about 1 metre from the tube). The bursting pressure was assumed to equal 2 bar (i.e. the rated strength given by the supplier). The building cladding, just 3 metres from the burst tube, was not subjected to any damage, nor were any other parts of the building. The enamel on the affected dryer was however damaged.

A major clean-up effort was required inside building B45 due to the presence of deposits (see photo).

The dryers were restarted in December 2011 after verifying their structural integrity and a recertification procedure, with the exception of the defective dryer, which was not placed back in service until July 2012.



Traces of reddish deposit on building B45 - Source: DREAL Environmental Agency (Brittany)

The European scale of industrial accidents:

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

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

The quantity of substances escaping from the dryer was estimated at 1 tonne, of which more than half was iodine. As a result, the "Hazardous substances released" index reached level 1 or 2, depending on the form of iodine in the emissions (%HI vs. %I2).

The overall "Human and social consequences" index was scored a 2 by virtue of the advisory issued to neighbours to remain indoors in the event of emergency plan activation (some 150 single-family homes were included in the plan perimeter).

The "Environmental consequences" index did not reach level 1, given the limited surface area of polluted ground.

The total amount of property damage and production losses was not provided by the plant operator. Only the cost of direct damage (i.e. premises and machinery: replacement and/or repairs) was announced on the order of €800,000; hence, the "Economic consequences" index was at least equal to 2.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

This accident arose subsequent to a malfunction in the drying temperature control process:

Communication breakdown between a relay managing the drying process sensors and the programmable controller assigned to regulate temperature

⇩

The controller did not receive appropriate information regarding the temperature reached

⇩

The controller continued to order heating of the thermal fluid, which in turn heated the dryer

⇩

The temperature reached became excessive, causing the DICOA substance to decompose

⇩

Pressure surge inside the dryer, leading to bursting a glass tube connecting the dryer with the vacuum pump

⇩

Release of a portion of dryer contents inside building B45, and then to the outside

The a posteriori diagnostic carried out revealed a deficiency on an electronic component of the designated input/output head (manufacturer's defective equipment).

Given that the dryer security system for a high temperature or pressure reading had not been set up independently of the malfunctioning operating system (i.e. same relay and controller as for temperature regulation), the dryer system proved ineffective. Detectors likely sent information that a high level had been reached, but since this defect stemmed from the relay, the information was not transmitted and thus did not trigger the alarm or an emergency shutdown.

Moreover, the accident occurred on a Saturday during a period with fewer personnel on the job and with less intensive monitoring of drying operations, i.e. limited to (deactivated) alarm verification at the site's supervision desk. Such a malfunction might have been detected prior to the accident by controlling the temperature curves, which displayed an abnormal profile (temperature had remained blocked for the 4 hours leading up to the accident).

ACTIONS TAKEN

The local Prefect issued an emergency order on 22nd November making dryer restart contingent upon the plant operator's submission of an accident information report and implementation of remedial measures to avoid a repeat occurrence. This order also insisted upon the fact that certain priority actions that should have been applied immediately upon detection of an event capable of affecting a third party or evolving into such an event were in fact introduced belatedly, especially regarding the notification of rescue services, the activation of the emergency plan siren and insuring that the rest of the operating facilities stay in a safe mode…

The following measures, with a direct bearing on the accident, were adopted by the operator:

- revision of the safety report relative to dryers;
- installation, for each dryer, of a cabled safety switch for controlling the thermal fluid temperature that remained independent of the controller, hence reaching a high temperature level automatically shut down the heating;
- installation, for each DICOA dryer, of a second cabled safety switch to control powder temperature inside the dryer, in which case reaching a high temperature level also caused the heating to shut off;
- introduction, on each dryer input/output relay, of a continuous control to ensure open lines of communication with the controller (triggering of safe mode in the event communications were disrupted);
- modification of the monitoring procedure for drying operations;
- scheduling of a second assessment of the independence of safety systems throughout the entire site;
- organisational improvements in order to better respond to priority requests in the event of an accident, i.e. personnel evacuation, notification of the local population and emergency services, transition to safe operating mode;
- supply of Dräger tubes to determine airborne iodine concentration and thus facilitate management of an accidental event involving iodine;
- creation of a backup supervisory and control station in case access to the primary station has been blocked. A third station had also been planned;
- overlapping of essential functions performed in the entrance and security office (e.g. communications, inventory of protective gear, gate opening/closing), in the event this office has been rendered inaccessible;
- revised layout of emergency shutoff switches on the dryers and their function (e.g. turn off drying, but retain the stirring operation, ventilation cut-off, injection of coolant).

The operator had also anticipated process modifications in order to reduce risks at the source by means of eliminating DICOA drying (e.g. improved spinning efficiency, use of slightly wet DICOA).

Other measures, decided subsequent to the safety report revision, were either adopted or planned:

- for each dryer, installation of a second backup heating cut-off valve, dedicated to the cabled safety switch controlling the thermal fluid temperature;
- a 3-metre elevation of the rupture disc outlet on screw dryers, for the purpose of minimising ground concentrations
- modification of the heating sequence for DICOCl, another intermediate product, after analysis of this step's criticality;
- placement of a flooding device on each dryer: a fitting that made it possible to connect a water pipe so as to ensure rapid cooling (however with the need for human intervention).

At the Prefecture's urging and with Mayoral backing, the operator financed the installation of an alarm and phone information system to benefit neighbours, by offering the possibility to simultaneously send instructions to all local residents on the protocol to follow or information messages regarding the evolution of an accident.

This company also made a study of new ways of purifying CMC cake and will replace in 2012 their vacuum belt filters by Rotary Pressure Filters (RPF). A RPF is a compact installation with less space (smaller risk of explosion hazards) and with all moving equipment (possible ignition sources) outside the installation.

LESSONS LEARNT

This accident has underscored the following points:

- The independence of process safety barriers is critical, especially with respect to events capable of causing the kind of accident these barriers are supposed to prevent or mitigate. In the present case, the system intending to place the dryer in safe mode when a high temperature is reached actually malfunctioned by being routed onto the transmission channel whose deficiency led to the accident in the first place (common defect mode);
- This accident offers a reminder of the care required to analyse risks and justify the hypotheses derived, as regards identifying the most feared events and selecting hazardous phenomena for input into the detailed risk analysis. The scenario involving a pressure surge and bursting inside a dryer had in fact not been listed in the safety report as potentially leading to effects offsite: this scenario had been rejected on the basis of a preliminary risk analysis. Moreover, such a decision could explain why the safety barriers installed around the dryers, specifically the high temperature level, had not received the same attention (i.e. an assessment of system independence) as those found to be correlated with a major accident;
- Special attention must be paid to periods when plants are operating with fewer staff members, to ensure that safety conditions remain at the same standard and moreover that the alarm and operational response to an accident are always quick and appropriate;
- Plant operators must be prepared and organised to relay an alarm very quickly to the appropriate rescue services and local population in the event of an accident displaying apparently uncontrolled effects or an incident that can evolve unfavourably due to rapid kinetics. Operators must therefore wisely integrate their responsibility to activate the emergency siren as circumstances dictate. The decision-making processes introduced within the scope of Internal Emergency Plans may prove too long in comparison with the kinetics of rapidly-developing hazardous phenomena. During this accident, the internal plan was not triggered before the external plan (1 hour after the event). The suitable training, drills and delegation of authority must also be provided by management to staff members designated to make fast decisions, e.g. during slack periods with fewer staff and when managers are absent from the site. One difficulty lies in the fact that since such incidents are (and fortunately so) most often of minor severity, both the organisation and practices have tended to focus on "removing doubt" rather than relaying an alarm quickly to the outside world;
- Whenever an accident occurring at a facility requires evacuating the entire workforce to the meeting point, questions arise over the safety conditions under which ongoing processes are conducted in the absence of onsite technicians. This issue must be anticipated (by deciding on the organisation to implement, identifying critical installations or operations to be rendered safe as a priority, i.e. even before leaving the workstation);
- The concern over maintaining installation control capacities in the event of an accident must also be anticipated, whether this entails intervening on the damaged installations or ensuring the safety of processes still ongoing. This emphasis could, for example, lead to protecting the premises housing the supervisor's station or adding a second station. During this accident, access to the supervisory posts (in building B45 itself and the adjoining main production building) had been obstructed by their location in an exclusionary zone, i.e. special gear (a diving suit) was required to obtain access. This situation may help explain the time delay before dryer cooling (3 hours);
- In addition to toxicological data, it is beneficial to be aware of odour thresholds for substances potentially released in case of accident, notably in order to facilitate the understanding and communication of health impacts. The lack of such impacts, despite odours perceived beyond 1 km from the site, must be justified;
- Administrative agencies also need to ensure the operational viability of their organisations in a crisis management context. Specifically, the external emergency plan called for informing the local population via the France Bleu Breizh Izel radio station: it turned out that this station was off the local airwaves certain times of day, including when this incident struck. For this reason, a phone-based information system was introduced as a follow-up measure;
- Risk prevention concerns need to be incorporated as of the installation design phase. Double cone dryers are not easily equipped with a device that allows channelling gases generated from an eventual pressure surge, whereby controlling discharge conditions allows reducing potential soil impacts. Furthermore, special attention must be paid to fragile components (glassware) in those devices capable of undergoing pressure surges.

Theme 2

Characterization of hazardous phenomena

Characterization of hazardous phenomena

The accidents recorded in the ARIA database present 3 major types of hazardous phenomena, namely: fires, discharges of hazardous substances, and explosions. The breakdown of these accidents in the ARIA base by type of event is listed in the following table, as a percentage of the number of French accidents involving classified facilities, i.e. out of a total of 22,585 cases between 1992 and 2012, inclusive, with 900 cases in 2012 alone.

Type of event (not mutually exclusive)	1992-2012 (%)	2012 (%)
Fires	64	61
Discharges of hazardous substances	43	50
Explosions	7.4	6.5

Fires and discharges of hazardous substances constitute the most frequent type of accident event. Though fewer in number, explosions still represent a high potential for destruction.

This document seeks to demonstrate how a better understanding of hazardous phenomena can, in particular, improve modelling of such phenomena; moreover, for two actual cases of fire and explosion, the correlations derived between existing numerical models and specific events will be presented. Some selected recommendations will also be provided, with the aim of enhancing the state of knowledge on hazardous phenomena through use of feedback.

1. Benefits derived from an improved knowledge of hazardous phenomena

The prevention of accidental risks implies a series of coordinated actions focusing on:
- reducing risks at their source by means of managing inventory;
- controlling urban development around industrial sites presenting a hazard potential (by including the French approach contained in Technological Risk Prevention Plans developed for upper-tier Seveso sites);
- adapting and regularly testing emergency rescue plans;
- disseminating prevention-related information to the public.

Regulating urban development at the periphery of industrial sites requires in-depth knowledge of potential accident scenarios, in particular their effects on the environment.

To assess the vulnerability of a given point and measuring the sensitivity of "targets" located across the zone in the presence of a given type of impact (e.g. pressure surge hazard), three tools are available:
- post-accident feedback in cases where an accident has already occurred;
- numerical modelling of the effects of hazardous phenomena;
- experimentation.

The first two approaches are related in the sense that the study of accidents helps improve calculation tools, and these are used to determine effects zones to limit the consequences of accidents. The experiment can be used to confirm the teachings of an accident or to understand the mechanisms and to improve the models.

Continuous improvements in modelling pave the way to establishing more accurate safety reports for industrial sites and to more effectively designing response devices or equipment as part of a strategy addressing the array of challenges, be they economic, environmental or human.

2. Modelling approach

The basic principles involved in modelling a fire, hazardous substance discharge or explosion rely on the same approach, whose first step consists of characterising a source term (e.g. volume of combustible present, physical characteristics). The next step entails modelling the propagation of this source in the environment based on meteorological conditions (wind speed, ambient temperature, etc.) or the environment (terrain, obstacle, building ...). This approach is aimed at modelling the "effect" of this phenomenon so as to compare it with known thresholds of the physical effects on "targets".

For purposes of review, the primary thresholds for "regulatory" physical effects (i.e. thresholds applied in safety reports) in the event of fire are as follows:

- with respect to human health:
  - 3 kW/m²: threshold for irreversible effects;
  - 5 kW/m²: threshold for the first lethal effects;
  - 8 kW/m²: threshold for significant lethal effects.
- with respect to built structures:
  - 5 kW/m²: threshold of significant destruction of windows;
  - 8 kW/m²: threshold for domino effects and serious structural damage;
  - 16 kW/m²: threshold for very serious structural damage (excluding concrete).

In the event of explosion, these regulatory thresholds are:

- with respect to human health:

3. Modelling of a fire

Event description

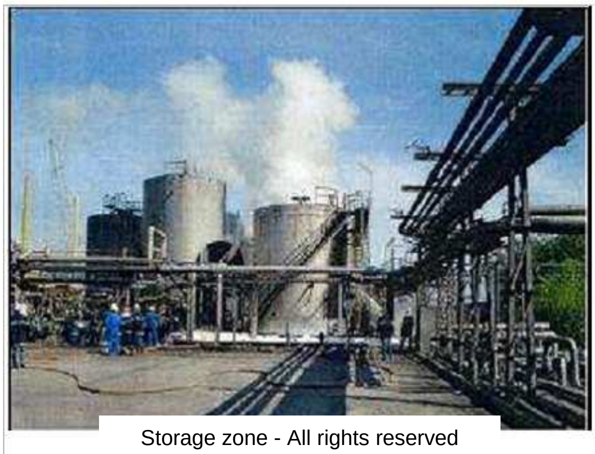
The analysis of ARIA accident 22459, which occurred on 18 May 2002 in Dunkirk,[4] exposes some pertinent factual elements:

ARIA 22459 - 18 May 2002 - 59 - DUNKERQUE
19.20 - Oil refining
In a plant manufacturing bitumen, base oils and other by-products, an explosion occurred on a 140-tonne tank storing an additive used in the road bitumen composition that contained **2 polymers with high flashpoints**. Insulated and **nearly full at the time of the accident**, this tank was equipped with an agitator and heating coil (**for a viscous product held at over 150°C**), along with a temperature indicator, a nitrogen inerting device and a vent. Due to the blast effect, the tank roof was blown off and landed nearby, while **the tank ignited**.
The internal emergency plan was activated. **The plant operator brought the fire under control within 10 min** using two turret nozzles. External fire-fighters were notified, though their presence was not required onsite.
No injuries were reported and **property damage was limited to the tank itself**. The wind was not blowing in the direction of neighbouring residences, but instead towards the docks.
Nearly all substances remaining in the tank were transferred to another container. The quantity of product lost during the fire was estimated at 1 m³. The retention basin was later drained.
At the Inspectorate's suggestion, the Prefect signed an emergency order suspending supply of this process additive for the time required to conduct the necessary investigations and appraisals, which revealed that **the 2 polymers present in the mix were indeed capable of decomposing in the presence of heat. The first one had decomposed into a substance with a flashpoint below 50°C and a highly flammable monomer with a flashpoint below 0°C**. The second polymer in the mix had the potential to release **extremely flammable gases**. This accident was caused by the slow decomposition of both additive constituents, which in the presence of air yielded organic peroxides or other substances capable of spontaneous combustion. These ingredients, which had been stored for a long time without any agitation, were also responsible for a large accumulation of static electricity. The simple nitrogen flushing of the tank had produced an air intake.
Beyond the immediate measures adopted, the Inspectorate proposed that the Prefect introduce the following equipment: continuous measurement and automatic regulation of temperature connected to a high-level alarm; nitrogen inerting triggered by pressure control; intensity controls on the agitator motor; and a flap valve vent or equivalent to limit air intake. A study was also requested on the feasibility of extending these devices to the site's other flammable liquid tanks.

[4] This accident was already the topic of a presentation at the IMPEL seminar on feedback from industrial accidents (Dijon, Nov. 4-5, 2003).

The detailed accident report (downloadable from the site www.aria.developpement-durable.gouv.fr) indicated that the tank had a capacity of 185 m³ (diameter: 6 m, height: 6.5 m). The composition of the suspected additive was also confirmed, i.e.: a mix of two polymers, one of which decomposed into a highly flammable substance in the presence of heat. During the fire, a flame height on the order of 10 m could be observed from the ground.

The following photographs reveal the physical state of the installations after the accident.



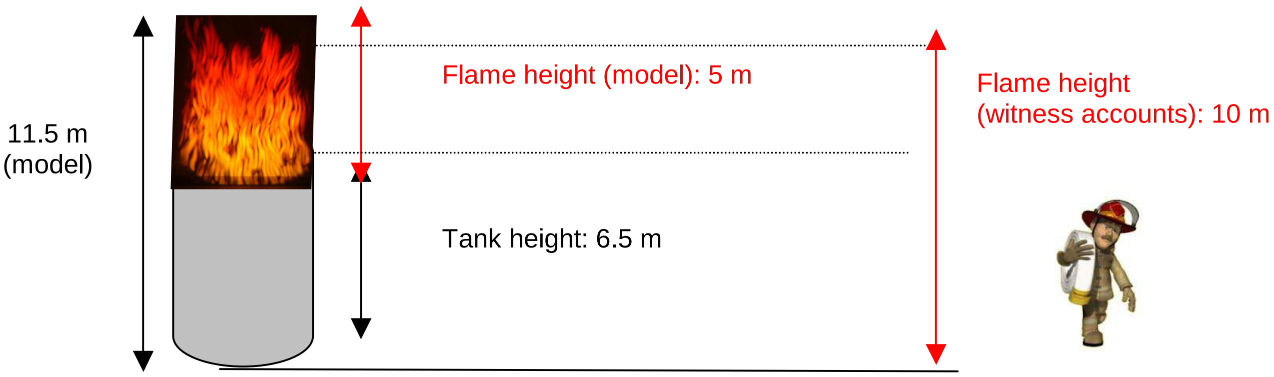
Storage zone - All rights reserved

Tank roof - All rights reserved

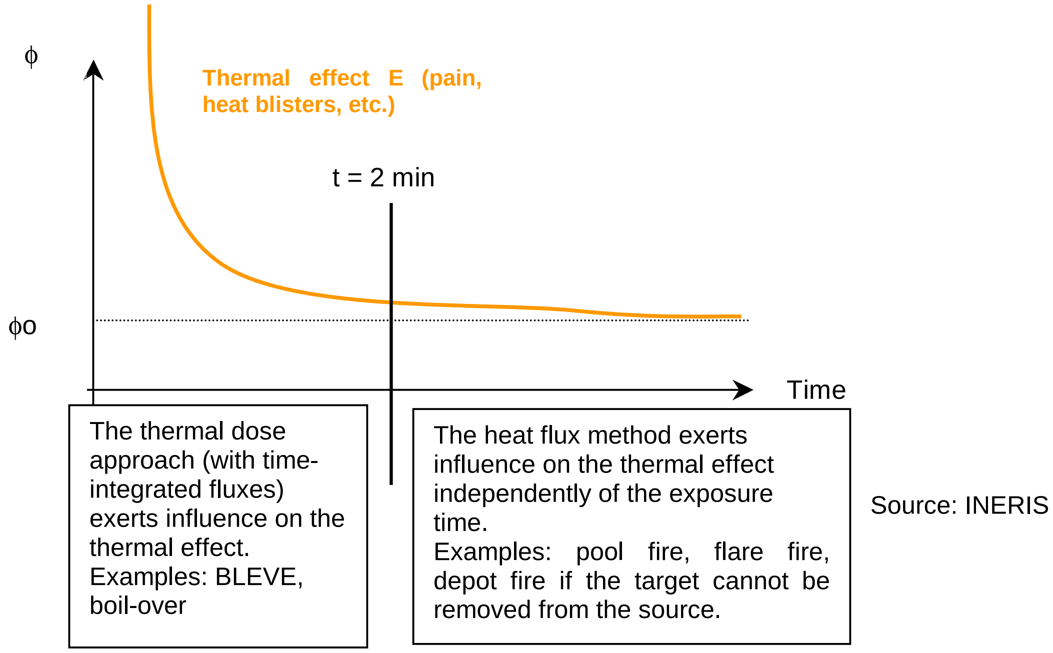
Numerical results

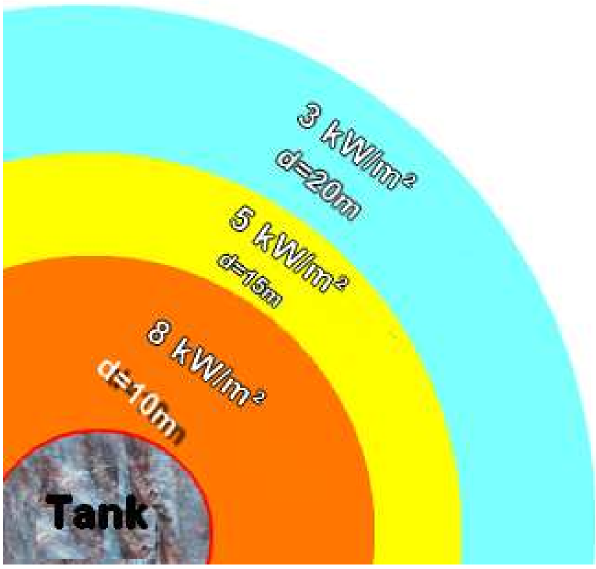
In applying the so-called "solid flame calculation model" appended to the 31st January 2007 circular integrated in the circular of the 1st May 2010 relative to hazard studies on deposits of flammable liquids, we have derived the following results by adopting the hypothesis that the characteristics of this originating product were comparable to those of a hydrocarbon (i.e. heat of combustion around 40 MJ/kg and a combustion speed on the order of 0.04 kg/m²/s).

The flame height was estimated at approx. 5 m above the top of the tank, which compares well with witness accounts indicating a 10-m flame height.



In assuming that the fire duration (10 minutes) exceeded the 2-minute threshold that defines the boundary between the thermal dose approach and the heat flux method (see diagram below), the following results are obtained for the generated heat fluxes.





Results of thermal effect modelling

Very little information is available in the accident summary on thermal effects, besides the fact that the damage is limited to the tank. Calculations suggest a threshold domino effects and serious damage on structures (radiative flux of 8 kW/m²) at about 10 m from the tank. Based on photographs of the accident scene, some equipment was located within 10 m of the tank.

The calculation performed was thus on the conservative side, which could be explained by:
- o materials and structures involved in the accident;
- o the hypothesis adopted, according to which the product behaved like a hydrocarbon.

4. Modelling of an explosion

Event description

ARIA 33085 – 07/05/2007 - 01 - DAGNEUX

49.41 - Road freight transport

At 8:24 pm, a passer-by noticed a cab fire in one of the three lorry tankers in a convoy transporting **liquefied petroleum gas (LPG)** that were parked at the premises of a landscaping firm. The fire quickly spread and around 9:15 pm, an initial blast occurred followed by one or several others; 2 of the 3 cisterns exploded (BLEVE-type incident), and the 3rd was thrown onto the roof of a neighbouring plant. The subsequent explosions and fires caused extensive **property damage within a 900-m radius, including the destruction of 4 warehouses covering 1,000 m² floor space each.**

Gendarmes set up a safety perimeter encompassing the entire industrial park; a motorway and the Lyon-Ambérieux railway line were closed for several hours. A large smoke cloud rose vertically, but no order was issued requiring evacuation of the local population.

Five adjacent businesses were destroyed or heavily damaged and in all some 20 industrial installations within the park sustained varying degrees of damage, resulting in 60 employee redundancies. A 100-kg metal part was projected through the roof of a single-family dwelling 700 m away.

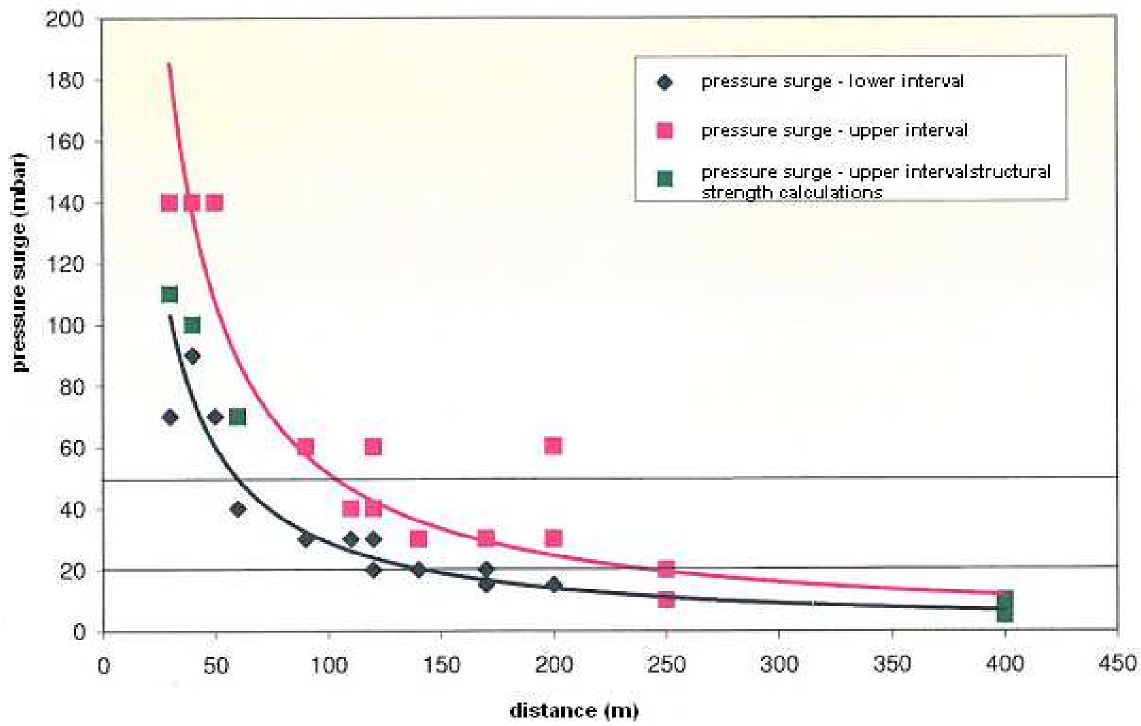
Three fire-fighters and two gendarme officers were slightly injured; **some 20 fire-fighters stationed 200 m from the explosion experienced ear, nose and throat disorders to at least some extent.**

A judicial investigation was carried out to determine the origin of this accident, without overlooking the possibility of criminal act. **Of the 3 cisterns involved, one had contained 2.5 tonnes of propane and another several hundred kg. The third cistern was empty but not yet degassed.** An independent appraiser was commissioned to collect technical data on the accident**. Initial results indicated that effects from the blast extended 50 m due to thermal radiation and up to 400 m (shattered window panes) due to the pressure surge.** Pieces of cistern, sprayed as far as 900 m, destroyed a company premises located 100 m from the lorries and burned a hedge at a distance of 250 m.

Damaged building - All rights reserved

Subsequent to this accident, the INERIS Institute estimated the effects of pressure and the distance over which the pressure surge had caused damage (see detailed accident data sheet downloadable from the site: www.aria.developpement-durable.gouv.fr). Pressure effects could be observed as far as 400 m away (a few shattered windows).

During their survey, appraisers also noted that the effects of pressure were more widespread than thermal effects (within a 50-m radius), which in general appeared as broken windows, cracks in building walls and the destruction of cladding.



Estimation of the effects of overpressure by INERIS from damage during the Dagneux accident.

The vehicles involved in this accident carried limited loads of 9 tonnes; their cisterns were either empty or nearly empty.

Numerical results

A numerical evaluation of the distances of pressure surge effects for an empty LPG cistern, as listed in the 10th May 2010 Ministerial circular relative to the methodological rules applicable to safety reports, is provided in the following table:

PROPANE or BUTANE, empty liquid tank						
Mobile tanks	Burst pressure	300 mbar	200 mbar	140 mbar	50 mbar	20 mbar
Tanker car 119 m3	27 bar	50	60	80	185	370
Tanker car 90 m3	27 bar	45	55	70	170	340
Road tanker 20 t	25 bar	35	45	65	130	260
Road tanker 9 t	25 bar	25	35	45	100	200
Road tanker 6 t	25 bar	25	30	40	90	180

Distances for pressure surge effects (in m) - listed in the circular issued on 10th May, 2010

These results appear to be consistent overall with the distances estimated after the accident.

5. Recommendations for handling feedback

As can be seen in the two examples highlighted in this document, the investigations conducted for feedback purposes subsequent to industrial accidents provide significant opportunities for improving our state of knowledge on hazardous phenomena. In this pursuit, it is essential that the investigation:

- generate technical information on the substances involved (physicochemical characteristics, toxicity, safety data sheets, etc.);
- yield the precise nature of storage facilities and their associated basins (dimensions, state of repair, component materials, etc.);
- evaluate the distances over which effects are recorded (shattered windows, thermal effects on structures and vegetation, length of polluted banks, distance from the point where the leak entered the watercourse);
- determine the flow rate of leaks, size of pipe breaks in the case of a pipe leak, number of individuals present in the vicinity of the site (in particular third parties);
- identify the number of injured, types of lesions caused and their position as the accident unfolded;
- collect background information on the meteorological conditions (wind speed, ambient temperature, etc.) and potential physical barriers capable of modifying the spatial evolution of hazardous effects (wall, bund wall, infrastructure, etc.).

The analysis of the site provided immediately following the accident must also be examined in fine detail.

Conclusion

The numerical modelling of phenomena has become a critical step in all sectors of society, including risk evaluation (whether industrial; natural or environmental).

Such modelling is commonly used to answer the question "*what would happen if…?*", due to the inability of physically replicating the experiment. It also allows testing a hypothesis that has not been taken into account when building the infrastructure, e.g. to measure the strength of a building or facility when exposed to a more intense natural hazard than that used as a design reference.

Though based on relatively simple models, the numerical results provided herein have proven to be quite close to the values recorded during actual accidents.

Against the backdrop of continued advances in the capacity of scientific calculations, interpretation of these numerical methods, in conjunction with post-accident feedback, has contributed to improving our knowledge of hazardous phenomena.

Fire and explosions at an aerosol storage warehouse
5 November 2010
Newton Aycliffe
United Kingdom

LPG / Aerosols
Flammable liquids
Explosive atmosphere / ATEX
Fire / Explosion
Lift truck
Organisation

THE FACILITIES INVOLVED

The site:

The accident occurred at a Top Tier Seveso site operated by a well-established warehousing and transportation company. The only dangerous Seveso material stored was LPG as an aerosol propellant. One of the company's activities was to serve as a UK distribution centre for a major EU manufacturer of anti-perspirant aerosols, liquid hair dyes and shampoos.

The involved unit:

The warehouse where the accident occurred contained approximately 4,000 pallets of aerosols with a typical composition LPG/Ethanol 60/40 %w/w. The warehouse also contained a similar number of pallets of liquid (aqueous) hair colourings and shampoos in plastic bottles.

Palletised products were stored on racks up to 6 levels high. Pallet handling involved 7.5 tonne electric flexi-trucks. Aerosol storage areas are not normally zoned under the ATEX Workplace Directive and the trucks at this site were not rated for use in a potentially flammable atmosphere. The warehouse was not sprinklered.

Figure 1: Interior of the facility prior to the accident

Figure 2: Unprotected electric flexi-truck in use at the site

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

A fire started around midday on a week day when the warehouse and wider site was in full operation. The fire service attended a few minutes after the fire was discovered but the warehouse was already well alight and rapidly burned to the ground. Witnesses reports and CCTV records revealed that the warehouse became smoke logged extremely rapidly after the fire started and there were at least two larger explosions that blew off part of the roof and shook cameras on neighbouring buildings.

Figure 3: Damage to the warehouse and contents caused by the fire

The Fire Service used water to cool surrounding buildings and prevent fire spread but avoided putting water on the burning warehouse since the fire had progressed well beyond the point where extinguishment was a possibility. This controlled use of water avoided immediate large scale dispersal of potentially damaging detergent products into local rivers.

The consequences of the accident:

The fire was discovered at an early stage and unsuccessful attempts were made to control it using a hand-held extinguisher. The fire alarm was sounded promptly and approximately 10 people who were working in the warehouse all successfully escaped within about 40 seconds. CCTV records suggest that the first mass explosion that triggered ultra-rapid fire spread and smoke logging of the building occurred about 80 seconds after the alarm was raised.
The fire service controlled use of water and found there was relatively little environmental damage but 200 fish were killed in a nearby river by detergents and hair dyes being washed from the site after the fire mainly by rain rather than fire water. The fire destroyed 30 per cent of the storage facilities leading to economic losses about 12 million €.

The European scale of industrial accidents:

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

The quantity of LPG burned during the fire is unknown. By default, parameter Q1 (Q1< 0.1%) of the "dangerous materials released" is thus 1. As the effects of the explosions had not been characterized, parameter Q2 was given a rating of 1. The overall "dangerous materials released" rating is thus 1. In the absence of any observed human and social consequences, the relevant index had to be assigned a "0" rating. About 200 fish were killed, leading to an index relative to environmental consequences equal to 1 (see parameter E10). Economic losses were about 12 million €, leading to an index relative to economic consequences equal to 4 (see parameter E15).

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

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

Excellent information on the location of the ignition is available from several witnesses who observed a small flame on a full pallet of aerosols at ground level. This pallet was not close to any lights or other fixed equipment that could have acted as potential ignition sources. Immediately prior to the discovery of fire, a 7.5 tonne electric "flexi" lift truck had been used to remove a pallet from racking across the aisle from the ignited pallet. The lift operation with this truck had involved: driving into the narrow aisle rack array; turning the front section of the truck into the rack; lifting a load at high level and reversing out with the load on the forks. This operation would necessarily have brought the back of the pallet truck close to the stored pallets at a time when the driver's attention was divided between safely extracting the pallet from the high level storage slot and controlling the truck body position within the aisle.

Fork lift trucks used in the warehouse were not suitable for use in areas where there was a risk of a flammable gas cloud. This is because motor brushes and other high-current electrical contactors would have regularly produced highly incendive sparks. These sparking components were not fully enclosed, which means that flammable gas around the truck could move into contact with the sparking components and the resulting gas ignition could propagate out of the truck body and spread to the rest of the gas cloud. The Fire Service investigating officer carefully reviewed evidence relating to all potential sources of ignition other than the lift truck (including arson and smoking). His conclusion was that there is no evidence for any such ignitions. All of the evidence is, however, consistent with ignition of flammable vapours from leaking aerosols being ignited by unprotected components in the lift truck.

There are several ways that a flammable gas cloud might be produced in an aerosol warehouse, many of which have caused major accidents in the past:

i. Loose cans on the floor can be run over, releasing a cloud of flammable gas and finely divided flammable vapour immediately under a lift truck. There are no reports of loose cans in this case and the fire became established on a pallet on the rack rather than the truck.

ii. A truck can collide with a stored pallet, crushing cans and releasing flammable gas and liquid. If this cloud of flammable vapour is immediately ignited by the lift truck, the vapour explosion will track back to the source of vapour and may cause ignition of spilled liquid or cardboard soaked in liquid. This then leads to a sustained, condensed-phase fire that can spread in the normal way. Given the fragility of cans and the mass of lift trucks it is possible for significant releases to occur without the truck driver's knowledge. There were no witness reports of crushed cans in this case but given the stressful circumstances during the accident it is possible that these could have been overlooked.

iii. Aerosols can leak because of manufacturing faults or can corrosion. Given the relatively long time period between manufacture of the aerosols and the accident it seems relatively unlikely that significant leakage would still be occurring.

iv. Aerosols can become damaged during handling by various types of impact or by inappropriate stacking of products (which stresses the caps and discharge mechanisms). This can lead to loss of gas and liquid contents. Full pallets are normally covered in a shrink-wrap cover which is tightly fitted around the pallet. Heavy gases released from cans may not immediately be able to drain downwards out of the load. Flammable liquids released within the pallet begin to vaporise quickly and this continues until all of the air enclosed by the plastic cover is saturated with vapour. Liquid vaporisation then stops and can only progress as saturated air leaks out of the wrapped pallet and is replaced by fresh air. Slow vaporisation of spilled liquid in this way could maintain a flammable vapour concentration within a wrapped pallet for a very long period (several days). A pallet in this condition requires only the lightest contact with a truck to pierce the plastic film and release the vapour cloud within. Again the cloud may be ignited by the truck and the explosion will then track back to ignite the remains of the liquid spill.

The ignition of plastic and cardboard observed by the witnesses tends to suggest that there was a liquid spill within the pallet. There is not enough information available from witnesses or from examination of the fire scene to be able to distinguish between these variations on the themes of leaking aerosols, truck impact and spark ignition.

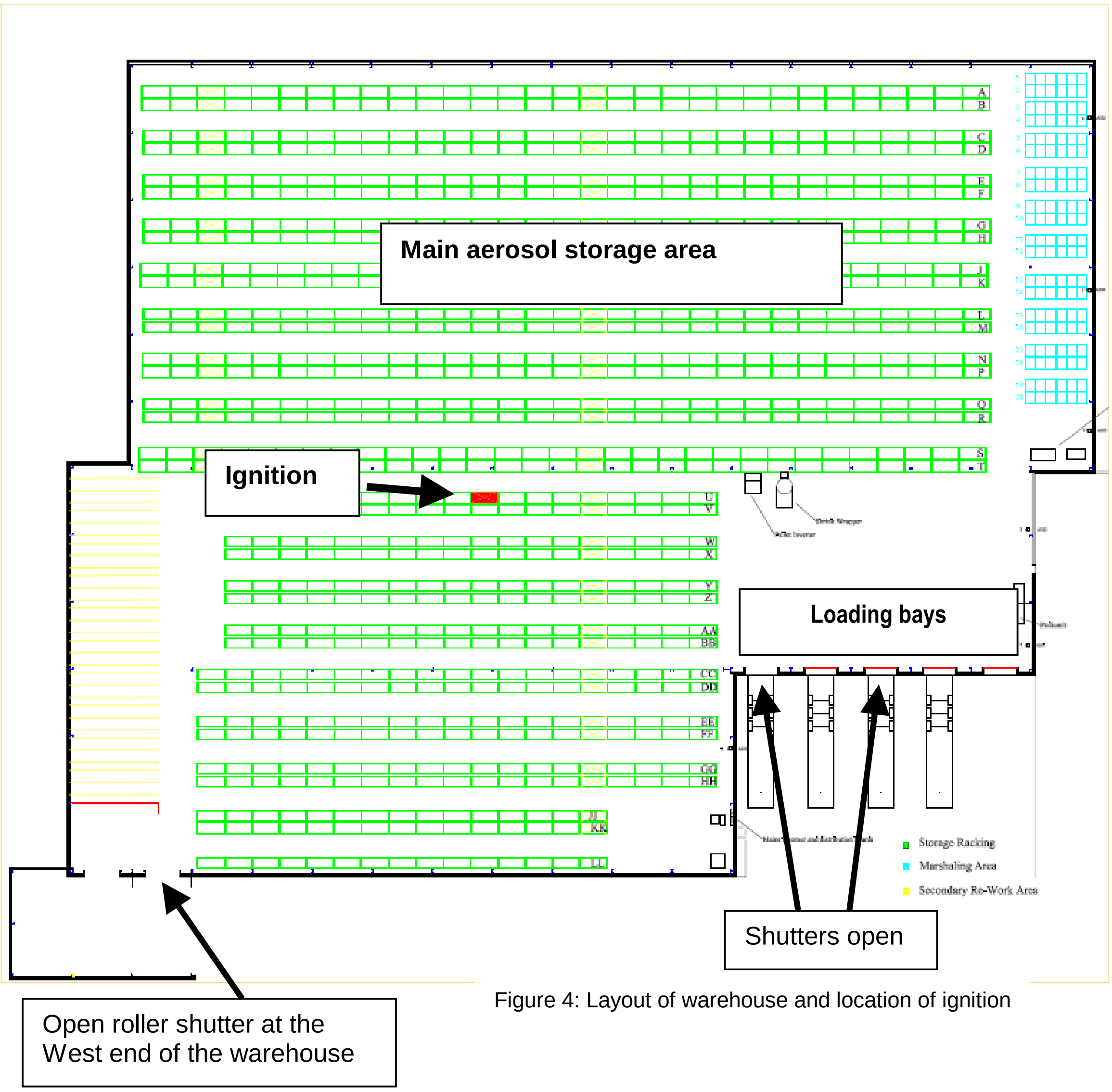


Figure 4: Layout of warehouse and location of ignition

When first spotted by the lift truck driver the flames were only 300mm high – towards the base of an aerosol pallet at ground level. A small foam extinguisher was used and initially the visible flame was knocked down but seconds later flames broke out again. Witnesses fighting the fire then heard a popping noise that they recognised as the failure of an aerosol can and started to run out of the building. The last worker to leave reported his final impressions of the fire:
"..the fire had started to spread to adjacent pallets on either side of it and above. It was spreading surprisingly quick and was beginning to spread towards pallets opposite. You could hear popping and rumbling. This all happened over seconds. There was thick dense black smoke which was spreading up and along the ceiling."

After evacuation was complete, information about the state of the fire comes only from external CCTV and the statements of witnesses who remained close to the aerosol warehouse. A fire development timeline developed from this evidence is shown in Table 1.

Time	Fire condition
-60 (?) seconds	Fire start
0 seconds	Operation of the fire alarm
40 seconds	Last witnesses leave the warehouse
80 seconds	First explosion – onset of rapid fire growth and smoke logging
110 seconds	Building smoke-logged to low level
150 seconds	Second explosion (portion of roof peeled off)
1200 seconds	Uncontrolled yielding of structural columns around warehouse perimeter

Table 1: Fire timeline focussing on the early stages of development

Some witness accounts of explosions early in the fire are reproduced below. The rumbling and cracking noises referred to are the failure of individual aerosol cans:

"I would have ran about 10m out of the gate when I heard the building go… As I ran from the building you heard rumbling and cracking building up, getting louder and louder. The rumbling and cracking did not stop for ages. However when I was running from the building there was one big boom."

"The noise got faster and faster until we heard a bigger bang. We saw a blast of air across the yard with smoke in it."

"There was loads of cardboard coming out through the roof, along with smoke and flames, this all again seeming to happen shortly after I left the building."

The later stages of the fire appeared reasonably typical of the progress of a (high fire load) warehouse fire. However, the complete destruction of steel cladding over areas containing a high density of aerosol pallets is unusual. This is probably due to the combined effect of high temperatures and millions of separate aerosol bursts. These bursts have a percussive local effect that dislodges the rust scale that builds up on steel sheet at high temperatures. The steel roof sheets can therefore rust away during the course of the fire at an unusually high rate.

ACTION TAKEN

The fire destroyed 30 per cent of the storage facilities but, since then, the company has recovered and replaced the lost business with new storage and distribution contracts.

HSE have given presentations on the fire at a conference of the British Aerosol Manufacturers Association (BAMA) and at an NFPA Seminar on High Risk Storage Challenges (Paris, 27th June 2012).

In the future National and European Trade organisations as well as regulators have an important role to play in improving awareness of risks associated with large scale storage of aerosols. The UK BAMA guidance is widely used but this does not clearly identify unprotected lift trucks as an important cause of fires. Similarly the speed with which fires develop and the shortness of the time available for evacuation is not generally understood.

These issues are most important for warehouses that store very large numbers of pallets of aerosols (Seveso sites). Many shops have relatively small numbers of aerosols mixed in with much large quantities of other goods. In these cases the risk of ignition is much lower and the rate of fire growth not unusual. For these stores investment in protected trucks may not be justified.

LESSONS LEARNT

Important process safety lessons to be learned

i. Unprotected forklift trucks represent a serious risk of starting fires in aerosol stores. There are many scenarios in which small vapour clouds can be created and ignited by an unprotected lift truck.

ii. Fire growth in aerosol stores can be extremely high. Even in large buildings the time available for escape can be as low as 100 seconds. This means that emergency planning is of prime importance. Fire evacuation should be practised regularly with 100 seconds being the target evacuation time.

iii. Careful attention should be given to mezzanine levels (that are rapidly affected by smoke) and any separate compartments from which escape is only possible through the warehouse. Special risk assessments may be needed where people are working at elevation and cannot get down quickly (e.g. scissor lifts). For example, it may be necessary to suspend the use of unprotected lift trucks within high rack storage areas (where they can start ultra-rapid fires) if there are people working in locations where they cannot escape quickly in response to an alarm.

Figure 5: Smoke flow from the building 135 seconds after the fire alarm was sounded

Potential for larger explosions at aerosol warehouses

This fire shows clearly that the release and combustion of flammable vapours from large numbers of aerosol pallets may not be a steady process. Aerosol cans may vent under conditions in which there is no immediate ignition; flammable gas and dispersed liquid then accumulates in the upper parts of the warehouse and there may be rainout of flammable liquid away from the established fire. Subsequent ignition can lead to an explosion and/or sustained burning of fuel rich volumes. The latter may generate a swelling fireball that could in principle engulf and ignite goods in a substantial fraction of the warehouse in a few seconds. Ignition of dispersed liquid may spread the fire to lower level over a wide area. This also has the effect of greatly increasing the subsequent rate of smoke logging.

The safety significance of such explosions depends on the circumstances. If the warehouse is very large and aerosols are stored (at high level) in one separate area there is potential for a large volume of gas to accumulate over a relatively long period of time (tens of minutes). Overpressure effects from explosion of such an accumulated cloud could be a significant threat to the Fire Service and any other people close to the burning warehouse. The risk is greatest if a fire starts in other goods remote from the aerosols and stabilises at a level corresponding to an upper layer temperature in the range 150 - 300℃. This type of explosion could be a Major Accident Hazard but is normally a possible but unlikely scenario. More likely is a fire that continues to develop rapidly. Upper layer temperatures > 300℃ cause rapid can failure but there is insufficient residual air to support a premixed explosion.

If the warehouse contains a high proportion of aerosols and these are distributed throughout the warehouse, explosions are likely to occur more rapidly but to be of smaller size and intensity. The aerosol store destroyed by fire described in this note was of this sort. In this case the significance of explosions is in accelerating the spread of fire and restricting the time available for escape.

The extent and consequences of vapour accumulation and explosion are likely to be highly variable and difficult to predict. In some cases no significant explosions will occur but, on the other hand, much more severe blasts might occur in a warehouse with a similar size and stock mix to that at this warehouse.

There appears to be a lack of published information of the rate of failure of palletised aerosols cans exposed to temperatures in the range 150 - 300℃. Without this data it is impossible to attempt to determine when and where areas of unburned gas and liquid may form and in what concentration. Consequently, there is a need for research on the behaviour of aerosols in these circumstances.

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Fires and BLEVE on LPG tanker lorries

27 July 2010

Port-la-Nouvelle (Aude)

France

Explosion / BLEVE
Transport of hazardous materials
Projections
Propane
Mobile storages

THE FACILITIES INVOLVED

The site:

This accident occurred at a site engaged in logistics, maintenance and parking specifically for tanker lorries transporting hazardous substances (primarily LPG and hydrocarbons). The company also uses the site for the storage of a small quantity of LPG cylinders, declared under the type 1412 of the French Regulation on Classified Industrial Facilities: « torage of liquefied flammable gases in manufactured containers », with a maximum of 6 to 50 tonnes of gas present at the same time.

The installation was located in the vicinity of the Port-la-Nouvelle harbour. The environment immediately adjacent to the company's premises was relatively unencumbered, especially given the presence of salt marshes to the north-west. A grain silo occupied a site 200 m to the south, a hydrocarbon storage facility (lower-tier Seveso) 300 m to the south-east and an LPG filling station (upper-tier Seveso) 500 m to the east. The closest dwellings lie on the other side of a channel some 400 m to the south of the company's parcel.

The regulations in effect relative to infrastructure for transporting hazardous substances specific to public parking zones (Articles R.551-1 and following of the Environmental Code) did not apply to this private "depot". Similarly, the "simple" act of parking vehicles carrying LPG does not, in and of itself, constitute an activity that falls under the jurisdiction of classified facilities legislation.

Precise accident location (red dot)

The unit involved:

On the day of the accident, eleven vehicles were parked at the designated LPG tanker lorry zone:

- two empty vehicles dedicated to the transport of liquid hydrocarbons,
- eight vehicles dedicated to LPG transport,
- abutting the repair shop, another vehicle (filled at 64% capacity with propane) that had undergone a mechanical inspection during the afternoon.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

During the afternoon of 27 July, the driver of a tanker lorry, whose 13.5-m^3 capacity was filled at 64% with propane subsequent to a product pickup order at a client's site, decided to return early to the base after noticing that the "overheated engine" indicator light had come on. Upon arriving at 6:20 pm, the indicator light turned off. Parked away from the other vehicles, his lorry was scheduled for repairs at the shop the next day. Between 6:30 and 11:20 that evening, despite a number of site entries and external patrol rounds, nothing out of the ordinary was reported. At 11:40 pm, the alarm was sounded by a safety officer who witnessed a glow on his control screen and received reports of a burning smell downwind to the east. At 11:58, the industrial park guard saw flames around the vehicle's bumper below the engine. Fire started to engulf the lorry, closing in on the cistern. A crew of 12 fire-fighters were at the scene 12 minutes past midnight and observed an ignited leak in back of the cistern, perhaps near the manhole; they sprinkled the entire vehicle.

Photograph of a fire-fighter arriving at the scene of the accident

In attempting to cool the cistern while remaining 100 m away, due to the inherent BLEVE risk, responders heard a whistling noise at 12:16 am and retreated to safety just before the BLEVE explosion of the tanker lorry and the ensuing "fireball" observed by eyewitnesses.
The BLEVE effects caused fire to spread to 2 buildings (the repair shop and the maintenance shop, built alongside the company's administrative offices) as well as to 2 empty hydrocarbon tankers parked nearby. Two gas bottles present in the repair shop also exploded.
Throughout their response effort, which lasted all night, fire-fighters protected the other LPG vehicles in order to avoid subsequent BLEVE explosions. The fire was ultimately contained during the morning of 28 July.
While fighting the blaze, the emergency response team encountered difficulties in accessing the site's water resources, which were needed for their cooling operation; they had to rely on the fire-fighting reservoir made available by a nearby hydrocarbon storage facility.

Consequences of the accident:

Some of this site's tanker vehicles were quite seriously damaged and nearly all vehicle windows and windscreens were destroyed:

- The 2 empty vehicles dedicated to hydrocarbon transport parked at the targeted zone were destroyed by fire and the walls of their cisterns completely torn apart;
- Among the 8 vehicles for LPG transport, 4 were partially destroyed by the blaze (mainly the cab area, as the cisterns could be spared by spraying water on their walls). Three of these lorries were empty but not yet degassed (displaying a residual pressure of 7 bar), and the fourth was filled with LPG to 82%, under pressure exceeding 7 bar.

Only the cistern on the vehicle responsible for the accident actually exploded. The administrative buildings also sustained damage due to the power of the blast.
Less severe damage was caused beyond the site boundary: shattered windows, hangar cladding deterioration, vents on the neighbouring silo blown off, brush fires in the salt marshes separating the company premises from the LPG filling station.

As typically noted during such accidents, thermal and mechanical effects were both induced.

Administrative offices and maintenance shop: concrete structure shifted due to the blast

Zone occupied by gas tanker vehicles: burned lorries

➢ *Human toll:*

No serious injuries were reported; one of the company's drivers sustained cuts to his hand due to the broken windscreen on the lorry he was removing from the parking lot as the fire was spreading; 12 fire-fighters complained of headaches and/or hearing problems (resulting from the blast effect). No one at the scene required hospitalisation.

➢ *Property damage:*

Recordings of damage and their corresponding valuations were logged by a third-party body, commissioned by the Ministry for Sustainable Development.

✓ ***Thermal effects:***

According to witness accounts, the BLEVE explosion created an ignited cloud with an elongated shape, rather than spherical, rising to considerable heights. The film recorded by an adjacent site's monitoring camera revealed the violence of the explosion, though the maximum size of the ensuing fireball could not be estimated.

No heat effect due to radiation was detected on structures located within tens of metres of the lorry explosion, e.g. no scaling or blistering effect on the paint could be ascribed to radiation from the fireball. The only thermal effects observed were related to the intense fire, which lasted several hours and led to the destruction of a number of tanker lorries.

✓ ***Pressure effects:***

The tanker lorry exposed to this BLEVE was destroyed by both the explosion and fire. The only part remaining on the ground was its engine, as the cistern was found "flattened" on the roof of the repair shop's metal building structure.
Pressure effects were reflected by damages of varied intensity to lightweight building structures: cladding, windows, doors, glass panes. Adjacent to the explosion, a concrete wall was also damaged.
Outside the site, many glass showcases and windows on facades directly exposed to the BLEVE pressure wave were destroyed. According to testimonies collected, some of the windows located on non-exposed facades also sustained damage. Shattered windows were reported up to 700 m from the ignited lorry.


Source DREAL Languedoc-Roussillon

Wrecked tanker lorry after exposure to the BLEVE


Source DREAL Languedoc-Roussillon

"Flattened" cistern thrown onto a roof

✓ ***Debris projections:***

The 13.5-m^3 cistern burst into several fragments, with projections mainly in the direction of the tanks' alignment.
Four large pieces of the tank were catalogued:

- the largest fragment, comprising most of the shell of the "flattened" cistern, was thrown onto the roof of the repair shop's metal building;
- two pieces were identified outside the site at 20 m and 70 m in front of the lorry, along its alignment;
- a bottom piece (steel flange) was projected in the opposite direction from the previous fragments, beyond the site boundary 150 m from the ignited vehicle.

Cladding was also projected outside the site, at distances in the range of 50-100 m from the tanker lorry.

The European scale of industrial accidents:

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

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

The level 3 rating of the "hazardous substances released" index reflects the 4.2 t of propane involved in the accident.
The 2 score assigned to the "human and social consequences" index is due to the one site employee and 12 fire-fighters injured (though not hospitalised).
Given the lack of any damage estimate, the "economic consequences" (parameters €16 and €15) could not be rated.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

This accident occurred on a tanker lorry that had returned to the base earlier than scheduled subsequent to activation of the "engine overheating" indicator light. As a result, the lorry was parked with product in its cistern adjacent to the repair shop, where it had been scheduled for inspection the next day. This parking spot did not correspond to a normal designated space at the depot site. The vehicle had been placed in a temporary position directly above a drainage pit that possibly contained oil. These circumstances however could not be singled out with certainty as the cause of the fire outbreak. It turned out that by the time the lorry had returned to the depot, the indicator light was no longer on; moreover, the fire started several hours after the lorry had come to a complete stop without any anomaly observed in the meantime.

The shared use of parking facilities by lorries carrying liquid hydrocarbons and LPG might have helped spread this fire, though this overlapping use was not responsible for other BLEVE.
This BLEVE occurred following an audible whistling sound. Since the cisterns had not been fitted with valves, such a sound could have been created by a loss of seal just a few moments prior to the explosion, e.g. around the joint on the manhole whose flange wound up being ejected 150 m.

ACTIONS TAKEN

An administrative investigation was conducted in order to determine the origin of the fire. Following a Classified Facilities Inspectorate site visit during the morning of 28 July, the Inspectorate proposed for the Aude County's Prefect to sign a Prefecture order imposing the adoption of emergency measures in application of Article L.512-20 of the Environmental Code, requesting that the site operator ensure the safety within 48 hours of the 4 LPG vehicles already partially damaged by the fire, by means of degassing the 3 empty lorries and draining the vehicle that had remained full.

The possibility of malicious intent could not be ruled out, as an opening in the fencing was remarked after the accident.
At the same time, the Ministry for Sustainable Development commissioned a third-party body to establish a record and analyse the thermal effects, pressure effects and flying fragments generated by the explosion.

LESSONS LEARNT

This accident illustrates the risks inherent in parking vehicles designated for transporting hazardous substances, especially LPG, on private lots. A review to enhance recognition of these risks, focusing on site supervision and fire-fighting resources (inadequate in the present case), was one approach that could be envisaged.

The BLEVE of a tanker lorry had typical effects (pressure surges, thermal effects and projections) associated with such a phenomenon.

No heat radiation effect could be detected on any of the structures. According to theoretical models for estimating thermal effects, if the cistern had actually been filled to 64% of its capacity at the time it burst, then a thermal load of 1,800 $(kW/m^2)^{4/3}.s$ would have been reached at a distance of about 50 m to 60 m. These differences might be explained by the fact that, according to testimony, the explosion gave rise to a high-altitude and elongated (rather than spherical) "fireball", whereas the theoretical model had assumed a spherical expansion. Moreover, it is entirely possible that a portion of the liquid initially present had leaked prior to bursting, as suggested by the whistling sound heard by fire-fighters. This leak may have stemmed from the onset of a crack, a broken tap or else a compromised seal around the joint on the manhole whose flange had been ejected 150 m.

An analysis of damage, as measured against the tables of typical damage, showed the 140-mbar threshold at between 30 m and 50 m, and the 50-mbar threshold between 50 and 200 m. These distances associated with blast effects fit overall with expected values. The effect distance for the 20-mbar threshold could not be located precisely (somewhere between 100 and 700 m). The few shattered window panes observed at 700 m by far exceed the distance corresponding to the 20-mbar threshold described in the regulations (180 m for a 6-tonne tanker lorry), yet they remind us that this threshold corresponds to a rate of broken windows equal to at least 10%.

Both the direction (along the cistern alignment) and the maximum observed distance of projected debris are consistent with feedback available on this type of BLEVE.

This accident also recalls the very short period of time required for a BLEVE to occur: less than 20 minutes between the observation of fire and the explosion. Nonetheless, the occurrence interval remains difficult to predict, since it depends on a whole array of parameters (e.g. fire intensity, quantity of liquid present in the cistern, tank shell specifications). The more reduced the volume of the liquid phase is and the intenser the fire surrounding the tank grows, the shorter the time lapse will get. The benefit of installing valves on the cisterns merits discussion (as a means of delaying the BLEVE occurrence and reducing the quantity of LPG involved), especially as regards the risks of additional leaks and associated consequences in cases where the lorry overturns during a road accident.

Lastly, the clustering of (curious) onlookers trying to catch a glimpse of the growing fire, unaware of the risks created by such an incident, more broadly raises the recurring issue of informing the local population (in particular summer tourists at resort locations).

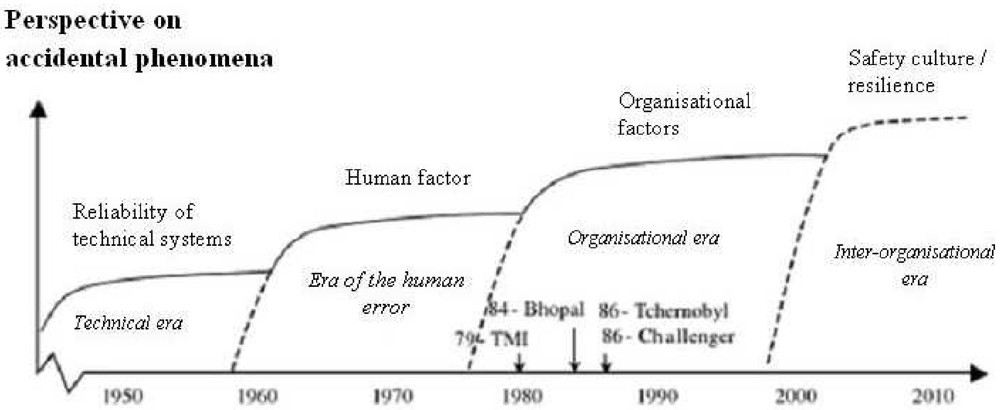
Theme 3

Human error or organizational failure?

Fact sheet

Human error or organizational failure?

Over the past several decades, companies have been developing technical measures to gradually improve reliability of their installations and prevent industrial risks. Safety management systems have subsequently been introduced to ensure overall operational robustness. Though progress has been observed over this period, the need to pursue these actions will still require an ever-increasing understanding of the challenges involved in the organisational and human factor (OHF).



Evolution in safety management approaches implemented (adapted from Groneweg, 2002; and Wilpert and Fahlbruch, 1998)

In this context, an analysis of deep-rooted accident causes is mandatory, in conjunction with a reliance on new fields of knowledge such as the human and social sciences, for application to "practical" problem situations as they arise. Beyond the technical and technological aspects and compliance with regulatory constraints, simply strengthening an installation's formal mechanisms fails to erect a sufficient barrier to limit the number of observed deficiencies (i.e. "safety on paper").

1. Extending beyond the operator error stage

As part of a post-accident investigation, one should not interrupt the assessment upon recognising inappropriate human action; individuals often fail to act as they should have or could have. This interpretation must nonetheless be placed into a context with respect to 6 major sources of bias when interpreting human error:

1/ ***Retrospective illusion or an all-knowing attitude:*** Interpretation of technicians' actions must not be based on events that only seem obvious after the fact.

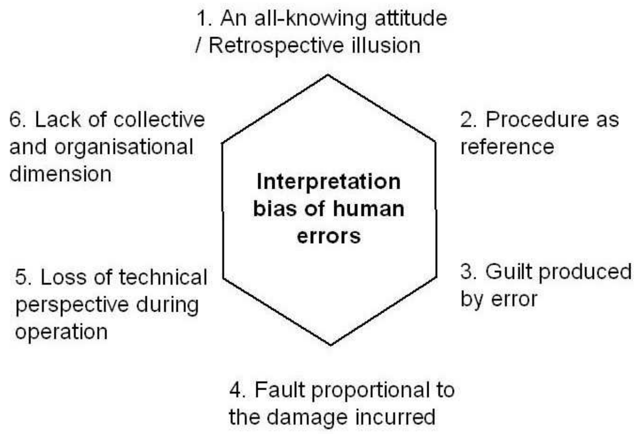
2/ ***The procedure as an absolute reference:*** The procedural description must not serve as the sole reference in interpreting actors' actions.

3/ ***Error-induced guilt:*** It is all too easy to blame someone who failed to perform what seems obvious after the fact; this trap must be avoided.

4/ ***The fault is proportional to the damage incurred:*** The seriousness of the damage must not be systematically correlated with an equivalent level of seriousness ascribed to the operator whose action triggered the sequence.

5/ ***A loss of workplace perspective:*** Operator behaviour should not be analysed independently and in isolation, but instead always be placed back into the event dynamic in interaction with the working context: equipment, interface, etc.

6/ ***Lack of collective and organisational dimension:*** An interpretation of actions must not single out any individual, but rather incorporate the collective dimension during teamwork, in addition to emphasising interactions among individuals.

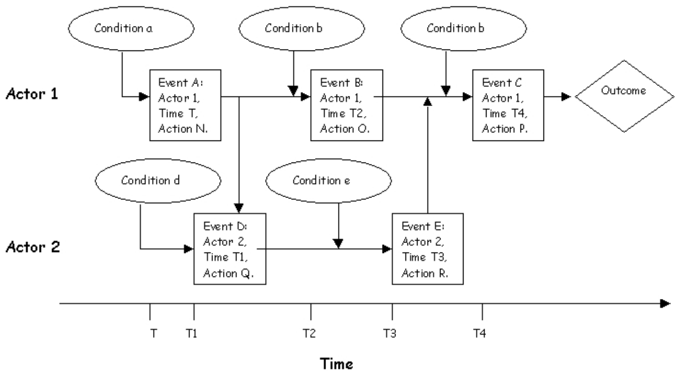


2. Two methods amongst others for "digging deep" into the organisation

During the 1990's, the work carried out by James Reason, who developed the concept of "holes in the Swiss cheese" (see p. 3), led to a set of deductive accident analysis methods based on an identification of root causes (i.e. the so-called "Root Cause Analysis"). These methods began with the observation of an accidental phenomenon arising due to atypical situations relative to either equipment status or operator behaviour. Mr. Reason's research has yielded a straightforward and widespread analysis method, referred to today as TRIPOD, that relies on 11 general categories of latent dysfunctions or deep-rooted accident causes; these categories are also called "Basic risk factors" and consist of:

- Adaptation / Working order of the equipment / Specifications (Hardware - HW)
- Design / Ergonomics (Design - DE)
- Maintenance management (MM)
- Operating procedures / Guidelines (Procedures - PR)
- Conditions conducive to errors / Physical and psychological factors (Error-enforcing conditions - EC)
- Workplace / Tidy layout / Cleanliness / Environmental setting (Housekeeping - HK)
- Incompatible goals / Productive pressures (Incompatible Goals - IG)
- Communication inter-site, inter-team (Communication - CO)
- Organisation / Supervision (Organisation - OR)
- Training (Training - TR)
- Technical / organisational obstacles (Defences - DF)

In conjunction with these research advances, another analytical method (labelled "STEP", for Sequentially Timed Event Plotting) proposed an innovative graphical representation, whereby the accident dynamic is not only presented chronologically but also by specifying the "actors" involved in all observed aberrant situations, along with their associated deep-rooted causes.



"STEP" method (Source: www.dcs.gla.ac.uk/~johnson/book/parts/chap11.pdf)

In reality, several readily apparent (though not mutually exclusive) causes are typically responsible for an accidental situation, which itself is often preceded by precursors and basic technical or organisational deficiencies. For the classified facilities alone, 919 accidents involving French sites were recorded in the ARIA base for 2012 alone. Out of the 601 events with identified causes, 372 (or 62%) explicitly invoke OHF while 82% of these 372 events point directly to organisational management: ineffective supervision; missing, incomplete or inappropriate procedures; instructions ignored; ergonomic flaws. A lack of oversight in the field or inadequate understanding of preventive procedures and guidelines is often cited, since these instances of noncompliance are typically associated with an absence of internal controls.

3. From the notion of human error to that of organisational flaw

ARIA 22836 – 28/01/2001 – 64 – MOURENX

21.10 – manufacture of basic pharmaceutical products

In a workshop manufacturing active pharmaceutical ingredients, at around 3:30 pm, a technician initiating a cleaning task transferred acetone from one reactor (level: 7 m) to another (level: 3 m), whose **low-point sampling valve had been left open** (level: 0 m). The solvent spilled out along the slope of the workshop floor towards a wall containing an unobstructed 10-cm wide opening, on the other side of which a subcontractor was cutting metal with a blowtorch.

A 2nd technician noticed the leak and closed the valve. **An explosimeter, inoperable for 3 days** (due to a connection problem), had still not been repaired. The acetone fumes ignited outside the workshop, then the fire instantaneously spread underneath the reactor and to the upper floors via a hopper. A safety technician activated the internal emergency plan siren, effectively locking down the workshop; electricity supply was shut off and the wastewater drainage network diverted to a retention basin. An onsite agent deployed a fire hose station from the 7-m level; the deluge sprinkler system was tripped a few minutes later and extinguished the fire. The water was left to cool installations for another 20 min. Employees wearing self-breathing apparatuses surveyed the workshop, and the emergency plan was lifted 30 min after its initial activation. **The site operator analysed this accident, which had occurred when conducting summer renovations, reconfigured the workshop floor drainage slopes and modified all working procedures involving hot work permitting**: memorandum circulated among workshop technicians; establishment of a defined works schedule; ban on open flames in all designated high-risk zones during operation phases; installation of dedicated electrical outlets for subcontractors, which were hooked up to the explosimeter detection system and solely supplied during the time period assigned to hot work permit tasks.

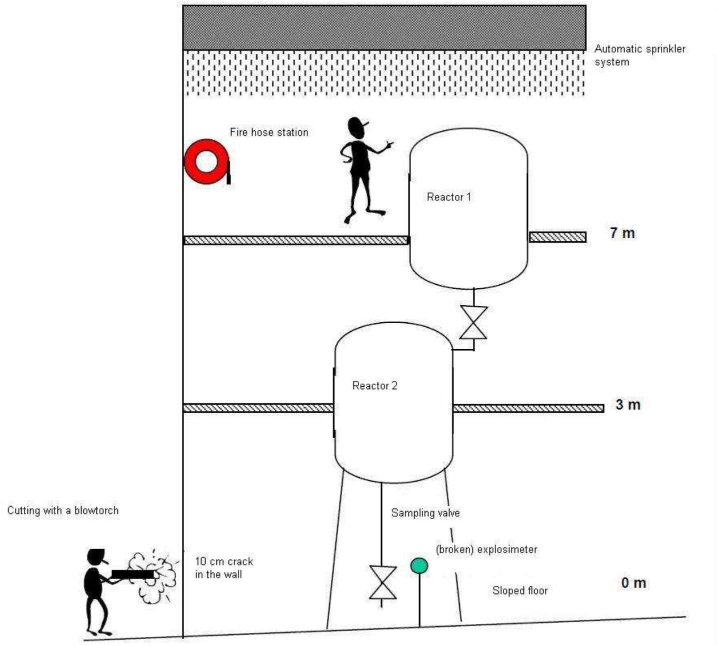


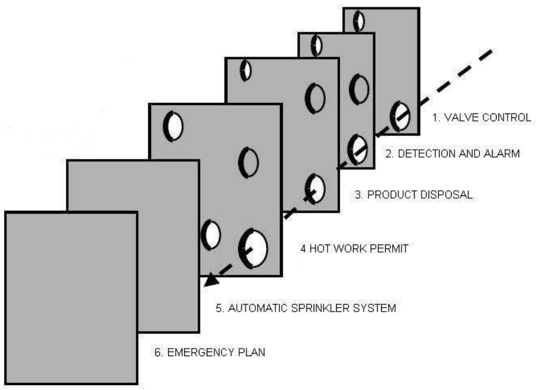
Diagram of the accident situation

This accident resulted from a sequence of events that passed through several technical and human barriers:

1. verification of the sampling valve
2. explosimeter-triggered detection (+ alarm)
3. disposal of product (drainage)
4. hot work permitting

Other barriers were then able to perform their function:

5. automatic sprinkler system
6. internal emergency measures



Depiction of the "slices of Swiss cheese" model (Reason, 1990)

While the human factor served as the trigger for this accident (an open valve / left open for a while?), such an accidental sequence should not necessarily be attributed to a single individual. The accident analysis, by focusing on the interpretation bias inherent in human behaviour, has exposed an entire set of circumstances, namely:

1. Had the 2nd-floor technician previously been assigned to perform cleaning after a sampling operation? Did he possess the requisite experience to anticipate the outcome? Perhaps these tasks had never before been sequenced, thus complicating the control function. While the appropriate steps appeared obvious during the post-accident investigation, such was not the case for the technician when faced with a brand new workplace configuration. In filling the reactor, could the 2nd-floor technician have reasonably expected this situation, even partially? Moreover, it remains unclear as to whether the technician had been instructed to verify valve closure before initiating the cleaning operation.

2. Were procedural descriptions relative to the cleaning phase applicable? Had they been revised for whatever reason, thus nullifying them in certain configurations? Had production constraints perhaps led to transitioning quickly between sampling and cleaning phases, whereas this transition was given ample time in the past for adequate control.

3. The personnel responsible for cleaning the reactor or maintaining the valve open without executing the proper controls cannot be considered "guilty". An error was indeed committed, but the accident resulted from system-wide, or systemic, inadequacies. Weren't workplace conditions on the day of the accident primed to commit an error (intense time pressures, several uncertainties requiring a substantial reorganisation of the work schedule) ?

4. Lastly, several hypotheses need to be examined in greater detail regarding interactions between the 2 technicians: perhaps the 2nd technician was in the process of closing the valve he had left open but was unsuccessful due to technical reasons; might he have been unaware that another technician was preparing to clean the reactors? These collective aspects, which are of tremendous importance, entail coordination, communication, cooperation and collaboration among individuals. Without such a collective and objective-oriented perspective, no overview is possible. For this accident, it should be determined what the organisation had planned regarding event control: the same person responsible for closing the valve and then performing verification vs. use of a 2nd person (built-in redundancy)?

A contextual analysis has thus exposed a number of organisational issues with respect to the formal management of onsite safety, e.g. by implementing a safety management system (or SMS) for Seveso-classified sites. Regardless of the eventual confirmation of certain hypotheses, these deep-rooted causes can still be analysed relative to the factors identified when running the TRIPOD method:

- Adaptation / Working order of the equipment / Specifications (Hardware - HW): Explosimeter inoperable
- Design / Ergonomics (Design - DE): Ground drainage slopes, installation set up on 2 levels (valve not in plain sight), wall temporarily permeable (penetration of an opening), presence of a hopper to facilitate the spreading of fire
- Maintenance management (Maintenance management - MM): Explosimeter defective yet still not repaired even after 3 days, task execution procedure (hot work permit), works carried out in the vicinity of an operating installation
- Operating procedures / Guidelines (Procedures - PR): Sequencing of operations (sampling, cleaning)
- Conditions conducive to errors / Physical and psychological factors (Error-enforcing conditions - EC): Smaller staff size, reduced summer schedule
- Workplace / Tidy layout / Cleanliness / Environmental setting (Housekeeping - HK): ?
- Incompatible goals / Productive pressures (Incompatible Goals - IG): Sustained productivity (installation remained operational)?
- Communication inter-site, inter-team (Communication - CO): Exchanges held between operations & maintenance staff members
- Organisation / Supervision (Organisation - OR): Information distributed to technicians (ongoing works), team oversight (production / facility repairs/improvements)
- Training (Training - TR): Installation supervision (sampling, cleaning, scheduled controls)
- Technical / organisational obstacles (Defences - DF): Electrical outlets hooked up to the explosimeter detection system (installed after the accident).

Conclusion:

- An accident is often the combination of direct, or immediate, causes (technical malfunctions and/or human errors) **AND** deep-rooted causes (whether human or organisational).
- The prevention of technical defects or human errors (direct causes) involves not just identifying these defects/errors and then applying the appropriate remedial measures, but more importantly identifying the breakdowns in workplace and safety organisation and introducing their corresponding corrective measures.
- The identification and search for direct and deep-rooted causes requires a multidisciplinary approach that includes the participation and/or interviewing of actors responsible for the broad cross-section of missions (technicians, designers, shop foremen, engineers, managers, etc.) **AND** the contribution of a wide range of scientific and methodological skills: chemists, explosion experts, ergonomics specialists, sociologists, investigators, etc.

Accidental release of phosgene
14 May 2012
Le Pont-de-Claix (Isère)
France

Chemistry
Phosgene
Leaks
Heat exchangers
Corrosion
Confinement enclosure
Organisation / Human factor

THE FACILITIES INVOLVED

The site:

This plant is part of the Pont-de-Claix chemical complex, an industrial park that includes several firms with close ties due to their respective manufacturing activities. The site is located in a densely urbanised environment on the outskirts of the Grenoble metropolitan area.
Park activities are based on producing chlorine and phosgene for subsequent use in the synthesis of isocyanates (intermediate compounds for polyurethane foams and paints) and several products intended for crop protection.
This upper-tier Seveso site is subjected to Prefecture oversight as prescribed in regulations governing classified facilities for the manufacturing, storage and use of hazardous substances, i.e. mainly chlorine, phosgene and isocyanates.

The specific unit involved in this accident:

The accident occurred inside an isocyanate production workshop. The process implemented consisted of generating a reaction from a phosgene solution on an amine compound under conditions of high temperature and pressure.

The number one hazard during workshop operations is the accidental release of a phosgene cloud. Phosgene gas, which is heavier than air and highly toxic, was notably used as a combat weapon during World War I (with a threshold for significant lethal effects after a 30-min exposure = 3 ppm - source: INERIS).

Given the hazard potential associated with the substances employed, this reaction was carried out within a confined enclosure held in a low-pressure state and featuring a safety column (for soda absorption), which served to dissipate the phosgene cloud emitted during an accidental situation.

This enclosure housed 2 tubular heat exchangers, one of which became the source of this accident.

Operations of the faulty equipment:

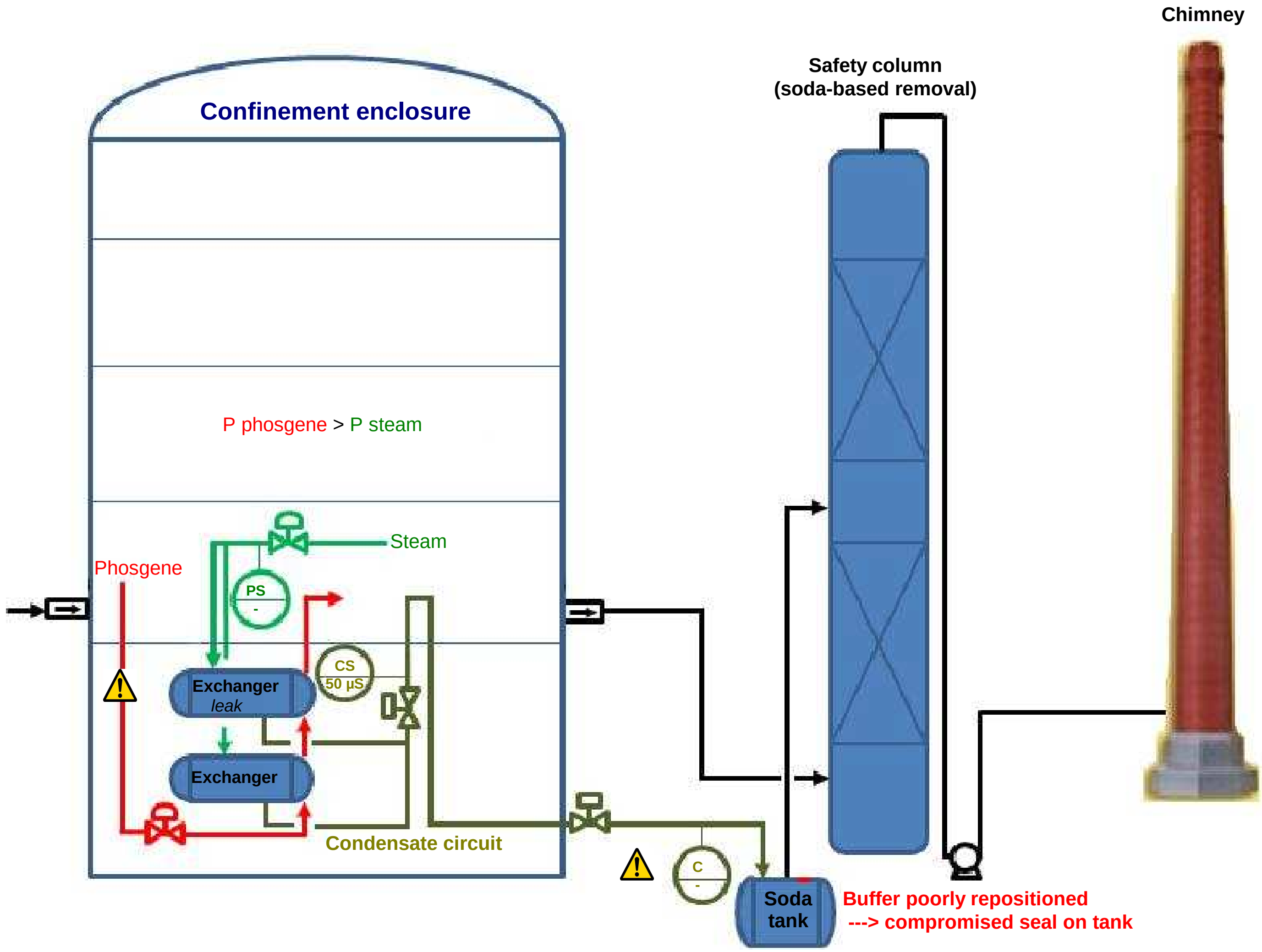
To proceed with isocyanate synthesis, the two tubular exchangers warm the phosgene solution prior to its reaction. This solution circulates inside the tubes, with the caloric contribution being generated at the level of the tubular shell by overheated steam. Pressure rising to several tens of bar around the dissolved phosgene by far exceeds the vapour pressure introduced. Drains at the base of exchangers collect the condensates, which are then channelled to a soda tank located outside the enclosure. The gaseous phase is directed to a chimney via the safety column.

During normal operations, phosgene and water are never in contact with one another. However, in the event of an exchanger tube leak, the phosgene solution spills into the steam circuit. Pressure increases in the circuit, and a portion of the phosgene reacts with the water vapour in forming hydrochloric acid. Both the phosgene and hydrochloric acid are then discharged through the condensate circuit to the soda tank on the safety column outside the confinement zone. To avoid such a scenario (identified in the safety report), 2 technical safety barriers had been designed, namely:

- a conductivity measurement on the condensate circuit, which triggers isolation of this circuit and shuts down the phosgene solution supply pump once threshold value tops 50 µS;
- a pressure switch on the steam circuit, which upon recording a "high pressure" measurement also isolates the condensate circuit and shuts down the phosgene solution supply pump.

Moreover, the installation contained an additional conductivity meter on the condensate circuit dedicated to system supervision, i.e. without any associated programmed action, as well as an automatic valve closure device for the confinement should the low-pressure state not be maintained.

<u>Simplified diagram of a portion of the HDI (isocyanate) workshop process</u>
(State of the installation on the day of the accident)



CS 50 µS — Sensor measuring condensate conductivity with a safety action programmed at 50 µS → isolation of the condensate circuit and shutdown of the phosgene pump

C — Sensor measuring condensate conductivity without triggering any safety action
⚠ **not operational on the day of the accident**

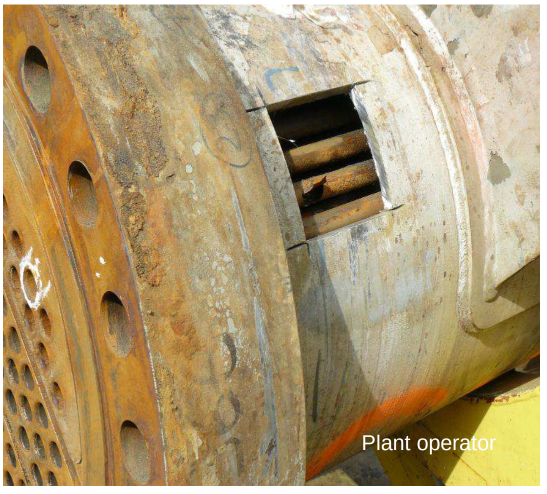
PS — Sensor measuring the condensate circuit pressure with programmed safety action → isolation of the condensate circuit and shutdown of the phosgene pump

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The accident occurred during the night of May 14th to 15th, while the isocyanate production unit was in operation:

- Subsequent to a seal defect on one of the tubes in an exchanger (due to a hole the size of a pinhead), a portion of the phosgene solution penetrated into the tubular shell and mixed with steam.
- Upon this contact, a portion of the phosgene reacted with water vapour to form hydrochloric acid, which eventually corroded the outer wall of the tube where the leak began and, to a lesser extent, the walls of adjacent tubes.
- The phosgene and hydrochloric acid were then conveyed, along with the condensates, to the soda tank, whose seal had been compromised due to faulty buffer repositioning following its most recent drainage. The tank pressure drop however was still sufficient to direct the gas to the safety column, thereby avoiding any direct phosgene release to the outside.
- In the presence of hydrochloric acid and phosgene, condensate conductivity increased to a point of reaching the 50-µS threshold. As expected, the programmable safety controller automatically isolated the condensate circuit and shut down the phosgene solution supply pump → activation of the 1st technical safety barrier.
- The 2nd conductivity meter, which was not operational on the day of the accident and whose replacement had been scheduled by the maintenance department, indicated a value of 0 µS. Technicians on duty at the time, who had not been notified of the device malfunction, decided to sample the condensate in order to confirm their reading.
- The sample was sent to the plant's onsite laboratory, informing the on-call manager that the safety controller had been activated.
- Following a discussion with technicians, yet without waiting for the laboratory to return its analyses, this manager approved circumventing (by-passing) the technical safety barrier that initially triggered installation shutdown and authorised restart of the production line.
- The installation was once again operational, and the phosgene release continued within the steam circuit. The ensuing hydrochloric acid very quickly corroded the steel composing the tubes, given the favourable temperature and pressure conditions. The quantity of phosgene increased in both the condensate circuit and the soda tank outside the enclosure. Due to this considerable inflow of phosgene, the pressure drop created in the tank had become inadequate to route all of the gas to the safety column. Some phosgene escaped into the atmosphere via the poorly-sealed tank buffer, thereby causing the external analysers to rise until reaching a state of saturation.
- Corrosion at the level of the tube where the leak was initiated was such that the tube's residual thickness was no longer sufficient to resist the pressure. The tube ripped open abruptly, with a large quantity of phosgene instantaneously flowing into the steam circuit, whose pressure then suddenly jumped. Once the pressure threshold had been reached, the safety controller isolated (as was programmed) the condensate circuit and turned off the phosgene solution supply pump → activation of the 2nd and final technical safety barrier.


Plant operator

- As a result of this pressure surge in the condensate circuit and the sudden valve closure, a "water hammer" phenomenon broke one of the bleed valves at the base of the exchanger.
- The released quantity of phosgene immediately flowed into the confinement enclosure, causing a loss of depressurisation in the enclosure and subsequent closure of its check valves.
- The phosgene cloud was effectively trapped.
- The laboratory returned its results, confirming the high level of conductivity detected in the condensate sample.

Consequences:

This event was not responsible for any impacts beyond the chemical complex boundary; 4 onsite workers, who felt ill from the release, were taken to the plant's infirmary, but all quickly resumed their work shifts.

The maximum volume of phosgene released into the confinement was evaluated at between 580 kg and 960 kg.

In all, prior to isolating the enclosure, the low level of continuous degassing around the soda tank via the leaking buffer, as well as the undetected degassing once the tube had torn (for just a few seconds prior to closure of the shutoff valves), was estimated to have amounted to less than 14 kg.

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 II' directive on handling hazardous substances, and in light of the information available, this accident can be characterised by the four following indices:

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

The "hazardous substances released" index was rated a "4" to account for the release of at least 0.6 tonnes of phosgene.

The "human and social consequences" index was given a "1" score due to the 4 employees adversely affected by the release.

The "environmental consequences" index could not be rated, since no consequences of this type were actually recorded.

The "economic consequences" index was assigned a "1" as a result of the property damage sustained by the unit as well as the significant operating loss, whose total amounted to between €100,000 and €500,000.

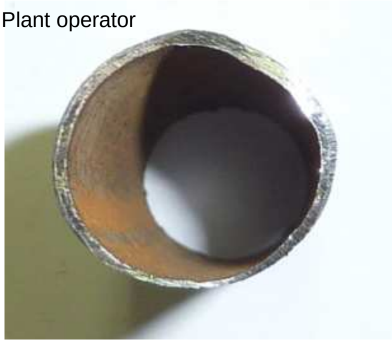
THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

This accident stemmed from the perforation of one of the tubes on an exchanger. The expert appraisal conducted by the chemical complex's certified inspector revealed that:

- Phosgene / steam contact followed the internal corrosion of a tube, which caused a "pinhead"-sized hole (diameter: 0.5 mm);
- This phenomenon likely happened due to the presence of deposits that had become corrosive after insufficient cleaning of the exchanger and then "activated" once the three following conditions had occurred:
  - presence of phosgene under the deposits during exchanger downtime;
  - partial elimination of deposits at the time of cleaning;
  - water retention under the deposits despite completion of a drying step (nitrogen flushing) after cleaning.

The presence of phosgene and residual water under the deposits led to the formation of hydrochloric acid.

The phosgene release in the direction of the exchanger's tubular shell subsequently induced external corrosion on the tube that eventually leaked and, to a lesser extent, on adjacent tubes. For the originating tube, the level of corrosion was such that the residual steel thickness was no longer adequate to resist the differential pressure, which in turn caused the tube to burst and a major release of phosgene within the shell.



Phosgene release into the atmosphere resulted from poor repositioning of the soda tank buffer following its most recent drainage; its seal however would have allowed eliminating phosgene via the safety column.

Event management response by the team on duty was another contributing cause of this accident. The post-accident investigation indicated a succession of errors and negligence that could have been avoided, namely:

- poor assessment on the part of assigned employees regarding proper operations of the conductivity meter that had placed the facility in safety mode due to the conflicting "0" reading on the "supervisory" meter, whose sensor was out-of-order;
- decision to circumvent the technical safety barrier, even though it was operational, without waiting for the laboratory's analysis results relative to condensate conductivity, in order to confirm the good working order of the safety barrier;
- non-compliance with both internal procedures and Prefecture orders regarding installation operations, as no compensatory measure was implemented to guarantee an equivalent level of security after bypassing the safety barrier;
- a misinformed approach adopted by the onsite team, proof of denial of the inherent risk.

ACTIONS TAKEN

This accident gave rise to a joint inspection by the Classified Facilities inspector and the staff member assigned to monitor the "Pressurised equipment" activity, in a step that enabled observing the violations noted in the previous section.

Following the accident, the facility operator undertook a number of remedial actions:

- of a technical nature:
- evaluation of condensate circuits for those exchangers exhibiting the same problem in the event of perforation (other workshop instruments and other isocyanate workshops);
- repositioning of the soda tank buffer into its proper place and verification of its seal;
- repair of the defective conductivity meter, increased calibration frequency (quarterly instead of semi-annually);
- and of an organisational nature:
- modification of the exchanger cleaning procedure and establishment of criteria for evaluating the quality of exchanger drying;
- change in the soda tank pumping operations procedure so as to avoid opening the tank buffer;
- availability of basic instruction sheets to formalise appropriate workstation practices and decision-making regarding technical safety barriers, supplemented by detailed information provided by individual teams;
- revision of the safety "bypass" procedure: standardisation across workshops, specification of roles, bypass conditions, etc.;
- feedback from the incident and enhanced awareness by all production staff of the safety bypass procedure: plant technicians, shift foremen, workshop managers, etc.;
- awareness building training dedicated to the bypass procedure also offered to on-call personnel, followed by a formalised commitment by this personnel category to strictly comply with the revised procedure;
- modification of the technician certification training programme, with an additional process safety module;
- disciplinary actions taken against onsite employees present on the day of the accident.

LESSONS LEARNT

This incident reveals that a succession of human errors and negligent conduct can lead to an industrial accident. The infrequency of such accidents and the routine nature of these operations are just two of the factors that over time had resulted in risk underestimation. This event provides a reminder of the need for regularly training plant employees so as to ensure that the required level of vigilance, commensurate with the presence of major risks, is always maintained.

The operator wound up expanding onsite process safety training by undertaking the actions set forth in the previous section. For year 2012, a total of 4,600 hours of training were devoted to safety and the environment for all 550 site personnel.

The management procedures applicable to technical safety barriers were reviewed and standardised. The operator renounced the notion of "replacement" safety equipment, which had been applied to justify, in certain cases, overlooking one barrier due to the simple existence of a second barrier.

This accident has also confirmed the relevance of confinement for such installations, which handle highly toxic gases at high pressures. For the second time, this constructive measure has proven its efficiency. A similar phosgene leak (850 kg) had previously been successfully trapped following corrosion of an arm guard (due to an inappropriate alloy) on 11th July 1988 shortly after the workshop's inauguration (ARIA 390). On two occasions, this measure has served to avoid the consequences of accidents that could have been disastrous, especially given the densely urbanised environment around the Pont-de-Claix facility.

Hydrocarbon spill during a transfer operation

17 July 2010

Speyer

Allemagne

Refinery
Hydrocarbons
Unloading
Pipe
Leak
Site clean-up
Procedures

THE FACILITIES INVOLVED

The site:

The refinery is located along with other firms in the city's industrial park adjacent to the banks of the Rhine River. This site was producing hydrocarbon-based compounds with high added value along with solvents for use in many sectors, including the automobile industry, pharmaceuticals, phytosanitary products, cosmetics, and as inputs in fine chemicals, the electronics sector and plastics transformation.

The site's installations consisted of a distillation unit, several tank farms and a transfer facility comprising filling stations for road and rail tankers, as well as a system for loading and unloading boats (i.e. a floating wharf) set up in a dock also used by the park's other tenants.

Aerial view of the site

The involved unit:

A rack of pipes connected the port to various storage facilities and was required to cover distances ranging between 300 and 500 m. The aboveground pipes were positioned from 30 to 50 m from the floor, which had only been sealed in spots; the pipe layout ran below (underground) the municipal street system and above roads within the plant boundary.

Wharf in the industial dock

Production facilities and pipes rack

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

The accident occurred during transfer of a hydrocarbon mix from the river barge to the plant's on-site tank farm.

In preparation for a transfer of n-alkanes C5-C6 from a 500-tonne barge (containing approx. 750 m³) on 17 July 2010, measures were carried out the previous day (16 July) until 3:45 pm to prepare the filling of a 1 000 m³ fixed roof tank. For the tank hook-up, it was also necessary to install a hose (nominal diameter: 80) on a pipe rack connection (nominal diameter: 150).

These works were performed by means of checklists describing each manual step of the task. Once all required actions had been completed, the operations manager inspected again all connections and pipes.

Another pipe inspection was conducted on the 17th at midnight by an operative on the night shift.

Chronology of events:

12:30 am: The barge moored at the wharf. A routine briefing was then held between the boat's crew and site staff.

12:45 am: A sample was taken for laboratory analysis. The product received was mainly hazardous due to its characteristic of being an very flammable liquid highly toxic for aquatic organisms. Under the Dangerous Substances Classification and Labeling Directive, this product was classified as corresponding to the following risk labels: R 11, R 38, R 48/20, R 50/53, R 62, R 65 and R 67.

1:30 am: After acknowledging laboratory results in the control room, the crew received authorisation to start the boat's pump at an initial service pressure of 50 m³/h. An operative witnessed flow inside the tank (thanks to acoustic verification, flow noises).

1:45 -2 am: The pump malfunctioned twice, for undetermined reasons. Installations (i.e. pipes, valves, and measurement, control and regulation devices) were all checked, and no defect was observed.

2:30 am: An operative surveyed the pipes between the tank and the port, without detecting any leak.

2:45-3 am: The boat's pump was restarted, this time under high pressure (100 m³/h).

3:10 am: In the control room, an operative noticed differences between the pump's operating mode and the tank’s filling status.

3:12 am: The pipes were surveyed again; this effort led to identifying a puddle of hydrocarbon fuel.

Transfer operations were immediately halted; fire-fighters from both the site and municipal department were called to the scene. The spill was covered with foam. Gas measurements were undertaken outside the site boundary.

The puddle was subsequently pumped by a specialised subcontractor.

The consequences of the accident:

Restarting the boat's pump at high pressure (100 m³/h instead of 50 m³/h) had caused an expansion compensator installed on the pipe to burst. The leak released 120 m³ (i.e. approx. 80 tonnes) of hydrocarbons, which in turn penetrated into the unsealed ground.

Dislodged pipe bracket

Damaged expansion compensator

The European scale of industrial accidents:

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

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

The "hazardous substances released" index was rated a "4" due to the discharge of 80 tonnes of n-alkanes C5-C6.

No human or social consequences could be identified; the corresponding index was therefore not scored.

Some land area and groundwater were polluted by hydrocarbons. The "environmental consequences" index was thus estimated at "1".

The decontamination of polluted soils cost €480,000, yielding an "economic consequences" index value of 3.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The pipe's expansion compensator burst due to the pump's repeated malfunctions and restarting under high pressure. Post-accident investigations revealed that a water hammer phenomenon occurred and was then accentuated by the following technical aspects:

- The 450 m long pipe could not be positioned along a constant incline due to both geographic constraints and the site layout.
- Repeated pump malfunctions led to its cavitation, triggering the formation of cavitation bubbles.
- Pump start-up under more strenuous operating conditions led to a pressure surge that exceeded the pipe design pressure (16 bar).
- The narrowing cross-section (a nominal diameter drop of 150 to 80), combined with improperly placed support systems and the expansion compensator design, was responsible for leading to the breaking point.

Flexible hose for tank connection

Pipes rack

Expansion compensator before the accident

Expansion compensator taken apart after the accident

General purpose information on the water hammer phenomenon:

- Definition: Peak pressure reached following a very abrupt velocity change
- Circumstances: Inside a pipe during pump malfunctions / restarts* and valve closures
- Cause: Fluid inertia / difference in fluid compressibility
- Consequences: Destruction of pipes, compensators, supports, foundations and ancillary facilities
- Preventive measures: Special start-up procedures subsequent to pump malfunctions; predefined valve closing times; use of vacuum release devices.

* Following pump malfunction, the system restart process becomes a critical step. Cavitation bubbles suddenly burst in the event of a pressure increase, and the existing velocity differences generate peak pressures capable of reaching 2 or 3 times the values output by Joukowsky's formula[5].

ACTIONS TAKEN

The hydrocarbon spill was immediately covered with a foam blanket. This task was further complicated by the difficulty of sorting spilled hydrocarbons from extinction water that remained after a fire drill held shortly before that time by local fire-fighters. The gas measurements recorded outside the site boundary indicated that the lower flammability limit had not been exceeded. The next morning, a specialised subcontractor proceeded to pumping of the foam blanket and hydrocarbon puddle. The bulk of the product (some 100 m³) however had penetrated into the unsealed ground (sandy soil). A long-term procedure, approved by the appropriate authorities, was launched: soil decontamination, well drilling and pumping out hydrocarbons (insoluble in water) from groundwater aquifers. This process is still currently underway.

[5] Joukowsky's formula: dp = rho x a x dv
dp = pressure variation
rho = density
a = wave propagation velocity
dv = velocity variation

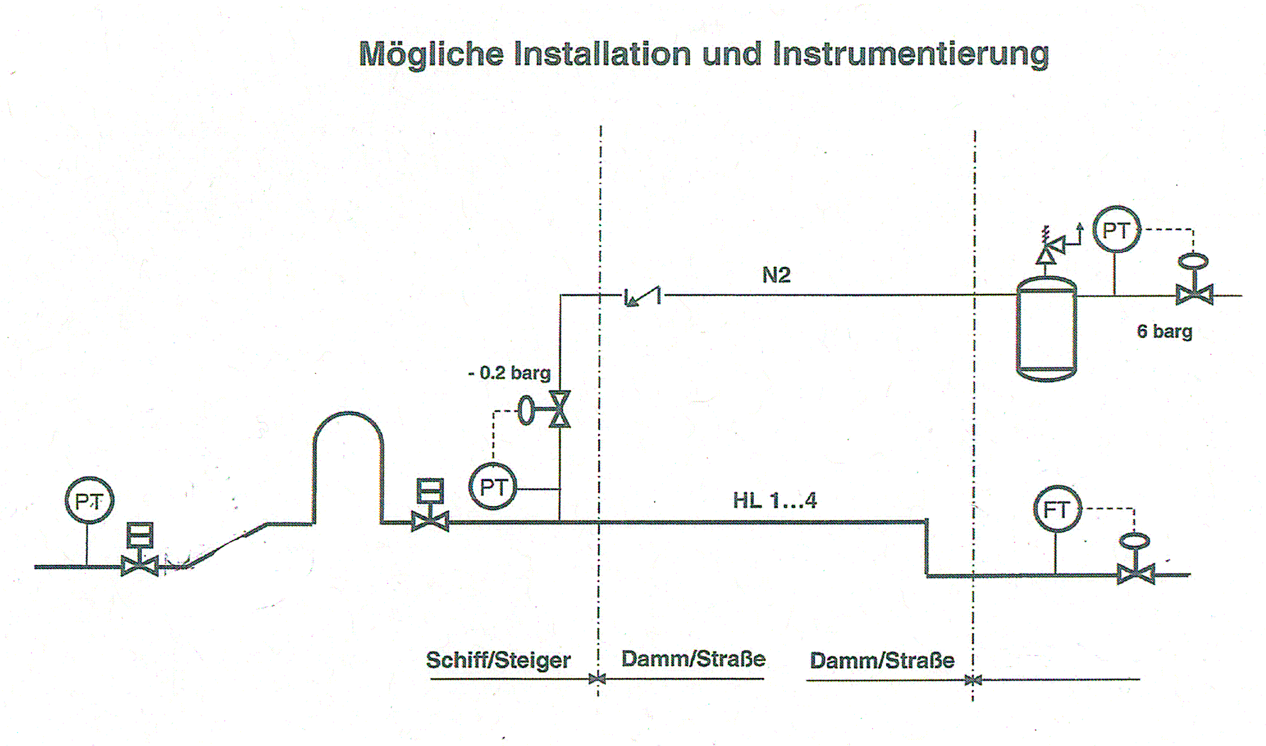
Place of the accident the day after

Hydrocarbons pumping

LESSONS LEARNT

Given the infeasibility of exercising direct authority over a boat's crew or controlling all technical characteristics of their installations, other pump malfunctions are capable of occurring in the future. A system equipped with a vacuum release function was therefore installed to mitigate the ensuing water hammer risks: flow rate measurement equipment around the wharf detected flow rate drops at the outlet and activated a compressible gas (nitrogen) injection, so as to ensure that moving fluid masses would not collide with the static fluid masses in causing peak pressures beyond the pipe's designed strength. Moreover, the number of narrowing cross-sections and expansion compensators was reduced to the bare minimum required. Once the installation had been renovated, just a single pipe was responsible for conveying product between the port and on-site tanks.

In addition, the loading/unloading instructions provided to site personnel and vessel crews were verified and updated.



Planned installation and instrumentation layout

Theme 4

Risks analysis and works projects

Risk analysis and works projects

Accidents analysis related to works projects, whether maintenance, modifications, improvements, or even the dismantling of installations, are often discussed and point to the seriousness of such events, particularly in terms of human consequences. Over the 20-year period 1992-2012, while these phases ***gave rise to circumstances surrounding 10% of all accidents occurring at France's classified facilities, they were the source of 30% of all recorded accidents involving deaths****; this high value can be explained at least in part by additional human presence in the vicinity of installations when carrying out these works. These observations encompass tasks conducted not only by site personnel, but also subcontractors more or less frequently present in this environment not always familiar to them.*

Many accidents recorded in the ARIA database illustrate that works-related tasks are too often being performed today ***without first thoroughly analysing the risks****. All industrial sectors are involved (led by chemicals, steelmaking and food processing), including the most common ones like filling stations.*

This **"risk analysis" constitutes an essential preliminary step** to any works intervention regardless of its scope and moreover requires a detailed description of the scheduled tasks. To ensure its thoroughness, an analysis takes into account the specific unit targeted by the project in addition to all nearby units likely to be affected, shared supplies, measurement chains and common safety functions. The concern for **workers' safety** must be an integral component of the evaluation undertaken prior to initiating the works, namely as regards toxic risks or asphyxia. Attention must also be focused on **potentially "ATEX" explosive zones**, both those easily identifiable (vapour space of flammable liquid tanks, enclosures with accumulation of combustible dusts, gas tanks, etc.) and all **confined zones** used as the site of future hot works; atmosphere verification using an explosimeter, draining and "rinsing" of containers, and inerting are just some of the measures capable of mitigating risks.

Source: BARPI

In many instances, an imprecise representation of the installation (due, for example, to an **overly cursory examination** or drawings that fail to be updated following unit modification) yields a faulty risk analysis, hence a potential source of accidents.

Ultimately, this analysis must lead to **adopting procedures** and a works schedule, as well as to laying out safety instructions and, if applicable, hot work permitting. **An accurate and detailed dissemination of information to task participants** (supervisors and crew members) and all site personnel eventually involved proves essential. In addition to this information, subcontracted personnel must also be informed about the site's inherent risks (e.g. gas or dust explosion, fire, product toxicity), existing knowledge of the targeted installations and adjoining facilities, emergency response measures and evacuation exits, and contacts to notify should a problem arise.

Beyond this essential risk analysis phase prior to initiating works, the operational phases, which consist of **preparing the worksite, ensuring compliance with safety procedures and measures by assigned work crews, accepting the completed works and restarting installations**, are elements just as critical whose absence or inadequacy has been the cause of many accidents.

1. Hot liquid leak in a refinery:

ARIA 26757 – 25/11/2003 - 76 - PETIT-COURONNE

19.20 - Oil refining

Inside a refinery, during repair works conducted while a vacuum distillation unit was down, 3 workers were sprayed by a hot liquid and a product leak was detected. At the outset, the work crew employed by a subcontractor was scheduled to repair two devices: exchanger 602, which had been inoperable since March 2002 and whose gland needed to be disassembled; and exchanger 581, which had to be plugged by means of joint replacement subsequent to a water leak. On 25th November around 2 pm, the crew was informed that the sleeve on the 602 device had been successfully disassembled. The workers proceeded to climb the scaffolding and began to remove some of the exchanger equipment when a hot oil leak occurred: all 3 of them on the scaffolding were sprayed by the 200℃ product and sustained 2nd-degree burns. A loss of confinement was detected at the level of the column corresponding to exchanger 581. **In reality, the accident was caused by mistaking one piece of equipment for another:** the crew was working on the other exchanger, which was still running since it had been scheduled for only minor repairs. The device did not seem abnormally hot to the crew. Following this accident, the refinery operator adopted plans to: **improve information disseminated to crews prior to performing works,** better prepare work zones (clear indication of devices, site accompaniment, **systematic risk analysis before initiating repairs**). The operator also made an effort to explain the technique for quickly operating safety showers, since their use was delayed during this accident.

2. Bursting of a tank at a chemical plant:

ARIA 43284 – 18/10/2010 - 91 - VERT-LE-PETIT

20.14 - Manufacturing of other basic organic chemical products

In an upper-tier Seveso-rated organic chemical plant, a subcontracted employee had been involved in welding work on a pipe running 2m aboveground for 30 minutes while perched on a stepladder. This repair job, requiring a gas tungsten arc welding (GTAW) station, was intended to connect a pipe used to inert a temporary solvent storage tank to the plant's nitrogen supply line. **This weld was undertaken following a quick nitrogen flush performed by the employee**. At 4:45 pm, just a few seconds after completing the operation, as the welder was climbing down from the stepladder and exiting the zone, the 10-m³ polypropylene tank burst, sending its plug through the roof of the hangar housing the storage tanks. The worker and two other subcontractors in the zone were not injured. The classified facilities inspectorate was duly notified. A level sensor installed on the tank plug was ejected onto the roof and fell to the ground; the manhole, filling tap and pressure relief valve were also found on the hangar roof.


Source: DRIEE Ile-de-France

The damaged tank had been drained 3 months prior and degassed. **All of the damaged pipe had previously been verified by running water through it**. No combustion traces, combined with the fact that the damaged tank had been the only one capable of receiving nitrogen on the day of the accident (i.e. its shut-off valve had remained open), led to the hypothesis of a pneumatic explosion inside the tank. Despite being set at 30 mbar (strength threshold of the tank), the nitrogen expansion valve was capable of supplying a maximum pressure of 37 mbar and moreover, its good working order had not been assured. In contrast, the tank's pressure switch found on the floor indicated a pressure of 27 mbar. The accident might also have been caused by the rapid dilatation of nitrogen subsequent to its reheating when passing through the pipe segment nearest the weld (the GTAW weld had reached 1,000℃), though the level of the tank's liquid seal had not varied (it should have risen and overflowed in the event of a pressure increase).

A works authorisation that included a hot work permit for welding had been issued for the maintenance operation. This operation was part of an installation optimisation programme conducted in experimental mode, for the purpose of both limiting the risks of product reflux from the tanks into the inerting network and identifying points where nitrogen was escaping from the network. This mode had been selected in order to carry out investigations as the tests progressed and to complete the works in accordance with observed findings. The programme was suspended until a determination could be provided of the specific accident causes. **An analysis of potential hazards had been primarily focused on risks tied to the presence of petroleum solvents**. The Classified Facilities Inspectorate noted that in addition to the lack of tank isolation, **these works had not been carried out within the scope of the SGS** installation maintenance procedure and furthermore displayed an **insufficient risk analysis** (regarding the risk of equipment subjected to a pressure surge or drop). In a span of 5 months, this accident was the 3rd on the site and the 2nd pertaining to works assigned to subcontractors.

As the logical consequence of the risk analysis, the **hot work permit** is the operational document associated with works carried out at hot spots (welding, grinding, slicing, etc.) and is to be produced ahead of the intervention. Co-signed by the site operator (user firm) or the operator's representative, as well as by the designee for physically overseeing the general safety of hot spot work and (when subcontracting is involved) by the contracted firm, this document is often regulatory in nature and legally frames the scheduled works. This **limited-term authorisation** is sometimes considered by companies as a simple obligation drafted in "superficial" terms by replicating standard clauses. The hot work permit must in fact provide a detailed list of all **risks associated with the particular works** (e.g. presence of dust, gas, the risk of explosion, spreading, projections of incandescent particles) and indicate the **safety measures to be implemented** regarding both prevention and protection (cleaning of the work zone, use of flame-retardant tarps, fire-fighting resources, alarm systems, site monitoring following the completion of work by hot spots over a suitable time period). If subcontracting is an option, then these safety measures must be determined out of a joint agreement between the subcontractor and the site operator (user firm). Explaining the nature of the hot work permit (both risks and related measures) to technicians is also essential.

TRAVAUX

dans les silos de matières végétales

DANGER!

Les circonstances dans lesquelles surviennent les accidents dans les silos de matières végétales méritent une attention particulière. L'expérience montre que la fréquence d'accidents est beaucoup plus élevée en phase de travaux, qu'il s'agisse de maintenance préventive ou curative, de modification, d'aménagement voire de démantèlement des installations. Cela vaut pour les travaux réalisés par le personnel du silo, mais aussi par les sous-traitants qui interviennent dans un milieu dont ils méconnaissent souvent les risques.

En l'absence de précautions suffisantes, les travaux impliquant l'emploi d'appareils de soudage, meulage, tronçonnage… sont susceptibles de contribuer à la mise en suspension de poussières inflammables et leur explosion. Les travaux générant des points chauds sont encore trop souvent à l'origine de « feux couvants » ou d'incendies déclenchés par projections d'étincelles, chutes de pièces chaudes ou échauffements des produits stockés par conduction thermique.

Outre les dommages occasionnés aux installations par de nombreux accidents en phase de travaux, des victimes sont à déplorer : 12 morts le 18 octobre 1982 suite à l'explosion d'une malterie à Metz, 1 mort dans une coopérative agricole le 15 juin 1989 à Bourges, 1 mort et 1 blessé grave dans un silo horizontal le14 mai 2001 à Albert, 5 blessés dont 2 graves dans une usine de fabrication d'aliments pour animaux à Aigueperse le 29 mars 2006 …

Aussi, avant de délivrer un « permis de feu », une véritable analyse des risques est-elle indispensable pour mettre au point les mesures de prévention à observer … La sécurité des personnes en dépend.

Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE L'ÉCOLOGIE, DU DÉVELOPPEMENT ET DE L'AMÉNAGEMENT DURABLES

Fact sheet developed in 2008 by a professional body, in conjunction with BARPI, in order to build awareness among silo operators of the risks inherent in hot spot works and moreover assist them in improving their understanding.

VCE in a waste treatment tank of a pharmaceutical plant

10 June 2010

Brindisi (Apulia)

Italy

Explosive atmosphere
Modifications
Hot work
Fermentation
Risk analysis

THE FACILITIES INVOLVED

The site:

The plant, covering about 150.000 m², is located in Southern Italy in an industrial area situated in a natural port on the Adriatic coast (Figure 1).

It has been operating since 1966 and produces pharmaceutical intermediates and active principles for antibiotics through chemical and biological processes. It falls under Seveso II Directive (lower tier plant).

Fig. 1: Aerial view of the facility (source: Google maps)

The involved unit:

The waste treatment unit (Figure 2) is part of the principle O antibiotic production process, which is composed of the steps below:

- production of active principle B through inoculation of specific microorganisms into the fermentation broth;
- oxidation of principle B into principle O (end product) by reaction with sodium persulphate;
- stripping of principle O by solvent: the oxidized broth is mixed with chloroform and sodium lauryl sulphate, in order to separate the product (top layer) from the aqueous phase (bottom layer). The latter, which is the waste from stripping, is called BES. The stripped product goes on with the process, whereas the BES is sent to the solvent recovery unit for further stripping to eliminate chloroform and residual solvent traces, and then to the TKX in the waste treatment unit;

- concentration and crystallization of principle O in alcoholic environment;
- centrifugation of principle O;
- drying and packaging of principle O powder products.

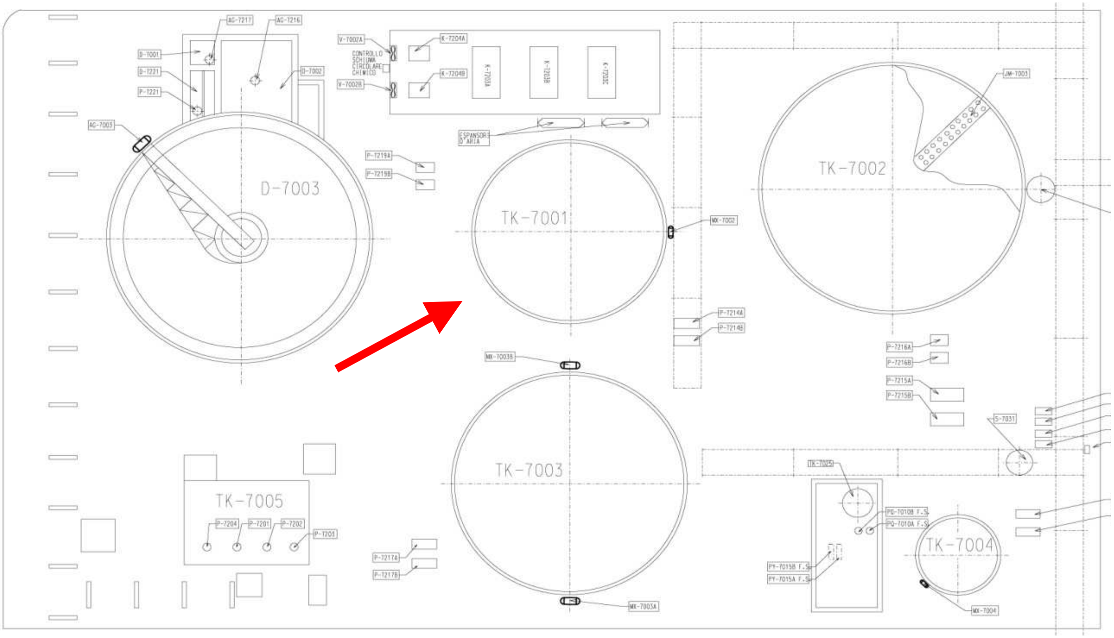


Fig. 2: Waste treatment unit layout (source: operator)

The equipment at the origin of the accident:

The accident occurred in a fixed-roof cylindrical atmospheric tank (TKX), with a capacity of 320 m³, 7.62 m of diameter and 7.9 m of height. It was equipped with an internal helical lateral mixer, in radial position, and with a 20 cm-diameter vent installed at the centre of on the roof of the tank.

The TKX, located in the waste treatment unit of the principle O production process, was used to homogenize the BES for its storage. The BES, with high organic amount and a COD (chemical oxygen demand) of 80 g/l, was sent to the TKX from the stripping unit at a flow-rate of about 2-3 m³/h. The maximum design-filling of the TKX was 50% of its capacity. During its 2 to 3-day stay inside the TKX, the BES was shaken by the internal helical lateral mixer and mixed with a caustic soda solution at 30% in order to maintain a fixed pH (around 8-8.5).

After homogenisation and equalization in the TKX, the BES was transferred to a bioreactor (TKY) for the stabilization treatment: a biological pre-treatment to reduce COD by almost 70% before sending the BES to a lagoon.

In its original design, the TKX was equipped with an internal system to insert and spread the air and an external system to suck air out. These systems, not operative at the moment of the accident, should have been active during normal TKX operation (Figure 3), planned as follows:

1. introduction of air into the internal liquid mass (BES) through the sparger system at the bottom of the tank;
2. extraction of air and gas formed through a sucking system, located on the roof and connected to the vent.

In March 2000, during revamping of the TKX, the air system was considered as "additional" with respect to the internal helical lateral mixer, and "responsible" for causing bad smell and foam. As a consequence, it was locked off.

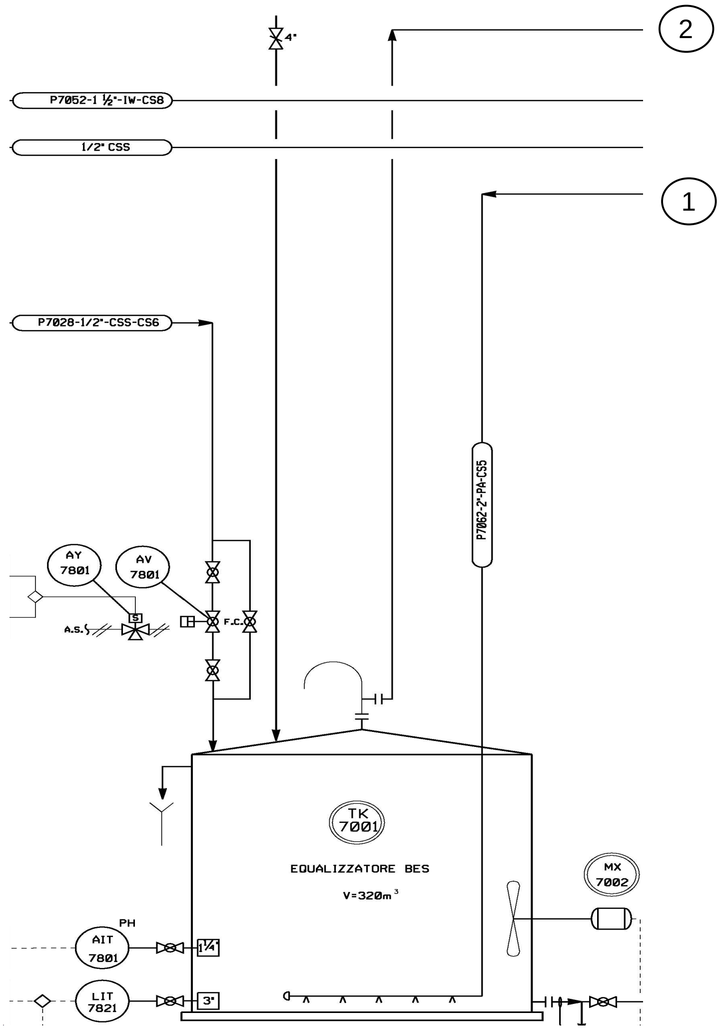


Fig. 3: Normal TKX operation principle (source: operator)

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

On 10 June 2010, a Vapour Cloud Explosion (VCE) occurred in the TKX containing BES during hot works on the tank feed line. The tank roof and debris were thrown far away.

The aim of the operation was to add a second feed line to the TKX (Figure 4). Coming from the fermentation unit, it should have allowed the delivery into the TKX of the waste broth from a new antibiotic production unit. The existing feed line had been cleared up and disconnected from the tank, without closing (blind flange) the tank or the line. The tank was half filled with BES.

The maintenance works were carried out by one employee of the operator and four contractors. One of the contractors started to cut the line with an electric disk cutter generating sparkles. These ignited the explosion of an explosive atmosphere inside the tank, probably due to a fermentation reaction still going on in the BES.

The facility was immediately put in emergency. Four wounded workers were transferred to the nearest hospital, the fifth was found dead by the firemen.

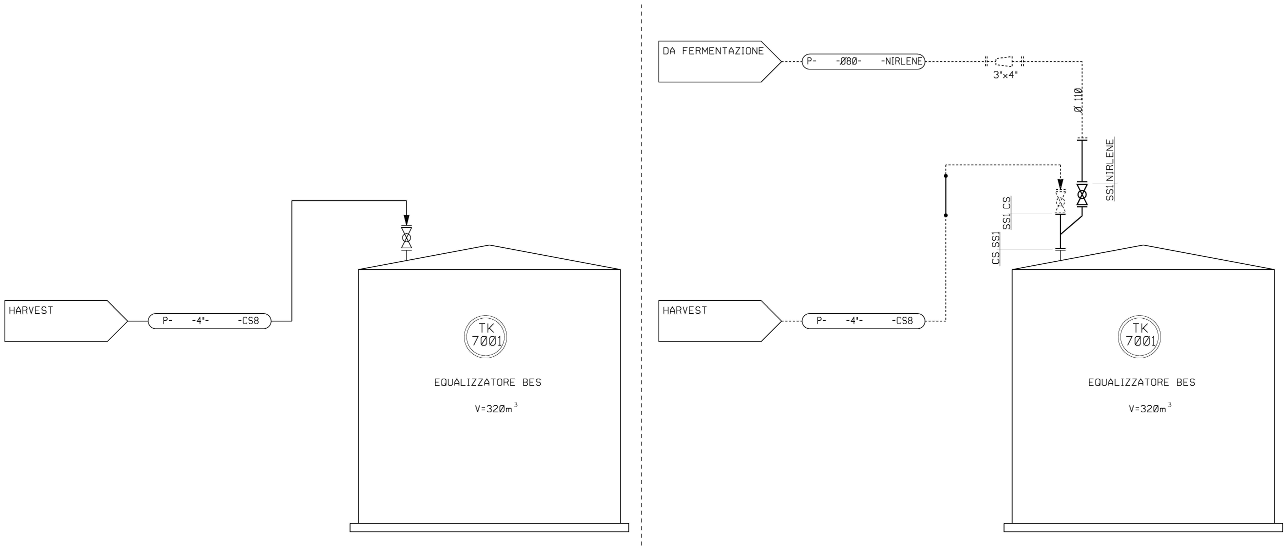


Fig. 4: (Left) Existing TKX; (Right) modification project at right (source: operator)

The consequences of the accident:

Human consequences

Five workers were present when the explosion occurred: four contractors and an employee of the operator. One contractor standing on the roof was holding the line to be cut, the others workers were on the walkway leading to the tank (Figure 5).

When the explosion occurred, the roof was torn out along the circular welding line (Figures 5 to 7) and thrown at a distance of 20 m, pulling up the air sparger line (Figures 8 and 9). The contractor on the roof was thrown on the roof of the TKY and died.

The four operators were injured by tank and roof debris, seriously burned by the explosion and thrown on the closest tank walls and to the ground by the wave pressure. Promptly helped by the internal assistance, the three contractors and the employee had respectively 40, 166, 198 and 120 days of sick leave.

Material consequences

According to a preliminary evaluation made by the operator, the accident generated a € 2.6 million loss:

- € 1.8 million of equipment, structure and production losses;
- € 0.8 millions for response and restoration of the establishment.

The accident can be called 'major' according to the Seveso II Directive as both human and material consequences exceed the threshold values indicated in Annex VI.


Fig. 5: Pulled-off sparger line on the TKX viewed from the walkway (source: ARPA Puglia)

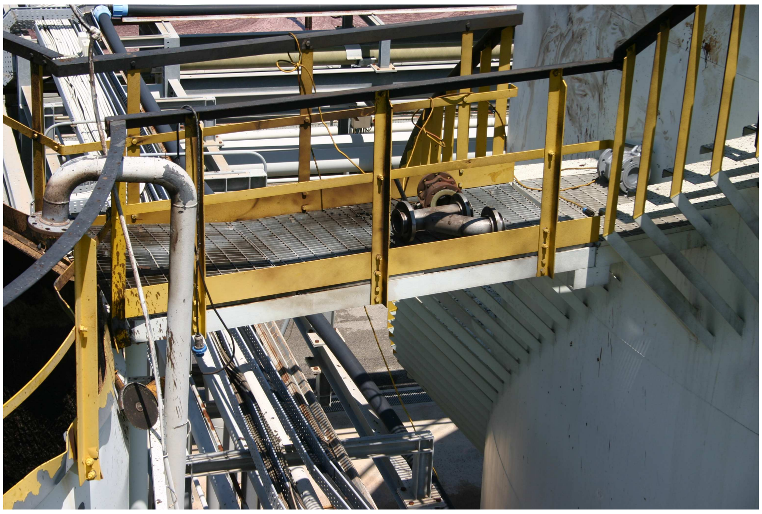


Fig. 6: Walkway between TKX and TKY (source: ARPA Puglia)

Fig. 7: Exploded TKX (source: ARPA Puglia)

Fig. 8: Projected roof at the foot of the TKX (source: ARPA Puglia)

Fig. 9: Exploded roof, note the absence of plain flange on the air line (source: ARPA Puglia)

The European scale of industrial accidents:

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

Dangerous materials released	■ □ □ □ □ □
Human and social consequences	■ ■ □ □ □ □
Environmental consequences	□ □ □ □ □ □
Economic consequences	■ ■ □ □ □ □

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

The index on quantities of dangerous substances released is set to 1: some exploding gases were present even if the quantities could not be precisely estimated (parameter Q1 – quantity of substance released).

The death and injury toll of the accident led to a grade 2 for human and social consequences (parameters: H3 – number of deaths, H4 – number of severely wounded people).

The economic consequences set the index at 2 with €1.8 M property and production losses inside the site.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

The main suspected direct causes of the accident are the presence of undesired explosive atmosphere inside the TKX (probably produced by anaerobic fermentation of BES) and the irrelevant maintenance works organization.

The substances involved:

The equipment at the origin of the accident (TKX) was not expected to contain dangerous substances. In order to understand the situation before the accident, the operator carried out a specific analysis on the components present inside the tank to ascertain what could have led to the production of an explosive atmosphere.

Liquid phase: the composition of BES before the accident (conform to normal operating condition) was determined through the analysis of samples collected in April and May 2010 and analysed by a specialized laboratory. It contained 93% of water and 7% of mycelium and organic remains of microorganisms (high COD 80g/l), traces of chemicals used during process (metals, chlorides, sulphates, sodium persulphate, ammonial nitrogen, flammable solvents) and solids. Some flammable solvents were found: isopropanol (500 – 1000 ppm), ethanol (about 500 ppm), acetone (< 100 ppm), tetrahydrofurane (1.5%), ethyl acetate (< 0.5 ppm), methanol (about 300 ppm). Chloroform was detected in the range of 500-600 ppm. The amount of all the solvents present in the liquid phase could not generate enough flammable vapour could in the TKX to reach the lower explosive limit (LEL).

During the investigation of the root causes of the accident conducted by the operator, additional tests have been carried out to analyse the BES composition at the moment of the accident. Samples collected immediately after the explosion showed a flammable solvent quantity below 700 ppm, and a chloroform concentration below 0.2% in the liquid phase. According to these results as well, not enough flammable vapour could have been generated from the liquid phase to reach the LEL. Same results were obtained from BES samples collected 10 days after the accident.

Gas-vapour phase: after the accident, BES samples were collected from the bottom of the tank. After an anaerobic fermentation in sealed ampoules, a gas-chromatography identification of gases formed was done. A high pressure had developed inside the ampoules, and some of them exploded due to overpressure after three weeks (Figure 10). The gas analysis confirmed the presence of traces of methane (CH_4), hydrogen (H_2), methanethiol (CH_3SH) and flammable sulphides compounds, probably formed from the solid phase accumulated at the bottom of the tank in the absence of aeration system.

Ion chromatography of liquid phase carried out by the operator the day of the accident showed the presence of sulphates, phosphates and thiosulphates with other anions. Persulphate is normally used in the oxidation process to transform principle B into principle O. Not all the product is converted in sulphates. The oxidation could have continued inside the TKX with organic harvest and possibly formed organic sulphates, carbonyl sulphide (COS), carbon disulphide (CS_2) and other organic sulphur derivatives responsible for the foul-smelling bubbles observed inside the water. The same was also detected on the liquid phase inside the tank after the accident.

Solid phase: the analysis carried out by the operator on gas produced by the solid phase or paste residues collected in December 2010 from several parts of the tank (bottom and lateral sides, Figures 11 and 12), revealed the presence of carbon disulphide, carbonyl sulphide, tetrahydrofurane (THF), dichloromethane (CH_2Cl_2), chloroform ($CHCl_3$) and other residual solvents present in the production processes.

In particular, different techniques showed that flammable solvents based on sulphides like CS_2 and COS were present in the solid phase. Both compounds show high flammability with a flash point (FP) below room temperature:

- CS_2 is a low boiling point (46℃) solvent, has a FP of - 30℃, wide explosive limits range of 1.3 – 50% v /v, and a very low auto ignition temperature (90℃). Moreov er, this compound has very low water solubility (2.9 g/l) and its vapour is denser than air.
- Carbonyl sulphide (COS) is a nasty-smell gas with a FP below - 30℃. The boiling point is about -50℃ and the vapour density at room temperature is higher than air. It remains in the bottom part of the tank above the liquid phase. It is a stable compound in anaerobic ambient, and is oxidized in sulphide moieties in presence of air.

Both these two compounds can be obtained by anaerobic fermentation: e.g. methanococcus maripaludis, methanothermobacter marburgensis, thiobacillus thioparus strains. Several references in literature show the role of these strains in the degradation of volatile organic sulphur compounds (carbon disulphide, methanethiol, dimethyl sulphide, dimethyl disulphide). Unfortunately, the presence of these microorganisms could not be checked as most of them are degraded in aerobic environment.

As a conclusion, the main substances responsible of the TKX explosion were the whole mix of flammable compounds generated by anaerobic fermentation in the solid and liquid phases which moved to the gas-vapour phase and stratified according to their density: hydrogen and methane (lighter than air) in the upper part close to the roof, sulphide gas compounds remaining just above the liquid level.

The exact amount of the gas mix compounds involved is difficult to estimate. The only available data is the tank free volume, completely filled by the gas mix: about 170 m³.

The dangerous compounds of the flammable mix are listed below:

	CAS	Risk classification
Hydrogen	1333-74-0	R12
Methane	74-82-8	R12
Carbon Disulphide	75-15-0	R11, R-36/38-48/23-62-63
Methanethiol	74-93-1	R12, R20, R50/53
Carbonyl Sulphide	463-58-1	R12, R23

The presence of the dangerous substances above, not expected by the operator because not normally processed or present, was also made possible by the presence of identified dangerous substances (persulphates).

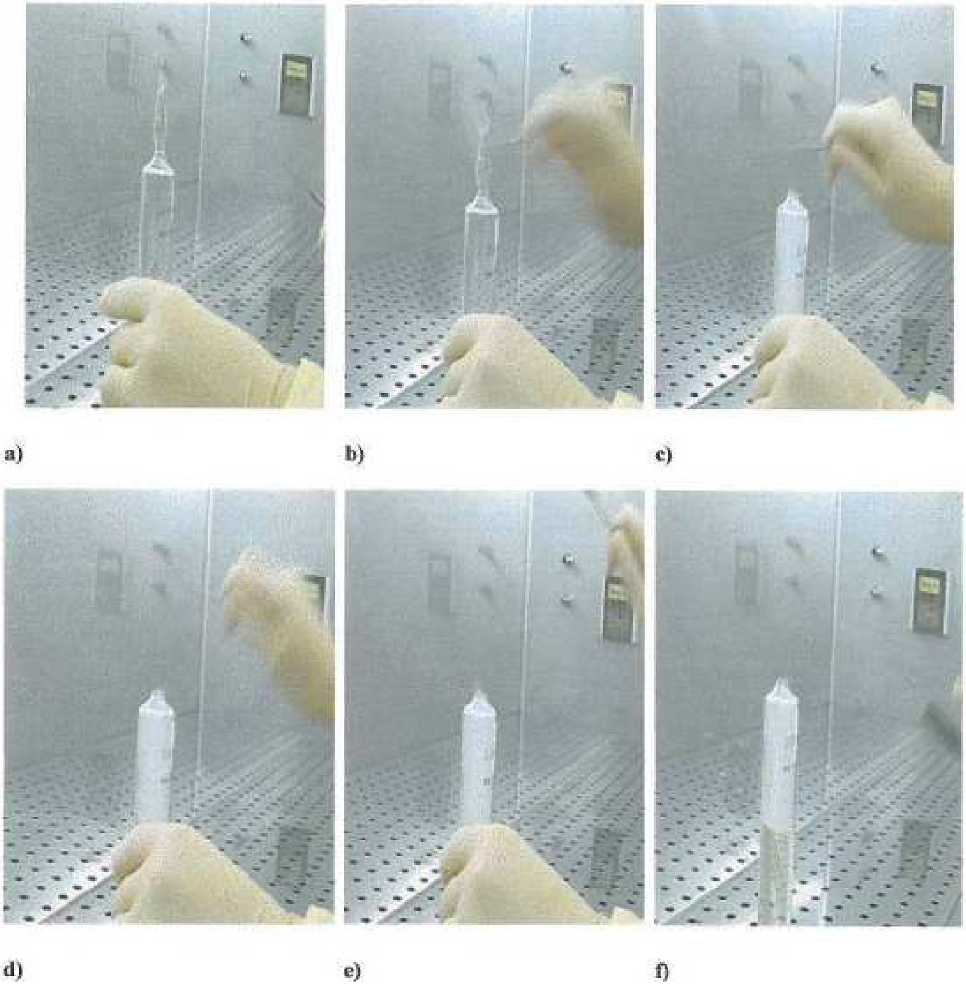


Fig. 10: Gas overpressure after anaerobic fermentation in sealed BES samples ampoules (source: ARPA Puglia)

Fig. 11: TKX after emptying in December 2000 - solid residues collected from the bottom (source: operator)

Fig. 12: Solid / paste residues collected from the exit nozzle (source: operator)

Direct causes:

Considering the analysis results mentioned above and the investigation results available in July 2012, the direct causes identified for the accident are:

A. An explosive atmosphere was present inside the TKX, which was ignited by the sparks generated while cutting the feed pipeline by the electrical cutter. The feed line had been cleaned up and disconnected from the tank without closing them with blind flanges, and leaving the nozzle on the tank opened (Figures 6 and 9).

B. The explosive atmosphere was produced by the fermentation of BES still going on inside the TKX in anaerobic condition. Different types of bacteria hard to identify are involved.

C. BES anaerobic fermentation was caused by the accumulation and permanence of mud and organic residual paste for a long time inside the tank (bottom, sides) due to:

a. high organic content in BES: COD 80 g/l;

b. temperature of TKX (40-50℃) favourable to bacteria fermentation according to analysis and research conducted by the Regional Environmental Agency ARPA Puglia (Agenzia Regionale per la Prevenzione e la Protezione dell'Ambiente) and data from scientific literature on the anaerobic fermentation process;

c. absence of oxygenation: the internal systems for air spreading and sucking should have been active during normal TKX operation according to the initial tank design. The air spreading system had been locked off after revamping of the tank (in 2000) because it was considered redundant with respect to the internal helical lateral mixer and "responsible" for causing bad smell and foam and for disturbing the stability condition of the BES (otherwise guaranteed by the basic pH, presence of residual chloroform and limited time of permanence inside the tank);

d. inadequate mixing and homogenisation of the BES: only the lateral helical mixer was active, without the strong support of the air system mentioned in point c. The helical mixer was too small to provide an adequate mixing for the whole liquid mass, which could have prevented the solid phase accumulation at the bottom and on the walls;

e. long stay (2-3 days) of the BES inside the tank, which facilitated the fermentation. The positioning of the exit nozzle 40 cm above the tank bottom allowed the accumulation of up to 40 cm of solid phase.

Chemical analysis of liquid and solid phases, carried out by the operator, confirmed the production of methane (CH_4), hydrogen (H_2), methanethiol (CH_3SH), carbonyl sulphide (COS), carbon disulphide (CS_2) and other flammable sulphide compounds generated by the anaerobic fermentation. These substances could have been some of the explosive mix compounds inside the tank.

Root causes:

Beyond the direct causes mentioned above, root causes (underlined in the text below) can be identified and analysed according to the issues addressed in the Seveso II Directive SMS (see in Annex the SMS check-list in use in Italy):

A. Explosive atmosphere inside the tank ignited during hot work[6]:

a. The contact between the sparks generated while cutting the feed pipeline and the explosive atmosphere was made possible by the absence of mechanical closing of the tank with blind flanges. This should have been done before the maintenance operation, according to the work permit procedure of the operator that required indicating:

i. on a general permit, the type of work, the possible hazardous situations and the risks they generate;

ii. on a specific permit, all the safety measures to implement for the type of work to be done, in relation with the risks identified on the general permit.

Both operator and contractor signed the work permit without filling the parts related to risks and safety measures to be adopted for the hot work. In particular, the use of an electrical cutter, the absence of explosiveness test and closing of the tank showed that the zone was not considered as an ATEX area: risk assessment fault; personnel training fault.

b. An interview of the chief of contractor-workers by the firemen showed a confuse understanding of the work permit procedure by the contractors and the employee involved, as well as insufficient know-how of the mechanical closing of equipment. Moreover, a SMS inspection by the Regional Environmental Agency pointed out that the process of maintenance works authorization, delivered by the Direction/SMS responsible to the contractor, was not clearly described: personnel training fault; maintenance procedure fault.

It should be underlined that the application of a proper work permit procedure alone could have avoided the accident, regardless of all other SMS faults.

B. Explosive atmosphere was produced by the anaerobic fermentation process of BES inside the TKX:

a. BES, supposed to be an exhausted waste from the microorganism fermentation process (only containing water and dead organic mycelium), was not considered dangerous by the operator: dangerous substances identification fault.

b. The possibility of anaerobic fermentation during BES treatment inside the TKX was not identified in the risk assessment phase. No detailed analysis (like HAZOP) of the tank was performed: dangerous process identification fault.

c. The waste treatment unit was not classified as ATEX area during risk assessment, due to the reasons mentioned above. In addition, risk assessment was not correctly updated after the revamping of the plant in 2000, during which the internal air system was wrongly locked off: risk assessment fault and management of change fault.

C. The accumulation and permanence of mud and organic residual paste for a long time inside the tank (bottom, sides) made the BES anaerobic fermentation possible:

The locking (during 10 years after revamping of the tank) of the internal system for air spreading and aspiration resulted in the absence of internal oxygenation and inadequate mixing and homogenizing of the BES (essential to avoid undesired anaerobic fermentation). This was an infringement of the plant safety requirements from the original tank design: fault in following the safety requirements and management of change fault.

ACTIONS TAKEN

Emergency measures:

The internal emergency plan was immediately activated; the internal team provided first aid for the four injured operators, and transferred them to the nearest hospital. The plant was shut down and put in safe condition.

External fire brigades arrived 15 minutes after the accident, found the dead worker on the roof of the TKY and checked the safety of the area using an ATEX detector. The fire brigades were not called by the operator, but by people from outside the plant who heard the explosion.

The emergency situation was cleared within 4 hours. Local authorities arrived together with the judicial authority, which closed and sealed the whole area.

Other actions taken in the aftermath:

A detailed investigation was carried out by the judicial authority, supported by the Regional Environmental Agency and technical experts. In July 2012, 15 persons were charged (among which the supervisor and the safety responsible of the plant).

The SMS inspection by the Regional Environmental Agency pointed out enough serious SMS faults to order the interruption of operations on part of the plant for 15 days.

[6] Hot work is any work that can create a source of ignition of flammable material, or a direct fire hazard even if no flammable material is present: welding, soldering, metal cutting, brazing, grinding, drilling, etc.

The operator assisted by a consultant produced a detailed accident analysis, which provided the conclusions mentioned above. The operator then drew up a safety plan containing all the internal management and technical additional safety measures to implement in order to seriously improve their implementation of the SMS.

LESSONS LEARNT

The analysis puts in evidence several SMS faults in:

- **Identification of possible accidental events, safety analysis and residual risk**: the risk assessment did not identify all ATEX areas inside the establishment, as expected from the operator. The classification, size and location of a particular zone depend on the probability of an explosive atmosphere to appear and its persistence if so. The classification needs to take into account not only the present hazardous substances, but also the possible unwanted formation of other dangerous substances.
- **Personnel training**: the work permit procedure was not adequately applied during the maintenance operation and work permits forms were not correctly filled by both contractor and operator. In particular, the safety measures required for ‘hot' maintenance operations, such as the closing of openings, were not adopted.
- **Operational control and maintenance procedures:** the written procedure was unclear and not easily understandable by the staff, particularly as concerns the delivery of authorization to the contractor by the Direction/SMS responsible, as noted above.

Biotechnology is a field in fast expansion where processes similar to that involved in this accident are used to obtain different products. A proper risk assessment should be conducted to take into account all substances that can be produced.

ANNEX: ELEMENTS OF SMS SEVESO INSPECTORS CHECK-LIST

1. The document on prevention policy

1.i Definition of prevention policy
1.ii Verification of the SMS structure and its integration with the establishment organization
1.iii Policy Document Contents

2. Organization and personnel

2.i Definition of responsibilities, resources and planning of activities
2.ii Information activity
2.iii Training and formation activities
2.iv Human factors, operator/plant interfaces

3. Evaluation and identification of major hazards

3.i Identification of substances and processes hazards; definition of safety requirements and criteria.
3.ii Identification of possible accidental events, safety analysis and residual risk
3.iii Planning and updating of technical and/or managerial solutions for the reduction of risks

4. Operational control

4.i Identification of plants and equipment to be subject to inspection plans
4.ii Process documentation
4.iii Operating procedures and instructions in normal, abnormal and emergency conditions
4.iv Maintenance procedures
4.v Materials and services procurement

5. Management of change

5.i Technical and organizational plant modifications
5.ii Documentation updating

6. Emergency planning

6.i Accident analysis, planning and documentation

6.ii Roles and responsibilities
6.iii Controls and verifications of the management of emergency situations
6.iv Alarm and communication systems and support to the external intervention

7. Monitoring performance
7.ii Performance evaluation
7.ii Accident and near-accident analysis

8. Audit and review
8.i Safety audits
8.ii Review of safety policy and of Safety Management System.

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2. Regional Environmental Agency. *Technical Report on the Accident,* May 2011
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Explosion of a paper pulp storage tank
18 January 2011
Nogent-sur-Seine (Aube)
France

Explosion
Hydrogen
Paper mill
Victims
Works / modifications

THE FACILITIES INVOLVED

The site:

The Nogent-sur-Seine paper mill manufactures and sells paper for corrugated board; the pulp used for these operations is exclusively produced from recycled paper and cardboard.

The factory is owned by a French industrial group specialised in the design and manufacturing of cardboard packaging.

The 24-ha site, which launched production in 2005, features the following installations:

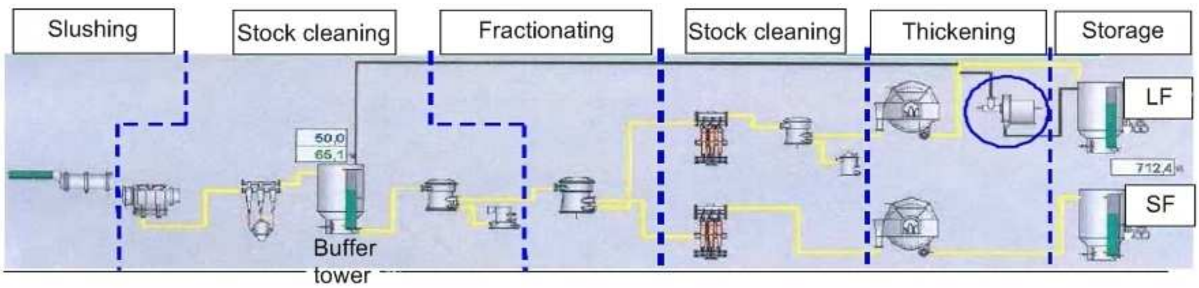
- external zone for storing bales of recycled paper and cardboard,
- steam production room,
- paper pulp preparation workshop,
- workshop dedicated to manufacturing paper reels for corrugated board,
- finished product storage building,
- units and activities ancillary to the production process, including the industrial effluent treatment plant.

The factory offers an annual production capacity of 270,000 tonnes with a permanent workforce of some 100 employees.

The unit involved and the process being applied:

The incident occurred at the periphery of the paper pulp preparation workshop, whose operations entailed a purely mechanical implementation process devoid of any chemical product input.

The various stages of this process were as follows:



The paper pulp processing path is depicted by the yellow line.

The slushing step consisted of placing the recycled paper and cardboard into suspension in water heated to 50℃, within a pulper, in order to obtain paper pulp with a dryness of between 4% and 5%.

The stock cleaning operation, conducted over several stages, was intended to eliminate all undesirable solid matter. This cleaning was being performed by centrifugation and screening through calibrated holes.

Next, fractionating served to separate short fibres (SF) from long fibres (LF) by means of injection into a rotating basket with very narrow slits.

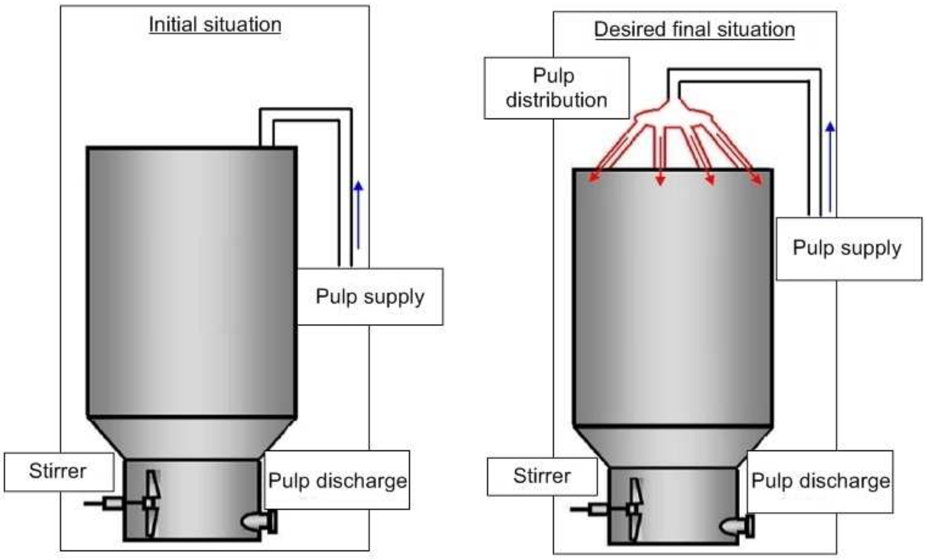
The thickening step, carried out in parallel on both the LF and SF lines using a disc filter, yielded a dryness equal to 10%.

Two categories of paper pulp were under production, one with long fibres the other with short fibres, and then stored in two distinct towers (designated LF and SF). Each tower held a capacity of 1,000 m^3 and was placed near a 1,200-m^3 "buffer" tower, containing paper pulp at a dryness to 3.5%.
The subsequent step in the paper production process involved other products, notably starch.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

A preliminary transformation completed in December 2010 had included pre-installing a new pulp distribution system on the LF storage tower by replacing the single pipe with one splitting into four tubes (shown in red in the figure below). On the day of the accident, the mission assigned to a subcontractor specialised in sheet metal work entailed connecting the pulp supply pipe to the distribution system.



At 8:20 am, in preparation of this works, technicians turned off pulp supply into the tower and proceeded with a 10-minute sequence of pipe rinsing with water. This procedure consisted of rinsing all process equipment by injecting 20 to 40 m^3 of water into the pipes, thus adding to the quantity of pulp already present in the tower.

At the same time, they shut down the pulp bleeding operation; once rinsing water had been introduced, the paper pulp level in the LF storage tower then remained constant throughout the subcontractor's intervention.

The characteristics of pulp still inside the tower were as follows:

- a tower fill rate on the order of 95%,
- pulp dryness of approx. 10%.

The LF storage tower exploded some 40 minutes after supply shut-off and pulp bleeding.

Two temp workers, commissioned by the specialised sheet metal firm to perform these works, were stationed on the tower roof.

One of them was cutting the pulp supply pipeline with an grinder, while his partner was positioned near the middle of the roof to avoid debris flying from the tool. The explosion occurred just as the grinding disc punctured the pipe wall. A witness observing the scene from an adjacent tower confirmed this account of the event and noticed the presence of a flame leaving the same tower.

The blast violently raised the tower's sheet metal roof, throwing the technician over the guardrail and causing him to fall onto the roof of an adjoining building 15 metres below.

Mill employees, including the site's emergency response team, heard the deflagration and rushed to the scene to rescue the victim, who was still conscious but unable to move.

Public rescue services, along with a physician from emergency medical services, arrived at 8:55 am; the injured subcontractor was taken by helicopter to a Paris hospital, where he succumbed to his injuries in the early evening.

Consequences of the accident:

The human toll amounted to the one death (the worker ejected from the roof).
As for property loss, the LF storage tower sustained heavy damage and its use was immediately prohibited by the Inspection Authorities for Classified Facilities. This decision led to a production shutdown, as the tank involved was critical to factory operations.

Economic losses were assessed at €1.5 million.


Source DREAL Champagne-Ardenne


Source DREAL Champagne-Ardenne

The European scale of industrial accidents:

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

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

The level 1 assigned to the "hazardous substances released" index corresponds to a TNT equivalent of less than 100 kg (damage being confined to the tank - parameter Q2).

The level 2 scored for the "human and social consequences" index was due to the death of the subcontractor's employee.

The "economic consequences" index (parameters €16 and €15) was rated at 2 or more, given the financial losses valued at €1.5 million.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

A specialised consulting firm analysed the circumstances of this accident and appraised all damaged equipment so as to develop a complete understanding of the causes. The paper pulp samples extracted in the tank on the day of the explosion were tested by this firm as well as another consulting firm in an effort to reproduce in the laboratory the conditions leading up to the accident.

The conclusions of both organisations matched, and the causes of this explosion could be stated with certainty: paper pulp stored under a given set of conditions can ferment and produce hydrogen.

The final appraiser's report established that the explosion occurred according to the following sequence:

- paper pulp stored in the tower released hydrogen at a rate such that the lower explosive limit (LEL) could be reached within a few hours,
- the hydrogen then mixed with air present in the tower vapour space to form an explosive atmosphere (ATEX),
- the source of ATEX ignition was a spark generated by the grinder during cutting of the pipe connected to the tower vapour space,
- the pressure surge created by the explosion caused the tower roof to fail at the level of the seam on the tie-in weld with the cylindrical shell.

It is likely that this ATEX atmosphere had not always been present in the tower vapour space and moreover that it was especially dependent on variations in the tower filling rate. On the day of the explosion, all conducive conditions (ATEX formation and ignition) were present, which had not been the case during previous hot spot works (conducted at a much lower tower filling rate).

ACTIONS TAKEN

A few hours after the explosion, the Classified Facilities Inspectorate made an unannounced visit to the site. Since the damaged tower risked collapsing and the roof, already partially torn off, risked falling or blowing away entirely at any time, the site operator was requested to mark off the hazardous zone and limit access.

With the operator's consent and for the purpose of learning the composition of the gaseous atmosphere under the roof of the exploded tank, the Inspectorate immediately undertook an analysis of the gas present in the adjacent so-called "buffer" tower, which was the only one still accessible. This analysis was performed with a small portable device calibrated for H_2S, CO, CH_4 and O_2, in taking all the necessary precautions (i.e. turning off the electric power supply and proceeding with a harness). The results did not indicate the presence of an explosive atmosphere. Moreover, none of the site managers interviewed were able to provide input that could potentially explain the underlying causes of this accident.

In light of these circumstances, on 20 January 2011 (2 days after the accident), the operator was issued a formal notice outlining emergency measures, as stipulated in the following points:

- prescribe the measures required to put the facility in safe condition,
- request the operator to extract a representative paper pulp sample in order to perform analyses and reproduce, to the greatest extent possible, the conditions leading to this accident,
- submit in 2 months' time a detailed accident report,
- update the site's safety report within 2 months of the date of receipt of the accident report,
- require a verification of installations by a consultant specialised in structures before reusing the damaged tank and its accessories.

The tank verification report was submitted on 21 January and the operator authorised to resume site activities as of that same date, provided that the tank was only being used up to a maximum 50% of its capacity and that basic works had already been completed to ensure site safety, as proposed by the consultant.

Moreover, within the scope of the safety report update, additional measures were introduced, for the most part on a semi-continuous basis, in other storage facilities typical of paper mill operations.
These measures suggested that for large tanks (i.e. > 1,000 m^3), like the one that had exploded, when the filling rate is high and pulp is beginning to move (via filling or bleeding) following an extended downtime, the release of H_2 means that the LEL may be quickly reached. Gas bubbles, most likely trapped inside the fermenting pulp, were freed as the pulp began to move. For smaller tanks, this same phenomenon was observed without the LEL actually being reached (max. 80% of the LEL threshold).

The H_2 concentration can therefore, in certain configurations, exceed LEL and lead to the formation of an ATEX atmosphere over part of the vapour space in some towers and storage facilities.

The updated safety report acknowledged these findings; it identified a new set of hazardous phenomena, i.e. storage tower explosion and (to a lesser extent) the explosion of storage facilities used to prepare paper pulp.
The modelling of these phenomena, which relied on conservative hypotheses, revealed that the effects of an explosion did not spread beyond the site boundary. Consequently, no special measure was required to ensure the protection of third parties outside the mill.

In contrast, measures were required to provide for employee protection, namely a more accurate redefinition of the ATEX zones. A mapping of the typical movements of personnel in various areas on the facility's grounds, cross-referenced with the impact zones in the event of an explosion, confirmed that the placement of additional safety barriers was unnecessary.

Nonetheless, in order to avoid an ignition source during onsite works, intervention procedures were enhanced and updated to recognise the possibility of hydrogen release, as this phenomenon had not been taken into consideration prior to the accident. The "training of technicians on detection of explosive atmosphere" was in particular included to ensure technicians were skilled in the use of portable gas detectors.

Even though the effectiveness of such a measure remained difficult to quantify, the large-capacity storage tanks and mixing tanks installed adjacent to an outer wall in the workshop were nonetheless equipped with additional vents.

LESSONS LEARNT

The Nogent-sur-Seine accident revealed that paper pulp, obtained without a chemical process using recycled paper and cardboard, may give rise to acetogenic microbial activity.
This phenomenon produces hydrogen that, under certain conditions (high filling rate, stirring of pulp following extended downtime), causes the formation of an explosive atmosphere in paper pulp storage tanks.
In this type of paper mill, the risk of pulp tank explosion must therefore be taken into account, especially during the risk analysis preceding any kind of works-related activity.

Theme 5

NaTech Risks

The "NaTech" risk, or technological accidents triggered by a natural event

A natural hazard (flooding, earthquake, forest fire, storm, ground movement, avalanche, cyclone, extreme cold spell, heat wave, etc.) may affect industrial installations and cause an accident or series of accidents with serious impacts on human health, property or the environment beyond the site boundary. In this case, the term "NaTech accident" is employed, indicating a contraction of the words "natural" and "technological". These consequences may be direct (property damage: plant, equipment, facilities, etc.) or else indirect (social, operating losses, loss of market share / opportunity cost, etc.).

1. Natural disasters in Europe and in France

An inventory conducted over the period 1975 to 2008 allows to evaluate the distribution of natural disasters which occurred across Europe (Fig. 1) and caused significant human, social and economic consequences. The countries surface can not alone explain the frequency of natural disasters occurrence. The coastline exposition, climatic context, subsoil composition and level of urban density all constitute factors capable of exacerbating or mitigating the effects of these major natural events.
Moreover, the breakdown among the various types of natural phenomena varies from one country to the next. Storms and flooding account for the majority of disasters recorded in Austria, Belgium, Denmark, France, Germany, Ireland, the Netherlands, the United Kingdom and the Scandinavian countries. As an example, on February 2010, the Xynthia storm accompanied by strong precipitation and flooding, crossed and impacted many European countries. The continent's southern countries are also exposed to storms and flooding, yet they must also cope with heat waves capable of sparking forest fires, such as those seen in the south of France, Spain, Italy, Greece and Portugal. In addition, Greece and Italy are the two European countries most frequently shaken by earthquakes. The Aquila earthquake in 2009, along with those occurring in the Emilia-Romagna region in 2012, provide recent and deadly illustrations for Italy.

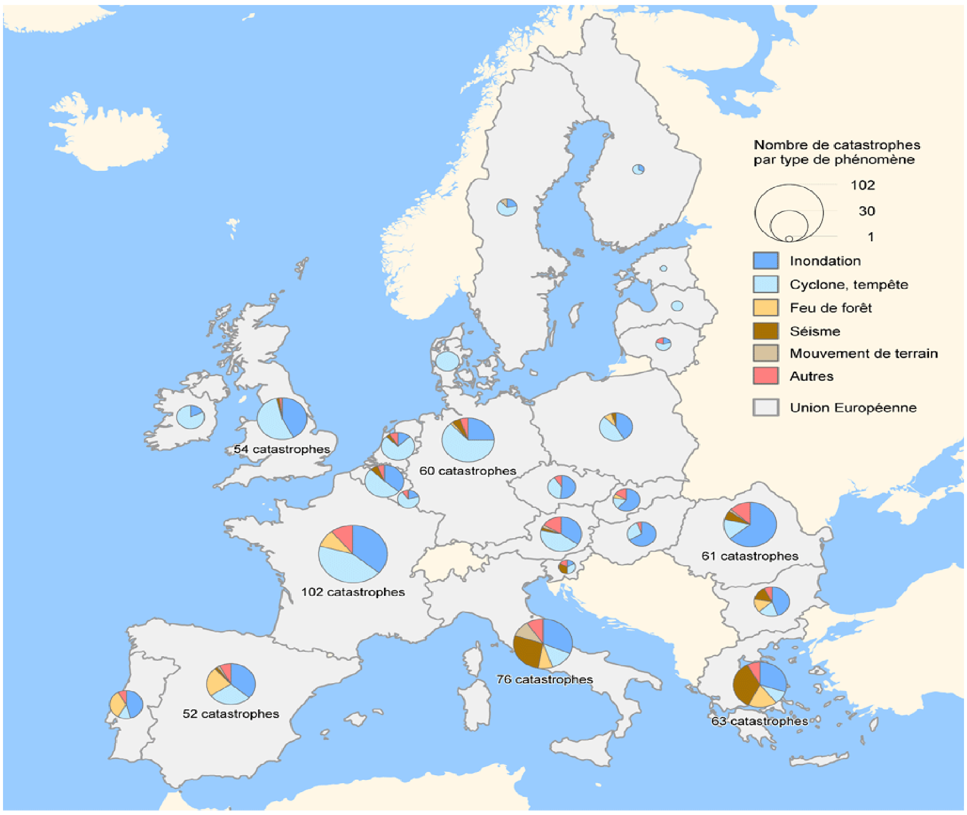


Figure 1: Natural disasters occurring in Europe between 1975 and 2008
Disasters causing 9 or more deaths, or affecting more than 99 people, or giving rise to a declared state of emergency, or a call for international relief aid; other: avalanche, heat wave, tidal wave, volcanic eruption (Source: EM-DAT, the OFDA/CRED International Disaster Database, 2009)

France is included among the European countries most heavily affected by natural disasters. Floods and storms represent nearly three-quarters of all recorded events in the country.

Figure 2: Natural events causing damage in France between 1900 and 2007

(Source: DGPR, database on natural disasters since 1900 in France, figures released in September 2009)

2. Typology of "NaTech" accidents

The ARIA base has recorded a total of 920 accidents occurring at classified or similar facilities, for which natural phenomena were cited as one of or the single initiating event, over the period 1992 to 2012.

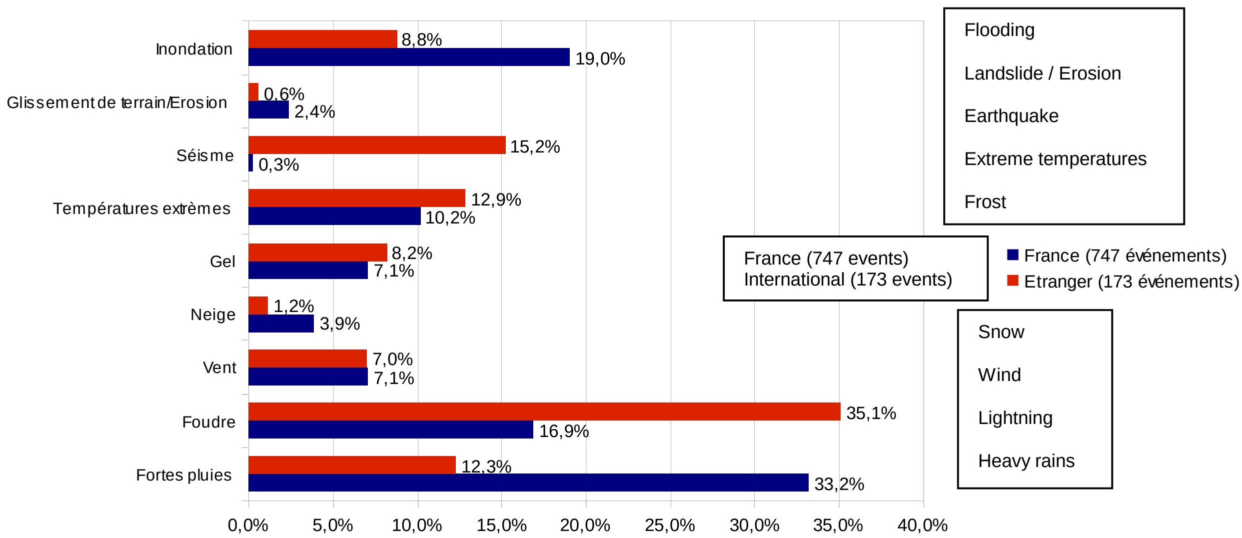


Figure 3: Breakdown of the 920 NaTech accidents occurring at classified facilities and recorded in the ARIA base over the period 1992 to 2012

2.1 Earthquakes

Earthquakes and their often dramatic consequences constitute a sizeable share of the NaTech type accidents recorded abroad (15%). These cause the weakening or collapse of structures (ARIA 42563) or else triggers tsunamis that in turn generate major flooding events (ARIA 40258).

2.2 Heavy rains and flooding

NaTech accident records in the ARIA base (Fig. 3) are correlated with the predominance of natural disasters tied to rainfall and its consequences (Fig. 2), inasmuch as heavy rains and flooding make up half of all phenomena leading to industrial accidents across the country. Floods are often caused by intense, extended rainfall events giving rise to high water levels above the designed protections in place at industrial sites (ARIA 35792), or to major rises in water levels via storm drain networks (ARIA 39616).

2.3 Thunderstorms

Thunderstorm phenomena are responsible for several risks occuring at industrial sites: heavy rains (Section 2.2), in addition to lightning strikes and disturbances to internal and external power supply. Lightning causes fires as well as explosions on flammable liquid tanks (ARIA 40953). The loss or outage of power supply leads to dangerous interruptions of industrial processes (ARIA 38617).

2.4 Extreme temperatures

Heat waves or severe cold spells are seasonal phenomena capable of affecting all sectors of activity. Fires are associated with both of these extreme cases, sparked during the summer by self-ignition (ARIA 42604) or triggered during winter by the low relative humidity rates (ARIA 41754). Frost phases are conducive to the bursting of pipes conveying hazardous fluids (ARIA 23839), in addition to obturating fire extinction water networks (ARIA 41638).

Source: Site operator (Risks Directorate)

3. Conclusion

The consideration of natural phenomena in evaluating risks to classified facilities within safety reports has already made it possible to prevent certain types of accidents or to limit their consequences through laying out technical and organisational measures adapted to the particularities of each site.

Several recent NaTech accidents, occurring in France and elsewhere in the world, have nonetheless served to reaffirm the need to implement appropriate protection at industrial sites against large-scale natural hazards. For this reason, the Ministry of Sustainable Development has launched an initiative to formalise the "NaTech action plan", intended both to put into perspective all approaches conducted over the past several years and to propose awareness-building campaigns and a new set of regulatory tools to improve prevention efforts relative to various NaTech risks: earthquakes, flooding (flash floods, submergence, etc.), extreme cold, heat waves, forest fires, strong winds, ground movements (landslides, rockslides, underground collapses), and snow.

For further information:

Consult our site www.aria.developpement-durable.gouv.fr for a wide array of NaTech accident analyses:

Earthquakes:

- "Overview of the industrial accidents arising during the massive Tohoku earthquake and tsunami" (Japan)
- Detailed fact sheet: "Devastating earthquakes in a zone of moderate seismic risk in Emilia-Romagna (Italy), 20th and 29th May 2012".

Heavy rains and flooding:

- Synthesis: "Atmospheric precipitation and floods: Inputs to industrial accident statistics"
- Press article: "Industry and flooding, feedback elements"
- Detailed fact sheet: "The impact of floods at Seveso-classified facilities: Series of events from 1993 to 2003 in the Provence-Alpes-Côte-d'Azur and Languedoc-Roussillon regions (France)".

Lightning:

- Synthesis: "Lightning: Industrial accident statistics"
- Press article: "Industry's response to lightning: Serious potential consequences".

Extreme temperatures:

- ARIA news flash: "Severe cold spells: Beware of freezing… and then thawing!"
- ARIA news flash: "Heat wave and scorching heat: Greater risk of fire but that's not all!"
- Detailed fact sheet: "Cyclohexane leak at a chemical plant in Chalampé (France), 16 December 2002".

Natural triggering event:
Extended period of intense cold

Rupture of a benzene pipeline

16 February 2012

Martigues (Bouches-du-Rhône)
France

THE ACCIDENT AND ITS CONSEQUENCES

A leak occurred at 2:50 pm on an insulated benzene pipeline supplying an oil terminal. Approximately 4 m^3 of product spread over the ground. The internal emergency plan at the oil depot was activated, entailing: port closure, personnel evacuated to shelters, water curtains and foam blankets deployed, plus recordings of benzene concentration in the environment. The leak was plugged using a hose clamp. 50 m^3 of product remained inside the pipeline. Over the following days, other leaks were detected, each triggering an emergency plan response. Ultimately, a concrete sarcophagus was installed around the damaged section and the pipeline could be properly drained.

No human consequences ensued thanks to the efficient response of emergency crews and prevailing northerly winds, which diluted the product as it was evaporating into the air. Fouled earth in the zone was subsequently excavated.

ORIGIN / CAUSES

The freezing of benzene, which solidifies below 5°, caused this accident. The pipeline had been idle for 18 days and the system to maintain a constant temperature proved ineffective. The product froze during an intense cold wave and wound up contracting. Over an inclined pipeline stretch, some product filled the space freed during contraction; during the thawing period, the pipeline broke as a result of exposure to excessive pressure. This incident was attributed to the solidification of benzene in zones where the alignment had not been plotted (i.e. crossings via nozzles running beneath roads). These "plugs" created pipe segments isolated from vacuum relief valves, which experienced pressure rises due to a combination of two phenomena: a benzene volume increase during melting, and thermal expansion of the liquid benzene.

ACTIONS TAKEN

A metallurgical appraisal of the failed pipe sections was conducted, in conjunction with building a model to describe the phenomenon of benzene freezing in the pipeline, in order to confirm the mechanism responsible for these leaks. Moreover, the site operator undertook the following steps:

- revise and improve the temperature maintenance system during freezing periods;
- study the feasibility of introducing recirculation on the line or draining the pipe;
- design a device to allow verifying at all times that heaters are indeed operational.

LESSONS LEARNT

These events, triggered by widespread and unfavourable climatic variations, have demonstrated the importance of:

- re-evaluating risks related to the consequences of benzene solidification;
- implementing both remedial and preventive measures to cope with extended periods of intense freezing;
- verifying the use of appropriate techniques for maintaining temperature (e.g. insulation, plotters, temperature probes).

Natural triggering event: Severe cold spell

DREAL Alsace Regional Agency

Crushing of a butadiene tank at a marshalling yard

27 December 2010

Woippy (57)

France

THE ACCIDENT AND ITS CONSEQUENCES

A pressurised liquefied butadiene tank, which had been drained but not yet degassed, collapsed on one of the tracks at the Woippy marshalling yard during a period of intense cold weather (temperatures as low as -17℃). Du e to its ensuing deformation, the railcar was no longer in a state to circulate and furthermore caused a micro leak on a tank valve.

Prior to being moved, the tanker car first had to be inerted with nitrogen and drained onsite. This step was performed by technicians specially called to the scene as part of the TRANSAID accident response protocol. The entire sequence of steps was carried out under continuous supervision of fire-fighters with the Moselle Departmental Fire Services unit.

In order to avoid igniting a cloud of butadiene in the event the leak worsened during these operations, a 300-m safety perimeter was set up, in conjunction with total stoppage of night-time rail traffic on all nearby tracks, notably affecting traffic on the Luxembourg-Metz line.

No incident occurred during these operations, during which the tank was suddenly re-inflated and nearly restored to its initial shape, thus allowing it to be moved along the marshalling yard's adjacent tracks before transfer to the repair shop.

Nonetheless, the tank remained heavily damaged and unsuitable for transport (property loss: approx. €200,000).

ORIGIN / CAUSES

This drained, yet not degassed, tanker car had contained a residual quantity of some 870 kg of product, which during the winter period was exposed to temperatures below its boiling point (-4.5℃). The butadiene gas, which h ad formed the car's vapour expansion space, subsequently liquefied, triggering a pressure loss estimated at 0.35 bar (i.e. the tank's lower limit design pressure).

After being parked at an industrial site in Chalampé (department: 68), during its transit at the Woippy train station the tank was drained on 20 December 2010 and placed back on the tracks on the 22, headed for Creutzwald, where it was to undergo periodic maintenance in a repair shop. The ambient temperature at the time was around 0℃.

The industrial firm assigned to drain the railcar in Chalampé had followed a procedure that specified injecting nitrogen into the tank so as to avoid depressurisation, but this instruction was only applicable once the site's ambient temperature had reached -10℃.

It had not been anticipated therefore that the tank might subsequently be subjected to more severe depressurisation conditions. On 26 December, the ambient temperature dropped to -17℃ and exposed the tank to a substan tial pressure loss, eventually leading to its collapse.

ACTIONS TAKEN

The investigations, observations and analyses conducted by the Lorraine Region's DREAL Environmental Agency were transmitted both during and after the incident to the Risk Management Directorate as part of the Agency's technical and regulatory exchanges.

Additional investigations enabled analysts to determine that during construction of this tank (in 1968), no strength guideline had been adopted to cope with an external pressure surge of at least 0.4 bar; such a measure is now included in regulations governing the transport of hazardous materials.

An analysis of accident statistics revealed that a similar incident involving the same phenomenon but on a wider scale (over 20 butadiene tanks collapsed) had previously occurred during the winter of 1976 at the Neufchâteau train station (Vosges department).

Following this 1976 event, as of February of that year, professionals working with pressurised liquefied gas had recommended that industry actors adopt precautionary measures upon completion of unloading and before reshipment of tanker cars in order to avoid such accidents. These measures, applicable not only during the coldest period (1st December through 31 March) but at other designated times during the rest of the year, consisted of reinforcing this category of railcar and/or systematically injecting nitrogen whenever winter conditions arose.

The Woippy event resulted in two actions:

- as of January 2011, the particular railcar owner reminded all its clients of the recommendations already in effect since February 1976, as issued by the French Committee of Butane and Propane Professionals: in so doing, the owner once again drew their attention to the set of measures to be implemented in order to systematically maintain sufficient residual pressure inside the tanks during periods of intense cold weather;
- moreover, in March 2011, a proposed modification to the international legislation overseeing the transport of hazardous materials by both rail (RID) and road (ADR) presented by France was adopted, making it possible to alter regulations in favour of protecting tanks against the risk of deformation during periods of severe cold.

LESSONS LEARNT

This incident served to underscore that existing recommendations issued to gas industry professionals regarding necessary precautions during periods of intense cold were not adequate and, moreover, that it was preferable to include them in regulations governing the transport of hazardous materials so as to ensure mandatory application.

At present, the international regulation of such transport for both road and rail modes has set guidelines intended to protect empty tanks having previously transported liquefied gas at low pressure against the risks of deformation, by means, for example, of filling with nitrogen or another inert gas in order to maintain sufficient pressure inside the tank. Such steps are specifically aimed at avoiding the collapse of older tanks that were not designed or built to withstand pressure drops.

Natural triggering event: Lightning

Ignition of a process water tank at a refining unit subsequent to a lightning strike

17 September 2011

Feyzin (69)

France

THE ACCIDENT AND ITS CONSEQUENCES

During a storm warning phase, lightning struck the refinery in 2 spots: at a flare and on a tank. The tank in question (2,000 m^3, stationary roof) was recovering process water, which contained varying hydrocarbon load amounts, from the atmospheric distillation unit. Following the strike, the tank caught fire and ripped open along the weakest weld, with the tank roof becoming dislodged and dangling from the shell. The internal emergency plan was activated and adjacent units placed in safe operating mode.

The tank had not been equipped with a retention basin. Traces of foam reached the Rhône River Canal via the stormwater drainage network. The tank was isolated (installation of an effluent bypass leading to other facilities), placed in a safe mode and then drained and dismantled.

ORIGIN / CAUSES

Accident investigations confirmed that:

- the tank had indeed been struck by lightning;
- the tank had been properly grounded and inspected;
- the tank roof thickness was sufficient to directly withstand a lightning strike, in compliance with standard practices;
- the tank vents had been equipped with flame guard devices but not flame arrestors.

According to the hypotheses forwarded by an expert commissioned by the refinery operator, this event was caused by:

- the presence of a hydrocarbon supernatant (produced due to the malfunction of a stripper), resulting in the creation of a vapour space;
- ignition at one or more vents, with spreading of combustion inside the tank, which in turn caused the explosion.

ACTIONS TAKEN

The operator focused efforts on the following tasks:

- administrative modifications: evaluation of lightning analyses, with a request submitted to update risk analyses for the atmospheric distillation unit as well as the other units (as formalised by official notification);
- inventory of tanks operating under identical conditions and verification of the presence of flame arrestors;
- inspection of flares by use of a drone device;
- a contract established to identify the location of lighting strikes during stormy weather conditions;
- inclusion of the damaged tank in the unit's safety report, even though it was not performing the function of storing flammable liquids.

LESSONS LEARNT

On the scale of a refinery, the contents of smaller-sized storage facilities whose effluent may potentially comprise flammable liquids are vulnerable to the risk of lightning, which along with the risk of accidental spillage of contents must be included in the relevant safety reports.

Moreover, the terminology used to designate complex equipment must be clearly identified according to a protocol shared by all parties involved in refinery operations. According to the operator, the term flame guard (i.e. a "grating") was apparently widely used in the oil industry to refer to the more specialised flame arrestor device.

Natural triggering event: Thunderstorm

Discharge of styrene subsequent to thermal runaway during a thunderstorm

14 July 2010

Wingles (62)

France

DR: "La Voix du Nord" newspaper

THE ACCIDENT AND ITS CONSEQUENCES

This upper-tier Seveso-classified site includes two polystyrene production units featuring 3 continuously running lines. During a thunderstorm and subsequent to widespread electrical power outage, the installations could no longer perform either cooling or stirring. The loss of utilities triggered a thermal runaway on one of the lines, which caused a rupture disc to burst, leading in turn to a discharge of 10 tonnes of polystyrene and another 3 tonnes of styrene into the atmosphere. The consequences of this accident remained confined to operating losses tied to installation shutdown.

ORIGIN / CAUSES

10:20 pm: As a preventive step, the electrical power supply was switched to the self-production plant (a so-called "peak day outage" step).

10:43 pm: The thunderstorm caused one of the three units to be taken off-line.

10:46 pm: The peak day outage unit was placed in lockdown => shutoff of main electrical power supply; technicians prevented from switching to an alternative power source (10:53 pm: request for intervention of the on-call electrical team).

11:01 pm: Activation of the internal alarm, call placed to external emergency services.

11:05 pm: Pressure rise in one of the polymerisation reactors at the continuously-running station.

11:18 pm: Reconnection to the EDF power grid, gradual reestablishment of electrical power to the facility.

11:20 pm: Burst of the rupture disc on Reactor 1 of the second continuous line; discharge of 13 tonnes of reaction mix (10 tonnes of polystyrene plus 3 tonnes of styrene).

ACTIONS TAKEN

Two inspections conducted on 15 and 19 July 2010 led to the following outcomes:

- An emergency Prefecture order making facility restart contingent upon completing necessary upgrades and implementing remedial actions;
- An accident report submitted by 20 July, containing:
  - immediate measures to allow authorising facility restart (modification to the emergency shutdown procedure on the continuous line, change of protocol regarding power supply during thunderstorms);
  - medium-term measures (technical-economic study to ensure continuous line operations under safer conditions, a risk analysis focusing on lightning);
- An additional Prefecture order to proceed with the proposed modifications.

LESSONS LEARNT

The initial objective, as intended by the risk management measure (RMM) that led to installing the rupture disc (as a critical safety item, CSI) and that consisted of mitigating the effects of a runaway reaction during both the start-up phase and steady-state operations, was called into question. Given that the reactor design had incorporated the possibility of runaway during steady-state operations, the feared event was redefined to shift focus onto the start-up phases. The RMM objective was thus revised in order to limit disc rupture to thermal runaways during start-up, which entailed redesigning the disc. Once this modification had been completed, the process could be considered as intrinsically safe while operating in a steady state.

A protocol change regarding power supply management was moreover carried out, involving:

- the principle of constant redundancy (even during thunderstorm events),
- verification of the availability and operability of CSI (tied to a thermal runaway) should utilities be down,
- efficient lightning protection.

Theme 6

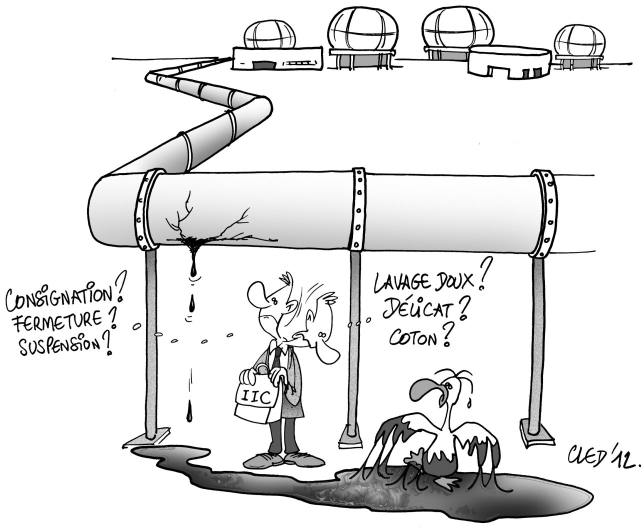
Follow-ups of an accident

Fact sheet

Follow-ups of an accident

During an accident, the Classified Facilities Inspectorate (CFI):

1. *Participates on behalf of the local Prefect in* ***managing the crisis at hand as well as the immediate repercussions*** *through the monitoring of : the placement of all involved installations in safe mode, eventual health and environmental impacts, initial administrative consequences (proposition of Prefecture emergency measures order) etc. The CFI also helps with efforts to keep the main actors informed of situation updates.*
2.
3. *Performs an "****accident investigation****" by staying informed of other expert appraisals and any relevant studies. The CFI might also feel compelled to propose and monitor longer-term consequences in the event of significant health or environmental impacts, whether actually present or feared (i.e.* ***post-accident management****).*



1. crisis management and immediate consequences

An immediate management response to the unfolding crisis during an accident primarily involves overseeing the placement of installations in safe mode and conducting an initial assessment of the accident consequences, especially with regards to health or environmental impacts, whether actually recorded or feared, and determining if a more targeted long-term monitoring campaign is necessary.

The CFI verifies that the operator has adopted all measures required to ensure site safety and avoid potential "domino effects". Difficulties may arise whenever clear lines of responsibility have not been drawn to match the urgency of the problem: a management structure designed with multiple supervisors, devoid of supervision, defective or unresponsive chain of command, execution failure, deadlines missed due to claims for appeal and then litigation (ARIA N°4225, 1 8379, 30269, 35035). Faced with managerial inaction and given the challenges and urgency inherent in certain situations, the assigned agencies may decide to implement specific procedures stipulated in regulations (Prefecture emergency measures order, requisitions, etc.) to identify the administrative response and action plan to be launched, including: shutdown of on-site activities, site monitoring, mandatory authorisation renewal prior to activity restart.

If a dedicated external emergency plan is activated during this accident management phase, **the CFI is typically requested by the Prefect to take part in the crisis unit set up at the departmental operations centre**, at which point the Inspectorate is convened to assist the Prefect by providing its knowledge of the particular installation (operating permit application, safety report, etc.) and overall competence in the area of pollution and risk prevention. If deemed necessary, the inspector's transfer to the DOC[7] or FCP[8] must be scheduled and planned to ensure safety, for example by selecting an itinerary that avoids crossing high-risk zones (ARIA 38242).

[7] DOC: Departmental Operations Centre
[8] FCP: Field Command Post / (on-site)

The inspection may involve requesting samples and analyses (toxicity of smoke, pollution of soils, surface water resources and/or groundwater) in order to evaluate the need for additional emergency measures, such as the closure of drinking water abstraction points and decontamination procedures. All sampling-related costs are absorbed by the manager of the responsible activity. Private or public-sector laboratories equipped with the proper sampling and analysis resources may be called upon, depending on the level of vulnerability, state of emergency and expertise required. The emphasis on reliable evidence and representative samples may prove to be very important during judicial procedures when these interpretations and risks are challenged. For this reason, a network of post-accident appraisers/experts has gradually been assembled[9].

Moreover, given the critical nature of protecting human health and the environment, in addition to saving physical data of potential value when conducting subsequent investigations, the CFI may under certain conditions find it necessary to request that the Prefect notify the appropriate legal authorities of either the urgency surrounding post-accident cleanup work (ARIA 13050), especially once a site has been sealed off, or the need to preserve subsequent evidence (ARIA 3969).

2. accident investigation and post-accident situation management

Once the emergency response has been wrapped up, the CFI must manage an array of follow-up steps, including: accident investigation; assessment of the site's operating status (e.g. damage to installations, waste management, decontamination, verifications prior to facility restart); participation in monitoring health and/or environmental consequences, if applicable; information dissemination to public authorities and the general population; and feedback processing.

The **accident investigation** yields information on the sequence of events and emergency response of rescue crews. It constitutes a pivotal step not only towards overseeing the return to installation safety, actions taken to assess potential impacts and ancillary control measures, but also informing a decision over the proposed activation of an interdepartmental post-accident crisis unit. Once the accident response sequence has been completed, this investigation will seek to detail the underlying circumstances and causes, along with measures adopted by the operator to avoid accident recurrence.

The procedures for handling waste generated by the accident must account for the inherent hazards, while paying special attention to the risks of spreading contamination to the environment or releasing an eventual source of pollution. These wastes may be composed of debris resulting from the collapse of buildings or installations, chemical substances, polluted water and earth, wastes of either animal or vegetable origin; on the other hand, they may stem from contaminated farm production and no longer be suitable for distribution. The manager of the responsible activity must be instructed to proceed with the disposal of designated wastes as quickly as possible using appropriate channels. This manager must be capable of proving that each type of waste has been removed in compliance with prescriptions. In exceptional cases, the magnitude of some accidents may necessitate creating temporary storage zones (ARIA 16879, 41474).

Installation restart may be made contingent upon the completion of new studies (risk analysis, safety report, etc.) or physical/chemical analyses of damaged materials, substances or equipment. A second opinion rendered by the CFI may serve as a prerequisite for verifying the adequate implementation of remedial or preventive measures.

If an **interdepartmental post-accident unit** is assembled, the CFI contributes to evaluating and managing post-accident consequences, in particular by offering to associate the competent agencies with respect to environmental concerns (regional health, veterinarian teams) and by issuing requests for the operator to conduct an impact study and introduce measures for managing consequences. Such a study produces a plan to perform and analyse samples with the aim of proposing more suitable long-term management guidelines: restrictions of use, a strategy for managing polluted sites, elimination of farm produce, etc.

Interdepartmental post-accident unit[3]

Unit designed to assist the Prefect, composed of various departmental or regional environmental-related agencies (DREAL, DD(CS)PP, ARS, DRAAF, etc.), to ensure the coordination of missions assigned to evaluate and manage post-accident consequences (environmental and health impacts). The unit is assembled by Prefect order on a case-by-case basis depending on the importance of the issues

[9] Circular issued on 20 February 2012 relative to the management of environmental and health impacts due to events of a technological origin (downloadable from http://www.developpement-durable.gouv.fr/Gestion-post-accident.html).

Lastly, the role of the CFI in generating **feedback** entails thoroughly examining all documents submitted by the operator (accident report - in compliance with Article R.512-69 of the Environmental Code, safety report update) so as to ensure that the preventive actions and measures to avoid a similar incident or accident have indeed been deployed and, if need be, to introduce additional prescriptions by means of a supplemental Prefecture order (Article R.512-31). The Inspectorate then transmits the lessons drawn to BARPI for feedback dissemination.

ARIA 18379 - 01/08/2000 - 95 - MARLY-LA-VILLE

52.10 – warehousing and storage

During on-site works carried out using a blowtorch on the roof of a warehouse, composed of 8 storage cells and rented by 4 different industrial operators, fire broke out in a group of cellulose cotton-wool balls and spread within 20 min via the roof, resulting in the partial collapse of a dividing wall. The 3rd cell that ignited contained agro-pharmaceutical products as well as animal feed.
Despite the site's water supply constraints, fire-fighters brought the blaze under control in 2 hours. […] During their intervention, 1,500 m³ of polluted extinction water were collected in a permeable stormwater tank; the water table and drinking water abstraction points were both threatened.

Given the refusal of this consortium of operators to comply with prescriptions set forth in the Prefecture's post-accident orders combined with the claims filed for appeal and then litigation, requisitioning measures were taken to quickly proceed with the pumping, storage and treatment of fire water, in addition to installing 2 piezometers to monitor water table conditions. […]

→ Feedback derived by the CFI:

- The fast spreading of this fire serves as a reminder of the importance of adopting appropriate construction measures, along with the need for impermeable retention basins for each warehouse cell (whenever applicable) and/or each site operator.
- Difficulties tied to the various operators, who had refused to comply with stipulations set forth in the Prefect's orders and initiated legal proceedings, required adopting emergency measures and requisitioning other firms.
- When installations are operated by various operators, it is essential to verify that the appropriate measures, which clearly identify the compliance manager, are taken in order to address the technical and organisational issues related to pollution prevention and risks.

For further details:
http://www.aria.developpement-durable.gouv.fr/ressources/18379_marly_la_ville_sj_ang.pdf

ARIA 35027 - 19/08/2008 - 45 – SAINT-HILAIRE-SUR-PUISEAUX

46.21 – wholesale of grain

2,100 tonnes of wheat and 1,000 tonnes of corn spilled following a break in the sheet pile wall of a silo. The grains partially buried a 95-m³ propane tank located 15 m from the silo; a pipeline burst and an LPG leak ensued due to a domino effect. First responders set up a safety perimeter and closed the valve upstream of the break. The owner used a flare to burn the stored gas. […]

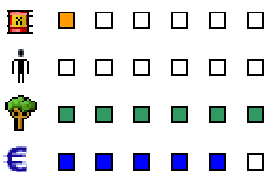
An emergency Prefecture order prescribed a set of measures to secure the site; these included activity stoppage, enclosure and monitoring of the premises, emptying the silo of its cereal contents and inspecting its state of repair. The restart of silo operations was made contingent upon Prefecture decision.

The Inspectorate visited the damaged silo along with a neighbouring silo owned by the same operator and noted several points to be verified/remediated by the operator regarding the use of silos and LPG depots. […]

The Inspectorate also requested companies owning LPG tanks at both sites to indicate the characteristics of their cisterns and safety equipment, as well as the measures adopted by these companies to ensure their LPG cisterns are being operated in accordance with required safety conditions. […]
As a direct application of feedback from this accident, the site's intact LPG cistern was inerted and then moved prior to being placed back online after renewed certification and approval of the fire water reserve tank design by the local fire safety department.

Other remedial actions were triggered by Prefecture order, with the establishment of a works schedule for installation readiness. […]

For further details:
http://www.aria.developpement-durable.gouv.fr/ressources/fd_35027_st_hilaire_sur_puiseau_ccgb_vfinal.pdf



ARIA 35035 - 22/08/2008 - 42 - SAINT-CYPRIEN
38.32 – recovery of sorted materials
Inside a wood recycling plant located on the former site of a company specialised in recovering electrical transformers, fire broke out from an unknown source on 22 August around 4 am at a 2,000-m² wood stockpile. The site watchman notified emergency services, who arrived at the scene equipped with several fire hoses. A thick cloud of smoke could be seen hovering over the town. **CFI officials visited the site and observed that the wood**, which had been stored on-site in quantities exceeding the permit authorisation, **could have been polluted by chemical substances. An emergency order prescribed 7 days after the accident a round of analyses on local groundwater and soils from nearby farms.**

Wind stoked the fire on 3rd September and first responders had to intervene a second time, **prompting the Prefect to enact several other orders: activity suspension, emergency measures aimed at site cleanup and waste disposal, plus an official warning to update the company's administrative situation.** It ultimately took 3 months to completely extinguish this fire.

On 15 September, a specialist organisation installed air quality control devices. The analyses communicated on 18 November revealed major emissions into the atmosphere of both dioxins and polychlorinated biphenyls (PCB). On 26 Nov., the public veterinarian's office sampled milk at a farm in the vicinity. Contamination was detected, as the regulatory threshold for the marketing of foodstuffs had been exceeded (European regulation 1881/2006/EC); site operations were placed into receivership.

These investigations gradually expanded from 1 to 2 km during March 2009 and then out to 5 km in April. On 25 May 2009, **the monitoring zone was widened to encompass 40 towns via Prefect order** and reached 42 towns in August 2009. In July 2009, a specialist body stated that this contamination event had originated in the soil and could not be easily determined beyond a 2-km radius. In all, 914 farms were inspected; a series of hygiene protocols were implemented and a total of 2,255 cows, sheep, pigs and horses had to be slaughtered. A local cement works burned the slaughterhouse residue, and the animal fat capable of containing PCB was processed in Belgium. Nearly 187,000 litres of raw milk were also discarded.

The **wastes generated** during this accident, i.e. 1,678 tonnes of milled wood and 8.14 tonnes of sludge (produced for the most part from scraping the ground), were transported to specialised processing channels between 10 and 31 July 2009; 70 lorry runs were needed to complete the disposal. An additional transport operation was organised for polluted individual protective gear as well as the water and cover of the cleaning tank. However, 7,600 m³ of polluted soil still had to be removed from the site. Given the cost of pollution cleanup, appraised at €2 million, and the fact that **the site had since been "tagged" for its deficient oversight**, the company was placed in compulsory liquidation on 23 July 2010. Only the **involvement of a public-sector entity** could provide for the facility's safety and propose a durable solution for managing the situation.

[…]

For further details:
http://www.aria.developpement-durable.gouv.fr/ressources/fd_35035_st_cyprien_ang.pdf

Failure of a black liquor tank in a paper mill

5 July 2012

Biganos (Gironde)

France

Releases
Paper mill
Corrosion
Rupture
Fixed storages (tank)
Pollution
Health (impact)

THE FACILITIES INVOLVED

The site:

The factory involved in this accident was a paper mill that had been doing business since 1928 in the town of Biganos; it was specialised in producing unbleached Kraft paper for corrugated board with the following raw materials:

- resinous wood;
- recycled cardboard;
- used crates;
- purchased bleached paper pulp.

The firm was manufacturing substantial quantities of food packaging. The Kraft paper pulp production amounted to 300,000 tonnes in 2011, yielding an output of 475,000 tonnes of paper. The factory employed some 450 personnel, including 240 in production activities (operating 24 hours a day, 365 days a year) and about 100 subcontractors.

The site was subject to special authorisation by virtue of French regulations applicable to classified facilities and moreover was required to comply with Heading 6.1.a of the IPPC Directive relative to industrial installations intended to produce paper pulp directly from wood or other fibrous materials.

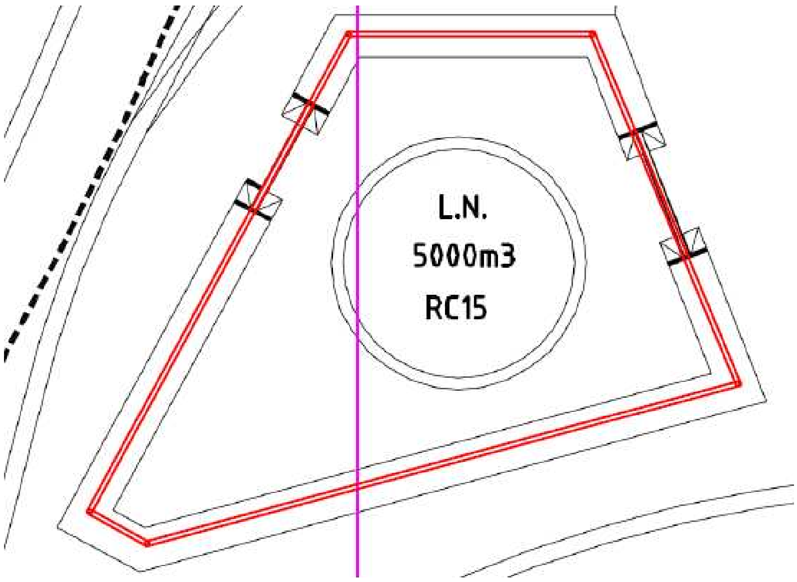
This factory, located 2 km from the Biganos Port at the mouth of the Leyre River on the Arcachon Basin, is immediately adjacent to the Grande Leyre and Petite Leyre valley (listed as a Natura 2000 protected site). Effluent discharged by the onsite stormwater treatment plant as well as at municipal treatment plants around the Basin was being released into the Atlantic Ocean via a collector pipe operated by the Arcachon Basin Joint Municipal Authority (SIBA).

Map of the vicinity

The specific unit involved:

The installations where this accident occurred comprised:

- a non-insulated storage tank (facility index: RC15) containing black liquor concentrated at 18% dry matter originating from paper pulp cooking; the tank's specifications were:
  - diameter: 20 m
  - height: 16 m
  - volume: 5,000-m^3
  - component material: carbon steel
  - date of construction: 1974;
- a 2,310-m^3 retention basin composed of earthen bund walls 2.10 m high.

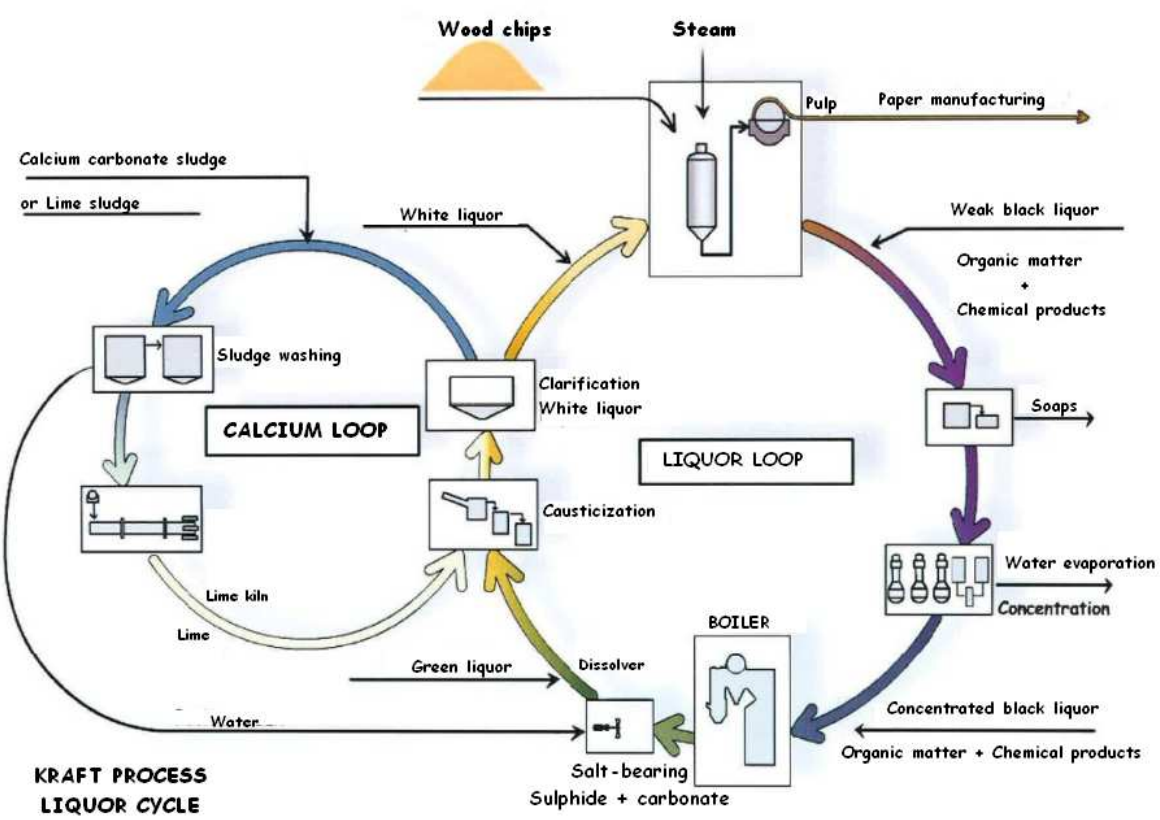


The tank and the retention basin

Photographs of the tank taken before and after the accident - Source: DREAL Aquitaine (Environmental Agency)

Black liquor:

According to the Kraft process, caustic soda (NaOH) is used in the presence of sodium sulphide (Na_2S) as a delignifying agent when heating wood at temperatures exceeding 160°C in order to obtain paper pulp. This cooking residue is called "black liquor" and contains approx. 15% solid matter, namely: lignin, as part of hemicelluloses, and the resin found in maritime pine trees, which in conjunction with caustic soda forms a soluble soap. This liquor features a pH above 13 and high corrosion potential; moreover, it must be concentrated at over 65% to combust. In its non-flammable state, black liquor releases hydrogen sulphide (H_2S) whenever acid is present.



The black liquor cycle within a paper mill - All rights reserved

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

On 5 July 2012 at 2:28 pm, a complete rupture on the RC15 tank sidewall (a vertical zip tear) as well as on both the top joint (beneath the lid) and bottom joint (base of the chest) caused 4,100 m^3 of black liquor to spill at approx. 80°C inside the site boundary. A portion of this discharge reached the Lacanau stream and ultimately the Leyre River.

Consequences of the accident:

The wave effect of this sudden spill caused the collapse of most of the retaining bund walls. This wave, which started out 10 m high, spread across the site destroying installations, yet without triggering a secondary accident.

The majority of liquor was confined within the site boundary in the factory's retention basin (referred to as the "Saugnac" basin). However, a ditch cut 100 m from the tank to recover stormwater wound up draining a portion of the pollution into the Lacanau stream. The facility operator evaluated this discharge into the natural environment at between 100 and 500 m^3, based on pH increases observed in the Leyre. Roughly 2 hectares of the site's land area were polluted.

The gendarmerie was mobilised first, before the fire-fighting unit, by the town hall, which itself had been notified by neighbours. The Deputy Prefect proceeded to supervise the Operational Command Post response directly at the site.

At 3:15 pm, the black liquor diluted in the Lacanau stream reached the Leyre watercourse, turning it a brownish colour. The Lacanau water pumping station, part of the factory's processing equipment, was placed in manual override mode to collect the maximum amount of water being diverted to the stream. This collected water was then channelled through the factory's sewer system and eventually transferred to the "Saugnac" basin.

pH measurements were recorded by fire-fighters, working in coordination with the operator, for the purpose of monitoring the evolution in pollution in the Lacanau and the Leyre as well as at the Biganos Port (a total of 8 measurement points).

At 4:34 pm, the Leyre had reached a pH of 11.15, immediately killing fish populations (approx. 300 kg of dead fish), as observed at the mouth of the Lacanau and halfway along the length of the Leyre.

By 5:34 pm, the pH of the Leyre had dropped to 7.6.

At 8:30 pm, with low tide being responsible for significant water inflow, pH at the port showed a value of 7.49.

Measures were also adopted to address human health concerns, namely:

- a municipal order temporarily prohibiting swimming at the Teich's beach;
- Prefecture-level order temporarily prohibiting swimming and boating on the Leyre at 8 pm, for a full 24 hours. As of 4 pm, canoe rental office employees had been notified;
- water quality monitoring at beaches on the south side of Arcachon Basin.

European scale of industrial accidents:

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

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

Despite the extensive discharge of black liquor in nearby watercourses, the "Dangerous materials released" index was not scored because the pollutant involved was not included in the list of substances appended to the Seveso Directive.

The "human and social consequences" index was rated a "2" since 3 individuals required psychological treatment for 3 months following the accident (parameter H9). Cases of chemical burns to the feet or legs and respiratory tract irritation were also recorded during site cleanup operations.

The "environmental consequences" index was assigned a "3" given a volume of polluted water equal to between 10,000 and 100,000 m³ (parameter Env 12).

The "economic consequences" index was rated a "4" due to production losses that topped €10 million (parameter €16) and pollution cleanup costs evaluated at over €1 million (parameter €18). Onsite property damage was estimated in the range of €2 million to €10 million, while offsite property damage / production losses remained less than €50,000.

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THIS ACCIDENT

The deputy public prosecutor visited the site and requested the Court to appoint a legal expert to lay the groundwork for an appraisal conducted on 10 July 2012. Conclusions of the judicial investigation (still underway as of January 2013), specifically appraisal results on the initially damaged tank, should provide a better understanding of the accident causes.

The expert commissioned by the factory operator reported that an instantaneous pressure surge caused an immediate opening of the tank at both the top and bottom, along with a "vertical zip" type of tear. This instantaneous pressure surge would have been triggered by a shockwave whose origin has yet to be determined.

An initial metallurgical appraisal of the damaged tank was assigned to the Classified Facilities Inspectorate by the gendarmerie. The content of this appraisal mainly focused on openings with crack lips observed on the tank. The break was exhibited by a "vertical zip-like" tear crossing metal sheets without following any weld lines, offset in a step-like pattern between each sheet. The appraisal also uncovered local buckling and the presence of a lower-quality steel.

After completing a thorough examination however, this study raised a number of questions. The sheet metal sample had actually been extracted quite far from the zone of the tear (6.5 m from the "zip"). Hence, the conclusion drawn regarding the phenomenon taking place could have been further refined by analysing closer samples on several shells. Moreover, no thickness measurements were conducted over a given part of the tank.

With the tank no longer sealed for inspection as of December, the Classified Facilities Inspectorate, with approval from judicial authorities, requested that the operator perform another round of sampling and undertake additional analyses on:

- the "zip" tear zone;
- an intact metal sheet, so as to assess the material's intrinsic characteristics;
- swelling previously recorded during a routine site inspection held in February 2012.

During the follow-up inspection, a leak was identified at the level of a shell on top of the tank; this discovery convinced the operator to schedule regular inspections (in-depth visits by an external body) beginning on 9th July 2012.

ACTIONS TAKEN

Immediate response to the accident:

As of 6 July, a Prefectural emergency order was enacted, requiring the factory operator to:

- recover and remove all products that had spilled and spread;
- monitor the environments adversely affected by the event;
- submit a study of the impact of this discharge on surface water resources, sediments, groundwater and soils;
- propose a series of remedial measures;
- identify accident causes and implement corrective measures prior to reactivating the site, while addressing in particular the state of repair of all tanks storing substances potentially hazardous for the environment.

Two orders, issued on 9 July and 3 August respectively, were intended to oversee the recovery and disposal of products stored in the "Saugnac" basin, specifically by authorising their treatment at the onsite plant (returned to service for this very mission), under discharge conditions strictly established in the 2010 plant permit approval.

The need to accelerate drainage of the "Saugnac" basin, which was critical both for preparedness in the event heavy rains caused a new pollution incident and for resuming normal factory activity, led the operator to propose adding several new treatment processes, namely:

- batch treatment with a solution that precipitates the lignin present in the effluent, performed in an onsite basin;
- treatment by oxidation and filtration/absorption on activated charcoal, performed on a mobile physicochemical system installed on the site;
- incineration using authorised external processes.

Site reactivation:

A Prefecture order issued on 20 July authorised partial and temporary facility restart by allowing for the tanks under inspection to be drained, along with the shutdown of all factory equipment for control purposes. In reality, these machines had been turned off while the process was ongoing (just after the accident) and still contained by-products.

Another partial resumption was authorised by a Prefecture order issued on 14 August to ensure draining the boiler as part of the maintenance procedure for black liquor injection pipes. This equipment could not be drained during the partial restart at the end of July.

Facility restart was approved on 23 August, in light of the full set of controls, repairs and countervailing measures adopted regarding tank operations.

The factory immediately resumed activity that very same evening by turning back on the evaporator and paper pulp cooking equipment. The other machines were placed back into service during the evening of 24 August. The facility reactivation procedure proved difficult to implement after such a long unplanned down time.

Moreover, the restart approval of 23 August 2012 created a monitoring commission for this paper mill and another nearby industrial site operating a biomass boiler.

Industrial safety:

The Classified Facilities Inspectorate organised a site visit on 25 July in order to lay out the protocol for inspecting the tanks identified in the 6th July Prefecture order (routine verifications, external or internal, controls performed on the tank bottoms, verticality and angle of inclination, etc.). A follow-up visit was scheduled for 10th August with the aim of evaluating the results of previous inspections and specifying facility restart conditions.

The tank verification criteria were defined by the Inspectorate on the basis of "Section I: Prevention measures dedicated to ageing-related risks of specific equipment" contained in the 4 October 2010 Ministerial decree on the prevention of accidental risks at classified facilities subject to authorisation. Even though only 12 of the site's 194 tanks contained substances (sodium hypochlorite, liquors, fuel oil, turpentine) of actual relevance to this decree, it was nonetheless decided to apply the control methodology to all tanks both before and after bringing them back online.

Prior to facility restart therefore, the operator's Certified Inspection Service proceeded with controls on:

- all tanks containing black liquor, caustic soda and acids (regardless of their volume, i.e. 17 tanks of black liquor): routine inspection, followed by external or internal visits depending on conclusions drawn from the routine visit;
- all tanks (with the exception of new ones) with a capacity above 100 m^3 (i.e. 66 tanks): routine inspection, with thickness measurements at the tank bottom (for all carbon steel and stainless steel tanks should they be in a poor state of repair or corroded), control of verticality, settlement and the measurement chain, combined with an external or internal visit depending on conclusions drawn from the routine visit.

A number of more detailed control procedures had to be deferred until after restart (delayed no later than issuance of the factory's technical memorandum at the end of 2012); these procedures were based on:

- conclusions of routine inspection visits;
- the volume and type of products contained in the various tanks;
- maintenance work performed on certain tanks (shell replacements, two sheets of metal reinforcements, stronger tank bottoms, etc.);
- countervailing measures (load limitation on some tanks, including the site's other 5,000-m^3 black liquor tank until its replacement - scheduled for 2013);
- the economic consequences stemming from this shut-down (over €300,000 a day).

Environmental impact:

The operator was not yet able to fully comply with the prescriptions set forth in the 6 July Prefecture order regarding both the impact of this accident on the environment and the remediation measures. This event caused soil pollution on those areas of the site where black liquor had spilled, as could be detected by effects on pH, sodium and sulphates.

1,500 tonnes of fouled earth were ultimately excavated and stored on a sealed onsite platform while waiting for an appropriate pollution clean-up operation. 6,200 tonnes of other wastes generated by the accident were also removed from the site and treated by specialised subcontracted processes.

As regards pollution outside the site boundaries, initial findings available have revealed locally acute fish mortality in both the Lacanau and Leyre watercourses; however, no significant impact on Arcachon Basin flora and fauna could be identified.

Nonetheless, government authorities are still anxiously awaiting additional findings, whereby analyses on the biological quality of watercourses are expected to confirm this diagnosis. A long-term flora and fauna monitoring protocol has been established by the operator, in collaboration with nature protection associations and the regional natural park.

These additional inputs will make it possible to decide on eventual application of the Environmental Responsibility Law (no. 2008-757, enacted 1 August 2008) and its accompanying decree (no. 2009-468, issued 23 April 2009).

LESSONS LEARNT

Ageing of installations in contact with liquors:

The various site inspections performed on tanks, along with the bibliographical review conducted by the Inspectorate, have confirmed the corrosive nature of the liquors involved in the Kraft process on tank material (even stainless steel), especially in the vapour space and the levelling zone or upon exposure to turbulence (stirrers). These visits revealed numerous punctures in the tank lids, in addition to thickness losses (as evidenced when the measured thickness falls below the design thickness). The bibliographical review also indicated that the rate of corrosion was capable of reaching 2.5 mm a year.

While the operator has definitely become aware of the corrosive nature of these products, no findings have yet to be provided on phenomenon kinetics relative to stored products. It would also seem pertinent to expand the state of knowledge on the corrosive properties of black liquor and similar substances (e.g. white liquors, green liquors) depending on their storage conditions (tank materials, temperature, etc.). For this reason, the 23 August 2012 restart authorisation prescribed a search for information on the potential degradations caused by black liquor and special substances used in the Kraft process (green and white liquors). The Inspectorate later acknowledged the additional elements required following analysis of the submitted documentation.

During this waiting period, it proved necessary to conduct investigations in the part of the tank exposed to the vapour space during operations, with emphasis placed on introducing enhanced monitoring in black liquor tanks until the phenomenon became better known.

Furthermore, for all new tanks installed at the site, corrosion test samples have been placed in the liquid compartment, as well as in both the fluctuating part (gas/liquid boundary) and vapour space.

Design of black liquor retention basins and tanks:

- The operator has undertaken works to replace both 5,000-m^3 black liquor tanks according to the following layout:
- reduction of storage volumes to 3,250 m^3 and 3,275 m^3 respectively, for a 35% decrease;
- use of stainless steel to improve corrosion resistance;
- introduction of corrosion test samples to identify any type of degradation;
- a shared reinforced concrete retention basin: with a volume corresponding to that of the tank with the largest capacity; designed from the operator's perspective to resist the wave effect; and fitted with an "anti-spill" rim to contain the product in case the shell-bottom joint breaks.

Stormwater management:

Prior to the accident, a ditch running along the site boundary had served to discharge stormwater in the direction of the Lacanau stream. On the day of the accident, pollution was being drained via this ditch until reaching the watercourse.

Since then, the operator has modified stormwater management practices by blocking the ditch and creating an infiltration zone with an overflow in the event of high flow rates. With this modification, stormwater is now being diverted to the site's treatment plant.

National action plan targeting paper mills:

- In response to this accident and a previous release of black liquor on a storage tank in Saillat-sur-Vienne (department 87) in July 2011 (ARIA 40542), the Ministry for sustainable development hosted a meeting in December 2012 for all of France's paper industry representatives in order to establish a national action plan. According to this plan, which is not exclusive to black liquor storage, operators are being requested to:
- list the storage facilities devoted to pollutants, including those outside the scope of the aforementioned 4 October decree;
- define an initial set of measures in terms of prevention and protection, i.e. routine inspections, in-depth visits during both operating and idle periods;
- plan actions over the medium term dedicated to tank monitoring following these early measures (guide for developing inspection programmes and plans);
- initiate longer-term actions to complement the safety reports for all targeted sites so as to better incorporate wave effects.

Intense tire storage fire

20 June 2010

Drama

Greece

Fire
Fire entombment
Air pollution : HAPs, dioxins, PCBs, heavy metals
Waste tires
Crisis management
Health impact
Thunder / natural risks

THE FACILITIES INVOLVED

The site:

The site was an open waste tire storage facility of about 4 ha (state owned area), 500 m from the industrial estate of the city of Drama in North-Eastern Greece.

It was bordered by a marble processing plant to the south and by flat grazing and agricultural land to the other directions, with a small creek running at a distance of 100 m to the east. Access to the site was provided by a rural road along to the west side of the facility. A second, soil paved road run between the site and the nearby creek to the east.

Three villages are located at a distance between 2.5 to 5 km, with a total population of 6,000. Drama lies 6 km to the east, with a population of 42,500.

The site had no fixed network of fire-fighting piping. Fire-fighting measures comprised of portable fire-extinguishers and hoses, fed by two 15 m³ water tanks. No open water sources were available in the area. Fire-engines could be supplied with water from the fire-fighting piping of the industrial estate nearby.

Aerial view of the site before the fire (GoogleEarth, 2007) he site theoretically consisted of 2 facilities, operated by two different firms, but in practice, as the 2 firms were owned by the same entrepreneur, the 2 facilities were operated as one unified site, used for the storage of waste tires, collected from areas of Northern Greece by authorized waste collectors.

According to Greek legislation, landfilling of waste tires of less than 1.4 m in diameter is not allowed since 2003. Hence, the tires were to be recycled at a nearby new recycling plant, owned by the same entrepreneur, that had started its operation 2 months earlier.

The site had been issued with environmental authorisation and permits (separately for each storage facility), for a total of 4 000 t of used tires. However, the permitting procedure that would allow the site to start operation had not been completed. Meanwhile, the operator had been authorised for other side activities on the same site, namely for the storage of bulk municipal wastes and Waste Electrical and Electronic Equipment (WEEE). Those activities were bound to start as well, once space was liberated through the recycling of the stored tires.

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:

At 02:10 am, a fire broke out on the pile of tires, which quickly expanded: in less than 20 minutes, about 15,000 t (roughly 1.7 million tires) were engulfed in flames, producing a dense plume of dark smoke. The smoke rose to a high altitude, raising protests from neighbouring villages and unofficial concerns even from neighbouring Bulgaria.

The first fire-brigade vehicle arrived on site at 02:20 am, but the fire had already expanded to most of the pile. Back-up forces had to be called and fire quenching with water and foam begun, which continued until morning. In all, 15 fire-engines and 50 fire-fighters from Drama and the neighbouring cities were involved on the first day, but quenching efforts with water and foam proved to be ineffective.

The service roadway that run from the entrance halfway to the centre of the site, could not be used by the fire-fighting forces, as it was surrounded by blazing tires. Thus, access to fire was achieved mainly from the marble plant to the south and the fields to the north.

The blazing pile during the first hours (photo taken by the Institute of Geology and Mineral Exploration)

Due to the intensity of the fire, the ineffective quenching efforts and the environmental and health hazards posed by the emitted pollutants, the Prefecture's Emergency Committee was activated from day 1, which decided upon the following:

- The fastest possible extinction of the fire was set as first priority, in order to minimise its adverse effects;
- Extinction strategy had to be switched to cover-up with soil;
- All available resources, including private contractors and the army, were called in to assist in the fire entombment campaign, by providing earthwork equipment and trucks;
- An ex-army general, occupied at the civil protection office, was appointed to lead the operation;
- As it was difficult for the bulldozers to approach the blazing pile, due to the immense thermal fluxes, it was decided to pump concrete on the pile from a distance, in order to diminish heat intensity. Concrete formed a solid crust over the blazing pile, which cracked quickly, but it was enough to enable the bulldozers to approach and push the soil over the pile.

As no soil reserve were available on site and the unused fields in the vicinity were rocky, soil had to be transported from various sites within a distance of 5 km. Marble wastes stored at the adjacent plant were also used as cover-up material. 45 trucks and earth-moving equipment were employed in the campaign.
Owing to the immediate and massive fire-fighting efforts, the burning pile was completely covered with soil after 3 days. Though smoke was no more visible, rubber pyrolisis continued within the pile for days. Fire-fighters thus remained in the area, in case of revival.

Concrete being pumped on the burning pile.

Burning pile being covered with soil.

(photos taken by the Environmental Inspectorate)

Consequences of the accident:

Fire outbreaks of waste tire dumps and depots are not unusual and are renowned for their difficulty to extinguish and the possible negative effects to the environment. Primarily, contamination of soil, waters and vegetation is feared, as a result of toxic substances released to the atmosphere, such as dioxins, PAHs and heavy metals. These in turn may have serious economic consequences, related to damage of agricultural and livestock production. Consequences are proportional to the extent and the duration of the fire.
Fortunately, no adverse environmental effects were concluded, apart from an initial survey indicating soil samples contaminated with heavy metals. This was largely owned to the relatively fast and effective fire quenching campaign.
The winds kept the smoke away from the city of Drama, but serious complaints about breathing discomfort from inhabitants of nearby villages were reported. Even so, no one needed to be hospitalised and no other health problem or injury was reported among the fire-fighters and equipment operators, even though simple dust masks were used.
On the other hand, economic consequences were significant and are attributed to:

- Fire extinction costs, raised considerably by the use of concrete;
- Investigative and monitoring costs for taking and analysing samples of air, soil, waters, agricultural and livestock products;
- Preventive detention and destruction of dairy products and compensation sums awarded to farmers;
- Fodder supplied to farmers due to the prohibition of grazing imposed.

From the first days of the event, legal procedures were launched by the Prefecture against the owner for the temporary seizure of property up to the amount of 1.000.000 €.

Overall, it is estimated that the economic consequences of the fire amount to 400.000 €. This sum does not contain the clean-up cost of the site. Although procedures for environmental liability were initiated, in line with EC Directive 2004/35[10], the fire extinction costs were eventually taken up by the Prefecture of Drama, which considered the event as a fire emergency, while the compensation costs to farmers were incurred by the Regional Authority.
Despite the high cost of the questionable use of concrete, a major advantage of the dry extinction of the fire has been the absence of polluted extinguishing water and the related adverse consequences to the environment. The limited

[10] EC Directive 2004/35: of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

amount of water that was used on the first day was absorbed by the pile. No extinguishing water or oily residue reached the nearby creek, or leaked beyond the site. Instead, larger volumes of solid wastes were created. Leaching tests of the resulting solids fulfilled the Council Decision 2003/33/EC[11] criteria for landfill deposition of inert wastes.

The European scale of industrial accidents:

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

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

The combustion of tires produced Seveso classified substances such as Haps, dioxins, PCBs... The quantities of dangerous substances released being unknown, the default index relating to the quantities of materials index is 1 (see parameter Q1).

No human and social consequences have been reported (no evacuees, no one hospitalized). The human and social consequences index thus reaches 0.

The blaze involved the pollution of an area of 4 ha, leading to an index relating to environmental consequences of 3. (see parameter Env13 : surface area to be decontaminated, between 2 and 10 ha).

Finally, the costs linked to the pollution generated and the actual intervention on the site lead to an index relating to economic consequences of 3 (parameter €18).

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

According to an alleged eye-witness, the fire initiated when a thunderbolt hit the pile. Official reports, including the fire brigade, refer to a severe storm that took place that night. The origin of the fire could not be officially corroborated, because of the destruction of all traces after the cover-up of the pile. No hints of arson, negligent action or electricity shortcut were found. No vehicles, machinery or buildings existed on the site.

The investigation carried out by the Environmental Inspectorate revealed that although the site had been issued with environmental permits, the permitting procedure, that would allow the site to start operation, had not been completed. On-site inspection by the local environmental and public health authorities was pending, in order to confirm that the installation met the appropriate specifications. Among others, the environmental permits imposed the arrangement of the tires in smaller piles, separated by fire lanes, a peripheral 10 m wide fire lane inside the fence and the provision of fire-fighting measures.

ACTIONS TAKEN

Preventive measures

As early as day 1, the Prefecture of Drama informed the Ministry of Environment, Spatial Planning and Public Works, asking for guidelines and the contribution of Environmental Inspectors. Next day, the National Centre for Scientific Research "DEMOCRITOS"[12] in Athens was contacted in order to provide guidelines for preventive actions.

From past experience, a 5 km zone was expected to be gradually affected, for which the following guidelines were given:

- people should remain indoors, keeping windows and A/C systems shut;
- sheep and goat herds should be kept within the stables, fed with stocked fodder or relocated;
- open irrigation or drinking water tanks should be covered;
- as vegetables and fruits do not absorb dioxins, people should be advised to rinse them meticulously before consumption.

Environmental Inspectors arrived at the site on 22 June 2010, conducted their investigation, following which an open consultation meeting was held at the Prefecture premises with the participation of all competent authorities and civilians from the surrounding villages. Past experience from a large dump fire in Northern Greece in 2006 was exploited in order to suggest restriction measures and monitoring actions. On the same day, the Prefecture of Drama decided upon the following restriction measures for a 5 km surveillance zone:

- prohibition of grazing and mandatory penning of all livestock. Free fodder would be provided to farmers ;
- seizure and refund of sheep and goat milk production ;

[11] COUNCIL DECISION of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC

[12] This laboratory is the accredited lab that was appointed to the EC as the national reference lab for dioxins and PCBs.

- prohibition of slaughter of cattle until further notice.

Restriction measures were in force between 22 June 2010 and 17 July 2010, during which:

- 50.5 t of sheep and goat milk were seized and destroyed. In particular, 18.8 t were destroyed through thermal rendering according to EC Regulation 1774/2002, and 31.7 t were used for the production of biogas and compost;
- 13.3 t of feta cheese were detained and released only after analyses for dioxins and PAHs rendered them safe for consumption;
- The Hellenic Food Authority (EFET) issued a news notification to the European Commission on 12 July 2010 via the Rapid Alert System for Food and Feed (RASFF).

Monitoring programme

In order to investigate and monitor the impact of the fire, a comprehensive sampling and analysis programme was agreed between the Prefecture and the college of experts and executed from 25 June 2010 to 21 September 2010 by accredited laboratories, covering an extended scope of samples from within the surveillance zone. In particular:

a) 37 fresh milk samples were tested for heavy metals, dioxins, furans, PCBs and / or PAHs by NCSR "DEMOCRITOS", the General Chemical State Laboratory (GCSL) and other accredited labs in Greece. Another 2 samples of fresh milk were sent by a diary firm to Eurofins Analytic Gmbh in Germany for dioxin, furans and PCB tests. Samples were found in accordance with EC Regulation 1881/2006[13];
b) 13 samples of dairy products were tested for heavy metals, dioxins, furans and PCBs / or PAHs by NCSR "DEMOCRITOS" and GCSL. All samples were found in accordance with EC Regulation 1881/2006;
c) 6 livestock meat samples were examined for heavy metals, dioxins and PCBs by NCSR "DEMOCRITOS" and found in accordance with EC Regulation 1881/2006;
d) 3 poultry meat and 15 egg samples were examined for heavy metals, dioxins, and PCBs by NCSR "DEMOCRITOS" and found in accordance with EC Regulation 1881/2006;
e) 1 grass sample was tested for heavy metals, dioxins, furans and PCBs by NCSR "DEMOCRITOS" and found in accordance with EC Directive 13/2006[14];
f) 19 samples of vegetables, cereals, fruits, clover, olives and olive leaves were examined by the Regional Plant Control Centre of Magnesia for heavy metals and found in accordance with EC Regulation 1881/2006;
g) A 24h air sample, taken on 28 June 2010, 1.5 km east from the site and analysed by NCSR "DEMOCRITOS" for heavy metals, dioxins, PCBs, PAHs PM-10 and PM-2,5 showed no pollution, with respect to the limit values of EC Directives 50/2008[15] and 107/2004[16];
h) 10 samples of underground water from irrigation wells of the three neighbouring villages and the industrial area were analysed for PAHs and other physicochemical properties by the Regional Public Health Laboratory of Alexandroupoli. All samples met the standards for drinking water, set by EC Directive 98/83, except for one with increased iron concentration from an unused well of the industrial area;
i) 7 samples of surface waters were collected around the three neighbouring villages and analysed for heavy metals by NCSR "DEMOCRITOS". Concentrations were either non detectable, or well below the limits set by EC Directive 98/83, except for one sample with increased iron concentration from a pond with still water.

Although measurements proved no contamination, the area was included in the national monitoring program for food control. Since 30 September 2010, another 8 samples of olives, milk and meat were tested for heavy metals, PAHs, dioxins and / or PCBs by accredited labs, all found safe for human consumption, according to EC Regulation 1881/2006.
A preliminary survey on the impact of the accident on the soil was conducted by the Institute of Geology and Mineral Exploration, with 20 samples collected in the end of June 2010. The approach of the survey was probabilistic and indicated soil samples around the site as contaminated / probably / or possibly contaminated with heavy metals. Even though background data were available for the area, different sampling protocols (surface samples of 1 vs 10 cm in depth) did not allow for a conclusive comparison. Moreover, no national or European standards existed for soil quality. A sample from the core of the pile revealed very high concentrations of Zn (4.3 %) and high concentrations of other metals and heavy metals (Al, Fe, Ti, Ba, Co, Pb, Sb, Sn and As).

10 samples of surface soil were collected on 05 July 2010 around the three neighbouring villages and the site. The samples were analysed for heavy metals by NCSR "DEMOCRITOS" and concentrations were found well below the limits suggested for sediments by the National Oceanic and Atmospheric Administration, U.S. 1999.

On 15 March 2011 "carrot" samples from depths of 0.5 and 2.0 m were taken from the soil of the buried pile (above and below the rubber mass). These were analysed a) for PCBs and PAHs by NCSR "DEMOCRITOS" and b) for heavy metals by the accredited Environmental Chemistry Lab, National University of Athens. Leaching tests for heavy metals, anions and DOC were also conducted. In all samples, contaminant concentrations were non-detectable or well below the limit values set by national and European legislation. Likewise, leaching tests fulfilled the Council Decision 2003/33/EC[17] criteria for landfill deposition of inert wastes. On the same day, groundwater samples were collected form

[13] COMMISSION REGULATION (EC) No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.
[14] DIRECTIVE 2006/13/EC of 3 February 2006 amending Annexes I and II to Directive 2002/32/EC of the European Parliament and of the Council on undesirable substances in animal feed as regards dioxins and dioxin-like PCBs.
[15] DIRECTIVE 2008/50/EC of 21 May 2008 on ambient air quality and cleaner air for Europe
[16] Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air.
[17] Council Decision 2003/33/EC establishing criteria and procedures for the acceptance of waste at landfills pursuant to article 16 of and Annex II to Directive 1999/31/EC.

the area of the surrounding villages. These were tested for heavy metals and anions, and were found well below the limit values set by EC Directive 98/83[18] for drinking water.
In view of the above results, no further action was taken so far with regards to the buried pile. Final decisions are to be taken by the regional committee for environmental damage, under the provisions of directive EC/2004/35 for environmental liability.

Sanctions
On the grounds of the serious risks incurred to the environment and the public health, as a result of the operator's failure to comply with the specifications of the permits granted, in particular the good storage practices and fire prevention measures, an administrative fine of 23.000 € was imposed by the Environmental Inspectorate to each of the two storage facilities. The operator has appealed against the fines and the case is pending in court.

Meanwhile, two separate judicial procedures are underway, one provoked by the Environmental Inspectorate against the owner of the facilities for criminal liability and the other initiated by the district attorney for endangering human lives and the environment.

In addition, the competent authority withdrew the authorisation and permits of both facilities, and the land rental contracts were interrupted.

LESSONS LEARNT

As expected, maximum efforts for fastest possible extinction of the fire were compensated by minimum environmental damage. Owing to the full-scale fire-extinction campaign, concentrations of harmful pollutants released by the combustion of the tires did not exceed safety limits.

Although questionable and expensive, the use of concrete proved beneficial by enabling the fast entombment of the fire.
The tire storage fire in Drama was "moderate in size", compared to other incidents of its kind. This made the entombment of the blazing pile feasible, while in the same time unwanted side effects from the use of quenching water were averted.

Regular briefings to the public and consultation meetings with the college of experts open to civilians contributed significantly to alleviate increased worries and protests by the public.

Likewise, the comprehensive and extended monitoring programme and the prompt disclosure of all results restored public confidence and the sense of safety.

Analysis, documentation and dissemination of facts, conclusions and best practices are needed for local and central authorities, in order to exploit the experience gained.

Environmental liability directive (EC/2004/35), which was incorporated in the Greek legislation in 2009, granted opportunities and powers to authorities, which need to be elaborated on and better exploited. Procedures need to be developed, in order to allocate cost of preventive and remedial measures to the liable operator promptly and impose necessary actions with no delay caused by legal disputes.

[18] DIRECTIVE 98/83/EC of 3 November 1998 on the quality of water intended for human consumption

Appendix

European scale
of industrial accidents

European scale of industrial accidents
Graphic presentation used in France

This scale was made official in 1994 by the Committee of Competent Authorities of the member States which oversees the application of the Seveso directive. It is based on 18 technical parameters designed to objectively characterise the effects or consequences of accidents: each of these 18 parameters include 6 levels. The highest level determines the accident's index.

Further to difficulties which stemmed from the attribution of an overall index covering the consequences that are completely different according to the accidents, a new presentation of the European scale of industrial accidents with four indices was proposed. After having completed a large consultation of the various parties concerned in 2003, this proposal was retained bythe Higher Council for Registered Installations. It includes the 18 parameters of the European scale in four uniform groups of effects or consequences:

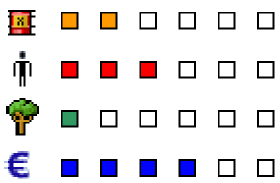
- 2 parameters concern the quantities of dangerous materials involved,
- 7 parameters bear on the human and social aspects,
- 5 concern the environmental consequences,
- 4 refer to the economical aspects.

This presentation modifies neither the parameters nor the rating rules of the European scale.

The graphic charter:

The graphic charter adopted for the presentation of the 4 indices is as follows:

When the indices are yet explained elsewhere in the text, a simplified presentation, without the wordings, can be used:



The parameters of the European scale:

	Dangerous material released	1	2	3	4	5	6
Q1	Quantity Q of substance actually lost or released in relation to the « Seveso » threshold *	Q < 0,1 %	0,1 % ≤ Q < 1 %	1 % ≤ Q < 10 %	10 % ≤ Q < 100 %	De 1 à 10 fois le seuil	≥ 10 fois le seuil
Q2	Quantity Q of explosive substance having actually participated in the explosion (equivalent in TNT)	Q < 0,1 t	0,1 t ≤ Q < 1 t	1 t ≤ Q < 5 t	5 t ≤ Q < 50 t	50 t ≤ Q < 500 t	Q ≥ 500 t

* Use the higher "Seveso" thresholds. If more than one substance are involved, the higher level should be adopted.

Human and social consequences		1	2	3	4	5	6
H3	Total number of death: including - employees - external rescue personnel - persons from the public	- - - -	1 1 - -	2 – 5 2 – 5 1 -	6 – 19 6 – 19 2 – 5 1	20 – 49 20 – 49 6 – 19 2 – 5	≥ 50 ≥ 50 ≥ 20 ≥ 6
H4	Total number of injured with hospitalisation ≥ 24 h: including - employees - external rescue personnel - persons from the public	1 1 1 -	2 – 5 2 – 5 2 – 5 -	6 – 19 6 – 19 6 – 19 1 – 5	20 – 49 20 – 49 20 – 49 6 – 19	50 – 199 50 – 199 50 – 199 20 – 49	≥ 200 ≥ 200 ≥ 200 ≥ 50
H5	Total number of slightly injured cared for on site with hospitalisation < 24 h : including - employees - external rescue personnel - persons from the public	1 – 5 1 – 5 1 – 5 -	6 – 19 6 – 19 6 – 19 1 – 5	20 – 49 20 – 49 20 – 49 6 – 19	50 – 199 50 – 199 50 – 199 20 – 49	200 – 999 200 – 999 200 – 999 50 – 199	≥ 1000 ≥ 1000 ≥ 1000 ≥ 200
H6	Total number of homeless or unable to work (outbuildings and work tools damaged)	-	1 – 5	6 – 19	20 – 99	100 – 499	≥ 500
H7	Number N of residents evacuated or confined in their home > 2 hours x nbr of hours (persons x hours)	-	N < 500	500 ≤ N < 5 000	5 000 ≤ N < 50 000	50 000 ≤ N < 500 000	N ≥ 500 000
H8	Number N of persons without drinking water, electricity, gas, telephone, public transports > 2 hours x nbr of hours (persons x hours)	-	N < 1 000	1 000 ≤ N < 10 000	10 000 ≤ N < 100 000	100 000 ≤ N < 1 million	N ≥ 1 million
H9	Number N of persons having undergone extended medical supervision (≥ 3 months after the accident)	-	N < 10	10 ≤ N < 50	50 ≤ N < 200	200 ≤ N < 1 000	N ≥ 1 000

Environmental consequences		1	2	3	4	5	6
Env10	Quantity of wild animals killed, injured or rendered unfit for human consumption (t)	Q < 0,1	0,1 ≤ Q < 1	1 ≤ Q < 10	10 ≤ Q < 50	50 ≤ Q < 200	Q ≥ 200
Env11	Proportion P of rare or protected animal or vegetal species destroyed (or eliminated by biotope damage) in the zone of the accident	P < 0,1 %	0,1% ≤ P < 0,5%	0,5 % ≤ P < 2 %	2 % ≤ P < 10 %	10 % ≤ P < 50 %	P ≥ 50 %
Env12	Volume V of water polluted (in m^3) *	V < 1000	1000 ≤ V < 10 000	10 000 ≤ V < 0.1	0.1 Million ≤ V< 1 Million	1 Million ≤ V< 10 Million	V ≥ 10 Million
Env13	Surface area S of soil or underground water surface requiring cleaning or specific decontamination (in ha)	0,1 ≤ S < 0,5	0,5 ≤ S < 2	2 ≤ S < 10	10 ≤ S < 50	50 ≤ S < 200	S ≥ 200
Env14	Length L of water channel requiring cleaning or specific decontamination (in km)	0,1≤ L < 0,5	0,5 ≤ L< 2	2 ≤ L< 10	10 ≤ L < 50	50 ≤ L< 200	L ≥ 200

* The volume is determined with the expression Q/C_{lim} where:

- ✓ Q is the quantity of substance released,
- ✓ C_{lim} is the maximal admissible concentration in the milieu concerned fixed by the European directives in effect.

€ Economic consequences		1	2	3	4	5	6
€15	Property damage in the establishment (C expressed in millions of € - Reference 93)	0,1 ≤ C < 0,5	0,5 ≤ C < 2	2 ≤ C< 10	10 ≤ C< 50	50 ≤ C < 200	C ≥ 200
€16	The establishment 's production losses (C expressed in millions of € - Reference 93)	0,1 ≤ C < 0,5	0,5 ≤ C < 2	2 ≤ C< 10	10 ≤ C< 50	50 ≤ C < 200	C ≥ 200
€17	Property damage or production losses outside the establishment (C expressed in millions of € - Reference 93)	-	0,05 < C < 0,1	0,1 ≤ C < 0,5	0,5 ≤ C < 2	2 ≤ C < 10	C ≥ 10
€18	Cost of cleaning, decontamination, rehabilitation of the environment (C expressed in millions of € - Reference 93)	0,01 ≤ C < 0,05	0,05 ≤ C < 0,2	0,2 ≤ C < 1	1 ≤ C < 5	5 ≤ C < 20	C ≥ 20

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 maintained by the Ministry of Sustainable Development has been providing professionals and the general public with lessons learnt from the analysis of technological accidents. The main sections of the website are presented both in French and English.

Under the general sections, the Internet user can, for example: enquire about the French state's action, become familiar with the ARIA database, discover the presentation of the European scale of industrial accidents, enquire about the principles of the "on the spot communication" process in case of incident.

Accidents description, which is the raw material of any method of experience feedback, represents an important part of the website material: event, consequences, origin, circumstances, established or supposed causes, actions taken and lessons learnt.

Two hundred and fifty detailed and illustrated technical reports describe accidents selected for their particular interest. Numerous analyses covering technical subjects or selected activities are also available: fine chemistry, pyrotechnics, confined spaces, lightning, hydrogen, gas boilers, sensors... A multicriteria search engine allows to reach information about accidents arisen in France or in other countries.

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

www.aria.developpement-durable.gouv.fr

industrial accidents database:
> www.aria.developpement-durable.gouv.fr

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