LESSONS LEARNT from INDUSTRIAL ACCIDENTS

13th SEMINAR

22-23 May 2019 • Rennes

IMPEL
European Union Network for the Implementation and Enforcement of Environmental Law

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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. The analysis of disruption factors and root causes, known or supposed, 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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MINISTÈRE DE LA TRANSITION ÉCOLOGIQUE ET SOLIDAIRE

13e SÉMINAIRE
RETOUR D'EXPÉRIENCE sur ACCIDENTS INDUSTRIELS

13th SEMINAR
LESSONS LEARNT from INDUSTRIAL ACCIDENTS

22-23 mai 2019 / 22-23 May 2019 • Rennes

DANS LE CADRE DU RÉSEAU IMPEL / HELD WITHIN THE FRAMEWORK OF IMPEL NETWORK

LESSONS LEARNT

from industrial accidents

IMPEL Seminar

Rennes, 22 and 23 May 2019

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Controlling new risks

According to the French Federation of Insurers, climate change, disruption of business sectors and cyber risks will be among the top three emerging risks by 2022. In parallel, the ARIA technological accidents database already contains numerous events involving emerging energy sectors. What are these new risks and can they be controlled?

1. New risks

1.1. Energy production and storage

Growing awareness that fossil fuels are not inexhaustible and that they have a detrimental effect on our environment encourages the emergence of **new energy sectors with technologies that have not yet matured**. Developments include solar energy with photovoltaic solar panels, wind energy with wind turbines, recycling of waste into units of fuel, and the use of decomposed organic matter through methanisation.

Do these sectors have any common characteristics as pertains to accidents?

One common feature is difficulties for the firefighters called to the scene:

ARIA 37736 - 14/01/2010 - Val-de-Reuil (Eure) - France
Photovoltaic panel fire and intervention difficulties
A fire broke out at around 3:30 p.m. on the roof of a 15,000 m² warehouse covered with 1,000 m² of photovoltaic solar panels (i.e. 660 panels). The building, which had been inaugurated in November 2009, was certified High Environmental Quality (HQE).
Forty firefighters rapidly responded and were able to bring the fire under control in 6 hours. The emergency services encountered several difficulties during the intervention: lack of suitable equipment to dismantle the panels, the inability to stop the production of electricity and the need to cover the photovoltaic solar panels, risk of electrification, difficulties in accessing the space between the roof and the panels, propagation of fire via the cables and the waterproof covering.
The intervention required the use of a special tool (an electric screwdriver equipped with a specific tip) to dismantle the 200 panels on either side of the burning area. This operation prevented the fire from spreading via electrical arcing between the panels. Following a visit to the site, the Classified Facilities Inspection authorities asked the operator to implement a procedure to facilitate the intervention by the fire brigade in the event of a solar panel fire.

Another common characteristic is massive smoke emissions, with varying degrees of toxicity, depending on the materials burnt, as in the case of the fire in a 50,000 m³ wood chip storage facility in Gasville-Oisème (ARIA 50270) where post-disaster monitoring was requested by the administration.

In addition to the energy production sectors, **the storage of energy in pressurised tanks or batteries is a source of accidents**. The use of tanks **made of composite materials** in the automotive sector is on the rise owing to weight savings and the development of the hydrogen sector (with new-generation tanks at 700 bar!) of compressed natural gas (CNG).

ARIA 43036 - 29/10/2012 - The Netherlands
Fire in a CNG-powered bus
A city bus operating on compressed natural gas (CNG) caught fire at about 11 a.m. due to a failure of the cooling fan's drive motor. The driver was able to evacuate all the passengers, attempted to put out the fire and then move the bus to a safe location. The heat from the fire triggered the safety system on the CNG's composite cylinders, causing the gas to be released laterally and thus spewing out flames, over a distance of 15 m, perpendicular to the direction of traffic. The direction of the flaming jet was contrary to the safety objectives defined in the best practices, which recommend orienting the thermal fuse openings in an upward direction. The fire brigade was able to put out the fire after the CNG had been completely released. The public transportation company inspected all of its vehicles.

Used lithium batteries also pose problems in waste **treatment centres.** The development of electric vehicles with new types of batteries (often containing lithium or sodium) is unlikely to improve the situation.

ARIA 38858 - 26/08/2010 - Dieuze (Moselle) - France
Fire in a battery and storage cell recycling centre
In a battery and storage cell recycling centre, a fire broke out in a compartment containing used lithium batteries.The automatic powder-based extinguishing system was unable to contain the fire which spread to other cells used to store different types of batteries (lead, mercury, nickel-cadmium) and miscellaneous sub-products (scrap metal, nickel hydroxide). Employees from nearby companies were evacuated and examined owing to the toxic fumes released (sulphuric acid and lithium hydroxide). The 1,000 m² building was destroyed and batteries were thrown 200 m from the accident. The potential projectile effect due to fire in the lithium battery storage area had not been taken into account in the operator's hazard study. The extinguishing water was pumped and disposed of as hazardous waste (heavy metals, phenols and PCBs were detected).

1.2. Disruption or permanent adaptation to change

The "good health of a production facility" is often decisive in terms of industrial success. An accident which occurred in the Port of Antwerp (ARIA 52726) illustrates this: **properly inspecting one's equipment is cheaper than having to manage an accident or immobilising a unit**. In response, new **inspection methods** are beginning to appear throughout the industry. Predictive maintenance triggering curative maintenance via the use of IIoT (Industrial Internet Of Things) and inspection operations conducted by drones are only at an early stage. It would be worthwhile to discuss problems already encountered (what happens in the event of a drone crash, for example?).

ARIA 51339 - 08/04/2018 - Village-Neuf (Haut-Rhin) - France
Drone crash on a chemical plant
At around 8 a.m., a drone crashed on a warehouse belonging to a Seveso high threshold company specialised in the manufacture of pharmaceutical products. An investigation was initiated by the Air Transport Gendarmerie. A warning was issued by the Prosecutor's Delegate. The drone was seized and identification of the owner was requested. The crash resulted from a loss of control by the pilot (a minor).

The **regulations governing drones** are evolving to take into account the legitimate needs of operators and those of citizens in terms of environmental protection. In France, a decree covering multiple categories has been drafted specifically for the logistics industry in light of the deep-seated changes in the sector : development of e-business, a need for surface area and storage height, increasingly rapid delivery times... However, with storage facilities can now accommodating several types of combustible materials (wood, paper, tyres, etc.), it is all the more important to remain vigilant regarding the types of extinguishing media required for the materials being stored (e.g. sprinkler systems).

1.3. Climatic hazards

Flooding, heavy rainfall, snow and wind... climate change issues deserve continued attention and the implementation of good practices to manage them. Recent events in France and abroad show that these phenomena are becoming more and more intense.

ARIA 50402 - 31/08/2017 - Crosby - United States
Fire and explosion of drums of peroxide during flooding in a chemical plant
Several fires and explosions occurred in a chemical plant manufacturing organic peroxides.
Following the announcement of a pending hurricane in the region (ARIA 50399), the operator took the precautions deemed necessary and in line with its procedures: the plant's operations were shut down, emergency generators were mobilised, other generators were brought in to supply power to the storage buildings (containing 227 t of peroxides) in the event of a power failure, refrigerated containers were mobilised on site as an additional precautionary measure.
The hurricane caused flooding throughout the plant, with water reaching 1.80 m, and the site's power supply failed. The higher-than-expected rise in water levels caused the loss of the permanent generators, emergency generators and a liquid nitrogen emergency cooling system. The site was no longer accessible.
The operator moved its products into 9 refrigerated containers powered by diesel engines, but the rising waters flooded the engines.

1.4. Cyber risk

An industrial site's cyber "environment" is often vulnerable. Failure to transmit an alert by a remote alarm system (ARIA 50755), computer viruses (ARIA 51131), lack of updating of electronic components (ARIA 42931), and incorrect programming of PLCs (ARIA 5989) are just a few examples taken from the ARIA database.

2. Control of emerging risks

The **precautionary principle**, first affirmed in the Barnier's Law of 1995, and set out in the French Constitution through the **Environmental Charter,** is a necessity, now more than ever before:

"...when the occurrence of damage, the extent of which may not be fully scientifically understood, could affect the environment in a serious and irreversible manner, public authorities must ensure, under the precautionary principle and within the scope of their authority, that risk assessment procedures are set out and that provisional and proportionate measures are adopted in order to avert such occurrences".

The website www.aria.developpement-durable.gouv.fr includes a number of studies containing recommendations on how to control these new risks (Summary on new energy sectors: wind turbines, methanisation, photovoltaic solar panels; News flash on lithium batteries; Memo on cybersecurity in industry; Articles on natural and technological risks…).

Wind turbine toppled during a storm

1 January 2018

Bouin (Vendée)

France

Wind turbine

Renewable energy

Failure

Natural hazards (wind)

THE ACCIDENT AND ITS CONSEQUENCES

A wind turbine with a rotor measuring 80 m in diameter and a hub rising 60 m in the air was felled in the early morning by Storm Carmen. The force of the winds ripped the 55 m tower from its base and sent it toppling down, littering the ground with debris consisting mainly of its blades. The impact was so strong that the rotor was driven into the ground. Emergency services were immediately alerted. The same day, the operator's on-call teams and the manufacturer set up a safety perimeter and posted security guards. No injuries were reported in the accident.

The turbine was part of a group of eight turbines operated by two different companies. Three (including the demolished one) were owned by one operator and five others were owned by another operator. After making initial observations, both operators completely shut down their wind farms. That same day, the inspection authorities for classified facilities were informed about the accident by its on-call team. They discussed the situation with the operator and visited its wind farm the following day.

The damaged wind turbine belonged to the first generation of a model marketed in France by the manufacturer. It was commissioned in 2003. The only other identical wind turbines in service in mainland France were the seven turbines still in operation in both wind farms.

THE ORIGIN AND THE CAUSES

The operator performed an assessment with the manufacturer. Technical experts were also called in and they visited the operator's wind farm several times. Various items of equipment and materials were collected. To conduct the necessary investigations, all the technical data about the wind turbine was collected (metallurgical analysis of the tower, chronology of the accident, remote management of the wind turbine by the operator, analysis of the blade pitch control system's brake blocks). This analysis was made necessary by repeated errors in the system used to control the pitch of the three blades.

The turbine was equipped with an aerodynamic braking system controlled by both the pitch of the blades and a pneumatic brake (rotor brake). The aerodynamic brake was the turbine's main brake. The rotor brake acted as a backup to the aerodynamic brake to keep the rotor from turning.

The investigations found that multiple factors caused the turbine to fall:

- the combination of undetected abnormal wear of the brake blocks and wind speeds in excess of 40 m/s, caused the pitch of the three blades to change uncontrollably and made the turbine automatically stop. The control system had been designed to automatically stop the turbine in the event of a deviation in the blade pitch control system;
- as the reported wind speeds were much higher than the upper limits for safely working in the turbine, on-site troubleshooting was impossible. Only remote operations could be performed;
- following a misinterpretation of data, an operator used the remote management system to manually reposition the turbine. This caused the rotor speed to quickly increase and exceed the safety limit. Although the overspeed protection system kicked in, the condition of the brake blocks on the pitch control system and the extremely high wind speeds made it impossible to stop the turbine. The mechanical loads acting on the tower greatly exceeded the turbine's design limits, causing it to collapse.

The operator's investigations revealed that the mechanical linkage between the blade pitch motor and the brakes was not covered by the maintenance inspection protocol. As a result, the accumulated wear had not been detected during the annual inspections.

FOLLOW-UP ACTIONS TAKEN

Following the on-site visit, the inspection authorities for classified facilities issued an emergency prefectural order for each farm operator. Both orders were revised to include clarifications made by the operators.

The emergency order for the operator of the demolished wind turbine contained the following recommendations:

- immediate safety measures;
- filing of an accident report;
- waste removal (collection with mapping and disposal);
- soil pollution (analysis followed by treatment where necessary);
- metallurgical analysis of the demolished wind turbine and assessment of the towers of the other turbines;
- halt in the operation of the remaining two turbines pending a check of the overspeed protection system. The halt is also depending on the metallurgical analysis results for the other towers and the accident report findings;
- conditions for building a new wind turbine.

The emergency order for the other operator of the other farm covered the following aspects:

- immediate safety measures;
- submission of a report on the operation, monitoring, and maintenance of its wind turbines;
- assessment of the metallurgical characteristics of the towers;
- definition of the conditions for maintaining the turbines in service (checks of the overspeed protection system and inclusion of the recommendations in the accident report for the other farm).

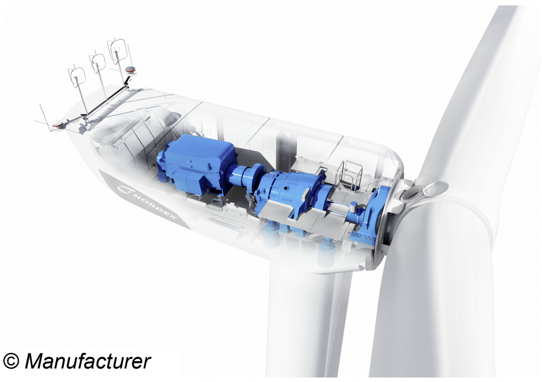
Both orders were signed on 5 January 2018. Follow-up meetings were held regularly with both operators. Following the replacement of the brake blocks and a series of tests, both farms were allowed to resume operation. They were inspected on 14 June 2018. A final follow-up meeting was held on 13 July 2018. All the solutions implemented were found to be satisfactory on 27 September 2018.

At the writing of this summary, the inspection authorities for classified facilities are reviewing the application to rebuild the demolished wind turbine.

LESSONS LEARNT

To provide feedback and improve the operation of wind turbines of the same type, the operators took the following measures in consultation with the manufacturer:

- they revised and clarified the maintenance procedure to be followed in the event of failure of the blade pitch control system and trained their maintenance technicians;
- they updated their maintenance instructions. From now on, all or a portion of the components of the blade pitch control system’s brake blocks (gear wheel in particular) are to be replaced every five years and the replaced components are to be inspected by sampling to confirm this frequency;
- since March 2018, they have been using special software that assesses the condition of the blade pitch control system’s brake blocks by comparing the actual position of the blades against the setpoints sent electronically;
- a safety warning has been written for operators who have not signed a maintenance agreement with the manufacturer and who own the same type of wind turbine.



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Short-form accident feedback

Short-form accident summaries on the topic of controlling new risks.

Tank overflow in an methanisation plant

ARIA 50072 – 21/06/2017 – Plouedern (Finistère) – France

A tank used for storing and mixing biodegradable material before it is sent on to a digester overflowed at an agricultural anaerobic digestion plant. The plant's employees noticed the overflow when they arrived at 7:30 a.m.. They increased the flow rate to the digester in order to lower the level inside the tank. A portion of the tank's contents flowed down onto the cement floor, with 10 m³ being collected in buckets and returned to the tank. The remaining traces were left to dry and then cleaned up. The remainder seeped into the soil. The operator had the affected area dug up and the soil was dumped onto a compost pile.

What caused the tank to overflow was foam produced following the addition of 25 tonnes of cereal's draff in one go the day before. This type of waste had never been added before. The foaming was increased by the high temperature in the tank. At around 4:30 p.m. the day before, the tank's high-level sensor triggered an alarm. The stirrer override was activated, which temporarily solved the problem. However, later on that night, the alarm sounded again although stirring was still taking place. The on-duty technician did not increase the amount of substrate being sent to the digester and did not go see the tank. The tank overflowed sometime in the night.

Following this incident, the operator decided that draff should be added in small amounts and the reaction inside the tank should be monitored. It told its technicians to be more vigilant when alarms are triggered.

Wood mulch fire

ARIA 50270 – 21/08/2017 – Gasville-Oisème (Eure-et-Loir) – France

At around 3:00 a.m., a deep-seated fire broke out in a 50,000 m³ pile of wood mulch at a waste recycling plant. The pile, which measured 24 m in height, was in an outdoor storage area located along the plant's property line. A large amount of smoke could be seen in the sky over the urban area and the A11 motorway. The size of the heap made it difficult for the firefighters and their vehicles to access the site. The wind caused the flames to spread. An expert specialised in deep-seated fires was called in. The Emergency Support Unit (CASU) was contacted to provide smoke dispersion simulations. Due to the human health risks involved (healthcare facility 400 m away, A11 motorway 300 m away), air quality measurements were taken. Cyanide, phenol, and benzene were detected in the smoke.

Two days later, the firefighters noted that the town's potable water supply for the 1,350 residents had run out. The water tower was refilled, the water in the reservoir was super-chlorinated, and the town's inhabitants were told not to use the tap water until further notice. In the meantime, bottles of water were distributed. Emergency services connected 4.5 km of hoses to a fire hydrant located in a neighbouring industrial area.

Probes measuring 2 m in length were inserted into the heap to measure the internal temperature and rods measuring 6 m in length were used to collect samples from the centre for analysis. The seats of the fires were located using core samples. It was decided to gradually level the heap, spread the wood mulch, and douse them. The mulch was then moved to a nearby field to cool for 48 hours and then sent to a storage facility or particle board plant.

Consequences and actions taken

The 3,500 m³ of extinguishing water was contained in a 1,000 m³ tank on the site, three portable tanks, and a 1,000 m³ capacity available in a former nearby wastewater treatment plant. It took four weeks and considerable human and technical resources (70 firefighters from eight different counties at the height of the fire) to finally extinguish the fire. The economic toll was very high. CASU installed gauges and samplers at various points in the surrounding environment for post-accident analysis. An emergency prefectural order is issued.

Cause analysis

The fire is believed to have been caused by fermentation inside the mulch pile. The alternating sunshine and rain over the previous days accelerated this fermentation and produced gases and some overheating. Combustion occurred several weeks before any of the external signs were observed.

The operating permits specifies that the maximum tonnage allowed for all types of material combined is 5,120 m³. Of this amount, just 370 m³ is authorised for wood. However, on the day of the fire the pile consisted of 50,000 m³ of wood mulch. The operator explained that a weakening of the lumber industry (reduced capacities of wood-chip boilers and chipboard manufacturers) was the reason for this excess mulch.

Fire at a waste sorting plant outfitted with solar panels

ARIA 49648 – 10/05/2017 – Bozouls (Aveyron) – France

At around 12:15 p.m., a fire broke out in a 6,000 m² building where hazardous and non-hazardous waste were sorted. The fire burnt unnoticed for 30 – 45 minutes while the workers were on their lunch break. As it smouldered, it produced a great deal of smoke, which rose to the building's ceiling. When the temperature inside reached 600 °C, the pyrolytic gases released by the combustible materials ignited, spreading the flames to the rest of the building. That was when the workers noticed the fire. They alerted the firefighters, who arrived and attacked the blaze with nozzles and water cannons. However, they had to contend with falling cladding panels, an insufficient flow rate from the plant's fire hydrant that forced them to hook their equipment up to an offsite hydrant, and solar panels that posed an electrical hazard.

The fire lasted for three days. The nearby creche, retirement home, and recreation centre were told to shelter in place. A person with both asthma and diabetes fainted and was taken to hospital. Air-quality measurements taken inside the building and outside the site did not identify any major health hazards. The flow rate of the extinguishing water was so high that the bypass between the containment and the underground tank failed. A portion of the water flowed to the tank, which overflowed and spilled into the natural environment. A plug was fitted to divert the water to the retention basin and, at around 5:00 p.m., a pump was turned on to prevent the basin from overflowing.

The building, waste, and vehicles parked inside it were destroyed. An emergency prefectural order is issued to shut down the plant pending its repair and an updating of its hazards study.

A prohibited substance buried inside the heap of ultimate waste is believed to have ignited the fire. Stacking of the skip may have provided the oxygen needed to fuel it. The visual inspections that were being conducted failed to systematically locate prohibited items and customers had continued to send these items to the plant despite being told not to. The wind rushing through the building's open doors, its non-functioning smoke extraction system, and the lack of both a fire alarm and sprinkler system and fire-resistant walls made it difficult to bring the fire under control. Two major fires, one in July 2013 (ARIA 44131) and another in July 2016 (ARIA 48200), had already occurred at the plant and took five to seven days to be put out.

Flammable-gas leak at a Seveso-classified petrochemicals plant

ARIA 52726 – 25/04/2015 – Anvers – Belgium

At around 1:00 p.m., a large amount of flammable gases (ethylene and methane) began leaking from the cold section of the distillation unit at the steam cracker outlet. The gas detectors triggered an alarm, prompting the technicians to activate the emergency stops, set up a water curtain, and sound the evacuation alarm. The operator implemented its internal emergency plan. An analysis of the pressure graphs at 1:55 p.m. located the leak on a manual drain valve in the cold blow down line of an intermediate reboiler of the steam cracker. The pipe was isolated and decompressed to the flare. At 6:00 p.m., the pressure measured in the line was zero. Maintenance to replace the valve therefore was started. Suddenly, 45 tonnes of methane and ethylene were discharged into the air. The gases did not ignite and no one was injured.

What caused the leak was the ejection of the cap on the drain valve. Usually this cap is fastened onto the valve body with rods and nuts. However, the eight carbon steel nuts assembled on the four stainless steel rods were severely weakened by a combination of galvanic and atmospheric corrosion. The nuts burst, allowing the cap to shoot off and the gas to leak out. As the fluid flowing inside the valve was at low temperature (–6°C), the water vapour in the ambient air condensed on the valve, leading to moisture-induced corrosion. The nuts were not protected against atmospheric corrosion and the valve was not thermally insulated.

According to the original specifications, the drain valve (installed in 1984) should have been made of carbon steel (low temperature), not stainless steel. It was difficult to determine whether the drain valve in question was the original one fitted in 1984 or if it was a replacement valve. The pipe on which the drain valve was fitted was periodically inspected based on the system's criticality (low risk according to the criticality matrix). A visual inspection is conducted every five years. The drain valve's condition was not sufficiently assessed during the last inspection and there was no visual-inspection procedure.

Following the accident, the operator inspected more than 400 valves before restarting the steam cracker. The following corrective actions were implemented to prevent any such future accidents:

- development of a positive material identification programme (PMI) in order to boost quality controls of materials and of delivered and fitted equipment;
- launch of a campaign to raise awareness of galvanic corrosion, which did not seem to be clearly understood;
- development of a visual inspection protocol for valves;
- fitting of an additional valve to reduce the section to be isolated in the event of future leaks (still under investigation).

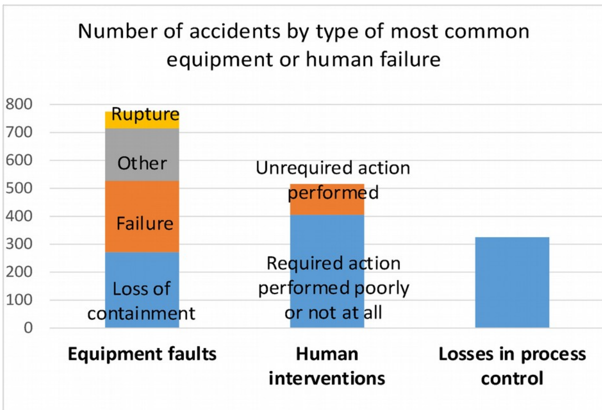
Preventing multiple failures

Since 2016, 25% of accidents in ICPEs (classified facilities for environmental protection requiring authorisation or registration), impacting people and property, have been caused by multiple failures involving equipment faults or human interventions. Most initial post-accident verifications focus on the incriminated system: did it function as intended and were the necessary human actions taken? One failure is already one too many; this is all the more true for multiple failures. It is therefore important to know how to analyse cases of multiple failures accurately and with all the requisite objectivity, as this will guide investigations into the nature of their root causes: were there common modes? were there generic failures? were there failures specific to an isolated system that was insufficiently analysed? were there deeper failures caused by organisational methods? All these clues provide the information needed to help explain the causes of multiple failures and prevent them from recurring.

1. What are the most common multiple failures?

In accidents occurring at ICPEs since 2016, involving multiple failures, the primary cause has been equipment failures (loss of containment, breakdown, rupture). This is followed by human errors and actions that were performed either incorrectly or not at all (misjudgement, misinterpretation, poor decision-making or inappropriate actions) and lastly by losses of process controls (incompatible mixtures, reaction runaway, or parasitic reactions).

Multiple failures can aggravate an initial event, for instance when safeguards designed to limit the severity of a hazard do not work (water curtains that fail to activate, a faulty detector that fails to identify an incident in time...). Some failures in risk control measures may result in major accidents having effects that extend beyond a site's confines: *odours, visual or noise impacts* (*such as a gas alert), and even trigger the implementation of a site's external emergency plan (ARIA 51372 and 52842).*



2. Actions required at various levels to prevent multiple failures

2.1. Is making equipment changes shortly after an accident enough?

Following an event caused by multiple equipment failures, the system containing the defective equipment must be analysed closely. The analysis findings can lead to a number of changes:

- retrofitting of defective equipment, such as changes in valve or detector technology or the fitting of explosive atmospheres certified equipment;
- process control changes, such as ensuring that certain functions are maintained during shutdowns and restarts, and improvements to control mimic panels;
- addition of safety equipment: sensor redundancy, detection/action loops, etc.;
- increased monitoring: CCTV, webcams, more frequent rounds;
- improved system inspection and maintenance, such as changes in the frequencies of inspections, tests, and maintenance plans (*ARIA 47654, 49388, 49575, 50121, 50150).*

To implement these changes, operators must call on skilled people to choose the right equipment and processes. A **study of the ergonomics of a plant's systems** or control rooms can support the choices made *(valve access, availability of information on mimic panels).*
Operators must take a broad view of events, analyse them in depth, and look for potential common failure modes. Because simply retrofitting equipment is not enough, operators must take a hard look at the system that has caused multiple failures as well as any systems that are similar to it or interact with it. It is essential to review their **risk analyses,** identify common causes, and widely implement preventive measures based on these new analyses. The analytical and organisational methods used may also be challenged (*ARIA 50254, 52784, 51220).*

2.2. What resources are necessary to facilitate decision-making?

Despite support from supervisors and maintenance teams, technicians and shift crews sometimes misjudge a situation, or commit errors that lead to unwanted events. When multiple errors occur, organisational factors are always the culprit. Lack of communication may also explain why the right people were not consulted and why inappropriate actions were taken.

ARIA 51220 – 19/09/2017– Aramon (Gard) – France

At 9:20 a.m., a rupture disc of a reactor used to produce an organomagnesium compound burst when the reactor's internal pressure rose too high. The incident was caused by a nonconforming mixture that had formed in the reactor. First, the ambiguous instructions led a technician to add an insufficient amount of initiator. Then, seeing that the reaction had not yet started, a second technician added more reagents.

The process sheet indicated that the reagent could be added after, but only after receiving the supervisor's approval. The operation took place on a Saturday and the chemical engineer belatedly informed the on-duty engineer. This lack of communication between the workers of both shifts and the technicians' lack of experience are what set the stage for the incident. The operator subsequently implemented a number of changes : tracking of technicians who are accredited to carry out synthesis operations has been reinstated ; the process sheet now indicates the amounts of reagent to be added and includes hold points for the start of the reaction ; the reaction may no longer be carried out over the weekend and it must be scheduled at the beginning of a shift so that workers may monitor it from start to finish. In addition, the operator conducted an in-depth review of organomagnesium compound synthesis in order to establish production standards and problem-management guidelines applicable at all its similar production sites.

Cumulated difficulties in making the right decisions when managing incidents can be mitigated by leveraging various organisational strengths:

- **clear procedures and instructions facilitate decision-making:**

The retrofits mentioned earlier often result in updates to the associated procedures and operating instructions:

- improved operating procedures, such as process sheets with hold points for complex operations, quick-response procedures to be used when abnormal situations arise, shutdown/restart procedures, tests, inspections, and maintenance plans;

- improved emergency-response procedures, such as incorporating a new scenario to a site's internal emergency plan, changing the on-duty call procedure, and updating the telephone numbers of external resources.

Analysing events makes it possible to find out what the control-room technicians needed to make the right decisions. Procedures and sheets must be legible, easy to reach and to use by all. To ensure that they are simple to understand, the relevant people and resources must participate in their design. Indeed, some accidents highlight the importance of bringing in various professions and perspectives when drafting these documents. Once written, supervisors and managers at all levels must efficiently work together to ensure that they are systematically implemented (*ARIA 50339, 49109, 52021, 52324, 52384).*

Another aspect that deserves special consideration is control-room ergonomics. The technicians working there should be consulted to find out whether equipment retrofits are appropriate and well designed.

- **put the emphasis back on training and personnel qualification:**

Updating instructions and procedures also requires teaching personnel how to adopt these changes. This entails organising actions such as awareness-raising, training sessions, accreditation (in some cases), knowledge testing, and role-play simulations. It is important to involve contractors in awareness and training courses and, more generally, within a plant's organisation (*ARIA 49970, 50686, 52553).*

Refresher training courses for technicians, especially those regarded as 'experts', should be designed to keep them aware of the reality of the risks of the facilities they operate.

- **efficient workplace organisation, supervision, and communication:**

One way to develop efficient means of communication (*such as safety flashes and safety meetings/confabs*) is to hold a brainstorming session between all the sites in a company or a particular sector of business. The goal is to create and implement long-term communication actions.

All changes must be supported by a solid system for managing modifications and degraded modes. Management as a whole must be the first to adopt the process (*ARIA 51172).*

3. Lasting, in-depth changes

Incidents involving multiple failures remind us that it is important to take an in-depth look at **root causes**, **defence mechanisms** (barrier and risk management measures) and **risk analyses** on the whole. Their lessons make it possible to establish thorough, long-term means of prevention and protection, reduce the recurrence of such incidents, mitigate their consequences, and check the appropriateness of accident scenarios.

Despite this, a decline in vigilance may occur when the number of incidents and accidents drops within a plant. However, improving safety requires constant alertness and attention to **weak signals** or **situations with a high severity potential**. Taken individually, incidents may be of little consequence. But when combined with other circumstances, they can result in extensive damage.

The messages to be delivered must also reach the right people. It is therefore essential to use several methods of communication, such as drawing up success trees (versus causal trees), bringing in a neuroscientist to explain human factors, or investigating **risk perception** at all levels within a plant.

Release of a chlorinated organic chemical

2 June 2017

Mazingarbe (Pas-de-Calais)
France

Chemicals
PVC
Polymerisation
Runaway of an exothermic reaction

THE ACCIDENT AND ITS CONSEQUENCES

At around 3:15 p.m., vinyl chloride monomer (VCM; which is carcinogenic, mutagenic, and toxic to reproduction) was released following the thermic runaway of a reactor at a polymerisation facility of a basic-plastics (PVC) manufacturing plant.

At around 2:50 p.m., the emergency diesel generators started up to power the safety and monitoring-control systems after the plant's main power supply shut off and the 20 kV emergency electrical supply failed to take over. The plant's units automatically placed in the safe position.

Without electricity, the polymerisation reactors were no longer being stirred. As a result, substances known as 'polymerisation stoppers' or 'reaction killers' were automatically fed into them. However, this did not occur in one of the facility's 22 reactors because its inhibition system failed. The uncontrolled polymerisation that ensued in this reactor caused its internal pressure to rise. When this pressure reached 16 bar, one of the two pneumatic relief valves (automatic safety) failed to open, allowing the reactor pressure to continue to increase. The site's technicians manually opened the second valve by turning on an emergency air compressor, but the reactor pressure continued to rise, ultimately causing the 20 bar safety valve to open and release VCM into the atmosphere.

At around 3:30 p.m., the 20 kV supply was restored and stirring in the reactor restarted. This cooled down the reactor and decreased the pressure. The situation was brought under control at around 3:50 p.m. when the valve closed after the pressure returned to 13.9 bar.

The amount of VCM released into the air was continuously measured using a fibre-optic infrared analyser. The operator estimated that 90 kg of VCM was emitted from the site's 40 m-high stack (referred to as a 'cold flare').

The emission limit value of the chemical oxygen demand (COD) for waste water was exceeded for several days due to the reaction killers (which contained DEHA [N,N-Diethylhydroxylamine]), being injected into the reactors that were operating when the electrical power supply was lost. Internal treatment of the effluent did not completely compensate for the high COD concentration.

THE ORIGIN AND THE CAUSES

The accident was caused by a series of technical failures on various components that work together to ensure the facilities remain safe:

- loss of the main power electric supply:

The significant rise in temperature inside the 45 kV transformer room, which occurred when the main network's fans shut off, is what caused the main power supply to shut off. The electrical panel powering the network's fans had a faulty electrical outlet that caused the panel to trip when a device was plugged into it. A high-temperature alarm on the 45 kV electrical network tripped during the technicians' rotation. However, they did not deem it a priority;

- secondary-network switchover failure:

A programming fault in managing the alarms of the 45 kV network prevented the switchover to the 20 kV secondary network;

- failure of the reaction inhibition system on a reactor:

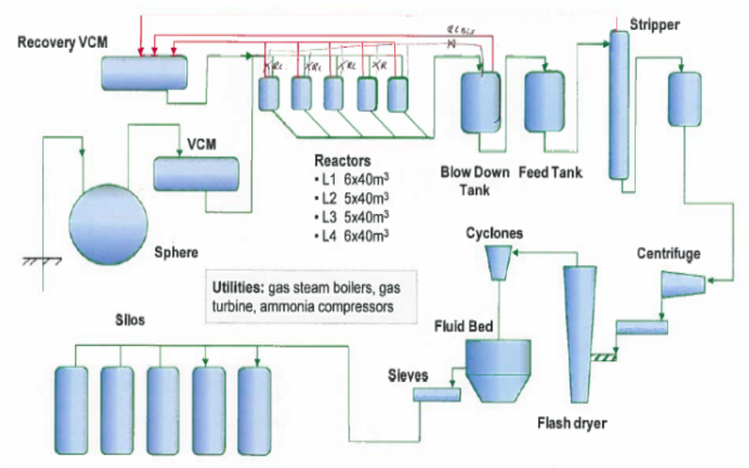
The reaction inhibition system is an active safety function that trips when the pressure in the reactor is high (15 bar) or when stirring is lost. When the accident occurred, the 'reaction killer' was injected due to the second situation. This injection, carried out using nitrogen as a driving gas, failed for one of the 22 reactors due to a loss of pressure in the nitrogen line that made it impossible to achieve the pressure difference needed to break the rupture disc between the tank and the reactor;

- lack of pressure in the compressed air network:

When the reactor pressure reaches 16 bar, two reactors relief valves (actuated using compressed air) automatically open to the 120 m^3 blowdown tank (BDT). One of the two relief valves upstream of the BDT and fitted on the relief line shared by the reactors did not open due to the lack of pressure in the compressed air network. The compressor supplying the network is backed by a diesel generator but requires that a technician be physically present to restart it. This operation took some time and, all the while, the reactor pressure was increasing;

- the reactor valve, the last line of defence:

Each reactor has a relief valve (setting of them 20 bar). Each valve is connected to the gas discharge network, which leads to a 40 m-high stack fitted with a continuous measurement system.



© Site operator
Simplified diagram of the PVC manufacturing process

FOLLOW-UP ACTIONS TAKEN

Following the accident, the inspection authorities for classified facilities arrived at the site to hear the operator's initial analysis and ask it to look for the root causes. Corrective actions were quickly taken, in particular:

- correction of the programming fault that prevented the 45 kV from automatically switching over to the 20 kV network;
- update of the list of equipment that automatically starts back up or must be started and writing of the associated operating instructions;
- check of the inventory of outlets in the facility and creation of a dedicated electrical supply for the 5 kV transformer's fan;
- check of the relief valves at the reactor outlets leading to the BDT.

After performing a causal tree analysis, the following actions were taken:

- creation of an overall supervision view of the reactors and creation of an alarm that appears when there are problems with injecting reaction killers into the reactor;
- leak detection by means of loss of nitrogen pressure (with alarm);
- closer follow-up of electrical check reports and main-to-backup power supply switchover tests.

The inspection authorities requested that the action be implemented. This implementation is being monitored closely.

LESSONS LEARNT

This sequence of technical failures prompted the operator to look into equipment and processes that would prevent this type of accident from recurring.

The operator made two changes to the electrical network's supervision alarms. It added an audible and visual alert that activates when a problem is detected on the 45 kV network and characterised their management priority based on the required response time. A clearer message allows technicians to take the right decisions based on the various alarms to be managed.

The operator also analysed the electrical vulnerability of its facilities. This analysis confirmed that risk management measures will operate properly in the event of a major accident and that the organisation currently in place was relevant. Avenues for improvement were nevertheless identified.

The reliability of the three safety levels currently in place to avoid the risk of runaway reactions is increased by the use of diesel generators associated with a supervision system. That ensures that the reactors are stirred at rated power if the main power supply is lost and planned replacement of the compressor with automatic restart along with the display of information on the control room panel (air network pressure, compressor states, alarms).

The operator is also considering whether to create a second reaction killer injection channel.

Phosgene discharges in a chemical plant

12 August 2017

Le-Pont-de-Claix (Isère)

France

SEVESO

Isocyanates and by-products

Chemical manufacturing

Subcontracting

THE ACCIDENT AND ITS CONSEQUENCES

At around 11:00 p.m., phosgene ($COCl_2$) and chlorobenzene began leaking inside the containment building of a chlorinated chemicals plant. The leak was detected at levels between 13 and 22 ppm by analysers inside the containment. The analysers' control system automatically directed the air inside the containment towards the caustic scrubber. Technicians began looking for the cause of the leak.

While one of them was suiting up to enter the containment, the analysers detected an even larger leak (500 ppm) at 12:20 a.m.

The technicians placed the circuit in a safe position by shutting off the pump (which stopped the leak) and isolating the containment, but not before 400 kg of phosgene and 600 kg of chlorobenzene spread inside the containment. Although the analysers did not detect anything unusual, there was a noticeable odour outside, near the containment.

At 2:00 a.m., the technicians began cleaning the containment by injecting air inside the scrubber. They could smell something in the air although none of the analysers in the surrounding production facilities and labs detected any phosgene. At around 2:40 a.m., outside analysers detected phosgene at levels between 0.12 and 0.2 ppm.

The operator estimated that 4 – 5 kg of phosgene escaped to the atmosphere via the containment's stack.

Phosgene is a gas used under pressure. It is a dangerous substance classified as "Acute toxic, category 2, all exposure routes".

Chlorobenzene is a category 3 flammable liquid, and other flammable liquids with a flash point of < 60°C, stored at high pressure or temp.

Both are SEVESO substances.

THE ORIGIN AND THE CAUSES

The analysis revealed that the releases to the atmosphere were caused by a long string of events.

Release of gases inside the containment

The initial leak inside the containment was caused by a leak on the pressure sensor of a pump and a leak on a flange's seal upline of a flow meter connected to this pump. The flange's seal had been replaced by a subcontractor called to assist an other subcontractor shortly before the accident. However, it had been incorrectly fitted. Seal installations are supposed to be inspected and inspected seals have to be identified with a label. As no label was on the valve in question, there was no way of knowing if an inspection had indeed been performed.

It was not clear who was responsible for performing inspections (the contractor, its subcontractor, or the operator). In addition, the subcontractor called as additional help had only been recently trained in the fitting of seals. Perhaps they lacked sufficient knowledge about the risks related to incorrect fitting, the inspections to be conducted, and the consequences of leaks on the facility. Lastly, a number of operating procedures for sensitive equipment were not written out.

Flange's seal upline of the flow meter

A helium leak test conducted before the facility was restarted did not reveal these leaks. The operator called into doubt the reliability of the helium leak test for this type of equipment, pointing out in particular technicians' inexperience due to training issues and the choice of material used.

Release of chlorinated gases outside the containment

The bypass very closed valve on the scrubber also had a leak, but the leak had not been found because the valve is located between two very closed pipes, making it difficult to access. A portion of the gases to be treated by the scrubber therefore was directly discharged to the stack.

Three phosgene analysers are fitted on the stack's outlet. They use 2/3 voting logic, meaning that phosgene must be detected by two of them in order to activate risk management measure and close the valves leading to the stack. On the day of the accident, phosgene was detected by just one analyser. The flow rate of the sample loop was too low for the second analyser and the third analyser was sampling the ambient air, not the air inside the stack. This 2/3 voting logic did not allow the technicians to stop the flow of phosgene to the stack.

The analysers were calibrated but the sample loop had never been checked.

The access hatches on the containment's valves also leaked, making total containment impossible. Before the accident, these valves had been opened for maintenance. However, the seals, ordered from the maintenance department, had not yet been repaired. Though valves are under the responsibility of the central maintenance department, their integrity is the responsibility of sectoral maintenance. A resealing notice had been issued in June, but nothing had been done. This fact revealed a lack of coordination among maintenance crews and a lack of interdepartmental communication when defining priority actions. In addition, the operator did not have software to track assigned maintenance tasks.

Lack of detection outside the containment and no-triggering of the gas leak alert

The outside analysers did not detected phosgene because they were not placed where they could detect a loss of containment. Instead, they were positioned to detect leaks from the low-pressure phosgene synthesis unit next to the containment. In addition, the instructions to be followed in case of a gas leak at the facility had not been revised whereas the plant's internal emergency plan had been modified subsequent to previous events. The gas leak alert was supposed to be given when the phosgene level detected by at least one analyser in the containment exceeded the upper limit. In the present case, the limit had been exceeded but the facility's employees were unaware of the procedure to follow. As a result, the gaz leak alert was not given and the proper steps were not followed. Nevertheless, the crew on duty responded appropriately by shutting off the phosgene pump.

FOLLOW-UP ACTIONS TAKEN

The inspection authorities for classified facilities visited the plant and the incident was added to a study conducted by BARPI and the French National Institute for Environmental Technology and Hazards (INERIS). This study, which went beyond the present event, examined how the operator analysed and applied feedback following various accidents that had occurred at the plant in 2016 and 2017. The aim was to take a critical look at the operator's analysis of the incidents/accidents. It highlighted the need to look more closely for organisational causes when conducting analyses and showed which risk factors were liable to cause accidents, in particular:

- the existence of bias when analysing risks (financial/technical biases, focus on major accident scenarios, difficulties in factoring in transitional phases);
- the potential for errors due to inadequate, non-existent, or multiple procedures and instructions.

LESSONS LEARNT

Improved reliability of critical elements

After the accident, the operator replaced all its defective equipment and began implementing corrective measures, particularly on the tracking and coordination of maintenance tasks among the various maintenance crews.

It audited the safety devices installed at its facilities.

In particular, it began implementing:

- weekly testing of the sample loops used by the phosgene analysers in the stack and other critical analysers around the plant;
- testing, under a pressure of 20 mbar, of the containment after each opening of the hatch and at least once a year.

The closure effectiveness of the valves was also investigated. The operator also began enhancing the reliability of helium testing.

Revised practices regarding critical elements

The operator revised the procedures to be followed if gas is detected inside the containment so that they are consistent with the procedures in the internal emergency plan, and distributed them to each facility.

A working meeting was held with the contractor in order to:

- redefine inspection rules;
- clarify inspection responsibilities;
- introduce sealing checklists;
- establish rules of communication with the contractor.

A safety moment was then held to once again go over everyone's responsibilities and the safety rules that apply to contractors and their subcontractors. A multiple-choice quiz on sealing and a practical test were conducted before operations on the site to check whether the relevant instructions and procedures were well understood. The number of people authorised to assess workers was increased.

The operator implemented operating procedures for general work performed on critical elements.

The calibration standards (training, procedure, plan) were revised.

After the disturbances identification, what about the root causes?

Every year, Bureau for analysis of industrial risks and pollution (BARPI) records in its technological accidents database ARIA between 800 and 1 100 events that have occurred at classified facilities for environmental protection. A look at the past three years shows that 65% of events involved at least one disruption and only 30% involved at least one cause. Identifying causes is essential to define efficient measures that will prevent future accidents occurring. These findings show that there is still much progress to be made in understanding and analysing industrial accidents.

1. What is the difference between a disruption and a cause?

Disruptions are deviations from expected operating conditions that lead to a hazardous phenomenon. Equipment failures, inappropriate human intervention, mixing of incompatible products, and natural or technological hazards are just a few examples.

The source of these disturbances may not be so obvious. These are the real 'causes', or 'root causes', of accidents and they can be of several types:

Organisational factors	Related to work environments and risk-management measures, such as the organisation of controls, management of training and internal and external resources, procedures and instructions, risk identification, organisation of labour and management, communication, ergonomics, choice of equipment and processes...
Human factors	Factors that disrupt the physical/cognitive/mental abilities of a site's employee and which are not caused by the organisation.
Imponderables factors	Causes of a disruption that could not be anticipated or controlled by the organisation at the site of an accident. One example is manufacturing defects.

2. Why identify root causes?

There are multiple reasons for searching for the causes of an accident:

- Prevent future accidents recurring at a same site;
- Sharing experience feedback from accidents benefits all risk-management professionals and practitioners;
- An efficient way to identify failures at a site and solve them by implementing suitable measures, not just measures aimed at managing the symptoms (disruptions);
- Provide the authorities with a more realistic view of an industrial site's safety organisation. The organisation of safety at Seveso sites must be described in specific chapters of their safety management systems (SMS). However, in the case of sites subject to permit, Prefectural order do not always deal with these organisational factors. Only a few chapters discuss training, procedures, and instructions.

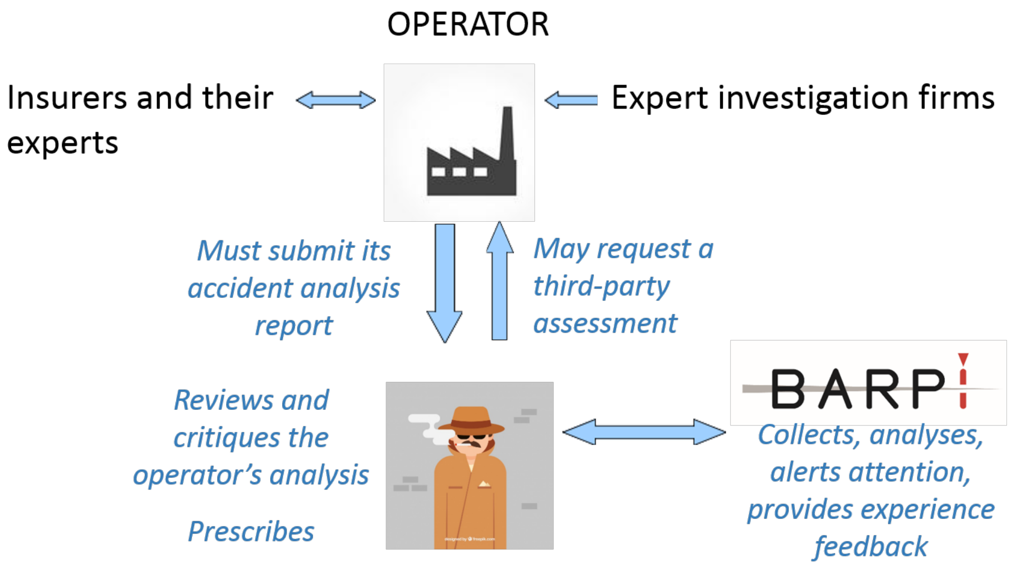
> 23% of accidents in silos that contain wood mulch or sawdust occur at sites that have already had accidents.

> Lessons from experience feedback on hot work benefit people in a wide range of fields, including chemicals, waste management, silos, refining, livestock farming, metallurgy, and surface treatment.

3. How to identify root causes?

3.1. Who identifies the causes of an accident?

- Following an accident, operators are required by regulations to provide inspection authorities with a report. This accident report must include the exact causes of the accident or incident. Operators may call on experts to assist them in analysing the accident.
- This report is reviewed by the inspection authorities for classified facilities and then sent to BARPI, which disseminates the experience feedback to all risk-management professionals and practitioners.



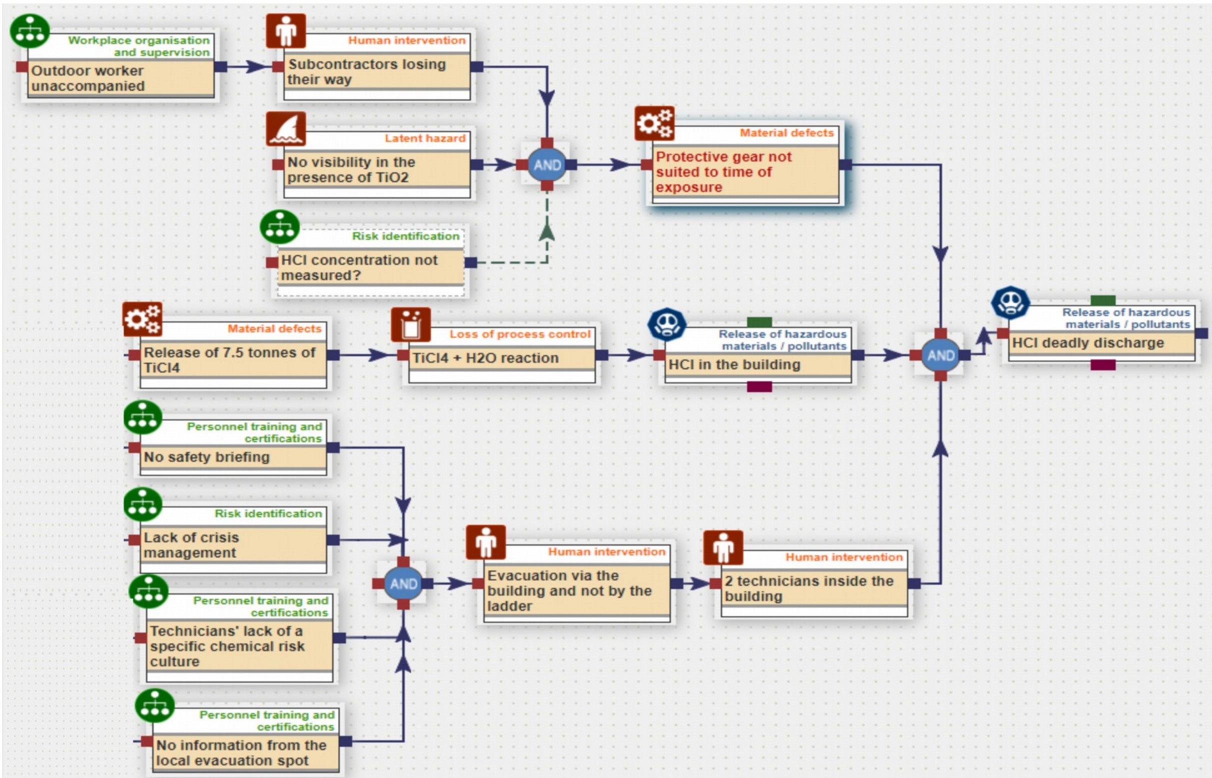
3.2. BARPI's method for analysing accident reports

Operators are free to use the method of their choice to analyse the causes of accidents or incidents at their sites. Many methods are available, including causal tree analysis, the 5 Whys, bow-tie analysis, etc.

BARPI has developed its own method for analysing accident reports. This graphical modelling tool makes it possible to:

- structure the analysis of an accident;
- distinguish between disruptions and causes;
- push the analysis down to root causes;
- reveal recurring failures on operator's sites;
- obtain a basis for discussion.

The method consists in identifying first the hazardous phenomenon, then the disruptions that led to it, and lastly the causes that gave rise to the disruptions. With each step, a block is created in the model. The predefined vocabulary for each block is a tool for reflection on the problem. BARPI implements a number of awareness-raising actions (especially via a role-playing game called BARPIDO) to help all risk-management professionals and practitioners to conduct in-depth analysis of accidents.



Leak and fire in an oil terminal

12 July 2017 and 8 August 2017

Amsterdam

The Netherlands

Management of Change
Root causes
Incident investigation
Hot spot work

THE ACCIDENT AND ITS CONSEQUENCES

The 12 July, the cargo of a ship at an oil terminal in Amsterdam was pumped to a storage tank. In the evening, the content of the tank (gas oil) was homogenized. Usually, homogenisation takes place by blowing nitrogen through an air cross at the bottom of the storage tank. Because the air cross was in maintenance and therefore not in use, it was decided to homogenise the liquid with air through the product line. After homogenisation it was recognised that about 100 litres of product had leaked through the dome of the tank into the tank pit. Because there was a lot of rain water in the pit, the floating gas oil was dispersed over a large area of the pit.

Four weeks later, at the same oil terminal, a fire in the tank pit occurred, which was caused by welding activities at the tank of the first example. The dry grass in the tank pit was still contaminated with gas oil and sparks ignited a fire.

THE ORIGIN AND THE CAUSES

1st incident

Around midnight, early morning of 12 July, the order was given to discharge gas oil from a sea vessel into a storage tank at the oil terminal up to 461 mm beneath the top edge of the tank. The maximum working level (MWL) of the tank is set to 400 mm beneath the top edge of the tank. This means that at that moment the maximum filling capacity was not recognised as critical. Following the filling of the tank, an order was given to homogenize the gas oil in the tank. This was done by injecting air through the product line. Early morning, it also rained heavily which eventually caused an excessive flood of water on the terminal and in the tank pit.

The nitrogen installation with which the homogenisation is normally performed could not be used. Therefore, no nitrogen or air could be blown through the air cross at the bottom of the tank. For this reason, it was decided to use a product pipe to blow air into the tank. After the job was done, it was noticed that product was released at the top of the tank (under the edge of the dome) and was present as a floating layer on the rain water in the tank pit.

- Direct cause according to the company: it is probable that the moving of air in the tank caused a wave higher than 461 mm, which caused the spill of gasoil leaking between tank roof and tank shell during the process of homogenisation.
- Root cause according to the company: the tank roof has been changed from an External Floating Roof (EFR) to a dome. A Management Of Change (MOC) was performed and the maximum working level could be changed to 400 mm from the tank roof. In the MOC, the filling level of the tank was considered as safe.

2nd incident

Leaking tank was emptied and cleaned for maintenance and in order to perform welding activities. On the specific day of the 2nd incident, a contractor was welding the railing of the roof of tank. This work was a small part of the overall maintenance that was going at that time on this tank. The welding work on that day was started on the north side of the tank and the welders were gradually advancing towards the east side of the tank. Around noon, a worker saw a patch of grass burning at the foot of the tank on the east side, directly under the place where the welders were working. The fire was controlled with a fire extinguisher which was near at hand. A total lot of 8 (m) x 2 (m) grass had been on fire.

- Direct cause according to the company: dry grass at the bottom of the tank caught fire due to the deposit of hot welding residues from above the tank.
- Root cause according to the company: due to the spill on 12 July, the grass in the tank pit died and the dry grass became combustible material. The Last Minute Risk Analysis (LMRA) did not mention the dry grass as combustible material.

FOLLOW-UP ACTION TAKEN

1st incident

After investigating the first incident by the company, the following recommendations were reported to the authorities in order to avoid similar incidents in the future:

- lowering the maximum working level (MWL) to 1000 mm instead of 400 mm;
- hire a cleaning company at an earlier stage to save on the costs of soil remediation;
- in the case of a change of the MWL, verify that all possibilities for liquid to flow out has been reviewed in the MOC.

2nd incident

After investigating the second incident by the company, the following recommendations were reported:

- keeping the area wet when performing welding operations at tank;
- clear instructions for the firefighter to recognize flammable material in time.

LESSONS LEARNT

From the examples mentioned above it is clear that the quality of incident reports is inadequate. The correct root causes that could explain direct cause are not described:

- The MOC alternative homogenization was inappropriate. What is the reason for it? Why the MOC did not identified this?
- The dome of the tank turned out not to be closed. The cause of this structural mistake is not investigated.
- The dangers of contaminated tank pit bottom was not identified. What can explain it?

The consequence is that the recommendations identified to prevent similar incidents in the future, are incorrect. Unfortunately, this is a trend in many of the incident reports received by the competent authority. Thus in many cases, the legal obligation for a thorough investigation of the root causes of incidents, is not met. In view of this shortcoming, the competent authority must take corrective actions against the operators.

Guidance document for incident investigation

The Environmental Service North Sea Canal area (ODNZKG) has decided to stimulate structural improvement of accident reports. By communicating to companies why, which and how companies must provide information when submitting accident reports, ODNZKG expects to make a positive contribution to improving the quality of the reports. As a result, it is expected that correct root causes are better identified, and recommendations are formulated which may lead to substantial improvements. This insight will also contribute to a higher safety awareness for the companies. In addition to the preventative approach, ODNZKG also has the legal competence to deploy enforcement measures.

In the Netherlands, the obligations for providing information about incidents to the competent environmental authority is laid down in the Environmental Act (article 17.2). This article is not very clearly formulated, and can be interpreted in various ways. For this reason, ODNZKG has made a guidance document for the companies, in which the service indicates how it deals with the interpretations of the article mentioned above.

The guidance document is divided into the following parts:

- a flowchart to determine the use of the limited or extensive reporting requirements. This includes the assessment of whether there is a notification obligation in accordance with article mentioned above;
- requirements for a limited accident reporting;
- requirements for an extensive accident reporting.

In drafting the flowchart use is made of case-law jurisprudence, case studies, and other existing helpful material and schemes. The flowchart offers a step by step approach, with examples and/or an explanation for each step.

Following the flowchart it should be clear whether a company needs to submit a notification of an incident to the competent authority and when this is the case, which form of incident reporting will be needed.

The result is a guidance document for Seveso and Industrial Emission Directive 4 (IED4) companies, in which is indicated when an accident should be reported to the competent authority and what information should be supplied by the company, in case an accident report is needed.

When companies provide their information in accordance with the guidance document, the content of the document should be assessed uniformly. To do so, ODNZKG is developing an assessment protocol for the accident reports. In addition, the protocol describes the working process of ODNZKG to verify proper implementation and working of the recommended measures included in the accident reports.

Leak of sulphur containing gases in a refinery

1 march 2018

Grandpuits (Seine-et-Marne)
France

Safety culture
Communication
Internal emergency plan
Preventive maintenance

THE ACCIDENT AND ITS CONSEQUENCES

At around 8:00 a.m. on 1 March 2018, which was an icy-cold day, around 300 reports of an odour of gas were made by residents in three counties in the Paris region. The county fire and rescue service and the Seine-et-Marne gendarmerie spent several hours going around to a number of industrial sites, including those operated by GrDF (a natural-gas distribution company) and GRTgaz (a natural-gas transmission company), but found nothing. The event was reported by the local press and on social media.

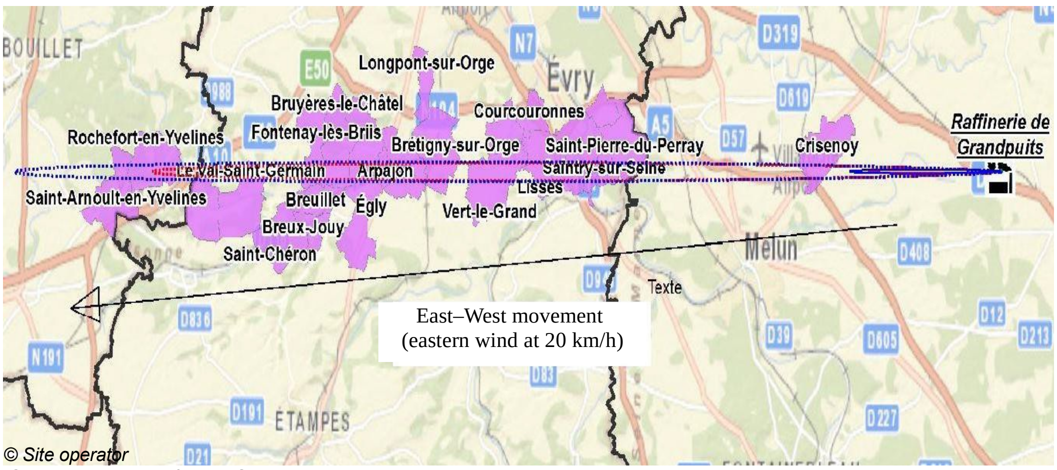
At around noon, the operator of the Grandpuits refinery, an upper-tier Seveso facility, confirmed that a leak had occurred on a check valve of a unit used to purify sulphur containing gas and that the leak had been stopped 30 minutes earlier. The gas primarily consisted of hydrogen sulphide (H_2S), which is toxic, flammable, and has a pungent odour at low concentrations.

The refinery's internal emergency plan was implemented at around 2:00 p.m. and a team from the Regional and Interdepartmental Directorate for the Environment and Energy (DRIEE) was dispatched to the site. The operator indicated that no alarm had been triggered by any detectors and this appeared to be corroborated by the shift log. However, information provided by the operator afterwards showed that in fact 25 alarms had been triggered (10 ppm of H_2S) at the start of the leak and that two of them were high-threshold alarms (40 ppm of H_2S). The unit's operating crew searched for the leak without informing anyone else at the refinery. As a result, neither the refinery's safety department nor the department supervisor provided satisfactory answers when contacted that morning by the rescue service.

THE ORIGIN AND THE CAUSES

An analysis of the event showed that the leak occurred on a valve on the gas line between the purification column and the gas-flaring system. It was found that the valve's cap had been distorted by ice (outdoor temperatures below –5° C). During normal operation, the gas contained in the line does not flow. Heat tracing is used to prevent the formation of condensation, but the operator noted that it was not working. The expansion of the ice caused a crack to form in the valve. This crack then allowed the gas to leak out when the ice thawed. The lack of insulation and the fact that the valve was positioned at the bottom contributed to the build-up of water in the valve.

An estimated 187 kg of gas was released. The icy temperatures, strong wind, and atmospheric stability that remained very high throughout the event and the area explain why the odour was noticed in three counties. Computer models and air-quality measurements taken near the site show that the H_2S concentrations were very low (less than 1 ppm) and thus there were no offsite toxic effects. However, the significant lethal effect thresholds[1] may have been exceeded in some areas near the leak inside the refinery.



© Site operator
Geographic extent of the H_2S plume

1. 414 ppm and 1720 ppm for 60 minutes and 1 minute of exposure, respectively.

FOLLOW-UP ACTION TAKEN

In addition to the ice-induced damage to the valve, significant shortcomings on the operator's part prevented on-time detection of the leak, placement of the refinery in a safe state, and implementation of its internal emergency plan. After the analysis of the event, the operator proposed technical and organisational safeguards to prevent a similar accident from recurring. More particularly, it checked and reinforced the refinery's heat insulation and heat tracing systems. It also lowered the H_2S detection thresholds to 5 and 10 ppm in order to speed up the localisation of leaks.

In terms of incident management, communication, sharing of information, and procedures specifying actions to be taken in the event of H_2S leaks were revised and presented to all the operating personnel. Procedures on triggering the internal emergency plan were also revised and supplemented with an odour-detection scenario sheet. Lastly, the reporting of information to the authorities was consolidated.

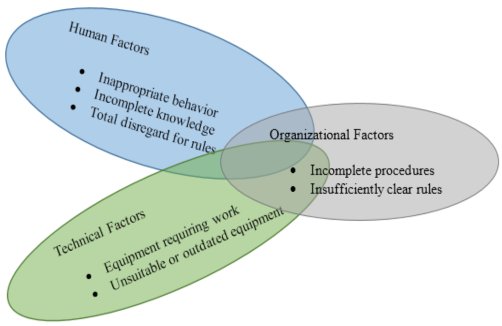
LESSONS LEARNT

It is important to point out that the event was one of a long string of incidents. In fact, ten incidents of various types had already occurred at the site between 2017 and 2018. Following this latest incident, the operator was summoned by the subprefect of the Seine-et-Marne county and then by the director of DRIEE to explain why the incidents had occurred. Both asked about the technicians' training, their safety culture, the organisation of operations, and management's involvement in maintaining a true safety culture at the refinery. The operator stated that the safety culture at the refinery had been assessed in 2017 by an independent organization (ICSI) and that the assessment was based in particular on a questionnaire sent to all the refinery's employees and contractors. Presented during a meeting of the refinery's corporate committee for health, safety, and working conditions (CHSCT), the assessment revealed a number of alarming findings:

- too-little focus on major risks;
- normalisation of deviance, particularly in relation to major risks, with a focus on productivity that is sometimes detrimental to safety, and little regard for initiatives and suggestions;
- declining confidence in the technical base of the work and a loss of meaning for those performing the work;
- leaders who are rarely in the field;
- management mostly gives orders and rarely participates;
- strong inertia at interfaces between functions and departments;
- insufficient culture of transparency.

Deficiencies in communicating information about incidents to external parties were also found and appeared to corroborate a certain carelessness or at least a lack of focus on safety.

Lastly, the investigation showed that technicians inadequately understood basic safety rules despite thinking that they were following them and that technicians continued performing operations even if they did not go as planned (fear of being singled out as responsible for abnormal situations and for losses in site efficiency). In addition, half the refinery's technicians stated that they preferred to keep silent about safety incidents out of fear of being punished. Employees no longer gave managers feedback because they feared bothering them and, because of a lack of responsiveness and pragmatism, have little motivation to take part in the process.



© Site operator
Characterisation of the root cause behind various incidents

Following this assessment, a programme was launched to improve the safety culture at the refinery, focused on human and organisational factors. Using feedback from employees, the refinery's management committee proposed four areas of improvement:

- create conditions for enforcing workplace rules that are understood and followed by all;
- build an approach focused on the greatest risks for the site;
- develop safety leadership based on the exemplary behaviour and commitment of all;
- recognise performance.

All four have been passed down to four cross-disciplinary working groups made up of employees from all departments and levels of management. A call for volunteers garnered a pool of 30 candidates. A concrete action plan is expected to be developed to identify avenues for improvement for each area and thus improve the refinery's safety culture by 2020.

Safe subcontracting

Supply of skills, cost reduction, and flexibility… Subcontracting offers a whole range of advantages which manufacturers are eager to seize: 74% of them make use of subcontracting, according to the French statistics board (INSEE). Subcontracting is an integral part of a company's life cycle from its creation, during construction, operation and all the way to dismantling. It is therefore not surprising that subcontractors were involved in 10% of the accidents which occurred between 2015 and 2018 in Installations Classified for the Protection of the Environment (ICPE) and subject to registration or authorisation. However, we mustn't assume that, when an external party is involved in an incident, that they were responsible for the situation. Although this aspect doesn't often appear in the operators' accident analysis, subcontracting a service doesn't mean that the risk is also subcontracted. Though not exhaustive, this sheet describes some of the difficulties involved with subcontracting and provides recommendations to limit the risks.

1. The impact of subcontracting on risk control

1.1. The risk of a loss of expertise among internal staff… and its consequences

Subcontracting can diminish the user company's knowledge of its own facilities and the work being conducted there. This can make it difficult to draft specification documents precisely describing the activities to be subcontracted, though the service provider needs such information to properly estimate the service in terms of expected results and the resourses to be mobilised. The risk is that the supplier's proposal will appear satisfactory, when in fact the allocation of resources (personnel, equipment) is inadequate. The service provider is therefore operating in a degraded situation, and is told to follow potentially inappropriate risk prevention procedures. *Examples: ARIA 45448, 47871, 48294*

The loss of in-house expertise could also complicate the support given the service provider as it performs its mission. Out of tocuh with the realities in the field, internal staff may have difficulty conveying their knowledge, particularly regarding safety instructions. In the same vein: is the supervisory ability of in-house staff always up to the task? The fact that the client's employees no longer perform the technical procedures may reduce their ability to judge the quality of the work carried out. If the company loses practical knowledge about its installations, how can it properly control them? *Examples : ARIA 52089, 51004*

1.2. The problem of concurrent activities

In addition to a lack of clarity for the service provider concerning the work conditions and unfamiliarity with the risks present at the site, there is an additional risk related to concurrent activities. Several interventions may take place at the same time: some performed by the external company and others by the operator or by other service providers. This timing can be problematic, particularly when some of the works conducted by the operator result in changes in the environment, the materials present, the operation of processes… or any other element of the context in which the subcontractor must operate. *Examples: ARIA 50424, 41059, 51652*

Silo explosion linked to inappropriate management of concurrent activities (ARIA 51652)

1.3. Time constraints and hierarchy of relations are sometimes detrimental to risk prevention

The constraint of deadlines weighs on the time allocated to site preparation, monitoring and closure, which is sometimes considered "unproductive" even though these steps are crucial for safety. For practical reasons, the subcontractor's participation in these phases can be complicated, particularly if they are not conducted at the same time as the actual intervention. *Examples: ARIA 49384, 46253, 46694*

In addition, subcontracting often leads to the neglect of tasks with low added-value or those outside the core business activity (cleaning, waste management...). These tasks, which are considered non-strategic, are not always considered in risk analyses. And yet, these peripheral activities can also be a source of accidents.

Finally, the relationship between the client and the subcontractor means that the latter does not always dare raise his concerns (fearing a loss of business) even when he is aware that the intervention will not be performed under optimal conditions. The non-reporting of information is an adverse effect of rating systems applied to service providers.

2. A few recommendations for subcontracting

2.1. Prioritize risk prevention when selecting a service provider and in the contractual framework

National-level contracts, negotiated between the client's central services and the service provider, tend to establish requirements far removed from specific local situations, which may hinder the proper performance of interventions. To remedy this problem, purchasing departments must gain an understanding of operational and field constraints.

As early as the contract stage, the roles and responsibilities of each player must be formally established for the preparation of the site, with everyone's tasks being clearly defined in terms of the checks to be performed before, during and after the works. *Examples: ARIA 49018, 40790, 46253, 43836, 36198, 47654*

Furthermore, if the client does not provide training for the subcontractor's personnel, leaving this obligation instead to the subcontractor, it must inform all those intervening on the site of the risks specific to its installation (with periodic refresher training provided). In addition to checking the certifications held by a subcontracting company, the client should always inquire about the experience of the individual technicians sent by the service provider, with particular attention to temporary and newly hired staff. *Examples: ARIA 44466, 4417, 8781*

2.2. Pay special attention to pre- and post-intervention phases

Risk analysis is the key step before works are performed. It must take into account the unit or the equipment concerned, but also the units and equipment that are connected or located nearby. It must be conducted jointly by the operator and subcontractor to identify the risks for each party, including those related to concurrent activities (to be managed through proper planning and communication with all the departments concerned).

Once prerequisites have been met, works should not commence until the client has performed a mandatory review to ensure that the actual conditions for the intervention comply with what had been planned, particularly regarding lockout/tagout procedures. Upon completion of the work, client acceptance is the ultimate action to detect any defects that may cause accidental damage in the short or long term (e.g.: a residual hot spot). An acceptance inspection after any intervention, backed up by a checklist of points to be verified before putting the site back into operation, is standard practice in the nuclear sector and should be implemented in the field of Installations Classified for the Protection of the Environment (ICPE). *Examples: ARIA 49384, 40790, 46253, 43836, 36198, 47654*

In the case of equipment supply, an inspection conducted by an independent body may be useful to verify the suitability of the equipment and parts delivered. When equipment must meet certain standards, certificates of compliance must be produced by the supplier. *Examples: ARIA 48294, 48555, 51004, 29827*

2.3. Ensure rigorous supervision, adapted to the nature of the risk and the type of work performed by the subcontractor

The operator must have sufficient skills to be able to monitor and evaluate the subcontractor's work: it must either have skills in-house or outsource them. One example is safety advisors for the transport of dangerous goods. Such advisors, requiring training and renewable accreditation, ensure that the operator has the basic knowledge to conduct risk analyses, establish rules, control performance and safety compliance, audit service providers, analyse accidents, etc.

Release of nitrous vapours following an unsupervised unloading operation (ARIA 49018)

Supervision of the service providers by in-house staff must be contractually established to ensure compliance with procedures and safety measures (with special attention given during periods of reduced activity such as holidays). The use of stopping and alert points during works at the site allows the client and the subcontractor to prioritise risk management and integrate key control points. Though the level of supervision should be high in the case of a first-time subcontractor involved in a risky activity, it can be reduced to a simplified monitoring plan in the case of a well-known and historically reliable subcontractor. *Examples: ARIA 25836, 37944, 49018*

2.4. Establish a relationship of trust and dialogue to benefit from feedback

Depending on how the contract is drafted and implemented, the relationship between the client and the subcontractor will not be the same. Though it is important to remain vigilant, clients should take care that the clauses on service performance (including penalties for delays, rating system) don't create an obstacle for the provider to report dysfunctions and other difficulties. Contractual clauses focused on prevention rather than deterrent repression can contribute to risk prevention by allowing better collaboration for accident analysis and the implementation of joint corrective measures. The subcontractor may play an early-warning function, and it is essential that the operator be prepared to listen and react to these alerts. Such feedback can be used to update the safety management system, the prevention plan or the occupational risk evaluation document.

3. Conclusion: when subcontracting enhances risk control

Shifting from "doing it" to "having it done" is no small endeavour for an operator. Creating new tasks (expressing a need), changes in certain departments (increased role for the purchasing department, creation of a project supervisor position)... For a smooth transition, the company must identify these changes and mobilise the necessary resources to handle them.

Despite the difficulties mentioned above, subcontractors can prove to be valuable partners in controlling risks. As experts, they know more about the technology and the risks specific to their activity and therefore are typically better at preventing problems. Thanks to their experience, the subcontractors will theoretically perform technical works more safely and of a higher quality. In addition, the subcontractor serves as a channel for sharing feedback. The expertise of an entire industry of specialised subcontractors working on multiple sites for multiple clients is an asset: local best practices can be transposed to new sites and clients.

Explosion of an underground solvent storage tank during a maintenance operation

21 March 2018

Saint-Sulpice (Tarn)

FRANCE

Explosion

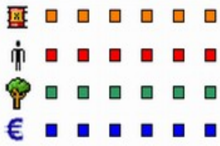
Explosive atmospheres

Maintenance

Subcontracting

Organisational and human factors

THE ACCIDENT AND ITS CONSEQUENCES



A contractor at an upper-tier Seveso plant was cleaning an underground tank so that it could be filled with a different product. The tank was located in an outdoor area comprising 12 horizontal underground multi-compartment tanks, each having an overall capacity of 60 m³ (nominal compartment capacities of 10, 15 and 35 m³) and containing flammable liquids (solvents or petroleum products). Cleaning began at 8:30 a.m. At 9:55 a.m., an explosion occurred in the 35 m³ compartment containing ethyl acetate.

Damaged pipes

The force of the explosion sent the tank's cover as well as tools and debris flying across a distance of several metres. The contractor's two employees suffered severe burns. The visible property damage was limited to empty pipes used to transfer solvent, which received slight damage from falling objects. The explosion cut off the plant's electricity supply, in turn shutting off its computer system and the automated systems used to monitor equipment on the underground tanks.

The operator administered first aid to the two injured employees (absolute emergency), immediately called emergency services, initiated its internal emergency plan, and notified nearby businesses. A large number of first responders (30 gendarmes, 56 firefighters from the Departmental fire service (SDIS), and 14 vehicles) were quickly mobilised.

Departmental fire service halted railway traffic between the towns of Albi and Toulouse and set up a 500 m safety perimeter around the site. The gendarmerie halted road traffic. The director of a primary school located 700 m away implemented the school's safety plan and ordered pupils to shelter in place. Other schools in the town followed suit.

Departmental fire service tested the air around the tank and across the site with an explosimeter. Once finding that there was absolutely no risk of explosion, it inerted the tank by filling it with water. After doubts had been dispelled by rescue service and the Emergency Support Unit (CASU) of the French National Institute for the Environmental technology and Hazards (INERIS) issued its opinion about the risk of secondary accidents occurring in the tank's other compartments, the prefect lifted the containment restrictions and reopened road and railway traffic at 12:00 p.m.

THE ORIGIN AND THE CAUSES

The explosion was sparked by the combined presence of both an explosive atmosphere (ethyl acetate concentration between its LEL and UEL [2%; 11.5%]) and an ignition source. Ethyl acetate has a flash point of 4°C.

When the accident happened, the manhole cover on the tank's compartment had been resting on a tripod and the contractor's employees had inserted a hose in the tank to begin emptying it.

The findings of the legal investigation under way are not yet known, but the following assumptions have been made:

Manhole cover

- regarding the presence of an explosive atmosphere, the employees failed to do three things to ensure that no flammable fumes were still present in the manhole: (i) they did not obstruct the flanges on the manhole to limit fume emissions before opening it; (ii) they did not extract fumes from the manhole vent pipe; and (iii) they did not test the atmosphere in the vent pipe with an explosimeter. And yet, these points are specified in the operator's prevention plan and procedure.
- regarding the presence of an ignition source, the employees failed to take the necessary precautions to limit the associated risks: (i) they did not connect the manhole to earth; (ii) neither the hose used to drain the tank nor the steel tools found nearby were certified for explosive atmospheres; and (iii) they opened the manhole with an unsuitable item of lifting equipment that may have produced impact sparks.

These immediate causes reveal the following organisational and human root causes:

- **Training / identification of risks**: contractors who lack sufficient knowledge of the risks involved and who do not follow basic safety instructions;

• **Procedure and instructions**: the procedure did not ensure that degassing and cleaning of tanks containing flammable liquids are performed safely; the safety actions and safety checks required at each step in the procedure were insufficiently clear and specific; and the procedure did not sufficiently take into account recommendations from technical guides for this type of operation (INRS guide);

• **Organisation of inspections**: the operator failed to prepare and supervise the operation: it does not have a contractor accreditation process; there were no supervision hold points in the procedure; a number of basic requirements for ensuring safety during the operation were not mentioned in the prevention plan (contractor accreditation, equipment compliance, weather conditions…); and a safety inspector was not involved in the process despite being set out it the prevention plan;

• **Conception of installations/ergonomics**: the access to the tank was uneasy (it was necessary to go through a small and isolated door and to step over several pipes). Such conditions could have played a negative role during the sub-contractors' intervention.

FOLLOW-UP ACTIONS TAKEN

In the evening after the accident, and following a proposal by the inspection authorities for classified facilities, the prefect signed an emergency-measures decree:

• barring the operator from emptying or filling the 12 underground flammable-liquid tanks or transferring their contents to the packaging area until the level gauges and leak detectors on the tanks were once again operational;
• barring the operator from cleaning or inerting any of the flammable-liquid tanks until the supervision and maintenance procedures had been revised;
• requiring the operator to visually inspect or check the integrity of the affected tank's compartments and its pipes.

A legal investigation of the operator and its contractor was launched. All the parties involved were questioned by the gendarmerie, with the inspector of Directorate for the Environment, Development and Housing (DREAL)assigned to the site interviewed as a witness. Using feedback from the accident as a basis (focus on the change in the tank cleaning and degassing operations), DREAL and the Regional Directorate for Enterprises, Competition Policy, Consumer Affairs, Labour and Employment (DIRECCTE) investigated the actions implemented by the operator.

LESSONS LEARNT

1° An effective means of reducing risk at the source

The fact that there were no consequences off the site shows that the use of underground tanks to store flammable liquids is effective in limiting effects following an explosion.

2° Collaboration among authorities is essential

Information shared among the inspection authorities, rescue service, emergency support unit of INERIS, and DIRECCTE was valuable in understanding and analysing the accident. The inspection authorities' visit in the presence of DIRECCTE made it possible to finalise the drafting of the order on emergency measures and identify when the tank instrumentation system failed (this information had not been provided by the operator at the time of the accident). By working together on this accident, which involved aspects relating to France's environmental and labour codes, DREAL and DIRECCTE were able to put forward consistent proposals.

3° Too many grey areas in the accreditation of contractors

The obligations imposed on operators of upper-tier Seveso facilities with regard to contractor training and qualification remain difficult to ascertain unless there is a prevention plan between both parties. The prefectoral order authorising the plant's operation called for the creation of a contractor accreditation procedure (which, following the accident, was found to be nonexistent). However, depending on the sector, not all upper-tier Seveso facilities call on certified contractors (MASE-UIC). The issue of contractor certification at high-risk sites remains unresolved.

4° DREAL's role in the criminal prosecution case

The criminal investigation conducted by the gendarmerie raises the question of the role of the inspection authorities for classified facilities in the post-accident investigation. Although DIRECCTE followed the criminal procedure as an expert, DREAL's inspection authorities were merely questioned as a witness. They therefore did not have access to all the information in the case or to the depositions filed by the parties involved.

5° Progress achieved through feedback

The media coverage of the accident acted as a catalyst for the advancement of ongoing files. The operator's highest level of management stepped in and leveraged this feedback throughout Europe (presentation of the case made to all its European sites). In France, it distributed to all its sites a prevention plan template designed specifically for the maintenance and degassing of flammable liquid tanks. It also developed requirements for the qualification of contractors that conduct these operations and defined mandatory supervision hold points.

The investigation revealed that the explosimeter used by the contractor was not designed for detecting ethyl acetate. Both rescue service and the operator wondered if their own explosimeters were compatible. Lastly, the contractor discontinued its flammable-liquid tank degassing operations.

Short-form accident feedback

Short-form accident summaries on the topic of safe subcontracting

Ignition of a gas mixture in an hazardous waste treatment plant

ARIA 49472 – 31/01/2017 – Changé (Mayenne) – France

At around 10:30 a.m., a mixture of biogas containing 33% methane (which has a lower explosive limit [LEL] of 5%) ignited in a 30 m³ water tank connected to a cogeneration boiler at a hazardous waste treatment plant. A contractor was taken to hospital to be treated for severe burns. The facility was placed in a safe position. The boiler was shut down for 30 days. The financial loss was estimated at €50,000.

The event occurred while the boiler's water tank was being serviced and retrofitted with new nozzles. The boiler had been shut off, drained, and locked out beforehand. While this was happening, filters on the nearby biogas compressors were being serviced. The electricity had been shut off, causing the site's biogas plant to shut off as well.

During normal operation, the contents of the biogas filters are dumped to a wastewater tank. The volume of residual biogas is then discharged into the wastewater tank, which has a breather valve fitted with an activated carbon filter and a connection leading to the site's biogas collection pipes. The purpose of this connection is to continuously scavenge the headspace to remove all remaining traces of biogas. The boiler's water tank (which was being serviced) is also connected to the wastewater tank and the drain valve at the bottom is left open.

Just before the accident, the shutdown of the biogas plant for maintenance resulted in scavenging of the wastewater tank headspace to shut off. It is likely that the biogas released during the dumping of the filter travelled along the sewer system, up to the biogas compressor, and ultimately on to the boiler water tank being serviced. The amount of released biogas was probably sufficient to create an explosive atmosphere inside the 30 m³ tank. Sparks from grinding probably ignited the gas mixture inside the tank, resulting in a flash fire. The technician was burnt by hot gases exiting the nozzles that were being retrofitted.

The operator identified multiple root causes, e.g. a design flaw (single sewer system for waters of very different types, absence of traps or water seals to prevent gases rising via the sewer system) and insufficient analysis of the maintenance-related risks.

To prevent a recurrence of the accident, the operator separated the sewer systems, modified the maintenance procedures for replacing the biogas filters and shutting down the biogas plant, and now monitors the scavenging of the headspace in the wastewater tank.

Explosions and fire in a fuel, oil, and additives plant

ARIA 50600 – 26/10/2017 – Meuzac (Haute-Vienne) – France

An explosion followed by a fire occurred at around 1:30 p.m. in a 50 m³ additive tank at a plant where engine oils, lubricants, and greases are produced. The force of the explosion catapulted the tank into the air and dropped it into a field located 50 m away. The tank's contents, which were ignited in the explosion, spread flames to the adjacent buildings and other outdoor tanks. Three minutes later, a second tank exploded, shooting into the air and falling near the plant's administrative buildings. A huge plume of black smoke rose into the sky and was visible 45 km away in Limoges. A safety perimeter was set up and nearby residents were evacuated. The town's population was told to stay indoors. A hundred firefighters drenched the site with their nozzles and a total of about 17 m³ of foam compound, some of which was brought in by the fire and rescue services from two other counties. At first, they were only able to evacuate the employees and residents to safety and cool down the nearby homes because they neither had the foam compound required for this type of fire nor the equipment needed to deploy it. They brought the main seats of the fire under control at around 9:30 p.m. and the blaze was completely extinguished two days later. The intense heat (temperatures greater than 1300 °C) vitrified and destroyed the tanks' concrete bunds and forced the firefighters to rotate frequently.

A boilermaker who was working on the first tank was killed during the accident. The 6,000 m² plant was destroyed and 49 employees were temporarily laid off. Fortunately, it was virtually empty when the accident occurred, as most of the employees had left on their lunch break. The extinguishing water, which was laden with hydrocarbons, was collected and channelled to a nearby retention basin and lagoons dug by the firefighters during the fire. It was subsequently pumped out by a specialist firm. Damage was estimated at €29 million.

A sleeve (the 11th of the day) fitted on the tank by the boilermaker is believed to have caused the accident. Tank fires probably had not been considered when determining its dimensioning criteria and pressure rating. The characteristics of the product contained in the tanks may also have been a factor.

Violent explosions in a grain silo with vertical open-top storage bins

ARIA 51652 – 06/06/2018 – Strasbourg (Bas-Rhin) – France

A first explosion followed by a second, more violent, occurred at around 9:20 a.m. at a grain silo with open-top storage bins. Two contractors and one site technician suffered severe burns; another employee was injured. One hundred firefighters responded to the explosion and a 300 m safety perimeter was set up. The gas supply adjacent to the site was placed in a safe position. As a precaution, ten schools were put on lockdown all morning. Two roads were closed along several hundred meters and nearby businesses were evacuated. Fertilizer that was being stored at the foot of the silo was evacuated to clear access to the site and because the services overseeing the operations did not have information about its exact characteristics at the time.

The accident resulted in significant property damage. Pieces of the asbestos-cement roof were thrown as far as 300 m away. The grain elevator equipment was heavily damaged. Concrete slabs in the lower tunnel were thrown up and flipped over. The 24,500 tonnes of maize that were in the storage bins were doused for four days to control the smouldering fires inside. The ambient air outdoors and in five nearby businesses was monitored for asbestos. The results were less than five fibres per litre. Pieces of asbestos were removed from the road. The storage bins had to be emptied due to the risk of the structures collapsing and the risk of the wet maize heating up. The silo's structural resistance was analysed by the Technical and Industrial Centre for Constructional Steelwork (CTICM). An asbestos removal plan was scheduled to take place before the storage bins were emptied. Due to the technical constraints involved (presence of asbestos and risk of structural collapse), the emptying operations were expected to last for several months.

At the time of the accident, the silo was shut down for annual maintenance in anticipation of the beginning of the harvest season. Contractors were performing a scheduled welding operation in the grain elevator on the fourth floor at the conveyor. At the same time, two technicians were cleaning on the seventh floor (a blow gun was found near the dispenser access hatch, which was open at this floor). The first explosion occurred in the grain elevator at the conveyors. The flame front and shock wave then propagated to the storage bins.

According to the initial findings of the accident analysis, dust in the elevator system may have been dispersed into the air when the dispenser hatch on the seventh floor was opened. The technician on the fourth floor was welding a plate onto an elevator chute. According to witnesses, the first explosion occurred just when the technician started welding. The spark and heat that triggered the initial explosion in the grain elevator created a blast wave that propagated via the lower tunnel and the spaces between the silos and threw into the air the dust present in the top portion between the roof and the tops of the storage bins. This initial explosion set off one or more extremely violent secondary explosions.

Hydrogen chloride release following a maintenance operation

ARIA 53041 – 09/12/2012 – Germany

Ten kilos of hydrogen chloride gas were released from a flange that had been fitted by a contractor just a few weeks earlier, triggering alarms and resulting in internal emergency intervention. The incident had no significant consequences.

A contractor performing maintenance was instructed to remove the pressure sensor from a device and replace it with a blind flange. Due to the corrosive environment (HCl), the plate on the pressure sensor was coated with tantalum. After being removed, the pressure sensor was supposed to be closed off with a Teflon®-coated full flange. As none were in stock in the site's workshop, the contractor was given a standard flange and a Teflon® sealing disc. This type of substitution is routine.

After the incident (which occurred several weeks after the maintenance operation), the flange was found to be corroded and a large hole could be seen extending through the steel plate. It is this degradation that caused the hydrogen chloride release. When the flanged seal was opened, the operator saw that instead of the Teflon® sealing disc, there was a Teflon® O-ring. The result was that the steel flange was left unprotected.

The contractor had 40 years of job experience and regularly used this type of seal at the plant. The main issue raised by this incident is the supervision and checking of maintenance work performed by contractors. The operator's safety management system should be revised to include supervision and post-maintenance checks. In addition, two technical measures were immediately put in place:

- the Teflon® sealing discs (made in the site's workshop) have a protruding tab that makes it easy to locate and identify them (impossible to mistake them for O-rings);
- documentation is compiled when flanged seals in contact with hazardous materials are fitted: seal specifications, manufacturer certificates, photos of the fitted bolts and seals prior to tightening.

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 by the Higher Council for Registered Installations. It includes the 18 parameters of the European scale in four uniform's groups of effects or consequences:

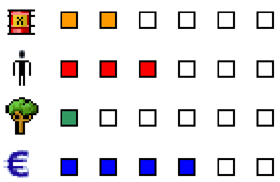
- 2 parameters concern the quantities of dangerous materials involved,
- 7 parameters bear on the human and social aspects,
- 5 concern the environmental consequences,
- 4 refer to the economical aspects.

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 environment 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

Notes

Notes

TECHNOLOGICAL ACCIDENTS ON LINE

For the past 18 years, the ARIA (Analysis, Research and Information on Accidents) website has given the general public access to its database of technological accidents and incidents, as well as numerous publications presenting the lessons learnt from analysing these events.

Recently, the site is being revised, in both its French and English versions, in order to better meet Web users' expectations and to integrate the latest technologies, with enhanced ergonomics and a completely overhauled search engine.

Thanks to this new version of ARIA, the BARPI is consolidating its role as the **"Interactive reference media library specialised in industrial accident studies"**.

Users can access:
- nearly 53,000 accident summaries (sequence of events, consequences, circumstances, disturbances, root causes – both proven and suspected – actions taken and lessons learnt);
- nearly 300 detailed and illustrated accident report presenting accidents of unique informative interest;
- summaries of accident statistics either by topic or by industrial sector, e.g. automated mechanisms, corrosion, fine chemicals, pyrotechnics, confined spaces, lightning, hydrogen, gas boiler rooms, sensors;
- a multicriteria search function to find information on accidents occurring in or out of France;
- saved requests and automatic notification by email should a new element arrive in your fields of interest.

Please feel free to consult the website on a regular basis, as the database expands every year by some 1,200 accidents plus a wide range of publications!

ARIA
dgpr srt barpi

www.aria.developpement-durable.gouv.fr

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

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